Abstract Book
AquaConSoil 2025

Abstract ID: 111
Monitoring design during in situ remedy implementation

Johanna Moreskog[1], Josephine Molin[2], Brant Smith[2]
[1]Ramboll Sweden AB, [2]Evonik Corportion

A properly designed monitoring program is an underappreciated aspect of remediation and yet it is often critical to the understanding the success and impacts of a remedial application. Monitoring prior to, during and post a remedial application provides the validation of the remedy's efficacy required by the regulators to obtain closure at the site. Although a monitoring program could be reduced to simply analyzing the contaminant levels, pre-, during and post implementation, a well-designed monitoring program can provide much more information valuable for post-delivery follow up, multi-application optimization, and site closure.

Due to heterogeneous site conditions and other challenges, In Situ remediation technologies sometimes result in a varied response, especially if applied via injection. The variation in performance can have a multitude of explanations, including under dosing, lack of distribution/contact, insufficient contact time, rebound from sorbed mass or recontamination from inflowing groundwater over time. Following the application of remediation substrate, there are a number of geochemical parameters which combined results in a technical fingerprint or signature. The parameters includes for example the oxidation-reduction potential (ORP) and other redox indicators, electric conductivity (EC), dissolved organic carbon, cations, DO, pH, as well as direct monitoring of the substrate used and substrate breakdown products. By including the parameters that can be used for trouble shooting already in the baseline sampling multiple lines of evidence can be built to argue not only the effectiveness of the remediation, but also trouble shoot when post-application behavior is not as anticipated.

In reviewing the variation in treatment performance relative changes in geochemical parameters, it can often be possible to determine the underlying cause of mixed or partial results, including distinguishing between distribution issues, underdosing and chemical interferences. In the case of a temporary treatment result, geochemical monitoring can help distinguish between a true rebound (repartitioning of contaminants from soil) vs recontamination from inflowing untreated groundwater. These distinctions then helps guide the next action and potential modifications to achieve site goals. The session aims at discussing the various phases of a monitoring program of a remedy implementation including baseline sampling, application monitoring, distribution monitoring and performance monitoring. It will also provide case examples of how geochemical parameters were used to trouble shoot remedies and helped guide modifications to application and dosing strategies for successful implementation.

Significance
This session will target the fundamentals on monitoring program and how to improve the utility of the collected data.

Public Interaction
The session will include 2-3 short discussion breaks between the participants, as well as a Q&A at the end.

Equipment and Attendance
Typical set up of screen, computer, powerpoint, projector, microphone, and podium. A microphone for the audience would be nice to have.
Attendance is not limited.

Abstract ID: 115
Gaining insight into the role of nematode community structures in the regeneration of forest soil following fire events
Tesleem Bello[1]
[1]Federal College of Education Abeokuta

Fire is a crucial part of the evolutionary history of most forest ecosystems worldwide, resulting in destruction of aboveground biomass and alteration of belowground physical, chemical, and biological processes. Although several authors have tried to reveal the impact of fires on forest vegetation composition and structure as well as the impact on soil processes, there still exists a paucity of data on the effects of forest fires on soil biota. Nematodes being an important part of the below-ground biota, occupying a central position in the soil food web, possess distinctive characteristics that make them valuable indicators for assessing soil conditions. Nematode communities in forest ecosystems have received less attention with only a few recent studies conducted in some sub-tropical and tropical forests. Nematodes were recovered from core samples obtained from a 7-ha fire-suppressed tropical forest reserve managed by the Ogun State Ministry of Forestry, Nigeria in 2020. Faunal analysis was done using the Nematode Indicator Joint Analysis (NINJA) program R code (Sieriebriennikovet al., 2014). Burn treatment plots have been burned every 2-3 years since 2011. Our findings revealed substantial variations between the burned and unburned sites in terms of their nematode assemblage. The presence of Prismatolaimus sp. and Panagrolaimus sp. (bacterivores), and Aphelenchus sp. (a fungivore) wassignificantly higher in the burned sites compared to the unburned ones, suggesting they may serve as indicators of the ecosystem's recovery trajectory after the fire events. Our findings contribute to a broader knowledge of the importance of soil biodiversity in soil health and ecosystem resilience being the first in this regard from African tropical soil. By identifying the key functions that nematodes perform in post-fire soil restoration, land managers and soil ecologists can better design strategies to accelerate recovery in fire-prone ecosystems.

Abstract ID: 118

Large Scale In-situ Thermal Remediation Inside a Manufacturing Factory in Belgium: Challenges and Lessons Learnt

James Baldock[1], Joanne Dinham[1], Rony Annaert[1], Matthias Verbeeck[1]

[1]ERM

As a result of historical industrial activities, chlorinated solvents had entered soil and groundwater beneath an active manufacturing building. A pump and treat system was installed and operated for nearly two decades, but contaminant recovery had declined and significant mass was thought to remain in the subsurface. Therefore, ERM refined the remediation approach and deployed In-Situ Thermal Treatment (ISTT) using site supplied steam as the heating source.

There were numerous challenges throughout the remediation programme related primarily to the entire treatment zone being inside a factory building with >100 workers and overlapping with site production activities, including:

• Health and Safety: The site continued manufacturing whilst remedial activities took place and the significant overlap between remediation infrastructure and work zones meant continuous monitoring for vapour intrusion and steam specific hazards. A robust programme of building stability monitoring was also implemented.

• Logistical: The factory layout meant there was limited access for drilling rigs and pipework had to be carefully placed away from work zones, often at height. There was also insufficient space for process equipment to be installed adjacent to the well field, as would normally be the case, and this instead had to be placed over 100m away and joined by pipework installed in confined space tunnels. Additionally, the project staff in the field and office spanned multiple countries, with equipment shipping and delivery delays adding further complexity.

• Technical: The well array of both the injection and extraction locations could not be installed on a uniform grid, as placement was controlled by access. The need to pump groundwater during steam injection was also inhibited by ingress of silt and drawdown restrictions put in place to reduce potential stability issues. During the design process, the local regulators also introduced a requirement to include PFAS monitoring and treatment.

• Stakeholder Management: The presence of multiple vendors, scheduling installation works to avoid disrupting factory operations, consideration to surrounding residential properties and daily client interaction all had to be carefully managed during the remediation works.

The restrictions on well placement were managed by installing additional shallow vapour wells in limited access areas with smaller drilling equipment. The extraction system was also continually optimized. The well array for most in-situ remediation projects would be enclosed to segregate factory worker activities from these works, although this was not possible in all areas and several wells were located directly in factory working zones; these wells were protected by metal structures to reduce impact or heat risks, with pipework also lagged.

An intensive manual and automatic monitoring programme was also implemented via an innovative continuous real time vapour monitoring system and a stability monitoring plan. Close and regular co-ordination and co-operation between all stakeholders was key to facilitating this project.

Despite the numerous challenges of this unique project, the system worked safely and recovered significant contaminant mass. The lessons learnt during these works demonstrate that, if carefully designed and managed, ISTT can be effectively deployed in environments that historically would not have been considered possible.

Abstract ID: 120

Preliminary study on the influence of temperature and coal content on benzene mobility in coal waste dumps: implications for health risk assessment in Wallonia (Belgium)

'- Foucart[1], - Lambert[1], - Luthers[1], - le Bussy[1], - Kaison[1], - Gohy[1], - Fays[1], - Collart[1]

[1]ISSeP

In Wallonia, a Decree on soil management and remediation (Walloon Soil Management Decree - WSMD) sets a series of threshold values for different parameters, including a limit concentration of benzene in soils. These thresholds are more or less restrictive depending on the type of land use. For a residential use, the benzene concentration analysed in the solid part of coal waste dumps (CWDs) often exceed this threshold and in such a case, the WSMD requires a risk study to determine the need for soil remediation. The risk assessment model used in the frame of WSMD considers reversible sorption/desorption with an empirical Koc determined on natural soils. In this model, benzene is consequently considered to be mobile leading systematically to a human health risk and therefore a risk management on site. The aim of this study is to investigate the mobility of benzene in CWD. The influence of combustion on the mobility of benzene will be assessed. This will help to refine the methodology for assessing the risks to human health of benzene associated with CWD and to specify the precautions to be taken in terms of risk management measures.

We investigated 15 CWDs spread over the 4 major Belgian coalfields. Two types of CWD deposits were studied: (1) CWDs used as backfill and (2) CWDs placed in the form of conical or valley waste heaps. 6 of the CWD's investigated present at least one burning zone. Survey campaign consisted of 3 boreholes per site with soil sampling and analysis and the installation of 3 surface air sampling wells for soil air analysis. The boreholes were placed in a line, each 2 m apart. 47 soil samples and 47 soil gas samples were collected. Benzene, carbon organic content assimilated to coal content, total sulphur content assimilated to pyrite content were analysed in soils and benzene was analysed in air samples. Moreover, a monitoring over a period of 7 months and under contrasting meteorological conditions was carried out to determine the potential impact of pollutant emissions from the only burning CWD for which the risk to human health could not be ruled out. The measuring station in the form of a trailer was installed approximately one hundred metres north-east of the CWD backfill, downwind of the prevailing winds. The station was equipped to continuously measure the concentrations of benzene, carbon monoxide (a tracer of incomplete combustion) and key meteorological parameters.

The results of analyses coupled with field observations show there is no correlation between benzene in soil and benzene in air content. Benzene would be trapped in coal present in CWD, mainly in the deformed micropores. Benzene desorption would be only possible by degassing the adsorbent when the coal is heated to higher temperatures. In addition, it appears that the benzene released in the combustion zones studied is not related to the benzene exceedance observed in the soil and would come from the pyrolysis of organic matter in the anoxic conditions inside the CWDs. The monitoring of the burning CWD show higher concentrations at night when wind speeds are low and the targets are absent. This profile is explained by the proximity of the station to the continuous emission source and by the fact that wind speeds are higher during the day, favouring a better dilution of the concentrations at these times.

This study suggests that for CWDs, Koc of benzene used in the risk assessment model of the Soil Decree must be reviewed and that the risk to human health from the benzene content in CWD cannot be assessed independently of the risk of combustion of these CWDs.

Abstract ID: 124
Twinning TISR®: A 'Hot' Take on Digital Design and Remote Monitoring for Sustainable Remediation

Jonah Munholland[1]
[1]*Arcadis*

Purpose of Study This study explores the development and deployment of a fully digitalized design and monitoring workflow for a low-temperature thermal in situ remediation (TISR®) system, designed to mitigate soil and groundwater contamination. The aim is to advance sustainable environmental remediation by utilizing digital twin technology for comprehensive data integration, management, and real-time monitoring. This approach emphasizes early-stage digital planning, streamlined data harmonization, and continuous monitoring throughout the asset's lifecycle.

Methodology The project leverages Autodesk's suite of digital tools to establish a seamless workflow from planning to asset management through digital twins. Autodesk Forma optimizes early-stage site planning and project feasibility, while incorporating upfront solar energy analysis into initial heat transfer modeling to accurately assess renewable energy potential and enhance system design efficiency. Autodesk Construction Cloud (ACC) serves as the Common Data Environment, promoting standardized data formats, interoperability, and secure data exchange across stakeholders. Revit facilitates detailed 3D modeling of the TISR system, including parametric family creation, comprehensive 2D drawings, and Bill of Materials for streamlined construction documentation. Once the TISR system is operational, Autodesk Tandem integrates telemetry and performance data into the digital twin, supporting real-time monitoring and predictive maintenance.

Summary of Findings/Results The digital twin framework has effectively streamlined each stage of the TISR system's lifecycle. The use of Forma and ACC in early-stage planning and data management improved coordination across design, engineering, and environmental monitoring teams. Revit's 3D modeling capabilities facilitated the accurate depiction of the TISR system, enabling rapid adjustments to design and layout in response to site-specific needs. Integration with Autodesk Tandem for real-time performance data has proven critical for monitoring system efficiency and sustainability, offering valuable insights into system uptime, temperature distribution, contaminant migration.

Conclusion/Take Home Message The implementation of a fully integrated digital twin approach for TISR systems marks a significant advancement in sustainable environmental remediation technology. This digitalized workflow not only optimizes each stage of the project lifecycle through efficient design automation but also enables remote system monitoring. This capability reduces the need for on-site visits, directly contributing to a lower carbon footprint and reducing greenhouse gas emissions throughout the remediation lifecycle. The success of this approach demonstrates the transformative potential of digital twins for environmental assets, providing a replicable model for efficient, low-impact management of contaminated sites.

Abstract ID: 127
Study of PFAS degradation by e-beam in water and adsorbed on activated carbon matrix

Aude Smeets[1], Aurore Schneiders[2], Rudi Labarbe[1], Georges Scholl[2], Ariadnne Vargas Rivadeneira[1], Jeremy Brison[1], Gauthier Eppe[2], Stéphane Lucas[1]
[1]Ion Beam Application (IBA), [2]University of Liège

Introduction:
 PFAS (per- and polyfluoroalkyl substances) are persistent environmental pollutants posing significant health risks. Traditional methods like incineration and activated carbon adsorption for PFAS treatment have notable limitations. Incineration is energy-intensive and can lead to incomplete degradation, releasing harmful by-products. Activated carbon, while effective in adsorbing PFAS, does not destroy them, requiring further disposal.

High energy electron beam treatment offers a compelling alternative, leveraging accelerated electrons to break down PFAS molecules efficiently. This method operates at ambient temperatures, ensuring energy efficiency, minimizes hazardous by-products, and achieves effective degradation, making it a promising, sustainable solution for PFAS remediation. This study explores the feasibility of high-energy electron beams (e-beam) for treating contaminated carbon filters and enabling their regeneration. Additionally, it evaluates the impact of e-beam treatment on filter integrity post-irradiation.

 Materials and Methods:
 Two types of samples were prepared: first tridistilled water spiked with either PFOA or PFOS at 500 ng/L, second Filtrasorb ® 400-M activated carbon, 8g contaminated by 400 mL of a solution of PFOA or PFOS at 1mg/L, for 48 hours with stirring.

Different pH (neutral/alkaline) and dissolved oxygen concentration were tested.
 Samples were irradiated at x different doses within 250 kGy to 2 MGy using a TT300 Rhodotron® 10 MeV.

The irradiation levels were checked with alanine pellets.

After irradiation, PFASs have been analyzed in the water samples by Solid Phase Extraction (SPE) followed by LC-MS/MS (AquityIclass (LC) and Orbitab Q Extactive (MS/MS).

Irradiated activated carbon samples and reference were analyzed by SEM (Scanning Electron Microscope (SEM) FEG 7610F) and XRD (Inel equipment with a curved detector (120°, 4000 cells) to assess the impact of irradiation on the integrity of activated carbon.

A radio-kinetic model (cf figure 1) developed using Matlab® software, based on ordinary differential equations (ODE) related to the equations involved in the degradation mechanism of PFOA or PFOS by aqueous electron and OH• radicals, was developed to predict optimal degradation conditions.

 Results:
 Following the interaction of the beam electrons with water, free radicals and aqueous electrons are produced (water radiolysis). These aqueous electrons will launch the PFAS degradation mechanism [1]. Byproducts of irradiation include short-chain PFAS.

A constrained optimization of the rate constant for the reaction of the different degradation products with electron lead to a fit of the model with the experimental results (concentration of PFAS by-products as a function of the applied dose) as presented in Figure 1.

An alkaline pH with a low dissolved oxygen concentration appears to promote the degradation of PFOA and PFOS. This confirms the data presented in the literature [1], [2].

Discussion and Conclusion:
 The electron beam degradation process of PFOA and PFOS is a complex process that may involve different degradation pathways [2]. In order to increase treatment efficiency, optimal irradiation conditions must enable the main degradation pathway to be promoted. These different pathways can be included in the radio-kinetic model to predict the concentration of secondary pathway by-products and try to find conditions to minimize it.

 The rate constants of the rate-limiting degradation reactions can be very different depending on the length of the chain. For example, for PFBA (C4 chain), the rate constant is much lower than for longer

chain PFAS. The use of the radio-kinetic model allows the fast and easy exploration of irradiation parameter space to search for a plausible optimum irradiation condition. This allows reducing the number of experiments to do and to focus the experiment plan in the most promising region of the parameter space.

This approach seems to be promising in the search for optimal irradiation conditions.

Abstract ID: 130
Integrated chelator-based removal of toxic metals and aerobic digestion of sewage sludge - a pilot scale study

Barbara Fojkar[1], Domen Lestan[1]
[1]*University of Ljubljana, Biotehnical faculty*

Sewage sludge (SS), a by-product of wastewater treatment, presents dual challenges and opportunities. On one hand, it contains toxic metals (TMs) such as Zn, Cu, and Pb, which pose environmental and regulatory concerns. On the other, SS is a valuable resource for phosphorus (P), an essential macronutrient critical for global agricultural productivity, particularly as phosphate rock reserves are depleting.

The direct use of untreated SS in agriculture is limited by contamination, high water content, and poor dewaterability. Current treatment options, such as anaerobic digestion and chemical extraction, often target either solids reduction or nutrient recovery but fail to integrate these goals. There is a pressing need for a comprehensive approach that simultaneously reduces SS volume, recovers P, and removes TMs to meet environmental and regulatory standards.

This study aims to develop a scalable, integrated process for SS management that combines EDTA chelation for TM removal with aerobic digestion for solids reduction. By leveraging the ReSoil® method for EDTA recycling, the process also seeks to enhance economic feasibility and environmental sustainability. Specifically, this research investigates whether the integration of these technologies can efficiently remove TMs, recover P in a plant-available form, and maintain compatibility with existing WWTP infrastructure.

The study employed a novel combination of EDTA chelation and aerobic digestion in pilot-scale bioreactors. SS was treated in three consecutive batches with 35 mM EDTA, followed by pH-gradient recycling using the ReSoil® method. The dynamics of TM removal, EDTA recycling, SS solids reduction, and P availability were evaluated over a six-day aerobic digestion period. Analytical methods included ICP-OES for quantifying TMs and P, and the Olsen method for assessing plant-available P. The process was benchmarked against a control without EDTA to measure performance improvements.

The integrated process effectively removed significant amounts of Zn (70%), Cu (40%), and Pb (59%), with Cr largely resistant to removal due to its oxidation state. The EDTA chelator was preserved during aerobic digestion, allowing for efficient recycling (82% recovery) across multiple treatment cycles. Additionally, the process enhanced SS solids reduction, achieving an 18.4% reduction in dry matter compared to 7.4% in the control, indicating improved digestion efficiency.

The concentration of plant-available P in treated SS increased by 1.6 times compared to untreated controls, enhancing its value as a fertilizer. However, this improvement came with a trade-off: a 24.6% loss of total P due to EDTA-induced sludge fragmentation and subsequent P washout. The process produced minimal chemical waste, highlighting its potential for integration into existing WWTP operations.

The study demonstrates the viability of a scalable, integrated process for SS treatment, effectively removing TMs, enhancing P recovery, and reducing sludge solids. The approach aligns with circular economy principles, transforming waste into a resource while minimizing environmental impact. This novel method offers a sustainable alternative to conventional SS management practices, such as incineration, by supporting agricultural productivity through P recycling.

This work addresses pressing environmental challenges by advancing a method that promotes the sustainable reuse of SS. It offers a dual benefit of TM remediation and P enrichment, contributing to the reduction of dependency on non-renewable phosphate rock. The process's compatibility with existing WWTP infrastructure underlines its practical applicability and potential for large-scale adoption in the wastewater management sector.

Abstract ID: 132
Case study: In situ remediation of a PFAS source area under a factory
Jack Shore[1], Kris Maerten[1]
[1]*REGENESIS*

Background: A textile manufacturing facility in Belgium utilized per- and polyfluoroalkyl substances (PFAS) in its production processes. Over time, spills and leaks during chemical handling and transfer resulted in the accumulation of PFAS in the shallow soil, which leached into the groundwater. These conditions resulted in a diffuse PFAS plume composed of fluorotelomers 6:2, 8:2, and 10:2 FTS, along with C-4 to C-9 carboxylic acids, including perfluorooctanoic acid (PFOA). The site's subsurface geology is heterogeneous, with a top layer of sand and loamy clay transitioning to clay-dominant soil at a depth of 1.5 meters. This dense clay is underlain by a saturated, peat-containing sand layer approximately 3 meters below the surface. A capillary zone extends into the clay layer above the confined, saturated sand unit. PFAS are largely retained in the clay layer, with concentrations decreasing at greater depths. Nested shallow and deep groundwater monitoring wells revealed dissolved-phase PFAS concentrations exceeding 10,000 ng/L in the clay (capillary zone)—over 20 times higher than in the underlying saturated sand layer. Therefore, a solution was needed to eliminate the long-term PFAS flux from the source zone and prevent further plume development.

Approach: A proof-of-concept pilot test was conducted to assess the application of a liquid colloidal activated carbon (CAC) material for reducing PFAS leaching. The CAC material consists of activated carbon particles less than 2µm in diameter, suspended in water. This formulation allows for the permeation through and coating of activated particles onto the soil matrix. CAC was injected using a low-pressure, rotating auger injection system that ensured even distribution through both the saturated sand and confining clay layers. Four injection points were arranged in a square pattern with 2-meter spacing. Two pairs of nested monitoring wells, with 1-meter screens, were installed in the clay (shallow, capillary zone) and sand (deep, saturated zone) layers—both within the grid and 1 meter outside of it.

Results/Lessons Learned: Following CAC application, total PFAS concentrations in groundwater decreased by an average of 89% within the first month. Concentrations continued to decline steadily, reaching reductions greater than 99% for all PFAS over five months. Reductions were consistent across all PFAS, with PFBA (a C-4 compound) achieving the lowest reduction (89.7%) and PFOA the highest (99.7%). Monitoring is ongoing to evaluate performance through seasonal groundwater changes and the project is now moving towards full-scale treatment. These promising results demonstrate the effectiveness of this in situ remediation approach as a solution for mitigating PFAS leaching and plume development, with broad-based applicability at similar sites to reduce environmental and public health risks.

Abstract ID: 136
Increasing LNAPL density and viscosity are indicators of Natural Source Zone Depletion

Jonathan Smith[1], Emiliano Hinojosa[2], Alan Hill[1]
[1]Shell Research Ltd, [2]Equilon Enterprises LLC

Natural source zone depletion (NSZD) acts to reduce the mass and/or toxicity of light non-aqueous phase liquids (LNAPL) in the shallow subsurface. Several indirect measurement techniques are commonly used to estimate LNAPL mass depletion based on CO_2 generation by hydrocarbon mineralisation, heat production by exothermic biodegradation processes, and sub-surface gas concentration gradients (Smith et al., 2022). Each of these methods has its advantages and disadvantages (see Table 1 of Smith et al., 2022) and, except for the LNAPL chemical composition method, they are all indirect measurements of LNAPL depletion.

This paper presents data on LNAPL density and viscosity and shows changes that result from NSZD processes. Increasing trends in LNAPL density and viscosity were observed in field data collected over an eight-year period (2016 – 2024) at a well-characterised LNAPL site (Statham et al 2023), which provided a qualitative line-of-evidence for NSZD.

When LNAPL density and viscosity were compared to contemporaneous LNAPL chemistry analysis it was possible to correlate changes in the physical properties to depletion of alkanes from the LNAPL in a manner that would inform a quantitative NSZD assessment (with R2 values of 0.9 to 0.97) (Figure 1). LNAPL density and viscosity measurements are relatively cheap and reproducible, and increasing trends in LNAPL density and viscosity provide additional lines-of-evidence for NSZD.

Figure 1. LNAPL density plotted against chemical concentrations (wt %), nC17 and nC18/conservative marker ratios (unitless) and kinematic viscosity (mm2/s)

The increased density, viscosity (and associated surface tension) over time also means that the oil mobility would also likely decrease, such that the NSZD processes would have the contemporaneous effects of: Decreasing LNAPL mass Decreasing LNAPL mobility Depleting soluble and volatile components that typically drive risk via sub-surface pathways.

Applied at other NSZD sites, measurement of LNAPL viscosity and density over time have the potential to provide additional evidence for NSZD, and with suitably designed investigations may allow quantitative estimates of the depletion of certain LNAPL components.

References
Smith, J.W.N., Davis, G.B., DeVaull, G.E., Garg, S., Newell C.J., Rivett, M.O. 2022. Natural Source Zone Depletion (NSZD): from process understanding to effective implementation at LNAPL-impacted sites. Quarterly Journal of Engineering Geology and Hydrogeology 55. https://doi.org/10.1144/qjegh2021-166

Smith, J.W.N., Hinojosa, E., Hill, A.F.M., 2024. Increasing LNAPL density and viscosity are indicators of Natural Source Zone Depletion. Quarterly Journal of Engineering Geology and Hydrogeology. https://doi.org/10.1144/qjegh2024-104

Statham, T.M., Sumner, R., Hill, A.F.M., Smith, J.W.N., 2023. Transition from active remediation to natural source zone depletion (NSZD) at a LNAPL-impacted site, supported by sustainable remediation appraisal. Quarterly Journal of Engineering Geology and Hydrogeology. https://doi.org/10.1144/qjegh2022-140

Abstract ID: 140

Electrochemical Oxidation for PFAS Destruction: Lessons Learned from Field Demonstrations Inform the Treatment Train Model

Gavin Scherer[1], Rebecca Mora[1], Rachael Casson[1], Hanna Temme[1]

[1]AECOM

Electrochemical Oxidation for PFAS Destruction: Lessons Learned from Field Demonstrations Inform the Treatment Train Model

Background/Objectives

A treatment train that combines PFAS separation and concentration with a PFAS-focused destruction technology is an effective remediation model. Coupling PFAS concentrating technologies with DE-FLUORO™ electrochemical oxidation (EO) treatment was demonstrated in the field to determine its effectiveness for destroying PFAS in different concentrates and to optimize the design of full-scale treatments. This abstract refers to three field demonstrations—two complete and one scheduled for early-2025— of a mobile DE-FLUORO system. The DE-FLUORO PFAS destruction technology has advanced from bench-scale to pilot to field demonstration with applications varying from stand-alone systems to ones specifically designed to couple with PFAS concentrating technologies. The benefit of performing multiple field demonstrations is that lessons learned from the previous studies can be used to modify and optimize the system prior to the next demonstration. Our objective is to optimize EO performance within a PFAS treatment train that may include separation, concentration, and, of course, destruction for a more cost-effective solution.

Approach/Activities

In each demonstration, the mobile DE-FLUORO unit is mobilized to a PFAS-impacted site for coupling with a concentrating technology. We first evaluated treating secondary foamate derived from surface water and groundwater treated using an on-site surface activated foam fractionation (SAFF) system provided by EPOC. At a second site we deployed Cyclopure's DEXSORB®--a novel sorbent--that removed PFAS from groundwater prior to onsite sorbent regeneration. EO treatment of PFAS-laden sorbent regenerant was optimized at the bench-scale before deploying the DE-FLUORO mobile unit for on-site treatment. At the third site, the mobile DE-FLUORO unit was coupled again with the SAFF technology but this time in a closed loop system where the SAFF foamate is treated by EO and effluent is recirculated back to the SAFF influent. In each demonstration, we evaluated the destruction efficiency by testing for targeted PFAS and total organic fluorine (TOF). In addition, we analyzed for select anions, total organic carbon, and metals. Simultaneously, we monitored operational parameters: pH, temperature, current, and voltage. The goal was to identify operational improvements that support future commercial operations.

Results/Lessons Learned

The first demonstration achieved 98% reduction of TOF and up to 99% reduction of regulated PFAS. Additionally, observed operational differences in treating surface water- and groundwater-derived foamate demonstrated EO's flexibility to achieve PFAS destruction while managing foam, filters, pH, and conductivity. The second field demonstration achieved >99% reduction of PFOS, PFOA, and PFNA as well as 83% reduction of PFHxS. The presence of ethanol in the spent regenerant proved to be a challenge; however, learnings supported recommendations on how this treatment train could be optimized in the future. The results of all three demonstrations of the DE-FLUORO mobile system will reflect the effectiveness of design changes as treatment optimization continues, and how that can be incorporated into a treatment train. We will share EO operational performance data, and address the system improvements made to optimize destruction, including changes to temperature control, aerosol management, air emissions control, foam control, and maintenance tasks. Lessons learned will also be shared on site-specific and waste-specific concerns, such as having operated at ambient temperatures ranging from -10 to 90 degrees Fahrenheit, and adapting to the ethanol-based regenerant solution used by Cyclopure.

Abstract ID: 143

Monitoring the effects of a colloidal activated carbon barrier for stabilisation of PFAS: Insight into the development of AFFF contamination now and in the future

Robert Earon[1], Dan Berggren Kleja[1], Michael Pettersson[1], Sara Sahlin[1], Malin Montelius[1], Fritjof Fagerlund[2], Henning Persson[3], Klas Arnerdal[3]

[1]Swedish Geotechnical Institute, [2]Uppsala University, Department of Earth Sciences, [3]Geological Survey of Sweden

Purpose of study

Per- and polyflouroalkyl substances (PFAS) are highly mobile in saturated media with limited mobility in the unsaturated zone, recalcitrant and possibly harmful to human health even at low concentrations. Aqueous film-forming foam (AFFF) impacted sites as a source of PFAS-loading to groundwater is currently the focus of a concerted international research effort, including but not limited to understanding the role of sorption in the unsaturated zone, transport characteristics, and longevity of loading at impacted sites.

Remediation techniques are needed to limit the transport of PFAS as traditional remediation technologies are often ineffective. Supported by the Geological Survey of Sweden, the Swedish Geotechnical Institute (SGI) has received a governmental assignment with the overall goal to contribute to an increased pace of remediation of PFAS-contaminated sites. Within this assignment, SGI is carrying out a pilot study at one such site using an injected colloidal activated carbon (CAC) barrier to limit the mobility of PFAS.

This presentation will illustrate the effect of the CAC barrier on PFAS-impacted groundwater with examples from comprehensive monitoring data from more than 80 groundwater monitoring wells, as well as detailed soil, porewater data and modelling approaches from the unsaturated source zone.

Methodology

Currently, SGI has accumulated a comprehensive database of PFAS-concentrations as well as TOP-Assay analyses and other hydrogeochemical data in soil, surface water, groundwater and porewater, both pre- and post-implementation of the barrier.

Installation of closely spaced groundwater observation wells both up- and down-gradient of the CAC barrier allow for monitoring its impact as well as predictions of efficacy relating to downstream recipients.

In the source zone, tension lysimeters in conjunction with soil analyses allow for high resolution descriptions of PFAS loading in the unsaturated zone to the groundwater surface.

Numerical hydrogeological flow models were used as a basis for reactive transport modelling of the saturated zone to model the efficacy of the CAC-barrier. Modelling approaches aimed at accounting for the air-water interface on PFAS transport in the unsaturated zone are being tested.

Summary of results

As of September 2024, the barrier has reduced concentrations of PFAS in groundwater 80m downgradient by more than 99% relative to the same period in 2023 prior to implementation of the barrier. Preliminary results show reductions of short- and long-chain PFAS as well as precursors.

Numerical groundwater modelling indicates that loading to the groundwater surface is of the order 10-100 $\mu g \cdot yr-1 \cdot m-2$ with a potential reservoir of the order of tens of kilograms in the unsaturated zone, indicating a possibility that less than a percent of the total PFAS reservoir loads the groundwater surface yearly. Additionally, numerical modelling of field-scale partitioning coefficients, supported by lab and field estimates, indicates that PFAS-mobility may be underestimated in post-glacial soils with low organic content.

Detailed investigations of PFAS in soil and porewater illustrate that arrival of peak concentrations at the site have not been reached for several PFAS, particularly PFOS and 6:2 FTAB, illustrating the vital role of understanding the sorption processes in the unsaturated zone.

Conclusion/take home message

Detailed investigations collected during the test of a CAC barrier as a remediation measure for PFAS impacted groundwater emphasize the importance of site-descriptive modelling of the

hydrogeological system to characterize environmental risk and longevity from AFFF-impacted sites. Several major contributors to the total PFAS concentrations in groundwater may not have reached peak loading, likely due to interactions with the air-water interface.
Significance / contributions of study
This study increases the knowledge of fate and transport of PFAS from an AFFF-impacted site and illustrates the potential of CAC reactive barriers to stop the spreading of PFAS to downstream ground- and surface waters.

Abstract ID: 145
NINFA - Taking action to prevent and mitigate pollution of groundwater bodies

Annemieke Marsman[1], Petra Krystek[1], Romee Van Dam[1], Imke Falkena[1], Ainhoa Gaudes Saez[2], Yves Andres[3], Henrietta Whyte[3], Ahmed Mahmoud[4], Marco Petitia[5]
[1]Deltares, [2]Leitat, [3]IMT, [4]WETSUS, [5]Sapienza

Proposal for an interactive session: NINFA - Taking action to prevent and mitigate pollution of groundwater bodies

Summary
Groundwater is an essential water source, but its quality is threatened by saline intrusion, agricultural pollutants, pharmaceuticals, heavy metals, and microplastics, as well as climate change. More research is needed to understand the combined effects of these stressors and to improve cost-effective monitoring, prevention, and mitigation strategies. NINFA aims to enhance decision-making in groundwater management by expanding knowledge on water flows, pollutant behavior, and developing predictive models to support water treatment, reuse, and quality improvement, considering of these stressors.
The NINFA approach focuses on establishing an early warning system and a comprehensive knowledge database, known as the NINFA platform. By combining a knowledge base with advanced technologies and a risk assessment tool, Ninfa aims to help organizations proactively identify potential challenges and opportunities for groundwater quality.
Interactive session
The objective of this session is to obtain insight in the experience of local, regional and national government on the challenges and opportunities (boosters and barriers) associated with risks for groundwater quality they encounter.
We will start the session with four presentations. First, we will introduce the NINFA project, the objectives and outcomes and a short introduction to the two main case studies in the Netherlands and Spain. After this, two presentations will go into further detail: on the use of model and sensors in the case studies and 2. On water scarcity and treatment technologies. In the fourth presentation we will show the risk assessment approach on groundwater quality affected by climate and global changes using the bow tie analysis. This presentation will be succeeded by an introduction for the interactive session.
We will end the short presentations with an interactive session, where we want the participants to give input on risk assessment aspects. The intention of the interactive session is to test the risk assessment method for usability and to supplement it with risks and or measures that were not yet known.

Proposed program (90 min): Short presentations (10 minutes each)   Welcome and Introduction (incl. short intro to Casestudy 1 and Casestudy 2) Models and sensors Technologies, water scarcity Risk assessment, bow tie analysis
  Interactive session (40 minutes)
The purpose of the interactive session is to focus, in four groups, on different parts of the bow tie analysis for groundwater quality that was introduced earlier. Each group will assess whether their assigned section of the risk analysis/bow tie analysis is complete and identify any missing elements. Participants will be asked to provide additions in the form of boosters and barriers they have encountered in relation to these sections. Every 10 minutes, the groups will rotate so that each group can address every part of the risk analysis/bow tie analysis Conclusions (10 minutes)
The interactive session will be concluded with a plenary summary of the key aspects of the boosters and barriers that have been identified.

List of Presenters:
Ainhoa Gaudes Saez (Leitat)

Yves Andres (IMT)
Henrietta Whyte (IMT),
Ahmed Mahmoud (WETSUS)
Petra Krystek (Deltares)
Romee van Dam (Deltares)
Annemieke Marsman (Deltares)
Marco Petitta (Sapienza)

Required extra equipment: screen and 4 flipovers

Abstract ID: 147

Stabilization and Solidification of metal-contaminated soil using Bioash, Ground Granulated Blast Furnace Slag (GGBFS), and Cement: Optimizing binder ratios and evaluating performance

Sepideh Gholizadeh Khasevani[1], Ivan Carabante[1], Lale Andreas[1], Jurate Kumpiene[1]
[1]Luleå University of Technology

Metal contamination in soils poses a critical environmental and health risk. We focus our work in the remediation of an industrial site in Skellefteå, Sweden, The metal contamination in this site comprises lead (Pb), cadmium (Cd), zinc (Zn), and arsenic (As) due to long-term airborne industrial emissions. Stabilization and Solidification (S/S) was considered a promising remediation approach for this site, aiming to reduce metal mobility by incorporating binders that encapsulate contaminants within a stable matrix. The contaminated area, with ca. 70 ha, showed an average total concentration in the soil of As, Cd, Pb, Cu, and Zn of around 403, 514, 806, 526, and 398 ppm respectively. These concentrations exceed the guideline values for land use in Sweden and therefore an urgent remediation is required to develop the contaminated site into an industrial area.

Two different binder systems were evaluated: bioash with ground granulated blast furnace slag (GGBFS) and bioash with cement. The tested formulations included 35%bioash: 5%GGBFS, 35%bioash: 15%GGBFS, 22.5%bioash: 10%GGBFS, 10%bioash:15%GGBFS, and 35% bioash: 5%cement, 47.5% bioash: 5%cement, 35%bioash and 50% bioash. Mechanical strength and leaching behavior were analyzed to assess the effectiveness of each formulation in immobilizing metal contaminants and improving soil strength.

The results identified 35%bioash: 15%GGBFS and 35%bioash: 5%cement as the most effective recipes, achieving optimal performance in both mechanical strength and reduction of metal leachability. The most promising formulations were then selected for a pilot trial at the Nässudden area of Skellefteå to validate their field performance.

To further assess the durability and environmental performance of this optimal formulation, additional tests will be conducted during the coming months, including diffusion test, freeze-thaw cycles, permeability, wet-dry cycling, and column leaching, to simulate field conditions and assess long-term stability. This research provides a framework for employing bioash and GGBFS, Cement in on-site remediation of contaminated soils, offering an economical, environmentally friendly solution with potential scalability for application at metal-contaminated sites in the world.

Abstract ID: 150

Enhanced PFAS removal from groundwater using iron-coated peat and electrochemical remediation techniques

Jean Noel Uwayezu[1], Andrea Luca Tasca[1], Ivan Carabante[1], Jurate Kumpiene[1]

[1]*Waste Science and Technology; Luleå University of Technology*

Poly- and perfluoroalkyl substances (PFAS) are raising environmental concerns due to their occurrence and adverse effects. Their extensive use has led to significant soil and groundwater contamination. Thus, developing effective remediation techniques is essential to prevent further environmental spread. The use of carbonaceous adsorbents (e.g., activated carbon) or mineral-based sorbent has shown potential in retaining PFAS from water. However, PFAS breakthrough requires advancing the technique before in situ remediation. This study explores the use of iron-coated peat (Fe-P) as a reactive membrane barrier to reduce PFAS mobility in groundwater and the application of electricity to remove PFAS from spent Fe-P.

The Fe-P, with a BET-specific surface area of 2.16 ± 0.03 m^2 g^{-1}, is prepared by mixing powdered peat particles (a byproduct of a granulated peat-based production) with iron oxides. Its hydrophobic nature, combined with the incorporation of iron species, facilitates PFAS binding through hydrophobic and electrostatic interactions. To prevent material saturation and PFAS breakthrough, electricity is applied, inducing the migration of charged molecules in the opposite direction to the water flow, thereby minimizing and delaying PFAS leaching. Additionally, the retained contaminants are destroyed through electrochemical degradation using appropriate electrodes.

Tests were initially conducted on a laboratory scale to assess the capability of Fe-P to bind PFAS in a flow-through system. Experiments involved passing PFAS-contaminated water through an adsorption bed reactor at a constant flow rate of 25 mL min^{-1}. Afterward, the migration of PFAS within the spent Fe-P was assessed by applying a continuous electric current using graphite electrodes. Subsequently, the degradation of PFAS was performed using boron-doped diamond (BDD) electrodes. Preliminary results indicated that Fe-P primarily binds long-chain PFAS, retaining over 55% of these compounds after two days, with long-chain PFAS constituting 71% of the total PFAS in the water sample. Short-chain PFAS demonstrated weaker binding, with retention reaching 18% after four hours. When graphite electrodes were inserted into the bed and a 25 mA electric current was applied, results showed that both long-chain and short-chain PFAS were effectively mobilized. Approximately 70–90% of these compounds were concentrated near the anodic region, except for PFOS, which displayed slower displacement. These results suggest that combining Fe-P with electricity has potential as a method for controlling PFAS mobility in water. Ongoing experiments will further evaluate this approach by varying water flow rates and optimizing the electric current to simultaneously reduce PFAS mobility and destroy the contaminants. The final step will involve field trials to validate the technique.

Abstract ID: 153
Harnessing the sustainable potential of groundwater in Saudi Arabia via remote sensing

Mohammed AlRayaan[1], Fahad Alghamdi[1]
[1]Saudi Aramco

Groundwater resources in water-stressed regions, such as the Middle East, face significant challenges due to low precipitation, high temperatures, and elevated evaporation rates, which are compounded by anthropogenic stresses. In this context, Saudi Aramco (the national petroleum and natural gas company of Saudi Arabia) has contributed in the search for potential groundwater sources to ensure an adequate supply of potable water for the country's citizens, agricultural needs, and industrial usage. In this study, we combined geographic information system (GIS), remote sensing (RS) and analytic hierarchy process (AHP) techniques to evaluate the vulnerability of groundwater potential (taking Hail as a case study). With a total of 7 thematic layers (i.e., geology, slope, lineament density, land use/land cover, annual rainfall, drainage density, and soil texture), we found that groundwater potential zones with moderate to high coverage account for 91.9%, which is notably close to the borehole data, with a groundwater potential validation accuracy of 90.0%. The obtained results offer a crucial tool for decision-makers and managers, enabling them to develop timely protection and monitoring measures for groundwater resources.

Abstract ID: 155
Scaling up phytomanagement in Wallonia: insights from the WALLPHY project to support large-scale applications on a pilot demonstration site

Florian Liénard[1], Laurence Haouche[1]
[1]*Institut Scientifique de Service Public*

Phytomanagement is an innovative strategy to manage industrial and anthropized soils while promoting biodiversity and sustainability. In Wallonia, the WALLPHY project, carried out from 2017 to 2022 by ISSeP in partnership with Valbiom ASBL and SPAQuE, investigated the potential of this approach across three experimental sites, each with distinct issues and characteristics. Among these, a former sediment deposit contaminated with heavy metals and organic compounds became the focus of a phytostabilization experiment using two woody plant consortia. Monitoring of porous water, contaminant uptake in leaves and ecotoxicity testing demonstrated promising results, suggesting a reduction in trace element mobility and limited bioaccumulation compared to spontaneous vegetation. These findings highlighted the ecological potential of nature-based solutions and their capacity to deliver broader economic and societal benefits.

Building on these outcomes, funding from the Smart Specialization Strategy (S3) was granted by the Walloon Region to expand and refine these findings through a larger-scale experiment on the same sediment deposit. This new project focuses on comparing the phytostabilization potential of tree species planted in monospecific plots and in mixed-species plots against spontaneous vegetation. To further increase site biodiversity, additional non-monitored plantings of long-lived and shrub species will complement the experimental design. These plantings are part of the broader phytomanagement strategy, which extends beyond the sole objective of remediation.

This initiative aligns with the INNO4CFIs project, funded by the European I3 program, which aims to enhance carbon farming through agroforestry and environmentally friendly practices. The work will be conducted in partnership with NOVOBIOM, a consortium member of the INNO4CFIs project specialized in mycoremediation. As part of this collaboration, ISSeP will draw on its expertise from the WALLPHY project, including its knowledge of species suitability and site-specific challenges, to lead the selection of trees, the experimental design, the physical-chemical and ecotoxicological monitoring, and the results interpretation. NOVOBIOM will oversee site preparation, planting, and maintenance, as well as tasks related to INNO4CFIs, including environmental modelling, metagenomic analyses to study microbial community evolution over time, and the investigation of plant-soil microbiota interactions.

By building on the results of the WALLPHY project and integrating them into new experimental layouts, this work provides a foundation for scaling up phytomanagement practices. It underscores the relevance of nature-based solutions in soil management and their potential for replication on other contaminated sites, advancing ecological restoration and sustainable land use.

Abstract ID: 157
Application of an All-In-One ISCO Technology for the treatment of Monochlorobenzene, BTEX and Chloroform in groundwater at a Former Pharmaceutical Facility in Italy
Alberto Leombruni[1]
[1]Evonik

Background/Objective. Activated Klozur® persulfate creates a multi-radical attack providing greater oxidation power capable of treating common and the most recalcitrant compounds alike. Klozur® persulfates include both sodium (SP) and potassium (KP) products. Both dissolve to provide the persulfate anion, which is typically stable for weeks to months. Sodium persulfate is highly soluble and available to react at the time of application whereas the low solubility of potassium persulfate has been observed to provide extended release of the persulfate anion over months to years. This allows immediate distribution in the subsurface with the stability providing a greater radius of influence and allowing more time to make contact and degrade a wide variety of contaminants in soil and groundwater, including chlorinated solvents, petroleum hydrocarbons, and PAH's. Klozur® CR, a blend of Klozur® SP (sodium persulfate) and PermeOx® Ultra (extended-release calcium peroxide), coupled with Klozur® KP has been selected as the best long-lasting treatment solution for the contaminants of this site by providing immediate treatment with the Klozur® SP and extended treatment with both the PermeOx® Ultra and Klozur® KP.
Approach/Activities. Klozur technology has been successfully applied at several sites in Italy within the past few years. This presentation will discuss the broader program using specific sites as case studies. One of these specific sites was at a densely populated urban area site in the northern Italy. The site was characterized by historical contamination of various toxic compounds. The site, a dismantled former pharmaceutical facility, was impacted by the storage of Hydrocarbons and Chlorinates Solvents which have resulted in the groundwater contamination, including benzene (~ 1000 μg/L), monochlorobenzene (~ 250000 μg/L), chloroform (~ 54000 μg/L) and light TPHs (~ 16000 μg/L). In 2022, a successful pilot has been implemented injecting on site a total of 5600 kg of Klozur CR along with 1700 kg of Klozur KP in a 25% aqueous solution. In 2023, full scale has been completed applying approximately 29 MT of Klozur CR and 9 MT of Klozur KP in a 25% aqueous solution.
Results/Lessons Learned. The combined remedy of ISCO followed by bioremediation has proven successful in treating petroleum hydrocarbon and chlorinated solvent contamination. With regard to the Northern Italy site, following 12 months after the full-scale application, the concentrations of contaminants had reached and maintained concentrations below the remediation goals in all monitoring piezometers in the treatment area. In particular, TPHs were reduced by greater than 85 percent, while MCB was reduced by greater than 95 percent. Monitoring data confirmed sustained elevation of oxidation-reduction potential (ORP) and dissolved oxygen (DO) as necessary subsurface conditions to support treatment.

Abstract ID: 159
Applying sustainability initiatives in remediation of a UK petrol filling station to deliver CO2 savings and additional benefits

Emma Evans[1], Lauren Hunt[1], Jay Hall[1], Gavin Leeks[1], Ruth Chippendale[2]
[1]Arcadis UK, [2]Shell International Petroleum Co Ltd

The presentation will describe the application of sustainability initiatives during remediation of a petrol filling station in Watford, Greater London, with particular focus on i) transport of materials off-site, and ii) reduction of carbon emissions during installation of remedial wells.

The United Kingdom's Sustainable Remediation Forum (SuRF-UK) has promoted the application of sustainable remediation since 2007, embedding principles to help assessors better consider sustainability in land remediation decisions. The remediation solution for this project was selected using the SuRF-UK Tier 1 Sustainability Assessment Tool, which focusses on the impacts of the remediation technique as a whole.

The project provides examples of practical techniques which can be employed to reduce the carbon footprint of a remediation scheme. These examples promote the use of the three pillars of sustainability (Environment, Society and Economy) and the UN Sustainable Development Goals.

The site has been in use as a petrol filling station since 1965. The site required modernisation to allow installation of Electric Vehicle (EV) charging points and planning permission was granted for a 'knock down rebuild' in 2021. The planning conditions required site investigation and remediation. The remediation solution was selected with sustainability principles at its core. The potential to embed sustainable solutions into the implementation phase led to this being a focus of the remedial well installation works. The existing site infrastructure was removed including demolition of the shop building and canopy, removal of fuel filling infrastructure (including 10 operational and 10 disused below ground fuel tanks) and removal of 4,200 tonnes of contaminated soil. Following the demolition, 22 remediation wells were drilled, followed by remediation design and pilot testing.

The following activities were identified as having the potential to generate carbon emissions, with measurable benefit considered possible through thoughtful design of the scheme and sourcing of alternative equipment.

Transport - innovative use of rail instead of road transport for waste management, which avoided 36 heavy good vehicles (HGV) journeys. Carbon savings were calculated using UK conversion factors for average HGV and rail transportation.

Welfare facilities - adopting a hybrid solar/diesel powered welfare unit. The roof mounted photovoltaic panels were used to charge an onboard battery to power lighting and plug sockets.

Security - procurement of solar/methanol fuel cell CCTV units for on-site security.

Plant - use of an electric pallet mover for soil cores and equipment to reduce manual handling, lower carbon emissions and enhance energy efficiency.

Fuel - the adoption of Hydrotreated Vegetable Oil (HVO) to power drilling rigs and generators.

The presentation will discuss the reduction of CO_2 emissions during the site demolition and 12-week remediation well drilling project, which also delivered an estimated 4% cost saving when compared with diesel-operated equivalents. Carbon savings were calculated for site equipment using manufacturer estimates and standard conversion factors for the CO_2 emissions saved vs the equivalent diesel-operated equipment.

In addition, efforts have been made to optimize water conservation through the reinjection of treated groundwater extracted by the remediation system back into the aquifer, demonstrating a commitment to reduce water consumption and increase sustainability.

The presentation will discuss how remediation project design with sustainability in mind can lead to real and meaningful decreases in a project's carbon footprint, while also realising other positive impacts such as cost savings. The presentation will also share lessons learnt.

Abstract ID: 161
MICROSENSE : Development of a novel microbial bioindicator/biomarker to evaluate biodegradation potential of micro- and macro pollutants in environmental matrices (soil and water)
Gilles Quabron[1], Charlotte Balent[1]
[1]CEBEDEAU

Numerous harmful chemical compounds from urban, agricultural and industrial activities are continuously released into the terrestrial environment. The scientific community is increasingly focused on detecting, understanding, and controlling these agents that harm human health and ecosystem sustainability. Monitoring these toxic substances is challenging and costly, mainly due to the complexity and expense of identifying the chemicals involved. Despite many analytical methods, collecting sufficient samples promptly remains a significant obstacle in assessing environmental damage. Moreover, traditional chemical analyses have limited environmental applicability because they do not account for the effects on organisms or the interactions between substances (additive, antagonistic, or synergistic), nor their bioavailability. Researchers, therefore, emphasize the need for biological methodologies to achieve a comprehensive ecosystem approach.
The MICROSENSE project aims to investigate interactions and links between pollutants, nutrients, and the intrinsic capacity of microbiomes to metabolize these substances. To achieve this goal, we combined analytical, enzymatic, and metagenomic methods to identify microorganisms, genes, and enzymes involved in the metabolization processes of these compounds. The complementarity of these technologies enables the detection of the dynamics and functioning of microbial communities in the different studied matrices (soil and water/wastewater) and the identification of relevant bioindicators/biomarkers. The first step of the project was to conduct a state-of-the-art review and select several micro and macro pollutants of interest in Wallonia (Belgium). A pilot test with several bioreactors, in which activated sludge was treated with a dose of previously selected pollutants, was developed. Several monitoring campaigns were carried out. Various physico-chemical, enzymatic, and microbiological parameters are analyzed to determine the presence of a unique pollution indicator (gene, enzyme, indicator species, etc.). The final objective of the project is to develop a field kit to evaluate the potential contamination of the environmental matrix of interest.

Abstract ID: 164

Plant species evaluation for energy crop production and phytoremediation of hydrocarbon-impacted soils under mediterranean climate (Spain).

Alba Catalan Merlos[1], Romina Mariel Gargarello[1], Francesca Audiño[1], Natàlia Blázquez-Pallí[2], Foix Soler-Balaguer[2], David Garriga[2], Marçal Bosch[2], Sonia Sanchis[1]

[1]Leitat Technological Center, [2]LITOCLEAN S.L

In Europe, about 2.5 million sites are potentially contaminated (European Environment Agency, 2022). Worldwide, soils in agricultural systems are under pressure due to the food, feed, fuel competition. In this global framework, the Phy2climate H2020 project aims to alleviate the pressure on lands by establishing a global phytoremediation approach for the recovery of the quality of arable soils, and allowing the use of such marginal or polluted lands to obtain biomass for biofuel production.Within this framework, laboratory pot tests were carried out to evaluate several plant species for their potential for phytoremediation and for biomass production to obtain biofuels. The polluted soils used were collected from an industrial site located in Catalunya (Spain), contaminated by total petroleum hydrocarbons (TPH). A first series of pot tests was established to study four different plant species and amendments to assess the efficiency of each treatment in TPH removal and biomass production. This study was presented in the previous AquaConSoil edition and highlighted that Sorghum sp. amended with compost, biochar and PGPR was tolerant to TPH contamination, producing the highest biomass yield and a significant TPH degradation.A second series of pot tests were later set up to deepen the knowledge on the feasibility of TPH degradation under different agronomic management approaches. For this purpose, Sorghum sp. seeds were grown in 3 L pots with 3 kg of TPH contaminated industrial soil, in natural conditions or sterilized (and later spiked with LNAPL sampled from groundwater from the study site) amended with compost 5% v/v; biochar 5% v/v, and 0.05 g/pot of commercial PGPR solution of 10 g/L. Pots were incubated in a climatic chamber at 25 ºC, 50% humidity, and a photoperiod of 16 h light and 8 h darkness; in aerobic or anaerobic conditions (in sealed plastic bags with anaerobic atmosphere generators). Pots were manually irrigated to reach 80% of field capacity. After four weeks, the seedlings were thinned to three plants per pot Each treatment had four replicates, one used for an intermediate sampling event, the rest used as triplicates in the final sampling event. Visual inspections were carried out weekly to evaluate lushness and pest development. Soil samples were analysed at the beginning and end of the experiment, including i) typical agronomic characterization (P available, K available, total P, total K, N, C, S, total C, total N, organic matter), ii) physicochemical characterization (pH, electric conductivity, water content), and iii) soil pollution, TPH and polyaromatic hydrocarbons (PAH).Considering the results from both pot experiments, the best degradation performance (97%) was observed for Sorghum sp. amended with biochar, compost and PGPR under aerobic conditions. This set-up also gave an attractive biomass yield (height 120 cm and 12 g wet biomass/kg soil). Although similar values could be obtained only with compost addition, the other two amendments were maintained and applied to improve soil structure (biochar) and crop development (PGPR). Assays with sterile soil under aerobic conditions exhibited a lower TPH elimination rate in the absence of amendments and plants, but evidenced a significant contribution of only-compost on TPH degradation (93,28%). Under anaerobic conditions with naturally contaminated non-sterile soil and absence of plants, TPH degradation in non-amended scenarios was comparable to that obtained in the amended ones . All these results demonstrate that Sorghum sp. was able to grow in TPH-impacted soils and suggest that microorganisms could be driving TPH degradation. In addition, they also point to volatilization being an additional attenuation pathway for TPH. These observations were of valuable knowledge in setting up the agronomic management of a phytoremediation and energy crop production strategy on an experimental site for three years.

Abstract ID: 166

Synergistic Effects of Electrokinetic Remediation and Iron Amendment on In-Situ Arsenic Immobilization in Contaminated Soils

MODUPE AKINDOLIE[1], Ivan Carabante[1], Jurate Kumpiene[1]

[1]Waste Science and Technology, Lulea University of Technology, Lulea, Sweden

Arsenic (As) contamination in soil remains a persistent environmental challenge due to its high toxicity to humans and animals. While several remediation strategies, including chemical amendments with iron and electrokinetic techniques, have been developed to mitigate heavy metal mobility in water, their application for in-situ soil remediation is constrained by the inherent complexity of soil systems. Among these approaches, immobilization has emerged as a more viable solution for reducing arsenic mobility and bioavailability. Notably, soils often contain indigenous iron, yet its potential activity in immobilizing arsenic under stimulated conditions remains insufficiently understood. This study hypothesizes that applying an electrical current can activate indigenous soil iron, enhancing its capacity to immobilize arsenic. However, the efficiency of this approach relative to other remediation techniques is not well established.

To address this, three treatment scenarios were evaluated: (1) the combined application of electricity and iron rods, the rods playing a dual function of electrodes and chemical amendment (Treatment A); (2) the use of electricity with graphite electrodes (Treatment B); and (3) the application of iron rods as chemical amendments without electricity (Control). Changes in soil chemical properties were assessed to determine the influence of each treatment on arsenic mobility and speciation. Preliminary findings confirm that the electrokinetic approach effectively stimulated indigenous iron. Iron concentration increased from 124 mg/L to 990 mg/L and 881 mg/L in Treatment A and B, respectively. However, arsenic leaching similarly rose, from 16 mg/L under Treatment A to 35 mg/L by Treatment B. Importantly, arsenic speciation analysis revealed a smaller proportion of the highly toxic As (III) species of 25% by Treatment A compared to Treatment B with 38%. This reduction aligns with the observed decrease in arsenic leaching in Treatment A, which is likely due to enhanced immobilization. Notably, arsenic bioavailability was reduced by 18% under Treatment A, whereas Treatment B showed no comparable effect. These findings demonstrate that while electrokinetic techniques can activate indigenous soil iron, their efficacy in reducing arsenic bioavailability depends on the availability and reactivity of iron species. The combination of electrical stimulation and iron amendments in Treatment A represents a promising, cost-effective approach to in-situ arsenic immobilization. However, the study highlights the limitations of standalone electrokinetic remediation and underscores the need for integrated strategies that leverage the synergistic effects of chemical and electrokinetic processes for arsenic-contaminated soils.

Abstract ID: 168
The Incomplete Imprecise Spatial Data Interpolator for anomaly analysis of the ISLANDR project

Stephane Belbeze[1]
[1]*BRGM*

The ISLANDR project (Information-based Strategies for Land Remediation) is a multidisciplinary project whose primary aim is to contribute to the EU mission "A Soil Deal for Europe". ISLANDR's research activities are designed to provide tools and methods to support: (1) the delineation of polluted soils across Europe, (2) an evidence-based assessment of the risks posed by polluted soils, (3) the promotion of sustainable and risk-based land management practices, (4) the inclusion of a wider valuation approach in financial and investment cases, and (5) a closer integration of land contamination and spatial planning decision-making. Regarding the 1st objective, ISLANDR aims to produce methods for interpolating maps of diffuse pollution based on European soil data. The project's input data is primarily publicly-available geochemical data, including a combination of background measurements, mining surveys, and monitoring of urban and polluted sites. Spatial interpolation is a complex problem that aims to estimate a value based on measured values. There exists a plethora of interpolation methods, most of which have their Achilles' heel when it comes to real-world data that is often "SIC" (scarce, imprecise, clustered). In order to obtain as much information as possible from soil data, a new method of interpolation has been designed by BRGM as part of ISLANDR in order to address SIC data. Such data is not easily processed using classical kriging methods for example, especially when the aim is to detect soil quality anomalies, because the kriging method has a smoothing effect on the interpolated data. We therefore adapted an information dissemination algorithm that was developed in the 2000s, so that it could fully meet the requirements of "SIC" data. The new interpolator has been applied to various data sets: small sets such as those typically encountered in small-scale environmental studies, large sets such as the GEMAS database and intermediate sets such as the one collected for the Toulouse metropolis area for geochemical background estimations. Results highlight the benefits of the proposed algorithm in terms of identifying anomalies when dealing with SIC data, compared to other methods.

Abstract ID: 170
Forensics and big data analytics to identify PFAS sources near and far

Theresa Guillette[1], Allan Horneman[1], Bethany Parker[1], Tessa Pancras[1], Jeff Burdick[1], Matthew Kelly[1]
[1]Arcadis

Purpose of Study
The widespread detection of per- and polyfluoroalkyl substances (PFAS) across the globe and enforcement of stringent environmental regulations necessitate forensic approaches for distinguishing between multiple sources of PFAS in the environment, as well as separating out contributions from anthropogenic background. Given the vast array of industrial, commercial, and consumer sources, it is critical for facilities with potential impacts to distinguish between background PFAS levels and releases from other local sources, such as industry, landfills, and airports. Analytical techniques are the foundation of understanding PFAS presence in the environment, with quantification across various matrices key to source fingerprinting. However, detection alone does not suffice for source attribution, particularly in mixed-use industrial and urban environments. A holistic understanding requires integrating enhanced statistical tools, local background knowledge, release mechanisms, site hydrogeology, and geochemistry to differentiate among potential sources effectively.

This investigation presents case studies using big data analytics and geospatial statistical techniques to investigate background contamination in the Netherlands, United States, and Belgium. Geostatistical tools such as kriging and spatial regression were employed to analyze the spatial distribution and trends of PFAS. Additionally, advanced statistical techniques, including Positive Matrix Factorization (PMF) and Principal Component Analysis (PCA), were compared for their efficacy in source attribution. This approach aims to develop a comprehensive framework for identifying PFAS sources, visualizing spatial trends, and improving source apportionment accuracy to inform environmental policy and remediation strategies.

Methodology
PFAS characterization data from public databases were assessed for quality control and aggregated to evaluate statistical distributions across environmental media in the United States, Netherlands, and Flanders. Geostatistical methods were applied to analyze PFAS spatial patterns, revealing hotspots, release mechanisms, transport pathways, and spatial correlations with urban versus rural land use. PMF and PCA were used to quantify contributions from specific sources, including industrial activities, including air emissions, agricultural runoff, and biosolid applications. An added layer of complexity arises from aerosol transport of PFAS through seafoam, as observed in Scandinavia, which increases background levels of longer-chained PFAS.

To integrate geostatistical outputs with source-specific contributions from PMF, a workflow was developed that interpolated model results to visualize source contributions at unsampled locations. Spatial regression was conducted to correlate model results with spatial predictors, such as proximity to point sources, land use, and hydrogeological variables. Machine learning techniques were incorporated to handle non-linear relationships between PFAS and potential sources.

Summary of Results
PFAS forensic investigations at complex sites demand a weight-of-evidence approach for source attribution. The study focused on a mixed-use watershed characterized by diverse pollution sources, including urban, agricultural, and industrial activities. Geostatistical analyses revealed that PFOS concentrations were highest in agricultural zones, while PFOA hotspots were associated with industrial and commercial areas. Spatial interpolation of PMF outputs highlighted regions of overlap between agricultural and industrial contributions, suggesting cumulative impacts. Spatial regression analyses further established significant relationships between PFAS source contributions and land-use practices, emphasizing the need for localized management interventions.

The importance of background studies was underscored, as surrounding PFAS concentrations were higher in urban areas compared to rural regions. Differences in PFAS fingerprints provided critical insights for source attribution, particularly at sites associated with unique chemical fingerprints. The

study also highlighted the utility of combining advanced statistical tools with GIS-based visualizations to enhance clarity and interpretation. Furthermore, integrating hydrogeology and geochemistry into PFAS investigations was shown to provide context for understanding contaminant transport and transformation.

This research demonstrates the necessity of a comprehensive approach to PFAS forensic investigations, leveraging geospatial analytics, statistical models, and advanced machine learning techniques. The integration of these tools offers insights for policymakers, site managers, and environmental scientists aiming to address PFAS effectively.

Abstract ID: 173
An Evolving Closure Strategy at a Large Scale Phosphrous Impacted Sediment Lagoon: How to Implement and Lessons Learnt

Joanne Dinham[1], Paul Hesketh[1], Oliver Phipps[1], Chris Rice[1]
[1]Environmental Resources Management, UK

Effective management of Soil-Sediment-Water (SSW) systems is crucial in addressing environmental impacts, particularly in complex settings such as waste disposal lagoons. This case study provides a detailed overview of how an evolving closure strategy has been developed, refined and implemented by ERM at such a site in the UK, together with lessons learnt.

The lagoon in question is divided into two sections (small and large, comprising a total area of 37,500m2) by a granular fill embankment (the 'Causeway'). The site has been regulated under a Waste Management Licence (WML) since its use for disposal of solid by-products, predominantly white Phosphorus (P4), between the 1940's and 2005.

In 2013, significant remediation works were carried out by ERM, focusing on sustainable practices that not only addressed contamination but also aimed to restore the lagoon ecosystem above the capped waste. The works included widening the Causeway for access, dredging the small lagoon, and 'capping' the base of the large lagoon with a liner to eliminate a contact pathway between the onsite ecosystem and deposited P4. A pumping system was also installed to prevent flooding of the Causeway and therefore mitigate potential cross-contamination between the small and large lagoons. Despite completion of these remedial works, the WML remains in force and includes a requirement for ongoing pumping and monitoring that has been carried out by ERM since the remediation works were completed. This monitoring has two purposes: 1) to satisfy WML requirements and regulatory objectives, and 2) to validate the requirements of the liner warranty to confirm its temporal effectiveness and integrity.

Site monitoring is typically completed on a biannual basis. Unlike most contaminants, the laboratory analysis of P4 can take up to six months before results are obtained, introducing further complexity into the project.

As we reach a decade since remediation, the site owner now wishes to surrender the WML, prompting a need for the current management strategy to evolve, including review of all of the environmental information collected to date to develop a 'line of evidence' based closure approach. To date, this comprises the following:

•Additional review of the WML show that its original requirements were based on a very different environmental setting (i.e. ongoing disposal of P4 and prior to sediment remediation), that does not reflect current conditions.

•Monitoring works to date indicate that the capping method has successfully contained the waste since it was installed, with no significant increase in P4 concentrations detected in the large lagoon or the surrounding groundwater regime.

•An initial water balance study was completed to identify the potential risk of flooding if pumping were to cease. The results show that the water level is estimated to rise by approximately 120mm per year, suggesting that the Causeway could flood within 1 to 3 years. To address this concern, a pumping cessation trial has been specified by ERM with the aim of understanding the dynamic interactions within the SSW system without abstraction. This study will also include analysis of potential climate change impacts.

This case study demonstrates how the challenges of managing a legacy site with complex and unusual contaminated waste can be addressed. The lessons learnt to date are that defining appropriate monitoring strategies and adaptation of these are needed to meet regulatory and other stakeholder requirements. It also shows how management of contaminated sediments will evolve pre and post active disposal and completion of remedial measures, and in response to evolving client needs, as the strategy now moves from one of compliance to demonstrating that permit surrender is now acceptable, while also fostering the creation of natural habitats that enhance biodiversity and ecological resilience.

Abstract ID: 175
A method for evaluating the effects of gentle remediation options (GRO) on soil health: Demonstration at a DDX-contaminated tree nursery in Sweden

Paul Drenning[1], Yevheniya Volchko[1], Anja Enell[2], Dan Berggren Kleja[3], Maria Larsson[4], Jenny Norrman[1]
[1]Chalmers University of Technology, [2]Swedish Geotechnical Institute, [3]Swedish Geotechnical Institute; Swedish University of Agricultural Sciences, [4]Örebro University

Keywords: Contaminated sites; Gentle remediation options (GRO); Soil functions; Ecosystem services; Nature-based solutions (NBS)

Purpose: The purpose of this poster is to present the overall method developed in a recent study to evaluate the effects of gentle remediation options (GRO) – i.e., nature-based risk management strategies/technologies that use plants, bacteria and fungi for effective risk management and improving soil functions – on soil health, including selection of indicators, statistical analysis and the conceptual connection to soil functions and ecosystem services. Main results from the study where the method was applied for a field experiment at a historically DDX-contaminated tree nursery site will be highlighted.

Methodology: To test the effectiveness of eight GRO strategies to manage risks due to DDX contamination and improve soil quality, a pilot-scale field experiment was established at the Kolleberga site in Ljungbyhed (Southern Sweden) by: (1) thoroughly homogenizing the soil, (2) using a randomized block design of test plots, and (3) planting suitable plants in each plot in a triplicate, either in combination with or without biochar as a soil amendment. Physical, chemical and biological indicators were selected via a 'logical sieve' to assess both the fate of the contamination as well as resulting impacts on soil functions. The indicators were aggregated into higher-level categories within specific ecosystem services (ES) to assess whether there resulted an increase or decrease in a particular ecosystem service's provisioning as result of GRO application. The soil health assessment results are visualized as radar diagrams.

Summary of findings/results: The results indicate that GRO can have significant positive impacts on soil health, which may be primarily due to the addition of biochar for improving soil fertility and improving microbial activity as well as reducing uptake of DDX in vegetation and earthworms. Effects of the different plants on soil functioning vary depending on the plant species. The radar diagram shows different degrees of positive or negative effects from the treatments on soil functions and ecosystem services compared to the experimental control. In general, the mix of leguminous clover and alfalfa with biochar are shown to have the most positive effects, though the effects of biochar vary per the different ecosystem services.

Conclusion/take home message: Research results have shown that the tested GRO strategies can have positive impacts on soil health thus improving the delivery of ecosystem services. Biochar amendment especially is shown to be effective for managing the risks of DDX contamination while also improving many physical, chemical and biological indicators relating to specific soil functions. The method demonstrated here can provide valuable input into the ongoing work to manage contaminated sites while accounting for soil health.

Significance/contributions of study: The sustainable and risk-based alternative proposed here instead is referred to as 'phytomanagement' – i.e., the long-term combination of GRO with beneficial land use (e.g., biofuel crop production) to gradually reduce risks at contaminated sites while also restoring ecosystem services. Phytomanagement is highly relevant to bring into the conversation as a proactive and multifunctional contaminated land management strategy for managing risks and improving soil functioning. There is also a clear connection to the recent initiatives relating to the EU Green New Deal and coming EU Soil Monitoring Law. The method followed here to evaluate the effectiveness of GRO treatments using soil health assessment provides valuable information that will be useful in communication with stakeholders. This study is well-suited to Theme 1 (Soil-Sediment-Water (SSW) Systems Management) subtopic 1: Enhancing Ecosystem Services.

Abstract ID: 178

A new methodology coupling LCA with matrices for multidimensional sustainability assessment of remediation based on social media

Meng Xiao[1], Xianglan Li[1], Hongzhen Zhang[2]

[1]Faculty of Geographical Science, Beijing Normal University, [2]Soil Protection and Landscape Design Center, Chinese Academy of Environmental Planning

Sustainable assessment is vital for balancing environmental, social, and economic impacts of remediation to maximize net benefits and promote Green and Sustainable Remediation (GSR). However, current sustainable assessment methodologies lack a unified framework to address multidimensional impacts and incorporate public participation effectively. Moreover, there is a scarcity of robust methods and reliable data for indicator weighting. This study developed a concise and efficient sustainable assessment methodology that integrates multiple impacts by coupling Life Cycle Assessment (LCA) with matrix assessment. The study also generated a set of weighting data utilizing social media big data, identifying public perceptions to create data that is widely applicable, spatiotemporally characterized, and updatable. The results showed that the environmental, social and economic dimensions were weighted at 73.75%, 19.20% and 7.05% respectively. Employing this established methodology and weighting data, the study conducted a comprehensive decision-making between in-situ remediation (IR) and ex-situ remediation (ER) alternatives at a specific contaminated site. The results indicated that the comprehensive sustainability scores for IR and ER were -306.01 and -354.81, with IR emerging as the more sustainable remediation alternative. The sustainable assessment methodology and weighting data developed in this research offer a replicable and scalable feasible pathway and data support to enhance assessment efficiency, reduce evaluation costs, and drive the development and implementation of GSR at contaminated sites.

Abstract ID: 180
Leaching of Arsenic Released from Excavated Rock with Atmospheric Exposure under Unsaturated Water Migration
Noriko Manabe[1], Masahiko Katoh[1]
[1]*Meiji University*

A large amount of rock/sediment/soil is excavated to create underground space for the construction of modern high-speed railways and roads around the world. Such excavated solid materials contain geogenic hazardous metal(loid)s such as arsenic during the sedimentation and hydrothermal metamorphism. The arsenic content in the excavated rock is the background levels, but the excavation often alters the arsenic phases to more soluble due to the increase of specific surface area, exposure to water and air, and drying. The excavated rock becomes an environmental concern if the level of arsenic release exceeds the acceptable level for soil. Thus, it is important to understand how arsenic is released from the excavated rock for their reuse without posing environmental risks. The excavated rock is re-used as embankments and roadbed materials. In these applications, the rock pores are filled with water and air, and water migrates through the pore. As the water migration, the rock surface may be exposed to wetting or drying conditions, repeatedly. The atmospheric exposure to wetting and drying condition may alter the arsenic phases to more (in)soluble, resulting in the enhancement/suppression of arsenic release and leaching from the excavated rock. This study performed the up-flow unsaturated water percolation test to understand how the leaching behavior of arsenic released from the excavated rock are altered with the atmospheric exposure under the unsaturated water migration.

This study designed and conducted the up-flow suction percolation test with three layers: excavated rock layer, recovery sorbent layer, and cover soil layer from the bottom of the pot. Water was added from the bottom of the pot to maintain 60% of the water-holding capacity of solid material for 12 months. This experimental design allowed the water to flow from the lower parts toward the upper parts under the unsaturated water condition by suction. The samples of the excavated rock collected after the test was subjected to the analysis to determine the amounts of water-soluble arsenic and the arsenic phases by the sequential extraction procedure in the excavated rock. The recovery sorbent was also collected from the recovery solvent layer to determine the amount of arsenic leached during the test period.

The amounts of water-soluble arsenic in the excavated rock increased with the increase in the test period. However, the amounts of arsenic leached from the excavated rock did not increase during the test period. The dominant arsenic phases were the specifically bound and amorphous iron/aluminum oxide bound, which are relatively less mobile phases. Thus, arsenic released from the excavated rock would be less migrated even under the atmospheric exposure. This study suggests that it is necessary to evaluate the mobility of arsenic depending on the situation of the reuse site because the arsenic phases alter after the reuse.

Abstract ID: 183
Choosing the Right Machine Learning Prediction Strategy for Pump and Treat (P&T) Evaluation: Multivariate Analysis and Regression-Based Methodology

Krzysztof Kowalski[1]
[1]*Capital Region of Denmark*

Purpose of Study:
Pump and treat (P&T) systems still play a role in groundwater remediation and are often presented as expensive, but unavoidable, alternative with substantial operational and environmental costs, primarily due to granular activated carbon (GAC) usage and electricity consumption. Previous studies demonstrated the feasibility of utilizing historical operational data to evaluate these burdens and suggested strategies for optimizing P&T plant performance. This study investigates the potential of machine learning techniques to enhance predictions of operational effectiveness and carbon footprint, supporting informed decision-making in the design and evaluation of remediation systems. Moreover, it could help in benchmarking any new remediation against not only investment, but also operational burden of the pump and treat (P&T) systems.

Methodology:
This work utilized historical data on energy and GAC consumption from multiple P&T plants, linking these to pollutant removal efficiencies and CO_2 emissions derived from GAC and electricity usage. Principal Component Analysis (PCA) was employed to reduce the number of parameters from dozens to few selected, by capturing variability and relationships influencing treatment effectiveness. Machine learning models were trained on aggregated datasets to predict key outcomes, such as energy consumption and GAC usage, which gave opportunity to subsequently recalculate those into the CO_2 footprint of P&T operations.

Summary of Findings/Results:
- PCA effectively captured multivariate parameter variations and their influence on treatment effectiveness, reducing the number of parameters while maintaining essential variability.
- CO_2 footprints were modeled separately as functions of GAC and electricity use, revealing distinct predictive relationships that highlight the need for tailored modeling approaches.
- Random forest (RF) and linear (Linear) regression models demonstrated strong predictive utility, with scatter plots of predicted vs. measured values showcasing model performance (see Figures 1 and 2). Bubble sizes indicate pollutant concentration (for GAC) and flow rates (for electricity).
- GAC consumption predictions were closely tied to pollutant concentrations, while energy predictions correlated with flow rates, reflecting the differing dynamics of these two key variables.
- The analysis highlighted the importance of identifying and addressing outliers, which often represent real-world operational challenges. Incorporating these outliers into the models helps account for uncertainties inherent in P&T operations.
- Challenges in integrating independent variables within a single predictive framework were evident, underscoring the need for flexible modeling approaches. In some cases, dependent variables, such as pollutant load and GAC saturation, were incorporated as part of the solution to enhance model robustness and accuracy.

Conclusion/take-Home Message:
Machine learning methods offer promising avenues for modeling P&T system performance and environmental impacts. However, balancing predictive accuracy with model simplicity requires careful selection of input variables. Different levels of operational management may require varying levels of accuracy, ranging from high precision for detailed analysis to simpler models for routine decision-making. A linear regression approach with fewer variables may offer a practical compromise, enabling robust predictions while maintaining interpretability across these different operational contexts.

Significance/Contributions of Study:
This work advances the application of machine learning for P&T evaluation by addressing key challenges in data-driven modeling, emphasizing the need to balance model simplicity, applicability,

and accuracy. A well-designed, simple, and interpretable model can provide accurate insights, making it a valuable tool for comparing P&T systems with lower-emission alternatives.

Abstract ID: 187
Advances in situ chemical oxidation remediation technology through surfactant based in situ soil flushing pre-treatment to enhance recovery: full scale application
Guido Piepoli[1]
[1]ASTC REMEDIATION

The combined use of physical and chemical remediation approaches synergistically increases soil and groundwater in situ treatment efficiency, saves costs, and meets an inflexible remedial deadline. The use of tailored surface-active agent followed by an oxidation, provides improvements than standard remedial technologies as is.

The site on which we developed this project, is located in Ferrara's province (Italy) in a high populated residential area closed to the Adriatic Sea.

The most challenging problem, was to reduce concentration of the hydrocarbons at a depth of 2÷5 m bgl, without spreading out the pollutants, damaging the adjacent buildings. The contamination is constantly submerged by sea water.

The technology chosen was a combined approach through an in situ soil flushing traement (ISSF), folloved by an in situ chemical oxidation treatment (ISCO), in order to reach the Italian Environmental Law Limit (D.Lgs. 152/06, All. 5, Tab.2).

We realized 88 injection wells and 22 monitoring wells divided on three source areas. The radius of influence for the wells, were determined through pumping tests done into the monitoring wells. The final installation chosen was an hexagonal shaped multilayer well system.

To apply these tecnologies, we've developed and patented a semi-authomatic injection plant with remote controle of the process and its parameters.

Abstract ID: 190
Endophytes-stimulated phytoremediation of zinc in the topsoil of a scatter field

Stephanie Vandionant[1], Martin Slooijer[2], John Dijk[1], Remi Peters[3], Christopher Cohu[4], Renee Murphy[4]
[1]GreenSoil B.V., [2]GreenSoil International B.V., [3]GreenSoil International B. V., [4]Intrinsyx Environmental

Purpose of study
In 2024, GreenSoil was asked to propose a remediation concept for a zinc contamination (61 – 6200 mg/kg dry weight) in a sandy loamy topsoil (0 – 10 cm bgl) of scatter fields with a total contaminated surface of 800 m2. These fields are used to scatter the ashes of deceased people after the incineration process and can be visited by beloved ones hereafter. Due to the sensitive nature of this location, the remediation technique can not disturb the integrity of the site. Therefore, GreenSoil has proposed to use biological-stimulated phytoremediation on-site. The phytoremediation process will be enhanced by the use of endophytes, provided by one of GreenSoil partners, Intrinsyx (CA, USA)

Methodology
This project will consist of two phases. Firstly, a lab test will be conducted in 2024/2025. The results of the lab test will be implemented in a following field pilot, starting in 2025. The lab test will consist of 4 conditions in which two plant types (Brassica napus and Brassica juncea) will be tested with or without the addition of the endophytes. The endophytes will be administered by coating the 3-week-old seedlings. The zinc content and dry weight of the soil, roots and aboveground biomass will be analysed at the end of the lab test, which has a duration of 4 months. The zinc content of a T0 soil sample shall be measured as well in addition to the nutrient content, dry weight, pH and conductivity. The pH and conductivity of the soil will be followed-up weekly. In addition, leafy parameters will be weekly measured, including plant height.

Summary of findings/results
Since the lab test of this project will soon be executed, at the moment no results can yet be shown. We expect to have all lab test analyses in April 2025.

Conclusion/Take home message
No conclusions can yet been drawn, but we expect that one of the plant types will be more suitable for the remediation of the scatter fields. In addition, we expect that the endophytes will enhance the ability of the plants to take up the zinc in the topsoil, this due to a shortening of the time period or due to a higher uptake rate.

Significance/Contributions of study
Although endophytes are previously used to enhance agricultural yield, now they are applied to make the plants more resilient against high contaminant concentrations and to increase the uptake of the contaminant by the plant.
With this test, GreenSoil aims to be able to remediate sensitive or cultural sites where standard techniques are too invasive to use. In addition, GreenSoil intends to use this technique for a preventive use. For example, the scatter field exists of several smaller fields where ashes can be scattered. By only using a number of fields per year, other fields could be used for the phytoremediation technique, preventing high contaminant concentrations. The use of each field could be switched between the years in order to still use fields whilst also being able to remediate in a preventive way. In this way, contamination on a location can be controlled throughout the years. Lastly, GreenSoil intends to use this remediation technique as a potential approach for metal contaminated sites, where the contamination is focused in the topsoil (root depth). It is difficult to achieve a general remediation technique that is able to work well for all kind of heavy metals. Although we will focus on zinc in these tests, other metals are also a problem and can be examined. This way, we aim to overcome the necessity of using several techniques for metal remediation.

Abstract ID: 192
Phytoremediation, soil quality recovery and revalorization of harvested biomass for clean biofuel production at a TPH polluted site in Spain

Natàlia Blázquez-Pallí[1], Foix Soler-Balaguer[1], Alba Catalán Merlos[2], Francesca Audino[2], Romina Mariel Gargarello[2], Christopher Kick[3], Sonia Sanchis[2], David Garriga[1], Marçal Bosch[1]
[1]LITOCLEAN, [2]LEITAT, [3]Fraunhofer UMSICHT

In Europe, about 2.5 million sites are potentially contaminated (European Environment Agency, 2022). Worldwide, soils in agricultural systems are under pressure due to the food, feed, fuel competition. In this global framework, the Phy2climate H2020 project aims to alleviate the pressure on lands by establishing a global phytoremediation approach for the recovery of the quality of arable soils, and allowing the use of such marginal or polluted lands to obtain biomass for biofuel production.

To prove the feasibility of such an approach, an industrial site located in Catalunya (Spain), contaminated by total petroleum hydrocarbons (TPH), was selected as a case study for the development of a phytoremediation field pilot test that lasted for three growing seasons. The crop species selection was performed through a series of laboratory pot tests, presented in the previous AquaConSoil edition, and with extended experiments submitted as a separate abstract for this AquaConSoil conference. Based on those results, Sorghum sp. was selected because of its TPH-tolerance and highest biomass yield when combining the soil amendments PGPR, compost and biochar. Notwithstanding, a crop rotation with rapeseed was initially considered to ensure a vegetative cover all year long. The pilot area covered a total surface of 800 m2, in which two different phytoremediation parcels were delimited: a control and experimental parcel located over non-contaminated and contaminated soil, respectively. Given that TPH contamination in the non-saturated zone was located between 1,5-3 m depth, the experimental parcel was excavated and refilled prior to the first and second season to bring polluted soils to the surface. An additional parcel without plants was later established in the experimental parcel. The monitoring of the in situ phytoremediation pilot included several lines of evidence: i) weather conditions; ii) visual inspections to monitor pests and phytopathologies, nutritional deficiencies, height and phenological stages of plants, and biodiversity changes; iii) soil characterization (typical agronomic physicochemical parameters, TPH and metal(loid) concentrations); iv) characterization of soil microorganisms (total microbial biomass and metagenomic analyses); v) plant tissue characterization (TPH and Pb in above- and belowground plant biomass), and vi) produced pellet characterization. The soil characterization was performed from composite-soil samples collected across the studied parcels and in depth. Broadly, the results obtained in the field agreed with the insights from the laboratory pot tests, but some aspects were remarkably significant when implementing such a strategy in the field. First, only Sorghum sp. was maintained and sown every season, since rapeseed's sowing period coincided with the wet season of the area and germination was greatly hindered. During the first Sorghum sp. growing season, the most polluted subparcels exhibited poorer germination, plant development and growth compared to those less polluted and to the control. However, plant development and growth generally improved with every consecutive season, except for the parcels that were impacted by unintended nearby herbicide application. In soil, pollution was heterogeneous and starting TPH concentrations 70% TPH decrease); some were close to the national environmental regulation (50 mg/kg). The harvested biomass quality and yield achieved every season was enough to meet the requirements of the biofuel production process.

In summary, the phytoremediation approach implemented here was able to fulfil both the needs of improving arable soil quality and harvested biomass revalorization, demonstrating its potential for the recovery of ecosystem services and climate change mitigation.

Abstract ID: 194

Cultivating flooded rice (Oryza sativa) in rotation with sugarcane to improve soil and environmental quality from agricultural watersheds within South Florida, USA.

Jehangir Bhadha[1], Abul Rabbany[1], Xue Bai[1], Noel Manirakiza[1], Suraj Melkani[1], Tanjila Jesmin[1], Matthew VanWeelden[1]

[1]*University of Florida*

During summer months (June- August) more than 202 km2 of fallow sugarcane land is available for rice (Oryza sativa) production in South Florida, USA. The net value of growing flooded rice in the region as a rotational crop with sugarcane far exceeds its monetary return. Soil conservation, pest control, and phosphorus (P) load reduction are some of the benefits to ecosystem services. With no P fertilizer applied, rice cultivation in Florida can potentially function as a sink for P because of particulate settling and plant P-uptake, while harvested whole grain rice can effectively remove P from a rice field per growing season. A controlled experimental plot was designed to quantify the reduction in P concentration and loads between inflow and outflow over a 110-day rice cultivation cycle. Daily water samples were collected from inflow and outflow over a six-week period once a permanent flood was established. Inflow water P concentration was manipulated weekly, from 0, 0.075, 0.22, 0.50, 0.22, and 0.075 mg/L P. Approximately 160 L of water was treated daily. On average, 28% reduction in total P (TP) concentration and 51% reduction in soluble reactive P (SRP) was observed between inflow and outflow, corresponding to significant P load reductions using this treatment technology. Soil health benefits include increased water holding capacity, and reduced active carbon compared to fallow fields due to the decrease in soil redox potential. A significant increase in Mehlich-3 P content was observed at soil depth of 15-30 cm after rice cultivation, probably resulting from the root biomass structure. In addition, P load reductions were increased over the flood depth. Future research work includes (i) evaluating P use efficiency in crop management by identifying and selecting rice varieties tolerant to low P inputs; and (ii) groundwater interactions with surface water.

Abstract ID: 196
New spatial strategies for redelevopement of brownfields

Geert Roovers[1], Jesse Wijnen[2], Rick Dijkstra[2]
[1]Saxion, [2]Saxion University of Applied Science

Purpose In recent decades thousands of contaminated sites have been globally identified and partially remediated. However, resource constraints often prevent full cleanup. Instead, contamination is contained and monitored to minimize health risks, enabling limited use of these contaminated sites. In the Netherlands, about 600 "controlled pollution" sites cost an estimated 6 to 10 million euros annually to manage, with over 250,000 additional polluted sites still awaiting intervention. The need for scalable, integrated solutions has never been more pressing. Polluted sites, while often seen as liabilities, hold significant potential for new spatial developments that align with ecological, recreational, and economic goals.

This contribution presents results of research by Saxion University of Applied Science and Rotterdam University of Applied Science. This research is done in a broad consortium of public and private partners. There is exchange of views and results with the EU-project ISLANDR.

Methodology
The research is primarily action-research done around five contaminated locations and their main stakeholders. With a design research approach the potential of these locations is investigated. With case-study research opportunities and barriers for redevelopment are specified. Based on these results, new strategies are designed which combine a spatial and environmental approach with area-development.

Summary of results
The results which will be presented are structured around three key issues The first issue focuses on cataloging and categorizing technical solutions for soil contamination. By compiling a toolkit of remediation methods, the research examines how these techniques can be integrated into spatial design through design-driven research. Each case adopted a unique planning and spatial strategy, allowing researchers to assess the potential of contaminated sites through site-specific design interventions. The second issue investigates the complexities of soil contamination from a governance perspective. Through case studies, the research has deepened known barriers that frequently impede site redevelopment, examining the intricate web of factors that play a role in the planning and decision-making processes. By dissecting these dynamics, this part of the study sheds light on the role of soil contamination within these complex, multi-layered frameworks, revealing the procedural and regulatory bottlenecks that often hinder progress. The third issue is a future-oriented, area-development approach, focusing on prospective changes in legislation and the need for systematic solutions to soil contamination in the Netherlands. This part of the research calls for a shift in policy and governance approaches, advocating for structural changes and a proactive stance among policymakers to pave the way toward a cleaner, sustainable future. By identifying necessary transformations on a meta-level, this research pathway aims to foster a new mindset that prioritizes ecological resilience and sustainable land use in contaminated areas.

Conclusion and significance
Our research highlights that sustainable spatial transformation can be realized through accessible, scalable solutions for soil contamination, especially when integrated into the urban fabric. From a design perspective, many low-threshold remediation methods can be incorporated into public spaces and existing streetscapes, enabling interventions that do not require large-scale redevelopment. This approach positions soil decontamination as a gradual, long-term process that becomes a visible part of the urban environment, rather than an isolated response during major projects.

This contribution builds upon earlier contributions about this topic on ACS2019 and ACS2023.

Much images of spatial design of this research available.

Abstract ID: 202
Critical mineral recovery to support the energy transition

Sarah Hale[1], Jeffory Gillow[2], Emilie Dal[1]
[1]Arcadis (UK) Limited , [2]Arcadis U.S., Inc.

Critical minerals (CM) are elements of the periodic table (and a few minerals, e.g., graphite, fluorspar, barite) that are needed for manufacturing advanced materials and renewable energy technologies. Critical minerals are key to meet the demands of a shift towards renewable energy such as solar, wind, hydrogen and battery power. Increased supply of minerals such as lithium, nickel and cobalt for battery cathodes; rare earth elements for electric vehicle and wind turbine motors; and gallium, germanium, indium and tellurium for photovoltaics, is needed. The energy transition will result in a shift from hydrocarbon based energy generation to metals and minerals as the raw materials of green energy technologies.

Conventional mined sources of many of these elements are limited or not available, especially in the UK and Europe, or exist within regions where geopolitics and social aspects are unfavourable for sourcing. Unconventional or "secondary" sources such as waste materials from energy generation, mining (e.g., coal production in the UK and Europe), milling, and industrial activities are therefore gaining increasing attention. Site environmental managers and full-value resource logisticians need to be aware of the opportunities and benefits of critical mineral recovery to the life cycle costs of waste liabilities, and costly and lengthy permitting timeframes associated with conventional sources can be avoided through development of unconventional sources at brownfields sites.

Building on case studies, the presentation will provide information about how these critical minerals can be recovered and at what cost. The case studies will include examples from the UK and America related t:

sampling and analysis of mining and industrial waste solids and waste waters for the full list of critical minerals process engineering evaluations of CM recovery from waste materials and wastewaters including capital and operation/maintenance costs for processing and cost estimates. coordination of pilot tests to refine the engineering evaluation and assess feasibility of CM recovery. pre-feasibility and feasibility engineering evaluations to determine if CM recovery can be implemented to 1) valorize constituents in wastewaters (to supplant water treatment) and 2) enhance value and sustainability with ongoing operations, and 3) offset site remediation and closure costs through recovering value associated with CM, and gaining more regulatory/stakeholder acceptance/support for projects.

The case studies will show the possibilities available, their feasibility, challenges and benefits of recovering CM from unconventional sources. The presentation will also highlight the current political landscape and how it can be used to meet the future demands on CMs.

Abstract ID: 205
Impact of nematodes on N_2O emissions from soils amended with organic materials of varying quality

Malaika Mariana Andrade[1], Junwei Hu[1], Stefaan De Neve[1]
[1]Ghent University

Agriculture significantly contributes to global anthropogenic N_2O emissions, primarily due to extensive nitrogen (N) fertilizer use, which enhances microbial processes such as nitrification and denitrification—key pathways for N_2O production. While fertilization type and management practices are well-documented factors influencing N_2O emissions, the role of soil fauna, particularly nematodes, remains underexplored. As the most abundant soil fauna, nematodes play a crucial role in nitrogen cycling through interactions with soil microorganisms, potentially affecting N_2O fluxes.
 This study aimed to quantify the effect of soil nematodes on N_2O emissions under varying nitrogen fertilization regimes and soil textures. A 58-day microcosm incubation experiment was conducted using soils treated with no nitrogen addition (CK), chemical nitrogen fertilizer (CF), pig manure (PM), and green manure (GM) in two soil textures—sandy loam and loamy sand. N_2O emissions were measured in the presence and absence of the entire soil nematode community.
The results demonstrated that nematodes significantly increased N_2O emissions, particularly in organic fertilizer treatments (PM and GM) in loamy sand soils ($P < 0.05$). Organic fertilizers not only stimulated nematode activity but also promoted population growth, leading to increased nematode abundance. In the CK treatment, nematode presence significantly enhanced apparent nitrogen mineralization ($P < 0.05$), indicating their key role in nutrient cycling.
These findings highlight the significant influence of nematodes on N_2O emissions and underscore the need to include soil fauna dynamics in emission models and mitigation strategies. By understanding the interactions between fertilization practices, soil texture, and nematode activity, this study contributes to more accurate predictions of N_2O emissions and provides insights into effective approaches for mitigating greenhouse gas emissions from agricultural soils.

Abstract ID: 209
Reactive ZVI-biochar for chlorinated ethylene remediation in groundwater aquifers

Jinxin Zhao, Dominique Tobler, Weizhao Yin, Mette Broholm, Annika Fjordbøge, Klaus Mosthaf, Hans Chr. Hansen
University of Copenhagen#Jinan University#Technical University of Denmark

Purpose of Study:A highly efficient, cost-effective, and sustainable ZVI-biochar granular material has been developed to address the widespread issue of chlorinated ethylene (CE) contamination in groundwater. A highly efficient, cost-effective, and sustainable ZVI-biochar granular material has been developed for both fast removal and full destruction of chlorinated ethylenes (CEs) contaminated groundwaters. The biochar component ensures continuous freeing of sorption sites for CEs, while the tightly associated ZVI component ensures full degradation of the CEs to benign products.
Methodology:This new granular composite material, consisting of biochar and ZVI, is produced using a one-step carbothermal method. Specifically, wood pellets are first impregnated with an iron(III) salt and urea, and then pyrolyzed under oxygen free conditions to induce the reduction of iron(III) to ZVI by the syngas that is produced as the wood is turned into biochar. The reactivity of this composite material towards CE degradation has been vigorously tested, to determine its selectivity and reactivity in different water matrices and in the presence of single and multiple CEs, as well as its maximum reducing capacity and longevity under different redox conditions. Currently, we perform sand column studies with artificial and real groundwater from a vinyl chloride contaminated site in Denmark to test the performance of this granular filter material under fast flow.
Summary of Findings/Results:Batch experiments have showcased complete and fast removal of high doses of TCE (up to 1000 μM, with ZVI loading of 0.13 g/L) within 30 hours via adsorption, and fast production of acetylene demonstrating about 70% of CE degradation within the first 24 h. When testing other CEs (PCE, cis-DCE and VC) and different groundwater matrices, we observe similar fast removal and degradation rates, demonstrating the composite's versatility and applicability to CE contaminated groundwaters. Notably also, testing high TCE doses demonstrated that 90% of the composite reducing capacity can be used for CE degradation. In aging tests performed in anoxic waters and in air, a loss of reducing capacity of the composite is observed with increasing aging time. However, when testing TCE reactivity after several weeks aging, removal and degradation rates are still as fast as when tested on non-aged materials. Column studies are currently underway, and results will be discussed and interpreted with modelling.
Conclusion/Take-Home Message:Granular ZVI-biochar with high hydraulic conductivity and high reactivity towards TCE dechlorination was successful produced by one-step carbothermal reduction. The reductive dechlorination ability of the composite was significantly improved by optimization; its versatility has also demonstrated that the composite is efficient for other CEs.
Significance/Contributions of Study:This study showcases a new granular ZVI-biochar composite material for permeable reactive barriers or filter system, that not only ensures fast removal of CE from a fast-flowing contaminated water, but also the follow up full dechlorination to benign products. The composite material is produced using a simple carbothermal method, using cheap and sustainable materials which has potential for up-scale and broader application at contaminated sites. The composite also stands out from similar Fe-C material by its efficiency and degradation of challenging compounds like VC.

Abstract ID: 216
Leaching potential of PFAS compounds from soil: Insights from batch and column experiments

Jette Kjøge Olsen[1], Morten Birch Larsen[1], Nanna Thomsen[1], Peter Bundgaard Mortensen[2], Jens Muff[3], Anne Tipsmark Ottosen[4]
[1]Ramboll Denmark, [2]Eurofins, [3]Aalborg University, [4]The Region of Southern Denmark

Purpose of Study: The study aimed to evaluate the leaching potential of PFAS (per- and polyfluoroalkyl substances) from unsaturated soil and to assess the impact of soil handling and homogenization on PFAS mobility, with a focus on the risk towards groundwater contamination associated with soil excavation and soil relocation.

Methodology: The project involved collaboration between Ramboll, Aalborg University, Eurofins, and the Region of Southern Denmark and was divided into three work packages, focusing on literature review, fieldwork, and leaching experiments. The field work was focused on measuring concentrations of PFAS in soil and pore water in the unsaturated zone by installing suction cells and taking out soil cores. The third work package included both batch and column tests, with soil analysis conducted before and after leaching accompanied by water analysis to assess mass balance. The alternative analytical approaches, involving PFAS 22, TOP (Total Oxidizable Precursors), AOF (Adsorbable Organic Fluorine), EOF (Extractable Organic Fluorine), and PFAS70, are being applied in steps to select the most effective analysis methods for identifying undetectable PFAS in soil matrices.

Summary of Findings/Results: Preliminary results from ongoing leaching and batch tests on intact and homogenized soil cores indicate that PFAS compounds could leach from soils with soil concentrations below detection limits, causing risk of groundwater contamination. The findings also suggest that the leachates from homogenized soil may exhibit an increased leaching over intact soil cores, indicating an increased risk of groundwater contamination from excavated soils.

Conclusion/Take Home Message: This study suggests that there is a need for more precise analytical methods to detect PFAS in soil and highlights the importance of considering potential risks associated with low PFAS concentrations, especially during excavation, handling or transport of the soil. The project provides a better understanding of the distribution of PFAS in the soil, air and water phases in the unsaturated zone and improves the risk assessment for ground and surface water contamination.

Significance/Contributions of Study: The research provides a substance-specific risk assessment for PFAS leaching from soil to groundwater in the unsaturated zone, and insights into risk changes due to soil excavation, handling and transport of soil. It emphasizes significant learnings ('take-home messages') that are useful when handling PFAS contaminated soil.

Abstract ID: 218

An Innovative Automated Flux Chamber for Real-Time Monitoring of VOCs Emissions from the Subsurface at Contaminated Sites

Nicolò Tonolo[1], Alessandra Cecconi[1], Srey Mom Vuth[1], Donato Abruzzese[1], Daniele Carnevale[1], Alessandro Bigi[2], Sergio Teggi[2], Simona Berardi[3], Maria Paola Bogliolo[3], Iason Verginelli[1]

[1]*University of Rome Tor Vergata,* [2]*University of Modena and Reggio Emilia,* [3]*Institute for Insurance against Accidents at Work (INAIL)*

Measurement of emission fluxes of Volatile Organic Compounds (VOCs) from the subsurface is an effective tool for characterizing and monitoring contaminated sites. Current monitoring campaigns for evaluating VOC fluxes are generally conducted with seasonal frequency, relying on either soil-gas sampling and subsequent laboratory analysis or the use of high-cost instrumentation for rapid and expedited concentration measurements. These methods, while providing representative results of average values over specific and narrow time intervals, do not allow for the assessment of the dynamic behavior of VOC fluxes, which are known to exhibit significant fluctuations on both daily and seasonal scales. To overcome this limitation, there has been growing interest in recent years in developing low-cost systems that allow for continuous monitoring of VOC emissions.

This study presents the design of an innovative and cost-effective Automatic Flux Chamber for continuous and real-time monitoring of VOC fluxes from the subsurface. The chamber employs a low-cost commercial Photoionization Detector (PID) sensor to measure contaminant concentrations within the chamber and is equipped with two air pumps dedicated to periodic automatic air exchange, ensuring the system's operational continuity. The sensors and pumps are automatically managed by an Arduino Uno microcontroller, which is equipped with a data acquisition system (SD card) and a LoRa communication system for data transmission to remote servers. The monitoring device also features connectors for photovoltaic panels, enabling energy self-sufficiency for field applications.

The PID sensor was calibrated using a commercial gas analyzer through a series of dynamic column tests conducted in the laboratory with various types of VOCs, in order to assess the influence of the contamination source on calibration parameters. Furthermore, laboratory tests were carried out using the developed flux chamber prototype to measure VOC emissions from an artificially contaminated soil, with the objective of evaluating the repeatability of VOC flux measurements from the subsurface over several consecutive hours. Concurrently, a numerical model was developed using the software Comsol Multiphysics with the purpose of simulating the laboratory test conditions, specifically the diffusion of vapors through the soil layer and within the chamber volume and the periodic air exchange driven by the pumps activation. The results obtained from these tests are highly satisfactory, demonstrating a stable and reproducible behavior in the accumulation and discharge trends of VOCs within the chamber, perfectly aligned with the predictions of the numerical model. Future developments include field application of these prototypes to evaluate their long-term performance.

This study was conducted as part of the BRiC project (ID21-2022), entitled "Monitoring system of air concentrations and subsurface emissions of volatile compounds in contaminated sites", funded by INAIL.

Abstract ID: 222
Quantitative risk assessment of representative perfluoroalkyl acids under multiple land uses
Yudong Feng[1]
[1]*Institute of soil science, Chinese academy of sciences*

Per- and poly-fluoroalkyl substances (PFAS) are emerging contaminants that are persistent in the environment due to their strong carbon fluorine bond energy. In this study quantitative human and environment risk assessments were undertaken for the four representative perfluoroalkyl acids (PFAAs) under various land uses that incorporated multiple exposure pathways including non-soil background sources and groundwater migration. Specifically soil and groundwater assessment criteria were derived that are protective of both human health and the water environment, with their respective carcinogenic risks and noncarcinogenic hazards being quantified.

The appropriate health and environmental risk assessment models in USA, UK and China were reviewed and selected under various land uses including agricultural, residential and commercial land uses. An integrated conceptual hydrogeological and exposure model was formulated for a hypothetical site that underpin the risk assessment and derivation of site-specific assessment criteria in which human health and the water environmental risks were based on toxicity and maximum contaminant levels (MCL) respectively. The Contaminated Land Exposure Assessment (CLEA) model was used for deriving soil screening levels (SSLs) under the agricultural land use with data reviewed and obtained from published literature in China. The SSLs under residential and commercial uses were derived using Health and Environmental Risk Assessment (HERA) model. In addition, the Remedial Target Worksheet (RTW) model was adopted to deriving the soil and groundwater assessment criteria for protecting surface water and groundwater environment. As part of the risk assessment, average daily exposure, media concentrations, pathway contributions, non-carcinogenic hazards and carcinogenic risks were also calculated.

The multiple exposure pathways included vegetable consumption, oral ingestion, dermal contact, vapour inhalation, soil leaching to groundwater, lateral groundwater migration. The background exposure of non-soil sources was considered from consuming eggs, fish and meat. The other exposure parameters used in the model included the soil and receptor properties, the physio-chemical and toxicological parameters of four PFAAs. Additionally, for calculating MCL-based remedial targets, site specific properties, such as hydraulic properties, length and width of contaminant sources, and mixing zone thickness were collated. In addition, the soil-pore water coefficients, dilution and lateral attenuation factors, and the concentrations of PFAAs at the compliance points were calculated in the RTW model.

SSLs of PFAAs under agricultural land use are 55, 613, 1.84 and 0.38 µg/kg respectively for PFBA, PFBS, PFOA and PFOS, which are lower than those of residential and commercial land uses as plan uptake is considered as a critical pathway. The lowest SSLs of PFOS compared to the rest of PFAAs under multiple land uses were caused by contaminant toxicities. MCL based soil remedial targets were 1800, 175, 21.7 and 105 µg/kg respectively for PFBA, PFBS, PFOA and PFOS, mainly driven by contaminant retardation factors, MCL and the distance to the compliance point. Similarly, groundwater remedial targets were 229, 25.9, 1.22 and 0.61 µg/L respectively.

Overall, SSLs and remedial targets derived under multiple land uses are useful in the assessment of potential risks to human health and the water environment which can assist in developing PFAS risk control measures. It is generally agreed that SSLs under the agricultural land use are more stringent than those under residential and commercial land uses. In particular, SSLs of PFOA and PFOS are lower than those of PFBA and PFBS, due to more toxic nature of the former two. It is recommended that the probabilistic risk assessment may be undertaken to improve the accuracies of the assessment results.

Abstract ID: 225
PFAS Mapping and Treatment of Leachate from Odense landfill

Sylvie Braekevelt[1], Anita Rye Ottosen[2], Per Henrik Nielsen[2], Caroline Elisabeth Flyger[3], Dorte Harrekilde[3]
[1]Ramboll , [2]Vandcenter Syd, [3]Ramboll

Key Messages

The Danish Wastewater Utility Vandcenter Syd (VCS) has conducted analyses of PFAS levels in the wastewater discharged from their Odense Nordvest Treatment Plant (ONVR) into Odense Fjord. Findings show a PFOA-equivalent concentration of 0.039 μg/l, significantly higher than the new environmental water standard of 0.0044 μg/l. The ONVR plant receives leachate from the Odense landfill and investigated the impact and mitigation of this upstream activity in this study.

During their partnership in 2022-2024 funded by ao. the Danish VUDP fund, VCS, Odense Renovation, Rambøll, Envytech, Enspired Solutions and ETC2, have mapped the landfill's PFAS contributions, confirming it as the primary PFAS source to ONVR. Additionally, TOP (Total Oxidizable Perfluoroalkyl Precursors) analyses were conducted on leachate and wastewater at the plant's inflow and outflow points. Furthermore, various PFAS treatment technologies were tested at laboratory and at pilot scale at the ONVR treatment plant. These trials explored the removal efficiency of heavy metals, selected pollutants, and the reduction of nitrification inhibition.

Abstract

PFAS has emerged in wastewater and surface waters, causing concerns for human health and the environment. While regulatory limits for PFAS are still under development, an environmental water standard for PFOA-equivalents has been set at 0.0044 μg/l (for example, in freshwater such as Odense Fjord). In 2022, Vandcenter Syd (VCS) analyzed PFAS content in the effluent from the ONVR treatment plant and found a PFOA-equivalent concentration of 0.039 μg/l, well above the 0.0044 μg/l standard.

Current treatment technologies are limited and costly, suggesting that mitigation efforts are best directed upstream, at the pollution source, rather than solely at treatment plant discharge points. A major source of PFAS in wastewater is landfill leachate, which flows to municipal treatment facilities. ONVR receives leachate from two Odense landfills owned by Odense Municipality and managed by Odense Renovation (OR).

In 2022, Rambøll produced a report for OR mapping PFAS pollution from two landfill sites, ONM and Stige Ø. This mapping indicated that landfill leachate accounts for 80-85% of the total PFAS content in ONVR's influent wastewater. Some sections of the landfill showed notably higher PFAS levels, with the leachate particularly high in compounds like PFBA, PFBS, and PFHxA—short-chain PFAS that are especially challenging to remove.

In response, OR and VCS partnered on a VUDP project with Rambøll and ETC2 (formerly Vandrensning.com). New analyses reinforced that Odense's landfills are the primary, and likely sole, PFAS source for ONVR. Additional TOP (Total Oxidizable Perfluoralkyl Precursors) analyses showed that standard PFAS testing detects most PFAS compounds present in the leachate and influent wastewater at ONVR.

Throughout 2023 and early 2024, the VUDP project conducted laboratory and pilot-scale tests on leachate samples from Odense landfills, trialing flocculation, foam fractionation, ion exchange and finally foto-active reductive fluorination as a PFAS destruction technology. The main objective is to develop a feasible treatment solution, focusing on effective removal of short-chain PFAS. Based on these tests, operational and capital cost estimates are being prepared for a PFAS treatment facility to address PFAS in Odense's landfill leachate.

Furthermore, funding from the Rambøll Foundation has enabled the project to investigate removal rates for select heavy metals and other environmental pollutants, as well as effects on nitrification inhibition.

The full (Danish) report on the latest VUDP project can be found on the VUDP website https://vudp.dk/afsluttede-projekter.aspx.

Abstract ID: 227
Variation in VOC concentration over time – results of two years' measurements

Susanne Arentoft[1], Winnie Hyldegaard[1], Karin Birn Nielsen[1], Boerge Hvidberg[1]
[1]Central Denmark Region

Purpose of study: In Denmark the guideline for measuring indoor air concentration of volatile organic compounds (VOC's) are recommended to be a passive method over 14 days in the cold period - October to March. The reason for this is the expectation of higher indoor air concentrations during the cold period in contrary to the summer period – thereby the result gives a more solid risk assessment.

Over a period of 2 years (2020-2022) we have measured VOC's in sub-slap soil vapor and in indoor air together with a range of other parameters. The measurements were performed at a former drycleaner site contaminated with primarily PCE.

The aim is to measure the variation in VOC concentration over a time period of two years in an unoccupied residence and on the basis of the data asses when to measure in sub-slap soil vapor and indoor air to give a solid risk assessment. Furthermore, the aim is to investigate which parameters that have an impact on the time variation of VOC concentration.

Methodology: The concentration of PCE, TCE, DCE and Vinyl Chloride have been measured over a period of two years and as given below: Sub-slab soil vapor: 11 points with carbon-tubes – active method over 100 minutes. New measurement ones a month. Indoor air: 8 points with ORSA-tubes – passive method over 14 days. New measurement every 14 days. Sewer system: 2 points in sewer wells and 2 points behind water trap – passive methods over 14 days. New measurement every 14 days.

In addition, there has been logging of Radon, differential pressure, temperature, atmospheric pressure, groundwater level and temperature.

Summary of findings/results:

The sub-slap soil vapor concentrations of PCE shows clear variation over the seasons, with the highest concentrations in summer/autumn and the lowest in winter/spring. The high concentrations in summer/autumn is approximately a factor 2-3 higher than the concentrations measured in winter/spring. There is a fine correlation between variation in concentrations in the sub-slab soil vapor and the temperature in the groundwater.

The variation in indoor air concentrations follow the same pattern as the concentrations in sub-slap soil vapor with the highest concentrations measured in summer/autumn and the lowest in winter/spring. The high concentrations in summer/autumn is approximately a factor 3 higher than the concentration in winter/spring. At our test site the data indicates that the variation in sub-slap soil vapor concentration have a bigger impact on the indoor air concentration than other parameters as differential pressure over the slab or differential temperature outside/inside (stack effect).

Conclusion/take home message:

For most homes, the highest indoor air concentrations will be found in the cold period, cf. references, but this study shows that in some homes, the highest concentrations can be found in other seasons. The data shows that measuring indoor air concentration only in the cold period pose a risk of underestimating the average concentration in indoor air, and hence perform a false risk assessment. To perform a robust risk assessment, knowledge about the time variation in indoor air VOC concentration are needed.

Radon concentrations in indoor air has been found as a god indicator for variation in VOC-concentration over time, and hence a useful tool to optimize sampling strategy.

Significance / contributions of study:

Based on results of this study, we are considering whether we should change our strategy for measuring to ensure the most robust risk assessment. The variation in sub-slap soil vapor concentration over the year makes it important to consider the purpose of the investigation before planning when to perform the sub-slap soil vapor measurements.

Abstract ID: 235
Addressing Agricultural Challenges: Innovative Approaches for Nitrogen and Phosphorus Removal

Kim Gommans[1], Stefan Jansen[1], Joachim Rozemeijer[1], Vince Kaandorp[1], Niels Mulder[1]
[1]Deltares

Nitrogen and phosphorus: a persistent challenge
The quality of water bodies across Europe continues to deteriorate, with nitrogen (N) and phosphorus (P) pollution posing significant challenges, particularly in the Netherlands. The agricultural sector, a major contributor to diffuse nutrient pollution, faces difficulties in managing these pollutants, while staying economically healthy. With the Water Framework Directive's deadline approaching, innovative methods for N and P removal on farms are crucial. However, farmers often lack sufficient knowledge on transitioning to more sustainable practices, despite their valuable understanding of their soil-water system. Therefore, closer collaboration between research and practice is essential.
A collaborative effort between research and practice
To address the question of how farmers can conserve nutrients and minimise losses to surface waters, the 'Freshwater Farmers' (Zoetwaterboeren) project was initiated. This four-year initiative, located on a practical farm in Anna Paulowna, the Netherlands, aims to develop, study, and demonstrate an integrated water management system tackling water quality issues in agricultural settings. One of the innovative techniques that is being tested on this farm is a bioreactor with woodchips and iron coated sand to purify excess drain water.
Promising methods for nutrient removal
Woodchip bioreactors enhance the natural process in which soil bacteria convert nitrate into nitrogen gas. Iron coated sand filters bind phosphate to iron oxide, preventing its entry into soil and water bodies. Both materials can be placed on a field, or around drain tubes in the subsurface. These methods offer compact systems and rapid processes, suitable for agricultural applications without requiring extensive land. They blend industrial water purification with nature-based solutions, bridging technical and natural approaches. Pilot studies from across the Netherlands have already shown promising results.
Until now, the two methods have mostly been implemented separately so that either nitrate of phosphate is removed from the water. However, to optimise land use, a combined bioreactor is being tested on the farm in Anna Paulowna. Woodchips and iron coated sand were deposited in an uncovered pit, and drain water is led through the bioreactor. Successful implementation of such a method depends on understanding potential side effects and mitigating them, which is why the bioreactor is monitored closely by taking samples from the water going in and coming out of the bioreactor. In this process, the farmer is closely involved, addressing not only nutrient pollution but also fostering a positive working relationship.
What to expect for next year's presentation
This presentation will highlight first insights from the pilot study, while emphasizing the importance of collaboration between researchers and farmers. It will showcase the first results of efficiency of the bioreactor, potential barriers, monitoring outcomes, and the possibility of scaling the woodchip-iron coated sand bioreactor to other regions facing similar water management challenges. By sharing key insights and lessons learned, this project aims to contribute to global efforts in sustainable soil-water solutions.

Abstract ID: 238

Roadmaps for co-designing strategies for sustainable regeneration of contaminated and brownfield land

Begoña Arellano Jaimerena[1], Linda Maring[1], Marissa van de Wijngaard-Frambach[1], Paul Drenning[2], Teodora Todorcic Vekic[2], Marianne Valkama[3], Nazaré Couto[4], Jesse Wijnen[6]

[1]Deltares, [2]Chalmers University, [3]GTK, [4]NOVA, [5]IDOM, [6]Saxion Applied University

Background: When looking at the future use of contaminated land, remediation and redevelopment are central to the activities. But how to ensure that the future use is the best for people, environment and economy? And how can the road to this future use be as sustainable as possible? In some cases, the economic case is clear and redevelopment options are plenty where the redevelopment benefits exceed the costs. In many cases the road is more rocky and narrow and actors involved should be more creative and consider the potential wider values to build the value proposition for remediation and redevelopment.

Significance: For the latter cases, different applied research projects focus on developing roadmaps for considering viable alternatives for remediation and redevelopment. These roadmaps bring different kinds of actors together and support the sustainable, cost-effective and supported cocreation of future uses of contaminated and brownfield land. New ideas and collaborations are needed to improve the success rate to beneficial use. This also supports European objectives of no net land take and soil health. This session will showcase some ideas and discuss them with the audience.

Summary: In the EU Soil Mission project ISLANDR, a roadmap has been developed that supports different users with different user journeys in the decision-making process (single and portfolio sites, diffuse contamination and prioritization of actions). For each stage of the redevelopment / remediation journey, building blocks developed by the ISLANDR project are offered to provide decision-support. The building blocks support spatial planning and remediation strategies and give input to -for example- Sustainable Risk Based Land Management, choice of sustainable remediation techniques, identification of wider values of the redevelopment / remediation, and the improvement of Soil Health.

ISLANDR also involves other projects and initiatives to support and broaden the discussion, such as the Dutch RAAK project that has developed guide for spatial planners how to consider contaminated land in their designs for redevelopment and remediation of land.

Interaction plan: The session is divided into 3 parts, reflecting on different topics of the roadmap: 1) Early creation of spatial planning strategies, 2) Improvement of soil health, and 3) Uptake by the actors.

In each part of the session, the topic will be briefly introduced by one or more of the presenters/moderators listed below and strongly supported by visual content. The presentation will be followed by a moderated discussion with the audience using Mentimeter, where targeted questions will be asked to the audience to generate discussion about the different topics in the context of remediation and redevelopment and elicit feedback on the roadmaps.

Agenda:

[15min] 1. Early creation of spatial planning strategies to support collaboration, cocreation and integration

[15min] Discussion

[15min] 2. Improvement of soil health, identification of wider values and the use of ecosystem services

[15min] Discussion

[15min] 3. Uptake by the actors, what are unique selling points to get actors engaged?

[15min] Discussion

Speakers, reflectors and moderators: This special session is being led and presented by professionals that are in a mid or new career stage:

Deltares (Netherlands) : Begoña Arellano Jaimerena, Marissa van de Wijngaard-Frambach, Linda Maring Chalmers University (Sweden), Paul Drenning, Teodora Todorcic Vekic GTK (Finland) Marianne Valkama NOVA (Portugal) Nazaré Couto IDOM (Spain) Beatriz María Ortiz de la Torre Juanas Saxion Applied University (Netherlands) Jesse Wijnen
List of required equipment: Wifi, informal setting, flipover and makers, no limited amount of attendees.

Abstract ID: 240

Full-scale application of In Situ Bioremediation with Hardwood Mulch Bioborings as a Sustainable, Nature-Based Approach for Reductive Dechlorination

Edoardo Masut[1], Luca Ferioli[1], Kevin Morris[1], Anna Legnani[1], Caterina Righetto[1]
[1]ERM Environmental Resources Management

Purpose

This work summarizes ERM's recent experience with the development of a full-scale in situ bioremediation involving the application of hardwood mulch as an electron donor for Enhanced Reductive Dechlorination (ERD) in a contaminated Site in northern Italy, where groundwater impacts by chlorinated ethenes were identified.

Hardwood mulch provides a slow-release electron donor, which helps to maintain reductive redox conditions in the aquifer, and supports the complete anaerobic dehalogenation of the chlorinated solvents. Wood mulch is a cheap and often locally available material, a secondary product of the wood processing industry, (e.g. landscaping, biofilters) and its use as bioremediation amendment may help improve the economic viability, circularity and the environmental sustainability of a remediation project.

Methodology

After several years operating a Pump&Treat system near the downgradient Site boundary as hydraulic containment, ERM assessed alternative in situ bioremediation options to treat both the contamination source and mitigate migration of the downgradient dissolved plume.

A laboratory bench-scale study, and a field pilot test were executed which provided proof of concept that the application of hardwood mulch with a "bioboring" configuration in the subsoil, together with a commercial bioaugmentation inoculum, could support the complete anaerobic reductive dichlorination of the site contaminants (mostly TCE and 12-DCE) to the innocuous end product, ethene. However, due to the high initial concentrations of chlorinated ethenes in the pilot test area, the extent of the biological reductive process triggered by the tested amendment was observed to be limited.

Considering the results of the pilot test, a full-scale application was designed and implemented which involved the installation of additional mulch bioborings, grouped into transects aligned perpendicular to the main groundwater flow, and the addition of a commercial Emulsified Vegetable Oil-based product (EVO) in the amendment mixture in the most critical contaminated areas. Microbiological and chemical groundwater monitoring was conducted before the start, and after the completion of the bioboring installation activities.

Results

The field pilot test and the preliminary full-scale results showed decreasing trends of Dissolved Oxygen and oxidation-reduction potential (ORP) in the wells downgradient the bioboring areas, together with the depletion of nitrate and sulfate, and increase in dissolved Iron (II), chloride, TOC and methane, which provide multiple lines of evidence indicating the occurrence of anaerobic reducing conditions, and the biogeochemical precursors of reductive dichlorination processes. An increase in the microbial communities capable of performing the biological degradation of the site-specific contaminants has also been observed.

A decrease in dissolved TCE concentration was observed in the monitoring wells downgradient of the treatment areas, together with an increase in cis-1,2-DCE and VC concentrations. Ethene was detected in groundwater in a concentration higher than 100 µg/L starting from 5 months after the mulch bioborings installation, which provided a proof of concept that complete anaerobic reductive dichlorination could be achieved in the aquifer with the tested amendment.

Conclusion

The groundwater monitoring results after bioborings installation provided proof of concept with multiple lines of evidence that complete in situ anaerobic reductive dechlorination of TCE all the way to ethene, can be achieved in the aquifer with the use of a hybrid in situ bioremediation strategy (application of hardwood mulch and EVO). However, additional monitoring data are considered

necessary to define the long-term effectiveness of the tested technology in the full-scale configuration.

Significance

The results of this work confirm that a sustainable and nature-based carbon source amendment such as hardwood mulch can be a valid aid in the in situ remediation of contamination sources and plumes of chlorinated aliphatic compounds in groundwater, and it may help lower the project life-cycle of conventional and energy-intensive plume management measures such as Pump&Treat systems.

Abstract ID: 243

Effects of biochar and peat on immobilization of metals and PAH in an urban soil: Results from a five-year field experiment

Charlotta Tiberg[1], Anja Enell[1], Maria Larsson[2], Ayan Au Musse[2], Linn Möller[3], Sigrun Dahlin[4], Sara Hallin[4], Jaanis Juhanson[4], Ingrid Rijk[2], Alf Ekblad[2], Carin Sjöstedt[4], Dan Berggren Kleja[1]

[1]Swedish Geotechnical Institute, [2]Örebro University, [3]NSR-AB, [4]Swedish University of Agricultural Sciences

Purpose
Biochar amendment is a promising technique for remediation of contaminated soil by immobilizing metals and organic pollutants while enhancing soil health. However, information on long-term stability of treatments effects at field conditions is very limited. The BALANCE project aims to develop a sustainable framework for treating contaminated soil with biochar from organic waste, promoting resource efficiency and a circular economy. This presentation will focus on biochar and peat effects on the solubility and bioavailability of metals and PAH in a field experiment over a period of five years.

Methodology
In 2019, a field trial was established to investigate the effects of biochar and peat on a soil contaminated with metals (Ba, Cu, Hg, Pb, Zn) and PAH. The soil was amended with 0, 3, or 6 wt.% biochar and 0, 1.5, or 3 wt.% peat in a factorial design, resulting in nine different treatments (including controls). The soil-mixes were filled in 2x2x0.5 m cultivation beds, repeated in triplicates, and ryegrass Lolium perenne were sown in the beds. Comprehensive sampling was conducted in 2019, 2023 and 2024 to analyse metal and PAH content in soil, grass and earthworms, and assess soil quality indicators such as pH, organic carbon content, soil nutrients, cation exchange capacity, and microbial respiration. Grass biomass and effects on the soil microbial community and microorganisms responsible for different steps in the nitrogen cycle were also assessed. The solubility of PAH was assessed using passive samplers (polyoxymethylene membrane). Lysimeters were installed for porewater sampling, twice a year 2019-2024, for analyses of metals, dissolved organic carbon and nutrients.

Summary of findings/results
- Amendments with 3% of biochar significantly reduced the solubility of PAH, Cu and Hg after the first growth season by more than 90%, 80% and 70%, respectively, compared to the control, while the effect on Zn, Pb and Ba was small. Biochar also decreased the uptake of Cu and Zn in grass and earthworms.
- Treatment with biochar initially reduced grass biomass, but after 5 years the growth reduction remained only for treatments with 6% biochar and 1.5% peat. On the other hand, biochar increased microbial biomass and activity. The growth reduction of grasses is likely due to nitrogen being assimilated or transformed by microbes (Rijk et al., 2024).
- Results from the fifth year of sampling are currently being evaluated, although it is obvious that the biochar's effect on Cu and Hg solubility remained over the whole studied period.
- Preliminary results suggest a lasting effect also on the stabilization of PAH.

Conclusion/take home message
- Adding biochar to contaminated soil significantly reduced the solubility of PAH, Cu, and Hg, an effect lasting at least for five years after the application.
- Using biochar can be a sustainable alternative to replace contaminated soil with fresh soil, promoting a circular economy and better resource use.

Significance/contributions of study
Moderately contaminated soil is by far the largest waste stream to Swedish landfills. During development work in the cities, new soil masses are often used to fill excavated areas. Soil is a valuable and limited resource that must be managed in a sustainable manner. We show that in-situ treatment with biochar can be an alternative to replacing the contaminated soil with virgin materials,

binding pollutants and improving soil quality at the same time. Mixing biochar into a contaminated soil in-situ therefore has great potential to reduce the amount of soil mass deposited.

Reference
Rijk et al 2024 Science of the Total Environment 936 (2024) 173454

Abstract ID: 251
Silverton Mill – Return to Nature
Jo McKay[1]
[1]*Ramboll*

Silverton Mill – Return to Nature
This presentation is a case study of how a holistic approach was taken to regenerate a former brownfield site and return it back to nature. By integrating the demolition and remediation activities with the long term aspirations of biodiversity net gain, wetland restoration, soil management and climate resilience, the site now forms part of England's National Trust land for the enjoyment of the public.
The case study evolved from Ramboll's support of the surrender of a lease of a former paper mill located within the National Trust estate of Killerton in Devon, UK. By discussing the regeneration activities with the client and the landlord, Ramboll transformed the regeneration work into a project that provides real community and environmental benefits.
The main objective was to remediate the remaining legacy contamination that was present in the ground, ensure there was no risk left to the environment, and restore the land back to an undeveloped floodplain.
Ramboll worked closely with its Client to understand their sustainability commitments, strategy and objectives. The project also aligned to Ramboll's sustainability strategy and contributed to the National Trust's green recovery programme for the restoration of the floodplain and creation of wetland habitat at Killerton.
 The work carried out included the following: Initial environmental surveys - including invasive species, flood risk, wetlands and a controlled waters risk assessment. Design of a sustainable remediation strategy. Breakout, crushing and removal of all hardstanding. Investigation and removal of underground structures and areas of localised soil contamination. Reinstatement, including import of soil sympathetic to the area and to provide a growing medium and seeding. Design and implementation of a planting scheme by Ramboll's landscape architects.
Project Outcomes
Waste minimisation: Achieved by taking a risk-based approach to the remediation to minimise the amount soil that was disposed off-site. We also undertook robust verification of the soils, groundwater and surface water to confirm there was a low risk to the environment.
Betterment: Improvement of the ground quality via removal of buried asbestos cement and segregation and removal of a contaminated waste pile.
Reduced carbon footprint: Site won crushed concrete was re-used locally within the Killerton Estate. The imported soil used as a growing medium was also sourced locally.
Increased biodiversity: The planting scheme included native trees and shrubs. Seeding of the land with grasses has helped to create new wetland habitat.
Floodplain capacity increased: Capacity was increased by removing the hardstanding which lowered the site level and increased permeable land on the floodplain.
Wetlands: creation of habitat.
The project contributed to the client and landowner's sustainability strategies. In addition, it met UN Sustainability Development Goals.
 Lessons learnt included:
 Taking a risk-based approach helped to minimise waste and remediation efforts. Planning was important ahead of starting groundworks on a flood plain. This included timing the works to reduce the likelihood of encountering a flood event and having a Flood Risk Activity Permit in place. Early discussions with stakeholders helped to understand sustainability objectives as well as long term plans for the site. Discussions with the National Trust enabled the opportunity for crushed concrete to be re-used locally within the Killerton Estate.

Abstract ID: 253
Nature assisted dewatering of dredged sediment and transition into soil. A 600 ton pilot at the Municipality of Rotterdam.

Miguel Angel de Lucas[1], Mathieu Lassus[2]
[1]*Medeina Engineering,* [2]*Municipality of Rotterdam*

The City of Rotterdam annually dredges approximately 100,000 m³ of slurry from its canals, a process that presents significant challenges due to the high water content and prolonged dewatering times. Traditional dewatering methods are resource-intensive, environmentally taxing, and yield low-quality soil with limited reuse potential. Accelerated dewatering techniques, while faster, often exacerbate costs and environmental impacts without addressing the poor quality of the resulting material.

This study evaluates an innovative, nature-based dewatering method developed by the Netherlands-based start-up Medeina Engineering. The solution employs endemic flora and fauna, particularly the aquatic worm Tubifex tubifex, to enhance the natural dewatering process. For the first time, this approach has been implemented on a large scale through a pilot project at Rotterdam's Terbregseveld sediment depot, treating 300 tons of dredged slurry per depot.

The primary objective of this research was to quantify the dewatering efficacy of Medeina's method compared to standard city practices. Direct measurements and observations at the pilot site revealed a 15% increase in solid content in treated ponds within 12 weeks, whereas untreated reference ponds showed negligible change. By 16 weeks, treated ponds exhibited soil strengths between 10–20 kPa, compared to 5 kPa in the reference pond. These results indicate sufficient structural stability for practical applications. Secondary analysis included core sampling and visual inspection, which identified a well-structured, non-anoxic soil with active root colonization in treated ponds—a feature absent in the untreated controls.

This pilot study demonstrates that Medeina's nature-based solution not only accelerates the dewatering process but also enhances the geochemical and biological quality of the resulting soil. These findings underscore the potential of integrating sustainable, cost-effective, and ecologically sound practices into urban dredged sediment management, offering significant improvements over conventional methods.

Abstract ID: 255
Exploring bioavailability reductions as a paradigm shift in soil bioremediation

Jose-Julio Ortega-Calvo[1], Rosa Posada-Baquero[1], Carmen Fernandez-Lopez[2], Jose-Luis García[1]
[1]*Instituto de Recursos Naturales y Agrobiologia de Sevilla, CSIC, [2]Centro Universitario de la Defensa, CUD-UPTC*

Introduction
Nature-based solutions (NBS), such as bioremediation and phytoremediation, offer promising avenues for soil restoration. Traditional NBS approaches focused solely on total pollutant removals have proven unpredictable and often fall short of legislative remediation goals. With a focus on hydrophobic organic pollutants and bioremediation, this overview presentation will explore the paradigm shift towards addressing bioavailability, surpassing mere total pollutant removals, to reach acceptable risk reductions. To achieve this, two questions must be addressed: (1) How to influence bioavailability processes related to the biodegradation of contaminants? And (2) How can this knowledge be used to sustainably reduce chemical risks in soil?
How to influence bioavailability processes related to the biodegradation of contaminants?
Contaminants that are not bioavailable to degrading microorganisms can be bioavailable to humans and ecological targets. It is therefore necessary to bring forward microbial activity to acceptable levels of risk reductions. Our nature-based engineering components were demonstrated to enhance biodegradation and reduce environmental risks, mainly channelled through the water phase, at various levels of bioavailability processes, encompassing interactions between contaminants and soil, their transportation, and biological processing (see figure). Biodegradation can be enhanced through solubilization (representing the surfactant action on phase exchange; -process A), tactically-driven microbial mobilization (represented in the figure by chemotactic bacteria; process B) and attachment to interfaces, what allows the direct acquisition of the sorbed contaminant (process C). D represents the pollutant uptake by the microbial cells, necessary for biodegradation processing, eventually leading to mineralization or cometabolism (E). The specific focus in our research was to unveil low-risk strategies such as the controlled increase in bioavailability to microorganisms targeting slow-desorption pollutant fractions with (bio)surfactants [1], fine-tuning the deposition and motility of microbial degraders [2], co-mobilizing non-motile inoculants [3], and effectively capturing pollutants through plant/biochar arrangements [4], showcasing their potential to transform soil remediation practices.
How can this knowledge be used to sustainably reduce chemical risks in soil?
In the bioremediation context, operating on bioavailability requires the use of standardized methods that can systematically be used to measure bioavailable fractions, evaluating more realistically remediation operations and end-points, in addition to assessments based on total concentrations only. Over the last 30 years, significant progress has been achieved in clarifying bioavailability concepts and methods, providing standardized options for practical application [5]. These concepts are the basis for different methodologies, ready to be used: desorption extraction, passive sampling, and biological tests. Desorption extraction is especially useful in bioremediation and constitutes the basis for an ISO standard on soil quality [6]. Our group has already used this approach in the evaluation of bioavailability-oriented bioremediation [1, 7], proposing application paths in the context of sustainable recovery of soils contaminated by military activity [8].
We can therefore conclude that a change in paradigm in bioremediation is possible, by 1) operating on bioavailability processes that limit biodegradation and 2) more realistic risk assessments based on standardized bioavailability measurements.

4. References

[1] Posada-Baquero et al. Sci. Total Environ. 720: 137608, 2020.
[2] Castilla-Alcantara et al. Sci. Total Environ. 832, 154938, 2022.
[3] Balseiro-Romero et al. Environ. Sci. Technol. 56:13975-13984, 2022.
[4] Castilla-Alcantara et al. Sci. Total Environ. 868: 161600, 2023.
[5] Ortega-Calvo et al. Environ. Sci. Technol. 49: 10255-10264, 2015.

[6] ISO Technical Committee, 2020. Soil-Quality-Environmental Availability of Non-polar Organic Compounds- Determination of the Potential Bioavailable Fraction and the Nonbioavailable Fraction Using a Strong Adsorbent or Complexing Agent; ISO No. 16751: 2020 (E).

[7] Posada-Baquero et al. Sci. Total Environ. 803: 150025, 2022.

[8] Fernandez-Lopez et al. Sci. Total Environ. 843: 157007, 2022.

Abstract ID: 259
Thermal Desorption of VHOC Contaminated Soil and Vapor Management at Lucciana, France

Tom Renson[1]
[1]*Haemers Technologies*

Background/Objectives: As electricity consumption in Corsica experienced significant growth, the EDF group embarked on the renewal of its thermal power plants across the island to address escalating electricity demands. The demolition of the existing Lucciana power plant and the site remediation were pivotal steps in the construction of a modernized facility. Indeed, soil gas analysis have been conducted to assess the land quality and revealed the presence of Volatile Halogenated Organic Compounds (VHOC) contamination up to a depth of 11 meters at the aquifer's roof. The contamination necessitated treatment before proceeding with new construction.

Approach/Activities: In response to the VHOC pollution challenge, EDF's Lucciana power plant issued a call for tenders in 2020/2021 to remediate the soil at the upcoming facility. In 2022, Haemers Technologies, in collaboration with Englobe, implemented an In Situ Thermal Desorption (ISTD) strategy to remediate the two affected areas to a depth of 13 meters. Two distinct batches of treatment have been carried out.

The first batch, covering an area of 250 square meters, underwent treatment employing 33 Smart Burners™. For the second batch, spanning 400 square meters and with a contaminated zone between 5 and 13 meters, 51 remote flame Smart Burners™ were used to concentrate energy precisely on the impacted area.

In addition to the heating system, a Vapor Treatment Unit (VTU) was integrated into the setup. This VTU included a heat exchanger, condensate tank, three pumps, a knock-out, an extractor, and two activated carbon tanks. To ensure optimal treatment conditions, a water table lowering system was installed, ensuring that the water level remained below the heating zone. The thermal desorption project was executed concurrently with a venting and sparging system, demonstrating the compatibility of both technologies.

Throughout the treatment process, rigorous monitoring encompassed gas emissions and consumption, ground temperature, and pressure to maintain precise control over the installation.

Results/Lessons Learned: The project culminated in the successful treatment of 6,500 cubic meters of contaminated soil. For batch 1, the average concentration in soil gases was 142,000 µg/m³ of VHOC, while batch 2 exhibited 708,520 µg/m³ of VHOC. Each batch underwent a 70-day treatment regimen, with a 5-day period at the target temperature of 85°C, effectively reducing gas soil concentration below 15,000 µg/m³. The project achieved its overarching objectives, with the cold point temperature reaching the desired 85°C and all remediation targets being met.

Abstract ID: 262
Innovative Underground Skimming Technology for Efficient LNAPL Recovery: A Case Study from Northern France

Thomas Pieters[1]
[1]*Haemers Technologies*

Background/Objectives: The efficient recovery of Light Non-Aqueous Phase Liquids (LNAPL) from groundwater presents significant challenges due to diverse soil characteristics, groundwater conditions, and pollutant characteristics. Many conventional recovery methods struggle to address these complexities effectively. However, underground skimming technology has emerged as a promising solution, offering a unique approach to overcome these challenges.

Approach/Activities: This technology's key advantage is the use of skimmers, with a central float being a crucial component. The float, specifically designed for prolonged exposure to hydrocarbons, consistently keeps the skimmer positioned atop the LNAPL layer, even in varying conditions. Remarkably, the float can adapt to groundwater fluctuations of up to 2.5 meters. The skimming process, combined with vacuum pumping, prevents clogging and enables the recovery of LNAPL with differing viscosities. Vacuum pumping in wells creates an imbalance that induces the pollutant to migrate toward it under the influence of gravity, facilitating the comprehensive recovery of the floating layer.

A notable application of this technology is an ongoing project located in Northern France since 2012. This project operates within an industrially restricted site within an ATEX zone. The targeted pollution consists of a complex blend of heavy garage oils, exhibiting a honey-like texture that poses significant recovery challenges with a viscosity of 0.5 Pa.s at 288K. The groundwater depth varies from 17 to 22 meters, experiencing fluctuations of up to 1.5 meters annually. The installation includes two containers and eight strategically positioned wells across the site. The pollutant is routed to the first container, housing the pumping unit, and subsequently stored in the second container with two 2500L IBCs. Impressively, over the course of ten years, a total of 22,124 litres of LNAPL have been successfully recovered using this technology.

Results/Lessons Learned: This abstract presents a compelling case study demonstrating the effectiveness of underground skimming technology in addressing the challenges associated with LNAPL recovery in complex groundwater environments.

Abstract ID: 264
Novel Sustainability Scoring Method for Soil Remediation Technologies
Ysaline Depasse[1]
[1]Haemers Technologies

Background/Objectives: The concept of sustainability is ever more pervasive in all aspects of today's society, and soil remediation should be no exception. Several of the goals set by the United Nations are particularly relevant to soil rehabilitation, such as resilient infrastructure development, safety, resiliency of land management and sustainable consumption.
Governments, including California EPA, are using scoring methods to determine which sites have priority in funding for remediation. Scoring methods have been used for years to determine the most sustainable remediation technologies.
Unfortunately, the sustainability of a remediation method is too often understood solely as its correspondent greenhouse gases emission. While being a key factor, it is only a limited part of the big picture. Furthermore, several of tools are available for the stakeholders to estimate CO2-equivalent emissions of different technologies but, depending on their scope and assumptions (which are not always disclosed), results can vary significantly.
Approach/Activities: In order to properly choose the most sustainable technologies depending on project- and pollutant- specific constraints, a sustainability scoring method is proposed. It is based on three main pillars, namely the economic (ECO), environmental (ENV) and socials (SOC) criteria.
The economic criterion is the most straightforward as it relates to the remediation cost. It includes the total cost, degree of uncertainty and change in land value. The social indicator, often the most neglected, relates to the impact of the remediation on society and individuals. It covers safety, education and employment, stakeholder involvement, land use, dust, odours, traffic, and noise generated. Finally, the environmental criterion evaluates the efficiency of remediation, risk of secondary contamination, gas emissions, impact on soil and water characteristics and generated waste.
Each sub-criterion is rated thanks to an evaluation grid, attributing a note ranging from 0 to 10 based on the performance of the given remediation method. When a numbers-based rating is not possible, which is typically the case for some social indicators, a clear description of different scenarios is used to make their objective assessment possible.
After each of the main three pillars have been attributed a score based on the mean score of the topics that they cover, a final scoring method is proposed such that:
Each of the main pillars (ECO, ENV, SOC) is given the same weight.
A poor score in one of the pillars is highly penalizing for the final overall score.
For those reasons, necessary to select truly sustainable technologies, the final sustainability score is the geometrical mean of the three main scores, written as $\sqrt[3]{ECO \times ENV \times SOC}$.
Results/Lessons Learned: To highlight the method and conclude the paper, a small case study is used, where "remediation" using excavation (dig & dump) is compared against thermal desorption. While studies relying on CO2- equivalent emissions sometimes favour one method or the other based on their respective scopes and assumptions, the weaknesses of the excavation are properly highlighted using a full sustainability scope.

Abstract ID: 266
Thermal desorption combined with soil vapor extraction in Pocatello, Idaho (US)

Lucie Devaux[1]
[1]*Haemers Technologies*

Background/Objectives: The Site was the former Fashion Cleaners dry-cleanersfacility that operated from approximately 1949 through 2014, andused tetrachloroethene (PCE) and trichloroethene (TCE) in the dry-cleaning process.In 2011, approximately 7,900 pounds of waste PCE and TCE sludge and filters were transported offsite for disposal. In 2019, during a Phase I and Phase II Environmental Site Assessments on an adjacent property, PCE and TCE were detected in three soil vapor samples above vapor intrusion screening levels. As a result, the Idaho Department of Environmental Quality (DEQ) requestedan initial site characterization at the Former Fashion Cleaners Site. The 2019 site investigation included 3 soil borings and two soil vapor samples that detected PCE and TCE. In 2020, the EPA Environmental Response Team collectedadditionalsoil gas samples and subcontracted the installation and sampling of groundwater at and around the site. Five of the soil gas samples exceeded removal management levels for PCE. PCE also was detected in the groundwater samples, but at concentrations well below the maximum contaminant level (MCL).

Approach/Activities: In 2022, anunderground storage tank (UST) was discovered during the removal of a heating oil tank by the owner. This UST had apparently been used to store dry cleaning fluid. Tetra Tech removed the tank and fifteen 55-gallon drums of contaminated soil. Tetra Tech collected additional groundwater, soil and vapor samples in February/March 2023.Groundwater exhibited detectable concentrations of PCE that were less than the MCL. However, as long as residual PCE and TCE remain in the soil column, transport to groundwater is possible via infiltration and/or vapor transport.In addition, the highest soil impacts weregenerally located 15 feet below ground surface on top of a clay layer. Below the clay layer, the soil is generally sandy, and the concentration decreases significantly with depth. As a result, remediation efforts were focused on how to target the removal or treatment of the soil below the former tank and adjoining area. An alternative analysis eliminated excavation due to the proximity to the building.

In-situ thermal remediation (ISTR) has been selected to remediate the remaining soil contamination and to achieve site closure. This method was selected over other remediation alternatives based on treatment time, cost, and space constraints at the site. Haemers Technologies, Inc. was selected as the technology provider and contracted in August 2023. Once the ISTR activities have been completed, contaminant concentrations will be reduced in site soils to below their respective RSLs.The ISTR remediation will begin in early 2024 and conclude late Spring 2024

The Site Closure Plan was developed by Tetra Tech andwas approved by DEQ. The closure schedule is anticipated to be completed in 180 days with the exception of waste removal and decontamination due to:

Uncertainty in the time required for the in-situ thermal remediation to reduce soil contamination levels below RSLs.

Co-location of the contaminated soil with site structures (buildings), which requires additional and more complex remediation set-up and controls.

Results: After approximately 70 days of heating, the treatmentwas completed in May 2024, achieving a reduction in TCE/PCE concentrations in the soil to levels at least10 times below the respective target thresholds of 0.41mg/kg dry soil and 8.1mg/ kg dry soil.

Abstract ID: 268
Evaluating Energy Efficiency and Carbon Footprint in Soil Treatment Technologies: the case of In Situ Thermal Desorption

Jonas Guerniou[1]
[1]Haemers Technologies

Purpose of Study In Situ and On-Site Thermal Desorption is increasingly applied worldwide due to its performance and reliability in soil remediation. However, its energy consumption and overall sustainability have been questioned. This study aims to provide concrete data on the carbon footprint and energy consumption of In Situ Thermal Desorption projects compared to alternative methods. Specifically, it focuses on evaluating direct heating technologies (fueled by fossil or biofuels) versus indirect heating technologies (using electricity generated from renewable or fossil fuels). The goal is to identify the most sustainable and efficient approaches within thermal remediation technologies. Methodology The study begins by evaluating energy consumption across a broad range of soil remediation technologies, including biological, chemical, physical and thermal methods, to establish a baseline for their relative energy demands. It then focuses on thermal remediation, which, despite its effectiveness, varies significantly in energy use and carbon footprint depending on site-specific and regional factors.

Key variables such as contaminant type, soil composition, target temperature, and local energy grid characteristics are analyzed to compare direct heating systems (fossil fuels or biofuels) with indirect heating systems (electricity - renewable or fossil-based). Quantitative data on energy efficiency, lifecycle losses, and CO_2 emissions are evaluated, alongside the inefficiencies of electricity supply chains and the combustion efficiency of gas-fired systems. The potential of biofuels to mitigate environmental impact is also assessed, emphasizing their integration into existing systems and carbon savings compared to fossil fuels.

Summary of Findings/Results

Thermal remediation technologies, often criticized for their energy intensity, perform better than expected compared to other soil treatment methods. Their efficiency and reliability, particularly in challenging conditions, make them competitive when efficient systems are used. While biological or chemical methods may use less direct energy, total carbon footprints must also consider external energy use, such as chemical production.

Within thermal remediation, gas-fired systems generally consume less primary energy than electric systems due to inefficiencies in electricity generation and transmission. However, the choice between gas and electric depends on the local energy grid. In regions with high renewable energy use, electric systems may have a lower carbon footprint, while gas systems are more sustainable in fossil fuel-dominated grids.

The key to sustainability lies in reducing energy consumption overall. Both gas and electric systems benefit from renewable energy sources like biofuels or renewable electricity, enabling significant carbon footprint reductions. Tailoring solutions to regional contexts ensures optimal environmental and operational performance.

Conclusion/Take-Home Message

Thermal remediation is more sustainable than often perceived, provided efficient systems and renewable energy sources are utilized. The choice between gas-fired and electric systems depends on local energy grid composition and project specifics. Prioritizing energy efficiency and sourcing renewable energy—whether through biofuels for gas systems or renewable electricity—are key to reducing the carbon footprint.

Significance/Contributions of Study This study emphasizes the need for lifecycle analysis when evaluating energy systems, challenging the traditional focus on point-of-use efficiency. It contributes to the broader discourse on sustainable soil remediation by advocating for practical, cost-efficient, and environmentally responsible heating technologies. Additionally, it highlights the potential of biofuels to reduce the carbon footprint in industrial applications.

Abstract ID: 270

Retrieval of anisotropy parameters for geostatistical regularization in electrical resistivity tomography: Advancing subsurface characterization

Konstantinos Tsakirmpaloglou[1], Olivier Kaufmann[1]
[1]University of Mons

Electrical Resistivity Tomography (ERT) is widely used in geophysical surveys to depict underground conditions. Geometrical anisotropy is common in geosciences, especially in sedimentary environments where the bedding creates distinct spatial anisotropy. In this study, we explore how to improve ERT imaging by incorporating medium anisotropy as a prior in inversions with geostatistical regularization. Assuming the hypothesis of stationarity, geometrical anisotropy is represented as an ellipse in 2D problems. The lengths of the semi-axes of this ellipse correspond to correlation lengths, and the angle with the horizontal reflects the dip of the geological layers. We focus on retrieving these parameters by fitting ellipses to directional variograms derived from borehole data. The retrieval process minimizes an objective function to determine the best theoretical variogram models that fit with the experimental variograms. We also investigated the effect of borehole placement on anisotropy parameter estimation. Synthetic models with Spatial Random Fields (SRFs) were created to simulate realistic geological scenarios. These models were populated with spatial properties such as resistivity or porosity. The models were tested with different acquisition schemes, where cross-hole arrays and borehole data were used for inversion and anisotropy parameters retrieval. For each layer, directional variograms were analyzed separately, considering the available data pairs to ensure accurate geostatistical modeling. The results show that incorporating geostatistical regularization parameters into the inversion process leads to outcomes that are more resistant to noise and closer to the ground truth compared to classical inversion methods. The method effectively captured zonal correlations, even in cases with limited prior knowledge. Moreover, scenarios with well-informed priors performed significantly better, confirming the importance of accurate parameter retrieval. While the computational time for the inversions with geostatistical regularization was higher, the improvement in results justifies its application in cases where enough borehole data is available. This study highlights the advantages of using geostatistical regularization in ERT inversion, particularly for subsurface imaging in complex geological settings. By integrating prior knowledge derived from borehole data and variogram analysis, the method offers an interesting alternative to classical regularization inversion, enhancing the resolution and accuracy of geophysical surveys.

Abstract ID: 272

Example of identifying sources of PFAS that are causing contamination in a drinking water supply, and how to prepare for mitigation measures technically and administratively?

Nanette Schouw[1], Susanne Petersen[1], Bente Hyldegaard[1], Christian Høimann[1]
[1]Region Zealand

In the eastern part of Denmark, there is an area with former and existing gravel extraction sites that have over time been filled with waste. It covers approx. 10 km2. The same geological gravel layers in the subsoil is called the 'Hedelandsformation' and constitutes one of the most important groundwater and drinking water resources in Denmark. Furthermore, the area is characterized by extensive industrial activities and fire training facilities at Roskilde Airport. Consequently, the water supplies in the area are directly affected by PFAS in concentrations, which exceed the current quality criteria for drinking water. The task of the regional authority, Region Zealand, is to identify, investigate, and mitigate the worst point sources of contaminations first to ensure most value for the money. This abstract describes how Region Zealand has approached this task administratively and technically. A formal collaboration has been established with the neighboring Capital Region and four municipalities Greve, Ishøj, Høje Taastrup and Roskilde kommune, as well as the largest water supply in the area, HOFOR. The main aim of the collaboration is sharing the latest data and coordinating all PFAS mitigation efforts in the area. Additionally, synchronized monitoring rounds of the groundwater level and extensive chemical analyses of existing wells are used to map the current state and follow the development very closely. This knowledge is used to compare chemical fingerprinting to increase the probability of identifying the relevant point sources to what is found in the drinking water abstraction wells. Thereby the Region can prioritize between the different contaminated sites on an informed base. Results of groundwater flow models are compared to the chemical mapping and is thereby also used to assist in the determinatione of which PFAS sources should be mitigated first. In parallel with identifying and investigating the sources in the area there was an urgent need for mitigation near Tune Vandværk, the most polluted water supply in the area. A collaboration has therefore been established in 2024 to mitigate the hardest-hit wells and treat the water using ion exchange technologies. This collaboration is constructed in an untraditional way, which has been a source of inspiration to the field. The pumping and subsequent purification of contaminated water ensures that citizens safely can drink the water extracted in the area, and at the same time it acts as a hydraulic barrier, significantly reducing the risk of PFAS problems to downstream water supplies in the area. An area, which is critical to the security of the Danish water supply, and therefore has significant political awareness.

Abstract ID: 274
Safe and responsible drilling to the second aquifer in Utrecht Implementation of four test drillings for deep subsurface research

Christian Soeter[1], Martijn Ypma[2], Alex Ooijevaar[3]
[1]Arcadis, [2]Wiertsema & Partners, [3]Gemeente Utrecht

In the trade fair area of Utrecht, many new buildings will be constructed in the coming years. One of the sustainable sources of heating and cooling for these new buildings is aquifer thermal energy. The first aquifer (about 10 to 50 m deep) in the trade fair area is already intensively used for aquifer thermal energy. There is not enough space in the 1st aquifer to meet future heat/cold demand via an open aquifer thermal energy system. The groundwater in the 1st aquifer is locally highly contaminated. Under current municipal and provincial policy it is not permitted to install aquifer thermal energy systems in the 2nd aquifer (approximately 70 to 150 m deep). The groundwater in the 2nd aquifer is extracted by drinking water utility Vitens in water extraction areas such as Leidsche Rijn and De Meern (about 5 km west of the trade fair area) for public drinking water supply.

The municipality of Utrecht and the province of Utrecht are working on a project to answer whether it is possible to safely and responsibly apply open aquifer thermal energy storage systems in the 2nd aquifer. Previous desk studies have shown that this is theoretically possible under (strict) conditions. This will be further investigated through practical research.

More information was needed about the deep subsurface (deeper than 50 m) for the practical research. For this purpose a deep test drilling was carried out for the first time in the trade fair area on behalf of the municipality of Utrecht and the province of Utrecht. Wiertsema & Partners and Arcadis took extra measures to carry out the drilling work safely and responsibly. The first deep test drilling was carried out successfully into the 2nd aquifer to approximately 150 m -gl in 2022.

In order to gain more insight into the structure of the subsurface and the current contamination situation, the municipality of Utrecht intends to have additional 3 deep drillings carried out into the 2nd aquifer. We have been working on this since September 2024. The goal of the work is to gain insight into the soil structure, physical and chemical qualities of the soil into the 2nd aquifer in Utrecht. To achieve this goal, pulse drilling must be carried out at 3 locations to a maximum of 140 m -gl. This also involves drilling through the protective clay layer at a depth of approximately 50-70 m -gl. An important point of attention here is that during drilling, as well as in the future, there should be no leakage of contaminants through the clay layer into the 2nd reservoir (safe and responsible drilling). Work is carried out under strict conditions to prevent the migration of contaminants. The drilling operations will be carried out under the supervision of an environmental supervisor. The results of the deep drilling will be used for the update of the new geohydrological model and the update of the area plan area-specific groundwater management by the municipality of Utrecht. In the presentation, we share the latest results of the investigation. We also discuss the certainties and uncertainties we encountered during the execution of the drilling and the interpretation of the results.

Abstract ID: 276
Case Study: The Application of Combined FRAC IN/Electric Current Enhanced Remediation on a Low Permeability Site

Ondrej Lhotsky[1], Vladislav Knytl[1], Jaroslav Nosek[2], Jan Němeček[2], Petra Najmanová[1], Jan Kukačka[1]
[1]DEKONTA, a.s., [2]Technical University of Liberec

Purpose of study:
This case study explores a novel approach to the remediation of chlorinated ethenes (ClE) in low-permeability aquifers. It involves the integration of pneumatic fracturing with the hydraulic emplacement of waste zero-valent iron (ZVI) particles and/or sand to provide solid reactive materials in the aquifer and/or to enhance its permeability. Followed by long-term low-flow injection of diluted glycerol and iron trichloride solutions accompanied by the application of an electric current aimed at promoting electro-osmotic flow to enhance substrate distribution.

Methodology:
Two adjacent pilot fields were selected.
Field 1: Treated via the FRAC-IN injection of waste iron/sand mixture followed by low-flow iron trichloride injections. An electric current was applied aimed at enhancing both the iron distribution and the in situ chemical reduction (ISCR). Three months prior to the end of the study, low-flow glycerol injections were applied to enhance the biological reductive dechlorination (ERD).

Field 2: Treated via the FRAC-IN injection of sand and low-flow glycerol, with the application of an electric current to support the ERD.

Tracer tests using, as well as core sampling, were performed aimed at evaluating the fluid migration and distribution of the remediation agents. The real-time monitoring of the physico-chemical parameters of the groundwater and the substrate migration was performed via the use of an online system that included an amperometric chlorine sensor. The data obtained was used for the supervision of the real-time electric current and the application of the remediation agent solution.

Summary:

Electro-osmosis induced in situ: The elevated/decreased groundwater table levels during the application of the electric current indicated the initiation of successful electro-osmotic flow that led to the enhanced distribution of the remediation agents as proved by the rapid appearance of chlorides and glycerol in the monitoring wells.
Tracer and core sampling results: The continuously injected fluid migrated through narrow preferential pathways. The FRAC-IN injections served for the even distribution of tracers while he sand/iron deposits were observed to localize within discrete zones enhancing the permeability of the natural preferential flowpaths. Post-treatment site survey: The significant degradation was observed of the contaminants bound within the aquifer materials in the zones affected by the remediation agents, while zones of the aquifer were identified that were not affected by the treatment. Contaminant reduction during the 19 months of testing: Field 1 (ISCR + ERD): The mean ClE concentrations decreased from 23,900 μg/L to 5,570 μg/L. The mean chlorine number decreased from 2.26 to 1.53. The low acetylene levels confirmed the abiotic degradation. Field 2 (ERD): The mean ClE concentrations decreased from 4,360 μg/L to 600 μg/L. The mean chlorine number decreased from 1.58 to 0.9. Microbial activity: The enhanced presence of anaerobic (including specific Dehalococcoides) and aerobic (mainly ethenotrophic) degradation genes, with a higher abundance in Field 2 (ERD-only). Ongoing evaluation: The reactive mineral presence is still being analysed; the results are expected prior to the conference.

Conclusion:

The combination of FRAC-IN injections and electro-kinetically enhanced remediation provides a robust and efficient approach to the treatment of ClE in low-permeability aquifers. Even though the efficiency of the treatment is diluted due mainly to the preferential pathway network, these pathways align with the contaminant migration routes, thus ensuring overall effective treatment. Whereas back diffusion from the untreated zones is anticipated, it should be mitigated by the continuation of the processes in the treated pathways.

Significance:

This study emphasizes the importance of innovative remediation technologies for application in complex geological settings. It provides a replicable, cost-effective framework for users when addressing the treatment of ClE and other reducible contaminants when faced with tight timelines and challenging aquifer conditions.

Abstract ID: 279

Evaluating soil sampling methods for accurate quantification of volatile organic compounds in polluted sites: A comparative analysis

Sophie Favéreaux [1], Stéphane Belbèze [1], Pauline Moreau [1], Dorian Davarzani[1]

[1]BRGM

Volatile organic compounds (VOCs), including chlorinated solvents like tetrachloroethylene (PCE) and trichloroethylene (TCE), are hazardous pollutants due to their flammability, toxicity, and carcinogenic effects on humans and ecosystems. Detecting VOCs in contaminated soils is a critical step in environmental risk assessment and remediation planning. However, the inherent heterogeneity of soil properties complicates sampling and analysis, often leading to significant variability in measured concentrations. This study was designed to evaluate the influence of different soil sampling techniques on VOC concentration.

The primary objective of this study was to compare four commonly used sampling methods for measuring PCE and TCE concentrations in polluted soils: methanol vial (MV), gas jar (GJ), and two coring cylinders (small core (SC), 16 mL, and large core (LC), 100 mL). The study aimed to determine how these methods impact VOC recovery, assess their applicability across varying soil types, and highlight the limitations and strengths of each technique. By minimizing operational variability through controlled field and laboratory protocols, the study offers insights into the reliability and accuracy of these methods.

The field study was conducted on two distinct zones with varying lithological characteristics: sandy loam and marly soils. Soil samples were collected using a windowless core sampler, ensuring minimal disturbance. To maintain consistency, a single experienced operator followed pre-defined protocols, and all analyses were performed by a single laboratory to eliminate inter-operator and inter-laboratory variability. VOC concentrations in soil samples ranged between 20 and 900 mg/kg dry matter, reflecting realistic pollution scenarios.

Each sampling method was assessed based on its ability to minimize VOC losses during sampling, transport, and analysis. The MV method involved direct immersion of soil samples in methanol The GJ method consisted of filling containers with a spatula with minimal headspace to limit volatilization. The small core and large core methods relied on mechanical coring, with VOC preservation dependent on soil cohesion and sample handling protocols.

The MV method consistently produced the highest concentrations of PCE and TCE across both zones, confirming its effectiveness in minimizing VOC losses during sampling and storage. The SC method showed substantial variability among replicates, particularly in marly soils with coarse materials, resulting in significant underestimations of VOC concentrations. This method is best suited for cohesive soils with minimal coarse fragments.

The GJ method exhibited moderate VOC losses but maintained relatively small and consistent deviations compared to MV, suggesting that a strict field protocol can mitigate volatilization risks. The LC method, however, consistently underestimated VOC concentrations due to its limited ability to prevent VOC escape during sampling and handling, making it unsuitable for VOC investigations.

In terms of soil type, sandy loam samples exhibited lower variability than marly soils across all methods, reflecting the influence of lithology on sampling effectiveness.

The findings emphasize that sampling method selection significantly impacts the accuracy and reliability of VOC measurements in soils. The MV method is the most robust technique for high-precision assessments, particularly in detailed investigations of chlorinated solvent pollution. The GJ method may serve as a practical alternative for less rigorous studies, provided that strict handling protocols are followed. The SC method is applicable for cohesive soils but is less reliable in heterogeneous conditions. The LC method is not recommended for VOC analysis due to its consistent underestimation of concentrations.

This study compares sampling methods for VOCs, offering recommendations for environmental practitioners, regulators, and laboratories. The results improve reliability in VOC measurements and support effective environmental management. Future research should explore additional soil types,

VOCs, and sampling techniques to refine best practices and ensure adaptable, precise methodologies for diverse conditions.

Abstract ID: 281
How to terminate eternal soil remediations
Nanne Hoekstra[1], Tom Bosma[1], Jacques de Jong[2], Laura Timmermans[3], Sem Braaksma[1], Henry Schouten[4]
[1]Deltares, [2]Municipality of Amsterdam, [3]Municipality of Zwolle, [4]Bodembeheer Nederland

At many contaminated sites, where complete removal of pollutants was in the past not deemed feasible, containment measures where installed, that will remain necessary for a long time. Often, these measures are even planned for eternity. Because substantial reinvestments will be required in the decades to come, a burden is passed on to future generations. To reduce this constraint, a consortium led by Deltares investigates in a project, which is subsidized by the Top Sector Delta Technology, how this long-term 'aftercare' can be phased out.

The project includes a series of pilots with diverse soil contaminations, including landfills, chemical laundries, industries using solvents and production sites for gas, tar, metals and freons. The pilots are situated throughout the Netherlands: Almelo, Amsterdam, Arnhem, Barneveld, Kortenhoef, Krimpen a/d IJssel, Leidschendam, Nijverdal, Weert and Zwolle. The sites are contaminated with a wide range of pollutants, such as mineral oil, volatile aromatics, poly-aromatic compounds, chlorinated hydrocarbons, chlorofluorocarbons, (heavy) metals and PFAS.

The final project product will be a guidance for problem owners to re-evaluate their containment measures and a roadmap to implement nature-based solutions instead. In order to make this guidance as useful and user-friendly as possible, we propose a special session in which we will not only present the most recent findings in this project, but also ask input from the audience.

Different types of nature-based solutions, as developed recently in soil remediation practice, are the building blocks for the development of a new approach for contained-contaminant-sites of which there are many thousands merely in the Netherlands. In the project, we investigate whether the current containment measures, such as sheet piles and groundwater extraction systems, are still necessary, or if they can cost-effectively be replaced by:
• Reactive zones with natural or stimulated degradation or retention in the soil.
• Helophyte filters, possibly in combination with wind or solar pumps.
• Purifying trees in tree wells.

These types of measures acquire a significant amount of space in already crowded cities. But a combination can be sought with climate-adaptive measures such as water retention and reduction of urban heating while establishing refuge facilities for biodiversity, which consequently increases local recreational values for city dwellers. In this way, inherited problems from the 20th century can be solved while meeting 21st century challenges.

Nature-based solutions also take time but less than conventional containment measures since the natural processes have the potential to remove the contaminants completely from the groundwater, eventually. In the meantime, site management efforts can be reduced to a low level once the natural processes have proven to be robust and risks are diminished.

In the proposed special session, we will elucidate our interesting and promising findings. The session starts with three presentations by the researchers who will explain how the nature-based solutions mentioned above are applicable for persistent contaminants and show that degradation and precipitation processes offer prospects for future site closures. Also, the perspective of site owners and governments will be presented. Following the presentations, there will be a round-table discussion about opportunities and challenges for the phasing out of long-term containment measures at severely contaminated sites. Since thus far our conceptual product is based on Dutch cases only, we seek interaction with an international audience for comparison and to improve the quality and range of our guidance (for which a flip-over would be convenient).

All the authors plan to be present and participate with (parts of) presentations and contributions to the discussions.

Abstract ID: 283

Side-by-Side Evaluation of Field-Scale Treatment of PFAS-Impacted Sediments: Smoldering, Thermal Desorption, and Soil Washing followed by SCWO, HALT, and UV/SGM

Sarah Suehnholz[1], Hannah McIntyre[2], Elisabeth Hawley[2], Rula Deeb[2], Christopher Higgins[1]
[1]Colorado School of Mines, [2]Geosyntec

Recent reports highlight the prevalence of poly- and perfluoroalkyl substances (PFASs) in soils, particularly at sites impacted by aqueous film-forming foam (AFFF), with concentrations ranging from 100 to 460,000 µg/kg. AFFF-impacted soils often contain high levels of polyfluorinated substances, or perfluoroalkyl acid (PFAA) precursors, comprising up to 28% of total PFASs. With numerous AFFF-contaminated Department of Defense (DoD) sites, effective treatment processes for PFAS remediation are crucial. Studies show that the majority of PFAS mass at AFFF-impacted sites resides in source zone soils and aquifer materials.

To address PFAS-contaminated sediments and soils, various remediation approaches have been explored, including immobilization, mobilization, and direct destructive treatment like smoldering. Immobilization techniques aim to reduce PFAS mobility and bioavailability by incorporating PFAS-adsorbing or -precipitating agents like activated carbon and cationic polymers. In contrast, mobilization strategies involve "flushing" PFASs from the sediment or soil. Soil washing as well as thermal desorption have been tested at scale for numerous sites.

In the project, we employed a combination of techniques, including smoldering, thermal desorption, and soil washing coupled with foam fractionation. Additionally, downstream destruction technologies such as supercritical water oxidation, hydrothermal alkaline treatment, and photocatalytic oxidation were utilized.

Before evaluation of the treatment technologies, PFAS-impacted materials were fully characterized to assess PFAS concentration, types, and physical and chemical characteristics affecting remedy performance. The leachability of PFASs from materials were evaluated using standardized protocols to ensure treatment efficacy. For comparison of the various technologies, a standardized testing framework is used to evaluate various PFAS treatment technologies side-by-side, including the destructive methods. Side-by-side comparisons and independent efficacy assessments will provide valuable data for DoD decision-making. The presentation will showcase bench-scale and field site test results, and introduce the used evaluation framework.

Abstract ID: 285

Cost-effective and efficient in-situ groundwater remediation with TrapOx®: an innovative ISCO technology from the laboratory to full-scale application

Sarah Suehnholz[1], Julian Bosch[1], Anett Georgi[2]

[1]Intrapore GmbH, [2]Helmholtz Zentrum fuer Umweltforschung

Near Catania in Sicily, soil and groundwater contamination caused by organic pollutants, primarily high concentrations of gasoline components, was discovered due to an underground storage tank. To address the issue, an in-situ remediation plan using TrapOx® microparticle suspension, based on zeolites, was implemented. TrapOx® enables the combination of adsorption and catalytic oxidation of pollutants. The goal of the remediation was to sustainably reduce pollutant concentrations below regulatory limits and prevent the spread of contamination.

Laboratory studies conducted in August 2021 demonstrated the potential of TrapOx® technology for the adsorption and degradation of pollutants. In May 2022, an initial pilot injection of the zeolites was performed, followed by an oxidant injection in October 2022. The results were highly successful: pollutant concentrations, including TPH, ETBE, and MTBE, dropped significantly below regulatory limits and in some cases below detection limits. The method proved particularly effective for treating MTBE and ETBE in source zones, achieving reductions from approximately 10,000 µg/L to ~10 µg/L. This confirmed that iron-doped TrapOx® zeolites are a highly efficient method for in-situ remediation of petroleum-based contamination, especially for MTBE and ETBE in source zones.

Due to the success of the pilot test, the TrapOx® technology was fully scaled up to cover the entire remediation area in 2024. Even in full-scale application, the results again demonstrated the high effectiveness of the zeolites in sustainably reducing pollutant concentrations and preventing further spread of the contamination, leading to the completion of the remediation. With TrapOx®, Intrapore, in collaboration with UFZ, has developed a highly effective, innovative, sustainable, and cost-efficient ISCO solution for in-situ groundwater remediation and demonstrated its feasibility under real field conditions.

Abstract ID: 287
Adsorption of 2,4,6-trinitrotoluene by biochar and its application in soil remediation

Bin Dong[1], Chengxu Lai[1], Xu Yang[1], Mengwei Han[1], Sanping Zhao[1], Junbo Zhong[2], Yongbing Zhu[1]
[1]State Key Laboratory of NBC Protection for Civilian, [2]Key Laboratory of Green Chemistry of Sichuan Institutes of Higher Education, School of Chemistry and Environmental Engineering, Sichuan University of Science and Engineering

2,4,6-Trinitrotoluene (TNT) is a widely used nitroaromatic explosive that poses significant environmental and biological risks due to its toxicity, particularly in conflict zones where increased residue and hazards remain from indiscriminate use. The removal of TNT through adsorption and immobilization using biochar is proposed as a safe and cost-effective remediation strategy for TNT-contaminated sites. This study evaluates the potential of biochar derived from four different waste sources for TNT adsorption. The plant-based biochars (from wood and coconut shell) demonstrate high organic carbon content (68.72%–69.42%), significant specific surface area (535.09–578.99 m2/g) and total pore volume (0.65–0.69 cm3/g), resulting in superior TNT adsorption capacities (257.2 and 240.0 mg/g) compared to the bone- and sludge-based biochars. The kinetic of TNT adsorption on biochar obeys the quasi-second-order kinetic model (R2>0.97), indicating that chemisorption is the dominant mechanism. The adsorption isotherms fit well with the Freundlich model (R2>0.99), suggesting an inhomogeneous multilayer adsorption process. Primary mechanisms of TNT adsorption may include π-π interactions and pore filling. Notably, the adsorption of TNT by biochar exhibits good environmental adaptability across varying temperatures, pH levels, and in the presence of coexisting substances. The incorporation of just 2% biochar effectively immobilized 1000 mg/kg of TNT in soil. This research highlights the promising potential of biochar as an effective adsorbent for TNT and underscores the practical applications of biochar in the remediation of TNT-contaminated soils.

Abstract ID: 289
How to Improve the Efficacy of Arsenic Remediation

Helena Nord[1], Jurate Kumpiene[2], Jonny Bergman[1], Therese Hjälm[3], Jonny Sävenhed[4], Mike Müeller[5]
[1]Sheeba Environmental Engineering, [2]University of Luleå, [3]Structor Miljö Öst, [4]Municipality of Finspång, [5]Evonik

Purpose of study: Understanding and controlling arsenic leaching at contaminated sites. In areas that have been remediated by excavation and/or soil washing, As levels in groundwater can increase significantly after the remediation has been completed. The excavation of As-contaminated soil can alter redox conditions, which may affect the leaching of underlying soil with low residual pollution. Nevertheless, insufficient attention has been paid to understand the causes behind the increased leaching of As over time in remediated areas, which exceeded the levels found prior to remediation.

This TUFFO funded research project aims to demonstrate how excavation, soil washing and stabilization of arsenic can affect the remediation outcome on site. The project therefore aims to investigate the potential reasons for the elevated leachability of arsenic in remediated sites, and to test and recommend strategies to mitigate this.

Methodology: The field works are carried out in Lotorp, Finspång municipality in Sweden. A former wood preservation plant has resulted in extensive soil contamination with arsenic as the dominating contaminant. Arsenic levels above the acute toxicity values (up to 2,900 mg/kg) are present in the soils that are dominated by sand and silt as well as clayey areas in an area with large amounts of construction wastes. The trials are carried out in the unsaturated zone and consists of 8 different treatments. For stabilization, the commercial products MetaFix and GeoForm were applied to the soil in order to stabilize the arsenic by forming stabile hydroxide and iron sulphate precipitates and reduce the residual risks for arsenic leaching.

Several different trials has been performed (in duplicates).
Control Excavation and backfill with crushed bedrock Sieving and homogenization Homogenization + MetaFix Homogenization + MetaFix + GeoForm Sieving + homogenization + MetaFix Sieving + homogenization + MetaFix + GeoForm No treatment (control)

The results of the trial were measured by sampling using suction lysimeters, mainly installed in barrels filled with treated soils and placed in the ground beside the treated pilot areas. Sequential leachate test will also be used for evaluating site performance in order to determine the reduction of the bioavailability of arsenic.

Summary of findings/results: The field works were completed and the field experience provides important information on how to perform these treatment practically, and also how to use these technologies in full scale. The finding will be presented at the conference.

Conclusion: The field works were carried out in September 2024, and a control programme is ongoing. Results will be presented at the conference.

Significance/contributions of study: The results of the study will be used in order to select a remediation strategy for the area. It will also be used in order to prevent higher arsenic levels after remediation. The results will also be used to provide proof of concept for in situ stabilization of arsenic in Sweden as heavy metal contaminated sites, by tradition, has been almost exclusively treated by excavation.

Abstract ID: 292
Contaminated soil data and predictive modelling of soil health and risks

Hans-Peter ARP[1], Hans-Christian BRUUN-HANSEN[2], Yoann BOISSON[3], Michel CHALOT[3], Dominique GUYONNET[4], Timo TARVAINEN[5], Roar Aesker JENSEN[6], Bjarne STROBEL[2], Mahrooz REZAEI[7], Coen RITSEMA[7], Radu GIURGIU[8], Tomas REZNIK[9]
[1]NTNU, [2]University of Copenhagen, [3]University of Franche-Comté, [4]BRGM, [5]GTK, [6]DHI, [7]Wageningen University, [8]ILVO, [9]Masaryk University

This interactive session will generate a discussion on soil and contaminant data acquisition and its best use for providing information on soil health and risks in order to guide decision-makers regarding soil management, remediation, restoration and policies. It will gather, as chairs, at least one representative from six ongoing MISSION SOIL projects dedicated to contaminated soils (in alphabetical order):

ARAGORN (Achieving remediation and governing restoration of contamination soils now). Sites contaminated by persistent chemicals (PFAS, organochlorine/bromine contaminants, petroleum-coal, and metals) have left vast areas tainted. ARAGORN offers a comprehensive framework to reduce risks, and means to remediate and restore the health of soils, ecosystems, and their resilience. The project builds upon existing experiences and introduces mapping, sampling, and monitoring tools. It tests remediation technologies and restoration practices fit for each site and contaminants, taking into account local financial, spatial, and cultural boundaries.

EDAPHOS (Advanced mapping, risk assessment and nature-based depollution methods are combined to accelerate the recovery of contaminated soils and ensure that ecological restoration enters mainstream business) - With an aim to reduce soil pollution and enhance restoration, EDAPHOS proposes a holistic approach that combines nature-based solutions (NBS) and advanced technologies to accelerate the recovery of contaminated lands and make ecological restoration a mainstream endeavour.

ISLANDR (Information-based strategies for land remediation) provides remediation strategies, risk-based methods and spatial planning and financial models supporting the decontamination and reuse of land in urban and rural areas. It develops informational tools to help the public and private sector prioritize and deploy activities for decontamination and reuse of land and support for capacity-building for the multi-actor community. ISLANDR builds upon data sets regarding contamination at various scales to provide an overview of soil pollution in Europe, major data gaps and methodologies for identifying hotspots with the aim of prioritizing remedial action on the ground.

PHISHES (Physically-based integrated soil health simulation platform). PHISHES aims to bridge the missing link between data on soil health and actions for the safeguard of soils. This link entails predictive capability in terms of the consequences of actions on the provision of soil functions and associated ecosystem services, taking into account soil use, soil contamination and various drivers such as climate change. PHISHES builds upon pre-existing integrated simulation tools; e.g., the MIKE SHE model for integrated hydrologic modelling and the DAISY model for the soil-plant-atmosphere system.

SOILPROM (Modelling pollutant transport across the soil-water-atmosphere continuum, and impacts on ecosystem services). SOILPROM aims to enhance soil pollution modelling for contaminants with high risk for the environment and human health including metals, PFAS, nutrients, microplastics, and pesticides. Models focus on 13 different soil-related processes across soil, water, and atmosphere compartments, studied within the 7 SOILPROM use-cases. It uses existing European databases and collects new standardised local datasets in accordance with DestinE and EUSO requirements. SOILPROM will provide access to soil pollution information via a modelling platform and support stakeholders towards sustainable land management strategies and policies for healthy soils in Europe.

SOILWISE (Open access knowledge and data repository to safeguard soils) – the SoilWise project aims to make accessible the scattered and heterogeneous soil data and knowledge in Europe to support informed decision-making and the Soil Monitoring Law (SML). The project's focus is on making these resources FAIR (Findable, Accessible, Interoperable and Reusable) and fostering trust and willingness

to share and reuse such valuable information. Through collaborative efforts involving stakeholders, SoilWise intends to streamline existing workflows and repositories, enhancing their discoverability and interconnection.

Abstract ID: 296
The Catchment Pesticide Diagnosis Unit : a tool to develop strategies to reduce drinking water catchment pollution

Florence Williscotte[1], Bernard Weickmans[1], Bruno Huyghebaert[1], Nicolas Triolet[2]
[1]Centre wallon de Recherches agronomiques, [2]Société Publique de Gestion de l'Eau

Intensification of the Walloon agricultural system has contributed to large use of fertilizers and Plant Protection Products (PPP). Due to this, drinking water standard set up by the Walloon Water Code concerning PPP as 0,1 µg/L for an active substance or some metabolites and 0,5 µg/L for the total of PPP quantified are often exceed in raw groundwater intended for human consumption. In order to protect those abstraction points and improve their water quality, the Catchment Pesticide Diagnosis Unit (CDPU) was created. This Unit aims to determine the contamination sources of abstraction points by PPPs to better understand the existing relations within the environment and target solutions/strategies to implement at the field scale within the catchment area. This level of scale is necessary to ensure a good management of the contamination risk in the considered area. The CDPU was set up in 2005, as part of a collaboration between the Public Water Management Company (SPGE) and the Walloon Agricultural Research Centre (CRA-W) to provide to the water producers a scientific frame and expertise in agronomic and hydrogeological matters. When PPPs concentrations of the raw groundwater are above drinking water standard in an abstraction point, the CDPU performs a diagnosis to evaluate the pollution in four different steps. The first step consists of the documentary work to gather relevant information related to the studied site and observed PPPs to better understand the elements that impact the fate of a PPP to the groundwater. This important step allows us to make assumptions on putative contamination paths. At the second and third steps, field visits as well as a survey of PPP users are performed to identify how water circulates in the plot and define the applied PPP in the studied area to validate the first hypothesis. Finally, the last step consists of the diagnosis itself and the proposal of solutions. Since the beginning, the CDPU has handled approximately forty cases. Most studied cases often involve diffuse pollution (drift and leaching). Point-source contaminations are complementary to diffuse pollutions. Transformed products from root herbicides are frequently found as for example metolachlore ESA or metazachlore ESA. Some contact products are also present such as bentazone, particularly worrying in karstic sites. Most of herbicides found in groundwater are used to crops such as sugar beet, maize and oilseed rape. Because of the way they are grown, these crops request herbicides that are more prone to leaching. Although farmers cannot influence the geological and hydrogeological properties of the cultivated plot, agricultural practices do exist and can be put in place to better preserve the water resource. Since 2018, the CDPU has been part of the Protect'eau framework whose mission is to preserve water quality due to a sustainable management of nitrogen and PPPs in farming sector. The CDPU diagnosis is also part of 'catchment agreements' that aim to draw up an action plan with the stakeholders and invite farmers to co-design solutions that will be implemented in their fields. More than 46 catchment agreements have been settled since its creation leading to the raise of farmers' awareness of the impact of their farming practices on the environment and to introduce innovative farming practices.

Abstract ID: 298

LIFE REMAR Project, Pioneering Solution for Treated Wastewater Renaturalization using Soil-Aquifer Treatment with Reactive Barriers at Pilot Scale

Sara Bagés Estopà[1], Tiphaine Chantal Anderbouhr [1], Joan Campos Ferré [1], Miranda González Rodríguez [1], Silvia Díaz Cruz[2], Jesús Carrera Ramírez[3], Cristina Valhondo González[3], Lurdes Martínez Landa[4], Xavier Sánchez Vila[5], Linda Luquot[6], Josep Martínez Vil

[1]*Comaigua, [2]Institute of Environmental Assessment and Water Research (IDAEA-CSIC), Barcelona, [3]Institute of Environmental Assessment and Water Research (IDAEA-CSIC), Barcelona. Associated Unit: Groundwater Hydrology Group (GHS: UPC-CSIC), [4]Department of C*

Water scarcity is an increasingly critical issue in Mediterranean countries, exacerbated by the impacts of climate change. To address the rising demand for water, groundwater extraction has intensified, leading to the overexploitation of aquifers. This challenge is particularly acute in coastal areas, where excessive groundwater withdrawal can promote seawater intrusion. The situation becomes even more pressing during peak tourist periods.

In this context, soil-aquifer treatment (SAT), a specific form of managed aquifer recharge (MAR) that uses treated wastewater for recharge, emerges as an effective solution to increase groundwater availability while improving the quality of the WWTP effluent. SAT systems implementing reactive barriers have shown exceptional efficiency in contaminant removal by fostering a sequence of redox states. This is achieved through the addition of organic carbon, which increases the number of sorption sites and promotes biodegradation. Furthermore, the unsaturated zone of the aquifer beneath these barriers acts as a natural filter, enhancing the removal of pollutants from infiltrating water, before it mixes with the aquifer water. Plant growth on the basin surface plays a dual role preventing clogging of the recharge zone and providing organic matter to the barrier at the end of its life cycle, further supporting the system's long-term sustainability.

The LIFE REMAR project (LIFE20 ENV/ES/000284) repurposes treated wastewater from the Cambrils WWTP to recharge the Plioquaternari Detrital Aquifer of Camp de Tarragona through a SAT system. This system comprises two infiltration basins that receive a portion of the effluent water via gravity flow. A reactive barrier, composed primarily of sediments from the aquifer and plant-derived organic matter, has been installed at the bottom of each basin to enhance the removal of emerging organic pollutants, microplastics, pathogens, and antibiotic resistance genes. To assess its performance, the system incorporates various plant species, including native and wetland varieties. Designed to recharge approximately 146,000 m³ annually, this system recharges 3–4% of the total volume of treated water produced by the WWTP, contributing to sustainable water resource management in the region.

Piezometers have been installed to monitor the recharge process and assess water quality. A sampling point upstream of the infiltration system serves as a reference for the native groundwater. Additionally, the infiltration water, comprising the WWTP secondary effluent, is sampled before it passes through the reactive barrier and infiltrates into the aquifer. The recharge process is monitored through various sampling locations; water is collected from the unsaturated zone of the aquifer, beneath the infiltration basins from shallower piezometers within the basins, and from the saturated zone, via two deeper piezometers. Downstream of the recharge area, three additional sampling points have been established to monitor the groundwater's level and quality as it flows toward the sea.

Since the start of the system operation, a significant reduction in nitrogen concentrations has been observed in the recharged water as it passes through the reactive barrier and the unsaturated zone before reaching the aquifer. Initially, nitrogen in the aquifer was present primarily as nitrates contributing to its poor qualitative state. Recharge has led to a considerable decrease in nitrate levels directly beneath the basins, in the saturated zone, while nitrate concentrations in downstream piezometers remain unaffected by the recharge process. Additionally, Escherichia coli concentrations in the WWTP effluent are significantly reduced during the recharge. These findings highlight the

project's initial success in removing contaminants and improving water quality. The results from this pilot system will inform the design of a larger-scale system implementation.

Abstract ID: 301

Shaping Tomorrow's Soil Health: A Focus on Prioritizing Contaminants of Emerging Concern (CECs) in soil and groundwater Investigations

Antoine Zanutel[1], Thomas Lambrechts[2], Karen Van Geert[1], Louis Druon[1], Laura Lefèvre[1], Clément Laurent[1]

[1]Arcadis Belgium, [2]Service public de Wallonie

Purpose of the Study

The study commissioned by the Walloon Minister of the Environment aims to define recommendations for investigations and analyses of emerging contaminants for authorized soil experts in Wallonia, Belgium. The study focused on the following groups of contaminants of emerging concerns (CEC): PCBs, Dioxins/furans, Phthalates and other plasticizers, Flame retardants, Bisphenols, Chlorobenzenes, Chloronaphthalenes (PCNs), Short-chain chlorinated paraffins (SCCPs), Hexachlorobutadiene (HCBD).

Methodology

A review of all CEC was conducted by the Walloon public service (SPW) to focus on a certain number of families of contaminants. The selection was based on the knowledge already acquired by the Walloon authorities and the need to address the compounds in soil and groundwater investigation studies for local pollutions.

Phase 1 involves the identification of all substances from the selected CECs, the pre-selection of relevant substances, literature research on physico-chemical and toxicological parameters, high-risk historical/current activities related to the substances, and analytical methods. A methodology has been formulated to gather all necessary information.

Summary of Findings/Results

Approximately 1000 substances were initially listed across all substance families. A pre-selection of 220 substances was made based on toxicological parameters (such as persistence and toxicity) and existing lists of concerning substances (such as the POP list, Norman list, etc.). Literature research is being conducted on these 220 substances. Accredited laboratories in Wallonia were approached to provide details on analytical methods, quantification limits, and costs. Information on guidelines from other countries (such as France, the Netherlands, the UK, the USA, etc.) was also gathered. In phase 2, a scoring system is developed to prioritize substances and identify those which might lead to soil and groundwater pollution.

Walloon public service will provide guidance values for each identified substance.

Conclusion/Take-Home Message

Emerging contaminants are not always considered in soil and groundwater investigation study due to the lack of knowledge among the soil experts. The study highlights the critical importance of identifying and prioritizing emerging contaminants for investigations. By following a robust methodology and utilizing a comprehensive set of criteria, this study aims to enhance the understanding of pollutant risks and facilitate decision-making in investigation. The results of this study will contribute to the development of targeted investigation strategies related to CEC.

Significance/Contributions of Study

The presentation will cover a variety of emerging contaminants included in the study, along with details on the methodology and scoring system used to inventory and prioritize pertinent CECs in soil and groundwater investigations.

Abstract ID: 304
MYCOTRAP – An innovative tool to evaluate natural biodegradation and biostimulation of organic pollutants in soil based on stable isotope probing (SIP)

Anko Fischer[1], José Luiz Vazquez Ramos[1], Kevin Kuntze[1]
[1]Isodetect GmbH

Within the EU-Life project MySOIL (https://lifemysoil.eu), the new monitoring tool MYCOTRAP for evaluating natural biodegradation and bioremediation of organic pollutants in soil has developed and tested. It bases on Stable Isotope Probing (SIP) using an in situ microcosm with 13C-labelled target pollutants for tracing the 13C-label into microorganism components (so called biomarkers) or mineralization products (e.g. CO_2) as consequence of the biodegradation of the 13C-labelled target pollutant. Thus, the biodegradability and success of bioremediation can be sensitively observed by the MYCOTRAP approach under in situ conditions. MYCOTRAPs are loaded with the 13C-labelled pollutant and deployed in soil for several weeks (Fig. 1). During the deployment, microbial communities from soil colonize the MYCOTRAPs. Microorganisms that are able to use the 13C-labelled pollutant incorporate the 13C-label in their biomass so that the evidence for biodegradation can be provided by the detection of a significant 13C-enrichment in microbial biomass components (e.g. fatty acids, proteins) or mineralization products (e.g. CO_2) using compound-specific stable isotope analysis (CSIA).

Besides MYCOTRAPs with 13C-labelled pollutants, MYCOTRAPs with deuterium (2H) labelled pollutants were tested. Similar as for MYCOTRAPs with a 13C-labelled target pollutant, biodegradation is ascertained by the detection of the incorporation of the 2H-label from the 2H-labelled target pollutant into biomarkers. This reveals the potential for cheaper MYCOTRAPs available for more target pollutants since 2H-labelled compounds are cheaper and for a higher variety of organic chemicals than 13C-labelled compounds.

The basic principle of the MYCOTRAP approach was tested in mesocosm studies in which the potential to enhance the biodegradation of petroluem hydrocarbons by using fungi was investigated. MYCOTRAPs were incubated with 13C- and 2H-labelled hexadecane in the mesocosms. After 10-12 weeks, these were removed and phospholipid fatty acids (PLFAs), which are components of the cell membrane of microorganisms, were extracted. The PFLAs were identified using GC/MS. Their 13C- or 2H-content was then determined by CSIA. There was a clear enrichment of 13C and 2H in the PFLAs and thus evidence of hexadecane degradation, which proved the basic feasibility of the MYCOTRAP approach.

The field applicability of the MYCOTRAP approach was tested during fungi-assisted biodegradation in soil piles (mycoremediation). MYCOTRAPs with 13C- and 2H-labelled hexadecane were installed in various piles of soil contaminated with petroleum hydrocarbons. Here, too, a clear 13C- and 2H-enrichment in PFLAs was detected. Thus, hexadecane biodegradation could be proven, which confirmed the suitability of the MYCOTRAP approach under in situ conditions. In addition, MYCOTRAPs were tested with 13C- and 2H-labelled biphenyl in piles of soil contaminated with heat transfer fluids (HTFs).

Abstract ID: 307
A multi-criteria decision support model for sustainability assessment of water supply alternatives and application to two case studies

Gitte Lemming Søndergaard[1], Maria Faragó[1], Liselotte Clausen[2], Martin Rygaard[2], Mathilde Hedegaard Jørgensen[2], Nina Tuxen[3], Gunver Heidemann Olsgaard[3], Marianne Wesnæs[4], Bo Lindhardt[4]
[1]Ramboll Denmark, [2]HOFOR, [3]Capital Region of Denmark, [4]Novafos

Purpose of Study: Denmark's reliance on groundwater for its drinking water supply faces challenges from persistent contamination by pesticide byproducts. This study aims to create a decision support model that brings multiple criteria into consideration for assessing the sustainability of treatment technologies for water supply. With a specific focus on the Copenhagen area, where N,N-Dimethylsulfamide (DMS) contamination in groundwater has been a recent concern, the project seeks to assess the sustainability of different alternatives for water treatment options for two major Danish water utilities.

The project was carried out within the scope of the Danish innovation network for clean and safe drinking water (InSa Drikkevand) in collaboration with the Danish water utilities HOFOR and Novafos, the Capital Region of Denmark, the Technical University of Denmark and Rambøll.

Methodology: A comprehensive, multidisciplinary approach informed the development of this multi-criteria model, which encompasses 21 sustainability indicators. These indicators are grouped into four main categories—environmental, social, technological, and economic indicators—and were identified through a thorough literature review and direct input from a diverse group of stakeholders. The environmental criteria include for example greenhouse gas emission, resource consumption, and waste production. A pivotal feature of this approach includes performing a life cycle assessment (LCA) for each option. Societal criteria include, e.g. safety and health effects. The technical indicators deal with the reliability and flexibility of the solutions as well as differences in obtaining permits, e.g. to discharge reject water to the sewer network. The economic indicators focus on the alternatives' impact on the water production cost and other potential costs and benefits.

Stakeholder involvement has been central throughout the project. Relevant stakeholders have been included both during indicator selection as well as during indicator scoring and weighting of indicators for each of the two case studies.

Summary of Findings/Results: The application of the multi-criteria model was demonstrated through two case studies, each considering various approaches for managing DMS in drinking water supplies. In the first case at HOFOR's future facility, alternatives ranged from simply increasing acceptable DMS levels in drinking water to incorporating advanced technologies like advanced oxidation with UV/H2O2 and membrane filtration using low pressure reverse osmosis (LPRO). The second case for Novafos evaluated similar technological options alongside strategies to reduce water production in the DMS-contaminated area and increase production in another utility. The evaluation identified advanced oxidation as a less preferred option in terms of sustainability, with optimal solutions involving increasing the DMS limit value in drinking water assuming that it is toxicologically safe to do so.

Conclusion/Take Home Message: The study underscores that more technologically advanced treatment options does not necessarily mean more sustainable, advocating for an assessment process that thoroughly evaluates treatment methods against a spectrum of sustainability metrics.

Significance / Contributions of Study: This study contributes a significant analytical framework to the field of water management, equipping water utilities with a multi-criteria tool for navigating the complexities of sustainable treatment selection. The multi-criteria tool is flexible as irrelevant indicators may be deselected and other indicators may be added. In that way it easily adapts to other regions, contaminants or treatment methods.

Abstract ID: 309
Integrating resin regeneration and destruction to enhance the sustainability of PFAS treatment

Steven Becker[1], Brian Pinkard[2]
[1]*SciDev Ltd.,* [2]*Aquagga Inc.*

Purpose of study
The purpose of this study was to demonstrate the integration of two field-proven remediation technologies, SciDev's non-solvent regenerable ion exchange (IX) systems and Aquagga's hydrothermal alkaline treatment (HALT), into an effective capture-and-destroy treatment train for the removal and destruction of PFAS in water and wastewater. The integration of these two technologies enhances the sustainability of these systems through reuse of process chemistry and the associated reduction in waste generated by the treatment process.
Anionic IX resins are commonly used for the removal of per- and polyfluoroalkyl substances (PFAS) from water and wastewater. Certain PFAS-selective ion exchange (IX) resins can be successfully regenerated and reused multiple times in treatment systems. The RegenIX™ process developed by SciDev Ltd is a non-solvent regeneration process utilizing a proprietary alkaline brine. The ability to regenerate and reuse IX resins reduces both waste generation and life cycle costs associated with long term or large volume PFAS treatment.
Hydrothermal alkaline treatment (HALT) is a PFAS destruction technology that operates under subcritical water conditions with the addition of sodium hydroxide (NaOH), which raises the pH and drives PFAS destruction reactions via thermal decarboxylation and nucleophilic substitution reaction mechanisms. This technology has been successfully demonstrated to achieve >99.9% PFAS destruction efficiency with 100% fluorine mass balance closure, including the reduction of TFA concentrations to below the limits of detection (Pinkard et al., ACS ES&T Eng., 2024). HALT operates most efficiently on a high concentration PFAS waste stream, therefore a PFAS capture and concentration step is needed to optimize treatment for lower concentration waters and wastewaters.
Methodology
Bench scale studies were conducted to evaluate the compatibility of non-solvent regenerable IX resin systems for PFAS capture and concentration and HALT for PFAS destruction. PFAS-laden IX resins were successively regenerated using the RegenIX™ process to assess the capacity retained after multiple regeneration cycles. The regenerate solution from these trials was retained and the composite solution sent for treatment using HALT. Treated effluent was then treated, filtered, and tested for reuse in the RegenIX™ process. The filtered mineral salts were contained, tested, and disposed of as non-hazardous waste.
Summary of findings/results
PFAS capture and concentration by non-solvent IX resin regeneration paired well with the HALT destruction technology. The combination of the two technologies was able to treat PFAS to non-detect levels. The spent alkaline brine solution required minimal pH adjustment to be optimized for treatment by HALT, reducing the overall chemical input to both systems. Further, the ability to treat and reuse the alkaline brine following treatment eliminated the need for post-treatment pH adjustment prior to disposal, reduced a liquid waste to a substantially smaller volume of solid waste, and further reduced the chemical inputs to the system through reuse of the alkaline solution. Based on the powerful results of these bench studies, opportunities to demonstrate this combination of technologies at the field scale are currently being sought.
Conclusion/take home message
The combination of RegenIX™ non-solvent IX resin regeneration and HALT is an example of a field-deployable treatment train that can both capture and destroy PFAS on site while enhancing the sustainability of PFAS treatment through a reduction in material inputs, waste minimization, and the reuse of materials that would otherwise be a waste product.
Significance / contributions of study

This study provides an example of how the careful selection of complementary technologies can be used to enhance the overall sustainability of a treatment systems, including but not limited to the context of PFAS treatment.

Abstract ID: 313
Use of Adsorbent-Based Remediation Technologies to Limit Surface Water Impacts from Contaminated Groundwater

Michael Mazzarese[1]
[1]*AST Environmental, Inc.*

Purpose. Sites impacted by common groundwater contaminants (e.g., petroleum hydrocarbons, chlorinated solvents, heavy metals, and per- and polyfluorinated substances [PFAS]) often have adjacent surface water bodies (e.g., streams, rivers, or lakes) that may also be affected. In the past decade, adsorbent-based remediation technologies have been increasingly employed to limit or prevent the migration of these contaminants into surface water.

Methodology. These technologies typically use trenching or direct push technology (DPT) for deployment. Adsorbent-based systems commonly utilize activated carbon or surface-modified clay (SMC), with or without a contaminant degradation mechanism. Volatile contaminants, like petroleum hydrocarbons or chlorinated solvents, can degrade once adsorbed onto the remediation platform (e.g., activated carbon). In contrast, non-degradable contaminants, such as heavy metals and PFAS, are primarily adsorbed to reduce the flux of contaminants into surface water. Depending on site conditions and project goals, these systems can be designed as cartridges for easy removal and replacement before breakthrough occurs, augmented with additional material to extend the lifespan, or modified with another material or biotechnology- as appropriate or as technology evolves.

Summary of Findings. Several application methods have been effectively used to limit the mass flux of contaminants into adjacent water bodies. The most common methods involve installing a permeable reactive barrier (PRB) for degradable contaminants or a permeable adsorptive barrier (PAB) for non-degradable contaminants. These barriers are typically installed using trenching (for shallow applications) or DPT injection (for both shallow and deeper applications). If the lithology does not support DPT due to shallow refusal, a pre-drill technique can be employed. This method involves pre-drilling injection locations using traditional drilling techniques (e.g., augers or roto-sonic), backfilling the borehole with engineered bentonite, and then re-drilling with DPT.

This presentation will present four projects utilizing different application methods:

Site 1: Shallow trenching to install a PRB upgradient of a stream to limit chloroform transport.

Site 2: Angled DPT injection of a PRB to treat tetrachloroethylene (PCE) discharging into a gaining stream.

Site 3: Pre-drilling and DPT injection to install a PRB to limit petroleum hydrocarbons discharging to a wetland.

Site 4: DPT injection of SMC into the bedding material of a stormwater pipe to sequester PFAS discharging into a wetland.

Conclusions. Extended monitoring data from the four project sites demonstrate that low-concentration project goals can be quickly achieved and maintained over extended periods.

Site 1: Achieved a greater than 99% reduction in chloroform concentrations in groundwater during the monitoring period.

Site 2: PCE concentrations in streambed piezometers decreased by 96% to 99%.

Site 3: Benzene, toluene, ethylbenzene, and total xylene concentrations decreased by over 99% compared to upgradient monitoring wells.

Site 4: PFAS concentrations decreased by as much as 93%.

Significance. With proper site characterization, modeling, and mass flux calculations, adsorbent-based remediation technologies can be designed to effectively reduce the discharge of contaminants into surface water. These systems can remain active for many years, and even decades, depending on contaminant mass flux and project goals.

Abstract ID: 315

Advancing the Remediation of Hydrocarbon-Contaminated Soils: A Comparative Study of SEAR, ISCO, and S-ISCO®

Aurora Santos[1], David Lorenzo[1], Arturo Romero[1], Raul García-Cervilla[2]
[1]Universidad Complutense de Madrid, [2]Universidad de Castilla la Mancha

This study aimed to evaluate and compare the effectiveness of Surfactant-Enhanced Aquifer Remediation (SEAR), In Situ Chemical Oxidation (ISCO), and Surfactant-Enhanced In Situ Chemical Oxidation (S-ISCO®) for treating aged hydrocarbon-contaminated soils. The main objective was to determine the most efficient remediation technique to optimize contaminant removal while minimizing challenges such as non-productive oxidant consumption and the complexity of on-site operations.

Experiments were conducted using sandy loam soil contaminated with 5556 mg/kg of Total Petroleum Hydrocarbons (TPHs). The study included column experiments that simulated field conditions, involving six pore volume injections of treatment solutions over 480 hours (total time). SEAR was tested using 5 g/L of anionic sodium dodecyl sulfate (SDS) and non-ionic E-Mulse® 3 (E3) as surfactants, focusing on their ability to enhance TPH desorption. ISCO employed sodium persulfate (PS) at 40 g/L, activated with 13.5 g/L NaOH, to oxidize contaminants. S-ISCO® (patented technologies owned by Ethical Solutions, LLC), integrated these approaches by using surfactants alongside the oxidant for combined desorption and in situ chemical oxidation.

The SEAR tests showed moderate TPH removal efficiencies of 12.3% with SDS and 14.8% with E3. These findings demonstrated that SEAR effectively mobilizes hydrocarbons but requires further treatment for the extracted effluents, posing additional operational steps. ISCO yielded a 23% TPH removal rate, benefiting from its oxidative capacity but facing limitations in oxidant contact with sorbed contaminants and substantial non-productive consumption due to soil organic matter and minerals. The S-ISCO® approach exhibited superior performance, achieving TPH removals of about 40%. The integration of surfactants enhanced the accessibility of contaminants for oxidation, effectively combining desorption and degradation within the same step and eliminating the need for post-extraction treatment.

SDS resulting in lower non-productive oxidant consumption than E3. This efficiency aligns with literature highlighting anionic surfactants' ability to minimize oxidant loss. While E3 also improved TPH removal, it displayed higher consumption rates due to interactions with the oxidant.

The findings suggest that S-ISCO® is the most effective and practical approach for remediating aged hydrocarbon contamination. This method enhances TPH removal and streamlines the remediation process by avoiding the treatment of contaminated emulsions, thus reducing the operational complexity and cost. Combining surfactant-aided desorption with in situ chemical oxidation is particularly effective for deeply sorbed contaminants, optimizing resource use and improving treatment outcomes.

This study provides crucial insights into selecting remediation techniques tailored to aged hydrocarbon contamination. S-ISCO® stands out as a comprehensive method that leverages the benefits of both SEAR and ISCO, enhancing contaminant removal and minimizing logistical challenges. The controlled use of surfactants ensures efficient oxidant consumption and reduced environmental impact. The results underscore the importance of matching remediation strategies with site-specific conditions and contamination characteristics. Future research should focus on optimizing surfactant and oxidant concentrations for balanced efficiency and sustainability and on understanding the biodegradability of surfactants in subsurface environments to mitigate any long-term ecological effects.

Abstract ID: 317
Data and Flux-Driven Approach for Targeted Remediation of Chlorinated Solvent Contaminations
Challenges in Investigating Chlorinated Solvent Contamination

Michael Borremans[1], Pieter Buffel[2], Jeroen VANDENBRUWANE[3], Goedele Verreydt[4]
[1]Tractebel Engineering, [2]EnISSA, [3]Injectis, [4]iFLUX

Chlorinated solvents are known to pose major challenges in terms of both investigation as well as remediation of soil and groundwater contaminations. The distribution of these dense non aqueous phase liquids (DNAPL's) is controlled by subtle variations of hydrogeological properties of the subsurface. As a result the architecture of source and plume is often very complex and unpredictable. Traditional investigation method with drilling and sampling of soil and groundwater cannot deliver the necessary data density to describe those complex contaminations. Conceptual site model (CSM) are flawed by data gaps and uncertainties; soil and remediation experts are required to make considerable generalizations and assumptions.

Present work describes how a revised historical investigation and a High Resolution Site Characterization (HRSC) approach shed a new light on the contaminant situation and remediation strategy.

The investigated site is situated in a highly urbanized area. Activities of a former printing company have caused extensive contaminations with chlorinated ethenes and ethanes. The main conclusions of the detailed soil investigation campaign, executed in the period 1998 – 2002 with conventional drilling and sampling techniques, were the following:

– Only one source zone was localized, originated on the site itself by discharging waste water directly into the groundwater via clarifiers;

– The chlorinated solvents plume, consisting mainly of TCE, stretches over a distance of 500 m; Enhanced anaerobic bioremediation is a suitable remediation approach in the source zone since no pure phase is present.

During the design of a groundwater remediation strategy in 2020, a supplementary survey campaign was required to have a better understanding of the distribution of the contaminant. Therefore the HRSC technique of EnISSA was selected. This technique is based on the conventional Membrane Interface Probe (MIP) technique combined with a mass spectrometer. The survey campaign was based on the results of additional historical research. The main conclusions of this supplementary assessment can be summarized as follow:

– The initial source zone area may contain residual pure product which makes enhanced anaerobic bioremediation less suitable;

– It is not a single plume originating from a single source zone but two different overlapping plumes caused by the two secondary source zones, identified at the level of (former) sewer lines;

– The preferential distribution horizons were clearly delineated and the plumes of chlorinated solvents dissolved in groundwater are sinking;

– The degradation sequence of the chlorinated solvents in the plumes was clearly demonstrated.

Based on the supplementary data the CSM was redefined. A re-evaluation of the groundwater contamination risk assessment is necessary.

Towards Targeted Remediation and Monitoring

Based on the updated CSM, a new remediation strategy has been developed. The first step is to address the source zones. For this purpose, the use of ISCO was selected. Activated persulfate is injected using the innovative SPIN® injection technology. This technology has been specially developed to ensure optimal contact between the injected reagents and the contaminants through precise and controlled injections at low pressure, adapted to all soil types.

An assessment framework is defined in which flux measurements form the basis for determining remediation targets and monitoring. With flux measurements, the dispersion behaviour of a contaminant can be more accurately monitored. From flux measurements and the area of the control surface, the mass discharge Md (total mass of contaminant flowing through the control surface per

day) can then be calculated. This approach is a more appropriate method of determining risk-based remediation goals and effects than mere concentration measurements.

Abstract ID: 319
Systematized portfolio of best instruments for assessment of soil functions and soil ecosystem services with potential to integrate in spatial planning

Teodora Todorcic Vekic[1]
[1]Chalmers University of Technology

Soil is a scarce and finite resource that is often overlooked in spatial planning. The integration of soil ecosystem services and functions into spatial planning strategies is crucial for achieving good soil health by 2050 at the EU level (Soil Monitoring Law) and would significantly contribute to fulfilling most of the UNs sustainable development goals. This can be achieved by bridging the gap between planners and soil experts through multidisciplinary use of existing soil inventories (tools and methods) across different application levels (local, regional, national) and contexts (agricultural, forestry, urban, semi-urban). Standardized portfolio of soil inventories would facilitate incorporation of soil health into broader environmental and climate adaptation strategies. Many of the ongoing and finalized projects in the EU have already investigated soil ecosystem services and functions on a national application level but none to our knowledge on a multi-national level across different climate types.

The purpose of this project is to create a systematized portfolio of existing soil inventories (scientific and grey literature) that would help answer soil quality, quantity, performance and planning challenges across different scales (local, regional, national) and use of application (rural, semi-urban, urban) to help and support the spatial planning process from an early stage from a soil scientists' perspective. Soil quality, quantity and performance challenges will include information such as soil fertility and nutrient cycling, soil pollution, desertification, soil compaction, soil erosion, landslides, land take, soil sealing, re-use of excavated soils, land-grabbing, climate buffering, heat stress, water management, carbon storage, biodiversity and more. Planning challenges will include information on subsurface planning, climate adaptation, biodiversity, energy transition, human health and well-being, densification, mobility and transport, nature restoration, agro-ecological planning, economic development of the rural areas, reconciling nature and agriculture and limited power-planning in the rural areas.

The portfolio will function as a semi-quantitative planning support tool where the user of the portfolio would be guided based on the input data the user has at his disposal (or may not); what challenges the user wants to address and potentially what more could be addressed based on the input data that he already has. This way, multiple users-planners, policy makers, land developers and managers, citizens/residents, etc., with different backgrounds (non-expert, intermediate, expert) could use this portfolio as a navigation for sustainable inclusion of soil in their planning and/or design decisions.

The portfolio will be tested among case studies involved through project consortium and adapted according to spatial planners needs, while contributing to increased soil literacy of planners and soil experts through mutual capacity building. As a result, planners and soil- experts will have a better understanding of the ability to make a transition towards soil-inclusive spatial strategies, which will in the long-term support achieving soil health other sustainability goals.

Key words: Soil health, soil and nature preservation, urban planning

Abstract ID: 322

Advancing from Bioremediation to Chemical Reduction and Sequestration: Remediation of Chlorinated Volatile Organic Compounds at a Former Industrial Site with a History of PFAS Contamination

Ravi Srirangam`[1], Christine Redfern[1], Heather Reccelli[1]

[1]Ramboll

Background : The investigation and remediation of a former industrial site in New Jersey used for vapor degreasing and plating operations has been ongoing for several decades. A Remedial Investigation completed in 2016 identified a plume of chlorinated volatile organic compounds (CVOCs) in groundwater, which predominantly consisted of trichloroethene (TCE), lesser amounts of 1,1,1-trichloroethane (TCA), petroleum hydrocarbons heavy metals and per- and polyfluoroalkyl substances (PFAS). An identified 275-meter-long plume originated in an on-site source area within the upper portion of a glacial till aquifer, predominantly consisting of sand and gravel. This plume follows a downward hydraulic gradient migrating into the deeper sections of the aquifer beyond the site boundaries. Contaminant sources were removed in the 2000s and resulting waste material properly disposed, except for a residual source of CVOCs (ranging between 30- 60 mg/L) and PFAS (> 700 ppt) impacting groundwater. Source zone remediation in the shallow aquifer is challenging with respect to three main criteria:

Presence of residual DNAPL bound in the soil pores acting as a long-term source impacting groundwater. Accessing the source mass trapped in low permeability zones using the most appropriate reagent delivery method that will enable contact between the contaminant mass and the reactive amendment. Selecting a remedial technology that effectively targets the CVOC plume without adverse impact on PFAS. Evaluating performance through an extensive monitoring program and modifying treatment approach based on geochemical indicators.

Approach: Multiple applications of enhanced in-situ bioremediation (EISB) have been implemented on site since 2014 through 2023. Permanent injection wells were installed on site within the shallow overburden including a secondary source area outside the building footprint and within portions of the site building, and in the deep till as an off-site L-shaped "biobarrier" to intercept the dissolved CVOC plume. Emulsified vegetable oil (EVO) was injected to create a biologically active zone (BAZ) to address both source and plume CVOC concentrations. Performance monitoring has indicated successful reduction of source area footprint (> 75%) in areas that have received treatment (with reduction of TCE concentrations by > 99%). Historical site constraints had limited our ability to conduct a comprehensive source investigation to identify all point sources. However, the existing infrastructure was demolished in 2024, leading to the finding of additional residual areas with high levels of TCE concentration (exceeding 90 mg/L), necessitating further remedial efforts. In anticipation of future construction of a warehouse, there was a need for an aggressive and sustainable solution to remove CVOCs and potentially sequester PFAS, given that no further disruptive activities would be permitted once the new facility's construction is completed. The chosen remedial approach for a recently concluded injection event in Fall 2024 was In-Situ Chemical Reduction (ISCR) in combination with a non-colloidal powdered activated carbon (PAC) amendment added to the ISCR reagents, aimed at addressing CVOCs and adsorbing PFAS. Accordingly, Top of FormBottom of Forma proprietary amendment combining fibrous organic carbon, microscale zerovalent iron (ZVI), and PAC was implemented through high pressured injections to integrate biotic, abiotic, and sorption mechanisms for accelerated groundwater remediation.

 Lessons Learned: Results from the historical EISB Injection event(s) and the current ISCR program will be presented including discussion of some key components essential for successful implementation of the remedial strategy including:

Optimizing the injection approach in shallow aquifers. Challenges and lessons learned in injecting large volumes of reagents in overburden aquifers using direct push technologies Post monitoring results from the 2024 injection event and tracking geochemical signatures to measure efficacy.

Integrating treatment strategies and the impact of applying ISCR augmented with PAC on measured PFAS concentrations and: Challenges in designing additional applications to progress towards long term MNA.

Abstract ID: 326
A new risk-based prioritization strategy of Contaminants of Emerging Concerns in soils.
Amelie Cavelan[1], Aline Coftier[1], Fatimah Sulu-Gambari[2], Jaana Sorvari[3], Jani Häkkinen[3], Jussi Reinikainen[3], Elisa Giubilato[4], Virginie Derycke[1]
[1]BRGM, France, [2]Deltares, Netherlands, [3]SYKE, Finland, [4]GreenDecision srl, Italy

Purpose of the study: The risks posed by Contaminants of Emerging Concern (CECs) in soil to human health and the environment are difficult to quantify. The vast number of CECs that may be present in soils creates challenges for regulators, contaminated site managers, and soil managers to implement monitoring plans and integrate these substances into future regulatory efforts. Therefore, it is crucial to prioritize these substances to better target future efforts on those posing the highest risks. As part of a comprehensive research initiative, this work explores a new method to prioritize CECs using a risk-based prioritization approach.

Methodology: This work was built upon existing methodologies and initiatives previously developed (e.g., EUSO TWG Soil Pollution, Zero Pollution outlook report, PREMISS project, ITRC CEC prioritization recommendations, NORMAN project). The objective is to enhance these existing approaches to develop a new strategy for CECs' prioritization based on their presence in soil and potential risks, considering factors such as emissions, fate, transport, and their toxicity to health and the environment. This strategy utilizes relevant conceptual frameworks involving source-pathways-receptor relationships. A step-by-step approach was adopted to construct this strategy, which serves as a foundation for developing a prioritization tool (illustrated in Figure 1). To overcome the limitations of past prioritization tools and initiatives, this prioritization strategy and tool should: (i) propose a simple, reproducible, and easily updatable procedure based on easy-to-find data to assess the risks and prioritize CECs rather than a generic model based on prediction of CECs in soil ; (ii) better integrate an estimate of the uncertainty of the proposed prioritization due to the lack of data/knowledge about CECs and present recommendations on actions to be taken to fill these scientific knowledge gaps. This substance-orientated approach assesses whether the emitted CECs can be transferred from soil to other environmental media, possibly affecting environmental receptors and/or human health.

Results: The project's outcome is a tool for prioritizing CECs in soils at national or European levels based on the risks they pose to health and the environment. The tool assigns a score ranging from 0 (no significant risk) to 4 (highest risk) for each soil CEC, considering its emissions, mobility, toxicity, and persistence. Additionally, the tool calculates a confidence level for the prioritization score, reflecting the reliability of the available data on the properties of each targeted CEC.

Conclusions and perspectives: Besides prioritization, this tool will help identify CECs with insufficient data needed to understand their behavior in soil and their potential toxicity to human health or the environment, highlighting areas that require further research. As a proof-of-concept, the tool has been tested on 50 CECs with differing environmental behavior and toxicity levels. As a further step, the tool will be applied at the EU scale using emissions data available from the REACH program. The feasibility of application at the national level will also be tested.

Contributions: This initiative aims to contribute towards establishing a European priority list of significant emerging contaminants in soil that pose considerable risks and require vigilance and priority action at both the European and national levels.

Abstract ID: 329
Experimental determination of Kd values for PFAS in Flemish soils

Ward Swinnen[1], Ilse Van Keer[1], Joni Dehaspe[1], Jan Jordens[1], Ingeborg Joris[1], Stefan Voorspoels[1], Laetitia Six[2], Griet Van Gestel[2], Georgios Niarchos[3], Katrin Vorkamp[4], Valeria Dulio[5]
[1]*Flemish Institute for Technological Research (VITO),* [2]*Public Waste Agency of Flanders (OVAM),* [3]*Swedish University of Agricultural Sciences (SLU),* [4]*Aarhus University,* [5]*Institut National de l'Environnement Industriel et des Risques (INERIS)*

Purpose of the study
Due to the diversity in properties and behavior of different per- and polyfluoroalkyl substances (PFAS), many questions still exist about their leaching dynamics in soils. Despite these complexities, an assessment of the dispersion risks of PFAS is needed for concrete cases. In the context of conducting soil investigations, there is an urgent need for guidelines to (systematically) evaluate dispersion risks. Based on the results of a literature study and exploratory model simulations, several research gaps were identified. One of these gaps related to uncertainties regarding the currently available soil-water partitioning coefficients (Kd values) for PFAS.

Methodology
To overcome this issue a soil sampling campaign was set up to develop a dataset of Kd values for Flanders. This campaign involved soil sampling at 25 different sites across Flanders with known PFAS contaminations and varying soil compositions. The publicly available PFAS database for Flanders was used as a starting point for the sampling location selection. This database contains PFAS measurements in both soil and groundwater, originating from past soil research projects. Using cluster analysis, the different locations present in the database were grouped based on the combination of the measured PFAS compounds present at each location (PFAS signature). The final selection of 25 locations was based on the results of this cluster analysis, ensuring that each cluster was at least sampled once. In addition, the sampling locations were selected to include a variety of sampling depths, soil textures, and the presence/absence of glauconite minerals.

Soil samples were taken from just below the ground level to a maximum depth of 4 meters. The collected samples were initially analyzed using Direct Analysis in Real Time Mass Spectrometry (DART-MS), to screen the variety of PFAS compounds present in each sample (PFAS fingerprint). The DART-MS technique provided a rapid screening technique without the need for sample preparation. These screening results were used to select a single soil sample for each of the 25 locations, based on the observed PFAS diversity.

To determine the Kd values a 24-hours batch test was carried out according to the new Flemish protocol for PFAS leaching tests with 0.01 M $CaCl_2$ as the leaching agent. Target PFAS analyses were performed on the soil sample, leachate, and solid residue after leaching. Emissions were calculated with the corresponding liquid-to-solid ratio. In a final step, Kd values were calculated based on the measured concentrations for each of the 25 locations, resulting in a dataset of Kd values for different PFAS compounds for Flanders.

Results and conclusions
The resulting dataset can be seen as representative for the variety of soil compositions and PFAS signatures present in Flemish soils and provides a basis for better understanding the sorption behavior of PFAS. As such, these results encompass a clear case to study how environmental conditions and molecular structures influence PFAS transport in soils and further to potential aquatic recipients? These findings will further enhance the predictive accuracy of transport models, aiding in risk assessments and the design of effective soil remediation strategies. Future work can expand the dataset to include additional soil textures or PFAS compounds to increase the robustness of the current database.

Abstract ID: 331
Pesticide residues in agricultural subsurface soils and the long-term effect on surface and ground water.

Anna Nielsen[1], Anne Esbjørn[2], Iben Nilsson[3], Charlotte Vesterlund[4], Tove Svendsen[5], Lars Pedersen[5], Katerina Tsitonaki[6], Annika Fjordbøge[7], Poul Bjerg[7]
[1]WSP/DTU, [2]VandCenter Syd, [3]DIN Forsyning, [4]TREFOR Forsyning, [5]Region of Southern Denmark, [6]WSP Denmark, [7]Technical University of Denmark

Purpose of study: Micropollutants pose an increasing threat to the supply of high-quality drinking water in Europe. A long history of agricultural management in Denmark has led to widespread groundwater contamination with pesticide metabolites. The majority of the detected pesticide metabolites originate from agricultural pesticides that were banned over 15 years ago, referred to as legacy pesticides, some of which have only recently been forbidden in Europe.

Residual concentrations of pesticides and their metabolites have been detected in the subsurface soils from both diffuse sources (agricultural fields) and point sources (e.g. agricultural machine stations). This has raised attention to secondary, long-term pesticide sources for groundwater contamination with pesticide metabolites.

This study aimed to improve the understanding of the fate of pesticides residues in soil and water systems and estimate the contaminant mass discharge (CMD) of the legacy pesticides chloridazon, terbuthylazine and chlorothalonil and their metabolites from diffuse sources and their long-term impact on the surface water and groundwater resource.

Methodology: Soil samples from organic and conventional fields were collected from two sites and analyzed in the laboratory with detection limits of 0.1 ug/kg DS. Subsequently, the contents of organic material and clay were analyzed. Water samples from two nearby streams were collected at low- and high flow seasons. Simultaneously, groundwater samples were collected. All water samples were analyzed for 276 different pesticides and metabolites and redox conditions at accredited analytical laboratories. The mass discharge of pesticide residues in streams and groundwater was calculated based on measured water flow.

Summary of findings: At one site chloridazon concentrations were detected only in topsoil layers of agricultural fields. The detected concentrations of the metabolites of chloridazon, desphenyl chloridazon (DPC) and methyl desphenyl chloridazon (MDPC), were vertically distributed and with concentrations reaching 2.6 µg DPC/kg at deeper samples.

In surface water the same CMD was seen at both high and low flow for glyphosate, AMPA, 1,2,4-triazole, DPC and MDPC. The mass discharge of DPC was the highest (>10 g/day). In the same area the three metabolites, DPC, MDPC and 1,2,4-triazole, were detected in groundwater 50 m bgl.

At the other site, the groundwater is contaminated with DPC and the metabolites of terbuthylazine (LM3, LM5 and LM6). LM3, LM5, LM6, glyphosate and DPC were detected in surface water both at high and low flow periods, whereas the metabolites, AMPA and MDPC, were not detected at all. At this site hydroxy-terbuthylazine was detected in the top-soil samples.

Conclusion: The results show that even 16 to 30 years after the last application of these legacy pesticides in Denmark their metabolites are still detected in the soil from agricultural fields and have a long-term impact on the groundwater resource and nearby surface waters.

The results indicate that it is the retention of chloridazon in the topsoil layers from agricultural fields and the ongoing degradation, that causes the concentrations of DPC exceeding the groundwater quality threshold of 0,1 ug/L.

The pesticide metabolites detected in the two streams both at low and high flow periods correspond to the metabolites detected in both soil and groundwater at each site. These results suggest that surface water samples could serve as a potential screening tool for identifying future problematic micropollutants in groundwater.

Significance: This study contributes to an improved understanding of the fate of pesticide metabolites in soil, surface water, and groundwater systems. It highlights key knowledge gaps, particularly in the retention and accumulation of pesticide metabolites in soil at both diffuse and point sources. This is

especially relevant within a European perspective, where the findings can inform policies on groundwater protection zones and support the development of long-term water treatment strategies.

Abstract ID: 333

Characterization of known and unrecognized fluorinated substances on PFAS-contaminated soil after lab-scale thermal experiments

Felicia Fredriksson[1], Ingrid Ericson Jogsten[1], Malin Montelius[2], Leo W.Y. Yeung[1], Michael Pettersson[2], Dan Berggren Kleja[2], Anja Enell[2], Klas Arnerdal[3]

[1]Man-technology-environment research centre (MTM), Örebro university, [2]Swedish Geotechnical Institute (SGI), [3]Geological Survey of Sweden

Purpose of study

To date, finding efficient and sustainable methods for managing contaminated areas with per- and polyfluorinated alkyl substances (PFAS) is one of the greatest environmental challenges. Due to the thermal and chemical persistence of PFAS, high temperatures (>700°C) are required to destroy PFAS in contaminated soil and even higher temperatures are needed to mineralize PFAS. Lower temperatures have been suggested as an alternative, but there is a large knowledge gap about whether PFAS are partially degraded, transformed, and/or volatilized. Limited information on this topic is due to the constraints of current analytical methods of how to capture and measure PFAS after thermal treatment. The purpose of this study is to improve the understanding of thermal treatment on PFAS contaminated soil; with the primary goal to assess its limitations and uncertainties. The project is designed to answer the following research questions; how PFAS decomposed by thermal treatment; and how to perform a more trustworthy fluorine mass balance?

Methodology

A PFAS-contaminated soil has been thermally treated on a laboratory scale at several different temperatures (150, 250, 350, 450, and 600°C) during different treatment times (15, 30, 60 min). The PFAS-contaminated soil used in the current study was collected in 2023 and the site is an airport impacted with aqueous film-forming foams. The thermal experiments were conducted with a top loading kiln which thermally treats the soil with continuous air flow. The air flow was connected to a sample collection train which included an alkaline buffer for polar PFAS and XAD-2 sorbent for the volatile PFAS. The goal of the experiments is to evaluate the degradation and volatilization of PFAS, as well as the mass balance for fluorine. To achieve this goal and to understand as much as possible about the species of fluorinated substances after treatment, these samples (treated soil, alkaline buffer, XAD-2) have undergone extensive chemical analysis which included target analysis of more than 100 individual PFAS, extractable organofluorine analysis, total oxidizable precursors assay to understand the fluorine mass balance.

Summary of results

The soil was characterized before thermal treatment with the comprehensive analytical workflow. The sum of all measured PFAS in untreated soil was 1900 ng/g d.w. and its profile was dominated by the precursor 6:2 FTAB (1400 ng/g d.w.) and PFOS (410 ng/g d.w.). Our results showed that up to 450°C is required to reduce the PFAS from the soil (>99%). After 350 °C, more than half of the initial concentrations were reduced. However, elevated levels of other classes of PFAS that were not detected before treatment was observed, indicating degradation of precursor compounds. After treatment at 350°C, the EOF level increased by 15% but non-detectable level was found after treatment above 450°C. This suggests thermal treatment at 350°C released some non-extractable organofluorine but at 450°C all EOF volatilized. To complete the mass balance, the gaseous emission after thermal treatment will be presented to understand what happens to precursors and their breakdown products.

Conclusion

The extensive characterization of fluorinated compounds before and after treatment, at different temperatures, provides a good understanding of the amount of known and unrecognized fluorinated

substances in the different compartments. Furthermore, the analyses of gaseous emissions give indicates of the unknown risk applying thermal treatment on PFAS-contaminated soil.

Significance
Most of the present thermal treatment studies focus and report on a few numbers of PFAS and skip the gaseous emission due to the limitations that current analytical methods. This study will present results from an extensive number of PFAS both known and unrecognized fluorinated substances, together with including all compartments of migration, which greatly improves the knowledge of thermal treatment on PFAS-contaminated soil.

Abstract ID: 335
Development of a Machine Learning Model for Assessing PFAS Vulnerability in Danish Groundwater

Bastian Germundsson[1], Christian Nørby Friis Sørensen[1], Maiken Lundstad Nielsen[2]
[1]COWI A/S, [2]The Danish EPA

Purpose of Study: This study aims to develop a machine learning model to assess the risk of PFAS (per- and polyfluoroalkyl substances) contamination in Danish groundwater. The model utilizes publicly available analytical and geological data and artificial intelligence to identify areas with high vulnerability to PFAS contamination. The objective is to assist municipalities, regions, and other stakeholders in prioritizing investigation, remediation, and construction efforts.

Methodology: The idea behind the project builds upon an existing machine learning pesticide vulnerability assessment tool developed by COWI. The new PFAS model incorporates 11 parameters, including aquifer type, water level, net infiltration, and land use, to predict PFAS vulnerability of groundwater for different geological formations in Denmark. The 'XG Boost Classifier' algorithm from Python is employed to achieve accurate predictions. Since new PFAS analysis is carried out almost daily a dynamic approach for retraining the model is preferred. The model therefore undergoes dynamic updating, allowing for continuous refinement as new PFAS data becomes available.

Summary of Findings/Results: The model demonstrates an accuracy of 83% and a precision of 79% in predicting PFAS contamination risks for different geological structures covering the entire geography of Denmark. The analysis reveals that the thickness of clay over the well intakes is the most crucial parameter in determining the presence or absence of PFAS since the clay thickness is strongly correlated to the groundwater age. Additionally, land use, particularly airports, industrial areas, and mineral extraction sites, correlates strongly with PFAS contamination. Conversely, agricultural activities, forests, and natural areas are associated with lower PFAS contamination rates. These findings provide valuable insights into the factors influencing PFAS vulnerability in Danish groundwater.

Conclusion/Take Home Message: The developed machine learning model serves as a valuable tool for assessing PFAS vulnerability in Danish groundwater. It offers reliable predictions and assists in decision-making processes related to environmental protection and public health. The model's dynamic updating capability ensures that predictions are based on the latest available data, enhancing its practical utility. The model is expected to improve further as more data becomes accessible, contributing to ongoing efforts in managing PFAS contamination.

Significance/Contributions of Study: This study contributes to the understanding and management of PFAS contamination in Danish groundwater. By utilizing machine learning and publicly available data, the model provides a robust and accessible tool for assessing PFAS vulnerability. Its implementation through the "Danish Environmental Portal" (a Danish public database for different map content) ensures widespread access and ease of use for various stakeholders. The model's ability to prioritize investigation and remediation efforts helps allocate resources efficiently and supports informed decision-making regarding environmental protection and public health initiatives. As more data becomes available, the model will continue to evolve and enhance its accuracy and practical value.

Abstract ID: 337
A toolbox for aplication of Nature-Based Solutions for petroleum hydrocarbons at industrial sites
Frank Volkering[1], Mirte van der Vlist-Golverdingen[1]
[1]TAUW bv

Sustainable land management at industrial sites involves the strategic planning, development, and regulation of land use to support industrial operations while minimizing environmental impacts. The goal of SLM in industrial contexts is to balance economic growth with environmental conservation and social well-being, ensuring that land resources are used efficiently and sustainably for present and future generations.

The application of Nature-Based Solutions (NBS) is one of the practical pillars of SLM. In this context, NBS can be defined as nature-based interventions for the conservation, sustainable use, and restoration of the subsurface

Specifically for use at industrial sites contaminated with petroleum hydrocarbons, TAUW has developed a toolbox including several existing and innovative NBS (see table for an overview) and an assessment matrix. Many of these sites are characterized by intensive land use and a combination of historical and recent organic contaminatoins, as well as area of undeveloped land with historical contaminations.

(Table with overview of NBS added as separate figure)

Aerobic bioremediation, natural attenuation, and reactive barriers are undisputed and frequently applied NBS, whereas NSZD and phytoremediation are proven NBS rapidly gaining acceptance. ESZD and passive anaerobic bioremediation are innovations TAUW is currently developing and testing at several petroleum hydrocarbon-contaminated sites.

The NBS toolbox can be used for short-term risk mitigation, but is especially suitable for long-term strategies for dealing with contaminated soils.

At AquaConsoil, the toolbox will be presented with special attention to innovative NBS. Two recent practical examples of the application at industral sites wtih very diffrent charactersitics will be given: a historical contamination at a demolished site and recennt naphtha spill at an active chemical production plant

Abstract ID: 343

Fungal Stimulation Biopiles: A Sustainable Innovation for the Bioremediation of Hydrocarbon-Contaminated Soils

María Cecilia Medaura[1]

[1]Mico

Soil contamination by high molecular weight hydrocarbons, resulting from petroleum-related activities, presents a major environmental challenge due to the complexity of their degradation. This work introduces the development and field application of an innovative bioremediation technique called fungal stimulation biopiles in Mendoza, Argentina. Unlike traditional composting approaches, this method focuses on enhancing fungal growth instead of bacterial activity, taking advantage of fungi's ability to break down complex organic compounds, even under extreme environmental conditions.

The technique is applied in situ to heavily contaminated soils in industrial petroleum zones. The amendment used consists of diverse local agro-industrial wastes, providing essential nutrients to stimulate fungal proliferation. Over more than a decade of implementation, this method has successfully treated over 70,000 m³ of soils contaminated with heavy hydrocarbons and high salinity. The results have consistently shown a significant reduction in hydrocarbon levels, under 10,000 mg. kg-1, meeting the regulatory standards for soil industrial quality in Argentina.

The methodology involves creating biopiles that foster the growth of diverse fungal groups, which possess metabolic mechanisms that are particularly efficient at degrading complex hydrocarbons. Local agro-industrial waste not only serves as an abundant resource but also accelerates the biodegradation process, reducing both the treatment duration and associated operational costs.Multiple case studies from various treatment sites demonstrate that fungal stimulation biopiles offer superior efficiency compared to traditional bacteria-based soil bioremediation techniques for complex hydrocarbons at concentrations greater than 40,000 mg. kg-1.Complete soil recovery has been achieved in all cases, even in environments with challenging conditions such as high salinity, which typically hampers microbial activity.

This study presents a series of case studies that highlight the success of fungal stimulation biopiles as a sustainable and versatile solution. It concludes that this technique is not only highly effective for degrading complex hydrocarbons, but also represents an ecologically sound alternative for the remediation of contaminated soils, particularly in remote or difficult-to-access areas.

Fungal stimulation biopiles contribute significantly to the development of sustainable environmental remediation strategies, with strong potential for replication across different industries and regions impacted by hydrocarbon contamination. The innovative use of local waste and the promotion of fungi as key biodegradation agents represent a substantial advancement in the management of contaminated soils.

Abstract ID: 345

Design of a low-cost environmental monitoring system for real-time control and recording of key environmental parameters in the extractive industry

Eduardo Conde Lázaro[1], Eduardo De Miguel García[1], Fernando Barrio Parra[1], Miguel Izquierdo Díaz[1], Luis Jesús Fernández Gutiérrez Del Álamo[1], Luis Felipe Mazadiego Martínez[1], Humberto Serrano García[1], Pablo Reina Peral[1]
[1]Universidad Politécnica de Madrid

Environmental monitoring is crucial for mitigating risks associated with aggregate extraction activities. This study presents the development of a low-cost system for real-time monitoring of key environmental parameters, including water pH, turbidity, temperature, and atmospheric particulate matter. The system leverages low-cost sensors, LoRa communication protocols, and custom-designed 3D-printed supports for sensor deployment in diverse environments. The collected data are designed to integrate seamlessly into an online platform, enabling efficient environmental risk management and compliance monitoring for aggregate extraction sites. By providing continuous, reliable, and cost-effective data collection, this system aims to enhance decision-making processes and promote sustainable practices in the aggregate industry.

Abstract ID: 348

Arsenic contaminated mega site: What is the smart approach to mitigate short and long-term risks?

John Flyvbjerg[1], Nina Tuxen[1], Anne Sivertsen[1], Kristine Rasmussen[1], Per Loll[2], Vinni Rønde[3], Torben Jørgensen[4], Bastian Germundsson[4], Neal Durant[5], Rasmus Jakobsen[6]

[1]*Capital Region of Denmark, [2]DMR - Dansk Miljørådgivning, [3]NIRAS, [4]COWI, [5]Geosyntec Consultants, [6]Geological Survey of Denmark and Greenland*

Background

The Collstrop site is a former wood treatment facility located near protected wetlands and Esrum Lake north of Copenhagen, Denmark. The soil and shallow groundwater at the 60.000 m2 site are heavily contaminated with arsenic, chromium and copper.

The primary risk associated with the site is leaching of arsenic into the wetlands 250 meters to the north. In the very long term, the leaching of arsenic could also pose a risk to Esrum Lake, located 1.000 meters north of the site.

Numerous investigations and risk assessments have been carried out since the facility closed in 1976. In 2020 the Danish Government provided funding for the remediation of mega sites such as Collstrop. Therefore, efforts to assess risks from the site accurately and find solutions to mitigate these risks have intensified over the past 4 years. Altogether there is an extraordinarily large volume of data and assessments of the site.

Purpose: The purpose of the presentation is to give an overview of:

The risks posed by the Collstrop mega site. Possible remediation measures under consideration

Methodology: Summary of and reflections on:

Findings and conclusions from several investigations and risk assessments. Reviews of possible remediation methods.

Summary of findings/results: The soil at the site contains an estimated 100 tons of arsenic. Approximately 200.000 m3 of soil at the site contains arsenic above soil quality criteria. More than 90 % of the arsenic contamination is in the upper 4 meters.

Shallow groundwater approx. 3-5 m bgs. is heavily contaminated, while little contamination is found in a secondary aquifer 10-20 m bgs.

The retardation factor for arsenic was estimated to be in the range 140 – 1500 based on field data and laboratory tests. Transportation times for dissolved arsenic from the site to the protected wetlands were estimated to be in the range several hundred to several thousand years.

There appears to be a "fast track" of arsenic transportation from the site with surface water run-off during heavy rainfall events. This risk is expected to be easily remediated by establishing a physical barrier that will retain surface runoff within the site.

The long-term risk from the site is associated with the slow transport of arsenic with groundwater through the secondary aquifer towards the protected wetlands.

Of the various methods that potentially could be used to remediate the long-term risk, the most suitable solutions include chemical immobilization (binding) of arsenic and other contaminants as a central element.

Conclusions/take home messages:

It is very expensive and un-sustainable to remove large amounts of soil from the site. Therefore, the overall strategy is to leave the contamination where it is and manage the risks. There is a short-intermediate risk associated with occasional surface water run-off from the site. This risk is expected to be easily remediated by simple methods. There is also a long-term risk associated with the very slow transport of arsenic through a groundwater aquifer discharging to the wetland areas. The long-term risk is on the time scale of hundreds to thousands of years. The timescale of this risk introduces uncertainties in the assessment that should be considered. Of the various methods that potentially could be used to remediate the long-term risk, in situ chemical immobilization to bind arsenic even stronger to the soils seems promising – also in the long term. Even after remediation has been carried out, the site and the surroundings must be monitored for a long time – in principle forever!

Significance/contributions of study: A practical perspective on risk assessment and remediation of mega sites contaminated with arsenic. Such mega sites are found worldwide – especially at old wood preservation facilities.

Abstract ID: 351
Fenton's reagent as a versatile driver for in situ chemical oxidation, biological oxidation and boosted soil vapor extraction for BTEX and light TPH compounds

Lionel Counet[1], Jeroen Vandenbruwane[1]
[1]*Injectis NV*

In general, it is not recommended to carry out a treatment of the unsaturated zone by injections and even less when it comes to implementing a treatment by chemical oxidation (ISCO). Indeed, the reactions stimulated by the injections need an optimal and prolonged contact between reagents and contaminants to reach good results, which is more when the degradation is done by chemical reaction as is the case of the ISCO where it is the direct contact between pollutant and reagents which makes the success of the treatment. This contact is optimal in an aqueous phase, so when the injections are carried out below the water table, in the saturated zone. If this is not recommended, it does not mean that chemical oxidation in an unsaturated environment (soil treatment) does not work at all. You simply have to know what you have to start with and remain aware of the risks of results. And if the oxidant is injected well with the most homogeneous distribution possible then we can expect satisfactory results.

Our client opted for this "complementary" ISCO treatment in order to guarantee the client the desired objectives. Indeed, the ISCO supported an ongoing treatment of the same area by soil vapor extraction preceded by a pump and treat campaign. Soil vapor extraction alone did not obtain the expected yields given the very high heterogeneity of the backfill (>10m) with more compact, impermeable passes containing significant concentrations of volatile compounds. The SPIN® injection technology was chosen to guarantee the most homogeneous distribution possible of the entire heterogeneous horizon treated and this, based on a successfully completed pilot.

In addition to the injection technique, the injected volumes can maximize contact and therefore the chances of success. To limit the costs of the reagents, it was decided to choose an inexpensive but very reactive oxidant: the Fenton reaction. To minimize costs, the injection work was carried out in 3 phases with monitoring of concentrations between each phase. To optimize the injection campaigns and successfully complete the project within the allotted time, the pilot allowed the injection to be optimized in 2 steps with several machines to also limit the risks due to the high reactivity of the contact of the reagents. It has been proceeded to injections in 2 steps: on the way down, the injection of iron and citric acid, and on the way up (delayed, the next day), hydrogen peroxide.

The monitoring results indicated that the observed mass removal of contamination was by far not only due to the direct chemical oxidation of the organic pollutants. The generation of oxygen during the oxidation reaction of the hydrogen peroxide had probably boosted the ongoing biological degradation by aerobic bio-oxidation. Besides, the high concentrations of sulfate applied as a side-product of the iron activator, served as the ideal electron acceptor for the anaerobic bio-oxidation by sulfate reducing bacteria. And on top of these accelerated degradation reactions, the generation of large gas volumes during the chemical oxidation served as sort of "in situ" air sparging, which increased the efficiency of the soil vapor extraction system significantly.

Abstract ID: 353

Transforming post-mining landscapes: nature-based solutions for soil restoration and ecosystem services assessment in coal regions

José Luis Gallego[1], Ana M. Díaz-Díaz[1], Aránzazu Estrada[1], Lorena Salgado[1], Lidia Moriano[1], Rubén Alba[1], Mauro Sanna[1], Eduardo Cires[1], Laura García de la Fuente[1], Arturo Colina[1], Eduardo Rodríguez-Valdés[1]
[1]University of Oviedo

The southwest region of Asturias (NW Spain) is a sparsely populated area undergoing significant economic decline, with abandoned open-pit coal mining sites leaving a great imprint on the landscape. A notable example is the Tormaleo mine, which has affected over 400 hectares and is currently undergoing substantial reclamation efforts. In this context, we initiated a comprehensive research program with the following objectives: (1) to thoroughly characterize the degraded soils resulting from mining abandonment, (2) to implement pilot-scale restoration trials to generate practical guidelines for full-scale restoration projects, (3) to enhance understanding of the effects of organic and inorganic amendments on degraded soils, and (4) to develop a tailored framework for assessing soil ecosystem services in the target areas.

The research began with an in-depth characterization of soils and vegetation to identify varying levels of degradation, potential contaminants, and create a detailed vegetation map. Restoration trials tested the application of Nature-Based Solutions (NBS), including organic (e.g., compost) and inorganic (e.g., construction and demolition waste, inert mining residues, or thermal power plant ashes) amendments combined, when possible, with hydroseeding techniques for slopes. These interventions aimed to promote the establishment of diverse vegetation, including herbaceous plants, shrubs, and trees, to restore ecological functionality. An additional aspect of this work—conducted at laboratory, pilot, and real- scales (Figure 1)—was the transformation of degraded soils into carbon sinks. To this end, within the research we analysed soil edaphic properties, the dynamics of labile and recalcitrant organic carbon fractions following amendment applications, and the ecological succession processes.

Furthermore, the monitoring of restoration progress using drone-based remote sensing and multispectral imaging, coupled with machine learning for spectral data analysis, represents an innovative feature of this study. Results demonstrated that organic amendments effectively improved soil quality by supplying essential organic carbon for vegetation growth and maintenance. Meanwhile, inorganic amendments did not introduce toxic elements at high concentrations; instead, they provided essential nutrients for plant growth and facilitated the immobilization of initial high levels of heavy metals such as barium in the degraded soils.

Socioeconomic aspects were also considered, analysing local social and economic demands for future soil uses in Tormaleo. These data were integrated with technical findings (e.g., soil degradation levels, revegetation potential), and, based on previous literature and recent advancements in related projects, a qualitative framework for Soil Ecosystem Services (SES) assessment was developed. This framework was subsequently applied to evaluate the potential SES supply resulting from the implementation of Nature-Based Solutions (NBS) technologies and the feasibility of new land uses. This approach also incorporates site-specific stakeholder engagement—including landowners, academics, community groups, technology providers, and regulators—for consultations and feedback.

This research exemplifies how an interdisciplinary approach, combining soil science, ecology, remote sensing, socioeconomic analysis, and stakeholder engagement may be useful to address complex reclamation projects. The methodologies and findings offer valuable insights for the restoration of other abandoned mining sites in the region, where similar efforts are planned in the coming years. Moreover, the framework developed has the potential to be adapted and applied to other mining-affected landscapes across Europe, contributing to more sustainable and efficient restoration practices.

Figure 1: Aerial view of NBS trials area at Tormaleo mine. Experimental plots and slopes treated with hydroseeding with organic and inorganic amendments are shown.

Abstract ID: 355

Nature-based solutions for contaminated soils: multi-scale spectral mapping, risk assessment, and phytomanagement innovations in the EDAPHOS project.

Yoann Boisson[1], Lisa Ciadamidaro[2], Manhattan Lebrun[1], Julien Parelle[2], Fabienne Tatin-Froux[2], Solofoniaina Andriamihajason[3], Efthymia Alexopoulou[4], Kostantinos Iordanoglou[4], Guillaume Bertrand[2], Walter Zegada-Lizarazu[5], Engracia Madejon[6], Paula Madejon[6],

[1]UBFC, [2]UFC, [3]UBFC / ONERA, [4]CRES, [5]UNIBO, [6]CSIC, [7]PHYTOWELT, [8]ONERA, [9]MIC, [10]INERIS, [11]GIG

The European EDAPHOS project, aligned with the "A Soil Deal for Europe" mission, explores the use of nature-based solutions (NBS) to address the environmental and socio-economic challenges posed by soil contamination. The project integrates state-of-the-art technologies and ecological practices to rehabilitate polluted soils, foster ecosystem services (ESS), and contribute to sustainable bioeconomic development. The project focuses on three interconnected work packages (WPs): WP1 leverages advanced remote sensing techniques to map soil contamination and vegetation health across diverse geographical scales. By integrating satellite imagery, airborne hyperspectral data, and drone-based observations, a comprehensive spectral signature library has been created. This database includes in situ soil and vegetation spectral measurements from seven European case studies (CS). These tools enabled the identification of contamination hotspots and spatial variability of key pollutants like Cd, Pb, Ni and Zn. For example, drone-acquired spectral data in France highlighted differences in soil composition and contaminant levels, aiding the design of site-specific remediation strategies. The WebGIS platform developed under WP1 offers a user-friendly interface to visualize and analyze spectral data, enhancing the decision-making process for land management. Early results underscore the utility of multi-scale mapping in monitoring NBS effectiveness over time. WP2 employs the TRIAD approach to assess initial soil quality (regarding chemical, ecotoxicological, and ecological indicators) and, at the project's end, evaluate improvements achieved through NBS. Advanced analytical methods, such as lab-on-chip technology, have been developed to streamline ecotoxicological testing. Furthermore, WP2 applies the Common International Classification of Ecosystem Services framework to quantify ESS, including carbon sequestration, nutrient cycling, and biodiversity enhancement. Soil composites from Greece and Spain revealed severe pollution, with high levels of As (>750 µg/g), Pb (>9000 µg/g), and Zn (>15000 µg/g). These findings confirm necessity of targeted NBS interventions. Preliminary enzyme activity measurements showed a decline in key metabolic processes, such as carbon and nitrogen cycling, in highly contaminated soils, reflecting significant ecological stress. Early ecotoxicological assessments, including tests on nematodes and plants, highlighted elevated toxicity levels, particularly in Poland. These metrics provide a robust baseline for monitoring the efficacy of NBS in reducing contamination and restoring soil health over time. WP3 focuses on implementing and monitoring NBS, using poplar hybrids as biological model. Other companion species will be tested for their possible hyperaccumulator (e.g., Alliaria petiolata, Brassica juncea, Chrysopogon zizanioides) and nitrogenous fixing (e.g., Lablab purpureus) capacities. Experimental plots in France, Spain, Greece, Italy and Poland tested the efficacy of these co-cropping systems under field conditions. Results showed that some poplar hybrids exhibited high adaptability to contaminated soils on all CS, producing significant biomass while extracting trace elements (TE) such as Cd, Ni and Zn. In some cases, the metal uptake capacity of companion species such as B. juncea was up to 10 times higher than poplars. Meanwhile, L. purpureus demonstrated resilience to contamination, although with lower metal accumulation but probably better benefits for soil due to nitrogen fixation. Use of amendments also showed some effects on biomass production and TE uptake by both woody and herbaceous species. These greenhouse and field trials highlight the potential of amended co-cropping systems to enhance soil decontamination while providing biomass for bioeconomic applications. The EDAPHOS project illustrates the potential of NBS in addressing the dual challenges of soil contamination and ESS degradation. By integrating innovative spectral mapping, ecological risk assessment, and phytomanagement systems, the project provides a comprehensive framework for sustainable land restoration. Preliminary results emphasize the synergistic benefits of these approaches, including improved soil health, enhanced ESS, and economic opportunities through

biomass valorization. EDAPHOS serves as a blueprint for integrating scientific innovation into practical soil management strategies, bridging the gap between research and real-world application.

Abstract ID: 357
Pollution in Soil and Sediments Caused by Livestock breeding and Higher-place Ponds Aquaculture on Coastal Zone Land: A Case Study in Wenchang, China

Sanping Zhao[1], Yongbing Zhu[1], Haiyang Zhang[2], Bin Dong[1], Xiaodong Liu[2]
[1]State Key Laboratory of NBC Protection for Civilian, [2] Anhui Province Key Laboratory of Polar Environment and Global Change, School of Earth and Space Sciences, University of Science and Technology of China

Livestock breeding and higher-place pond on coastal zone land are important human activities that can lead to coastal zone contamination. To assess the residual pollutant levels in a coastal area from aquaculture and livestock breeding, and their environmental impact on the local area, surface water, soil, and sediment samples from the northeast coastal zone of the Hainan Island, were analyzed to determine their physical-chemical properties, including the heavy metal and antibiotic concentrations. Metagenome tests and analyses were also conducted to determine the composition and diversity of the soil microbial community in some typical samples and their response to the pollutants. The discharge of wastewater from higher-place substantially changes the physicochemical properties of the receiving rivers, affecting the pH, salinity, and anion concentrations. It also leads to an increase in the concentrations of copper (Cu), chromium (Cr), and other heavy metals in surface water and sediment. Due to the coastal breeding industry, the concentrations of metals such as arsenic (As) and Cu in coastal surface soils have increased in recent years. As was present at moderate to heavy pollution levels in surface soils assessed using the Nemerow and geo-accumulation indexes. Abnormally high As concentrations were measured in a local well at an abandoned chicken farm. Fourteen different antibiotics were detected in five soil and sediment samples with a gradual reduction in the levels of single antibiotics, such as tetracycline, roxithromycin, and clarithromycin. The highest total amount of antibiotics was 73 μg/kg in a river sediment sample affected by discharged aquaculture wastewater. Antibiotics and heavy metals affect the diversity of the soil/sediment microbial population and their functional genes. Soil and sediment samples had a relatively high abundance of Cu and As resistance genes. Metal pollution enhanced the horizontal transfer of antibiotic resistance genes (ARGs) through the co-selection of ARGs and metal resistance genes (MRGs). This study identified the potential ecological environment risk factors in abandoned coastal breeding areas, and suggested the need for continuous monitoring and assessment of the pollutant abatement processes for the residual pollutants in the future.

Abstract ID: 359
ASSENAS - Sustainable Remediation Specialists
Renaud De Rijdt[1]
[1]ASSENAS

ASSENAS - Association of Remediation Specialists
https://assenas.be/
Non-profit association of Belgian contractors proposing sustainable integrated methods for soils, water and site remediation:
- General contractors involved in large remediation projects
- Soil decontamination centres (bioremediation, physico-chemical remediation, thermal desorption, phyto-remediation)
- In-situ remediation specialists
The association's objectives are as follows:
- Promote the technical, institutional and legal aspects of soil and groundwater remediation by organising training courses and conferences for public and private sectors;
- Working constructively with authorities and contractors to continually improve best practices and legislations;
- Encouraging the economic redeployment of Wallonia and Brussels by facilitating the reconversion of polluted sites, in particular by monitoring regulations, proposing legislation and promoting innovative techniques;
- Professionalising the remediation profession by drawing up minimum quality standards, promoting codes of good practice, and possibly technical certification;
- Protecting the environment by adopting a circular and sustainable development approach.Assenas sees itself as a relay point, representative of the soil and groundwater remediation sector, for communication and information between all the players: authorities, legislators, contractors, soil experts, inspection bodies, research centres, associations and federations.

Abstract ID: 361
A Decade of Efforts: Combining Natural and Physicochemical Techniques for Mercury and Arsenic Remediation in Two of Europe's Most Contaminated Sites

Jose Luis Gallego[1], Diego Baragaño[2], Eduardo Rodríguez-Valdés[1]
[1]*University of Oviedo (Spain)*, [2]*Instituto de Ciencia y Tecnología del Carbono (INCAR-CSIC), Oviedo, Spain*

The contaminated sites of La Soterraña and El Terronal in Asturias (NW Spain) exhibit severe impacts across multiple environmental compartments due to historical mining and metallurgical activities involving Hg ores and associated As-bearing minerals. Since the cessation of Hg mining in the mid-1970s, these sites have remained active sources of contamination, a situation largely overlooked by environmental authorities for decades. In recent years, extensive efforts, led mostly by the authors of this communication, have focused on understanding the distribution and behavior of contaminants from these sites and testing biological and physicochemical remediation technologies at various scales. These efforts have been supported by several EU-funded projects and have resulted in over fifteen publications in high-ranking scientific journals. This paper aims to summarize the key findings from these studies and propose strategies for full-scale remediation based on the lessons learned. Regarding site evaluation and risk assessment, contaminants from the weathering of extensive tailings dumps have transformed two point-source anomalies into widespread diffuse pollution, detectable many kilometers away in riverbeds, coastal sediments, and even recent geological records (e.g., peat bogs). A multi-purpose forensic approach examined mining-metallurgical waste deposits (exceeding 100,000 tons) and C&D waste as pollutant repositories. Fine-grained fractions from both sites showed high concentrations of Hg and As, with As(III) being the predominant specie in metallurgical residues, while As(V) was primarily observed in soils. Pyrometallurgical processes also contributed polycyclic aromatic hydrocarbons (PAHs), secondary oxy-PAHs, and PCBs with pyrogenic fingerprints. Toxic organometallic compounds (e.g., Hg-aromatics) and sources of dioxins and furans were also identified. Surrounding soils, river sediments, surface waters, and groundwater are severely impacted, and extreme microbial environments have been described. Notably, remote sensing technologies offered an innovative alternative to traditional geochemical methods for assessing soil and vegetation contamination.

Remediation trials included soil washing techniques, which encountered significant challenges in scaling up due to the complex nature of the contaminated matrices and the high concentrations of pollutants. At the El Terronal site, the mid-2010s marked the pioneering application of nanoscale zero-valent iron (nZVI) for remediating metal(loid)-contaminated soils under field conditions. Over six years of monitoring, nZVI demonstrated its capacity to significantly reduce the availability of As and Hg by promoting their immobilization in less bioavailable forms, highlighting its potential as a remediation tool for similar sites. Synchrotron analysis revealed changes in the speciation of As, Hg and Fe in soils at the microscale, providing insights into the immobilization mechanisms, including sorption and redox processes. Complementing these physicochemical approaches, extensive screenings of phytoremediation species identified plants capable of tolerating and accumulating contaminants. This was followed by pilot-scale trials using selected vegetal species and different amendments. These efforts have provided detailed insights into the synergistic interactions between nanoparticles, vegetation, and the primary contaminants, as well as the physiological and biochemical mechanisms driving detoxification. The combination of nZVI and Nature-Based Solutions (NBS) underscores a promising integrated approach, balancing technological and ecological strategies for effective remediation of heavily impacted sites. Simultaneously, attempts are being directed toward more circular and sustainable solutions, emphasizing the use of waste-derived materials as a viable alternative to nZVI.

Currently, both sites are undergoing full-scale engineering projects aimed at controlling contaminant leaching. These containment technologies are being supplemented with additional measures, such as leachate treatment systems and phytomanagement strategies, designed based on the findings of previous studies. However, these localized solutions address only the most prominent waste

accumulations and adjacent areas, leaving vast expanses of contaminated soils and the issues of subsurface and groundwater contamination unresolved. These challenges will require further attention and, one more time, a reexamination of these sites in the near future.

Abstract ID: 364
Effectiveness of sustainable zeolites for soil remediation

Mar Gil-Díaz[1], Carolina Mancho[1], Rosana Pérez[2], Beatriz Albero[2], Juan Alonso[1], Sergio Diez-Pascual[1], M. Carmen Lobo[1]
[1]IMIDRA, [2]INIA-CSIC

Soils provide ecosystem services that allow life on Earth. However, soils are subject to increasing anthropogenic pressure, giving rise to soil degradation processes. Among them, soil contamination, caused by the presence of metal(loid)s and/or toxic organic toxic compounds in high concentrations that generate toxicity problems, is considered one of the main threats to the soil which compromises its functionality. Different agents such as zeolites, phosphates, alkaline agents, iron compounds and organic materials have been tested to evaluate their ability to immobilize pollutants in soil. In addition, the increase in hazardous waste generation associated with rapid global industrialization, has become a relevant environmental problem. Thus, the conversion of hazardous waste into valuable materials contributes to waste management while reduce the use of resources and is in line with policies of "zero-waste" (Sánchez-Hernández et al., 2016). In this regard, zeolites obtained from hazardous aluminum waste have adsorption capacity, which could be effective in reducing the mobility of contaminants in soil. The aim of this work was to evaluate the effectiveness of two types of zeolites, LTA and NAP, to immobilize metal(loid)s and/or degrade PCBs in a soil with mixed contamination. An interaction test was carried out at microcosm scale; two doses of zeolites were tested (0.5 and 1%), and compared with a treatment with iron nanoparticles (Nanofer Star, NanoIron) in an acidic soil contaminated with PCBs, As, Pb and Ni. Two sampling times, 7 and 30 days were evaluated. The pH and redox potential of the soil were monitored and the effect on the physical-chemical properties of the soil, the availability of As, Pb and Ni using the TCLP test (USEPA 1311), the PCB content (Gil-Díaz et al., 2021) and phytotoxicity were evaluated (Gil-Díaz et al., 2014). The results showed that the application of zeolites increased the pH of the soils, especially with the LTA zeolite, as well as the electrical conductivity, although the mean values were within the range considered normal for soils. At the same time, an increase in the concentration of exchangeable sodium proportional to the dose was detected, especially for the NAP zeolite, although this did not lead to an increase in phytotoxicity. Different effectiveness was observed in reducing the availability of contaminants, generally lower than that of treatment with nanoparticles, with LTA being more effective for As and Ni and NAP for Pb. Treatment with zeolites did not significantly affect the PCB content. These results show that zeolites obtained from hazardous aluminum waste could be used in soil decontamination processes, contributing to the principles of circular economy. However, studies are needed with other doses of zeolites and/or in combination with other agents to increase their effectiveness without negatively affecting soil properties.

References
Gil-Díaz M., Alonso J., Rodríguez-Valdés E., Pinilla P., Lobo M.C., 2014. J. Environ. Sci. Heal. - Part A Toxic/Hazardous Subst. Environ. Eng. 49: 1361-9.
Gil-Díaz, M., Pérez RA, Alonso J, Miguel E., Diez-Pascual S., Lobo M.C., 2022. Sci. Rep. 12: 3541.
Sánchez-Hernández R., López-Delgado A., Padilla I., Galindo R., López-Andrés S., 2016. Micropor. Mesopor. Mat. 22: 267-277.

Abstract ID: 366

Low-pressure injection of an alkaline reagent for in-situ stabilization of heavy metals in low-permeable roasted pyrite ash fills of degraded estuarine landscapes

Eduardo Alzola[1], Barbara Angulo[1], Ibon Lekue[1], Unai Reyes[1], José Antonio Capón[1], Nerea Duroudier[1], Mari Luz Artíguez[1]

[1]AFESA Medio Ambiente, S.A.

Purpose of study

Roasted pyrite ash is an industrial waste rich in iron oxides typically containing high concentrations of heavy metals. In the past, roasted pyrite ash was commonly used as fill material, so it can be easily found in the soils and sediments of several degraded landscapes. Rural and urban areas affected by the abandoned pyrite ash waste dumps are common too. This material represents a global environmental concern as it releases heavy metals into the environment.

Disposal to landfill has been the main restoration strategy for roasted pyrite ash containing areas, but nowadays less invasive and low-cost methods are being investigated in order to transform heavy metals into less soluble, mobile and toxic forms for the soil-sediment-water (SSW) systems. Thus, the aim of this work was to develop a novel in-situ stabilization method applicable to soils containing low permeable roasted pyrite ashes located in an estuarine area of the Basque Country. For that, laboratory tests were performed and a pilot study was carried out to validate the stabilization method.

Methodology

A field study was conducted in order to identify the areas in which largest heavy metal solubilization is found along the site. Soil (pyrite ashes) and groundwater samples were taken in those "hot spots" and they were chemically analysed. In the laboratory, several assays were carried out to select the optimal stabilizer reagent. For that, a battery of stabilization reagents was tested and an alkaline reagent was chosen based on the results. The effectiveness of the alkaline reagent was evaluated both for salt and fresh water conditions running soil column test in an external laboratory. Salt water conditions were evaluated due to the closeness of an estuarine river to the site. After one month of assay, the key parameters influencing the effectiveness of the stabilizer were defined and the satisfactory long-term performance of the stabilizer was demonstrated.

An in-situ stabilization pilot test was designed and implemented on the site. The injections were performed using the SPIN® injection technology (Injectis, N.V.). This low-pressure injection technology is especially suited for low-permeable materials such as the roasted pyrite ash fills of the site. The stabilizer was injected in six different injection points and its performance was monitored along the monitoring wells previously constructed. Groundwater was monitorized before, during and one and six months after the injections to obtain information related to the injection volumes, radius of influence and evolution of heavy metal solubilization, among others.

Summary of findings

Laboratory assays revealed that an alkaline stabilizer significantly reduced the solubilization of heavy metals from pyrite ashes. Additionally, a reduction of As, Cd, Ni and Pb concentrations was observed in the eluate of the column tests. Even if saline water slightly promoted heavy metal solubilization, the alkaline reagent successfully reduced all heavy metals in the eluate.

The alkaline reagent was diluted in water in the pilot tests reaching an injection rate of 2000 litres of reagent per meter. A radius of influence of 3 meters was achieved. One month after the injection works a reduction of all heavy metals was measured in the groundwater.

Conclusion

Stabilization of roasted pyrite ash containing soils was achieved using an alkaline reagent and a low-pressure injection technology. Injection parameters measured in the pilot test indicate that this in-situ remediation technology is economically suitable in comparison to 'dig and dump'. Further monitoring works are needed to determine the long-term performance of the developed remediation technology.

Significance / contributions of study

These results improve the knowledge of the performance of a state-of-the-art technique for the in-situ stabilization of roasted pyrite ash containing SSW systems.

Abstract ID: 370
DECENTRALIZED SYSTEMS FOR WATER REUSE: ADDRESSING CHALLENGES & ADVANCING CIRCULARITY

Aymar de Lichtervelde[1]
[1]*REVALIO*

1. Purpose

Water reuse offers a critical pathway to mitigating water scarcity and achieving sustainable resource management. However, conventional approaches often face limitations, including inadequate contaminant removal, high energy consumption, and operational inefficiencies. Additionally, most water reuse systems merely concentrate pollutants into reject streams, creating undesirable externalities such as high salinity or concentrated toxicants. This project develops and evaluates a decentralized water treatment system designed to address these challenges, enabling efficient and reliable reuse of industrial and domestic wastewater.

2. Methodology

The project focused on the design and pilot-scale evaluation of a compact treatment system incorporating:

Biological Process Synergy: A two-step biological treatment process integrates anaerobic digestion with activated sludge oxidation. Methanogenesis is inhibited to recover volatile fatty acids as a carbon source for denitrification and acidity to stabilize pH. This real-time equilibrium minimizes chemical dosing for pH control and eliminates the need for additional COD dosing in the denitrification step. Digital Twin Modeling: Computational fluid dynamics and bioprocess simulations were employed to predict system performance under varying conditions, informing design improvements and operational strategies. Anti-Fouling Membrane Technologies: Advanced hydrophilic coatings were integrated into filtration membranes to reduce fouling and extend operational lifespan. Automated Monitoring and Control: A SCADA system continuously monitored key parameters such as dissolved oxygen, pH, and ammonium levels, dynamically adjusting process inputs to ensure consistent treatment performance. Advanced Contaminant Removal: Nanofiltration and advanced oxidation processes targeted trace micropollutants, while in situ electrochemical disinfection reduced reliance on external chemical supplies. The system was tested on wastewater streams with heavy organic loads from both domestic and industrial sources. Performance metrics such as effluent quality, energy consumption, sludge generation, and system resilience were rigorously evaluated.

3. Key Results:

The integration of anaerobic digestion with activated sludge oxidation allowed for efficient management of heavy organic loads while minimizing chemical inputs. Methanogenesis inhibition was shown to be inhibited, allowing recovery of volatile fatty acids for enhanced denitrification and pH stabilization. The predictive maintenance strategy and organic-repellent materials allowed minimization of membrane fouling and cleaning procedures. The digital control strategy was successful in ensuring stable process variables (pH, T, DO, TSS, TDS, NH4) and operation under fluctuating loads. The system demonstrated robust treatment capacity, effectively processing up to 35 m³/day of wastewater within a footprint of less than 1 m²/ (m³/day). The effluent was free of micro-organisms and suspended solids, and of quality close to WHO standards for drinking water, with COD below 20 mg/L, NH4-N below 0.5 mg/L, NO3-N below 45 mg/L, and no NO2-N. For heavy-loaded grey water, energy consumption averaged at 0.75 kWh/m³ and waste sludge amounted to less than 5 g dry matter/person-equivalent/day.

 4. Conclusion

This project highlights the potential for decentralized systems to overcome key barriers in water reuse. By integrating advanced treatment processes with intelligent automation and digital modeling, the system delivers high-quality effluents with reduced energy and chemical demands. These findings demonstrate a scalable and sustainable solution for addressing water reuse needs in industrial and domestic contexts.

5. Significance

The outcomes of this project contribute to a deeper understanding of how emerging technologies can enhance water reuse practices. By addressing persistent challenges such as pollutant removal, fouling, and operational inefficiency, the system establishes a new benchmark for decentralized wastewater treatment. The integration of innovative biological processes, real-time monitoring, and advanced materials demonstrates a practical pathway to achieving reliable and environmentally responsible water circularity

Abstract ID: 372

Treatment of chlorinated organic compounds-emulsions by activated persulfate: pollutants degradation or separation?

Yaiza Moreno-DelaFuente[1], Navarro Navarro[1], Andrés Sánchez-Yepes[1], David Lorenzo[1], Carmen Domínguez[1], Salvador Cotillas[1], Aurora Santos[1]

[1]*Department of Chemical Engineering and Materials, Faculty of Chemical Sciences, Universidad Complutense de Madrid, Avenida Complutense S/N, 28040 Madrid, España*

Soil contamination resulting from the production of outdated pesticides presents significant environmental and health risks. Lindane (g-HCH), was extensively used as an insecticide, leading to substantial hazardous waste. This waste consists of chlorinated organic compounds (COCs). Due to their low solubility in water and high density, these compounds form dense non-aqueous phase liquids (DNAPLs) that infiltrate soil and accumulate in bedrock pools. Consequently, DNAPLs continue to leach into surrounding groundwater, posing long-term risks to ecosystems and human health. This is the situation of Sardas and Bailín unlined landfills (Sabiñánigo, Spain).

Addressing DNAPL-contaminated sites demands a multi-faceted approach. The initial step typically involves the mechanical extraction of DNAPL through recovery or pumping methods. However, complete removal is often unattainable due to the intricate pathways DNAPLs traverse underground. Surfactant-enhanced aquifer remediation (SEAR) can be employed to mobilize and recover residual DNAPL. Surfactants effectively lower the interfacial tension between DNAPL and water, facilitating its solubilization and recovery. Biodegradable non-ionic surfactants like Emulse are particularly recommended for this purpose, boasting a high mass transfer rate (4.33 mmolCOCs gsurf-1) than commonly used anionic surfactants like SDS (1.32 mmolCOCs gsurf-1).

The emulsions produced during SEAR contain high concentrations of contaminants and surfactants, necessitating treatment before disposal or reuse. Advanced oxidation processes using persulfate present a promising alternative for treating these contaminated emulsions. Given the competition between surfactants and contaminants for the oxidant, various strategies can be pursued: selective degradation of contaminants (allowing surfactant reuse), complete degradation of all organic species, or partial degradation of the surfactant to break the emulsion, making it easier to separate the contaminants (DNAPL).

Persulfate can be activated to generate radicals with stronger oxidizing capabilities. Alkaline activation of persulfate leads to the formation of hydroxyl radicals, a method previously utilized to treat COCs-contaminated emulsions. Although the results have shown promise, achieving an acceptable conversion rate of contaminants can take long times (XCOCs=0.65, 28 days). Increasing temperature could significantly enhance reaction rates and reduce necessary treatment durations.

In this study, synthetic emulsions were used to simulate those obtained after applying the SEAR process in the polluted landfills. Emulse was used at a concentration of 3,500 mg/L, with contaminant levels ranging from 500 to 1,000 mg/L, including 28 COCs: chlorobenzene, dichlorobenzenes, trichlorobenzenes, tetrachlorobenzenes, pentachlorobenzene, pentachlorocyclohexenes, hexachlorocyclohexenes, heptachlorocyclohexanes and hexachlorocyclohexanes. Reactions took place in well-mixed batch reactors (PTFE), with varying oxidant concentrations (10-30 g/L), temperatures (40-60 °C), and reaction times (up to 96 hours). The pH was maintained above 12 (NaOH:PS=2:1) to ensure alkaline activation.

To assess the efficiency of the process, the concentration of contaminants (both dissolved and total), persulfate, and total organic carbon were monitored. Additionally, surface tension and surfactant capacity were measured using a force tensiometer.

The degradation of COCs is enhanced by increasing the concentration of persulfate and the temperature. However, the polyethoxylated chains of Emulse are susceptible to oxidation by radicals. Since the activation energy required for surfactant degradation is greater than that for the degradation of the contaminants, raising the temperature compromises the surfactant integrity in relation to the depletion of COCs. Depending on the conditions employed, contaminant removal in the aqueous phase can reach between 30% and 95% within just 48 hours, accompanied by varying

degrees of surfactant degradation. Additionally, the consumption of oxidants is significant, associated with the oxidation of the surfactant.

Abstract ID: 374

Optimizing chlorinated solvent plume remediation in urban environments through hydrogeophysico-chemical approach

Giulia Felli[1], Paolo Ciampi[1], Laura Ledda[2], Christian Nielsen[2], Carlo Esposito[1], Marco Petrangeli Papini[1]
[1]La Sapienza University of Rome, [2]Taw, Italy

Persistent chlorinated solvent plumes pose significant challenges for groundwater remediation in urban environments. Limited accessibility, heterogeneous subsurface conditions, and the presence of secondary source zones often complicate remediation efforts. This study demonstrates the efficacy of a high-resolution, integrated hydrogeophysico-chemical approach for characterizing and remediating a chlorinated plume in a challenging urban setting. The primary objective is to develop a robust conceptual site model (CSM) capable of guiding the implementation of sustainable, minimally invasive remediation strategies.

A comprehensive suite of hydrogeological, geophysical, and geochemical data were collected and integrated into a unified geodatabase. This included borehole logs, hydrogeological measurements, membrane interface probe investigations (MIP), and detailed chemical analyses of groundwater samples. Advanced geomodelling techniques were employed to reconstruct the subsurface hydrogeological architecture and delineate the three-dimensional extent of the tetrachloroethylene (PCE) plume. High-resolution MIP data played a crucial role in refining the CSM, providing detailed insights into the distribution of contamination and the presence of secondary source zones. This comprehensive CSM informed the selection and strategic placement of two remediation technologies: Coaxial Groundwater Circulation wells coupled with Air Sparging (IEG CGC-AS®) for contaminant extraction and targeted injection of micrometric zero-valent iron (S-MicroZVI®) and colloidal activated carbon (PlumeStop®) to enhance in situ degradation and adsorption. The IEG CGC-AS® barriers were strategically positioned to intersect the plume and interrupting the downstream migration of dissolved contaminants. The combined application of PlumeStop® and S-MicroZVI® offers a synergistic approach to in situ remediation, leveraging the adsorptive capacity of activated carbon and the reductive properties of zero-valent iron. A comprehensive hydrochemical monitoring was implemented to evaluate the performance and effectiveness of the combined remediation strategy.

Preliminary results indicate the efficacy of the integrated remediation approach. The CGC-AS system effectively contained the extent of the PCE plume, while the targeted injection of S-MicroZVI® and PlumeStop® demonstrated significant potential for reducing contaminant concentrations within the aquifer. This study underscores the value of a high-resolution, integrated hydrogeophysico-chemical approach for characterizing complex contaminated sites and optimizing remediation strategies in challenging urban environments. The development of a detailed CSM, shaped by diverse data sources and advanced geomodelling techniques, provides a robust framework for selecting and implementing sustainable, minimally invasive remediation technologies. The combined application of CGC-AS, S-MicroZVI®, and PlumeStop® offers a promising pathway for addressing persistent chlorinated solvent contamination in urban groundwater systems.

Abstract ID: 377
Mercury-Contaminated Site :Extraction and Reduction of Contaminant Mass using Thermal Desorption Technical and Metrological Challenges

Pierre-Louis Guillerm[1], Olivier SIBOURG[1], Pierre Guibert[1]
[1]RAMBOLL

1.Purpose of the study
The first phase of this project was presented at Aquaconsoil 2023. At that time, the project had just begun. Two years later, this marks the final stage of the project.
Following the closure of a former French ethyl acetate production plant, several investigative phases identified significant mercury contamination (presence of mercury beads in the soil) in a localized area linked to historical site activities, particularly near a sump close to former mercury furnaces. Various rehabilitation strategies were examined. Finally In-Situ Thermal Desorption was chosen because the volume of waste produced would be significantly reduced. The theoretical mass balance estimated that less than 5 tons of condensed mercury would be recovered using ISTD, compared to 2,000 tons of soil requiring excavation, stabilization, and disposal in salt mines in Germany. Additionally, the costs of ISTD are slightly lower than those of excavation work. 2.Methodology
The overall objective is based on reducing concentrations at the soil source to improve mercury concentrations in soil gases and ambient air.
The defined objective for this treatment is performance-based. The attainment of the set temperature must be validated by measurements taken at "cold points" in the core of the zone. The treatment will continue until the cumulative mass extraction curve over time approaches an asymptote.
To validate the asymptotic zone, the amount of pure product recovered over one week must be less than 10% of the maximum amount recovered during the extraction peak under normal operating conditions. When the amount of pure product recovered over a week is less than 5% of the maximum amount recovered during the extraction peak, and this condition persists for 14 days under normal operating conditions, the treatment asymptote will be considered achieved.

Figure 1 : Example of monitoring the quantity of pollutant recovered vs. the treatment temperature
3.Results
Initially the mass balance, based on analytical results from six soil sampling conducted in the area, estimated that between 10 to 20 tons of mercury would be condensed. A second mass balance was carried out by the contractor after conducting nine additional drilling before the start of the work. The amount of condensed mercury was then estimated at approximately 2 tons.
By June 2025 conference, this mass balance will be compared with the actual quantities extracted.
4.Take home messages Managing risks of vertical and horizontal mercury migration during the design of the venting system (extraction flow rate, action radius, and depth of installation). Implementing insulating covers and thermal insulation on heating and venting pipelines to minimize energy loss and reduce the risk of contact with hot surfaces. Thermal imaging monitoring to ensure no leaks along the treatment line. Using stainless steel treatment systems to ensure the durability of the installation. Deploying a treatment unit tailored to the project's requirements : residence time, acceptable concentrations, humidity, presence of acid vapors ..). Implementing measures for condensed mercury recovery, ensuring an installation capable of easily tracking the quantities of condensed mercury. Establishing a pathway and decontamination procedure (green and red zones). Defining ambient air thresholds and implementing collective protection measures. Using specific respiratory protection equipment. Discussion with the authorities and the contractors to adapt the objectives due to difficulties to reach the target temperature. Demobilizing the site, a critical phase due to residual mercury potentially present in the installations and the associated exposure risks. Mercury monitoring will also be addressed: SK-C badges, Carulite®. The challenge of measuring mercury in gases (at the air treatment unit inlet) using the JEROME detector will also be addressed.

Abstract ID: 380
Progress in Sustainable Land Management Worldwide

Nicola Harries[1]
[1]CL:AIRE, International Sustainable Remediation Alliance Secretariat

Sustainable land management has become an area of development globally with public and private sector organisations working closely together on projects and developing networks to improve and share knowledge. Initiatives in Europe, North and South America, Australia, New Zealand, Africa and Asia are now well established and known collectively as Sustainable Remediation Forums (SuRF) and now collectively have formed a broader alliance called the International Sustainable Remediation Alliance (ISRA) www.claire.co.uk/isra. ISRA's goals are to work together cooperatively on joint initiatives with global organisations with a mutual interest in sustainable land management. Networks in USA, UK, Australia & New Zealand, Italy, France, Germany, Canada, Taiwan, Brasil, Colombia, South Africa and Japan are now established. These networks meet regularly to share knowledge, work collaboratively and provide support with all information available through www.claire.co.uk/surfinternational

The purpose of this session is to provide a brief global round up of progress, showing how common themes and thoughts are broadening, developing and maturing to more sustainable resilient land management concepts across the globe.

The key development in the advancement of sustainable remediation theory and practice since ACS 2019 (when last presented) are:

New SURFs have continued to establish The maturing of the concept of integration of sustainable remediation in wider land management The embedment of climate resilience within sustainable remediation Continuation of the development of guidance to help promote outreach to educate and promote sustainable remediation.

This session will showcase some of the newest development areas that SuRFs have been working on. They acknowledge the challenge that they face broadening their discussion of sustainable land management outside of the technical scientific community and ensuring embedding engagement throughout the broad land management community.

Following a series of short presentations, the audience will be asked a series of questions about their experiences within their countries and how ISRA can collectively help to move forward and embed sustainable land management concepts forward further globally.

ISRA wants to continue their collaborative activities, try to encourage new SuRFs to establish and will use the ACS 2025 Special Session to help shape what they see are the next greatest challenges that need addressing to support the wider scientific community.

It is hoped that this session maybe repeated at EcoForum 2025 to gather further global thoughts about sustainable resilient land management.

Presenters will be from a wide number of the different SuRFs including UK, Japan, Germany, France and Italy. Further SuRFs may be able to join depending if IT permits. Names are to be confirmed later.

Required Equipment:

Round Tables, Flip chart per table, marker pens, roving microphones, lecturn, good internet to allow virtual presentation or recorded presentations from ISRA members not able to attend in person.

Abstract ID: 384

Interactive Insights into the OVAM EmConSoil Initiative: Advancing Emerging Contaminant Management in Soils

Johan Ceenaeme[1], Laetitia Six[1], Griet Van Gestel[1], Kris Van Looy[1], Karel Van Nieuwenhove[2], Pieter Schrooten[3]

[1]OVAM, [2]ERM, [3]Cornet & Renard

Session Overview
The OVAM EmConSoil initiative, led by OVAM (Public Waste Agency of Flanders), addresses the urgent issue of managing emerging contaminants (ECs) in soils and groundwater. This session is designed to bring together researchers, practitioners, and policymakers to discuss the unique challenges, innovative approaches, and collaborative solutions for assessing and mitigating EC impacts on soil health, ecosystem sustainability, and public safety.
The interactive session will foster knowledge exchange through an engaging format combining expert pitches, case studies, live discussions, and real-time polling. Attendees will gain a comprehensive understanding of the OVAM EmConSoil initiative's methods and results while contributing their perspectives and strategies for effective EC management.
 Objectives
Present the OVAM EmConSoil intiative and goals: Share the objectives, latest results and developments under the initiative, particularly in detecting, assessing and managing ECs such as PFAS, pharmaceuticals, and microplastics in soil and groundwater. Highlight Practical Applications and Policy Integration: Showcase how the project aligns with EU environmental goals and discuss policy frameworks that can facilitate the implementation of EC management strategies. Encourage Collaborative Knowledge Sharing: Through guided discussions and interactive polling, explore attendees' experiences and best practices for managing ECs in various European regions and beyond. Identify Future Research Directions: Collect insights from participants to inform future research, policy, and funding needs for EC management in soil and groundwater.
 Format and Structure
The session will last 90 minutes and will be divided as follows:
Introduction and Project Overview (10 mins): Brief introduction to the session and its objectives. Overview of the OVAM EmConSoil initiative, highlighting key findings and challenges encountered in EC monitoring and remediation efforts. Interactive Poll and Mapping Exercise (10 mins): Using a digital tool, participants will mark their geographical regions on an interactive map and indicate which ECs are most prevalent or concerning in their areas. Instant display of responses to create a visual representation of EC issues across Europe (and beyond?). Case Studies and Methodology Showcase (30 mins): Presentation/pitch of two or three case studies on approaches for EC management and policy development. Pitches of methodologies/strategies/policies used, focusing on advanced sampling, lab testing, and risk assessment techniques. Discussions (20 mins): Guided discussion questions will help identify region-specific challenges and innovative strategies for EC management. Findings will be summarized and key points shared on a digital whiteboard. Panel Q&A and Open Forum (15 mins): Panel discussion with experts and policy makers. Open Q&A to address questions and insights from attendees, fostering dialogue around shared goals and possible collaborations. Summary and Future Directions (5 mins): Wrap-up of session insights and action points. Collection of feedback on EmConSoil's approach and suggestions for next steps in EC management needs and policies.
 Expected Outcomes
Enhanced Awareness of issues dealing with Emerging Contaminants: Increase awareness among participants of the types of ECs affecting soils and best practices for management. Cross-Regional Exchange of Solutions: Facilitate the exchange of knowledge and strategies across European regions (and beyond), supporting the development of adaptable and effective EC management frameworks. Input for Policy Recommendations: Gather participant input to inform policy recommendations or needs that can be shared with environmental agencies and integrated into regulations. Collaboration

Opportunities: Foster connections for future research and policy collaboration within the AquaConSoil community, supporting ongoing efforts in soil and groundwater quality management.

Abstract ID: 388

Innovative Applications of Waste-Derived Biochars: Case Studies in Water Treatment and Agriculture

Anna Bogush[1], Ondrej Masek[2], Jhonny Quispe[1], Wolfram Buss[2], Konstantin Ignatyev[3], Luiza Campos[4]
[1]Centre for Agroecology, Water and Resilience, Coventry University, UK , [2]School of GeoSciences, University of Edinburgh, UK , [3]Diamond Light Source, UK, [4]Department of Civil, Environmental and Geomatic Engineering, University College London, London, UK

The transition to sustainable development and a circular economy is driving interest in synergistic solutions like industrial symbiosis, where waste and by-products from one industry become resources and/or materials for another. This study highlights two case studies showcasing innovative uses of waste-derived biochars in water treatment and agriculture, exemplifying integrated approaches to soil-water-waste management.

The first case study explores the development of a phosphorus (P) and potassium (K) enriched biochar fertiliser from sewage sludge of wastewater treatment plant. While conventional biochar is inert and safe to use, it typically contains low content of plant-available P and K, limiting its agricultural value. In an innovative process, sewage sludge from a wastewater treatment plant was treated with low-cost potassium acetate, followed by pyrolysis. This approach increased the percentage of water-extractable P nearly 240-fold compared to a control sample. Advanced analyses, including X-ray Absorption Near Edge Spectroscopy and synchrotron X-ray Fluorescence mapping, identified highly soluble potassium hydrogen phosphate as the key component. This modification is both simple and cost-effective, transforming waste into biochar with enhanced fertiliser potential while also contributing to carbon sequestration and improving soil properties.

The second case study evaluated a three-stage handwashing wastewater treatment system, integrating biochar derived from agricultural waste, sand filtration, and chlorination. In rural areas lacking piped water and drainage networks, school handwashing facilities often discharge wastewater into the ground, harming the environment and wasting water - particularly critical in low- and middle-income regions experiencing water scarcity due to climate change. The primary treatment using biochar filtration significantly reduced turbidity, color, chemical oxygen demand, total suspended solids, phosphates, nitrates, hardness, and E. coli by 96.6%, 95.5%, 56.3%, 98.4%, 84.7%, 41.9%, 62.8%, and 2.4-log, respectively. Secondary treatment with sand filtration further improved these reductions. Tertiary treatment with chlorine-based disinfection (0.1 mL/L NaOCl) achieved complete E. coli removal. The treated water met several WHO and USEPA water quality standards, and it complied with international guidelines for greywater reuse in toilet flushing, irrigation, and floor washing. This innovative treatment approach enables on-site cleaning and reuse of handwashing wastewater (including hand hygiene, garden irrigation, toilet flushing, and floor washing), offering rural schools a reliable source of clean water for critical needs during periods of water scarcity. Integrating biochar filtration, sand filtration, and disinfection presents a sustainable water recovery solution for remote rural schools, advancing the Sustainable Development Goals of good health (SDG 3), clean water and sanitation (SDG 6), and sustainable communities (SDG 11).

Both case studies underscore the principles of green chemistry, industrial symbiosis, and the circular economy, highlighting their increasing significance in sustainable development.

Abstract ID: 391

Enhanced degradation of 1,4-dithiane and 1,4-thioxane related to the chemical weapons abandoned by Japan in China with persulfate system activated by Vs-riched-FeSx/BC: Efficiency and mechanism

Yong-bing Zhu[1], Peng-fei Guo[1], San-ping Zhao[1], Shang-yi Li[2], Ting-ting Zhang[2]
[1]State Key Laboratory of NBC Protection for Civilian, [2]Department of Environmental Science and Engineering, Beijing University of Chemical Technology

The Japanese army made extensive use of chemical weapons in China during the World War II and abandoned large quantities of chemical weapons in China after its defeat and surrender. Mustard released from chemical weapons is gradually converted into 1,4-dithiane and 1,4-thioxane in the natural environment, which are targeted to the human respiratory system and organs, and have been detected in groundwater and soil in special contaminated sites in many countries around the world. In 2016, American National Standards Institute proposed a health recommendation value of 0.07 mg/L for 1,4-dithiane and a maximum allowable concentration of 0.003 mg/L for 1,4-thioxane as an unregulated contaminant in drinking water. Research was carried out on the activated persulphate degradation technology of 1,4-dithiane and 1,4-thioxane, the degradation products of mustard from Japan abandoned chemical weapons. We prepared FeSx/BC catalysts by the hydrothermal preparation method, along with the formation of structural defects in the sulphur vacancies modulating by hexamethylenetetetramine. The removal rates of 1,4-dithiane and 1,4-thioxane could reach 96.8% and 99.7% by FeSx/BC activated persulfate, respectively, within 30 min. FeSx/BC/Persulfate system had good applicability when the solution pH changed within 3~9, and it also had good anti-interference ability for the coexisting substances such as common anions and humic acids. It can be found from the results of quenching experiments and electron paramagnetic resonance tests that $SO_4^{\bullet-}$ and $Fe(IV)$ played a major role in pollutant degradation. GC-MS results showed that 1,4-dithiane, 1-oxide was the main products during FeSx/BC coupling with persulfate reaction system. The present study provides a feasible method for the degradation of 1,4-dithiane and 1,4-thioxane from mustard contaminated sites caused by chemical weapons abandoned by Japan in China.

Abstract ID: 394

Electro-Nano-Bioremediation of Chlorinated Hydrocarbons – Insights from a Long-Term Large-Scale Experiment

Simon M. Kleinknecht[1], Kathrin Leicht[1], Tobias Junginger[1], Norbert Klaas[1], Petr Kvapil[2], Jaroslav Nosek[3], Andreas Tiehm[4], Luca Trevisan[5], Timothy M. Vogel[6]

[1]VEGAS, Institute for Modeling Hydraulic and Environmental Systems, University of Stuttgart, [2]Photon Water Europe, [3]Technical University of Liberec, Institute for Nanomaterials, [4]TZW:DVGW Technologiezentrum Wasser, Department Water Microbiology, [5]BoSS Con

Purpose of Study

Sustainable land remediation is a key research focus. In-situ injection of nano-scale zerovalent iron (nZVI) particles can be applied for remediating contaminated groundwater. However, the high reactivity and limited lifespan of nZVI can result in incomplete contaminant reduction and high costs. Recent studies reveal that applying direct current (DC) can enhance the longevity and efficiency of nZVI. Bioremediation, involving microbial degradation of contaminants, requires specific groundwater conditions such as suitable physicochemical parameters and moderate contaminant concentrations. Combining these methods into a sequential remediation strategy could offer a synergistic solution. Electro-nanoremediation (nZVI with DC) can reduce the primary contaminant load, followed by bioremediation to address remaining contaminants and metabolites. The application of DC in both phases, if necessary, could further improve remediation outcomes.

Methodology

A large-scale groundwater experiment was conducted using two identical boxes (3m × 1m × 1m) under controlled boundary conditions. The unconfined aquifer setup included constant flux (inflow) and head (outflow) boundaries, with medium sand from the Rhine Valley. A reactive iron zone (1m × 1m × 1m) composed of nZVI (Nanofer Star) and micro ZVI (Atomet) particles mixed with sand was embedded during packing to ensure homogeneity. Perchloroethylene (PCE) at its maximum solubility was introduced with groundwater flow, with a residence time of 35 days (12 days/meter).

Steel electrodes along the flow direction provided DC (60 V). Box 1, the control, operated without DC, while Box 2 had DC applied. Key parameters—electrical conductivity, pH, oxidation-reduction potential (ORP), and concentrations of PCE, its degradation products, chloride, and gaseous byproducts (acetylene, ethene, ethane)—were monitored at the inflow, outflow, and ten sampling wells.

After 255 days of electro-nanoremediation, bioremediation began. Glycerol was injected weekly into Box 2 to boost microbial growth over 120 days.

Summary of Results

Electro-Nanoremediation Phase: In Box 2 with DC, downstream of the cathode, pH increased to 12 and ORP dropped to −500 mV in the reactive zone, enhancing nZVI longevity and maintaining a stronger reductive environment. By contrast, Box 1 exhibited pH values between 7.5 and 8.0 and a minimum ORP of −300 mV. Chloride mass balance showed 65% recovery in Box 1 and 57% in Box 2. Sampling wells indicated reduced chloride concentrations in Box 2, highlighting challenges in interpreting well data for field applications. Overall, chloride formation in Box 2 was 1.3 times higher than in Box 1. Gaseous degradation products showed higher acetylene formation in Box 2, with levels 1.9 times higher than that of Box 1, indicating a higher reaction rate. No significant levels of reductive dechlorination products (TCE, cis-1,2-DCE, VC) were detected. Reductive β-elimination might be the predominant degradation pathway in Box 2.

Bioremediation Phase: During this phase, DC was turned off while groundwater flow continued until pH normalized. Soil samples of Box 2 confirmed the presence of Geobacter, an iron-reducing bacterium, indicating potential nZVI regeneration. Weekly glycerol injections stimulated bacterial growth, and cis-1,2-DCE concentrations at the outflow appeared after 18 days and increased from 0.5 mg/L to 15.2 mg/L over 35 days. Chloride recovery reached 72%. The rapid increase in cis-1,2-DCE demonstrated effective stimulation of dehalorespiring bacteria, which could potentially degrade residual chlorinated solvents in low-contaminated areas after abiotic nZVI + DC treatment.

Conclusion and Significance

This large-scale experiment bridges the gap between lab and field applications of sustainable groundwater remediation. Electro-nanoremediation enhanced chlorinated solvent degradation, while subsequent stimulation of microbial degradation was achieved using glycerol as carbon substrate. Thus, Electro-Nano-Bioremediation, the combination of nanoremediation and bioremediation with DC, represents a promising strategy for a more sustainable remediation of contaminated sites.

Abstract ID: 398
Ferrate(VI) chemical oxidation enhanced with surfactant: a comparison on the effectiveness between soil and marine sediment

Federica De Marines[1], Marco Capodici[1], Frederic Coulon[2], Gaetano Di Bella[3], Enrico Licitra[3], Manuela Russo Tiesi[1], Giovanni Vinti[1], Gaspare Viviani[1], Daniele Di Trapani[1]
[1]University of Palermo, [2]Cranfield University, [3]University of Enna "KORE"

Purpose of study
Soil and marine sediment contamination due to total petroleum hydrocarbons (TPHs) is of big concern since they can pose a serious risk to both human health and the surrounding environment. Moreover, TPHs have specific characteristics (high oil/water distribution coefficient, low solubility in water) that make them a long-term persistent source of contamination.

The use of surfactants represents a promising remediation technology for TPHs removal. Together with surfactants, chemical oxidation is a widely used reclamation intervention. In recent years, potassium ferrate (ferrate(VI)) has emerged as a notable oxidant for chemical oxidation, having a higher oxidation potential than commonly used oxidants.

However, although the combined oxidation and surfactant treatment has been proven effective, to date, there is no scientific evidence on the applicability of this technique with the use of ferrate(VI), neither in soil nor in sediment.

To this regard, this study aimed to assess the feasibility of the combined use of ferrate(VI) and sodium dodecylbenzene sulfonate (SDBS, an anionic surfactant) for remediating diesel-contaminated soil and marine sediment.

Methodology
Experimental tests were conducted in slurry mode (100 g of soil and 500 mL of solution) by means of Jar Test. The concentration of ferrate(VI), 0.5%, 1%, and 1.5% by weight, and SDBS, 0.1%, 0.2%, and 0.4%, were evaluated in terms of their effectiveness in oxidizing and solubilizing TPHs. The marine sediments were obtained from Augusta Bay (Italy), a contaminated site of national interest.

Soil and marine sediment were artificially contaminated to achieve an initial TPH concentration of approximately 5000 mg/kgSS. After contamination and before starting the experimental tests, the sample was manually mixed for 15 days to allow the volatilization of the volatile fractions. Specifically, the spiked soil and sediment were mixed using spatulas; hand mixing was performed continuously during the addition of the spiking solution and for 15 minutes after spiking and on all subsequent days, to accomplish the homogenization. Regarding sediments, at the end of the mixing days, they were first dried in an oven at 40 °C for 72 hours and finally crushed and sieved two times (i.e., at 2 mm and 63 μm mesh) to focus on particles

Abstract ID: 400
Health risk communication. Why should we think about it as soon as we discover any kind of environmental contamination? Who say what, when and why?

Paula Hammer[1], Nina Tuxen[2], Katleen De Brouwere[3]
[1]Dept. of Occupational and Environmental Medicine, Poison Information Center, Bispebjerg University Hospital, Copenhagen, Denmark , [2]Capital Region of Denmark, [3]Department of Environment and Health, Flemish Institute for Technological Research (VITO), Mol

Summary
'To know and not to know. To act or not to act...?' These preface words from the European Environment Agency report 'Late lessons from early warnings: the precautionary principle 1896-2000 (https://www.eea.europa.eu/publications/environmental_issue_report_2001_22) remind us that we need information on environmental hazards to decide whether and how to act to prevent and reduce their consequences to the environment and human health. Often actions are required before we have strong proof of harm. And regardless the type of hazard any risk perception in the society affects human behavior. Therefore, risk communication is considered an important health intervention. But when and how should health risk communication be addressed in the process of mapping and assessing environmental contamination? Can we communicate too much or too early? How to address scientific uncertainty and expert disagreements to the community? How to handle conflicting interests in complex cases involving the community, authorities, stakeholders, and the media? Which experts should be included in the communication?
We suggest a workshop of 90 minutes that will include interactive sessions with case-based discussions of real-life environmental contamination in Europe. The primary target group is environmental consultants and authorities with the aim of raising awareness of these challenges and the possible positive benefits of involving health experts in the communication.
Suggestion for timeslots:
- Presentation of cases involving both water and soil contamination from European countries – 10 min
- Roundtable discussions – one case per group – based on preestablished questions and facilitated by the presenters of the workshop – 30 min. All cases will address questions like: Challenges in risk communication: populations vs. individuals, how to use, interpret and communicate divergent health-based and administrative-established limit values? Challenges in communication along the gradient of contamination from: absence of contamination, diffuse pollution, slightly to strong pollution and how they correlate with health effects. Who should be responsible for risk communication and who it should be addressed to? Purpose and timing of risk communication. Role of authorities, researchers, environmental and health experts, local/national policymakers, and the media.

- Plenary presentation of the key messages from roundtable discussions by each group – 35 min
- Take-home messages and closing remarks – 10 min

List of presenters/facilitators
Paula E. C. Hammer, Medical Doctor, PhD, Clinical Toxicologist, Department of Occupational and Environmental Medicine, Danish Poison Information Center, Bispebjerg University Hospital, Copenhagen, Denmark
Katleen De Brouwere, PhD, expert Exposure and Risk Assessment, Department of Environment and Health, Flemish Institute for Technological Research (VITO), Mol, Belgium
Nina Tuxen, M.Sc., Ph.d, Capital Region of Denmark
We are currently in contact with other potential presenters as well.
Significance
Besides the potential toxicological risk, environmental contamination imposes a threat to mental health for the community exposed – as pointed out by the Community Stress Resource Center at the

Agency for Toxic Substances and Disease Registry (ATSDR – https://www.atsdr.cdc.gov/community-stress-resource-center/php/science/index.html). This is mainly related to the fear of contamination-associated diseases, which is promoted by lack of timely and balanced risk communication. Therefore, early interactions with the community with transparent information promote trust and credibility even in the initial phases before a thorough risk assessment is complete. Such approach helps to prevent public panic and media-driven agenda allowing for a proper prioritization of resources with human health in focus.

Required equipment: possibility to show short presentations. Participant seatings organized in groups. Max number of attendees: around 40

Abstract ID: 402
LIFE CAPTURE: Combining novel analytical protocols with effective technologies for sustainable PFAS remediation

Jan De Vos[1], Axelle Mineur[1], Silvia Franz[2], Valeria Mezzanotte[3], Paolo Ronco[4]
[1]ABO Group, [2]Politecnico di Milano, Dept. of Chemistry, Materials and Chemical Engineering ,
[3]Università di Milano Bicocca, Dept. Of Earth and Environmental Sciences, [4]Centro RIVE – VIACQUA spa

Per- and polyfluoroalkyl substances (PFAS) are a family of man-made chemicals that have been widely used since the 1950s. PFAS is a class of thousands of substances (>6,000 compounds) characterized by extreme persistence and different behaviors/mobility in the environment. The efforts towards the substitution of old generation PFAS with short-chain and new generation PFAS has brought new concerns as these substitutes are once again poorly known, with similar mobility in the environment, and could lead to relevant health effects.

The overarching objective of LIFE CAPTURE is to develop sustainable management methods for dealing with Per- and polyfluoroalkyl substances (PFAS) in soil and groundwater. This targets concrete issues and challenges that are currently encountered when dealing with PFAS-contamination. These relate to characterization, assessment and mitigation of the contamination.

Up to now, far too little attention has been paid to the methodology for the PFAS analysis. Nowadays, only a very limited number is taken in account (approx. 40) during quantification, leading to sometimes severe underestimations of the PFAS presence in soil, water and other matrices.

Therefore, LIFE CAPTURE intends to develop a protocol for any type of PFAS contamination by enlarging the spectrum of the PFAS family that can be identified and analyzed. LIFE CAPTURE proposes a robust protocol that follows a staggered approach to: quantify whether any kind of PFAS is present; quantify the concentrations of a set group of well researched PFAS; determine if there are significant concentrations of other PFAS present; quantify and qualify those other PFAS.

During site investigation it is currently considered best practice to only look at concentrations. The use of flux-measurements would be a valuable addition, allowing more direct measurement of exposure and risks. It can also be used to drastically enhance the efficiency of mitigation measures such as remediation. Within this project, passive flux samplers that can be integrated in the new analytical protocol will be demonstrated.

Due to PFAS's chemical properties, most existing remediation technologies don't provide adequate sustainable treatment solutions. We proposes a toolkit of promising innovative remediation technologies for PFAS. Technology trains, including technologies such as foam fractioning, biological treatment, advanced oxidative practices and ventilated activated carbon, will be tested to optimize the remediation approaches in order to eliminate the contaminants from the environment. Notably, the LIFE CAPTURE project will pilot test the (cost-) effectiveness of tailored Advanced Oxidation Processes in eliminating PFAS from groundwaters in one of the most impacted aquifers in north-east Italy. This aquifer is currently showing sum of PFAS concentrations of thousands of ng/l .

The assessment whether a certain PFAS-contamination is harmful is typically governed by a regulatory framework. We propose to develop a pragmatic risk and effect assessment approach for varying soil types. This will be based on existing standardized ecotoxicity tests. Special attention will be given to risk assessment for mixtures of different known or unknown PFAS.

The poster will present a concise overview of the objectives of LIFE Capture and the main intermediary achievements at the half-way point of the project.

Abstract ID: 405
From screening to selection of methods for the remediation program for a mega plume

Britt Boye Thrane[1], Morten Birch Larsen[1], Dorte Harrekilde[1], Cecilie Fisker Ottosen[2], Grégory Lemaire[2], Poul L Bjerg[2], Mette M Broholm[2], Jørn K. Pedersen[3], Lone Dissing[3]
[1]Ramboll, [2]DTU Sustain, [3]Region of Southern Jutland

Purpose of study: The plume from the former Grindsted Factory – a Danish mega site - flows underneath the town before it discharges into a stream 1,200 meters downgradient from the source area. Here, it contributes to a contamination flux of pharmaceutical substances, primarily sulfonamides and barbiturates, as well as chlorinated ethenes and BTEX. The purpose of this remediation program is to assess and describe remediation methods that can ensure that there is no longer an unacceptable impact on the stream with the pollutants spilled on the factory site. Intensive investigations were initiated in 2021, with the purpose of supporting the development of a remediation programme. The results from the investigation were used to evaluate relevant parameters including:

-               Focus substances – determining which pollutants will be the risk driver for the remediation.
-               Hydraulic conditions - the groundwater velocity between the source area and the stream influences the choice of remediation method and the length of the   operation period.
-               Delineation of the remediation area based on the mass flux.
-               Redox conditions, which are relevant for the choice of remediation method.

Methodology: An in situ remediation solution was requested by the client just as there was a request for the remediation to be placed close to the stream to ensure a quick effect on the flux to the stream. The area along the stream is protected nature.

Based on the risk assessment and the risk driver, relevant remediation methods were screened. However, complex hydraulic conditions and high flow rates made it difficult to find an in situ remediation method that could meet the remediation requirements.

Due to the complexity of the chemical composition of the plume, it was decided to include on site remediation methods as well.

Summary of findings/results: Based on the flux estimates and the measured concentrations in the stream, the risk driver was found to be vinyl chloride, and it was estimated that the mass discharge should be reduced by 99.5%.

The results of the investigations narrowed down the treatment zone along the stream to 800 meters and a depth of 70 m. The area is subdivided into 6 sections where an approach to remediate the parts with the largest flux first is suggested, and monitoring should determine if further remediation is required.

Conclusion/take home message: The remediation strategy includes both in situ methods (Stimulated Reductive Dechlorination - SRD), sorption (activated carbon) and chemical reduction (Zero Valent Iron - ZVI), combined with onsite pump and treat with ozone treatment.

The suggested approach means that it may take several years to establish all parts of the remediation, but on the other hand, it ensures that the individual initiatives can be optimized, just as it ensures that no more initiatives are initiated than necessary.

A brief overview of the outcome of the site investigation program will be presented to give an overview how they have contributed to targeting the remediation efforts.

Based on site results, an overview of remediation methods targeting vinyl chloride and taking account of pharmaceuticals will be given focusing on the selected methods.

Significance / contribution of study: A traditional remediation program typically describes 2-3 possible countermeasures and compares these in terms of, for example, price and efficiency. Due to the extent and complexity of the pollution, this remediation program is structured differently. It describes six different remediation efforts spread over four different areas, as several coordinated efforts are deemed necessary to achieve a sufficient flux reduction and thus comply with environmental quality standards and proposals for environmental quality criteria.

Abstract ID: 407
Efficiency of nitrogen transformation under various operating conditions in soil aquifer treatment

Paola Sepúlveda-Ruiz[1], Marta Casado[2], Lurdes Martinez-Landa[3], Montserrat Folch[1], Benjamin Piña[2], Jesús Carrera[4], Cristina Valhondo[4]

[1]Biology, Sanitation and Environmental Department, University of Barcelona, Av. Joan XXIII, 08028 Barcelona, Spain, [2]Institute of Environmental Assessment and Water Research, IDAEA-CSIC, Barcelona, Catalunya 08034, Spain, [3]Dept. of Civil and Environmental

The growing demand for drinking and irrigation water driven by population growth has increased dependence on groundwater. However, aquifer overexploitation and pollution, mainly from nitrates, pesticides, and other contaminants, threaten groundwater sustainability. Nitrate is considered the most widespread groundwater pollutant, largely due to its high solubility and limited soil fixation. Managed Aquifer Recharge (MAR) is a nature-based solution to enhance recharged water quality and increase groundwater quantity. When the source of water used for MAR is treated wastewater the technique is defined as Soil-Aquifer Treatment (SAT). During infiltration, physical, chemical, and biological processes enhance water quality by transforming contaminants, such as nitrogen species, through interactions with the soil matrix and its microbial community. The transformation of nitrogen involves a series of complex biogeochemical processes driven by microorganisms, and affected by numerous factors including pH, alkalinity, temperature, oxygen, microbial activity, moisture content, and the presence of reactive nitrogen species.

This study examines the effects of operational parameters—recharge strategies, reactive barriers, and temperature—on nitrogen transformation during SAT in two pilot systems. The pilot SAT systems were built inside the facility of a wastewater treatment plant (WWTP) located in the Northern Mediterranean coast of Catalonia (Valhondo et. al, 2020). This study focuses on two SAT systems: one operates conventionally with sand (SS), and the other operates with a reactive barrier (RbS) consisting of a mixture of sand, vegetable compost, wood chips, biochar, zeolite, and clay. Over five recharge episodes across different seasons and two recharge strategies were applied: continuous and pulsed feeding. Throughout the recharge episodes, the water feeding the systems (INFw), as well as the water collected after passing through the unsaturated zone of the sand system (SSw) and the reactive barrier system (RbSw), were sampled weekly. Material filling the unsaturated zone of the sand (SSm) and the reactive barrier (RbSm) systems were collected at two distinct depths: near the surface (15-28 cm) and at the bottom (41-54 cm).

Key variables analysed include pH, DOC, alkalinity, nitrate, and ammonia concentrations, alongside microbial community dynamics involved in nitrogen cycling.

The results showed that nitrification varied significantly between the two SAT systems, depending on the feeding strategies used. In terms of denitrification, the RbS system performed better than the sand system. The RbS system consistently achieved nitrogen removal efficiencies of 80-93% across nearly all recharge episodes. On the other hand, the sand system showed improved efficiency when a pulse-feeding strategy was applied.

References: Valhondo, C., Martínez-Landa, L., Carrera, J., Díaz-Cruz, S. M., Amalfitano, S., & Levantesi, C. (2020). Six artificial recharge pilot replicates to gain insight into water quality enhancement processes. Chemosphere, 240, 124826. https://doi.org/10.1016/j.chemosphere.2019.124826

Abstract ID: 409

A Sustainable Approach for the in-situ Treatment of Deep CHC Contaminants Underlying a Manufacturing site in Germany using ZVI and Bio-augmentation

GORDON BURES[1], LARS ERPEL[1], JOACHIM FELDGES[2], WALTER LENZ[2], MIKE MUELLER[3]
[1]SENSATEC GmbH, [2]HG Büro für Hydrogeologie & Umwelt GmbH, [3]EVONIK OPERATIONS GmbH

BACKGROUND AND OBJECTIVES
Due to its heavy industrialization and densely populated urban areas, in situ remedial approaches are often the most practical and cost-effective means of mitigating contamination at industrial sites in Germany. Site owners are frequently faced with untenable cost burdens or disruptions to commercial operations when considering traditional remediation technologies. The Dexion plant in Laubach, Germany manufactures industrial shelving and modular storage systems whereby past activities associated with metal degreasing and enamel/paint coating operations have resulted in deep subsurface CHC impacts (to 22 m depth bgs) which largely underlie the existing plant facilities. Soil excavation and ex situ remedial options were initially considered but deemed impractical due to the necessity of removing (i.e. demolishing) much of the plant infrastructure to gain access to contaminated sediments, lost manufacturing capacity, and exorbitant costs. Pump and Treat measures only provide limited effectiveness due to the low permeability of underlying silty clay soils. An in situ remedial alternative approach was therefore investigated to sustainably mitigate CHC contaminants using the targeted emplacement of treatment reagents. The objectives of the work were to: Conduct a field pilot to determine the most favorable treatment process for the given site conditions and contaminant concentrations, and Implement the selected remedial process/technologies for achieving full scale site remediation.

METHODOLOGY
A field pilot trial was conducted in two separate contaminant plume areas at the site to evaluate and compare the performance of in situ chemical oxidation (ISCO) to in situ bioremediation (ISB) with biological augmentation. The results after 2 years monitoring indicated that both approaches had reduced ∑CHC concentrations by approximately 60%, although rebound effects were apparent in the ISCO trial (after depletion of the persulfate oxidant) which was not the case for the ISB trial. Therefore, a remedial approach for full scale in situ treatment of the site was developed using in situ chemical reduction (ISCR) with ISB. Targeted Solids Emplacement ("TSE")™ technology using direct push drilling and specialized mixing and pumping equipment was applied for full-scale treatment using Evonik's EHC® amendment in order to emplace 40 metric tonnes of amendment into low permeability soils located under the plant infrastructure. After injection of the EHC amendment (a mixture of organic carbon and micro-ZVI), each of the 40 injection points were constructed as injection wells for the infiltration of lab cultivated microorganism cultures containing the species Dehalococcoides Mccartyi (DHC-M) to further stimulate anaerobic dechlorination. This was followed by a comprehensive groundwater sampling program.

RESULTS AND CONCLUSIONS
Groundwater monitoring results from a network of 13 monitoring wells and 40 injection wells within and proximate to the contaminant plume have demonstrated a median reduction of 75% total CHCs in the first year following injection, despite the low permeability of clay soils. The effectiveness of ongoing contaminant degradation since the beginning of pilot scale work is attributable to a large extent by the mode of amendment emplacement (soil fracturing), which provides a greater radius of emplacement and shortening of diffusion pathways for treatment, and the longevity of EHC. The effectiveness of DHC-M bio-enhancement, which has not yet reached its full potential based on the results of qPCR analysis, is thereby also improved. Ongoing groundwater monitoring in the context of Remedial Process Optimization has identified a few isolated areas of contaminant rebound where additional treatment may be necessary.

Abstract ID: 417
Innovative approaches to identifying potential SVHC and PFAS source locations using large-scale GIS datasets

Lout Kuiper[1], Shaya Algoe[1]
[1]*Sweco Nederland*

The increasing awareness of the importance of healthy ecosystems has encouraged governmental organizations to invest time and resources in their protection. However, time and resources are limited, making it necessary to development effective methodologies that benefit this purpose. This study aims to leverage large Geographic Information Systems (GIS) datasets to enhance the detection and mapping of potential sources of Substances of Very High Concern (SVHC) like PFAS.
Identifying industrial SVHC source locations
The research utilizes the dataset of the Dutch Chambre of Commerce (CoC), which includes in the area of interest (≈ 410 km2) more then 700.000 businesses. Multiple filters are applied to the CoC dataset, in order to locate businesses that are a potential SVHC source. Every business in this dataset has it's own main business activity. Based on studies by the RIVM (the Dutch National Institute of Public Health and the Environment) and experts at Sweco, a filter is applied to the main business activities. Afterwards, additional filtering was performed in order to exclude small businesses and sole traders, as these are usually not the large-scale polluters that are of interest to governments. The refined datasets results in approximately 1100 potential industrial SVHC source locations.
In this study, it was not only important to identify potential SVHC sources, but also to asses for which locations the governmental organization should invest resources in for their monitoring plan. Now that the potential source locations are known, the SVHC-navigator, by the RIVM, was used to estimate the likelihood of SVHC emissions per main business activity. Adding this data to the dataset makes it possible to highlight locations that have a high probability of actually emitting hazardous substances.
(Former) landfills
Landfills are a known source of SVHC. For that reason, these locations were included in the analysis. A total of 135 known (former) landfills are added to the research.
Fire locations
Fire extinguishers can be a source of PFAS because these chemicals are highly effective in suppressing flammable liquid fires, and therefore these chemicals where often used in firefighting foams. Through web scraping, numerous news articles about fires in the region were collected. Reading through all these articles to pinpoint a location would be time-consuming. However, with the recent advancements in large language models (LLMs), it is now possible to use AI to analyze these articles and extract the location data for mapping. Those locations were also added to the dataset of this research.
Sensitive locations
Furthermore, GIS was used to asses sensitive locations in the proximity of the potential SVHC source locations. These sensitive locations consisted of playgrounds, schools, kindergartens, childcare locations, allotment gardens and water bodies.
Multi-criteria Analysis in GIS
All the above mentioned SVHC locations were integrated in a Multi-criteria Analysis (MCA) workflow and incorporated within an online GIS based dashboard, providing all employees of the organization with easy access (see figure 1). The integration of multiple data sources and filtering techniques allowed for a more targeted identification of potential contamination hotspots, enhancing the understanding of spatial relationships between potential sources and environmental risks.
This study demonstrates the effectiveness of utilizing large GIS datasets to identify potential SVHC and PFAS source locations. The findings underscore the importance of data integration and spatial analysis in environmental risk assessment, providing a robust framework for future investigations. The research is ongoing and future work will consist of adding historic SVHC measurements in both the soil and the waterbed to further refine the understanding of the contaminations.

Abstract ID: 421

Electrochemical activation of oxidants with diamond electrodes for efficient removal of anticancer drugs in aqueous effluents

Giovanni Scaggiante[1], Ana Hayat[2], José Leandro da Silva Duarte[2], Carmen María Domínguez[2], Daniela Zingaretti[1], Renato Baciocchi[1], Aurora Santos[2], Salvador Cotillas[2]
[1]University of Rome Tor Vergata, [2]Complutense University of Madrid

The consumption of anticancer drugs (ADs) has continuously increased over the last few decades due to the rapid growth of new cancer cases. These substances are only partially metabolized by the human body, resulting in a high percentage being excreted unaltered and entering wastewater as contaminants. Unfortunately, conventional technologies employed in Wastewater Treatment Plants (WWTPs) are ineffective in removing ADs, allowing these compounds to reach soils and aquatic ecosystems. A major contribution to this contamination is the effluents produced by hospitals, where high doses of these drugs are routinely administered.

Due to their high toxicity and persistence, the presence of ADs in the environment poses severe risks to human health and ecosystems. These substances inhibit cell growth and exhibit carcinogenic, mutagenic, and teratogenic properties. Despite these concerns, environmental science has explored the degradation of ADs less, and there needs to be more knowledge about effective technologies for their removal.

Electrochemical Advanced Oxidation Processes (EAOPs) have emerged as promising solutions for treating different persistent organic pollutants, including pharmaceuticals. These processes generate powerful oxidants in situ through water electrolysis and oxidation of the naturally present inorganic anions, enabling contaminant mineralization under mild operating conditions. Furthermore, persulfate-based oxidants, such as peroxydisulfate (PDS, $S_2O_8^{2-}$) and peroxymonosulfate (PMS, HSO_5^{-}), can be electrochemically activated to produce a broader spectrum of reactive species.

Boron-Doped Diamond (BDD) anodes have demonstrated excellent performance in degrading organic pollutants and activating PDS and PMS, making EAOPs with BDD electrodes a promising approach for reducing chemical consumption and energy-intensive operations. Further research is crucial to fully understand their potential for enhancing the sustainability of advanced oxidation processes.

This work investigates the electrochemical oxidation with BDD anodes as a reliable technology for degrading ADs in aqueous effluents. Dacarbazine (DTIC), a commonly used drug for treating various cancers such as metastatic malignant melanoma and neuroblastoma, was used as a model compound. Electrochemical oxidation tests were conducted using a parallel flow electrochemical cell under batch-operation mode. The effect of the nature of the electrolyte (sulfate, chloride, peroxymonosulfate and persulfate) on DTIC degradation kinetics was evaluated at different current densities (5, 10, and 50 mA/cm2). Key parameters such as the in situ generation of oxidant species, efficiency, evolution of dissolved ions, and DTIC mineralization were measured. Additionally, quenching tests were performed to estimate the contributions of different radical and non-radical species in the oxidation processes, highlighting the distinct effects of various oxidant systems.

The results confirmed that electrochemical oxidation is a promising technology for degrading ADs in aqueous effluents. Complete degradation of DTIC was achieved even at low current densities. Significant differences were observed when the oxidant species were generated in situ using SO_4^{2-} and Cl^{-} anions as electrolytes compared to systems with externally added PDS and PMS. Notably, while high DTIC degradation was achieved across all tested systems, the mineralization was substantially enhanced using persulfate-based oxidants due to the more significant contribution of $SO_4^{\bullet-}$ radicals.

Overall, EAOPs proved effective for using naturally contained anionic species in aqueous effluents to generate reactive species and degrade ADs, with persulfate-based oxidants enhancing contaminant degradation. These findings underscore the potential of EAOPs as sustainable and efficient treatment technologies for mitigating ADs pollution in wastewater.

Acknowledgements

Abstract ID: 423
A modelling tool to assess management alternatives of contaminated sediment basin including potential impacts and co-benefits of floating solar panels

Francois Clayer[1], Marianne Sekkenes[1], Nicolas Estoppey[2], Marion Børresen[2], Sissel Renneklev[1], Thea Christiansen[2], Arne Pettersen[2], Mārtiņš Pričins[3], Ivo Koliņš[3], Espen Eek[2]
[1]Norwegian Institute for Water Research (NIVA), [2]Norwegian geotechnical institute (NGI), [3]Liepaja Special Economic Zone Authority (LSEZ)

Purpose of study
Remediation of contaminated sediments is crucial for protecting water quality, ecosystems, and human health. In specific cases, remediation activities offer opportunities for renewable energy development, such as floating solar installations, supporting energy transition goals.
The sediments of the Karosta Canal in Latvia contain elevated concentrations of heavy metals, hydrocarbons, PCBs and PAHs inherited from the Soviet-era military activities. Since 2015, polluted sediments have been dredged from the canal and stored in a 7-ha closed basin. However, this site is connected to the canal through two 95-cm pipes presenting risks of secondary spreading of contaminants. In addition, large amounts of greenhouse gases (GHGs; including CO_2, CH_4 and potentially N_2O) can be emitted to the atmosphere from the bacterial degradation of hydrocarbons. Future management options for the disposal basin include leaving the basin open, capping, or converting it to land after adding 100,000 m³ of polluted sediment.
Methodology
The environmental impact of contaminants in sediment and water at the disposal site was assessed. In addition, the dissolved GHG concentration in water and the GHG emission was measured. Sediment to water fluxes were modeled for different scenarios (see abstract submitted by N. Estoppey). This abstract describes transport of contaminants from the disposal site to the Karosta Canal (estimated with the NIVAFjord model: a layered multi-basin model enabling sediment-water-air coupling) as well as GHG production and emissions for (i) the current situation and three scenarios: (ii) Scenario 1 – disposing an additional 100 000 m3 of polluted sediment, (iii) Scenario 2 – disposing an additional 100 000 m3 of polluted sediment and capping, (iv) Scenario 3 - disposing an additional 100 000 m3 of polluted sediment, capping, and filling the disposal site to convert it to land. For all scenarios except Scenario 3, installation of floating solar panels (FPV) was also considered and the impacts on water circulation, contaminant exports and GHG emissions were quantified.
Summary of findings
The pollution levels in the disposal site are of high concern, especially in the sediments. The water is a significant source of GHG, and the current GHG emissions can reach 150-220 tons CO_2 equivalent per year. According to the NIVAFjord model, disposal of additional polluted sediment (Scenario 1) would increase the GHG emissions by about 25% and the contaminant release to the Karosta Canal by about 6%. A 60 cm thick capping of the sediments (Scenario 2) would reduce contaminant exports by several orders of magnitude and GHG emissions by about 70% compared to the current situation. For the current situation and scenarios 1 and 2, FPV would reduce GHG emissions by about 10% on a 100-year horizon (reduced diffusive emissions), but also increase contaminant export to the Karosta Canal by up to 15% (reduced evaporation). The capping and filling of the disposal site (Scenario 3) would result in the lowest GHG emissions and contaminant exports to the Karosta Canal, but the differences compared to Scenario 2 are negligible for some contaminants.
Conclusion
Modelling the contaminants fluxes and GHG emissions from the disposal site allowed for a comparison of the environmental impacts of different management alternatives including quantifying potential co-benefits such as reduced GHG emissions with FPV establishment. The modelling was also essential for cost assessment as it allows monetizing the export of pollution to the canal and GHG emissions.
Significance

This study demonstrates how modelling tools, such as the NIVAFjord model representing contaminants and GHG dynamics through sediment, water and water-air interface, allow for a robust environmental and cost assessment of alternative management options for polluted sediment and development of renewable energy such as FPV.

Abstract ID: 427
PFAS Forensics: Distribution of PFAS in tree rings at an AFFF contaminated site

Charles Pijls[1], Amy Veenendaal[1], Adrie Luykx[2], Aiko Hensums[3]
[1]TAUW, [2]Province Gelderland, [3]Municipality Doetinchem

Introduction
The processing and recycling of hand-held fire extinguishers on a site in the Netherlands, from 2010 until 2020, has resulted in an extensive soil and groundwater contamination with PFAS on the facility, due to the long term storage and leakage of foam concentrates on the site. PFAS containing foam and groundwater contamination has migrated to an adjacent forest parcel. An investigation with tree core samplers demonstrated that the trees have taken up PFAS over the years through the uptake of contaminated groundwater, which is then further transported in the trees by tree saps.
Typically tree sap flows in the outer water-conducting tissue of the plant, the xylem. Xylem is refreshed every year, which can be identified as separate tree rings. Since the period in which the PFAS contamination has occurred is relatively small, the determination of the differences in the presence of PFAS in the annual tree rings may be a suitable method for determining the time of occurrence and hence the age of the PFAS contamination. As the trees needed to be cut for the soil remediation by excavation, there is an opportunity to investigate presence of PFAS in the rings of individual trees.

Methodology
A total of 8 trees, consisting of oaks, willows, wild cherry tree and ash trees, varying in age from 13 to 41 years, were selected for analyses of PFAS in the tree rings. To facilitate the sampling of tree rings, the tree sections were divided into discs of 4-5 cm using a band saw and the tree ring thickness was determined. Tree rings were then separated from each other using a hand chisel. Chips of a selection of year rings were sent to laboratory for PFAS analyses. Simultaneously a handheld Thermo Scientific Niton XL5 XRF was applied to identify presence of compounds that were also present in abundance in the foam concentrates that was stored on site (sulphur, zinc and phosphorus).

Results
No PFAS was observed in the old tree rings. However, since the transport of tree sap occurs not only in the outer tree ring but also in the inner and therefore older tree rings, the tree ring analysis does not provide an exact and sharp boundary for the year of the first contact with the PFAS contamination. Therefore the method confirms the timing of the occurrence of the contamination with an accuracy of a few years.
The results of the XRF analyses on sulphur, phosphorus and zinc do not allow any clear conclusions to be drawn regarding the year in which the soil contamination occurred. Also no correlation was found between the thickness of the annual ring and the PFAS concentration.
Differences were observed in the uptake of PFAS between the different types of trees. Oak trees generally contain lower concentrations PFAS in the outer rings than willow and cherry trees. It is not clear whether a difference in soil or groundwater concentration around the roots or a difference in water uptake may have caused this.

The overall conclusion is that the method of PFAS analysis in tree rings can be applied as reliable indicator of the period of occurrence of PFAS contamination of the subsurface.

Abstract ID: 430

Remediation of PFAS contaminated soil using the novel combination of biochar sorbent stabilization and phytoaccumulation: First insights

Ingrid Rijk[1], Dan Berggren Kleja[2], Anja Enell[3], Anna Kärrman[1], Maria Larsson[1], Alf Ekblad[1], Viktor Sjöberg[1], Felicia Fredriksson[1], Maria Florberger[4], Susanne Karlsson[5], Matilda Wiberg[6], Sigrun Dahlin[7], Christina Prevazi[1], Katinka Krahn[8], Erlend Sørmo[9]

[1]Örebro University, Sweden, [2]Swedish University of Agricultural Sciences / Swedish Geotechnical Institute, Sweden, [3]Swedish Geotechnical Institute, Sweden, [4]Geosyntec Consultants AB, Sweden, [5]Structor Miljö Öst, Sweden, [6]Structor Miljöteknik AB, Sweden, [7]

Abstract
Purpose
Biochar is a carbonous, porous material produced by pyrolysis of biomass, which can be potentially used as a sorbent for contaminants and nutrients in soil and water. In recent years, biochar has increasingly been put forward as an amendment that can be used for soil remediation, whereby contaminants are stabilized and ecological restoration of soil is promoted.

Two potential effective (bio)char types for remediation of soils contaminated with per- and polyfluoroalkyl substances (PFAS) are activated carbon (AC) and sewage sludge-based biochar (BC-SS). Both have demonstrated similar, large sorption capabilities for longer chain PFAS, however, sorption of shorter chain PFAS may be less effective. Furthermore, the profound effects that these sorbents can have on soil organisms also remain an area requiring further research.

Methodology
A potential solution may be a combined approach of sorbent stabilization with phytoaccumulation, where shorter chain, more mobile PFAS may be taken up by plants for subsequent removal and destruction. In this study, this novel in situ remediation concept combining sorbent stabilization and phytoaccumulation is tested. Additionally, the toxicological and ecological effects on soil organisms are also assessed, complementing the PFAS sorption and mobility study.

We added 2% of either a wood-based, commercially available AC or a SS-BC to PFAS contaminated sandy loam soil, together with 1% compost and inorganic fertilizer. These mixtures are tested for PFAS leaching, uptake in perennial ryegrass and earthworms, and effects on the grass, earthworms and the soil microbiological activity and community composition.

Summary of findings
This presentation will present the first insights on comparing the effectiveness of the two biochar types in this combined sorbent-phytoaccumulation approach, as well as compare the effects and uptake between different soil biota. Preliminary results suggest that the combination of 1% compost with fertilizer alone, resulted in a reduction of 23.0% of total PFAS in leachate. Meanwhile, the 2% AC together with the fertilizer-compost combination reduced total PFAS with 99.6%, and 2% of the SS-BC with the fertilizer-compost combination decreased total PFAS with 95.7% in leachate.

Take home message
The information on uptake in perennial ryegrass and earthworms, and effects on the grass, earthworms and the soil microbiological properties is of vital importance, as the potential usage of biochar-remediated low-to medium contaminated areas is most likely urban parks, where not only the contaminant stabilization, but also the ecological soil quality has to be taken into account.

Significance
This novel combination of biochar sorbent stabilization and phytoaccumulation could especially be a solution for larger areas with low- to medium level contaminated soil outside source zones. As a positive side effect, addition of biochar could also enhance the carbon content and soil quality of degraded soils.

Abstract ID: 433
Waste2bio, an ecosystem of Belgian stakeholders for the economic and environmental redevelopment of brownfields and polluted sites
Marc Hanikenne[1], Cécile Nouet[1], Pierre Lejeune[1], Pierre Tocquin[1]
[1]*Université de Liège*

dffgter

Abstract ID: 437

Applying Indexing for Evaluation of Existing Pump-and-Treat Plants with Regards to Operational Resources and Multiple Contaminants

Krzysztof Kowalski[1]
[1]*Capital Region of Denmark*

Aim of work

Pump-and-treat (P&T) plants remain a significant method for remediating groundwater contamination in the Capital Region of Denmark. However, their evaluation is challenged not only by variations in contaminants and operational resources but also by increasingly strict water quality criteria. This study aims to present a methodology for comparing remediation efforts across sites treating diverse or multiple contaminants. The proposed index integrates operational data, including granular activated carbon (GAC) consumption, electricity usage, contaminant removal efficiency, and the risk posed to drinking water aquifers.

Methodology

The study uses operational data from multiple P&T plants to quantify contaminant fluxes avoided through treatment. Key parameters include groundwater volumes treated, concentrations of chlorinated solvents, pesticides, and PFAS in treated water, and corresponding mass loads removed. The introduced indexing approach normalizes plant performance by combining resource consumption (electricity and GAC) and contaminant removal against Danish drinking water criteria for contaminant thresholds. This provides a universal metric enabling comparison across plants with varied operational contexts and contaminant profiles.

Summary of results

Quantifying Contaminant Load: Operational data allows estimation of the contaminant flux intercepted by P&T plants, representing mass avoided from entering aquifers.

Resource Use and CO_2 Footprint: Previous work showed that GAC contributes disproportionately to carbon footprints compared to electricity. Here, these contributions were condensed into a single CO_2-equivalent value, enabling resource impact assessment.

Indexing for Multiple Contaminants: A universal index was developed incorporating contaminant mass removed and risk thresholds, using Danish drinking water criteria for different groups, separately, sum of chlorinated solvents, sum of pesticides, and sum of 22 PFAS compounds.

Comparative Insights: The indexing approach revealed key differences in performance among plants treating varying contaminant types and volumes. Plants with higher contaminant concentrations generally showed better mass removal efficiency relative to resource use.

On the attached figure bar plots illustrate comparisons across sites with regards to annual treated volumes, resource usage, contaminant concentrations, and proposed indexed values. Mapping results highlighted plant proximity to aquifers and potential risks to drinking water sources.

The index can be improved by representing single contaminants, f.ex. vinyl chloride, with lower limit than the sum of chlorinated solvents, or multiple contaminants equivalents, like PFOA-equivalent, or any new pollutant or with regards to new water criteria.

Take-Home Message

This study introduces a practical indexing methodology to evaluate P&T plant performance across diverse sites. The index aids in prioritizing resources and optimizing operations by providing a unified metric for comparing remediation efforts, operational resource use, and contaminant risks to aquifers.

Signifficance

The proposed approach enables decision-makers to assess P&T plants from a broader perspective, offering insights into operational sustainability and risk management. While simplifying comparisons across sites, the methodology acknowledges limitations in representing individual contaminant properties, such as diffusion behavior. Further refinement, including site-specific adjustments and individual contaminant weighting, could enhance its application.

Abstract ID: 439
Why I love qualitative sustainability assessment…
Paul Bardos[1]
[1]r3 environmental technology ltd

Significance This oral paper is an opinion piece and a bit of a controversial polemic which I hope will amuse people over 15 minutes and leave them with one or two thoughts to go home with… Perhaps it will stimulate some discussions across the sessions dealing with sustainability assessment and tools such as LCA / S-LCA. It is a story: a distillation of my personal experience in sustainability assessment in contaminated sites management from the 1980s.

I will begin by suggesting that preferences for sustainability assessment approaches are strongly influenced by context: cultural stereotypes, backgrounds and experiences our needs.   Qualitative approaches are viewed with suspicion by some personalities, often that extends across countries. Some people "need" numbers ... It is simply how they are. Qualitative approaches need people and engagement, and this does not suit all circumstances Clients may need quantification to "justify" investment or funding choices Some people like quantification as it helps them win research grants. This is all a bit contentious, but I aim to make the points with humour and empathy.

Expressing complex systems as quantities has difficulties that can lead to a number of problems. Moreover, quantification is not the same as objectivity. Numbers can bury subjective choices most obviously about weightings or scale. Subjective choices are also embedded within the structure created for the assessment. It can get bogged down in arguments that are possibly a bit pointless: e.g. should a weighting be 0.7 or 0.8… It is easy to adopt someone else's choices because it is expedient, e.g. there is "precedent": other people have used the same. Some characteristics defy easy quantification, e.g. the value of a landscape or ethical value chains for material supply: how do we feel about the "look" of phytoremediation, or what do we know about the business ethics of our supply chain for H_2O_2 coming from outside Europe. Quantification can reduce the breadth of discussion and inevitably creates a specialised discipline which reduces accessibility for many different stakeholders who might otherwise have something valuable to say about sustainability. Quantification requires multiple judgements which may reduce the potential for wider engagement, whereas qualitative systems maximise transparency and their complexity is scalable for different types of interested party
I am not insisting that these opinions are totally and objectively correct, just that they are worth considering. These are why I "love" qualitative approaches. I am sure someone else will argue that weights and scores are super-transparent, but this depends on how comfortable you are with numbers and their accretion into formulas involving "sigma" and other things that many stakeholders may never have heard of. Perhaps, the more quantitative we get, the further we remove ourselves from reality of the project on the ground and the people involved with it or affected by it.

I will then draw things together, demonstrating my sympathy for quantitative and semi-quantitative methods even if I don't "love" them quite as much. This will (1) follow the argument for a "tiered approach" from SuRF-UK (2) the rationale for taking cost effective decisions; (3) show how "framing" of sustainability assessment can be similar at all tiers and (4) how "lines of evidence" for a qualitative comparison can be very robust and preferable to a faux quantification.

To conclude I offer two thoughts: We can use to qualitative assessment to narrow down where we really need to make an effort of quantification, and avoid this cost where qualitative outcomes are already crystal clear Using "sustainability linkages" which work like S-P-R linkages and could be a means of transferring broad models of sustainability to cost-effectiveness assessment.

Abstract ID: 441
In-situ remediation of an active DNAPL legacy site posing a serious threat to local groundwater by use of sustainable, safe and predictable approach
Gabriele Giorgio Ceriani[1], Mike Mazzarese[2]
[1]Ejlskov A/S, [2]AST Enviromental Inc.

Purpose. Tackle and solve a DNAPL legacy contamination in a complex hydrogeological setting and located at one of the main national industrial laundry facilities (the site). A final remediation solution had to be designed and implemented with the final objective to both maintain the industrial facility active (without causing any business interference) and reaching specific groundwater criteria at the site boundary.

Background. Tetrachloroethylene (PCE) contamination was found in soil and groundwater at the site. After 20 years attempting to stop a DNAPL plume from spreading off site, local authorities were forced to ban houseowners downstream of the site from using groundwater for irrigation and secondary domestic purposes. Despite several attempts to stop contamination spreading had been conducted (PCE tanks excavation, air-sparging/bio-venting and pump&treat), PCE concentrations at the site boundary (100+ meters away from the source), were still at 100,000 µg/L. Ejlskov was preliminary asked to provide a cost indication for the installation of a Permeable Reactive Barrier (PRB), to stop the contaminant plume.

Summary. By use of high-resolution remedial design (MIP, high density soil sampling (400 soil samples analysed free of charge) and additional monitoring wells), Ejlskov was able to delineate the presence of a significant PCE source (16,000 kg of soil mass), whilst assessing the main flux zones (due to local bedrock variations). The refined CSM, allowed Ejlskov to maintain the initially assessed budget for the PRB, but the final remediation design was focused on the treatment of the main source area by use of an innovative in-situ technique while the site was maintained active. The outcome of the treatment led to the sustained degradation of PCE to non-hazardous gases across all treatment zones and downstream. DNAPL initially measured in the source zone up to 40-50 cm in thickness was no longer observed after a few months. 72 months post-injections 50% soil mass reduction was confirmed by use of high resolution soil validation in the main source area and up to 95% conversion of PCE is observed at the site.

PCE concentrations at the site boundary were brought down 3 orders of magnitude from 100,000 µg/l, close to the final remediation target.

Motivational Text. Success of a total solution approach at complex active DNAPL sites can be achieved by investing up front during the remedial design phase. Injection works can be made safe and predictable while supporting clients to continue their daily operations. At this specific site, a large portion of the injection works occurred under the main building basement (completed thanks to Ejlskov customized equipment), but regardless site activities were maintained operational. Results came along as predicted.

Abstract ID: 443
Valorization of Brownfields Through the Production of Bioactive Molecules

Cécile Nouet[1], Georges Scholl[1], Michel Frederich[1], Bernard Bosman[1], Monique CArnol[1], Gauthier Eppe[1], Gilles Colinet[1], Marc Hanikenne[1]
[1]Universite de Liege

Due to its industrial legacy, Wallonia is home to approximately 3,500 polluted brownfields. The ECOSOL project aligns with both regional government and European Union goals to regenerate these sites. At the same time, there is growing competition for land use between agriculture, biomass production, and the development of bioactive molecules.

Addressing these dual challenges, the ECOSOL project explored the potential of pollution-tolerant plants found on brownfields to produce bioactive molecules for the pharmaceutical sector. This multidisciplinary initiative brings together five laboratories from the University of Liège, leveraging expertise in agronomy, biology, chemistry, soil science, and pharmacy. The project was supported by the Walloon Region and the European Union (ERDF) and conducted in collaboration with SPAQuE (Public Society for Environmental Quality Support) and the city of Sambreville.

Pilot Brownfield Site

The project's pilot site, a 5-hectare brownfield in Sambreville, was formerly home to a chemical plant (1850–1980). Soil investigations conducted by SPAQuE in 2010 revealed significant and heterogeneous contamination with heavy metals and polycyclic aromatic hydrocarbons (PAHs).

Project Timeline and Key Activities July 2016 – September 2022: The ECOSOL project ran in parallel to SPAQuE's regeneration efforts. Phase 1 (2016–2018): Plants naturally present on the brownfield and adapted to marginal soils were characterized. September 2018: Following deforestation and geotechnical stabilization by SPAQuE, the first plantation was established. Results, including biomass yield and bioactive molecule characterization, will be presented. March 2020: A second plantation was established prior to remediation work planned for 2020–2021. 2021–2022: A final plantation took place on the remediated soil.

Objectives and Expected Outcomes

ECOSOL aims to demonstrate how brownfields can be valorized through interim uses, such as the cultivation of bioactive molecule-producing plants. By repurposing polluted sites, the project supported sustainable land management and contributed to circular economy while creating opportunities for innovation in the pharmaceutical sector.

Keywords: bioactive molecules, metallic and organic contamination, valorization, interim use

Abstract ID: 445
Innovative groundwater remediation for PFAS contamination in Doetinchem

Dennis Scheper[1], Lukas Scholz[1], Albert Smits[1]
[1]NTP

Innovative Groundwater Remediation for PFAS Contamination in Doetinchem
Severe PFAS contamination at the Voltastraat site in Doetinchem, located near the Oude IJssel River, poses significant environmental and human health risks. This contamination originated from a foam processing facility, where leakage from storage containers caused the persistent pollutants to infiltrate the soil and groundwater. These compounds, characterized by their toxicity, bioaccumulation, and persistence, have spread through atmospheric deposition and leaching. As a result, soil concentrations of PFOS reached 24,400 µg/kg, while groundwater levels of PFOA equivalents peaked at 2,730 µg/L.

Remediation Strategy Commencing in November 2024, remediation will proceed in two phases. Phase 1 aims to reduce unacceptable exposure risks by addressing soil contamination, with groundwater remediation (Phase 2) to follow based on insights from Phase 1. Given the groundwater contamination and the lack of feasible discharge agreements with water authorities, the site will be excavated under wet conditions, divided into four sections treated sequentially.
A post-excavation rinsing phase involves multiple cycles of groundwater extraction, purification, and reinjection. This innovative treatment process incorporates coagulation and flocculation using iron(III) chloride, followed by dissolved air flotation (DAF) to remove suspended solids and powdered activated carbon (PAC). Final PFAS removal is achieved with three granular activated carbon (GAC) filters and a polishing resin filter. Foam control, a critical component due to the high foaming potential of the contaminated water, is managed with a specialized foam extraction and containment system.

Monitoring and Optimization
A comprehensive monitoring program will evaluate the purification system's performance and refine its design for similar sites, including the Soesterberg Air Base. This program also supports knowledge development and transfer to stakeholders, with plans to disseminate findings via the Bodembreed Academy.

Collaborative Approach
The project brings together multiple stakeholders, including the Municipality of Doetinchem, Stichting Bodembeheer Nederland, consultants (Tauw/Witteveen+Bos), and contractors (NTP). Contributions from these parties, both in-kind and financial, ensure the success of this initiative.

Conclusions
 This remediation effort highlights the integration of innovative technologies and collaborative strategies to address PFAS contamination. Insights gained will not only benefit the Voltastraat site but also provide a framework for tackling similar environmental challenges on a broader scale.

Abstract ID: 447
Examples of how local Policy Implementation can be completely different by region in two countries (Belgium and PRC (China))
Steve LEROI[1]
[1]Optimum Momentum BV

Local environmental policy-makers and environmental agencies have the freedom to implement policies within their territories. These implementations are guided by local geographies, geology, economic drivers, service providers (waste companies, housing agencies, etc …) and the available budget in their respective regions. Although science, risk assessment methodologies and technologies can be readily transferred around the world, the local policy options influence the available solutions. Local policy needs three baselines to be effective and successful : 1. Provide a longer term horizon for investors, 2. Assure the control mechanisms that the policy is implemented, 3. Create a financially viable path to get solutions in place.

In China the legislative frame work is the same all over the country but implementation of this policy is different in different cities. Chongqing and Shanghai have other geographies and historically different track-records of how they have put environmental policies in place. Also urban sprawl is organized differently in both cities.

In Belgium, the regions of Flanders and Wallonia have dramatically different geologies and different industrial histories. Thus there is a need for different policies.

Explaining the different drivers of the policies in each region provides insight why local options make sense. Additionally, the East-West comparison in China will provide parallels with North-South differences in Belgium. Policy-makers around the world will discover how they can take appropriate measures to set-up a successful policy that is sustainable on the long-term.

Abstract ID: 449

CO2POL – Carbon footprint of depollution projects and remediation sites – Design of a nationally shared methodology for emission calculations and provision of key figures

Sébastien Kaskassian[1], Baptiste Fillebeen [1], Niama El Kari[1], Christophe Chene[2], Louise Dessertine[2], Clotilde Johansson[2]

[1]TAUW France, [2]ORTEC SOLEO

Purpose of Study:

In December 2015, the UN Climate Change Conference (COP21) led to the Paris Agreement, which goal is to limit global warming. Thus, it was agreed that by 2030, greenhouse gas emissions should be reduced by 43% and carbon neutrality should be achieved by 2050.

To reach that purpose, the first step is to calculate emissions. In France, many tools have been developed to do carbon footprint assessments, few of them are tailored for the field of soil-remediation. Many emission factors are still missing and there is no consensus on the methodology to be used.

The aim of CO2POL project is to provide a national (France) methodological framework to standardize the GHG emissions assessments, and to calculate the medium carbon footprint of each remediation technique based on real case studies.

Reference figures produced by the project are supposed to be used in the decision-making process when choosing a remediation technique – thus including their environmental footprint as a criteria.

Methodology:

CO2POL Project is supported by an expert committee gathering actors from each profession in contaminated sites and soils: private works companies, engineering offices, project owners and institutions. The rules, design assumptions and methodology are discussed to lead to a consensus, adapted to the tools available and easy to use.

The emission factors selected for calculations will be taken from the CARBONE database of ADEME - France, but also from other clearly identified and justified sources, as required. This will lead to discrepancies, but as the aim of this project is not to choose one unique tool nor emission factors, the importance is to achieve consistency in the order of magnitude obtained. This study will possibly also identify gaps in the sources.

Then, carbon assessment will be performed on 60 projects, given by the expert committee and maybe other sources, selected among real cases and completed remediation sites, with 5 or 6 sites for each targeted technique.

Seven in-situ techniques are targeted, the ones most often used in France: venting, sparging, pumping-skimming, ISCO, ISCR, thermal desorption, bioremediation (aerobic/anaerobic).

Three on-site techniques: biopile, thermal desorption (pile), landfarming.

Four off-site techniques: based on excavation (with or without the use of tent, of sheeting…).

Other interesting and less usual types of remediation may also be included.

If possible, different sizes of sites will be selected for the same technique.

One and/or two different tools will be used for calculations (the ones developed by TAUW France and ORTEC SOLEO). For some key projects, both will be compared to validate the correct calibration of the applied methodology (similar order of magnitude).

Results:

The aim is to provide average values (with confidence intervals) per remediation technique with indicators representative for the field of contaminated sites and soils, such as CO2 emissions per units: kgCO2eq/m3, kgCO2eq/m2, kgCO2eq/t, kgCO2eq/€, kgCO2eq/day… – comparing emissions to the mass, volumes treated and to the cost of each remediation.

The CO2POL project has started in December 2023. To date, bibliography work is complete and has highlighted several critical issues regarding the methodology of GHG emission assessments. Discussions to define a common methodology are on-going, as well as the collection of real case studies. Calculations are planned to start in February.

On the day of the seminar, the methodology defined by the expert committee will be presented, as well as the first results obtained.

Abstract ID: 453
Geospatial Analysis for Monitoring and Assessing Oil Spills in Nigeria

Nguamo Jessica Angula[1], Christine Switzer[1]
[1]*Department of Civil and Environmental Engineering, University of Strathclyde*

The frequency of crude oil and refined product spills in Nigeria during exploration, extraction, and distribution yields devastating impacts on human health and the environment. Oil spills contaminate surrounding soils and water bodies, resulting in losses of agricultural lands, forest ecosystems, mangroves, and biodiversity within oil-rich territories. The health hazards created by these oil spills also add to the disease burden of the local people. This research investigates the documentation of oil spills, causative factors, repercussions, and challenges utilising the National Oil Spill and Detection Response Agency (NOSDRA) and Central Bank of Nigeria (CBN) databases.

NOSDRA and CBN have been tracking oil spills since 2006, respectively. Between 1990 and 2023, petroleum industry operators recorded 16,425 spills with NOSDRA. These statistics are self-declared by operators. Records from the spill databases were input to ArcGIS Pro 10.8 developed by Esri for spatial analysis and Origin for statistical analysis. Records between 1990 and 2005 are retrospective. Significant gaps also exist in data after 2006, particularly 2013 – 2014. In total, there are discrepancies of over 50% between industry-recorded and NOSDRA reported incidents. A Joint Investigation Visit (JIV) that involves NOSDRA, other government and non-government agencies, oil company, and community representatives confirms these spills before they are documented (reported) by NOSDRA. The JIV is a legal process that forms the basis for clean-up activities and compensation claims that may follow. This process has not yet been completed for >50% of industry recorded spills. NOSDRA-reported incidents accounts for an estimated 833,000 barrels of oil released to the environment, a loss of $65M in 2023 USD.

Spill causes included in NOSDRA records are sabotage, equipment failure, corrosion, operational maintenance error, others, and yet to decide. The most frequently recorded cause, sabotage, accounted for 65% of recorded incidents and 73% of the estimated volume of all oil spills. Similarly, spills caused by equipment failure cumulatively accounts for 11% of reported incidents and 17% of the estimated quantity spilled, which mostly occurred offshore. Some records, 9% do not include any identified cause and approximately 33% do not include estimates of spill volumes. The total estimate of crude oil spilled is significantly lower than the difference between produced and exported crude oil. Interpolation methods were used to estimate missing values to ascertain the extent to which the information difference may influence unaccounted crude oil. The findings showed that addressing the disparity increases the total volume of spilled crude oil by nearly 200% but exerts no significant impact on the overall volume or value of the difference between production and export of crude oil. Nigerian legal frameworks impose monetary penalties for petroleum spills attributable to equipment failure, corrosion, and operational maintenance error, whereas incidents of sabotage and other indeterminate origins remain exempt from liability. This inconsistency in liability may create incentives to attribute spills to sabotage. At the same time, the gap between oil production and export illustrates how lucrative sabotage is. Further investigation into Joint Investigation processes would be beneficial to understand how spill causes are verified and if impacted communities feel well represented by these processes. Crude oil losses, including spills, inflict negative consequences on communities, the environment, and the economy. heightening unlawful activities, discouraging investment, and weakening the national currency. Despite the progress made in documentation practices by the existing system, significant reporting gaps remain, and further improvements are crucial for a comprehensive and effective response.

Abstract ID: 455
Protection of sensitive groundwater extraction well, achieved via use of sustainable in-situ approach (combined techniques)

Gabriele Giorgio Ceriani[1]
[1]Ejlskov A/S

Purpose. Removing the threat posed by soil contaminated with hydrocarbons to reach a primary aquifer and a sensitive groundwater extraction well, using a sustainable and proven in-situ remediation approach. The treatment solution would allow to keep all contaminated soil on site without the need to transport contaminated masses to landfills and having to transport large masses of fresh soil to the site.

Background. A former service station in the Nordic Region, was abandoned and decommissioned during the late 1990s. As part of the decommissioning process soil was removed around the main underground infrastructures. Following site investigations, detected the presence of significant amounts of residual contaminated soils, which were assessed to pose a threat to the underlying primary groundwater aquifer and the nearby municipal groundwater extraction well. It was therefore made necessary to remove such risk by addressing the contaminated soil by means of in-situ or ex-situ treatment. Soil contamination was preliminary found to depths of 6-7 meters below ground level (m bgl), making excavation of soils quite expensive and unsafe due to site location (within two large roads).

Summary. Ejlskov solution started from performing a high-resolution remediation design to narrow down to the maximum extent possible the footprint and volume of contaminated soils on site. The preliminary contaminated soil estimates were based on approximately 50 soil samples leading to 900 m3 and a mass of 620 kg of TPH to treat. Following the remediation design phase an additional 190 samples were collected, leading to a revised assessment of approximately 450 m3 of soil and 600 kg of TPH to treat. Such assessment laid the foundation for a final in-situ remediation plan which involved soil mixing through accurate stocking on site of clean masses and blending of contaminated soils with Ejlskov Trap&Treat biological solutions. No soil was disposed of, nor imported on site. Within 21 months from completion of treatment, a high-resolution soil validation event (181 samples collected) provided evidence of soil contaminant mass reduction of approximately 90% compared to the initial 600 kg of TPH estimated within the treatment zones.

Motivational Text. Despite the site conditions, would have possibly favored dig&dump as a viable yet expensive solution, the use of a methodic approach with high-resolution remediation design upfront, made the use of an in-situ application the most cost effective and sustainable solution to remove the risk posed by soil contamination to the local primary aquifer. In-situ soil mixing can be easily performed in conjunction with retail sites demolition activities to minimize even further the need for future site mobilizations as contaminated soil is accessible while excavation pits are dug for infrastructures removal.

Abstract ID: 457

Assessment of natural attenuation and its stimulability at a former large-scale industrial site based on the combination of innovative in situ monitoring methods

Annika Beckmann[1], Joachim Richter[1], Phil Dennis[2], Jeff Roberts[2], Kevin Kuntze[3], Anko Fischer[3]
[1]HPC AG, [2]SiREM, [3]Isodetect GmbH

For the sustainable remediation of contaminated sites, the aim is always to find the most ecologically, economically and technically optimal strategy. Such remediation strategies may include the use of natural attenuation or enhanced in situ remediation processes, in either case their integration in the remediation conceptual site model (CSM) must be carefully examined. If biodegradation of pollutants can be demonstrated, inexpensive and sustainable remediation options may be possible. The characterization and quantification of biodegradation processes is therefore an important part of remedial investigations which will inform remedy selection and optimization.

In this presentation we explain the combined application of different innovative in situ monitoring methods (compound-specific stable isotope analysis, CSIA; molecular genetic analyses; in situ microcosms with 13C-labled compounds, BACTRAP®; metabolite analyses) to determine powerful parameters for natural contaminant degradation (e.g., mineralization rates, in situ degradation rate constants, degradation potential).

The data obtained were used for site-specific model calculations that allowed validated predictions of contaminant removal. At a former large-scale coal refinement site groundwater contamination with BTEX, PAHs and SCAPs were detected. A pump-and-treat system was in operation for more than 20 years. In order to consider a shutdown of this measure, the natural and potentially stimulated in situ degradation should be further investigated. For this, a variety of different monitoring methods were applied in an innovative combination. I) Metabolite analysis demonstrated the biodegradation of BTEX, phenol and naphthalene. II) The BACTRAP investigation provided evidence for the complete degradation of phenol both at the source area and in the contaminant plume. III) In situ degradation rate constants for BTEX and Naphthalene were implemented in a CSM.

With the help of model calculations, sustainable site-specific remediation scenarios were derived and the future development of the contaminant plume at different locations at this large-scale industrial site could be demonstrated. As a result, natural biodegradation was demonstrated to be an essential part of the most practical remediation strategy. This coordinated approach of monitoring methods made it possible to use synergistic effects of the individual methods in the best and most effective possible way and to enable mutual validation and the translation of study results into an effective site model.

Abstract ID: 459
Lessons learned at former AFB Soesterberg The unpredictable behavior of PFAS in the subsurface understood

Hans Slenders[1], Frank Strijbosch[1], Aiko Hensums[2]
[1]Arcadis, [2]Province of Utrecht

Introduction
The site of the former firefighting training area at the former Air Force Base Soesterberg is being redeveloped into a residential area. Soil and groundwater have become highly contaminated with PFAS due to training activities. An unsaturated zone of 10 m thick is highly contaminated and a groundwaterplume of over 600 m is spreading fast towards drinking water pumping stations. In 2024, remediation-oriented soil research was started to further detail the previously selected remediation alternative. It soon became apparent that the conceptual model used in the previous remedial investigation was no longer correct. The conditions at the site had changed due to the exceptionally high groundwater level. Whereas previously the concentrations in groundwater underneath the source zone were relatively low and conceptually a detaching plume was assumed, suddenly concentations were extreme and leaching from the source zone was high.
Moreover, scientific insights into the transport of PFAS in the unsaturated and saturated zone have also changed substantially in the last few years. During an oral presentation, we want to review several fascinating experiences and present the lessons we have learned.
Purpose
The purpose of deskstudies, field and laboratory work was to detail the remedial alternative and understand transport and cleansing possibilities. The experiences and surprises found led to a significant change in understanding and remedial approach.
Methodology and research activities
In the course of 2024, the following activities were carried out: geohydrological considerations and modelling, column and batch experiments, TOP analyses and advanced drilling through the source zone to rule out cross-contamination.
Findings
A different conceptual understanding
The recently available theory about retardation of PFAS in the unsaturated zone appears to apply to the Soesterberg site like no other. In the unsaturated zone, PFOS is virtually immobile due to the concentration at the soil-air interface, while when these interfaces are saturated and these interfaces are removed, PFOS is hardly adsorbed by the soil and moves fast with the groundwater. Multiple column and batch tests support this concept.
For Soesterberg, this meant that it was not a detaching plume, as assumed in 2022, but a plume with multiple core zones. Every time the groundwater rises, there can be strong leaching. In particular, the very wet winter of 2023-2024 and the extremely high groundwater level have caused an increase in concentrations in the source zone from 10 to 1,000 µg/l. This also means that within the fluctuation zone of the groundwaterlevel, some sort of smearzone may arise, a zone larger than the soil contamination above.
Drilling through source zones
During the vertical demarcation of the pollution in the source area, no demarcation was initially reached. The concentrations in the groundwater were >1.000.000 ng/l, the required level of detection less than 10 ng/l. Whereas hydrogeologically PFOS could not be present at 60 m, it was found repeatedly. Methodologically simple flushing of the water in the casing was not enough. PFOS may also stick to the casing. Additional precautions and measures are needed.
Conclusion and significance
PFAS, being a surface active substance, behave different from all other contaminants we are used to. The major differences being a. the tendency to be immobile in unsaturated zones and very mobile in saturated conditions, and b. the necessary low detection limits in combination with the properties of PFAS require a different understanding of our investigation techniques

This requires a substantially different conceptual understanding and above all, a different investigation and remedial approach. Without this understanding remedial efforts can only fail.

Abstract ID: 462
In-situ PFAS Stabilization by Injection of Organo-Clay (InSuFix Project)

Hans Baillieul[1], Jeroen Vandenbruwane[2], Ilse Van Keer[3], Ward Swinnen[3], Nick Pays[4], Lise Destombes[4], Nicolas Soenens[5], Marjan Joris[6]
[1]Sodecon, [2]Injectis, [3]VITO, [4]Port of Antwerp-Bruges, [5]Brussels Airport Company, [6]i-Flux

New challenges demand new approaches. With the support of Flanders/OVAM/ Knowledge Center for Innovative remediation Solutions (KIS), the applicability of innovative soil and groundwater remediation methods is being tested. One of the seven selected proposals is InSuFix, a project that investigates the use of organo-clay to immobilize PFAS contamination.

KIS encourages collaboration between research institutes, industries, innovative technology providers and developers and authorities to improve and accelerate the testing and outcomes as well as to define a sustainable policy regarding remediation and management of PFAS in soil, sediment and groundwater.

Strong Partnerships

To understand and improve the applicability of available technologies while also recognizing their limitations, it is important to bring together information and expertise from various fields and disciplines. Therefore, effective collaboration between partners from different sectors and research institutions is essential.

The InSuFix project involves a diverse mix of actors, such as: Sodecon, a remediation contractor with expertise in using organo-clay for water treatment and for the treatment of excavated soils. Injectis, a remediation expert with patented injection technology (SPIN®), suitable for improved injection in heterogeneous soils. VITO, a Flemish research institute with PFAS experts, laboratories, and testing facilities. BAC (Brussels Airport Company), site owner. Port of Antwerp-Bruges, site owner.

working in close collaboration with Witteveen & Bos and ABO (soil remediation consultants), iFLUX (expert in monitoring groundwater & dynamics), and EniSSA (expert in High Resolution Site Characterization).

Project Description

Organo-clay (OC) has a number of properties that make it more suitable than other adsorbents (e.g. activated carbon) for immobilizing PFAS in soil, such as a higher adsorption capacity. This project evaluates whether OC can also be applied by injection into the saturated zone via the SPIN® injection technology.

Initial tests are set up in laboratory conditions. The laboratory at Sodecon allows for testing the capacity and limitations of organo-clay and its interactions with different PFAS in a controlled environment. VITO will simulate long-term stability testing by accelerating weathering processes.

In addition to the laboratory testing, the products and technology will be tested in the field at two sites: one at Brussels Airport and the other at a firefighting training site in the Port of Antwerp. Since extensive soil investigations have already been carried out, there is good knowledge on the geology and the PFAS contamination at both sites. The site owners are project partners, seeking the best methods and technologies to remediate PFAS contamination on their site. Consultants who carried out the earlier investigations are actively involved. The information, available results, uncertainties, and gaps from the earlier investigations will be shared and discussed to adequately prepare and monitor the pilot tests.

During the pilot tests, Injectis will optimize both the injection parameters and the particle size distribution of the OC in order to distribute the adsorbent as homogeneous as possible in the treatment area. The pilot tests will be carried out at the two sites characterized by a different hydrogeology and PFAS signatures. The results of the pilot tests will be used to determine the radius of influence, to evaluate the applicability and limitations of the technology, and to understand the direct effects in source zones, as well as longer-term effects downstream. These results will be compared with other remediation techniques and used to develop a remediation plan for the two test sites.

Collaboration between various partners, including research institutes, technology providers, and authorities, is crucial for the success of the project and for accelerating the development of effective and sustainable solutions for PFAS remediation.

Abstract ID: 465

Enhanced in-situ remediation of light petroleum hydrocarbon-contaminated soils using a novel biopolymer-based emulsion

Bexultan Sabyrbay[1], Dorian Davarzani[2], Christophe Dicharry[3], Sagyn Omirbekov[4], Mélanie Lorthioy[5], Mohamed Krimissa[5], Stéfan Colombano[2]

[1]BRGM/EDF R&D/UNIV PAU & PAYS ADOUR, [2]BRGM (French Geological Survey), [3]CNRS/TOTALENERGIES/UNIV PAU & PAYS ADOUR, [4]Nazarbayev University / National Laboratory Astana, [5]EDF R&D

Background/Objectives:

Environmental pollution, notably soil contamination, is one of the most urgent problems today. Light-refined petroleum products (gasoline, diesel, engine oil, etc.), representing light non-aqueous phase liquids (LNAPL), are among the most widely spread environmental pollutants. Injecting non-Newtonian fluids such as aqueous polymers present a significant industrial application interest for in situ remediation of contaminated soil, especially for aquifers with significantly high permeability and strong heterogeneity. However, after flushing with the polymer solution, some LNAPL ganglia will remain trapped in pore space and cannot be mobilized anymore. In addition, there are some limitations on the use of high-viscosity fluids. For instance, injecting a high-viscosity polymer solution during soil remediation may increase the injection pressure and lead to injection difficulties or soil uplift. Consequently, developing eco-friendly, sufficiently viscous, and biodegradable fluid is highly in demand. Therefore, in this study, we show how the injection of polymer-surfactant-alcohol emulsion can improve the recovery of residual LNAPL (here, diesel fuel) in porous media.

Methodology:

In this study, various emulsions were prepared using xanthan gum (XG) as the biopolymer, sodium dodecyl sulfate (SDS) as the surfactant, and 1-pentanol as the oil-swelling alcohol, with 1-pentanol tested at varying volume fractions of 50%, 25%, 12.5%, and 6.25%. Bulk experiments, including rheological and IFT measurements, were conducted to characterize the properties of emulsions. One-dimensional (1D) sand-pack column experiments were conducted to evaluate the performance of the different emulsions under direct and post-injection scenarios, leading to the selection of the most effective emulsion for further testing. Subsequently, unconfined two-dimensional (2D) tank experiments, designed to mimic field-scale diesel contamination remediation scenarios incorporating both saturated and unsaturated zones, were carried out to assess the selected emulsion's effectiveness in enhancing diesel oil recovery.

Findings/Results:

Rheological experiments revealed that all emulsions with varying alcohol content exhibited non-Newtonian shear-thinning behavior, a characteristic that promotes stable and uniform propagation within porous media. Interfacial tension (IFT) measurements between diesel and the aqueous phase showed a more than twelvefold reduction in IFT with the addition of SDS, significantly facilitating diesel mobilization.

To further assess their effectiveness, emulsions with varying alcohol contents were directly injected into 1D column experiments for diesel removal. The remediation process for diesel-contaminated porous media using post-conventional methods involved sequential waterflooding followed by emulsion injection. The 1D column experiments demonstrated the exceptional performance of emulsions containing 50%, 25%, and 12.5% alcohol content, achieving 100% diesel recovery in both direct and post-injection scenarios. In contrast, the emulsion with 6.25% alcohol content achieved 100% recovery during direct injection but 97.5% recovery during post-injection.

Considering its high diesel recovery efficiency and cost-effectiveness (based on alcohol price), the emulsion containing 12.5% alcohol was selected for further 2D tank experiments. These ongoing experiments aim to evaluate the efficiency of the selected emulsion in diesel removal, particularly under the challenges posed by unsaturated zones. Preliminary results indicate effective radial propagation of the emulsion and its potential for achieving uniform displacement in both saturated and unsaturated porous media.

Conclusion and Take-Home Message:
The biopolymer-based emulsion demonstrates a promising advancement in in-situ remediation technologies. Its ability to mobilize and recover diesel through a combination of swelling, IFT reduction, and shear-thinning viscosity makes it particularly effective for heterogeneous soil systems. This innovative approach not only enhances remediation efficiency but also provides a cost-effective and eco-friendly solution for challenging subsurface environments.

Significance/Contributions:
This study introduces a novel emulsion-based flushing fluid capable of addressing the limitations of existing LNAPL remediation methods, particularly in complex subsurface environments. The ongoing 2D tank experiments further validate its applicability to real-world scenarios, paving the way for scalable and sustainable remediation strategies.

Abstract ID: 467

Assessment of soil toxicity of polycyclic aromatic hydrocarbons under biochar treatment using passive sampling and biota characterization

Maria Florberger [1], Ingrid Rijk[2], Dimin Fan[3], Brent Pautler[4], Phil Dennis[4], Sandra Dworatzek[4], Sigrun Dahlin Dahlin[5], Anja Enell[6], Alf Ekblad[2], Susanne Karlsson[7], Dan Berggren Kleja[8], Anna Kärrman[2], Maria Larsson[2], Viktor Sjöberg[2], Matilda

[1]Geosyntec Consultants, [2]Örebro University, [3]Geosyntec Consultants , [4]SiREM , [5]Agricultural University of Sweden , [6]Swedish Geotecnical Institute , [7]Structor Miljö Öst AB, [8]Agricultural University of Sweden (SLU)/Sweden, Swedish Geotecnical Institute, [9]St

According to the European Commission, over 60 % of European soils are unhealthy and are degrading due to factors including unsustainable land management and contamination. Soil remediation is commonly performed by soil excavation and landfilling, creating a significant environmental footprint and an ongoing contaminant source. Innovative approaches for contaminated land management are therefore needed that are in line with the requirements of the European Union (EU) soil strategy for 2030 and the 2023 Proposal for a Directive on Soil Monitoring with the aim to achieve healthy soils by 2050. Soil amendment with biochar may offer an alternative, environment-friendly treatment method for polluted soils compared to traditional remediation methods.

Biochar is a high-carbon containing solid material, produced from various organic wastes (e.g., wood, sewage sludge and crop residues) by pyrolysis, which is oxygen-free combustion. Biochar can be used as a soil amendment, to sorb and immobilize pollutants, reducing the ecotoxicity of the soil, and improving soil ecological properties at the same time. The aim with biochar treatment is that contaminated soil will not be an infinite waste but can be re-used instead. This study is part of larger project funded by the Knowledge Foundation (KKS) in Sweden and industrial partners to assess the potential for rehabilitation of soils contaminated by polycyclic aromatic hydrocarbons (PAH) and per- and polyfluoralkyl substances (PFAS).

In this study, soils contaminated with PAH, were treated with two types of wood-based biochar with the goal of sorbing and immobilizing the contaminants. To assess the bioavailability of the contaminants, equilibrium passive sampling was performed using a polyethylene-based passive sampler (SP3™) which was exposed to continuously mixed soils in a mechanical tumbler. After incubation, the polyethylene matrix was extracted and PAH compounds were quantified, which represents the non-sorbed bioavailable, fraction of the contamination, which is expected to decrease due to the addition of biochar. The passive sampler-based data will be compared to the toxicity of the soils to earthworms and springtails, and also to plant growth versus controls which were not treated with biochar.

In addition to passive sampling to assess the bioavailability, earthworm- and springtails toxicity and plant growth studies next generation 16S rRNA amplicon sequencing (NGS) will be deployed to characterize the microbial community of PAH exposed soils under biochar treatment. Changes in the microbial community under biochar treatment could be another measure of reduced toxicity and increasing soil fertility.

The combination of assessing bioavailable contamination using passive samplers compared to the assessment of the impact on biota will help validate the findings of the passive sampling approach for assessing soil toxicity and more broadly the data provided by this study will help determine if biochar is viable amendment to improve soil health.

Abstract ID: 469
LIFE NARMENA: Nature based remediation techniques for heavy metals in sediment – results of a constructed wetland in the Winterbeek site

Axelle Mineur[1], Jan De Vos[1], Froukje Kuijk [2], Karel Viaene[3]
[1]ABO consultancy, [2]OVAM, [3]ARCHE

The industrial legacy of western Europe has caused several problems with contamination. One particular issue that will be targeted in the LIFE NARMENA project is contamination with heavy metals in small watercourses that flow through nature reserves. While the source activities are often no longer present, the contamination remains in the sediment and on the banks of the stream. The sediment and banks act as secondary source zones, gradually causing further spreading of the stored contamination, exacerbating the problems caused by this heavy metal contamination. Beside human exposure, ecological exposure is an important issue not only in the streams itself but also in nature reserves through which they flow. Traditional remediation techniques for contaminated sediment typically rely on the removal of contaminated material. While this might be an effective technique in residential or agricultural settings, it is often not desirable in areas with a high nature value as significant ecological damage can be caused by such conventional techniques.

The objective of the LIFE NARMENA project is to demonstrate less intrusive, nature-based remediation techniques to manage heavy metal contamination in flood-prone watercourses.

The remediation concept will be aligned with the general water and nature management and requires an integrated approach to deal not only with the environmental issues but also the economic and social implications. To facilitate this, the LIFE NARMENA project brings together a diverse consortium of stakeholders: relevant public organizations, nature NGO's and technical partners.

The project consists of three test sites where different nature-based remediation concepts will be demonstrated.

Two of the sites will be used to demonstrate the use of free water surface constructed wetlands. Both sites are primarily contaminated with cadmium, and additionally contain lower traces of other metals (mainly mercury and arsenic). The contamination on both sites was caused by a combination of historical sediment deposition on the banks and significant seasonal flooding. The remediation concept consists of controlled inundation of the sites, hereby altering the geochemical conditions in the top of the soil/sediment, which results in a decrease in bioavailability and overall mobility of the contaminants.

For one of these two cadmium-contaminated sites, called the "Winterbeek", the works started in the fall of 2022 and the constructed wetland will be finished in 2023.

In the first year of monitoring post works, decreases in the bioavailability of Cadmium of more than 90% have been observed in some of the monitored areas, as well as significant declines in toxicity. At the conference, we will be able to share more details about the positive results of the use of constructed wetlands as efficient nature-based remediation technologies.

Abstract ID: 472

Pattern recognition of large scale PFAS forensic signature variations to identify emergent properties of environmental fate and transport : real life examples.

Julie McCurdy[1], Naoum Tavantzis[1], Teresa Amentt-Jennings[1], Nicole Lancaster[1], Tyler Bryant[1], Rosa Gwinn[1], William Leys[1]

[1]AECOM

Background/Objectives. To identify and characterize potential sources, the complex nature of per- and polyfluoroalkyl substance (PFAS) contamination requires a data-rich forensic fingerprinting approach, combining data science applications for pattern recognition with analytical chemistry techniques. We have developed and applied an exploratory, adaptive forensic investigation approach to maximize the information extracted from the data using statistical programming techniques. Using a large national PFAS occurrence dataset (n > 4,000), curated from more than 30 PFAS investigations performed by AECOM and several publicly available data sources, relationships that are typically only examined on a localized basis, can be computed, aggregated, and described on a large scale.

Approach/Activities. Using the curated PFAS compositional data from groundwater samples, a new dataset of spatially grouped observations was generated with parameters such as change in PFAS composition with depth and signature differences between groundwater samples. An exploratory data analysis was performed on the PFAS compositional data to identify patterns in the data and statistically define the relationships that differentiate the PFAS mixtures. The output of the pattern recognition process is a labelled dataset, where each sample is classified as part of a cluster of similar PFAS mixture signatures using algorithms such as hierarchical clustering. The distinct signature represented by each cluster can then be used as a forensic fingerprint

Results/Lessons Learned. Through our forensic data analysis, the predominant PFAS mixture signatures in the dataset were identified and statistically defined. The distinct collective PFAS signature represented by each cluster was then used as a forensic fingerprint to quantitatively explore the emergent properties of PFAS environmental fate and transport behavior across different matrices impacted by similar sources. Previously, relationships such as PFAS mixture compositional changes with depth were seen as location-dependent and only examined on a small scale due to limitations in the ability to aggregate such data from standard targeted-PFAS data and computationally identify these common relationships and high-level patterns in larger datasets

Significance/Contribution: Two European case studies (Belgium) are used to demonstrate the practical applicability and added value of forensic data analysis compared to the commonly used visual data analysis (Excel chart type). A first case study clearly demonstrates how to distinguish between background concentrations, an exogenous PFAS source/plume, a PFAS zone associated with a fire incident at a site, and a PFAS zone associated with operational activities. This analysis allowed the site owner's ultimate responsibility to be limited to a limited portion of the total PFAS. A second case study shows that the available data and data quality still determines the extent to which PFAS sources or plumes can be distinguished.

Abstract ID: 474
Treatment of PFAS-contaminated soil using soil washing and foam fractionation.

Dorte Harrekilde[1], Julie Katrine Jensen[2], Peter B Mortensen[3], Robin Axelson[4]
[1]Ramboll, [2]Norrecco, [3]Eurofins, [4]Envytech

Purpose of study
Currently, soil contaminated with PFAS above the soil quality criteria cannot be disposed of or treated in Denmark. There is therefore a great need to develop methods for treating PFAS contaminated soil. In this MUDP project, which is a collaboration between Norrecco, Ramboll, Envytech, Eurofins and Aksel Benzin, funded by the EPA, the possibilities of treating soil contaminated with PFAS are investigated. A focus of the project is to look at whether it is worthwhile to divide the soil into particle sizes and focus the remediation on selected particle fractions.
The project has included: Laboratory tests on 5 different soils to investigate the correlation between PFAS in soil and the potential for leaching of PFAS. Possibility to sort the soil into particle sizes with dry sieving, including the challenges that exist with clay soils. Experiment with soil foam fractionation. Experiments with washing of the soil at a large-scale soil washing plant, after which the water from the soil washing plant is cleaned with foam fractionation.
As an add-on, funds from the EPA have been received to investigate PFAS in aerosols and air from the foam fractionation plant in order to elucidate the mass balance of the treatment method and any working environment challenges.
The presentations will focus on treatment efficiencies from large-scale soil washing with a focus on reuse of different soil fractions Methodology   Initially, soils from 5 sites with PFAS contamination have been selected based on soil types, PFAS concentrations and composition. The 5 test soils were divided into 8-9 fractions each according to grain size. More than 50 solids analyses and more than 20 leaching tests have been carried out on different soil fractions. In the laboratory at SGI in Sweden, tests have been carried out with a soil foam fractionation unit with the aim of elucidating the treatment efficiency for different fractions of test soils. The content of PFAS in treated soil, outlet water and foam has been analysed. Estimation of mass balance for the treatment process Full scale tests on a soil washing plant have been carried out on approx. 1500 tons of soil divided into 2 test soils – a sandy fill soil and a clay soil. In the soil washing plant, a mechanical sorting of the washed soil into 4 fractions takes place, the washing water is recirculated, and eventually cleaned by foam fractionation. During the process, incoming and outgoing mass flows have been analysed for PFAS and AOF/EOF in order to elucidate the treatment efficiency for different soil fractions.
The overall tests give an impression of which soil fractions are sufficiently cleaned and thus which fractions and the amount of these can be expected to be recovered after remediation.
  Summary of findings/results
The experimental soils (sand and clay) contain PFAS in concentrations of 0.01-4.5 mg PFAS4/kg. Laboratory and full scale experiments and leaching tests show varying treatment efficiencies for the different fractions, with the highest efficiency for the coarse fractions and the lowest efficiency for the fine clay fraction, as expected based on the literature. The experiments also provide a clear picture of which PFAS are challenging when soil is washed. Conclusion
The project highlights the following: Potential for reuse of selected treated soil fractions Efficiency of soil washing and Soil Foam Fractionation and of Foam Fractionation Possibilities for management of the residual filter cake Challenges regarding analytical methods, mass balances and optimization of treatment process   Significance / contributions of study
The project elucidates challenges and solutions for a method to treat PFAS contaminated soil.

Abstract ID: 478

Coupling of 1,4-dioxane metabolism and co-metabolism with biodegradation of monoaromatic and heterocyclic hydrocarbon contaminants in groundwater

Alfredo Perez-de-Mora[1], Ludwig Immler[1], Jennifer Webb[2], Rachel Hallman[2], Sandra Dworatzek[2]
[1]TAUW GmbH, [2]SiREM Lab

At an industrial site in Germany groundwater contaminated with a complex mixture of hydrocarbons and 1,4-dioxane is pumped at a rate of $6 - 7$ m³/h and treated on-site using a multi-step water treatment unit consisting of the following in-line steps: i) sand filter, ii) stripping columns and activated carbon filters. In this system, air is forced through the sand filters to promote precipitation of iron oxides to better preserve the stripping columns and the rest of the unit. To evaluate the effectiveness of the water treatment plant in removing hydrocarbons, periodic monitoring is performed at each treatment stage at the following locations: inlet (raw water), after sand filters, after stripping columns and after activated carbon filters (outlet). During periodic monitoring of the water treatment, significant removal of hydrocarbon contaminants is observed at the sand filters, indicating that a native microbial community capable of hydrocarbon biodegradation has naturally evolved there. On the other hand, 1,4-dioxane remains unaltered throughout the treatment process with equivalent concentrations at the inlet and outlet.

In the present work, we investigate the biodegradation activity and composition of the enriched native microbial community of the sand filters named "SPY" and evaluate the potential to couple its activity with that of the commercial 1,4-dioxane-degrading mix culture "DXO-88TM" in laboratory batch experiments. Since the biotransformation of 1,4-dioxane can occur metabolically or co-metabolically depending on its concentration, the biodegradation potential of DXO-88TM was tested at concentrations below and above 100 µg/L in the presence of other hydrocarbon co-contaminants. Bench-scale treatability studies were conducted using contaminated site groundwater and solid material from the sand filters to evaluate the biodegradation of 1,4-dioxane in complex water stream containing monoaromatic (BTEX, chlorinated benzenes and chloranilines) and heterocyclic (2,6-dimethylmorpholine) hydrocarbon compounds. Four types of microcosms were set up, including two bioaugmented treatments and their respective autoclaved and chemically inactivated controls (using mercuric chloride and sodium azide). Metabolism of 1,4-dioxane at 400 µg/L and high co-contaminant concentrations (max. of 7.000 µg/L) was evaluated in one of the bioaugmented treatments and its control, while co-metabolism of 1,4-dioxane at 70 µg/L and at lower co-contaminant concentrations (max. of 1.500 µg/L) was evaluated in the other bioaugmented variant and its control. The bioaugmented treatments were supplied with oxygen, whereas the co-metabolic microcosmos received propane gas as co-substrate.

Changes in concentrations of co-contaminants and 1,4-dioxane were monitored throughout the experiment to assess the biodegradation of the target compounds. In addition, changes in the microbial community structure were assessed by 16S rRNA amplicon sequencing. The 1,4-dioxane biodegrading potential was monitored by quantifying genes involved in the metabolism (dioxane monooxygenase - dxmB and aldehyde dehydrogenase - ALDH) and co-metabolism (particulate methane monooxygenase - pMMO and propane monooxygenase - PMO) of 1,4-dioxane using real-time qPCR.

Results showed complete removal of BTEX, monochlorobenzene and chloranilines and significant removal of 2,6-dimethylmorpholine at the end of the incubation period (3-4 months), while dichlorobenzenes were only partially degraded. Amplicon sequencing analysis revealed Burkholderia and Methylotenera, and to a lesser extent, Woeserarchaeia, as the main microorganisms of the naturally enriched "SPY" community responsible for the biodegradation of the aromatic and heterocyclic hydrocarbons. Biodegradation of 1,4-dioxane was only observed for the cometabolic bioaugmented variant. When propane was supplied to the metabolic microcosms, 1,4-dioxane biodegradation was observed.

Our study highlights the potential of the native "SPY" community to treat a complex mixture of aromatic and heterocyclic hydrocarbons and the need to physically separate the biodegradation of

1,4-dioxane from the co-contaminants, for example, by incorporating an additional co-metabolic treatment step after the activated carbon filters.

Abstract ID: 481

Evaluation of the biodegradation of mineral oil hydrocarbons as part of an in-situ biosparging measure at an active industrial site in Spain

Alfredo Pérez-de-Mora[1], David Gramunt Colet[2], Enrico Coggiola[2], Pablo Sánchez Cueto[3], Marcos Parras Molto[3], Kevin Kuntze[4]

[1]TAUW GmbH, [2]TAUW Iberia, [3]LEITAT Technological Center, [4]Isodetect GmbH

At an active industrial site in northeastern Spain, an ongoing in-situ biosparging measure since November 2017 prevents the transport of petroleum hydrocarbons in groundwater from old and new contaminant discharges within the source area to downstream locations within the site and beyond the site boundaries. For the biosparging measure air is injected into the aquifer via eight 1' injection lances (filter screen of 1 m) along a central road at the industrial site. The width of the biosparging barrier is approx. 100 m, the thickness of the aquifer between 1.5 and 2 m.

Evidence of hydrocarbon removal from groundwater as a result of biodegradation processes was assessed in the frame of the EU-project "Biosysmo" using a combined approach including the following investigations: i) groundwater field parameters, ii) total petroleum hydrocarbon concentrations (C5-C40), iii) GC-MS hydrocarbon fingerprinting, iv) Compound Specific Stable Isotope Analyses and diagnostic ratios, v) metabolite analysis, and vi) amplicon and shotgun next generation sequencing. Groundwater was sampled in May 2023 from different locations including the contamination source (2 locations), the biosparging area (3 locations) and the downstream area of the biosparging barrier (3 locations).

Groundwater field parameters revealed the zonation of the study area into anoxic (source), highly oxic (biosparging barrier) and oxic (downstream) aquifer environments as a result of the biosparging measure. While groundwater pH was not significantly affected by the contamination (6.5 – 6.8 units), higher groundwater temperature (up to +8 °C higher) and electrical conductivity (8.000 – 12.000 µS/cm) was observed in the source and the biosparging locations.

Dissolved total petroleum hydrocarbon concentrations (C5-C40) varied from approx. 12.000 µg/L in the source area to 700 – 6.000 µg/L in the biosparging area. Downstream of the biosparging barrier contaminant concentrations were in the range 80 – 260 µg/L. Hydrocarbon fingerprint analysis using Gas Chromatography-Mass Spectrometry revealed monoaromatic hydrocarbons (C8-C12) including ethylbenzene, xylenes, C3- and C4-alkylbenzenes as the main substances in the hydrocarbon mix. Other compounds included naphthalene and methylnaphthalenes and indane.

The volatility of the main hydrocarbon mixture components, the relatively high groundwater temperature range (22-30 °C), and the different properties of individual compounds within the mixture suggested that both physicochemical and biological processes may be responsible for the concentration changes observed at the locations studied.

Component Specific Isotope Analysis (CSIA) for carbon (13C/12C) and hydrogen (2H/1H), and diagnostic ratios showed evidence of biodegradation of xylenes, trimethylbenzenes and methylnaphthalenes. Biodegradation of o-,m-,p-xylenes within the biosparging barrier as estimated by CSIA ranged between 30 – 95%. Additional evidence of biodegradation processes within the biosparging barrier was provided by the detection of metabolites involved in the aerobic and anaerobic metabolism of aromatic hydrocarbons including benzoacetate, hydoxybenzoacetate, methlybenzoacetate, methyl- and ethylcathecol.

The chemical zonation of the study area resulted in the enrichment of well-defined microbial populations as well as alpha and beta diversity as revealed by 16S rRNA amplicon sequencing. At the biosparging locations, the microbial community was dominated by gamma-proteobacteria with known hydrocarbon-degrading potential including Shewanella, Acidovorax, Thauera, Aeromonas, Pseudomonas and Aquabacterium. In the source area, various anaerobic genera of the gram-negative c_Synergistia thrived, including Thermovirga, Acetomicrobium, Aminovibrio and Syner-01. Candidatus_Omnitrophus was observed to thrive in the downstream locations. The biodegradation potential of the enriched microbial community in the biosparging barrier was further supported by shotgun sequencing data showing the detection of gene sequences associated with the metabolism

of hydrocarbons including bcrC, tmoA and bssA for aromatic compounds and alkB and CP450 for aliphatic compounds.

This study highlights the successful biostimulation of native communities for sustained in-situ removal of hydrocarbons in groundwater and the need to combine multiple lines of evidence to assess biodegradation processes in the field.

Abstract ID: 486

Ecological Risk Assessment for the reuse of impacted dredged sediments as construction materials for the new breakwater in the Port of Genoa

Daniele Susanni[1], Sara Ceccon[1], Francesca Arienti[1], Costanza Sironi[1], Sara Rossi[2]
[1]Ramboll Italy, [2]PerGenovaBreakwater

The new breakwater under construction in the Port of Genoa (Italy) will be a unique maritime structure in terms of complexity and size, with foundations resting on seabed up to 50 meters deep and a final total length of approximately 6,000 meters. Some 90 prefabricated reinforced concrete caissons up to 33 meters high will be installed on a rubble mound foundation, laying on the reinforced seabed. The breakwater would allow the operation of large container ships, over 400 meters long and 60 meters wide, into the Port of Genoa, and will make the port resilient to climate change threatens.

The entire project applies concepts of integrated sediment management and circular economy, as it entails the reuse of demolition materials from the existing breakwater and dredged impacted sediments from the port's channels, as raw materials to fill-up the caissons. This approach promotes circularity at the local scale, by minimizing transportation and the demand for virgin materials, while reducing off-site disposal.

During the environmental permitting process, Ramboll supported the PerGenovaBreakwater Consortium, the successful bidder for the EPC contract, to assess the compatibility of sediments' reuse within the caissons, according to the complex and changing regulations applicable on this unusual matter. The procedure required the development of an Ecological Risk Assessment based on the chemical characterization of the impacted sediments, characteristics of the caissons (wall thickness, geometry and permeability), procedures for backfilling and the hydrodynamic regime of the adjacent marine water bodies (simulated through the implementation of a three-dimensional model).

The risk analysis considered the impacted sediments within the concrete caissons as the secondary source of contamination and the seawater nearby as the main receptor. In the long-term scenario, the simulated pathway was the flow of interstitial waters in equilibrium with the impacted sediments through the external concrete walls of the caisson, to reach the sea water. An additional scenario considered the water flow through a hypothetical small fracture to be opened through the caisson wall, thus determining a quicker release of dissolved contaminants in the water phase. Finally, to account for the transient conditions occurring during the construction phase, a third scenario was evaluated consisting in the release of impacted water from the caissons during the filling operations with dredged sediments.

Even under hyper-cautious assumptions, the Risk Assessment proved that the quality standards for seawater are met both in the long term and during the construction phase.

The adoption of operative procedures during the backfilling of caissons and the execution of a specific monitoring plan on seawater within the working area would further confirm the assumptions and results of the Risk Assessment, during the installation phase.

After its validation during the construction phase, the complex Risk Assessment procedure developed for the specific case history could be eventually adopted as a standard for similar conditions in other Ports or marine environments.

Abstract ID: 488
It's more than just Dehalococcoides, reductive dechlorination takes a village

Kela Ashworth[1], Sandra Dworatzek[1], Philip Dennis[1]
[1]*SiREM*

Multiple strains of Dehalococcoides mccartyi (Dhc) are known to contribute to bioremediation of chlorinated ethenes. Some examples of these Dhc strains include those that tolerate oxidizing conditions, fix nitrogen, are tolerable of low pH, or completely dechlorinate tetrachloroethene (PCE) and trichloroethene (TCE) to ethene. Additionally, Dhc rely on other microbes including Geobacter (Geo), which dechlorinates high concentrations of PCE and TCE found in dense non-aqueous phase liquids (DNAPL), Dehalobacter (Dhb), which dechlorinates tri-halogenated compounds that are inhibitory to Dhc, and Acetobacterium, which synthesizes vitamin B12, an essential nutrient supporting Dhc. This study highlights how Dhc strains may vary across Sites and provide evidence that collaboration with other microbes enhance the success of remediation. The analysis of these key microbial populations, in conjunction with other monitoring parameters or treatability testing can help identify Site challenges and optimize bioremediation performance.

Using quantitative polymerase chain reaction (qPCR) and next-generation sequencing (NGS), samples at a number bioaugmented and non-bioaugmented chlorinated solvent remediation Sites were assessed for Dhc and other associated microbial populations. These Sites include those containing DNAPL, mixed contaminants, low pH sites as well as those under less extreme conditions. The quantification of Dhc reductive dehalogenase (Rdase) genes (pceA, tceA, bvcA, vcrA), Geo, Dhb and Acetobacterium as well as the nitrogen fixation gene Dehalococcoides Nitrogenase (nifD) was completed to observe the dynamics between the various Dhc strains.

Results of this study indicated variations of Dhc strain abundance varied at each Site. A common theme observed was that where detected, Dhc populations were dominated by Rdase genes with vcrA being more dominant than bvcA which has been identified as being more associated with oxidizing groundwater and pceA was the least abundant. Rdase gene ratios were also observed to shift, indicating evolving Dhc populations likely in response to changing conditions. There was high variability in the nifD gene abundance, likely reflecting Site-specific nitrogen bioavailability. Geo routinely was detected where Dhc were absent, likely due to the presence of high concentrations of chlorinated solvents unfavorable for Dhc. At Sites where the Dhc inhibitory 1,1,1-trichloroethane or chloroform were detected, quantification of Dhb correlated with Dhc colonization, facilitating a synergistic complete dechlorination. An additional benefit to bioaugmentation with KB-1® was the unique presence of Acetobacterium, likely a strong contributing organism to support achievement of high dechlorination rates.

This study underscores the importance of understanding and leveraging the diverse microbial communities involved in reductive dechlorination to optimize bioremediation outcomes.

Abstract ID: 490

Advancing LNAPL remediation: Enhanced stability and performance of Polymer Enhanced Foam (PEF) in porous media

Adil Baigadilov[1], Stéfan Colombano[1], Sagyn Omirbekov[2], Maxime Cochennec[1], Dorian Davarzani[1], Fabien Lion[1], Laurent Oxarango[3], Hugues Bodiguel[3]

[1]BRGM (French Geological Survey), [2]National Laboratory Astana (Nazarbayev University) , [3]Université Grenoble-Alpes

Purpose of the Study:

Soil and groundwater contamination by Light Non-Aqueous Phase Liquids (LNAPLs), such as diesel and gasoline, poses significant environmental and public health risks. Conventional remediation methods, including pump-and-treat and surfactant flushing, are often ineffective in heterogeneous soils due to low efficiency and poor recovery. Aqueous foam injection offers a novel solution for enhancing contaminant mobilization and sweeping efficiency but is severely limited by foam instability in the presence of hydrocarbons. This study explores the use of Polymer Enhanced Foam (PEF), incorporating Xanthan Gum (XG) biopolymer, to address these challenges. By improving foam stability and flow behavior, PEFs aim to enhance the recovery of LNAPLs from contaminated porous media, offering a sustainable and scalable in-situ remediation approach.

Methodology:

Two foaming solutions—Sodium Dodecyl Sulfate (SDS) and a mixed Sodium Dodecyl Sulfate and Cocamidopropyl Hydroxysultaine (SC)—were evaluated with varying concentrations of XG. Stability tests were conducted using bulk foam analysis to measure foam half-life and drainage rates in the presence of diesel. 1D sandpack experiments were employed to quantify mobility reduction factors (MRF) and diesel recovery yields. Foam flow and stability under realistic conditions are currently being assessed through 2D tank experiments.

Results:

Bulk foam analysis revealed that XG significantly enhanced foam stability, with SDS-XG showing up to a 10.8-fold increase in half-life compared to polymer-free SDS foam. In porous media, SDS-XG formulations achieved higher mobility reduction and earlier breakthrough times than SC-XG counterparts, attributed to better surfactant-polymer synergy. Diesel recovery exceeded 95% for PEFs, with XG enhancing foam tolerance to diesel and reducing its disruptive effects. Preliminary results from 2D tank experiments corroborate these findings, highlighting improved foam distribution and contaminant displacement efficiency.

Conclusion:

PEFs incorporating Xanthan Gum demonstrate superior potential for in-situ remediation of LNAPLs, addressing limitations of conventional foams. SDS-based formulations exhibit better performance due to the optimal interaction between XG and surfactants, enhancing foam stability and contaminant recovery. Further investigations in 2D tank setups will provide insights into scaling up this technology for field applications.

Significance of the study:

This research highlights the utility of PEFs as an advanced remediation technology, emphasizing the role of surfactant-polymer interactions in enhancing foam stability and efficiency. The findings pave the way for sustainable and scalable solutions for LNAPL-contaminated sites, addressing critical challenges in soil and groundwater remediation.

Abstract ID: 493
Plant-based Methods to Address Decreased Nutrients and Increased Salinity in Soil after Applied Smouldering Remediation

Christine Switzer[1], Rossane Delapp[2], David Kosson[2], Charles Knapp[1]
¹University of Strathclyde, ²Vanderbilt University

Applied smouldering remediation can effect 99+% contaminant mass reduction in soils and other porous matrices heavily contaminated with hazardous organic liquids. After smouldering, natural attenuation sees some biological activity return to soil during subsequent weeks and months; however, restoration is inhibited because of the nutrient poor status of the soil as well as increased salinity. This work examines plant-based approaches to follow applied smouldering to holistically regenerate heavily contaminated soils.

Applied smouldering remediation destroys heavy hydrocarbon contamination using self-sustaining flameless combustion. Smouldering is induced locally and external air is supplied to support the propagation of the smouldering front through the soil destroying the contaminant in its path. As a result of contamination and applied smouldering, soil loses some of the essential nutrients for supporting biological activity. Changes to soil texture and geochemistry alter how the soil interacts with water and its ability to store nutrients. Potentially toxic elements present as part of the contaminant load are often oxidised and made less mobile by applied smouldering; however, salinity elements such as potassium, sodium, magnesium, and calcium may become more available. Saline leachate impacts microbial colonisation and plant growth. Restoring biological function after smouldering is important as part of sustainable regeneration of the area impacted by contamination and may also be needed to support bioremediation or phytoremediation as a polishing step during that regeneration.

Soil washing presents a rapid and efficient way to address soil salinity but effectively results in the release of a bolus of saline elements into the surroundings or the generation of saline wastewater that may require further treatment. Our earlier plant growth studies in remediated soils may have taken this approach inadvertently. Regeneration was observed to improve with repeated growth cycles and, particularly, after transplant of microbes from healthy soils. Differences in plant heights reduced or disappeared; however, differences in plant biomasses were still observed, illustrating the need for further intervention.

The halophyte samphire was used to investigate the potential of a plant-based method to overcome salinity and residual contamination. Soil systems included microcosms that had been contaminated with coal tar or a mix of potentially toxic elements and coal tar followed by smouldering remediation. Soil systems where some regeneration has been observed in previous plant experiments were also compared to freshly remediated systems. Samphire seeds were germinated in compost for 4 weeks and then five robust seedlings were transplanted into each soil microcosms. Plants were grown for a subsequent 5 weeks, culled to 1 plant per pot if growth was observed, and harvested before they reached maturity. Carbon, nitrogen, and phosphorus nutrient solutions prepared according to the Redfield ratio for plants were supplied thrice weekly. At the end of the growth period, plant tissues were analysed for potentially toxic element and salinity content before a second round of samphire seedlings were introduced to continue the study.

Samphire thrives in saline and brackish environments. Growth was observed, although not in all systems, likely affected by the presence of residual potentially toxic elements in bioavailable forms in the systems where they were added. Unlike previous plant studies, fewer differences in growth were observed between samphire grown in freshly remediated soils compared to those that had been used to grow non-halophyte plants previously. This work shows that plant-based methods can contribute to sustainable enhanced natural attenuation and holistic regeneration of heavily contaminated soils with applied smouldering remediation.

Abstract ID: 495

Quantifying the Carbon Footprint of Applied Smouldering for Contaminant Remediation, Biosolids, and Municipal Solid Waste Treatment

Christine Switzer[1], Tarek Rashwan[2]
[1]University of Strathclyde, [2]Open Univeristy

Applied smouldering is capable of removing 99+% of heavy hydrocarbon contamination from soils and other porous materials over relatively short timescales. Analogously, applied smouldering for biosolids and municipal waste treatment achieves equivalent mass reduction and treatment effectiveness. The operating conditions support effective treatment of complex hazardous materials including polyfluorinated alkyl substances (PFAS) and polychlorinated dibenzodioxins and furans (PCDD/Fs), among others. Alongside treatment effectiveness, quantifying the carbon footprint is important for establishing the sustainability credentials of applied smouldering across all of these applications.

Applied smouldering induces flameless combustion locally within a porous matrix. For organic contaminant remediation, the contaminant is the fuel within an inert porous soil matrix. In biosolids and municipal solid waste treatment, the matrix is primarily fuel with a relatively small inert mineral constituent. Because of high water content associated with biosolids and municipal solid waste, these materials are often bulked with sand ahead of smouldering to avoid time- and energy-consuming dewatering processes; however, waste heat capture during smouldering can be harnessed for this step. Once the reaction is initiated locally, external air is supplied to support smouldering propagation through the porous matrix to destroy the contaminant or waste in its path. The result is 99+% mass destruction in contaminant remediation systems and around 70-90% mass destruction in biosolids and municipal solid waste systems, tied mainly to the amount of organic carbon present.

For the carbon assessment, remediation was parameterised around ex situ batch treatment of crude oil-impacted inorganic soil. Biosolids and municipal solid waste treatments wwere parameterised around semi-continuous. A spreadsheet tool was developed to capture the major contributions to operational and embodied carbon for each process. Operational carbon calculations included process emissions resulting from applied smouldering and electricity supplied to the reactor and supporting machinery. Two approaches to the emissions calculations were taken to compare independent measurements. Process emissions data from real time Fourier Transform Infrared Spectroscopy (FTIR) measurements during pilot scale tests were utilised as direct measurements. Organic carbon contents of initial contaminant or waste load were utilised as indirect measurements, with process emissions ratios used to determine the relative distribution of that carbon between carbon dioxide, carbon monoxide, volatile organic compounds, and other substances.

Two important contributions to carbon calculations were omitted. The operational carbon associated with mobilisation and demobilisation to the site, or equivalent haulage, were not included because these are site-specific considerations. Similarly, the embodied carbon associated with the fabrication of the reactor, which would be amortised over the working life of the reactor, and the fabrication other units involved in reactor operation. In the case of remediation, these units are usually hired locally and have service lives that extend beyond a particular project. In the case of biosolids or waste treatment, these units will remain with the system for its service life should be considered part of the reactor system. The spreadsheet tool is easily adapted to include all of these components.

Carbon assessment shows that in all three systems, the vast majority of the greenhouse gas emissions resulting from applied smouldering, ca. 90%, come from process emissions, chiefly carbon dioxide but also from small amounts of carbon monoxide and volatile organic compounds. Energy mix from renewable and non-renewable sources varies by country. While these differences impact the resulting carbon footprint calculations, they are significantly smaller than the contribution of process emissions. These results also highly the relative sustainability of applied smouldering for remediation and waste treatment in comparison to all other treatments that oxidise contaminant or waste. Applied smouldering achieves this outcome quickly and efficiently.

Abstract ID: 497

International Comparison of Important Indicators for Citizens in the Final Disposal of Soil Containing Radioactive Materials from the Fukushima Daiichi Nuclear Power Plant Accident

Masaki Takeda[1], Tetsuo Yasutaka[1], Momo Takada[1], Michio Murakami[2], Susumu Ohnuma[3], Yasuyuki Shibata[3], Thierry Schneider[4], Kosuke Shirai[1]

[1]National Institute of Advanced Industrial Science and Technology (AIST), [2]Osaka University, CiDER, [3]Hokkaido University, [4]CEPN

Introduction

In Japan, the large-scale environmental contamination caused by the Fukushima Daiichi nuclear accident in 2011 necessitated an extensive decontamination process. Consequently, approximately 13 million m³ of soil and waste containing radioactive cesium (hereafter referred to as "radioactive cesium-contaminated soil") was generated. According to current legislation, the final disposal of this contaminated soil must be completed outside Fukushima Prefecture by 2045. However, limited progress has been made in identifying and securing a disposal site. Previous studies by our research team have examined the social acceptability of out-of-prefecture final disposal in Japan through online surveys and interviews. These investigations have highlighted the critical role of procedural justice, distributive justice, and trust in governmental institutions (Takada et al., 2022, 2024; Shirai et al., 2023).

Radioactive soil and waste disposal is not a challenge unique to Japan but is a pressing issue in many countries operating nuclear power plants. Understanding the international dynamics of social acceptability in this context is essential. To address this need, the present study conducted an international comparison of stakeholder perceptions in three countries—Japan, France, and Finland—using an online questionnaire. The aim was to identify key factors influencing public acceptance of the final disposal of low-level radioactive soil and waste and to explore cross-national differences in these factors.

Methods

This study was approved by the Ethical Review of Research on Human Subjects at the Centre for Experimental Social Science Research, Hokkaido University (approval number FY5-18). The research utilized an online questionnaire conducted in Japan, France, and Finland in February 2024. The survey targeted a total of 3,000 respondents (1,000 from each country) and employed textual analysis to evaluate participants' attitudes toward the final disposal of radioactive soil and waste generated during the recovery process following a hypothetical nuclear disaster.

The survey began with an explanation of the hypothetical disaster, the occurrence of radioactive cesium-contaminated soil during environmental recovery, and the necessity of its final disposal. Participants were then asked to express their stance—support or opposition—on the final disposal of contaminated soil near their place of residence using a four-point Likert scale. Respondents also provided open-ended textual responses explaining their reasoning. These responses were collected in the respective languages of the three countries, translated into Japanese, and analyzed using KH Coder software. Correspondence analysis was performed with country and support/opposition as external variables to assess cross-national differences in attitudes and rationales. The study also evaluated the results against indicators of Sustainable Remediation to contextualize findings within broader sustainability frameworks.

Results

The analysis of responses yielded 16 key indicators influencing public acceptance of final disposal:

1. Safety, health, and environmental impacts
2. Unease or personal aversion
3. Economic benefits to recipient regions

4. Adverse economic effects, including indirect impacts due to rumors
5. Protected values
6. Opposition to nuclear energy
7. Use of interim storage or in-prefecture disposal
8. Disposal in regions benefiting directly from nuclear power (e.g., hosting facilities)
9. Disposal in regions benefiting indirectly from nuclear power (e.g., electricity supply areas)
10. Disposal in depopulated or uninhabited areas (including remote islands and space)
11. Perception of inevitability
12. Burden-sharing perspectives (including distributive justice)
13. Responsibility to future generations
14. Procedural justice (e.g., information transparency)
15. Trust in governmental authorities (including political figures)
16. Alignment with Sustainable Remediation principles

The findings indicated significant variations across the three countries regarding acceptance and opposition to final disposal, as well as the underlying reasons. These differences were evaluated in light of each nation's unique socio-political and nuclear energy contexts. Additionally, the 16 identified indicators were compared to international standards for Sustainable Remediation to derive actionable insights for policy development.

Abstract ID: 502

Electrochemical reduction of PFAS in situ – presentation of laboratory and field test results and most likely identified mechanisms of contaminant reduction.

Petr Kvapil[1], Namuun Gambat[1], Emily Brown[1], Ian Phillipps[1], Jaroslav Nosek[2], Alena Pavelkova[2], Jaroslav Semerad[3], Tomas Cajthaml[3], Jan Filip[4]

[1]Photon Water, [2]Technical University Liberec, [3]MBU AVČR, [4]Universita Palackeho Olomouc

Nanoremediation relies on the use of zero-valent iron nanoparticles (nZVI) in reducing water contaminants. An additional electric field enhances the transport of nanoparticles in an aquifer environment and improves the remediation performance of nZVI. The applied electric field both reduces the adhesion force between nZVI particles and the surfaces of sedimentary rocks and enhances their reactivity and longevity in contaminated groundwater environments. The combination of iron reduction and DC current substantially reduces PFAS concentrations in the aquifer. Laboratory and large-scale demonstrations at contaminated site have confirmed the performance of Electro-nanoremediation technology for PFAS contaminated groundwater.

A series of a total of 15 reactor laboratory tests were conducted to confirm the effectiveness of the proposed concept on both spiked and real PFAS-contaminated waters. The kinetics of contamination loss in water was analyzed along with the measurement of physicochemical parameters. Results of contaminant loss from groundwater reaching levels greater than 90% in 20 days under laboratory conditions. At the end of the reactor tests, a complete analysis of all phases, including electrodes and reactor materials was performed, including monitoring of organically and inorganically bound fluorine on the solid phase. Results shows very strong bonding of residual PFAS molecules on iron oxides/hydroxides. The stability of organically and inorganically bound fluorine was tested and confirmed by standardized leach tests.

The Trial Location was in Australia at Airport site contaminated by AFFF. Our objective was to confirm the applicability of in-situ electrochemical nanoremediation to reduce the PFAS concentration in groundwater and prevent subsequent migration of PFAS contaminants to the surrounding area. The presentation delineates a successful application of one such emerging in-situ solution within a contaminated aquifer hotspot. The global first field application of electrochemical nanoremediation of PFAS was delivered with the objective to empirically demonstrate the technology's efficiency in achieving mass reduction in concentration and flux of PFAS contaminated groundwater. The successful operation of this pilot project has provided a platform for further investigation and research in soil documented below, in addition to constitute scaled-up opportunities in groundwater remediation.

All findings (trial and reactor tests) of mass reduction was consistent with conclusions from post-trial reactor tests and experimental results.

While analysis and correlation factors can be found well by well and as a trial site, the positive correlation for all PFAS species, confirms that reduction in long chain species does not result in short chain PFAS and that precursors or intermediates are not created. Where wells performed well/influenced we saw reduction of PFAS concentrations over 90% with no further rebound observed.

The combination of iron reduction and DC current substantially reduces PFAS concentrations in the aquifer. In-situ Electrochemical Nanoremediation in this trial demonstrated the ability to reduce the mass and flux of PFAS in groundwater, at a very low environmental impact compared to traditional treatment methods.

It was made a compliance with NEMP 2.0 drinking and recreational water standards. No related by-products and intermediates were detected. The immediate effect of concentration reduction of PFAS delivered a sustainable value to the environment and a local community The underlying mechanisms leading to the loss of PFAS from groundwater were identified. Most likely, in an electrochemical environment, all of these mechanisms operate simultaneously to varying degrees depending on the actual physicochemical conditions.

Abstract ID: 506
Reactive transport models are core stone tools to optimize phytostabilisation management of mining residues

Nicolas Devau[1], Hugues Thouin[1], Samuel Mertz[2], Ulysse Moreau[3], Lydie Le Forestier[3], Vincent Milesi[3], Christophe Tournassat[3], Olivier Pible[4], Marina Le Guedard[5], Fabienne Battaglia-Brunet[1]
[1]French Geological Survey (BRGM), [2]ANTEA, [3]Institut des Sciences de la Terre d'Orléans, [4] Laboratoire Innovations technologiques pour la Détection et le Diagnostic (Li2D-DRF-CEA), [5]LEB - ADERA

Securing mining residues represents a major environmental challenge. Most metal mines produced waste containing iron (Fe) and sulfur (S), with other trace element such as arsenic (As) or lead (Pb). Phytostabilisation often appears to be one of the most appropriate options to minimise aqueous and particulate transport of contaminants, including As, by leaching and erosion at moderate cost, with a long-term and ecologically-friendly perspective. However, medium and long-term impacts of phytostabilisation on biogeocycles in the mine wastes and associated pollutant fluxes, still need to be quantified. Moreover, the impact of surface amendment with minerals and organic substances together with plant growth modify completely the physical, chemical and biological conditions at the surface of the tailings, but the nature and the magnitude of such modifications are still unclear. In consequence, there is a real need to develop a robust understanding and predictive tools allowing to forecast the consequence of phytostabilisation on pollutants migration from mine wastes to the surrounding environmental compartments, notably groundwater. Among the already existing predictive tools, reactive transport models (RTMs) seems very efficient. They quantitatively describe and predict the distribution of chemicals in different phases (solid, aqueous, gaseous) according to time and space, and to provide a rigorous way to test the understanding of observed results, the processes that cause those observations and the factor that control them. Nevertheless, the use of RTMs is still debated as some issues still raising. One of them is related to model parametrisation as input data are mainly acquired in laboratory-scale experiments that are far from complex environmental system, leading to optimise these parameter to fit geochemical observations obtained on site. Another is related to the capability of RTMs to account for microbially-mediated reactions, which are key processes controlling fate and transport of pollutants and biogeochemical cycles in a phytostabilised mining waste. Indeed, these processes are frequently simulated in RTMs without explicit representation of the microorganisms that carry them out. Examples will be provided to illustrate that these two pitfalls can be overcame. The first example addresses model parametrisation issue by demonstrating a framework to robustly parametrise RTMs to simulate water flow and mass fluxes at large-scale. The RTM developed is able to accurately reproduce Pb fluxes from a highly contaminated tailings before and after phytostablisation that have been measured during a long-term, pilot-scale experiment (one cubic meter instrumented column for 12 months). The main processes involved, i.e. dissolution of Pb-bearing phases partially limited by precipitation of secondary phases before phytostabilisation then decrease of Pb mobility due to the increase of pH induced by adding amendments at the beginning of the phytostabilisation stage, are also robustly captured by the model. The RTM has been then used to forecast potential risk on long-term groundwater contamination according to different scenarios of phytostabilisation. The second example illustrates a paradigm shift to tackle the second issue by developing a new framework to develop a stoichiometric metabolic reaction network model in a RTM to simulate the complex redox sequence suspected to occur in the tailings, notably after phytostabilisation. In addition, an illustration on the use of microbial data to parametrize the network model was also provided. These examples demonstrate that RTMs are suitable tools that can be used by operational managers and stakeholders as core stone to design secured remediation strategies for actual non-remedied tailings.

Abstract ID: 508
Soil quality and no net land take: methodological developments on Rennes metropolis (France)

Cécile LE GUERN[1], Benjamin DESLANDES[1], Bastien BOIVIN[1], Flora LUCASSOU[1]
[1]BRGM

Soil is a limited resource under pressure due to anthropic activities and climate change. Therefore, it is important to take it into account in territorial spatial planning, to preserve best soils and restore some degraded ones. Rennes Metropolis considers that No net land take objective cannot be dissociated from land degradation neutrality. In this frame, it has the ambition to take soils into account in a quantitative but also in a qualitative way, by developing a spatial tool able to assess the performances of planning scenarios. The objective here is to present the qualitative approach of soils that was developed within the QuaSoZan project to feed the tool under construction. The approach considers that soil ecological multifunctionality is a way to represent soil quality, which may be degraded by artificialisation, and especially sealing, as well as by contamination.

To map soil multifunctionality, the French MUSE method was adapted, to fill the lack of knowledge on urban areas and gain precision. Four indicators of ecological functions were assessed: carbon storage (C), biodiversity storage (B), infiltration capacity (I) and agronomic value (A) of soils. A downscaled version of the regional soil map (50 m large cells) and associated intrinsic soil characteristics (eg. texture, pH, coarse elements) extracted from the regional soil database were used to assess the agronomic value of soils. Extrapolation to the urban area considered a slight alteration of soil agronomic value on vegetated zones. An existing layer of the soil infiltration capacity was used. A poor agronomic value and infiltration capacity are considered in sealed areas. The carbon and biodiversity storage use a relationship between land use and regional and national statistics respectively. The assessed soil multifunctionality is derived from the combination of the 4 soil ecological functions indicators, by summing the score obtained for each function (1 to 5: very bad to very good), giving rise to a score ranging from 4 (very poor) to 20 (very good).

About 15 % of the Rennes Metropolis territory shows low soil multifunctionality (4-7 score), which is linked mainly to sealed surfaces. About 32 % shows medium multifunctionality (11-13 score), 50 % high multifunctionality (14-16 score) and only 3 % with very high multifunctionality (17 or 18 score). A total of 39 combinations of CBIA soil functions are obtained. To make the multifunctionality map more understandable, 15 clusters of combinations are made. 6 of them are more frequent: the types with low carbon, high biodiversity, high agronomic values, and medium to high infiltration capacity represent 29 % and 19 % respectively. It is mainly linked to soil used for agriculture (crops).

The produced soil multifunctionality and typology maps offer a state of knowledge on soils that is useful for territorial spatial planning. It is a way to represent soil quality and to raise awareness on soils. It can help to identify the soils that need to be preserved, and those that could be artificialized. Soil contamination maps are going to serve as an additional indicator of soil degradation. Soil sampling on main soil typologies is also planned to check the accuracy of the spatial model. Tests by Rennes Metropolis are also in progress to cross the typology of soils with surface information (including vegetation type and ecological protection zones) to produce stake maps, where further soil studies are necessary.

Replicability efforts were made so that the developed method can be applied in other French territories. The replicability at international scale will depend on the data available. Adaptations are probably going to be necessary.

Abstract ID: 510
Current needs, opportunities and bottlenecks in methodological support of life cycle modelling

Lenka Wimmerova[1]
[1]Czech University of Life Sciences, Faculty of Environmental Sciences

Purpose of study: The objective of the presentation is to give an overview on the latest development in the methodological support in the field of the LCSA framework.

Methodology: The presentation will focus mainly on the methodological documents related to the LCSA framework modelling prepared or being developed by the following organisations: ISO (International Organization for Standardisation), CEN (European Committee for Standardization), EFRAG (European Financial Reporting Advisory Group), WRI (World Resources Institute), WBCSD (World Business Council for Sustainable Development) and WFN (Water Footprint Network).

Presentation focus:

The methodological support of the live cycle modelling is very important regarding the current demand placed on it broaden applications, partially resulting from the recent changes in legacy obligations (e.g., eco-modulation principle, non-financial sustainability reporting or various protection strategies in water, soil and biodiversity field). Due to the fact of the existing fragmentation of the LCSA methodologies, especially in the case of footprints, and environmental reporting, and the lack of knowledge on the social part of the sustainable modelling is even more needed. The challenge is also given by the need of the upcoming ESG (environment-social-governance) reporting according to the CSRD directive (Corporate Sustainability Reporting Directive) and existence of the recently developed ESRS standards (sustainability reporting standards) as well as the requests given by the EU Taxonomy. While carbon and GHGs (greenhouse gasses) emissions' modelling has already some history and broader general knowledge, good examples of water, land use, and even soil or biodiversity applications in the LCSA modelling is lacking and to precisely model these are still challenging. The major obstacle in the LCSA field as well as the big attention must be given now as well as in the future to a methodological support related to data validity, especially data collected by the remote sensing (e.g., GIS or LIDAR), metadata management, uncertainty and sensitivity analyses, as well as the application of the methodological support of the less developed countries. Moreover, the current situation raises the question of whether LCA and LCSA experts should be subject to authorization, as e.g. in the case of EIA experts.

Summary of findings/results:

Since 2020 many new methodologies and standards related to carbon neutrality, water assessment, as well as addressing various environmental aspects within a specific area (i.e., resources, and waste, biodiversity) have been developed or are still being developed. However, there is still a lack of knowledge about these documents and some of them are still misused.

Conclusion/take home message:

The LCSA approaches cannot be applied as such, ad hoc, without deeper knowledge on the modelling approach but also on the modelled field. That is why the LCSA studies must connect experts from different fields, as the data and knowledge validation from the modelled field is essential for accuracy of the LCSA model itself.

Significance / contributions of study:

The significance of this presentation lies in showing the links of the methodological approach connecting individual areas of LCSA with the aim of expanding the knowledge potential of currently available and especially new methodologies, and also minimizing greenwashing in this field.

Keywords: standard, environmental, social, techno-economic, LCSA, validation, reporting, sustainability

Abstract ID: 518

Thermal treatment of PFAS in soil: Three field demonstrations show what is possible, including reaching non-detect concentrations and minimizing energy usage

Gorm Heron[1], Emily Crownover[1], Robert Glass[1]

[1]TRS Group

TRS Group (TRS) has completed three field demonstrations to show what is possible for treating per- and polyfluoroalkyl substances (PFAS) using thermal conduction heating (TCH). TCH involves installing narrow diameter steel pipes into the treatment volume and heating the pipes to many hundreds of degrees Celsius (^{o} C). The heat front propagates radially from the pipes, heating the surrounding soil, volatilizing the PFAS. We then treat the captured vapors. The projects include:

Treatment of an existing soil pile In situ treatment of topsoil in a fire-training area Treatment in an engineered soil pile, minimizing energy use

TRS has demonstrated the effectiveness of the thermal desorption of PFAS at temperatures between 350 and 700° C. While heat losses can be significant when treating in situ, TRS can minimize the losses by placing the soil in an engineered, insulated pile (see figure attached).

Treating PFAS-impacted soil at Joint Base Elmendorf-Richardsson in Anchorage, Alaska, TRS applied TCH to heat 1,700 cubic meters (m3) of soil in three months to an average maximum temperature of 638° C. We then collected 30 soil samples to document performance. All the samples had PFAS concentrations below USEPA and Alaska soil criteria; the combined sample was non-detect for all targeted PFAS, analyzed by EPA Method 1633.

TRS input 710.000 kilowatt-hours (kWh) of energy into the soil stockpile, which equates to 418 kWh/m3. This energy usage is low compared to other thermal solutions. Further, an analysis completed by the US Navy found that the TRS treatment method was more sustainable than alternatives such as excavation, off-site disposal, or incineration.

TRS treated the generated vapors via cooling, condensation and filtration. The approach consumed far less energy than thermal oxidation. TRS satisfied all local requirements for air and water discharges.

Note that TRS's thermal treatment method is suitable for all soil fractions, including the fines such as clay and silt, construction debris, asphalt and concrete. The final waste quantity is small - largely just the spent activated carbon, which can be regenerated or destroyed at a controlled facility. Importantly, TRS can reuse or recycle almost all the treatment components.

TRS Group is transferring our capabilities and know-how to our European partners.

Abstract ID: 524
ISTD Remediation pilot testing for technology validation. How to deal with surprises and improve full-scale design

Matteo Donati[1], Gorm Heron[2], Christian Gambelli[3], Alessandro Corcagnani[1], Robert Glass[2]
¹Ecologia Environmental Solutions srl, ²TRS Group Inc., ³Greenthesis spa

Purpose of study. A mixed waste landfill near Rome (Italy) owned by Tre Monti srl is scheduled for a large remediation scheme which includes also the use of thermal technologies. The soil underneath the waste layers contains volatile and semi-volatile compounds such as TCE, PCE, hexachloroethane and hexachlorobenzene. Before initiating full-scale design, a pilot test of Thermal Conduction Heating (TCH) was conducted on approximately 10% of the full-scale area. The pilot area was isolated by the installation of a 14 meter deep sheet pile cell. The test objective was to heat the soil below the buried landfill material to near 100oC, capture and treat the generated vapors, and to sample soil before and after to verify achievable reductions in VOC and SVOC concentrations down to remedial targets. Lessons learned during the pilot test were to be used to improve the full-scale design.

Approach/Activities. Sheet piles were installed to form a square pilot test area of 15 by 15 m. The target treatment interval was the soil underneath the buried waste from 9 to 13 m below grade. Thirty-nine heater borings with heaters from 7.5 to 14.5 m depth were installed. Seven extraction wells and four temperature monitoring borings were placed between the heaters. A TCH power delivery system capable of delivering 250 kW of power to the heaters was used. Vapors and liquids were conveyed to an on-site treatment system with cooling, condensation, phase separation and treatment of vapors and liquids using granular activated carbon.

Results/Lessons Learned. The presentation will focus on several unexpected observations, including: After installation of the sheet-pile cell, heaters and extraction wells, the water level was found 3-4 m below grade. The site conceptual model and the TCH pilot design was based on a water level deeper at 10m. With shallow groundwater, vapor extraction screens were submerged. Groundwater was pumped from seven wells to create drawdown and to make it possible to apply a vacuum to the formation. Heating was slower than expected. The ability to inject energy using TCH was limited by the upward flow of steam around the heaters. Where unsaturated soil was expected, groundwater was present and made the steam more buoyant. Water kept coming into the pilot zone from below and/or from the sides. A water balance showed that more than one pore volume of water was removed, yet the water level never dropped to the desired depth near the bottom of the treatment interval. Due to the steam migration issues and incoming water, target temperatures could not be reached in the whole test volume (especially at depth).

Conclusion/take home message. Despite these challenges, soil concentrations after the heating period showed substantial reductions from starting levels. TCE was reduced by over 99% to concentrations below 0.5 mg/kg, PCE was reduced by 98.5%, hexachloroethane was completely removed, and hexachlorobenzene concentrations were reduced by 31%. The full-scale design and the spacing between heaters will be derived and enhanced by these observations. The presence and migration of water will need to be considered. Also, water usage during installation of the thermal system will be minimized and monitored. A detailed characterization effort is being undertaken to ensure that the full-scale design is based on realistic data on geology, water levels and contaminants present.

Abstract ID: 535

Simultaneous removal of mixed PFASs and Cd from aqueous solutions by montmorillonite-supported nZVI?Behaviors and mechanisms

Xin Song[1], Qing Wang[1], Liangchun Jia[2], Yi Zhou[3]

[1]State Key Laboratory of Soil and Sustainable Agriculture, Institute of Soil Science, Chinese Academy of Sciences, Nanjing 211135, China, [2]College of Science, Nanjing Agricultural University, Nanjing, 210095, China, [3]College of Materials and Advanced Manu

The per- and polyfluoroalkyl substances (PFASs), along with their co-contaminants (e.g., cadmium (Cd(II)), have been recognized as a major environmental concern in this study. In the current study, two montmorillonite-supported nano-zero-valent iron (MMT/nZVI) were prepared for the removal of mixed PFOS and PFOA, and Cd(II) and chlorinated polyfluoroalkyl ether sulfonates (F-53B, a model compound of PFASs). The surface characterization of the MMT/nZVI, including increased hydrophobic angle, altered basal spacing and increased elemental sulfur content, demonstrated the successful preparation of the two nanomaterials. The removal isotherms and kinetics were evaluated under mixed and individual contamination conditions. The results revealed that the removal process of PFOS and PFOA by MMT/nZVI followed pseudo-second-order and pseudo-first-order kinetic models, respectively, and 99.0% of PFOS and 91.4% of PFOA were removed within 15 min. The removal efficiency of Cd(II) and F-53B co-contamination were 95.0% and 75.0%, respectively, at the dosage of 1.0 g/L MMT/nZVI. MMT/nZVI exhibited excellent removal performance for Cd(II) and was capable of simultaneously removing multiple PFAS compounds at environmentally relevant levels. The evaluation of MMT/nZVI performance demonstrated that it was more challenging to remove shorter carbon-chain PFASs compounds than those with longer carbon-chain from aqueous solutions. It was determined through multiple lines of evidence that the mixed contaminants adsorb to the interlayer and surface of MMT/S-nZVI through electrostatic attraction, ion exchange, and hydrophobic interactions, followed by precipitation and complexation reactions. These findings have important environmental implications for the remediation of heavy metals and PFASs co-contamination.

Abstract ID: 537
Exploring the limits of saturated zone in situ thermal remediation
Søren Eriksen[1]
[1]Krüger Veolia

Background
A widespread perception of in situ thermal remediation (ISTR) is that the boiling point of the contaminants must be reached in order to evaporate the contaminants.
Experience from ISTR of a range of contaminants with boiling points over that of water from the saturated zone demonstrate that this is not the case.
But what is the limit?
 Methodology
There is more to volatility data than the normal boiling point of a pure substance. By applying azeotropic and co-boiling points as well as Henry's law constants, the evaporation of some contaminants from a saturated soil at the boiling point of water is simulated. The results are compared with data from full scale ISTR projects as well as lab scale treatability testing.
 Findings/results
The boiling point of the contaminant is only part of the answer to whether the contaminant can be remediated from the saturated zone at the boiling point of water. In the presence of free phase co boiling may be lowering the boiling point, thus allowing remediation of free phase below the boiling point of water. However helpful co boiling is, the target treatment temperature in many cases must be the boiling point of water because of remediation targets being more stringent than the mere removal of free phase. When remediating contaminants in solution, Henry's law data giving contaminant vapor pressure in equilibrium with the aqueous solution, is a much better indicator for the possible extraction rate than the vapor pressure of the pure compound.

At a former chemical landfill site, chlorobenzenes with boiling point up to 175 $^{\circ}$C have been remediated to below 1 mg/kg (>99% removal rate) in the saturated zone by ISTR. Results for bisphenol-A (Bp. 220°C) and chloromethyl aniline (Bp. 239 $^{\circ}$C) are 50% and 75% removal rate respectively. Lab scale treatability studies on soils from PAH and TPH contaminated sites show comparable results for these compounds depending on molar weight.

Lab scale studies have shown well below 1 mg/kg results, for hexachloro ethane, hexachloro butadiene and even significant removal hexacloro benzene (67%)
 Conclusion
The lesson learned is that contaminants with boiling points in the 125-250 $^{\circ}$C range can, in many cases, be remediated from the saturated zone by ISTR in spite of the gap between contaminant boiling point and temperature achieved. In order to get a better understanding of the possibilities for thermal remediation and a realistic remediation target, the vapor pressure should be accessed using Henry's law constants available at relevant temperatures.
It should be kept in mind that ISTR in saturated soil is dependent on the steam generated by boiling groundwater to establish extraction pathways. Therefore significant evaporation is impossible below the boiling point of water.
 Significance
When designing ISTR realistic efficiencies of contaminant removal are extremely important.
The feasibility as well as the project economy is at stake. The question of how much steam generation is required to reach the remedial target directly affects the overall energy consumption.

Abstract ID: 539

Integrating Soil Health in Decision-Making: Insights from the SOILveR Webinar Series

Margot DE CLEEN[1], Ana ALZOLA[2], Esther GOIDTS[3], Cécile GRAND[4], Marta POPOVA[5]

[1]Ministry of Infrastructure and Water Management, Rijkswaterstaat, the Netherlands, [2]Public environmental management company (IHOBE), Basque country, [3]Public Service of Wallonia (SPW), Agriculture Natural resources & Environment, Belgium, [4]French Agency f

Soil health is a critical component of sustainable land management, yet it remains underrepresented in decision-making processes at various levels (regulatory, land planning, research, civil society, etc.). The European knowledge platform SOILveR is organising a webinar series to address this gap by examining the integration of soil health into decision-making processes, focusing on soil health assessment, sustainable soil management, and the challenges and opportunities associated with the European Soil Monitoring Law proposal. The series aim to explore key questions related to soil health data availability, measurement techniques, the spatial and temporal scales of analysis and decision-making, and the integration of soil health indicators into land-use policies. After having set the scene around the soil health concept in the countries and regions of SOILveR members, four topics were chosen to be deepened, based on these key questions in dedicated webinars: #1 Soil management and land planning, #2 Recycling brownfields, #3 Contaminated site management and #4 The concept of Technosol. Webinars for the last two topics are to come after summer 2025.

In the context of the proposed Soil Monitoring Law, which aims to establish a comprehensive framework for monitoring and assessing soil health across Europe, the first two webinars have tackled the implementation and regulatory challenges of soil health management linked to land planning and recycling of brownfields. Topics such as the availability of soil health data, the methodologies to assess soil health, and the tools available to land managers have been discussed. In particular, the webinars have focused on the need for a harmonized and scalable approach to soil health monitoring, which aligns with the goals of the Soil Monitoring Law.

Through the webinar series, SOILveR aims to bring together experts and stakeholders to discuss the integration of soil health into three key contexts: land planning and urban soil management, the management of brownfield sites, and the restoration of contaminated and degraded lands. In line with the European Soil Monitoring Law's objectives, participants have explored how to assess soil health at different scales (from urban areas to brownfield sites), how to integrate soil health considerations into land-use planning, and how to foster collaboration among landowners, policymakers, and the public.

This interactive session will present the key takeaways from the initial SOILveR webinars (#1 Soil management and land planning, #2 Recycling brownfields) and provide an outlook on the upcoming ones (#3 Contaminated site management and #4 The concept of Technosol). The findings emphasize the importance of cross-disciplinary approaches to soil health assessment and management.

The session will feature a diverse panel of experts from soil management, urban planning, and policy sectors. They will discuss how the insights gained can inform decision-making processes at various scales, aligning with the proposed Soil Monitoring Law.

Significance: The integration of soil health into decision-making is a cornerstone of sustainable land management and essential for addressing key societal challenges such as climate change, food security, and biodiversity conservation. By exploring the key messages of the Soil Monitoring Law, this session will provide valuable insights for policymakers, practitioners, and researchers working to improve soil management across Europe. It will also highlight the role of cross-sectoral collaboration in creating effective soil health monitoring frameworks.

Public Interaction: To engage the audience, the session will include interactive activities such as roundtable discussions and brainstorming sessions. Participants will be invited to share their experiences and perspectives on the challenges and opportunities of integrating soil health into policy and practice. Flip charts and live polling will be used to gather feedback on key questions, fostering a dynamic and collaborative environment.

Maximum number of participants: 30

Abstract ID: 543

Enhanced in-situ nitrate removal with zerovalent iron nanoparticles (nZVI) and acetate: from lab to field tests

Oriol Gibert[1], José Luis Cortina[1], Damián Sánchez[2]
[1]Universitat Politècnica de Catalunya (UPC), [2]Cetaqua Andalucía

In-situ removal of nitrate (NO_3^-) from groundwater through combined biological Heterotrophic Denitrification (HDN) and Abiotic Chemical Reduction (ACNR) by pulse injection of an organic compound (CH_2O) and zerovalent iron nanoparticles (nZVI) has attracted growing interest in the field of groundwater remediation. Both processes have proved to be partially successful in removing NO_3^- through its conversion into innocuous $N_2(g)$, but also that they are not exempt from hindrances. For instance, HDN can generate intermediates with additional environmental concerns (e.g. NO_2^-), produce excessive biomass, be a slow process and limited in a temperature range, and be limited by the competing process Dissimilatory Nitrate Reduction to Ammonia, whereby NO_3^- is converted to NH_4^+ instead of $N_2(g)$. On the other hand, nZVI can suffer from agglomeration and therefore reduced reactivity, and can reduce NO_3^- to NH_4^+. Later studies have reported that combination of HDN and ACNR can overcome part of these hindrances while ensuring satisfactory NO_3^- removals.

Given the scarce research on nZVI pulsed injection in continuous-flow systems (with or without supplementation of an organic substrate), this study was performed with the objective of evaluating the effect of biostimulation (with acetate) and pulse injection of nZVI on the removal of NO_3^- from groundwater. The study comprised three phases, in which NO_3^- removal was assessed in i) bench-scale batch experiments, ii) bench-scale column experiments, and iii) field-scale pilot investigation. The field study was performed on an aquifer located in Murcia (SE Spain) with a NO_3^- concentration of approx. 30 mg/L. The aquifer comprises three distinguishable layers isolated from each other by clay and sand with some gravel, and is currently exploited at a flow rate ranging between 20 and 50 m3/h through an abstraction well for irrigation of urban gardens. Two transects of wells were installed in the upper and intermediate layers for the study, each comprising, besides the abstraction well, an injection well (through which acetate and nZVI were introduced into the aquifer) and observation wells located up- and down-gradient the injection well. The delivery of acetate and nZVI was done under different feeding strategies regarding the type, the frequency and the dose of the reagent(s) applied.

Batch and column experiments showed that the application of nZVI and acetate in tandem yielded not only an enhanced NO_3^- removal (up to >95%, depending on the conditions of the experiments) but also to a better final N-products distribution, with $N_2(g)$ formation higher than that achieved when only acetate or nZVI were applied.

Field investigation demonstrated that the injection of acetate and nZVI could successfully promote HDN and ACNR with the subsequent decrease in NO_3^- concentrations. Moreover, the analysis of NO_2^- and NH_4^+ permitted to verify that there was a net removal of N from groundwater (i.e. that NO_3^- was converted to $N_2(g)$). The occurrence of HDN was confirmed with isotopic analysis. However, field results also made evident that hindrances might occur. First, the effect of the reagents injected on the NO_3^- removal was limited to the vicinity of the injection well, and this effect could get imperceptible if treated groundwater was mixed with non-mixed groundwater. Second, the application of too large amounts of acetate could result in severe clogging problems of the injection well. Third, complex hydraulics of the aquifer complicated by oscillating abstraction flow rates in the pumping well can make it difficult to predict NO_3^- removal percentages in treated groundwater.

From a broader perspective, and given the scarce data within this field, results contribute to a better understanding of feeding strategies of acetate and nZVI for their application in in-situ remediation of groundwater.

Acknowledgments

Abstract ID: 546

Isolation of an NMP (N-methyl-2-pyrrolidone) degradating bacteria and its usage in a fluidized-bed bioreactor

Balázs Fehér[1], Ingrid Zsilinszky[1], Laura Ábrahám[1], Péter Bernula[1], Attila Komoczi[1], István Kiss[1]

[1]aDepartment of Applied Microbiology, Division for Biotechnology, Bay Zoltán Nonprofit Ltd. for Applied Research

Isolation of an NMP (N-methyl-2-pyrrolidone) degradating bacteria and its usage in a fluidized-bed bioreactor

Graphical abstract

Purpose of study

NMP (N-methyl-2-pyrrolidone) is an industrial solvent utilized in the manufacture of adhesives, paints, fuels and pharmaceuticals, and it is widely used to produce lithium-ion batteries (1). Although physical and chemical methods, such as photodegradation (2), ozone oxidation (3), and membrane separation (4) can degrade NMP, biological treatment is significantly more effective while also being a sustainable and environmentally friendly technology.

Several bacterial strains are capable of utilizing NMP as the sole carbon and nitrogen source under aerobic, anoxic, and even strictly anaerobic conditions (5, 6, 7). During lithium-ion battery production, NMP is used as a solvent alongside other compounds, including carbonates (diethyl carbonate, ethylene carbonate, dimethyl carbonate, ethyl methyl carbonate) (8). Fluidized bed reactors utilize various materials as a biological attachment medium which usually have extraordinary biomass retention owning thanks to the extensive surface area of the carrier (9, 10).

Methodology

The NMP-degrading bacterium was isolated during an enrichment procedure. Experiments were carried out to characterise the tolerances (salt, pH, temperature) of the isolated bacteria. GC-MS and HPLC were used to monitor biodegradation of NMP and daughter compounds.

A fluidized bed bioreactor is a reactor device in which the biological degradation of pollutants takes place in continuous operation. In the reactor, the NMP-contaminated wastewater or groundwater is passed through the sand-attached microorganisms.

Results

Pseudomonas veronii T610 was isolated from groundwater sample from the Central Hungary region. Strain T610 can utilize NMP as sole carbon and nitrogen source under aerobic and anoxic, nitrate reducing conditions. Moreover, the strain is capable of the biodegrading not only NMP but also its daughter products. Furthermore, T610 can also eliminate other organic solvents used in battery production, including diethyl carbonate and ethylene carbonate.

The Gram-negative strain T610 is moderately halophilic, tolerating up to 60 g/l salt concentration. Its salt tolerance allows for its use in the biological treatment of NMP-containing wastewater.

The strain's wide pH tolerance range (pH 3.5–10.0, optimal pH range pH 5.0–7.5) and the wide temperature tolerance range (6-30°C, optimal range 15-25°C) make it suitable for diverse applications.

The effective volume of the sand filled reactor tube is 4,24 L, the NMP loading rate is 10g/day. The output NMP concentration was below detection limit (1,25 mg/l), the TC and TN values measured from the purified water were close to the detection limit (30 mg/l) during the 120-day duration of the experiment.

Conclusion

The isolated bacterium is capable of efficiently degrading NMP under both aerobic and anoxic conditions. The industrially relevant tolerance ranges of strain T610 were determined. A fluidized bed bioreactor was created to degrade NMP without significant by-product accumulation.

Significance

Strain T610 not only able to degrade NMP and its daughter products but also DEC and EC which are also solvents used in battery production. Furthermore, a fluid bed bioreactor was developed to verity the feasibility and long-term applicability of recalcitrant NMP biodegradation. This reactor is a potential candidate for industrial NMP wastewater treatment, or ex situ on site groundwater remediation. Depending on the amount of wastewater to be treated, the size can be increased.

References
1: https://doi.org/10.1016/j.biortech.2019.122185
2: https://doi.org/10.1021/ie200702b
3: https://doi.org/10.1021/es981061o
4: https://doi.org/10.1016/j.chemosphere.2017.12.013
5: https://doi.org/10.1016/j.chemosphere.2017.12.013
6: https://doi.org/10.2166/wst.2015.031
7: https://doi.org/10.1016/j.biortech.2019.122185
8: https://doi.org/10.1016/J.RSER.2018.03.002
9: https://doi.org/10.2166/wst.2003.0507
10: https://doi.org/10.1061/(ASCE)0733-9372(2002)128:9(842)

Abstract ID: 548

Innovative Analysis of Rainfall-Driven Contaminant Patterns in Groundwater: A Path Toward Climate-Resilient Water Management

Lazaros Sofikitis[1], Ahmed Abdelrady[2], Romee Van Dam[3], Marta Drausnik[4], P. Demestichas[15]

[1]*WINGS ICT Solutions,* [2]*Wetsus, European centre of excellence for sustainable water,* [3]*Deltares,* [4]*Wageningen University, Department of Digital Systems, University of Piraeus,* [5]*Department of Digital Systems, University of Piraeus*

This study investigates the influence of precipitation on groundwater contamination by analyzing the correlation patterns of various chemicals in the south Netherlands region, Netherlands—a region experiencing increased drought and groundwater pollution. Through a comprehensive correlation analysis, five distinct temporal patterns were identified, each representing unique behaviors in chemical mobility and persistence in response to rainfall. Pattern 1 aligns closely with rainfall autocorrelation, showing peak correlations around 20 days, suggesting moderate mobility and consistent infiltration to groundwater. Pattern 2 demonstrates an initial peak at 10–15 days followed by rapid decline, indicating short-term presence and partial degradation in shallow groundwater. Pattern 3 reveals pronounced fluctuations in correlation, likely reflecting dynamic chemical transformations triggered by rainfall. Pattern 4, displaying inverse correlations, suggests that certain chemicals (e.g., metals) are concentrated near the surface, with rainfall leading to dilution rather than infiltration. Pattern 5 exhibits delayed, elevated correlations, attributed to slow transport and adsorption to soil particles, particularly for hydrophobic pollutants.

These findings underscore the complexity of contaminant transport and the role of precipitation as a driver of temporal variations in groundwater quality. This research highlights the necessity of incorporating rainfall-driven contaminant behaviors into groundwater management, especially in regions facing climate change-induced droughts. The insights gained here are instrumental in informing climate-resilient water management practices to mitigate pollution risks and safeguard groundwater resources in drought-prone regions.

Introduction

The Netherlands' South region, known for its fertile agricultural lands and reliance on groundwater, faces increasing challenges due to prolonged droughts (Bayer et al., 2023). These droughts exacerbate groundwater quality concerns by reducing dilution capacity and lowering groundwater levels, making aquifers more susceptible to pollution (Kaandorp et al., 2021). Chemical contaminants, including pesticides, heavy metals, and organic pollutants, pose significant threats to water quality in the region. These contaminants originate from diverse sources such as agricultural runoff, industrial processes, and atmospheric deposition. To address these pressing issues, the Dutch government prioritizes improving the climate resilience of the South Netherlands region (Kaandorp et al., 2021).

A key aspect of this effort involves understanding the intricate interplay between precipitation patterns and chemical transport in groundwater systems. Rainfall, as a primary driver of infiltration and leaching, significantly influences the mobility and persistence of contaminants in groundwater. Fluctuations in rainfall patterns, particularly under changing climate conditions, can impact the accumulation and migration of pollutants, potentially leading to contamination of vital water sources (Yu et al., 2018).

This study aims to elucidate the correlation patterns between precipitation and groundwater contaminants in the South Netherlands region. By analyzing a diverse range of chemicals, the study identifies five distinct temporal patterns that characterize the response of contaminants to rainfall events. These patterns shed light on the variability in contaminant behavior, ranging from rapid infiltration to delayed or inverse reactions. By understanding these patterns, it is possible to assess contamination risks under different rainfall scenarios and tailor monitoring and remediation strategies accordingly. The findings of this study provide valuable insights for developing climate-resilient water management strategies in the South Netherlands region. By recognizing the specific behaviors of different contaminants in response to rainfall, policymakers and water managers can make informed decisions to protect groundwater resources and ensure sustainable water supply.

Methodology

To analyze the influence of precipitation on soil chemistry and the transport of chemical contaminants into the groundwater system over time, a time-lagged correlation approach was employed. This approach considers the infiltration time (t) required for precipitation to reach various soil depths, creating lagged correlations between precipitation data at time t and chemical measurements at subsequent time points t+i. Each measurement was systematically tested for correlation with precipitation data, and only correlation coefficients with an absolute value above 0.5 ($|r| \geq 0.5$) were included for further analysis, ensuring a focus on statistically significant relationships. A maximum time window of 365 days was used for correlation analysis, with a lag interval of one day. This daily interval allows for detailed examination of lagged effects and accommodates measurements taken from deeper soil layers where the infiltration process requires extended time periods. In cases where deeper infiltration or chemical interactions necessitates a longer observation window, the time window can be extended appropriately.

Autocorrelation, defined as the correlation of a time series with its own lagged values, was also calculated for precipitation data (Varadarajan et al., 2022). The precipitation autocorrelation (Figure 1) served as a reference for interpreting the lagged correlation patterns of various chemical measurements. If the lagged correlation of a chemical with precipitation followed a trend similar to the autocorrelation pattern of precipitation itself, this was taken as an indication that the chemical concentration was significantly influenced by precipitation events.

For chemicals showing substantial correlations with precipitation, the lag correlation diagrams were assessed for alignment with precipitation autocorrelation patterns following the peak correlation value. Such alignment would suggest a time-dependent response of the chemical concentrations to precipitation inputs, implying that rainfall is a key driver of the observed chemical patterns in soil.

Results and discussion

Through correlation analysis, five distinct patterns in chemical behavior in relation to precipitation were identified (Table 1). Each family reflects unique interactions and mobility patterns within the soil and groundwater, influenced by properties such as hydrophobicity, adsorption capacity, and degradation rates. The following summarizes each pattern observed:

Pattern 1 (Regular Correlations Resembling Precipitation Autocorrelation): This group demonstrates a correlation pattern closely aligned with rainfall autocorrelation, with correlation peaks occurring around 20 days and values ranging from 0.57 to 0.7. Such consistency suggests a predictable response to rainfall, indicating that these chemicals infiltrate and leach into groundwater in a manner directly related to precipitation events. Chromium within this pattern shows a secondary peak at 50 days, likely due to soil depth variations affecting its desorption and adsorption. Zinc exhibits a distinct pattern within the group, showing more pronounced peaks and lower troughs, indicative of a variable response to precipitation. Potassium, which aids organic compound biodegradation, shows intermediary behavior and might fit into either Pattern 1 or 2. This pattern's alignment with rainfall autocorrelation implies that the chemicals exhibit moderate mobility, enabling their leaching into groundwater through heavy rainfall, with infiltration typically occurring over a 20-day lag. This timescale reflects aquifer properties and indicates the direct influence of precipitation on these compounds.

Pattern 2 (Smaller Peaks with Higher Decline): Chemicals in this group show an initial peak correlation at around 10 to 15 days, followed by a rapid decline, with correlation values around 0.65. The steep decline suggests limited persistence in groundwater, potentially due to degradation or rapid dilution following infiltration. This group's consistency highlights stability across measurements, indicating a shallow groundwater presence and limited transport to deeper aquifer layers. Moderate hydrophobicity (LogP values between 1 and 4) results in moderate adsorption to soil particles during infiltration, reducing solubility in water (Lambert et al., 2022). Although rainfall can transport these compounds to shallow groundwater, their presence quickly diminishes due to dilution, adsorption, and partial degradation.

Pattern 3 (Higher Peaks and Lower Valleys with Similar Decline): This group resembles Pattern 2 but displays more pronounced peaks and valleys in its correlation, with peaks around 10 to 15 days. The

fluctuations suggest ongoing chemical transformations or reactions, likely facilitated by periodic rainfall, which may convert these chemicals into different forms with variable groundwater concentrations. Phosphorus, for instance, can strongly bind to soil but may enter groundwater under specific conditions, such as soil saturation or changes in pH (He et al., 2025). The variability in this pattern implies that rainfall and soil adsorption influence these chemicals dynamically, potentially introducing seasonal or depth-dependent changes in concentration and transport through the soil.

Pattern 4 (Inverse Correlations): This pattern displays negative correlations with rainfall, indicating that these chemicals' concentrations decrease as precipitation increases, likely due to dilution or runoff effects. Lead shows an immediate inverse correlation, while nickel and sulfate exhibit lagged inverse peaks at 5, 25, and 49 days, respectively, with correlation values between -0.68 and -0.58. These inverse relationships suggest that the chemicals are primarily concentrated near the surface and are diluted by infiltrating water from precipitation events. Their limited movement into deeper groundwater layers supports the hypothesis that these chemicals are largely surface-bound, influenced by rainfall and runoff patterns that restrict their percolation to deeper aquifers.

Pattern 5 (Unusual Correlations): This group displays unique correlation patterns with delayed peaks occurring between 15 and 22 days, indicating complex interactions with rainfall and potentially slow transport through soil. Correlation values for this pattern range from 0.6 to 0.8, with moderate-to-high hydrophobicity suggesting strong adsorption to soil particles and limited solubility in water. The observed delay likely results from prolonged interactions with soil or organic material, necessitating multiple rainfall events to effectively transport these chemicals into groundwater. The high hydrophobicity of chemicals within this group, particularly polycyclic aromatic hydrocarbons (PAHs), leads to significant retention within soil and organic matter, resulting in delayed and limited release into groundwater (Vijayanand et al., 2023). This pattern underscores the influence of rainfall on the sporadic mobilization of these chemicals, with infrequent but detectable shifts in groundwater concentration.

Conclusion

This study examines the influence of precipitation patterns on groundwater contamination, focusing on how climate-driven changes in rainfall impact the transport dynamics of various chemical contaminants. By analyzing correlations between rainfall and contaminant behavior, five distinct temporal patterns emerged: consistent responses aligned with rainfall, rapid initial peaks with declines, fluctuating peaks and troughs, inverse correlations, and delayed responses. These patterns reflect different mechanisms of chemical mobility and retention, such as soil adsorption and biodegradation, that affect contaminant persistence. This typology offers a basis for targeted monitoring and sustainable water management strategies, helping policymakers mitigate contamination risks. The findings enhance understanding of precipitation-driven contaminant transport, supporting adaptive groundwater management amid climate variability.

References

Bayer, L., Bandru, K., Chowdhury, S., Gómez, P., Sanchez, I., Nougues, L., Jordan, S., Maring, L., Barron, J., & Keesstra, S. (2023). Synthesis of soil needs and drivers of change for different land use types across 19 regions in Europe, including soil need appraisal guidelines for other regions. PREPSOIL D2. 1. PREPSOIL.

He, P., Yang, X., Zhang, Z., Dai, S.-S., You, M., Horwath, W. R., Zhang, P., Wang, W., & Li, L.-J. (2025). Shelterbelt influence on soil microbial carbon and phosphorus limitation in farmland: Implications for soil health. Agriculture, Ecosystems & Environment, 379, 109368. https://doi.org/https://doi.org/10.1016/j.agee.2024.109368

Kaandorp, V. P., Broers, H. P., van der Velde, Y., Rozemeijer, J., & de Louw, P. G. B. (2021). Time lags of nitrate, chloride, and tritium in streams assessed by dynamic groundwater flow tracking in a lowland landscape. Hydrol. Earth Syst. Sci., 25(6), 3691–3711. https://doi.org/10.5194/hess-25-3691-2021

Lambert, F. N., Vivian, D. N., Raimondo, S., Tebes-Stevens, C. T., & Barron, M. G. (2022). Relationships Between Aquatic Toxicity, Chemical Hydrophobicity, and Mode of Action: Log Kow Revisited. Archives of Environmental Contamination and Toxicology, 83(4), 326–338. https://doi.org/10.1007/s00244-022-00944-5

Varadarajan, S., Fábrega, J., & Leung, B. (2022). Precipitation interpolation, autocorrelation, and predicting spatiotemporal variation in runoff in data sparse regions: Application to Panama. Journal of Hydrology: Regional Studies, 44, 101252. https://doi.org/https://doi.org/10.1016/j.ejrh.2022.101252

Vijayanand, M., Ramakrishnan, A., Subramanian, R., Issac, P. K., Nasr, M., Khoo, K. S., Rajagopal, R., Greff, B., Wan Azelee, N. I., Jeon, B.-H., Chang, S. W., & Ravindran, B. (2023). Polyaromatic hydrocarbons (PAHs) in the water environment: A review on toxicity, microbial biodegradation, systematic biological advancements, and environmental fate. Environmental Research, 227, 115716. https://doi.org/https://doi.org/10.1016/j.envres.2023.115716

Yu, L., Rozemeijer, J., Van Breukelen, B. M., Ouboter, M., Van Der Vlugt, C., & Broers, H. P. (2018). Groundwater impacts on surface water quality and nutrient loads in lowland polder catchments: monitoring the greater Amsterdam area. Hydrology and Earth System Sciences, 22(1), 487–508.

Abstract ID: 552
Effects of adding different biostimulants and effects of temperature on the microbiological treatment of soil contaminated with high diesel concentrations

Jimena Sainz Cerezo[1], Jorge Diamantino Miranda[1], Norbert Nägele[1], Cynthia Alcántara Pollo[1]
[1]KEPLER Ingeniería y Ecogestión, S.L.

The main objective was to assess the feasibility of various biostimulants in the microbiological treatment of soil contaminated with Agricultural Diesel (AD) at initial concentrations of 18,000 mg/Kg of petroleum hydrocarbons (C10–C40) and 1,900 mg/Kg of volatile organic hydrocarbons.

The experiment was conducted using agricultural soil samples contaminated with AD due to a motor vehicle accident. Following soil characterization, a control containing 3 kg of untreated soil was prepared to evaluate natural attenuation by the native microbiota. Eighteen trays were treated with a diesel-degrading bacterial consortium and supplemented with one of six biostimulants at different concentrations: coffee grounds (CA) (1%, 5%, and 10%), EBC biochar (BI) (1%, 5%, and 10%), vermicompost and vermicompost tea from Eisenia foetida (HU) (1%, 5%, and 10%), okara (OKA) (1%, 5%, and 10%), 30% hydrogen peroxide (OX) (1%, 4%, and 7%), and S200 biostimulant (BE) (0.75%, 2.5%, and 5%).

Given the low permeability of the soil, which hindered microbial activity, moisture was controlled, and aeration was performed in all microcosms except the control. Until day 30, the trays were kept in a thermostatic room at an average temperature of 15.0 ± 1.2 ºC. After day 30, the temperature was increased to 25.0 ± 1.5 ºC. The experiment lasted for 90 days.

To evaluate the effects of the biostimulators on the soil, samples were taken on days 0, 7, 15, 30, 30, 45, 60 and 90 and analysed for concentrations of different fractions of petroleum hydrocarbons and volatile organic hydrocarbons. Microbial activity of DA degrading bacteria was assessed via plate counts in general and selective media, and enzymatic activities of dehydrogenase, urease, and total hydrolases were quantified.

CA demonstrated the best performance, achieving an average reduction of 64.3 ± 0.7% in initial AD concentration, compared to 8.3% in the control. CA at 10% exhibited the highest microbial activity in both total heterotrophic bacteria (3.7×10^9 CFU/g) and diesel-degrading bacteria (1.3×10^9 CFU/g). It also showed the highest enzymatic activities for dehydrogenase (85.0 μg/g·h) and hydrolase (2.8×10^{-2} U/g) compared to BI at 10%, which had the lowest activity among the biostimulants (3.9 μg/g·h and 8.7×10^{-3} U/g, respectively).

An increase in temperature to 25 ºC resulted in a significant drop in contaminant concentration in all samples except the control, confirming that at high contaminant loads the minimum temperature required to activate microbiology is higher.

The CA-supplemented sample showed the best results, confirming AD degradation via biological assimilation during the experiment. Additionally, the substantial fungal growth observed on coffee-amended soil highlights the potential of fungi and their ligninolytic enzymes in degrading organic compounds. High AD concentrations significantly influence the inhibition threshold of microorganisms, emphasizing temperature as a critical factor. A minimum activation temperature of 25 ºC was determined under the study conditions.

This study highlights the influence of biostimulants and evaluates bioremediation in soil with initial AD concentrations three times higher than typically addressed in bioremediation processes.

Abstract ID: 557
CO? footprint within thermal soil remediation - a comparison between 18 sites

Niels Ploug[1]
[1]Krüger A/S

Background
In-situ thermal remediation is a highly effective method for treating contaminated soil and groundwater, capable of achieving reductions in contaminant levels not attainable with other techniques. While this technology's efficacy is well-established, its energy-intensive nature and material requirements contribute to its carbon footprint. This study focuses specifically on optimizing our own thermal remediation processes to reduce CO2 emissions, rather than comparing sustainability across different remediation technologies.

Methodology:
We analyzed data from 18 of our own in-situ thermal remediation projects, executed over more than a decade. The research quantified the carbon footprint associated with energy consumption, material usage (including carbon steel, stainless steel, copper, and activated carbon), and transportation of equipment and personnel. By comparing these projects and their respective carbon footprints, we aimed to identify "low-hanging fruits" - areas where significant reductions in CO2 emissions could be achieved within our thermal remediation processes.

Findings:
The analysis revealed several key areas where carbon footprint reduction efforts could be most effective within our thermal remediation projects. While energy consumption for heater elements remained the primary contributor to the overall carbon footprint, we found that its impact varied significantly depending on the project location. Sites in regions with cleaner energy grids showed substantially lower CO2 emissions from energy use compared to those in areas heavily reliant on fossil fuels. This highlights the importance of considering local energy sources when assessing and planning remediation projects.

Additionally, we identified that carbon steel and activated carbon usage also had significant impacts on CO2 emissions. Notable variations in material usage and transportation-related emissions were observed across different projects. The study highlighted specific practices and technologies within our own operations that demonstrated lower carbon footprints, providing valuable insights for future project optimizations. These findings suggest that focusing on reducing or optimizing the use of carbon steel and activated carbon, alongside energy efficiency improvements and consideration of local energy sources, could lead to substantial reductions in the overall carbon footprint of our thermal remediation processes.

Outlook:
Building on these findings, we are exploring the application of machine learning to further enhance the efficiency of our thermal remediation processes. This approach aims to enable more accurate forecasting of energy requirements during operations, allowing for dynamic adjustments and optimizations. Future efforts will focus on refining our energy efficiency, exploring alternative materials with lower carbon footprints, and improving logistics to reduce transportation-related emissions. Additionally, we recognize the need to evaluate our CO2 emissions in the context of increasingly stringent reduction requirements. To this end, we propose looking at a metric that considers the percentage of risk removed in relation to the carbon footprint of the remediation process. This holistic approach will allow for a more nuanced understanding of the environmental impact and effectiveness of our thermal remediation techniques, enabling us to balance contaminant reduction capabilities with minimizing our carbon footprint.

Abstract ID: 562
Dissemination of information for the global land contamination community
Rob Sweeney[1], Nicola Harries[1]
[1]Contaminated Land: Applications in Real Environments (CL:AIRE)

CL:AIRE is a not-for-profit organisation committed to providing a valuable service for all those involved in land contamination and sustainable land reuse. We develop training resources, disseminate information and act as a credible resource for all stakeholders.
Since 1999, CL:AIRE has always had a heavy focus on sharing knowledge throughout industry. We continue to perform this role in a number of ways including the development of the online Water & Land Library (WALL) which has become the primary and ever growing location for relevant industry guidance and support material.
We develop guidance documents and materials to benchmark industry standards. We work with a number of international organisations to increase the reach of our output and the CL:AIRE network. All our publications are critiqued by Technology and Research Group, a voluntary group of 14 experts from industry and academia, to ensure they are fit for purpose.
On this poster, we will promote our latest publications by providing a brief outline and describing how they are accessible to all, free of charge:
Guidance on the Assessment and Monitoring of Natural Attenuation of Contaminants in Groundwater; Guidance on Natural Source Zone Depletion; Separate Generic Soil Screening Assessment Criteria reports on naphthalene, PFAS and inorganic mercury; Piling and Penetrative Ground Improvement Methods on Land Affected by Contamination: Guidance on Pollution Prevention; Implications of PFAS contamination on management of excavated soils; and PFAS analysis.
In conclusion, we would like to share the information that CL:AIRE publishes with the wider AquaConSoil community, and help direct to the large breadth of resources that are available and accessible from CL:AIRE's website www.claire.co.uk.