Stream A: Innovative Assessment and Remediation Technologies

Soil Vapour Intrusion Investigation at a Site in Northern Manitoba, and Implications for Health Canada's Guidance for Vapour Intrusion Assessment at Contaminated Sites

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Health Canada's vapour intrusion guidance for use at federal contaminated sites implements an attenuation factor approach to predict indoor air concentrations from soil, groundwater, or soil gas concentrations. However, many federal sites are located in the subarctic and arctic where conditions may be outside the default parameters of the Johnson and Ettinger (J&E) model that was used to develop these attenuation factors. Brochet School, in Northern Manitoba, was selected to study vapour intrusion in the subarctic.

The ground underneath the school was well above freezing (9^{o}C to 18^{o}C) even in the middle of February when air temperatures ranged from -5^{o}C to -23^{o}C and the soil temperature measured in a borehole outside the school was -5^{o}C. Likely contributing to elevated soil temperatures was a heated crawlspace. A thaw bulb of this type means neither permafrost or seasonal deep frost will impede vapours from migrating under the building. Soil vapour concentrations under the building ranged from 0.57 mg/m3 to 1,900 mg/m3 for CCME F1 petroleum fraction and 0.67 mg/m3 to 315 mg/m3 for the F2 petroleum fraction.

The attenuation of soil vapour with decreasing depth, observed at some multi-depth probe locations, along with oxygen concentrations of at least 18%, provide evidence that aerobic biodegradation of hydrocarbon vapours is occurring. Surface staining from fuel line leaks and indoor sources of volatile organic compounds (VOC) confounded the calculation of site-specific attenuation factors.

Further research is needed before it can be determined how widely Health Canada's guidance can be applied to sites in the arctic and subarctic, but this first detailed study suggests it can have utility as a screening tool.

Design and Construction of Soil Covers for Mine Waste Facilities in Cold Regions

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This paper examines phenomena that could affect the performance of soil covers constructed on mine wastes located in cold regions. It reviews the state of knowledge about such phenomena, and their occurrence in existing mine waste covers.

Soil covers are widely used in the management of mine tailings and waste rock. However, current soil cover design and construction practices are based largely on experience from temperate regions and on the theoretical basis provided by agricultural soil physics which is also derived largely from experience in temperate regions. As a result, they do not take into account many potentially important features and processes that are common in cold regions.

Several dozen features or processes affecting soils have been identified in cold regions. The most widespread processes are ground freezing and ground ice formation, ground thawing and thaw settlement, and freeze-thaw cycling. Cryoturbation, solifluction, gelifluction and convective cooling can also occur in limited conditions. Combinations of these processes with specific soil or hydrologic conditions can result in terrain features such as ice wedges, pingos, thermokarst, patterned ground, boulder fields, mounds or hummocks, and mudboils, as well as a number of less common features. The rates of these processes can be slow enough that they would not be obvious in current observations of soil covers, but fast enough that they might have significant effects over a cover's design life.

Cold regions also exhibit distinct hydrologic phenomena. The effect of freezing conditions on infiltration is one example of importance to cover design and performance. Other less obvious effects may also be important in particular circumstances.

Nearly 100 examples have been found of soil covers either proposed for or constructed on mine wastes in cold regions. Detailed information is seldom available, but it appears that very few of the constructed or proposed covers have been reviewed from a cold regions perspective. The limited cases where cold region considerations have affected cover design and cover performance are reviewed. As more northern cover performance data is becoming available, cover practitioners are in a position to learn from experience and this paper provides some of these insights, including: (1) where the use of covers fit into the broader mine waste management framework; (2) soil cover design principles and concepts in general, and the differences for northern applications; (3), soil cover construction in general, and specific northern concerns; and, (4) testing, monitoring, modelling and evaluating the success of soil cover system.

There is a need for additional research on fundamental cold regions phenomena, for development of predictive and design tools that take cold regions phenomena into account, and for the development of best practice guidelines. Some of these suggestions will be discussed.

Utilization of a Mobile Soil Washing Technology for the Treatment of Metals Impacted Soil at a DFO Lightstation Property

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Fisheries and Oceans Canada (DFO) in the Maritimes Region has many contaminated sites, predominantly coastal lightstations, with metals impacted soil resulting mainly from the historic use of lead based paint on building exteriors, battery use and mercury baths. Remediation at these sites can be challenging as many are located in hard to access or remote locations, making traditional remediation options logistically and financially unfeasible. Therefore, DFO has pursued the use of innovative technology for onsite remediation of metal impacted soil. DFO has partnered with CleanEarth Technologies Inc. (CleanEarth) for remediation using soil washing technology at the Swallowtail Lightstation located on Grand Manan Island, New Brunswick. Environmental Site Assessments have identified lead and barium soil exceeding CCME guidelines with available concentrations reported as high as 8,730 mg/kg for barium and 67,400 mg/kg for lead. In addition, leachate results from the highest area of lead concentrations were reported as 653 mg/L, indicating the soil is considered leachate toxic. A Human Health Risk Assessment calculated Site Specific Target Levels (SSTLs) of 870 mg/kg for lead and 900 mg/kg for barium and the requirement for remediation. The CleanEarth soil washing process utilizes physical separation modules to concentrate and remove particulate metals from the bulk soil matrix and if required, leaching/extraction to remove the remaining fine particulate metals or molecular/ionic species that may remain bound to the soil following physical processing. For Swallowtail, CleanEarth designed a scaled down version of their mobile soil-washing unit, capable of being airlifted to the site. The project is currently ongoing, requiring the treatment of an estimated 1,000 to 1,200 tonnes of contaminated soil. The prototype soil washing circuit was successfully airlifted to the Swallowtail Lightstation over the course of one day as unit pieces of equipment weighing less than 1,100 kg per piece. Initial processing activities were conducted in late fall of 2008 and continued until freezing weather conditions required the processing to be stopped. Processing activities have resumed in May of 2009 and to date results have been positive. With approximately 600 tonnes of soil processed, treated lead levels in the soil have been reported at concentrations ranging from non-detect to 400 mg/kg with an average lead concentration of 158 mg/kg. Numerous lessons have been learned in terms of mobilizing and processing contaminated soils at remote lightstation properties as the result of this pilot project. Following the completion of this project a second-generation soil washing circuit will be designed to incorporate the lessons learned and increase processing rates and treatment efficiencies.

A Novel Catalytic Technology for the Remediation of Soil Contaminated with Organophosphorus Compounds

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Organophosphorus (OP) compounds are a large and diverse family of organic chemicals with a wide variety of uses including pest control, pharmacology, and in the construction industry. Some OP compounds are extremely toxic and have been used as chemical warfare agents. Most OP compounds absorb easily to soil particles and can impact groundwater over extended periods of time. Products of hydrolysis of OP compounds are usually considered non-toxic. However, degradation by reductive, oxidative, and thermal pathways can lead to harmful products, some of which are much more toxic than their parent compound.

The primary objective of this study is to develop and evaluate a safe and rapid catalytic method to remove and degrade OP compounds from soils. The work builds on a novel process developed by Queen's University by which metal ions catalyze the degradation of OP compounds through their reaction with light alcohols. Metal-ligand complexes of La3+, Zn2+, and Cu2+ accelerate the methanolysis of OP compounds, including pesticides and chemical warfare agents, by up to nine orders of magnitude. Metal-ligand catalyzers attached to commercially available polymers have also been developed to form a solid catalytic system.

Two main processes are tested for soil remediation. The first process consists of the extraction of OP contaminants from soil using alcohols. The extracted contaminants are degraded by the catalytic system in the alcohol, which can be reused for further extractions. The catalyst can either be added in liquid form to the post-extraction solution or the post-extraction solution can be passed through a bed of solid catalyst. The second catalytic treatment process uses polymer beads to extract the OP agents from soil. Solid-phase extraction can be more selective for specific compounds and also prevents the extraction of water that inhibits the catalytic process. After the extraction step, OP compounds are degraded by either submerging the polymer beads in the catalytic solution or the catalytic solution is passed through a bed of polymer beads. In both cases, the contaminants are solubilized in the solvent and destroyed by catalytic methanolysis. After treatment, the polymer beads can be reused to extract more contaminants from soil and the catalytic solution is recycled to treat more polymer beads. This paper presents results of bench-scale experiments carried out on OP pesticides. Operating parameters are investigated and optimized for both processes to prepare for a pilot-scale demonstration.

Bioaugmentation: An Innovative Remediation Technology for the Remediation of Chlorinated Ethene Contaminated Sites

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KB-1® is a naturally occurring, non-pathogenic microbial culture that contains Dehalococcoides (Dhc), the only group of microorganisms documented to promote the complete dechlorination of chlorinated ethenes to non-toxic ethene. Although Dhc are found in the environment, research indicates these microorganisms are not ubiquitous and not all Dhc are capable of complete dechlorination of chlorinated ethenes. At sites where Dehalococcoides are absent, tetrachloroethene (PCE) and trichloroethene (TCE) dechlorination typically stalls at cis-1,2-dichloroethene (cDCE), despite ample electron donor availability. KB-1® is used to: establish complete dechlorination at sites that do not contain Dhc (or the right Dhc) and to accelerate dechlorination rates to achieve treatment goals. Bioaugmentation of aquifer systems with KB-1® provides an active microbial community capable of complete reductive dechlorination, ensuring that PCE, TCE and cDCE are completely dechlorinated to ethene, without undue acclimation periods, and at rates that are suitable for achieving remedial goals.

Bioaugmentation with Dehalococcoides based microbial cultures for remediation of chlorinated ethene contaminated sites has been performed using commercially produced culture in the US and Europe for over eight years. However, the use of this innovative technology could not occur in Canada until Federal and Provincial approvals for the production and sales of such a product were obtained. The KB-1® culture has been reviewed by Health Canada and

Environment Canada as part of the New Substances Notification program and was added to the Domestic Substances List in August 2008 for use in Canada.

This presentation will describe key pre-bioaugmentation conditions including Dehalococcoides (Dhc) status, chlorinated ethene concentrations, groundwater temperature, pH, oxidation -reduction potential (ORP), and the presence of inhibitory co-contaminants. Post-bioaugmentation parameters that require assessment also include Dhc growth rates, extent of spread and maximum concentrations of Dhc reached electron donor concentration, contaminant degradation rates, and the formation of degradation daughter products. A case study will also be presented.

Sustainable and Innovative Development of Slurry Bubble Column for Treatment of Acid Rock Drainage

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The development of an innovative process integrating chemical process and a soil mineral (clinoptilolite) in a slurry bubble column to remove metals from acid rock drainage (ARD) is summarized in this paper. It involves cyclic adsorption of metals from spiked ARD on clinoptilolite and regeneration of the sorbent by desorption of metals. Experimental results indicate that clinoptilolite is a good sorbent for Zn and Cu from ARD, the original structure of sorbent as shown from the XRD, SEM and TEM retained over 27 multiple adsorption/desorption cycles and at pHs $\geq$ 2.5. The Zn removal efficiency is much higher in slurry bubble column than packed beds and rotating columns, which required only 20 minutes rather than 24 hours. Slurry bubble column test shows that finer particle-size (300-500 μm) of clinoptilolite adsorbed 30% more Zn at a given time than coarse particle-size (850-1400 μm). The results appear to be a promising technique for treatment of ARD leachate. The on-going research includes the optimization of the operating conditions and predictive modelling.

Hydrocarbon Impacts in Fractured Bedrock: Remedial Options Analysis, Former Oily Waste Water Treatment Plan, CFB Esquimalt, BC

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The former Oily Waste Water Treatment Plant (OWWTP) located at CFB Esquimalt, BC, was historically used as a bulk fuel storage and wastewater treatment facility from circa 1940 to 2005. The former OWWTP included eight above ground fuel tanks prior to the 1970s used for bulk storage of Bunker C. The fuel storage facilities have since been decommissioned. Since the 1970s, the area was used for treatment of oily water from naval vessels and used oils from Department of National Defence (DND) equipment and vehicles. The oily water and waste oils were transferred to the OWWTP by tanker truck and drums or pumped from a barge via a nearby jetty.

Multiple investigations have been undertaken at the former OWWTP since 1994. Due to the historical use of the site, significant hydrocarbon impacts and hydrocarbon product accumulation were identified within joints, fractures and intrusions of the limestone bedrock, the overlying soil and within the groundwater. Remedial activities were initiated in 2005 and continued to March 2008. This work included the excavation of metals impacted fill soil and hydrocarbon impacted soil, blasting of hydrocarbon-impacted bedrock, and the pumping and treatment of impacted groundwater.

Following the remedial work in 2008, hydrocarbon impacts were found to persist within the overburden, bedrock, and groundwater at the site. SNC-Lavalin Environment Inc. was requested by Defence Construction Canada and DND to evaluate the remedial options for the remaining contamination. This included an evaluation of monitored natural attenuation, pump and treat, in-situ chemical oxidation, and excavation. The remedial option screening process included an evaluation of variables including technical feasibility, timing, operations and maintenance of any equipment needed, likelihood of success, and cost. Based on the options screening, continued source removal of hydrocarbon-impacted bedrock was chosen for implementation during the 2009/2010 fiscal year.

Pilot-scale Demonstration of an Innovative, Economical Method for Simultaneous PAH-Metal Extraction from a Site at the Montreal Garrison of the Canadian Forces

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This pilot-scale demonstration concerns the ex-situ "Organometox" procedure that could be commercially applied on site or off site. It follows development of a procedure outlined in the doctoral thesis of Julia Mouton and two previous studies commissioned by the BRI and MCEBR. The on-site option is generally preferable when sufficient quantities requiring treatment are involved. Excavating and re-depositing the treated soil usually accounts for 5% to 10% of the unit cost of treatment under reasonable conditions. Mixed contamination, i.e. the combined pollution of soil by lead (Pb) and PAH, is frequent and problematic. With procedures proven and applied in commercially successful undertakings, this type of mixed contamination requires applying several treatments one after the other in a chain of procedures. Accordingly, PAH are removed during the first procedure, such as a soil washing system that incorporates a surfactant, and then metals are solubilized in a second procedure, such as a chemical leaching or mining procedure. This combination of procedures is often costly in cases of contamination by only one type of contaminant. A relatively large number of technologies for treating these two types of pollutants separately is available, although decontamination for PAH with 4, 5 or 6 aromatic rings is far from easy. During this project, we demonstrated a combination treatment on a pilot-scale, in a single reactor and at the same time (simultaneous), for metal (primarily Pb) through chemical leaching and PAH through a new, non-toxic and biodegradable surfactant. The principal parameters are the choice of surfactant, the choice of acids and complexing agents, the solid content in the reactor, temperature, reaction times, number of washouts, the PAH-surfactant micelle recovery method, and the various types of soil in terms of grain size and composition (pH, grain size, grain chemistry, etc.). The development of a low-cost simultaneous procedure has the advantage of allowing the treatment of mixed contamination, which is currently much costlier, not to mention the advantage of its applications to cases of single contamination (metals or PAH). This possibility considerably expands the market potential for such technology. PAH concentrates are managed as a hazardous residual material, but their energy potential is currently under study. The metal concentrate is currently managed as a hazardous residual material, but recycling is potentially feasible in some cases.

Six bags of soil, one ton each, were excavated from the Montreal Garrison base. The soil was sent to the INRS-ÉTÉ pre-industrial environmental technology development laboratory in Quebec City. During trials lasting eight months, every stage of the procedure was tested and design criteria were developed for a first commercial application of the procedure. The removal of 65% to 95% of metals, and from 80% to 99% of PAH (especially heavy PAH) meets the soil reuse criteria. The results will be discussed during the presentation.

Integrating Heat with Biological, Chemical and Physical Processes for Soil and Groundwater Remediation

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The primary mass removal mechanism of Electrical Resistance Heating (ERH) is soil vapor extraction subsequent to the conversion of volatile liquid phase contaminants to the gas phase. At sites where ERH has been implemented, it has been unexpectedly observed that heat enhanced chemical, biological and physical processes provide a significant amount of remediation activity.

Hydrolysis, which is quite slow under normal groundwater temperatures (the half life of the reaction is normally measured in decades), becomes very rapid (less than a day) under temperatures that can easily be achieved using ERH. Heat-enhanced hydrolysis has been used to remediate halogenated alkanes from soils and groundwater at various sites, including sites in Georgia and Maryland.

Furthermore, ERH provides the appropriate conditions for accelerated biological activity for dissolved phase contaminant treatment. ERH increases dissolved organic carbon content by more than an order of magnitude, providing terminal electron donors for the biodegradation of chlorinated solvents. Bioactivity has been shown to increase during and after ERH.

For the treatment of oil and coal tar residues from manufactured gas plants, a process called steam bubble floatation physically moves the long-chain hydrocarbons to the top of the water table. Conventional multi-phase extraction equipment removes the contaminants. ERH-enhanced steam bubble floatation process can significantly reduce

(>85% concentration reduction) coal and oil tar constituents with boiling points of less than 300°C. Left behind are immobile, insoluble and non-volatile oil and coal tar fractions resulting in negligible impact to groundwater and greatly reduced risk from vapour intrusion.

Thus, chemical, biological and physical processes are increasing the applicability of ERH in environmental restoration projects, treating a wider variety of compounds than previously considered. Further, these mechanisms reduce energy costs.