NORDROCS 2018

Crossing borders

7th Joint Nordic Meeting on Remediation of Contaminated Sites

RGS NORDIC
RAMBØLL
SUEZ
SYNLAB
REGENESIS
Multiconsult
INNOVATION NETWORK FOR ENVIRONMENTAL TECHNOLOGY
ARKIL MILJØ-TEKNIK
COWIfonden
eurofins
Geovariances – Where no one has gone before
IFE
QM Environmental International BV

Program
Abstracts
Short papers
Information

September 3-6, 2018, Helsingør – a part of Greater Copenhagen, Denmark

Organizing Committee

Arne Rokkjær, M.Sc., The Capital Region of Denmark, Denmark/ATV Soil and Groundwater – Coordinator of NORDROCS 2018 Organizing Committee
Paul S. Cappelen, M.Sc, Norwegian Geotechnical Institute, Norway/Miljøringen
Peter Harms-Ringdahl, M.Sc., Environmental Consultant, EnviFix, Sweden/Renare Mark
Jarno Laitinen, M.Sc. (tech.), M.Sc.(econ), Project Manager, Pirkanmaa ELY-Centre, Finland/MUTKU

Assisting Organizing Committee

Mette M. Broholm, Associate Professor, DTU Environment (ATV Soil and Groundwater)
Morten Jartun, Ph.D., Norwegian Institute for Water Research (Miljøringen)
Ulrika Larson, Consultant, Empirikon (Renare Mark)
Lisbeth Verner, Head of Secretariat, ATV Soil and Groundwater

Review Committee

Paul S. Cappelen, M.Sc., Norwegian Geotechnical Institute, Norway
Mette Christophersen, Ph.D., Head of Department, Ramboll, Denmark
Annika Fjordbøge, Ph.D., Researcher, DTU Environment, Denmark
Patrick van Hees, Associate Professor (Örebro Univ.) Eurofins Sweden
Morten Jartun, Ph.D., Norwegian Institute for Water Research, Norway
Anne Krüger, Environmental Scientist, City of Vesterås
Marja Tuomela, Ph.D., Co-op Bionautit and University of Helsinki
Kim Yrjälä, Associate Professor, University of Helsinki

NORDROCS 2018 is arranged by

ATV Jord og Grundvand
Miljøringen
Nettverk for forurenset grunn og sedimenter
Nätverket Renare Mark
MUTKU

7th Joint Nordic Meeting
on Remediation of Contaminated Sites

NORDROCS 2018

Konventum, Helsingør
a part of greater Copenhagen, Denmark
September 3-6, 2018

Program, incl. social program.. 5

Map of Helsingør and surroundings... 10

Participants by country 11

Participants 12

Exhibitors 19

List of posters 20

Short courses Monday September 3, programs 25

Abstracts Tuesday September 4 31

Abstracts Wednesday September 5 87

Poster abstracts 165

Technical tours Thursday September 6, programs 247

Conference sponsors 253

Objective

The objective of the NORDROCS conferences is to address issues on assessment and risk management of contaminated land and sediments in the context of Nordic conditions. The meeting intends to provide a forum for the exchange of information gathered through research and project experience.
Target groups include scientists, regulators, consultants, contractors and other professionals working with contaminated sites and sediments in Nordic countries, countries in Northern Europe and around the Baltic Sea.

Konventum, Helsingør

Kulturværftet, Helsingør / Foto Steen Larsen

Kronborg /. Photo: Thomas Rahbek

PROGRAM

Monday, September 3

11.00 – 16.00 **Short Course 1 – PFAS – meeting room B-24**

Dynamic investigations with mobile lab at PFAS-impacted sites
please see separate program in the compendium

13.00 – 16.00 **Short Course 2 – Geostatistics – meeting room B-21**

An overview of Geostatistics for contaminated site characterization
please see separate program in the compendium

18.00 – 18.30 Transportation to Welcome Reception by bus or walk

18.30 Welcome reception at Kulturværftet, Helsingør incl. a light serving and drinks
Entertainment: Sct. Olai Vocal Ensemble

Tuesday, September 4

09.00 – 09.50 Registration and coffee/tea buffet

10.00 – 11.30 **Opening Session / Welcome**
Lecture hall Jorns

Ida Holm Olesen, Chairman, ATV Soil and Groundwater
Arne Rokkjær, Coordinator of the NORDROCS 2018 Organizing Committee

Key note presentation
Risk assessment of contaminated sites to water resources:
The role of the contaminant mass discharge approach?
Professor Poul L. Bjerg, DTU Environment, Denmark

Key note presentation
Sustainable remediation in practice
Professor Paul Nathanail, University of Nottingham, UK

11.50 - 12.50

Session A – lecture hall Øresund

EPA from the 4 Nordic countries
Risk management - regulatory perspectives

Risk assessment/risk management - leaning towards the more regulatory requirements with regard to Risk assessment and the regulatory challenges in risk - based decision making.

Chair: Tom Heron, Senior Vice President, Environment, Energy, Water and Informatics, NIRAS Denmark

Senior Advisor Kine Martinsen, Norwegian Environment Agency
Technical Advisor Preben Bruun, Danish EPA
Senior Advisor Jussi Reinkainen, Finnish Environment Institute
Senior Scientific Officer Magdalena Gleisner, Swedish EPA

Session B – lecture hall Jorns

Remediation – of Soil and Groundwater
Part I (B)

Chair: Marja Tuomela, Ph.D., Co-op Bionautical and University of Helsinki, Finland

Environmental forensics. Searching for a major unknown PCE source in an industrial area using different tools, Birkerød, Denmark
M.Sc., Ph.D. Thomas Hauerberg Larsen, Orbicon, Denmark

Development of an iron-based soil mixing remediation method for energyefficient treatment of chlorinated solvents
Ph.D. Per Lindh, Swedish Geotechnical Institut, Sweden

Da Nang – an outstanding thermal remedy 5 years later
Sales and Product Manager Niels Ploug, Krüger, Denmark

12.50 – 13.40 Lunch, poster session and exhibition, matchmaking .
Matchmaking arranged *by Danish Soil Partnership and Innovation Network for Environmental Technologies*

13.40 – 14.10 Poster session, exhibition and matchmaking
Matchmaking arranged by *Danish Soil Partnership and Innovation Network for Environmental Technologies*

14.10 – 15.30

Session C – lecture hall Øresund

Sustainability and Reuse - Part I

Chair: Jarno Laitinen, M.Sc., Project Manager, Pirkanmaa ELY-Centre, Finland

Key note presentation: A sustainability perspective on reuse and remediation
Professor Kristina Lindström, University of Helsinki, Finland

Reuse of concrete and risk assessments related to the expansion of Oslo Airport Gardermoen
Project Manager Ida Kristine Buraas, Golder, Norway

Efficient soil reuse – imperative for sustainable land management
Senior Advisor Jussi Reinikainen, Finnish Environment Institute, Finland

Session D – lecture hall Jorns

Remediation – of Soil and Groundwater Part II

Chair: Annika Sidelmann Fjordbøge, Researcher, Ph.D., DTU Environment, Denmark

Key note presentation: *In situ* bioremediation of contaminated soil; comparison and combination of different approaches
Professor Martin Romantschuk, University of Helsinki, Finland

Multidisciplinary approach to characterize natural degradation of PCE
Ph.D.-student Sofia Aakesson, Lund University, Sweden

Tools and concepts for quantifying in situ degradation rates at contaminated sites
Chief Consultant, Ph.D. Nina Tuxen, Capital Region of Denmark

15.30 – 16.20 Poster session and exhibition, matchmaking, coffee/tea break
Matchmaking arranged by *Danish Soil Partnership and Innovation Network for Environmental Technologies*

16.20 - 17.40

Session E – lecture hall Øresund

Sustainability and Reuse - Part II

Chair: Environmental expert Aura Nousiainen, Pöyry, Finland

Sustainable remediation assessment: How to include the societal cost in the equation?
Managing Director Jan Haemers, Haemers Technologies, Belgium

Strategic approach to climate protection and soil management to fulfill the Sustainable Development Goals (SDG 11, 12 and 13)
Joan Krogh, NIRAS, Denmark

Remediation of PCB-polluted soil using biochar: the uptake of PCBs in earthworms, plants and passive samplers – a pot experiment
Sigurbjörg Hjartardóttir, NGI, Norway

Sustainable and digital management in large infrastructure projects of acid producing rock and soil containing naturally high levels of heavy metals
M.Sc., Env.consultant Lars-André Erstad and Project Manager, Env.consultant Eva Aakre, Rambøll-Sweco ANS, Norway

Session F – lecture hall Jorns

Risk Assessment of Soil and Groundwater

Chair: Head of Dept., Ph.D. Mette Christophersen, Rambøll, Denmark

Key note presentation: Assessment of in-situ natural and enhanced chlorinated ethenes degradation by use of isotopic and molecular biology techniques
Associate professor Mette M. Broholm, DTU Environment, Technical University of Denmark

Direct radiotracer rate measurements of groundwater contaminants in intact cores – method and first results on cis-DCE dechlorination
Senior Researcher, Ph.D. Rasmus Jakobsen, GEUS, Denmark

Bacterial population dynamics in a groundwater plume from a heating oil spill quantified via 16 S rRNA gene amplicon sequencing
R&D Project Manager Poul Larsen, DMR, Denmark

19.00 – 19.30 Welcome drink and Polka Tesch – entertainment/music

19.30 - Conference dinner and dance. The Man – dance band

Wednesday, September 5

8.30 – 09.50

Session G – lecture hall Øresund

Contaminated Sediments – Risk Assessment and Remediation - Part I

Chair: M.Sc. Paul Cappelen, Geotechnical Institute, Norway

Key note presentation: In-situ remediation of contaminated sediments: Combining strong sorption with microbial dechlorination *Professor Upal Ghosh, University of Maryland Baltimore County, USA*

The Norwegian Management System of Risk Assessment - Contaminated Sediments
M.Sc., Senior Adviser Hilde B. Keilen, Norwegian Environmental Agency, Norway

Dispersal pathways of contaminants from organic-rich sediments – a field study of fibrous sediments in northern Sweden
Dr. Sarah Josefsson, SGU, Sweden

Session H – lecture hall Jorns

Investigation and monitoring of Soil and Groundwater - Part I

Chair: Associate Professor Mette Broholm, DTU Environment, Technical University of Denmark

Key note presentation: How groundwater velocity measurements can strongly support aquifer characterisation studies
Professor John Frederick Devlin, University of Kansas, USA

Multiple fluorescent dyes as a tool for understanding fate and transport for large scale plumes
Project Director Nicklas Larsson, NIRAS, Sweden

Porewater sampling in the unsaturated zone – a novel technique for measuring seepage concentrations directly
R&D Project Manager Poul Larsen, DMR, Denmark

9.50 – 10.20 Coffee/tea break

10.20 - 11.40

Session I – lecture hall Øresund

Contaminated Sediments – Risk Assessment and Remediation - Part II

Chair: M.Sc., Environmental Consultant Peter Harms-Ringdahl, EnviFix, Sweden

TREASURE: Novel and innovative methods used to characterize two of Sweden's contaminated fiberbank sediment sites
Professor Ian Snowball, Uppsala University, Sweden

Remediation of Oskarshamn hamn: challenges and lessons learned from contractor point of view
Regional Manager Bart van Renterghem, Envisan, Belgium

Quantification of microplastics in sediments from benthic and coastal environments
M.Sc. Heidi Knutsen, NGI, Norway

Nontarget analysis of sediment samples from Copenhagen, Denmark
Ph.D.-student Josephine Lübeck, University of Copenhagen, Denmark

Session J – lecture hall Jorns

Investigation and monitoring of Soil and Groundwater - Part II

Chair: Associate Professor Patrick van Hees, Eurofins, Sweden

High Resolution Site Characterization and 3D Geological Modelling – Tools for Interpretation of Plume Migration in a Complex Geology
M.Sc. Bo Tegner Bay, COWI, Denmark

Development of an innovative methodology for monitoring of in situ remediation of chlorinated solvents – the MIRACHL-project
Ph.D. Haakan Rosqvist, Lund University and Tyréns, Sweden

Use of geostatistical modelling in investigation of soil contamination - working toward a better definition of remedial mass and volume
R&D Manager, Ph.D. Per Loll, DMR, Denmark

Do we as practitioners have a general challenge with leaking wells causing cross-contamination to deeper aquifers ? Swedish and Danish results and paths forward
Project Manager Maria Heisterberg Hansen, NIRAS, Denmark, and Environmental Consultant Filip Nilsson, NIRAS, Sweden

11.40 - 12.40 Lunch, poster session and exhibition

12.40 – 13.10 Poster session and exhibition

13.10 – 14.30

Session K – lecture hall Øresund

Management

Chair: Environmental Scientist Anna Kruger, City of Vestarås, Sweden

Key note presentation: Strategic decisions, while planning and implementing the challen-ging remediation project in the heavily pollu-ted harbor in Oskarshamn, Sweden – the municipal perspective
Bodil Liedberg Jönsson, Strategic Develop-ment Manager, Municipality of Oskarshamn, Sweden

Stakeholder engagement in strategic research agendas related to soil and land use management
Ph.D. Yvonne Ohlsson, Swedish Geotechnical Institute, Sweden

The Finnish Clean Soil Program. A national state-funded program to investigate and remediate sustainably the significant risks to human health and the environment due to land contamination
M.Sc., Project Manager Jarno Laitinen, Centre for Economic Development-, Transport and the Environment, Finland

Session L – lecture hall Jorns

Surface Water - Interaction from Soil, Sediment and Groundwater

Chair: Research Manager Marianne Olsen, Nor-wegian Institute for Water Research, Norway

Key note presentation: Contaminant response in a multistress environment
Professor Katrine Borgå, University of Oslo, Norway

Bodø Airport – The story of PFAS' way from soil, through storm water to biota
Head of Section Marianne Kvennås, NGI, Norway

Using temperature to assess interaction between contaminated groundwater and surface water
Ph.D., Hydrogeologist Gro Lilbaek, NIRAS, Denmark

14.30 – 15.10

Poster session and exhibition, coffee/tea break

15.10 – 16.30

Session M – lecture hall Øresund

Indoor Air

Chair: R&D Manager Per Loll, DMR, Denmark

A detection dog, man's best friend during indoor air investigations
Mette Algreen, Projectleader, Ph.D., Orbicon, Denmark

Vapor Intrusion Gas Source Investigation by use of Stable Isotopes and Radiocarbon Dating
Environmental Engineer Katrine Moes Kristensen, NIRAS, Denmark

Revisiting dry-cleaning sites -30 years of improving environmental investigations from the perspective of a public authority
Environmental Engineer, Ph.D. Sanne Skov Nielsen, Region of Southern Denmark

Modelling of air flow in capillary break layers. A new approach to determine governing mechanisms in balanced ventilation systems preventing vapor intrusion of volatile pollutants
Project Manager Jakob Washington Skovsgaard, Ramboll, Denmark

Session N – lecture hall Jorns

PFAS

Chair: Ph.D. Morten Jartun, Norwegian Institute for Water Research, Norway

Immobilization of PFAS contaminated sandy soil from a Norwegian firefighting training facility
Director of Landfill and Contaminated Soil Hilmar T. Sævarsson, Lindum

PFAS Handbook: What, how and where to look, what are the risks and can we be sure?
Senior Consultant Jacqueline Falkenberg, NIRAS, Denmark

Mobility of PFAS: Do lysimeter results reflect concentrations monitored in a groundwater plume?
Regional Manager, M.Sc. Mikael Takala, Vahanen Environment Oy, Finland

What is the total budget of PFAS in contaminated soil and how does total oxidizable precursor (TOP) assay help comprehend the picture?
Associate Professor Patrick van Hees, Eurofins, Sweden

Thursday, September 6

09.00 – 13.30 **Technical tour 1**
Visit to practice range for fire fighting
please see separate program in the compendium

09.00 – 13.30 **Technical tour 2**
Innovation Garage, Skovlunde
please see separate program in the compendium

Social program

Monday September 3

18.30 Meet and greet / Welcome reception
Kulturværftet, Allegade 2, DK-3000 Helsingør, incl. musical entertainment, St. Olai Vocal Ensemble and a light serving.

Bus leaves Konventum at 18.00 - optional walk (approx. 2,7 km along the coast)

Evening meal at own expense – conference secretariat can provide a list of local restaurants

Tuesday September 4

19.00 Drink and musical entertainment, Band Polka Tesch, at 19.00 in the lobby and lecture hall Jorns

19.30 Conference dinner at 19.30 in the Restaurant at Konventum

22.00 (approx.) Dancing after dinner with band "The Man" in the Salon and Bar "Mødestedet"

Adjustments may occur

Map of Helsingør

Participants by country

(Registered by August 15)

Austria	1
Belgium	5
Czech Republic	1
Denmark	111
Finland	27
France	2
Germany	3
Netherlands	1
Norway	37
Sweden	86
Switzerland	1
United Kingdom	3
USA	6

Count of participants 284

Participants
(Registered by August 15)

A

Aakre	Eva	Rambøll	Norway
Aas	Eirik	Eurofins Environment Testing Norway AS	Norway
Adolfsson	Max	Breccia konsult AB	Sweden
Af Geijerstam	Jan	SpaceMatters	Denmark
Algreen	Mette	Orbicon	Denmark
Andersen	Hans Ole	ZenZors A/S	Denmark
Andersen	Johanne Aaberg	Geo	Denmark
Anfinset	Sander	Norconsult AB	Sweden

B

Banke	Lotte	Central Denmark Region	Denmark
Bastrup	John Ulrik	Geo	Denmark
Bay	Bo Tegner	COWI	Denmark
Bercoff	Alexandra	Ragn-Sells AB	Sweden
Bergman	Jonny	RGS Nordic	Denmark
Bergman	Lisbeth	Region Sjælland	Denmark
Bergquist	Samuel	Sweco Environment AB	Sweden
Bergsli	Anders	Horten kommune	Norway
Bergstedt	Erik	Geological Survey of Sweden	Sweden
Bermin	Jonas	WSP	Sweden
Binbach	Tommy	Wescon Miljökonsult AB	Sweden
Bjarne	Hansen	Forsvarsministeriets Ejendomsstyrelse	Denmark
Bjerg	Poul L.	Technical University of Denmark	Denmark
Bjornstad	Harald	Forsvarsbygg	Norway
Blæsbjerg	Helle	Central Denmark Region	Denmark
Borgå	Katrine	UiO	Norway
Brabæk	Lærke	Master student / DTU Environment	Denmark
Brandt	Ulla Kristine	Innovationsnetværk for Miljøteknologi / CLEAN	Denmark
Braungardt	Charlotte	University of Plymouth	United Kingdom
Broholm	Mette M.	DTU Environment	Denmark
Brusila	Sari	Oy Teboil Ab	Finland
Bruun	Preben	Danish EPA	Denmark
Brøndum	Mariann	Region Nordjylland	Denmark
Buck	Christian	COWI	Denmark
Buhl	Jurgen	Cornelsen Umwelttechnologie GmbH	Germany
Buraas	Ida Kristine	Golder Associates AS	Norway
Bymose	Martin	DGE Miljø- og Ingeniørfirma	Denmark

C

Cappelen	Paul Sverdrup	NGI	Norway
Carlström Ödegaard	Linn	Ramboll	Sweden
Christensen	Anders G.	NIRAS	Denmark
Christophersen	Mette	Rambøll	Denmark
Collins	John	AquaBlok, Ltd.	USA

D

Dahl	Mari	University of Helsinki	Finland
Dalgaard	Mikkel Ankerstjerne	Capital Region of Denmark	Denmark
Demougeot-Renard	Hélène	eOde Sàrl	Switzerland
Devlin	Rick	U of Kansas	USA
Dye	Christian	IFE (Institute for Energy Technology)	Norway

E

Edström	Ulrica	Resia	Sweden
Elderup Sadowski	Katrine	Region Sjælland	Denmark
Engelstad	Bjørn	NOAH AS	Norway
Erstad	Lars-André	Sweco Norge AS	Norway

F

Fabricius	Anne Marie	Capital Region of Denmark	Denmark
Fagerlund	Fritjof	Uppsala University	Sweden
Falkenberg	Jacqueline	NIRAS	Denmark
Faucheux	Claire	Geovariances	France
Fikse	Andrea Nymo	Avinor AS	Norway
Fjelkestam	Anna	Ramboll	Sweden
Fjordbøge	Annika	DTU Environment	Denmark
Flink	Jenny	Arup	Denmark
Flyvbjerg	John	Capital Region of Denmark	Denmark
Forsberg	Kristin	Sveriges geologiska undersökning	Sweden
Fransson	Martin	Sweco Environment AB	Sweden
Frogner-Kockum	Paul	Swedish Geotechnical Institute	Sweden
Fürst	Helena	WSP Sverige AB	Sweden

G

Gamst	Jesper	Eurofins Denmark	Denmark
Ghosh	Upal	University of Maryland Baltimore County	USA
Gjerstad Lindgren	Johanna	Norconsult AB	Sweden
Gleisner	Magdalena	Swedish EPA	Sweden
Granhøj Hansen	Anne Mette	Capital Region of Denmark	Denmark
Greiff	Siri	Multiconsult	Norway
Gulevski	Robert	Eurofins Environment Testing Norway AS	Norway
Gustavsson	Hans	Sweco Environment AB	Sweden
Gustavsson	Maria	Länsstyrelsen i Västra Götalands län	Sweden
Göransson	Cecilia	Breccia konsult AB	Sweden
Göransson	Gunnel	Swedish Geotechnical Institute	Sweden

H

Haemers	Jan	HAEMERS Technologies SA	Belgium
Hag	Maria	Capital Region of Denmark	Denmark
Hagerberg	David	Tyréns AB	Sweden
Hainari-Maula	Jan	Remsoil Ltd	Finland
Hakalahti	Teija	Vapo Ltd	Finland

Hallgren	Pär	Sweco Environment	Sweden
Hantzi	Katerina	Capital Region of Denmark	Denmark
Harms-Ringdahl	Peter	EnviFix	Sweden
Harrekilde	Dorte	Rambøll	Denmark
Hartmann	Hanna	Nätverket Renare Mark/Enviro Miljöteknik AB	Sweden
Hatschek	Hanna	ALS Scandinavia	Sweden
Heidkamp	Helen	Fortum Waste Solutions AB	Sweden
Heisterberg Hansen	Maria	NIRAS	Denmark
Herman	Sofie	Envisan NV	Belgium
Heron	Tom	NIRAS	Denmark
Hietala	Jari	Eurofins Environment Testing	Finland
Hindrichsen	Anne Gammeltoft	Orbicon	Denmark
Hjartardóttir	Sigurbjörg	Norges Geotekniske Institutt, NGI	Norway
Hjartland	Tore	Aquablok Norge AS	Norway
Holm	Jesper	Krüger A/S	Denmark
Holm	Lena	Tyréns AB	Sweden
Horneman	Allan	ARCADIS	USA
Horneman	Marina	Capital Region of Denmark	Denmark
Hostrup	Maren K.	Danish Ministry of Defence Estate Agency	Denmark
Hougaard	Thomas	Golder Associates A/S	Denmark
Hulth	Elin	Länsstyrelsen Blekinge	Sweden
Humala	Sami	Eko Harden Technologies	Finland
Huppunen	Jukka	Ramboll Finland Oy	Finland
Hvidberg	Boerge	Region Midtjylland	Denmark
Hänninen	Emmi	Uusimaa ELY-Centre	Finland
Højsted	Camilla	ALS Laboratorie	Denmark

I

Iverfelt	Ulrika	NIRAS Sweden AB	Sweden

J

Jacobsson	Paul	Nätverket Renare Mark/ Eurowater AB	Sweden
Jakobsen	Martin	KMC Nordhavn, Københavns Kommune	Denmark
Jakobsen	Rasmus	GEUS	Denmark
Jartun	Morten	NIVA/Miljøringen	Norway
Jensen	Christian Høimann	Region Sjælland	Denmark
Jensen	Kim Rikard	Arkil Fundering A/S	Denmark
Jersak	Joe	SAO Environmental Consulting AB	Sweden
Johansen	Freja Rebecca	Cowi A/S	Denmark
Johansen	Ingar	IFE	Norway
Johansson	Louise	Sweco Environment AB	Sweden
Joranger	Tore	Norwegian Defence Estates Agency	Norway
Josefsson	Sarah	Geological Survey of Sweden	Sweden
Juutilainen	Milla	GE Healthcare AB	Sweden

K

Kaakinen	Juhani	POP ELY	Finland
Kahn	Adrien	SUEZ	Belgium

Karkela	Miikka	Eurofins Environment Testing	Finland
Karlsson	Daniel	WSP Sverige AB	Sweden
Karlsson	Linda	Orbicon AB	Sweden
Karlsson	Rebecka	Naturvårdsverket	Sweden
Keilen	Hilde	Norwegian Environmental Agency	Norway
Keller	Carl	Flexible Liner Underground Technologies - FLUTe	USA
Kiming	Camilla Bacher	Arkil Fundering A/S	Denmark
Kiratsopoulos	Thomas	Eurofins Environment Testing Sweden AB	Sweden
Kjøge Olsen	Jette	NIRAS	Denmark
Knudsen	Tommy Bistrup	Region Nordjylland	Denmark
Knutsen	Heidi	NGI	Norway
Krogh	Joan	NIRAS	Denmark
Krokstad	Julie Stene	Avinor, OSL	Norway
Kruger	Anna	Västerås stad	Sweden
Kvennaas	Marianne	NGI	Norway
Køtter	Allan	Capital Region of Denmark	Denmark

L

Laastad	Eli Smette	Golder Associates AS	Norway
Laitinen	Jarno	Pirkanmaa ELY-centre	Finland
Larsen	Claus	DMR A/S	Denmark
Larsen	Jane	Region of Zealand	Denmark
Larsen	Poul	DMR A/S	Denmark
Larsen	Thomas	Orbicon	Denmark
Larson	Helle	Central Denmark Region	Denmark
Larson	Ulrika	Renare Mark/ Empirikon	Sweden
Larsson	Nicklas	NIRAS	Sweden
Ledskog	Lisa	Atkins Sverige AB	Sweden
Leerbech Jensen	Mads	Danish Regions - Environment and Resources	Denmark
Leerbech Jensen	Mads	Danish Regions - Environment and Resources	Denmark
Lehoux	Alizée	Uppsala University	Sweden
Liedberg Jönsson	Bodil	Oskarshamn Municipality	Sweden
Lilbæk	Gro	NIRAS DK	Denmark
Liljemark	Anneli	Liljemark Consulting	Sweden
Lind Gregersen	Jens	Capital Region of Demnark	Denmark
Lindh	Per	SGI	Sweden
Lindof	Anne Mette B	Danish Ministry of Defence Estate Agency	Denmark
Lindqvist	Lars	Eurofins Environment, Sweden	Sweden
Lindström	Kristina	University of Helsinki	Finland
Lintu	Yrjö	Eko Harden Technologies	Finland
Ljunggren	Lill	County Administrative Board Kalmar	Sweden
Ljunggren	Pernilla	Ragn-Sells Avfallsbehandling AB	Sweden
Loll	Per	DMR A/S	Denmark
Lukkari	Tuomas	Sitowise Oy	Finland
Lundgaard	Nicolai	MT Højgaard A/S	Denmark
Lundin	Per-Axel	Eurofins Environment Testing Sweden AB	Sweden
Lusua	Iisak	Eko Harden Technologies	Finland
Lübeck	Josephine	University of Copenhagen	Denmark

Löfdahl	Mikael	SYNLAB	Sweden
Löfroth	Hjördis	Swedish Geotechnical Institute	Sweden
Løyche	Majken	ALS Laboratorie	Denmark

M

Madsen	Emil Krag	Sten & Grus Prøvestenen A/S	Denmark
Malmqvist	Patrik	Eurofins Environment Testing Sweden AB	Sweden
Maniquet	Francoise	SUEZ	Denmark
Mariager	Tue	Region Sjælland	Denmark
Martinsen	Kine	Norwegian Environment Agency	Norway
Michelsen	Pelle Funder	NOAH Danmark	Denmark
Mielke	Thomas	HUESKER Synthetic GmbH	Germany
Milosevic	Nemanja	MOE	Denmark
Milter	Hasse	Region Zealand	Denmark
Moe	Kamilla	Avinor AS	Norway
Moes Kristensen	Katrine	NIRAS A/S	Denmark
Molin	Josephine	PeroxyChem	USA
Mortensen	Peter	Eurofins Miljø A/S	Denmark
Mueller	Michael	PeroxyChem	Austria
Murray	Alexandra	Ph.D.-student / DTU Environment	Denmark
Møller	Mads	Orbicon	Denmark
Mørkebjerg Fischer	Line	Capital Region of Denmark	Denmark

N

Nathanail	Paul	LQM	United Kingdom
Nejrup	Jens	KMC Nordhavn, Københavns Kommune	Denmark
Nessø	Pia Cecilie	Norwegian Armed Forces	Denmark
Nielsen	Sanne Skov	Region Syddanmark, Miljø og Råstoffer	Denmark
Nilsson	Filip	NIRAS Sweden AB	Sweden
Nilsson	Patrik	Projektengagemang	Sweden
Norberg	Anna	Fortum Waste Solutions AB	Sweden
Norberg	Petra	SYNLAB	Sweden
Norrbrand	Björn	Försvarsmakten	Sweden
Norrlin	Johan	Geological Survey of Sweden	Sweden
Nousiainen	Aura	Pöyry Finland Oy	Finland

O

Ohlsson	Yvonne	Swedish Geotechnical Institute	Sweden
Olesen	Ida	Region Syddanmark	Denmark
Olesen	Morten	NIRAS	Denmark
Olsen	Bettina M.	Region of Zealand	Denmark
Olsen	Marianne	NIVA	Norway
Ottosen	Cecilie	Ph.D.-student / DTU Environment	Denmark
Overheu	Niels Døssing	Capital Region of Denmark	Denmark

P

Paulsson	Anna	Sweco Environment AB	Sweden

Peders	Kristian	NOAH	Sweden
Pedersen	Rita Splidt	Eurofins Miljø A/S	Denmark
Péraudin	Jean-Jacques	Geovariances	France
Persson	Audrone	Atkins Sverige AB	Sweden
Piirtola	Panu	Ramboll Finland Oy	Finland
Pindstofte	Katrine	SYNLAB	Denmark
Pizarro Rajala	Emma	Atkins Sverige AB	Sweden
Ploug	Niels	Krüger A/S	Denmark
Pratt	Allan	Helsingør Kommune	Denmark
Precht	Ulrich	Eurofins VBM Laboratoriet	Denmark
Pulkkinen	Tomi	Sitowise Oy	Finland
Putula	Kalle	Sitowise Oy	Finland

R

Ramstad	Hanne M.	ALS Laboratory Group Norway AS	Norway
Ranne	Lulu	Pirkanmaan ELY	Finland
Rasmussen	Tone	Sea Eco as	Norway
Raun	Kristian	Region Syddanmark, Miljø og Råstoffer	Denmark
Reinikainen	Jussi	Finnish Environment Institute	Finland
Rekola	Outi	Suomen Erityisjäte Oy / Scanwas	Finland
Rokkjær	Arne	Capital Region of Denmark	Denmark
Romantschuk	Martin	University of Helsinki	Finland
Roos	Marcus	Orbicon AB	Sweden
Rosenberg	Louise	Ph.D.-student / DTU Environment	Denmark
Rosqvist	Håkan	Lund Univ	Sweden
Røysland	Silje	Multiconsult	Norway

S

Sahyoun Sørensen	Andreas	DTU student/Municipality of Gladsaxe	Denmark
Sauer Ngijo	Anette	Resia	Sweden
Schouw	Nanette	Region Sjælland	Denmark
Selonen	Ville	Remsoil Ltd	Finland
Shore	Jack	REGENESIS	United Kingdom
Sivertsen	Anne	Capital Region of Denmark	Denmark
Sjøberg	Beate	Eurofins Environment Testing Norway AS	Norway
Sjölund	Gustaf	Nätverket Renare Mark/Dåva DAC	Sweden
Skadsheim	Arnfinn	Stavanger kommune, BMU	Norway
Skoog	Kristina	Golder Associates	Norway
Skovgaard Nielsen	Line	Capital Region of Denmark	Denmark
Skovly	Joakim	Eurofins	Denmark
Skovsgaard	Jakob	Rambøll	Denmark
Smebye	Andreas Botnen	NGI	Denmark
Snowball	Ian	Uppsala University	Sweden
Sorelius	Anna	Sweco Environment	Sweden
Soveri	Tommi	Orbicon AB	Sweden
Sparrenbom	Charlotte	Lund University	Sweden
Specht	Anette	Central Denmark Region	Denmark
Storrvik	Hanna Marie	UnionConsult	Norway

Sundberg	Emma	Tyréns AB	Sweden
Sunde	Mari	Miljoringen / NIRAS	Denmark
Svensson	Janna	Sweco Environment	Sweden
Sævarsson	Hilmar Thor	Lindum AS	Norway
T			
Takala	Mikael	Vahanen Environment Oy	Finland
Thimm	Kristof	HUESKER Synthetic GmbH	Germany
Thomsen	Lars	Wescon Miljökonsult AB	Sweden
Thomsen	Nanna	Danske Regioner	Denmark
Thorling Sørensen	Sine	The Capital Region of Denmark	Denmark
Thorman	Marlene	Golder	Denmark
Thorsgaard	Iben	Region Sjælland, N & M	Denmark
Tilli	Risto	FCG Design and Engineering	Finland
Toft	Anna	Capital Region of Denmark	Denmark
Tohmo	Teija	Uusimaa ELY-centre	Denmark
Travar	Igor	Ragn-Sells AB	Sweden
Tryggvesson	Michelle	Sweco Environment AB	Sweden
Tuomela	Marja	Co-op Bionautit	Finland
Tuxen	Nina	Capital Region of Denmark	Denmark
Törner	Erik	SYNLAB	Sweden
U			
Utterström	Kent	ALS Scandinavia	Sweden
V/W			
Wagenveld	Robert	QM Environmental International B.V.	Netherlands
Van Hees	Patrick	Eurofins Environment Sweden/Renare Mark	Sweden
Van Renterghem	Bart	Envisan NV	Belgium
Wejden	Bente	AvinorAS	Norway
Verner	Lisbeth	ATV Jord og Grundvand	Denmark
Verreydt	Goedele	iFLUX	Belgium
Wigh	Johan	Länsstyrelsen Skåne	Sweden
Von Kronhelm	Thomas	Fortum Waste Solutions AB	Sweden
Vyhnánek	Radek	ALS Czech Republic	Czech Republic
Vængtoft	Basse	Danish Emergency Management Agency Hedehusene	Denmark
Ø			
Ødegaard	Emil	Væksthus Hovedstad / Entreprise Europe Network	Denmark
Ølund	Claus	COWI A/S	Denmark
Örnhagen	Theresa	SYNLAB	Sweden
Österås	Ann Helén	WSP Sverige AB	Sweden
Østlie	Bjørn Øivind	Lindum AS	Norway
Å			
Åkesson	Rickard	COWI	Norway
Åkesson	Sofia	Lund University	Sweden

Exhibitors

ALS Laboratory (2)

ARKIL Fundering 4)

Danish Regions – Environment and Ressorces (13)

COWI A/S (10)

Eurofins (15-18)

Geovariances (7)

HUESKER Synthetic (11)

IFE – Institute for Energy Technology (9)

Organizers (21)

PeroxyChem (1)

QM Environmental International B.V. (8)

Rambøll (3)

REGENESIS (6)

Remsoil Ltd. (19)

RGS Nordic (20)

Sweco (22)

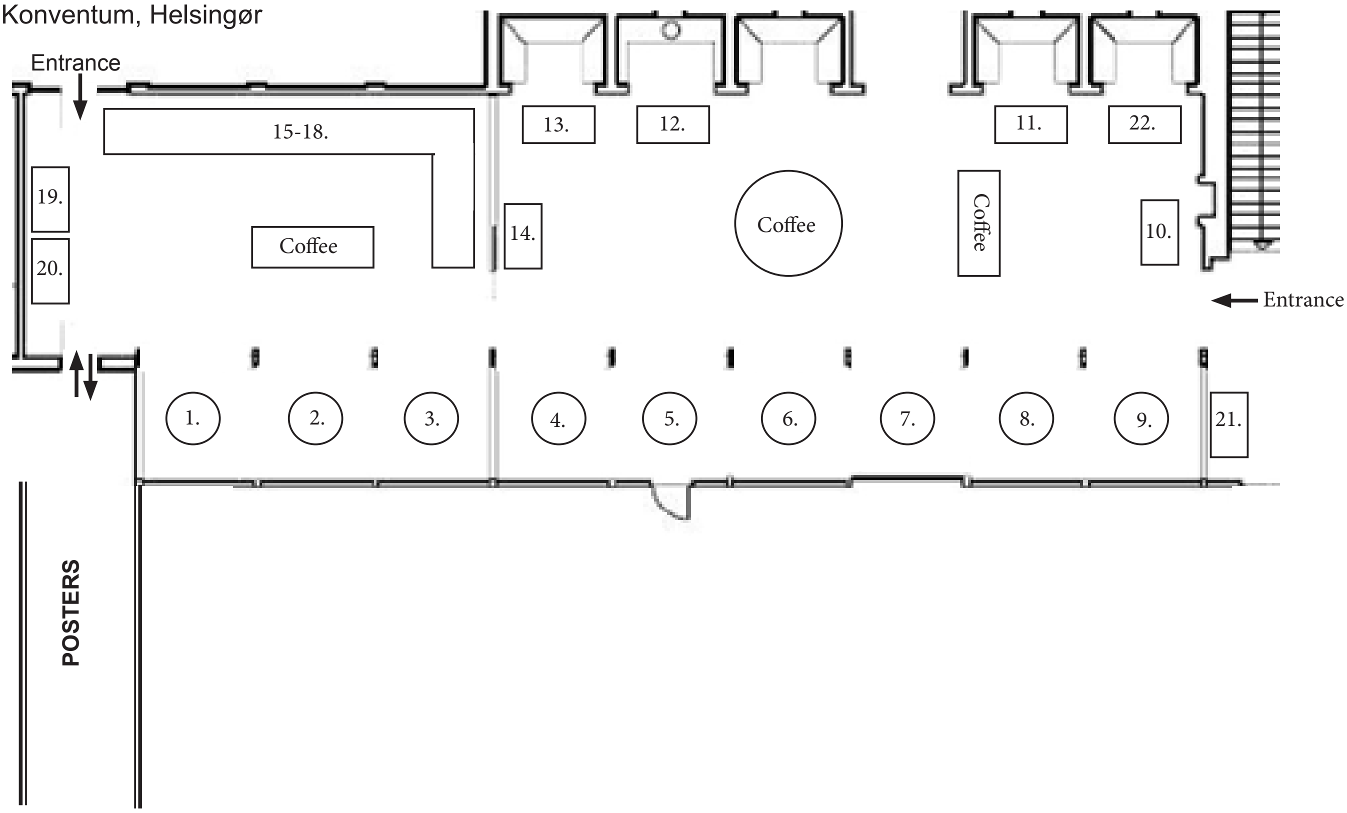
SUEZ (5)

SYNLAB (14)

Zenzors A/S (12)

The numbers indicate the location in the exhibition area :

Floor plan, NORDROCS 2018
Konventum, Helsingør



Posters

Title	Surname	First name	Organisation	Location number
A low-cost largescale investigation of contamination with chlorinated solvents and evaluation of remedial pumping	Soerensen	Andreas Sahyoun	Gladsaxe Muncipality	1
Assessment of slope stability of contaminated fiberbank deposits	Löfroth	Hjördis	Swedish Geotechnical Institute	2
PFAS in fire fighting foam	Olsen	Jette Kjøge	NIRAS	3
Evaluation of biodegradation capability of contaminated soil for *in situ* treatment	Tuomela	Marja	Co-op Bionautit	4
Improvement of traditional investigations by prior geophysical measurements	Blæsbjerg	Helle	Central Denmark Region	5
Investigation of possible contaminations from pesticide point sources	Banke	Lotte	Central Denmark Region	6
Novel passive sampling case study of Per- and Polyfluoroalkyl Compounds in groundwater and surfacewater	Jonge	Hubert de	Eurofins Environment	7
Passive Flux Sampling in Groundwater: Guidelines and Demonstration Cases with iFLUX Samplers	Verreydt	Goedele	iFLUX	8
Determination of polyflurinated compounds in soil and water	Šístek	Václav	ALS Czech Republic	9
Diving plumes - Understanding the parameters that affect contaminant transport in sandy aquifers	Moeller	Mads Georg	Orbicon	10
Electrokinetic in-situ remediation of a 75 tons xylene contamination in soil, bedrock and groundwater	Hougaard	Thomas	Golder	11
In-situ Thermal Desorption of Hydrocarbon-Impacted Soil	Haemers	Jan	Haemers Technologies	12
Mass discharge for vapor intrusion mitigation system analysis and vapor intrusion site assessment	Loll	Per	DMR A/S	13
Combination of enhanced reductive dechlorination and aquifer thermal energy storage – pilot test	Christophersen	Mette	Rambøll Danmark	14
Ex-situ treatment techniques for PFOS contaminated soils	Kahn	Adrien	SUEZ	15
New process for the treatment of perchlorate contaminated water	Kahn	Adrien	SUEZ	16
In situ soil washing of pentachlorophenol - a pilot study on a former saw mil	Forsberg	Kristin	Geological Survey of Sweden	17

l

Remediating DDT-contaminated soil using zero-valent iron – a pilot study on a forest nursery site	Forsberg	Kristin	Geological Survey of Sweden	18
In-situ adsorption of per- and polyfluorinated alkyl substances (PFAS) for remediation of contaminated groundwater	Fagerlund	Fritjof	Uppsala University	19
PFAS Treatment – Comparison of Remediation Approaches	Buhl	Jurgen	Cornelsen UmwelttechnologieG,bH	20
Remediation of chlorinated groundwater plumes in Denmark – a technology development project	Harrekilde	Dorte	Ramboll Denmark	21
Challenges in reusing clean soil	Harrekilde	Dorte	Ramboll Denmark	22
Side by Side Evaluation of BioGeoChemical, ISCR and ERD Reagents for Treatment of CVOCs	Molin	Josephine	PeroxyChem	23
Thermal Remediation of large contamination from former drycleaners in Kristianstad, Sweden	Holm	Jesper	Krüger-Veolia	24
Treatment of 1,4-Dioxane Comingled with TCA and DCA Using Both Oxidative and Reductive Pathways	Mueller	Mike	PeroxyChem	25
Using Amendments to Control Geotechnical Characteristics following Soil Mixing with ISCO	Mueller	Mike	PeroxyChem	26
An approach to estimate the risk of sediment and contaminant transport from marine fiberbank deposits	Göransson	Gunnel	Swedish Geotechnical Institute	27
Biological side-effects from activated carbon used in contaminated sediment treatment: From the design & implementation perspective	Jersak	Joe	SAO Environmental Consulting AB	28
Advancements and Case Studies in the Application of Activated Carbon for Contaminated Sediment Remediation	Hjartland	Tore	AquaBlok Norway	29
Remediation of a former industrial landfill using a multifunctional active surface sealing	Thimm	Kristof	Huesker Synthetic GmbH	30
Geotextile based solutions for treatment of contaminated subaquatic depositions	Thimm	Kristof	Huesker Synthetic GmbH	31
Historical EDC contamination in groundwater assessed by comprehensive DQO process	Takala	Mikael	Vahanen Environment Oy	32
Investigation on fibrous sediments in Sweden, an overview on objectives, geophysical method and results	Norrlin	Johan	Geological Survey of Sweden	33
Remediation of contaminated sediments in Nordic countries: a review	Lehoux	Alizée P.	Uppsala University	34
The challenges of capping fiberbank sediments ***in-situ***	Lehoux	Alizée P.	Uppsala University	35

Evaluating the current situation of PFAS in Lake Mälaren, Stockholm – distribution of PFAS in water column, surface sediment and sediment cores	Iverfelt	Ulrika	NIRAS AB	36
Unexpected contradiction between total metal contents and contaminant fluxes from marine fiberbank deposits	Frogner-Kockum	Paul	Swedish Geotechnical Institute	37
Finding ways to implement sustainability in remediation through procurement. Experiences from stakeholder engagement in a complex multisite 'design-build' tender for CHC contaminated urban groundwater remediation	Laitinen	Jarno	Centre for Economic Development-, Transport and the Environment	38
Thermal stripping as a method to remediation of PCB-contaminated tile and concrete prior to recycling in ground applications	Marlene	Thorman	Golder	39
Excavated soil reuse management in Central Denmark Region	Specht	Anette	Central Denmark Region	40
Geophysical monitoring of bio-remediation using the Direct Current resistivity and time-domain Induced Polarization (DCIP) method	Aakesson	Sofia	Lund University	41
Geostatistics of public data on urban soil contamination in the City of Copenhagen	Milosevic	Nemanja	MOE	42
Hydrocarbon background levels in Denmark in indoor and outdoor air	Hvidberg	Boerge	Central Denmark Region	43
Use of peat filtration to purify metals from runoff waters of a shooting range	Hakalahti	Teija	Vapo Clean Waters Ltd	44
Results of 20 years of monitoring of heavy metals in surface water from military training and shooting areas in Norway	Laastad	Eli Smette	Golder	45

Short Courses Programs

PFAS
- Dynamic investigations with mobile lab at PFAS-impacted sites

Monday September 3, 2018, 11.00 – 16.00

Organised by:
Anders G. Christensen, Expertise Director, NIRAS
Allan Horneman, Principal Geologist, ARCADIS
Nicklas Larsson, Project Director, NIRAS
Ian Ross, Global PFAS Leader, ARCADIS

Subject
In recent years, PFAS has been recognized as an emerging contaminant with numerous reports of impacted drinking water across the globe. This is also the case in the Scandinavian countries, where much attention has been given to the historical use of PFAS-containing AFFF-foams at firefighting training areas.

As a result of the complete lack of onsite analytical possibilities, investigations at PFAS sites are today carried out in a traditional manner. Hence, samples are collected in the field and subsequently analyzed at fixed laboratories with five days turnaround time. As a consequence, several separate investigations are required even at sites of "small" or "medium" complexity which leads to much extended projects and high costs.

In 2017, however, a mobile lab for PFAS analysis (LC-MS/MS) entered the market, making it possible to perform chemical analysis of 24 separate PFAS with detection levels down to single-digit ng/l. With a turnaround time of about one to two hours, data on PFAS-contamination is available at nearly real time, which enables dynamic work strategies even at PFAS-impacted sites and supports stronger conceptual site models and understanding of potential risks to receptors.

The course also includes a number of case studies where dynamic strategies have been used at PFASimpacted sites and information about the all-new mobile lab capabilities.

Program
- General introduction.
- Typical challenges involved when investigating and selecting remedy options at PFAS sites, including data
- needed to build a conceptual site model.
- Introduction to dynamic work strategies.
- Available tools to collect real time data on geology, hydrogeology and hydraulics (including Rotosonic, the
- Geoprobe platform, and more).
- Introduction to mobile lab to collect real time data on PFAS-contamination.
- Case studies from Scandinavia and North America.
- Closing remarks.

Geostatistics
An overview of Geostatistics for contaminated site characterization

Monday September 3, 2018, 13.00 – 16.00

Organised by:
Hélène Demougeot-Renard, Manager and founder, eOde
Claire Faucheux, Consultant, Geovariances
Per Loll, Development- and Project Manager, DMR A/S

Subject
As you are involved in the characterization or the remediation of contaminated sites, you regularly face the following issues:

- How to extract the main information from the whole set of data in order to improve the contamination understanding?
- How to map contamination and which interpolation method is appropriate?
- How to precisely assess contaminated soil volumes or pollutant masses?
- How to quantify uncertainties related to the delineation of impacted areas, while integrating geological heterogeneities?

During the short course, you will understand why geostatistics provides relevant methods to address these issues and how they can be applied in operational settings. Methodological talks illustrated with practical examples on real cases involving various types of pollution: chemical or radiological, leak from a source, reworked fills, etc. These examples involve several environmental media: soil, sediment, facilities (concrete).

Program
Understand and assess the spatial heterogeneity of pollution:
- Presentation of the classical approaches implemented for characterizing potentially polluted sites and for
- predicting contaminated soil volumes, as well as assessing their compatibility for future use.
- Pros/Cons and underlying assumptions of these approaches.
- Practical introduction to the concepts of heterogeneity and spatial variability of pollutants. Operational
- consequences on the feasibility of given remediation techniques.
- Recommendation for the sampling of potentially polluted sites.

Predict and map in-situ pollution:
- Introduction to the kriging and its advantages, compared to deterministic methods (inverse distance,
- nearest neighbors): Integration of the spatial variability, quantification of the attached uncertainty.

- Taking into account auxiliary information: site history, qualitative observations and quantitative measurements.

Quantify and locate contaminated volumes or pollutant masses:

- Risks attached to the use of interpolation methods for estimating contaminated volumes or source pollutant masses.
- Practical introduction to stochastic simulations.
- Presentation of results: Global estimation of contaminated volumes and attached uncertainty, local risk of exceeding cleanup levels.

Notes

Short Papers and Abstracts

Opening Session / Welcome

Ida Holm Olesen, Chairman
ATV Soil and Groundwater
and
Arne Rokkjær
Coordinator of the NORDROCS 2018 Organizing Committee

Risk assessment of contaminated sites to water resources:
The role of the contaminant mass discharge approach?
Keynote speaker Poul L. Bjerg
Professor, DTU Environment, Denmark

Sustainable remediation in practice
Keynote speaker Paul Nathanail
Professor, University of Nottingham, UK

Sustainable remediation in practice

Keynote speaker Paul Nathanail
Professor, Land Quality Management/University of Nottingham, UK,
mail: Paul@lqm.co.uk

Background
Sustainable remediation is the elimination and/or control of unacceptable risks in a safe and timely manner while optimizing the environmental, social, and economic value of the work (ISO 18504:2017; Nathanail et al., 2017).

Soil and groundwater contamination represents a threat to human and ecological well-being. Deliberate releases of pesticides or herbicides, accidental releases of liquid or solid wastes, acts of war, poorly constructed waste retention facilities – all can result in contaminants getting to places where humans, other animals or plants can be harmed or water resources can be rendered non-potable.

Remediation
In terms of risk based contaminated land management, remediation involves demonstrably reducing the risks posed to human health or other protected 'receptors' by soil or groundwater contamination. Remediation is carried out by reducing the contaminant concentration, changing its form so it is less available or less toxic, interrupting the pathway by which contamination reaches a receptor or by using institutional controls. Technologies can be combined to prepare the ground or contaminant for treatment, 'deal' with the risk and deal with the resultant waste. Combining individual technologies into remediation strategies can deliver considerable cost savings, improve social acceptance and reduce environmental impact of remediation. The legal context demanding remediation and other project objectives comprise constraints and boundaries within which a remediation strategy must fit if it is to be a reasonable strategy.

Aim
The aim of efforts around the world, and most notably that of a working group of the International Organization for Standardization that resulted in ISO18504:2017 Soil quality: Sustainable Remediation, is to improve the basis on which remediation strategies are selected.

Sustainable remediation
The ISO definition is easy to put in to practice. Consideration of the environmental and social aspects of remediation can result in improving the remediation strategy in ways that delivers cost savings as well. Once a preferred strategy has been identified, detailed value engineering and environmental footprint minimization can be beneficial.

Sustainable remediation forums (e.g. USA's SuRF and SURF ANZ member-based and project-based SURF UK) and networks (e.g. NICOLE) have developed informal guidance and raised the profile of sustainable remediation among practitioners, problem holders and regulators.

Conclusion

Remediation options appraisal involves developing a remediation strategy that is likely to achieve specific risk management objectives. Options appraisal depends on a detailed conceptual site model coupled with a sound grasp of the range of technologies available – and how they can be combined – to address legal and other project requirements within site specific constraints.

References

ISO. 2017. Soil quality - Sustainable remediation. ISO 18504:2017. 23pp.

Nathanail CP, Bakker LMM, Bardos P, Furukawa Y, Nardella A, Smith G, Smith JWN, Goetsche G. 2017. Towards an international standard: The ISO/DIS 18504 standard on sustainable remediation. Remediation. 28(1) 9–15. https://doi.org/10.1002/rem.21538???

Notes

Session A

EPA from the 4 Nordic countries

Risk management - regulatory perspectives

Chair: *Tom Heron*
Senior Vice President, Environment, Energy, Water and Informatics
NIRAS Denmark

Kine Martinsen
Senior Advisor, Norwegian Environment Agency

Preben Bruun
Technical Advisor, Danish EPA

Jussi Reinkainen
Senior Advisor, Finnish Environment Institute

Magdalena Gleisner
Senior Scientific Officer, Swedish EPAa

Risk management
- regulatory perspectives
EPA from the 4 Nordic countries

Kine Martinsen, Senior Advisor, Norwegian Environment Agency
Kine.martinsen@miljodir.no

Preben Bruun, Technical Advisor, Danish EPA
pbr@mst.dk

Jussi Reinikainen, Senior Advisor, Finnish Environment Institute
Jussi.Reinikainen@ymparisto.fi

Magdalena Gleisner, Senior Scientific Officer, Swedish EPA
Magdalena.gleisner@naturvardsverket.se

Background
Regulatory policies on contaminated land in all the Nordic countries are governed by chemical risks and their assessment. Hence, risk assessment has to comply with the regulatory requirements, but also provide justified information that can be used to implement reasonable risk management actions.

Risk assessment is used to identify and quantify potential harms that the chemicals on a given site may cause to human health or the environment. Site contamination is commonly assessed by established guidelines or screening values; or by applying site-specific models whereby contaminant exposure and the consequent effects on people or relevant environmental receptors (e.g. soil ecosystem, groundwater or surface water) can be estimated. Deficiencies and uncertainties are associated with both methods.

Risk management covers measures for the required risk reduction and control as indicated in the risk assessment, including soil and groundwater remediation, environmental monitoring and land use restrictions. Moreover, risk management in a wider scope involves many other considerations and decisions that may influence e.g. the usability or the value of the site in the future.

Aim
In this session, we will discuss the regulatory challenges of risk based decision-making;

Risk assessment methodologies can easily be manipulated or misunderstood. How do we provide enough understanding and transparency regarding both the possibilities and limitations of risk assessment methodologies?

Uniformity is an important regulatory aspect in terms of fairness and predictability, whereas flexibility is a key aspect in site-specific considerations. How do we find the optimal balance between uniformity and flexibility in risk assessments?

Risk assessments are often based on long-term estimates that cannot be verified in practice. Hence, regulators have to consider the tolerable level of uncertainty in the decision making process. How do we do that?

And how to find the optimum balance between the most effective and most cost efficient way of doing this by weighing advantages and costs.

Notes

Session B

Remediation – of Soil and Groundwater

Part I

Chair: *Marja Tuomela*
Ph.D., Co-op Bionautical and University of Helsinki, Finland

Environmental forensics. Searching for a major unknown PCE source in an industrial area using different tools, Birkerød, Denmark
Thomas Hauerberg Larsen
M.Sc., Ph.D., Orbicon, Denmark

Development of an iron-based soil mixing remediation method for energyefficient treatment of chlorinated solvents
Per Lindh
Ph.D., Swedish Geotechnical Institut, Sweden

Da Nang – an outstanding thermal remedy 5 years later
Niels Ploug
Sales and Product Manager, Krüger, Denmark

Environmental forensics. Searching for a major unknown PCE source in an industrial area using different tools, Birkerød, Denmark

Thomas Hauerberg Larsen, Ph.D., Env. Eng.
Orbicon, Denmark, mail: thla@orbicon.dk

Ida Damgaard, Ph.D., Env. Eng., Capital Region of Denmark
Anna Toft, Ms. Sc. Geology, Capital Region of Denmark
Arne Rokkjær, Civ. Eng., Capital Region of Denmark
Flemming Vormbak, Env. Eng., Capital Region of Denmark

A Soil Vapor Extraction (SVE) remediation performed at a TCE site in an industrial area showed no PCE content in the beginning of the operation. In addition, no sign of PCE was present in the thorough investigation at the site carried out over the previous couple of years. The initial removal rate of TCE was around 25 kg/y. After appr. 2 years of operation PCE started to show in the extraction wells together with an expected decline in the TCE content. After a period of appr. 2-2.5 years of operation the mass removal of PCE exceeded the TCE, and is now 20-25 kg PCE/y. The industrial area is characterized with many minor lots with a lot of different small-scale activities including metal degreasing. Thus, there are several known sources of TCE in the area, but only one known PCE source. That source is located around 275 m from the SVE remedy perpendicular to the general transport direction of the groundwater.

The geology in the industrial area is on the macroscale rather homogenous comprising of a clay till layer from the surface to appr. 12-13 mbg, followed by a sand layer of approximately 50 meters in thickness underlain by the limestone. The regional groundwater, which serves as the groundwater resource for the municipality downstream, is in the sand and limestone with a potential appr, 17-18 mbg. The unsaturated layer of sand of 5-6 m is where chlorinated solvents in the gas phase have spread by diffusion in all directions below the source areas. The SVE takes place in the unsaturated sand, with the aim to both remove mass from the sand layer but also to cut off further contamination emerging from the clay till.

Based on intuition and general knowledge of SVE operation it was difficult to accept that the known PCE site was the origin of the PCE found in the SVE wells. Over a period of more than a year several activities have taken place to determine if it is the source and if not, where could the unknown source be situated. The talk will present data and thoughts gathered during this process, including the use of specific isotopes. Activities and major findings are listed below.

Based on an initial pump test of air in the unsaturated sand pneumatic conductivity and leakage was determined. This was used for a model simulating 2 different SVE operations in the industrial area. The two plants has been in operation for different time periods and with different flows. Steady state pressure distributions (at different times) were used for particle tracking plots finding the travel times in the system from different spots in the catchment zone to the 2 SVE plants. Results showed that although the general transport time are reasonable from the known source, the distribution of PCE between the 4 extraction wells at the SVE site looks less probable.

Soil gas samples from the known source as well as extracted air from the SVE were analyzed for 13C/12C and 37Cl/35Cl. The results showing differences in the signature that could be explained as different sources rather than effects of transport.

Soil gas distributions in the unsaturated zone were taken in already existing filters as well as 6 new wells placed on the outskirts of the SVE site. Water samples were taken in the new wells as well as in other existing wells in the vicinity. Results showed that relatively high contents of PCE where present upgradient in both water and soil gas pointing in the direction of presence of a new unknown PCE source area in that direction. Samples were taken for the isotopes as well making it possible to compare water/soil gas distribution of the isotopes at both the known PCE site and at the SVE site as well as comparing the isotopes in the water at the two sites. Results are pending, but should strengthen the conclusions about the possibility of an unknown source.

Based on the preliminary results historical records of the lots around the SVE has been systematically collected and are in the process of being reviewed once more in order to look for potential candidates to further investigation.

It is expected that the potential area of interest will be narrowed down to a couple of lots in the next weeks which will be investigated further, probably during the year.

Development of an iron-based soil mixing remediation method for energyefficient treatment of chlorinated solvents

Per Lindh, PhD Geotechnical Engineering
Swedish Geotechnical Institute, mail: per.lindh@swedgeo.se

Annika Åberg, project manager Phase 1. Fil. Lic. Environmental Chemistry, Swedish Geotechnical Institute
Wilhelm Rankka, Project Manager Phase 1B, Fil. Lic., Swedish Geotechnical Institute
Fredrik Burman, Manager Geotechnical Laboratory,
Swedish Geotechnical Institute
Cecilia Toomväli, Manager Environmental Laboratory,
Swedish Geotechnical Institute
Erik Bergstedt, Swedish project coordinator, Swedish Geological Survey
Anna Toft, Technical Expert, Region Hovedstaden
Katerina, Hanzi, lead project manager, Region Hovedstaden

Background

Chlorinated organic solvents are commonly found as a soil- and groundwater contamination in Nordic countries. The Danish authority Region Hovedstaden has developed and tested a remediation technique based on in situ soil mixing: a zero-valent iron (ZVI) and bentonite-slurry is mixed into the soil and the presence of chlorinated solvents is reduced due to chemical oxidation on iron surfaces. Even though the technique is efficient for reducing the contaminant source term, treated soil has a reduced strength due to the bentonite amendment. Possible soil use alternatives after treatment are therefore limited. During 2017, Region Hovedstaden started an innovation-project “Sustainable Soil Mixing”, together with the Swedish authorities The Swedish Geotechnical Institute and The Swedish Geological Survey. The goal is to improve the geotechnical and energy efficiency performance of the soil mixing technique and to demonstrate the new functions in situ. The project is co-funded by Interreg Öresund-Kattegat-Skagerrak (2017-2020) and consists of two different phases: a laboratory phase during 2018 where the project builds new knowledge on how different binder combinations affect chemical degradation efficiency of TCE and development of strength, and a pilot phase during 2019 where the improved technique is tested and evaluated at two field sites. The final aim is to produce a technical guideline for stakeholders (consultants, problem owners and authorities), to facilitate acceptance and implementation of the technique.

Aim

We present results from the initial laboratory phase which was designed to find an optimal combination of binder components. Components include at least: Fe(II)-salts, cement and slag that are tested for chemical degradation and technical efficiency at different binder recipes. We discuss several experimental challenges and laboratory methods that were developed to resolve these challenges. We also present selected binder recipes which will be tested on Danish and Swedish field sites during 2019.

Some current challenges are related to expected binder-contaminant interactions: the original method was based on ZVI, which yields TCE chemical degradation pathways sensitive to high pH (9<). Cement is commonly used to gain strength in soil-and binder mixtures, but the addition of cement raises pH to 11<. If ZVI is substituted with Fe(II), the sensitivity for high pH is reduced, but perhaps also the TCE degradation efficiency. Addition of slag reduces the total carbon footprint of the method, and increase the setting time, which in turn should increase the chemical reaction phase. We are also investigating possible negative effects on strength in the presence of high TCE-concentrations. Laboratory testing is performed on two soils with different soil properties: a Danish clay till and a Swedish glacial clay.

Conclusion
We expect that the laboratory phase support conclusions related to following project questions:

1. is it possible to combine binder components and Fe-additives to reach acceptable strength in soil and chemical degradation of TCE?
2. which binder combinations should be used and how can they be optimized to increase the energy efficiency?
3. how can geotechnical and environmental laboratory methods be used to support optimization in preplanning phases?
4. How does recommendations for optimization differ between different soil types?

The Danish authority Region Sjaelland is following this project closely, contributing with ideas regarding the future use of the method.

Furthermore, we hope through this collaboration between Swedish and Danish authorities, to enable further collaboration regarding remediation and sustainable technology in our respective countries

Da Nang
an outstanding thermal remedy 5 years later

Niels Ploug, Sales & Product Manager
Krüger A/S, mail: nip@kruger.dk

Gorm Heron, Chief Technology Officer, TerraTherm
Jesper Holm, Projectmanager, Krüger A/S

Background
Chemicals like 2,3,7,8-TCCD (dioxin) are very persistent in the environment and very hard to treat. Approximately 87.000 m3 of soil and sediments located in 19 hectares around Da Nang Airport was impacted be chemical residues from handling Agent Orange during the Vietnam War. This included upland areas around the airport and the downstream wetlands. Some of the areas were still visual impacted. Despite a wet and warm climate, nothing has grown for more than 40 years due to persistence of chemicals.

In Da Nang, Vietnam dioxin concentrations in upland and surrounding wet lands where as high as 157.000 ng/kg in soil and 7.480 ng/kg in sediments.

In order to protect the environment and the wetlands U.S. Agency for International Development (USAID), who funded the project, and Vietnam Ministry of National Defense sat the objective of reducing dioxin concentrations to below150 ng/kg.

Aim
An environmental Assessment for remedy selection was performed by the client and his consultant. Four alternatives were evaluated: No Action, Passive Landfill, Active Landfill (Bioremediation) and In-Pile Thermal Desorption (IPTD). IPTD was evaluated as the only technology capable of reaching the cleanup goals. It was also evaluated to have the lowest potential environmental impact.

Due to the wide spread of the contamination an above ground pile structure was built to treat the soils and sediments in two batches of 45.000 m3. Treatability studies had shown a required treatment temperature of 335 °C for 21 days.

The pile structure was filled with 45.000 m3 excavated soil in phase 1 and dominantly sediments in phase 2. 1254 heater wells evenly spaced in the pile was used to heat the material. The pile was heated for more than 200 days achieving minimum temperatures well above 335 °C. As the soil heats up water and contaminants are vaporized and extracted from the pile. A comprehensive treatment plant was used to treat the outcome from the pile. These treatment steps included, cooling, NAPL (Non Aqueous Phase Liquid) separation, Macro Porous Polymer Extraction (MPPE) too overcome the high mass load, followed by activated carbon and finally arsenic removal. Off gas was treated using Activated Carbon.

When the water is vaporized from the pile, temperature rises and contaminants like Dixon is primarily removed by in situ destruction in the pile. When verification samples showed that treatment was completed, the pile was quenched with water and emptied for phase 2.

Both phases of treatment were hugely successful – the treatment goal of reaching 150 ng/kg of 2,3,7,8-TEQ was met and exceeded. For phase 1 one sample showed 50 ng/kg while the 95% UCL was 2,6 ng/kg and for phase 2 the 95% UCL was 0,24 ng/kg.

Conclusion

The ability to treat compounds like dioxin to extremely low concentrations using Thermal Conductive heating has been proven. Pre-design investigations, remediation technology testing, design through complete site cleanup were achieved in less than 9 years. IPTD met stringent treatment standards with > 99,99% removal. The source has now been removed and Da Nang Airport will be ready for transfer in 2018.

Notes

Session C

Sustainability and Reuse

Part I

Chair: *Jarno Laitinen,*
M.Sc., Project Manager, Pirkanmaa ELY-Centre, Finland

A sustainability perspective on reuse and remediation
Keynote Speaker Kristina Lindström
Professor, University of Helsinki, Finland

Reuse of concrete and risk assessments related to
the expansion of Oslo Airport Gardermoen
Ida Kristine Buraas
Project Manager, Golder, Norway

Efficient soil reuse – imperative for sustainable land management
Jussi Reinikainen
Senior Advisor, Finnish Environment Institute, Finland

A sustainability perspective on reuse and remediation

Keynote Speaker Kristina Lindström
Professor, University of Helsinki, Finland
Mail: kristina.lindstrom@helsinki.fi

Background
Sustainability as a concept is nowadays often used to “greenwash” strategies, economies and policies and make them socially acceptable. Therefire, it is important to critically examine those before just adopting practices labelled as sustainable. Agenda 2030 offers 17 targets (SDG:s) for sustainable development that have been widely accepted and can be used to analyze human activities in relation to the desired directions as pointed to in the agenda. Another useful concept for guiding human activities in a sustainable direction is to consider the planetary boundary values as described by Steffen et al. (2015), such as biodiversity loss, nutrient loadings, climate change and novel entities.

The National risk management strategy for contaminated land in Finland (Ministry of the Environment 2017), published first in the year of soils 2015, offers an excellent overview of the current situation regarding contaminated sites and a strategy for future actions in Finland. The strategic goal is formulated as Significant risks of contaminated land to the human health and the environment are managed in a sustainable way in 2040. A welcome novelty is the launch of a new state funding system.

According to the National Soil Database System MATTI, a majority of the contaminated sites in Finland are polluted due to fuel distribution. Remediation of oil contaminated soil also seems to receive the greatest attention as remediation target at the moment. Other significant pollutants are diverse toxic organic chemicals and heavy metals. Sediments are not listed in the database. However, the pulp and paper industry has through the years produced vast amounts of contaminated sediment, fiberbanks, that should be remediated. The environmental problems are global. For example oil pollution of coastal waters pose high risks all over the world and call for constant attention.

Aim
The aim of the talk is to discuss the strategy and some examples of remediation and reuse and apply principles from sustainability science to those. Could remediation efforts be part of future socio-technological transitions (Schot and Kanger 2018)?

Conclusion
The concepts bioeconomy and circular economy are tightly attached to remediation and reuse strategies. It is crucial that economic factors and business do not steer the processes but that biological, ecological and social factors are given enough weight. Remediation must rely on scientific methods and principles at all stages and enough resources must be reserved for research. The precautionary principle/approach should always be considered in the planning of land and water use in order to prevent the need for future remediation. In comparison with many other countries, the Nordic ones are in

the forefront of identifying these problems and developing solutions. We must in the end consider the whole globe, serve as a model poorer countries and collaborate with those in finding local solutions.

References

Ministry of the Environment 2017. National risk management strategy for contaminated land in Finland. 46 pp.
Schot J and Kanger L 2918. Deep transitions: Emergence, acceleration, stabilization and directionality. Research Policy 47, 1045-1059.
Steffen et al. 2015. Planetary boundaries: Guiding human development on a changing planet Planetary boundaries: Guiding human development on a changing planet Science 2015;347:1259855
United Nations 2015.
https://sustainabledevelopment.un.org/post2015/transformingourworld

Reuse of concrete and risk assessments related to the expansion of Oslo Airport Gardermoen

Ida Kristine Buraas, Project Manager
Golder, mail: ida.buraas@golder.no

Vidar Ellefsen, Project Director, Golder
Pål Fredrik Buraas, Environmental Consultant, Golder
Rune Nakstad, Environmental Construction Manager, ÅF Advansia

Background
The Non Schengen area of Oslo Airport Gardermoen is to be expanded and includes both terminal and airside (eastern pier expansion). 36.000 tons of concrete waste will be generated as a result of the expansion since old concrete paving must be removed. On behalf of the Oslo Airport department of Avinor (head of Norway's airport authority), Golder has carried out risk assessments and prepared an application to the Norwegian environmental agency (Miljødirektoratet) in order to reuse concrete from the demolition work. This will be the single largest reuse of concrete in a construction project in Norway.

The reused concrete will be repurposed for the establishment of internal roads, aircraft parking and airfields. Reused concrete is well suited to replace materials that otherwise would be produced and transported to the site, reducing thereby environmental impacts and health and safety hazards.

Results
The Norwegian Pollution Control Act sets normative concentrations as limits between contaminated and uncontaminated building materials, as well as hazardous waste limits for building materials. In order to reuse concrete with concentrations above the normative concentrations, a permission from the Norwegian environmental agency is necessary. Analytical test results of concrete samples at the airport indicated THC (total hydrocarbons) and/or metal concentrations above the Norwegian normative concentrations, but below the hazardous waste limits.

Almost all concrete samples contained THC (total hydrocarbons) concentrations above the normative concentration. Interpretation of chromatograms indicates residual oil, gas oil (air fuel) and engine oil and mixtures of those, as well as lignosulfonate. Lignosulfonate, a non-hazardous byproduct from the production of wood pulp, has been used as a concrete additive since the 1970s. As heavier THC fractions were found in small amounts in deeper parts of the concrete and in larger amounts in the top parts, the contamination is assumed to be due to operations at the airport as well as lignosulfonate. The assumption is based on interpreting chromatograms and core samples.

The concentrations of hexavalent chromium were of biggest concern regarding reuse. Despite the fact that an EU Directive, adopted by Norway in 2003, stipulates that soluble hexavalent chromium should be below 2 mg of chromium per kg of dry cement in all cements, concentrations of hexavalent chromium were detected above 2 mg/kg in many of the concrete samples. This is also the normative value in Norway.

There is no regulatory requirement for analytical methods for hexavalent chromium to evaluate reuse of concrete in Norway. Samples were analyzed using a spectrometric method (EN 15192) which indicates the total amount of hexavalent chromium and HPLC-ICP-MS, which indicates the soluble part of hexavalent chromium. All analytical results exceeded the normative value according to the spectrometric method, while none of the samples exceeded using HPLC-ICP-MS.

As concentrations of hexavalent chromium were detected above the normative value with one of the methods, column-leaching tests were performed to be able to evaluate the leaching behavior of crushed concrete and better clarify the environmental risk of transferring pollutants to groundwater. The test simulates short to mid-term and long-term leaching of chromium from the crushed concrete. The results demonstrate that actual leaching is significantly lower than theoretical values (Kd-values in soil) and the leachability of hexavalent chromium is greatest in the initial phase.

Since the leaching tests demonstrated concentrations of hexavalent chromium above the PNEC-value (predicted no-effect concentration), further assessments were made in order to demonstrate that reuse of concrete does not cause environmental risk of any damage or detriments to the environment. A risk assessment was conducted using site-specific parameters including leaching, amount of chromium leaching from concrete, and a site-specific calculation model for the transfer of pollutants through the unsaturated zone to the groundwater.

Conclusion

The risk assessment concludes that the environmental risk is acceptable. The results of the leaching tests and the risk analysis carried out by Golder demonstrates that only a portion of the THC and metals present in the concrete actually leaches into pore water and then groundwater at more than 10 meters of depth. Reuse of concrete is not expected to cause groundwater concentrations over acceptable levels at Oslo Airport Gardermoen.

The permit to reuse the concrete was granted by the Environmental Authorities the 8th of June 2018, nine months after the initial application was sent by Golder.

Efficient soil reuse – imperative for sustainable land management

Jussi Reinikainen, Senior Advisor
Finnish Environment Institute, mail: jussi.reinikainen@ymparisto.fi

Background
Although the Finnish policy approach on contaminated land strives for avoiding unnecessary remediation and using more innovative risk management methods, soil remediation is and will be often based on excavation. This results from the fact that the most typical drivers for remediation in Finland are related to site redevelopment activities where soil excavation, connected with conventional earth construction works, often is a practical solution. Hence, most of the redevelopment and remediation projects also involve management of excess excavated soils. Within the whole construction sector the annual amount of surplus soils, often disposed as waste, totals around 20-30 million tons. The wide range of impacts of transportation and disposal of such soils, as well as the consequent use of virgin soil materials can often be considered as the most critical factors for sustainability in the whole remediation or redevelopment project. Promoting environmental and economic sustainability in the soil management practice in earth construction is therefore a common objective for both regulators and practitioners.

Aim
To tackle the regulatory barriers for sustainable soil management, such as the likely obligation to apply for an environmental permit for soil reuse, a new government decree on the beneficial use of soils from construction activities, including remediation, is being finalized in the Finnish environmental administration in collaboration with key stakeholder groups. The objective of the decree is to promote reasonable, but controlled usage of surplus soils in earth construction by the adoption of a simple notification system that will replace the time-consuming environmental permit procedure. The decree is expected to be issued by the end of the year 2018.

The scope of the decree will be restricted to predefined waste materials, construction applications and site conditions, containing also principles and procedures for categorizing the excavated soils as waste. The materials, included in the decree, cover both contaminated and uncontaminated excavated soils that will be classified as waste, as well as certain waste-derived binders that can be used to stabilize soils for geotechnical purposes. The construction applications defined in the decree include traffic lanes, field structures, noise barriers, and filling applications, in addition to sites for temporary soil storage. The decree will also involve new risk-based environmental acceptability criteria for the leaching of contaminants from the soils to be reused alongside limit values for soil contaminant concentrations. Moreover, required quality assurance protocols covering e.g. standardized leaching tests and the necessary sampling approaches based on representative multi-increment samples will be given in the decree.

Conclusion

We believe that the forthcoming decree with the defined preconditions and the consequent simple notification system will strongly promote more efficient reuse of surplus soils originating from remediation and construction activities nationwide. Hence, it can also be expected to contribute to the attainment of more sustainable land management practice and advance the principles of circular economy.

Notes

Session D

Remediation – of Soil and Groundwater

Part II

Chair: *Annika Sidelmann Fjordbøge, Researcher, Ph.D., DTU Environment, Denmark*

In situ bioremediation of contaminated soil;
comparison and combination of different approaches
Keynote Speaker Martin Romantschuk
Professor, University of Helsinki, Finland

Multidisciplinary approach to characterize natural degradation of PCE
Sofia Aakesson
Ph.D.-student, Lund University, Sweden

Tools and concepts for quantifying in situ
degradation rates at contaminated sites
Nina Tuxen
Chief Consultant, Ph.D. Capital Region of Denmark

In situ bioremediation of contaminated soil; comparison and combination of different approaches

Keynote Speaker Martin Romantschuk
Professor, University of Helsinki, Finland
martin.romantschuk@helsinki.fi

Harri Talvenmäki, PhD student, University of Helsinki
Katariina Lahti, PhD student, University of Helsinki
Hannu Silvennoinen, CEO, Nordic Envicon Oy

Background
Organic contaminants in soil are a widespread problem that not only may cause damage to local biota, but also pose an ecological and health threat should they spread to groundwater aquifers and water ways. Therefore sites known to be contaminated should always be assessed preferable for both ecological and health risks. Based on the result of such assessments, remediation activities should then be performer to optimize the relationship between input of resources and the potential outcome. For more than twenty years we have developed and tested approaches for enhancement of bioremediation. Through collaboration between research facilities, contractors, and site owners, more than thirty actual sites presenting typical problems have been targeted for testing and optimization, first by laboratory modeling, and then by applying lab experiences in pilot scale and finally, full scale site treatments.

Aim
Through national and international collaboration we aim to recognize as many viable methods for in situ remediation as possible, and to test these methods in lab as well as in pilot and application scale together with expert scientists and contractors. By using established and novel methods in new innovative combinations we hope to be able to find functional in situ solutions for almost any contamination situation. Our aim is also to convince public authorities along with contractors to accept and welcome change. In situ solutions should become the norm rather than a curiosity.

Conclusion
Samples from various types of contaminated sites have been used in controlled laboratory conditions to build micro- and mesocosm- setups in which biological, physical, and chemical treatments are validated. Thorough knowledge of the site is vital for success, and therefore all site characterization efforts preceding remediation activities are crucial. In most cases the goal is to achieve optimal biostimulation and contaminant degradation. This is achieved by improving bioavailability of the target compounds and optimizing conditions for microbes by implementing nutrients and oxygen and in some cases, nanomaterials. Nanomaterials can work as a chemical treatment, but when used as a biostimulators, anaerobic corrosion of certain nanomaterials produces electron donors for contaminant degrading bacteria.

With compounds with low biodegradability, the introduction of selected bacteria may prove practical. Whereas pure cultures tend to be superseded by the existing soil microbes, importing them within special soil transplants from the humus layer or zones with similar contamination history has been proven a successful strategy. When needed chemical and physical means are harnessed to overcome the problems associated with in situ biostimulation. Biosurfactants can be used to dissolve non-soluble compounds to heighten their bioavailability, as long as the surfactants themselves don't act as the preferred carbon source for microbial digestion.

Further, we use electrokinetic pumping in combinations with biostimulation, bioaugmentation, nanoremediation etc. for maximal spreading of the intended effect. Many former fuel stations come with problems of mixed contamination and with volatile organic compounds more difficult to treat with biological methods. For these situations we have developed novel forms of underground flotation for removal of VOCs from soil and ground water. When needed, all the studied methods can be combined or used in sequence. At actual sites we have proven the functionality of a number of combinations, and additional ones are tested presently. Several SMEs are involved in our activities, and contacts with public authorities are dynamic.

The research has been funded by Interreg Central Baltic, Interreg Europe and Pirkanmaa Centre for Economic Development, Transport and the Environment.

Multidisciplinary approach to characterize natural degradation of PCE

Sofia, Åkesson, PhD student
Lund University, mail: sofia.akesson@geol.lu.se.

Robin Jansson, MSc student, Lund University
Charlotte Sparrenbom, Associate professor, Lund University
Catherine Paul, Associate professor, Lund University
Henry Holmstrand, Researcher, Stockholm University
Torleif Dahlin, Professor, Lund University

Background
In this study, we investigate natural degradation of tetrachloroethylene (PCE) and its metabolites at the Hagfors site, western Sweden. The site is heavily contaminated; however, degradation occurs even though the conditions are not ideal for the microbes.

To investigate the contamination and degradation status we are using an interdisciplinary approach. Primarily, we are using Direct Current resistivity and Induced Polarization (DCIP) tomography, a combined method to visualize the subsurface conditions and changes over time (see Fig. 1). In order to be able to interpret the geophysical models analyses of Physical- and BioGeoChemical (PBGC) properties and Compound-Specific Isotope Analysis (CSIA) are performed to characterize the chemical status and microbial degradation of PCE and metabolites.

We are searching for members the Dehalococcoides genus, known to degrade the pollutants. We will perform DNA extraction and PCR on filtered samples of groundwater, and hope to find Dehalococcoides from the same areas where we have enrichment of 13C and thereby quantify the degradation.

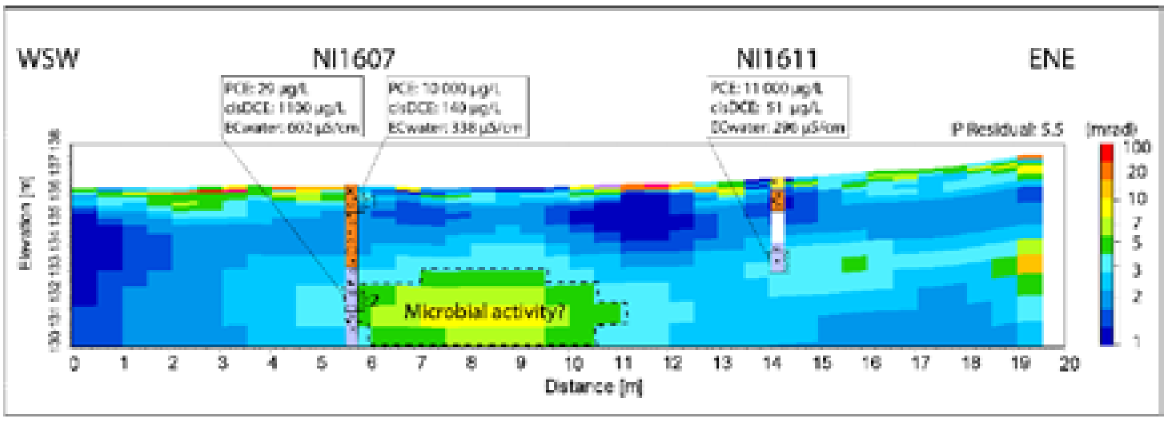


Fig. 1. Data of Induced Polarization over an area highly contaminated with PCE and an ongoing degradation.

Then we will compare the results with the DCIP models to see if the degradation is taking place in the area of the anomaly outlined in Fig. 1. We will also look into the possibility that the anomaly can be explained by the concentrations of pollutants or major ions in the groundwater.

The application of using the DCIP for monitoring remediation of PCE contaminations in combination with PBGC characterization and CSIA is a new approach.

Aim

This survey is part of the research project MIRACHL, which has the overall objective to use DCIP tomography as a monitoring tool of in situ remediation. By investigating an unaffected plume with natural degradation, we aim to understand the geophysical signals from in situ remediation. With our combined approach, we aim to retrieve a comprehensive coverage of the underground by the DCIP and by measuring the microbial activity via CSIA, qPCR and concentration analyses in pinpointed areas, understand and explain anomalies in the DCIP. If this is done through time, changes can be observed and degradation/reaction processes verified and possibly reduce uncertainties and costs for monitoring the in-situ remediation. We can then also deliver a more informative overview of the action underground for presentation and discussion with stakeholders.

Conclusion

The DCIP and groundwater concentration results indicates so far that natural attenuation occurs preferably in two zones in the studied area. At the present we are performing analyses for CSIA and microbial DNA and PCR to verify the microbial activity and degradation in the area. These results will be used to compare with ground water chemical concentrations and DCIP results to verify or discard if the DCIP anomalies shown are connected to microbial degradation or not.

Tools and concepts for quantifying in situ degradation rates at contaminated sites

Ida Damgaard, M.Sc., Ph.D., Env. Eng.
Capital Region Denmark mail: ida.damgaard@regionh.dk

Katerina Tsitonaki, M.Sc., Ph.D., Env. Eng. Orbicon A/S
Nina Tuxen M.Sc., Ph.D., Env. Eng. Capital Region Denmark
Henriette Kerrn-Jespersen, M.Sc., Env. Eng. Capital Region Denmark
Rasmus Jakobsen, Ph.D. Senior Researcher, GEUS
Christian Nyrop Albers, Ph.D. Senior Researcher, GEUS

Background
Chlorinated solvents from dry-cleaning and degreasing activities are the most common groundwater contaminants in Denmark, detected in approximately 10 % of drinking water wells. In Denmark, it is the state authorities, such as The Capital Region of Denmark, which are responsible for assessing the risks and manage the many sites polluted with chlorinated solvents. Active remediation is costly, hence Monitored Natural Attenuation (MNA) as a remediation strategy would probably reduce costs of site management. The usability of MNA will improve greatly, if reliable in-situ degradation rates for chlorinated compounds can be applied in risk assessments. In the last 10 years, several advanced analytical methods (such as Compound Specific Isotope Analysis (CSIA)) have been developed and applied by researchers but they have yet to gain broad applicability, partly due to some analyses not being available commercially and partly because consultants, regulators and site owners lack experience in using and interpreting this type of information.

Aim
The overall purpose is to be able to apply degradation rates with confidence in risk assessments. State of the art methods and tools that can confirm and quantify degradation processes were mapped with focus on their applicability at contaminated sites. Further tools and methodologies for quantifying natural degradation rates were developed.

Conclusions
After a comprehensive literature, review traditional methods such as hydrogeological, geochemical and chemical measurements as well as new promising techniques, microarrays (specific degraders and functional genes) and CSIA were applied at field scale at several sites.

Furthermore as part of the project a new method for measuring the in-situ degradation rate of cis-dichloroethylene in core samples was developed. In this method, core samples were injected and incubated with radiolabeled cis-DCE for a short incubation time (days). Using radiolabeled compounds enabled improved and rapid determination of the extremely low rates of dechlorination at near natural conditions.
An integrated approach combining the above tools was applied at several sites. At all sites, the approach succeeded in quantifying degradation rates.

In this project, a number of tools and suppliers were used and relevant information regarding each tool's applicability (sampling, price, detection limits, etc.) has been collected.

The presentation will discuss how the use of multiple lines of evidence to document degradation can be included in a concrete risk assessment and form the basis for decision making on remediation. Based on the lessons learnt from this project a list of the considerations for which tools can be used at certain phases in a site investigation depending on the site conditions has been compiled.

Notes

Session E

Sustainability and Reuse
Part II

Chair: *Aura Nousiainen*
Environmental Expert, Pöyry, Finland

Sustainable remediation assessment:
How to include the societal cost in the equation?
Jan Haemers
Managing Director, Haemers Technologies, Belgium

Strategic approach to climate protection and soil management
to fulfill the Sustainable Development Goals (SDG 11, 12 and 13)
Joan Krogh
NIRAS, Denmark

Remediation of PCB-polluted soil using biochar: the uptake of
PCBs in earthworms, plants and passive samplers – a pot experiment
Sigurbjörg Hjartardóttir
NGI, Norway

Sustainable management in large infrastructure projects of acid producing
rock and soil containing high, naturally occurring levels of heavy metals
Lars-André Erstad
M.Sc., Env.consultant and Project Manager,
Env.consultant Eva Aakre, Rambøll-Sweco ANS,Norway

Sustainable remediation assessment: How to include the societal cost in the equation?

Jan Haemers, Managing Director
HAEMERS Technologies, Brussels, Belgium,
mail: jan.haemers@haemers-tech.com

Background
The widely accepted definition of sustainability in policy is to fulfill the needs of the current generations without compromising those of future generations. It has therefore been widely discussed whether our current policies with regard to land remediation, in particular the Risk-Based Land Management (RBLM) is sustainable.

Another presentation of sustainability is to put sustainable policies at the crossroads of Economic, Environmental and Social parts of that policy. When applied to contaminated land management, one can position the main policies on that graph (Figure 1)

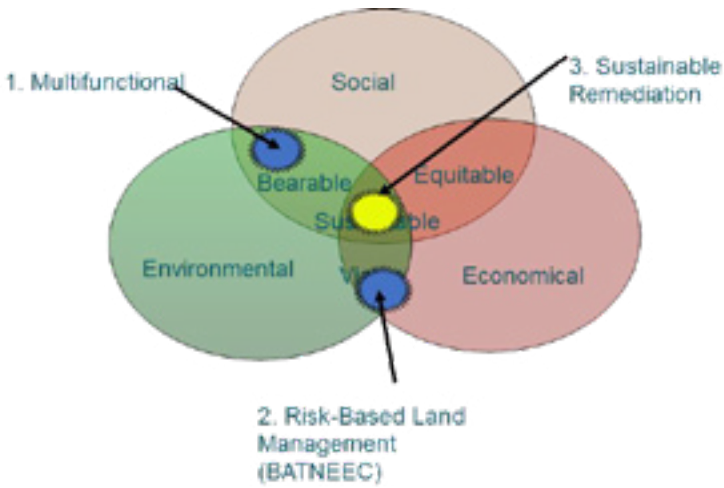


Figure 1: Sustainablity applied to succesive land management policies

A look back at history tells us that the first approach to soil remediation policy was to consider that the polluter should return the land in its pristine state, whatever the cost may be (the "polluter pays" principle). That was translated into 'Multifunctional' (Figure 1 – position 1), i.e. as a society, we should be able to decide unrestricted about future land use, as we do with 'natural' land.

Very quickly, this noble principle hit an economic limit. As shown on the graph, that position for multi-functional land management was 'bearable', as it took into account both environmental and social aspects, without considering economics.

The costs were unbearable. Mainly due to lack of technologies in those days (1980's – 1990's). Consequently, one came with the idea to manage the risks and impacts caused by pollution rather than to remediate completely, in order to keep the whole approach in balance with economical constraints. This concept was widely accepted as a method to prioritize the sites that needed to be fully cleaned-up and returned to society, and leave enough time for problem owners to finance the remediation, as well as counting on future technologies to bring innovative and more affordable solutions to restore the site in its pristine condition.

It was obvious that by imposing economically unbearable constraints, the factual result would be zero as problem owners would go bankrupt leaving the problem to the government.

RBLM is at the crossroads between economy and environment (the 'viable' section – Figure 1 – position 2). Indeed, it takes into account a minimization of environmental impacts while taking economic constraints into account. The social aspects are left out of the equation.

After almost 20 years of RBLM, there are more and more calls to move to the real center of the graph and have contaminated land management policies that are really sustainable, i.e. that integrate the social aspects.

Aim

Both policies (multi-functional and RBLM) can be illustrated by a simple example: A piece of land is contaminated with heavy hydrocarbons. There is no groundwater. The future use is undefined.

Under multifunctional land management, the site owner must remediation the whole site and bring all concentrations of heavy hydrocarbons to background level. Once that remediation is done, the local community can decide with no strings attached what to do with the site.

In RBLM, a possible solution is to reuse the site as a parking lot. A simple HDPE liner, covered by solid concrete will guarantee, based on a good environmental and human risk assessment that there is no risk of spreading the contamination and that a parking lot is a suitable use for the site, given its residual contamination and the constructive measures taken. Indeed, given the very limited potential exposure, the risks will be far within acceptable limits.

What this example illustrates is how the concept of RBLM has been misused. Indeed, where everyone agreed that the 'multi-functional' principle was unsustainable as it failed to take into account economic constraints, RBLM was supposed to be a carve-out to the 'Polluter pays' principle only if and when the multi-functional approach was too expensive. However, in most cases, that policy was stretched and the latter part of the condition (i.e. "if remediation costs are unbearable") was quickly forgotten. RBLM became the main policy, and people considered that the final objective is to mitigate risks, not to clean-up.

In other words, still referring to Figure 1, one went from 'bearable' to 'viable' without passing through 'sustainable'.

This abuse of the initial RBLM concept led to many instances of sites where remediation in the pristine state would have been perfectly bearable technically and economically, in particular with new and cheaper technologies existing today, but where they were not considered as they added no value to the problem owner. Governments have drafted legislation where Risk Management becomes the key drivers is remediation strategies and goals1. Therefore, economic actors will always choose the cheapest option if legal implications are equivalent.

Referring to the example above, for the problem owner, the case is fantastic as he will have almost no costs for his remediation, and will be able to use its land for economical benefits. One would argue that environmental issues are taken care of as it was proven that no contamination can leave the site since it is perfectly insulated, so there is no real environmental impact anymore, neither is there any risk for the people using the parking lot.

What is wrong with this approach?

Going back to the sustainable graph, this is the perfect example of a compromise solution between economic and environmental aspects. What is left out of the equation are the societal aspects. What are those?

By choosing for the 'parking' option, one has forced on society a land use it may not have chosen should all options have been open. The site might have been better suited for residential use for instance. Now residential development will have to be done elsewhere. Usually, this is then done at the outskirts of our towns and cities. Where agricultural land is turned into residential, creating economic windfall profits for agricultural land owners. Those areas are now built and people live there. Society will pay for extra roads, public transportation, utilities, etc. to be brought to those new developments. People will drive longer to work, creating mobility problems, but also more fuel consumption, pollution, etc.

This example shows that the RBLM approach, when it is applied without its legitimate restrictions (i.e. only applicable if and when proven that multifunctional remediation is economically unsustainable), will lead to private profits (for problem owners and agricultural land owners indirectly), and external costs supported by society (utilities, roads, mobility, less agricultural land available).

When evaluating remediation options, the immediate financial cost/benefit is always taken into account (total remediation costs are often #1 criteria and always in the top 3), whereas the societal costs are seldom considered.

One cannot expect problem owners to be candid and taken the societal costs into consideration when they choose which remediation is best for them. It is the government's main responsibility, as representative of society, to blend that element in the choice process. It is the government's responsibility to impose, whenever Risk Based Remediation is proposed, to demonstrate that multi-functional remediation would be economically unbearable. Failing to do so equates to transferring the liability (i.e.

[1] Often, a Risk assessment is compulsory as soon as soil contamination has been discovered. Even if and when it is clear that the problem owner is willing and able to fully remediate the site (very small sites for example), a risk evaluation will be imposed. Such Risk studies are meaningless and unnecessary burden if and when full remediation is economically viable.

the residual contamination) to the next generation, which is exactly the opposite of what sustainable development is.

Sustainable policies take care of the needs of current generations without compromising the needs of future generations. By leaving contamination behind, not only do we put a solid burden on the next generation (which will have to deal with it), but one compromises the quality of life of current generations elsewhere than on that site, as they will face the consequences of urban sprawl and agricultural land consumption, all of which are in part caused by our current policies allowing to leave contamination behind even if it is technically and economically feasible to fully remediate them.

Confusion about what social aspects mean for sustainable remediation

Sustainable Remediation is defined by The Sustainable remediation Forum UK (SuRF-UK) as "the practice of demonstrating, in terms of environmental, economic and social indicators, that the benefit of undertaking remediation is greater than its impact, and that the optimum remediation solution is selected through the use of a balanced decision-making process". Similar definitions were adopted by SuRF-US and similar groups.

The definition is relatively general and does not define further what the social indicators are. While looking more in detail, the various groups focus on the benefit for that site related to the local community for example. The larger aspects such as those mentioned above (urban sprawl, mobility, contamination left behind, etc.) are not addressed, mainly due to the difficulty to quantify them and to allocate those social costs. There is indeed no direct link between any given remediation and the larger urban sprawl and mobility issues, as there is no direct link between any CO2 emission and climate change. It contributes however to the problem, albeit its exact quantification is hardly impossible.

One should consider the social indicators as any burden transferred to the next generation. This aspect is essential is assessing sustainability, on site of far away from it.

Conclusion

Sustainable remediation is not remediating less, or greener. It is prioritizing the sites that need to be cleaned-up, using risk based land management, and once the sites are to be cleaned-up, to remediate until no contamination is left behind for the future generation.

Cleaning up land while leaving contamination behind is managing the problem, not solving it. It cannot be considered as remediation, and certainly not sustainable remediation.

References

Hadley, P. W., & Harclerode, M. (2015). Green remediation or sustainable remediation: Moving from dialogue to common practice. Remediation Journal, 25(2), 95-115. doi:10.1002/rem.21427

Simon, J. A. (2014). Editor's perspective-green and sustainable remediation: What does the future hold? Remediation Journal, 24(4), 1-6. doi:10.1002/rem.21400

Thavamani, P., Smith, E., Khavita, R., Mathieson, G., Megharaj, M., Srivastava, P., & Naidu, R. (2015, October). Risk based land management requires focus beyond the target contaminants: A case study involving weathered hydrocarbon contaminated soils. Retrieved from https://www.sciencedirect.com/science/article/pii/S2352186415000176

U.S. Sustainable Remediation Forum. (2009). Sustainable remediation white paper-integrating sustainable principles, practices, and metrics into remediation projects. Remediation Journal, 19(3), 5-114. doi:10.1002/rem.20210

Vegter, J., Lowe, J., & Kasamas, H. (2003). Risk-based land management - a concept for the sustainable management of contaminated land. Land Contamination & Reclamation, 11(1), 31-36. doi:10.2462/09670513.617

Woodward, D. S., Abrams, S. H., Geckeler, G., & Kessel, L. G. (2011). Sustainable remediation panel-projects that demonstrate the value of sustainable remediation. Remediation Journal, 21(2), 133-138. doi:10.1002/rem.20286

Strategic approach to climate protection and soil management to fulfill the Sustainable Development Goals (SDG 11, 12 and 13)

Joan Krogh, Cand. Scient. Geol.
NIRAS, mail: jkh@niras.dk

Morten Størup, architect m.a.a. market manager, NIRAS

Background

For many people, climate change is similar to sea water rises and the problems that evolves from these. Solutions include the establishment of new coastal dams. But climate change not only causes higher sea levels, but also a generally higher groundwater level due to higher amounts of precipitation.

Areas that have not previously experienced problems with high groundwater are already affected by climate change. Private householders experience problems with water in the gardens and damp houses and many farmers have problems with wet farmland and it is expected that the problem will be growing over the next decades. The traditional way of solving problems with high groundwater is often to establish drainage, and it is proposed to dig rivers and streams deeper to increase water capacity.

Aim

When municipalities are planning new urban development areas, increased groundwater levels are a challenge to which they must relate to as part of the climate protection of the area. A strategic approach to climate protection issues early in the planning process can lead to identification of other options for climate protection than excavation into drainage, larger streams or new lakes / wetlands. One option is to use surplus soil from nearby construction projects for terrain regulation of the new urban areas and in that way raise the terrain. This can decrease the problems with higher groundwater levels and also make the area more attractive to future buyers / developers. The terrain regulations can be regulated through local municipal planning.

When the new terrain is to be planned, one of the methods is to conduct a hydraulic analysis of the area, which makes it possible to designate which areas that can be raised with the best result and thereby also control the flow direction of rainwater. The result makes it possible to solve the problem of increased groundwater levels and flood problems from extreme rainfall by using surplus soil. The surplus soil then becomes the resource to solving the climate change problems instead of being a waste material, that often is transported over long distances to be deposited.

Examples of principle sketches of terrain-regulated areas.

Conclusion
As part of the strategic planning of the area around Favrholm, Hilleroed a hydraulic analysis has been carried out and combined with a model of local precipitation conditions and a surface model. The analysis showed that it is possible to make larger urban development areas where the surplus land from the construction works becomes an active resource in the terrain regulations and the total soil balance ended in equilibrium. The project is currently under construction.

At Åparken in Herning strategic planning on a new urban development area has begun in a low-lying area located close to a river. The purpose of the strategic planning is to ensure that the area is climate protected by using surplus land from other projects in the local area.

Both projects are examples that with a strategic approach surplus soil becomes a resource that can help fulfill the municipalities' commitments to fulfill the Sustainable Development Goals - primarily SDG11, 12 and 13.

Remediation of PCB-polluted soil using biochar: the uptake of PCBs in earthworms, plants and passive samplers – a pot experiment

Sigurbjörg Hjartardóttir, Environmental Consultant
Norwegian Geotechnical Institute – NGI, mail: sih@ngi.no

Sarah E. Hale, Technical Lead Contaminated Land, NGI.
Gerard Cornelissen, Expert Adviser Contaminants and Land use, NGI
Ludovica Silvani, Postdoc, NGI
Luca Nizzetto, Researcher aquatic contaminants,
Norwegian Institute for Water Research – NIVA
Lucie Bielska, Researcher, Research Centre for
Toxic Compounds in the Environment - RECETOX
Lucia Skulcova, Researcher, RECETOX

Background

The current move towards a more circular economy seeks to treat contaminated soil as a resource rather than as a waste. The remediation of contaminated soil in order to avoid unnecessary landfilling will help to achieve this aim. In recent years the popularity of biochar as a soil amendment has substantially increased. When added to contaminated soils in small amounts, biochar is able to sequester pollutants and make them unavailable for organisms and the surrounding soil. In addition to this property, producing biochar from biomass waste can contribute positively to waste handling issues, as well as the fact that the amendment of biochar to soil improves soil quality. Another large advantage with the use of biochar is that the production and use process results in a sequestration of carbon, thus a positive impact on climate change. Biochar represents a sustainable material for sorbent amendment and from a life cycle assessment perspective, biochar has been found to have lower energy demand and global warming potential impact than other amendment materials (such as activated carbon), and if engineered correctly be at least as effective as other materials for a lower cost.

Aim

This work provides additional knowledge in the area of PCB immobilization in agricultural soils following biochar amendments. The aims were to investigate the relationship between the uptake of PCBs by worms, plants and passive samplers as well as to compare the sorption capacity of two biochars, one made using a controlled high-technology method, and one made using an uncontrolled low-technology method.

A pot experiment was conducted using aged spiked PCB polluted agricultural soil that was amended with two different biochar types; mixed wood shavings biochar and rice husk biochar at two different doses 1% and 4%. The uptake of PCBs to two plants; ryegrass (Lolium perenne) and turnip (Brassica rapa ssp. rapa), to the earthworm species Eisenia fetida and passive samplers (polyethylene, PE) was assessed with and without biochar amendment.

Conclusion

The main findings from the work can be summarised as follows. The earthworms showed a preference for the presence of biochar and did not seem to be affected by the presence of PCBs. PCB uptake to earthworms was both dependant on PCB congener and biochar type, with rice husk biochar giving highest reduction in PCB-concentrations (up to 90% reduction). There was no effect of biochar dose suggesting that the remediation of PCB polluted soil with biochar could be effectively achieved with a small biochar addition. Ryegrass yield increased with the presence of both biochars, but was lower in the presence of PCBs. The turnip yield was inconclusive, but did not seem affected by the presence of the PCBs. Low concentrations of PCBs were detected in both plants with some difference between the PCB congeners. Turnip might be exercising phytoremediation and caution must be exercised if turnips are grown in PCB polluted, biochar amended soil with the intention of human consumption. Plant uptake was generally not affected by either type or dose of biochar. PE passive samplers sorbed PCBs and the uptake was PCB congener specific. Biochar reduced the uptake of PCBs to PE passive samplers and there were no real effects of biochar type or dose, however rice husk biochar seemed to perform better with respect to reduced PCB concentrations (up to 86% reduction) than mixed wood biochar.

The rice husk biochar made using an uncontrolled low-technology method, had a higher sorption capacity than the mixed wood biochar produced in a controlled manner. There was no correlation between the uptake of PCBs by PE passive samplers and by plants. However there was a correlation between the uptake of PCBs by PE passive samplers and by earthworms. This suggests that the accumulation of PCBs in PE passive samplers is a good proxy for the accumulation of PCBs in earthworms.

Sustainable and digital management in large infrastructure projects of acid producing rock and soil containing naturally high levels of heavy metals

Lars-André Erstad, M.Sc., Environmental geologist,
Rambøll Sweco ANS, Norway, mail: lars-andre.erstad@sweco.no

Eva Aakre, M.Sc., Head environmental geologist, Rambøll Sweco ANS, Norway
Marielle Øyvik, M.Sc., Head engineering geologist, Rambøll Sweco ANS, Norway
Kim Rudolph-Lund, M.Sc., Discipline expert hydrogeology, Rambøll Sweco ANS, Norway

Background
As part of the InterCity project, the Norwegian Railroad Authority (Bane Nor) is constructing 13,850 meters of new railroad track from Sørli to Åkersvika, in Norway. The area is known for its large occurrences of Cambrian and Ordovician black shale units. The units are enriched in heavy metals, uranium and sulfides. The high sulfide content can lead to environmentally hazardous acid rock drainage if not handled correctly during excavation.

A thick soil layer (till) deposited during the last glacial period overlies the bedrock. The till contains much of the same material as the underlying bedrock and can be potential acid sulfate soil.

The InterCity project will produce an estimated excess of 150,000 m3 of potentially acid producing bedrock, as well as an estimated 1 million m3 potentially acid sulfate soil enriched in heavy metals and arsenic. Deposition of bedrock and soil is costly as there are few qualified depots. The transport of these masses will have a significant CO2 footprint.

Stange municipality accounts for almost 10% of agricultural land-use in Hedmark county and this project is pioneering the re-use of excess soil and rock masses as compensation for lost cultivational areas.

Aim
The aim of this project is to further develop established techniques using handheld XRF in the construction phase which can be used to quickly decide further handling of acid soil masses. Part of this work has also involved software devolvement to improve the digital platform from field work to a multidisciplinary 3D model (Building information modeling, BIM). In this way technical solutions can be tailored after results from the fieldwork.

39 soil samples and 65 samples of drill cuttings from boreholes drilled in 2017 have been collected and analysed for their acid producing potential. Analyses were performed using both analytical chemistry and handheld XRF. This enabled calibration of the XRF

instrument for increased accuracy in field measurements. Another 178 boreholes were drilled during the winter season from 2017 to 2018. An average of three soil samples and one drill cuttings sample were collected at different depths in the same borehole. Samples were analysed with handheld XRF to decide further laboratory analysis.

The final goal of this project is to find a socioeconomically acceptable solution that allows for the re-use of the excess rock and soil excavated along the new railroad line. Alternative uses are landscaping and agriculture, which will conserve the environment and protect human health.

Conclusion
Further analyses of the results from this project will help to establish criteria for acceptable natural background concentrations for elements enriched in the soil. Acceptable background concentrations will form the basis for relocation and re-use of excess bedrock and soil which can be used, for example, in both landscaping and agriculture. Results from the geochemical analyses will be implemented in building information modeling (BIM) which will give greater predictability in cost estimation and make is possible for the project to tailor technical solutions if needed based on these conclusions at an early stage.

Use of XRF will allow for quick decisions in the field when it comes to handling excess masses, saving both time and money in the construction phase.

This presentation will focus on the systematic approach of sampling soil and bedrock and modification of established methods for identifying acid producing soil. The presentation will show an example of how results from the fieldwork is processed, systemised and included in a multidisciplinary 3D model (Building information modeling, BIM).

Notes

Notes

Session F

Risk Assessment of Soil and Groundwater

Chair: *Mette Christophersen*
Head of Department, Ph.D., Rambøll, Denmark

Assessment of in-situ natural and enhanced chlorinated ethenes degradation by use of isotopic and molecular biology techniques
Keynote Speaker Mette M. Broholm
Associate professor, DTU Environment
Technical University of Denmark

Direct radiotracer rate measurements of groundwater contaminants in intact cores –method and first results on cis-DCE dechlorination
Rasmus Jakobsen
Senior Researcher, Ph.D., GEUS, Denmark

Bacterial population dynamics in a groundwater plume from a heating oil spill quantified via 16 S rRNA gene amplicon sequencing
Poul Larsen
R&D Project Manager, DMR, Denmark

Assessment of in-situ natural and enhanced chlorinated ethenes degradation by use of isotopic and molecular biology techniques

Keynote Speaker Mette M. Broholm
Ph.D., Associate Professor, DTU Environment
mmbr@env.dtu.dk

Background
Chlorinated solvent contaminated sites continue to be a challenge in risk assessment and remediation. Source zone remediation has long been in focus in efforts to eliminate contaminant spreading and reduce risks. However, the often long and deep groundwater plumes continue to pose a risk, even where source remediation has significantly reduced the contaminant flux to the plumes. Hence, fate of contaminant plumes has recently gained focus.
Natural attenuation may be sufficiently effective to contain the plumes with or without source remediation. In other cases this may be obtained through stimulation of the degradation processes through addition of donor and/or bio-augmentation possibly enhanced by the addition of sorbents or reactants. In-situ documentation of chlorinated ethenes degradation and quantitative determination of the effectiveness (including in-situ degradation rates) of natural and enhanced degradation is challenging. The potential for in-situ assessment is facilitated by the introduction of new techniques, including compound specific stable isotope analysis (CSIA) for documentation and multi element CSIA for process identification, and molecular biology techniques to document and quantify microbial species, their genes and activities responsible for biodegradation. The continued developments in their use further the potential.

Aim
The presentation aims, through examples, to illustrate and evaluate the benefits of applying these new techniques in risk and remedial effect assessments of chlorinated ethenes plumes. Important process understanding gained through research application of these techniques at real sites is also presented.

Examples
One of the most extensively studied chlorinated ethene plumes is a > 2 km long plume of PCE and chlorinated degradation products, that has migrated downgradient from the source zone PCE DNAPL contamination at the former central dry cleaning facility in Rødekro, Region of Southern Denmark. The source zone was subject to thermal (steam) source zone remediation in late 2006. The plume has not undergone active remediation. Natural degradation of cDCE and VC as well as PCE and TCE within the plume prior to source treatment was documented by line of evidence including stable isotopes in 2006-7 (Hunkeler et al., JCH, 2011). Enhanced degradation within the plume caused by the release of dissolved organic carbon during thermal remediation of the source zone (Figure 1) was documented in an integrated approach including dual

element CSIA to distinguish biotic and abiotic processes as well as document degradation and molecular biological techniques to determine community composition and specific degrader presence and activity in 2014 (Badin et al., JCH, 2016). The analysis for microbial composition and specific degraders and their activity as well as dual stable isotopes has revealed high complexity in degradation processes and played an important role to substantiate the natural attenuation of the plume.
More recent studies (2017-18) have focused on furthering the understanding of the degradation processes, including the relative importance of the genera Dehalogenimonas and Dehalococcoides and potential competing organisms (iron and sulphate reducers), as well as the evolution in natural attenuation and risk of the plume (Murray et al. 2018). A special emphasis has also been put on the potential for estimation of degradation rates in the plume in 2017 investigations.

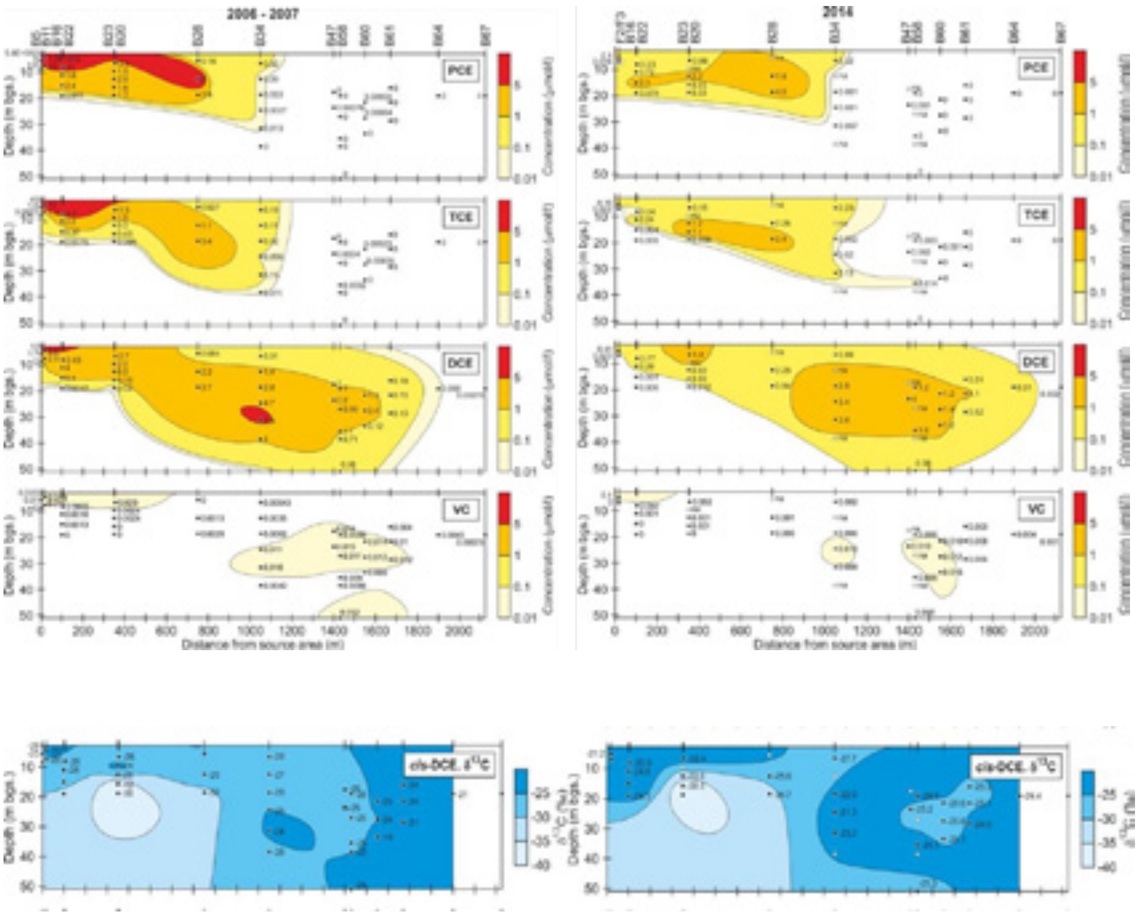


Figure 1. Chlorinated ethene concentrations and carbon CSIA data for cDCE for the Rødekro plume prior to and 8 years after the source remediation illustrating the concentration decrease and the increase in degradation documented by CSIA (Hunkeler et al. 2011; Badin et al. 2016).

This project is unique in the integrated characterization approach for line of evidence evaluation of the natural attenuation of cDCE and VC in the cDCE dominated plume and the monitoring of the effects of source remediation on plume natural attenuation.
The techniques are becoming more available to practitioners and are currently in use at a number of sites in the Capitol Region of Denmark where natural attenuation or enhanced biodegradation is evaluated. The conditions for and effectiveness of natural attenuation at these sites differ significantly from complete reductive dechlorination at

relatively high rates near source zones (Ottosen 2017) to very limited degradation prior to remedial enhancement (Tuxen, 2018), illustrating the breadth of challenges facing use of the techniques.

The techniques are currently applied in a TCE plume treated with liquid activated carbon amendment combined with donor stimulation and bio-augmentation. The sorption of the TCE and its degradation products to the carbon challenges the application of traditional analysis as well as the new techniques to aqueous as well as sediment samples. The compound specific retardation and the bioactive treatment zone challenge the interpretation of the processes and remediation effectiveness. This site offers the first ever results where the techniques are applied under the complexity of strongly enhanced sorption and biodegradation (Ottosen et al. 2019?). We expect the new isotopic and molecular biology techniques and further development of these will be critical for the assessment of the remediation effectiveness.

Conclusion and perspectives
Techniques that determine microbial community composition, specific degraders presence and activity, and dual element CSIA have revealed high complexity in degradation processes and played an important role to substantiate the natural attenuation of plumes. Some of the techniques have become available to practitioners and are likely to significantly improve site diagnostics, risk assessment and effects of remedial measures. Use of the techniques is expected to be critical for the evaluation of process stimulation and differentiation in the ever more complex remediation schemes involving both physical, chemical and biological contaminant removal.

References
Hunkeler, D., Abe, Y., Broholm, M.M., Jeannottat, S., Westergaard, C., Jacobsen, C.S., Aravena, R., and Bjerg, P.L., 2011. Assessing chlorinated ethene degradation in a large scale contaminant plume by dual carbon-chlorine isotope analysis and quantitative PCR, J. Contam. Hydrol., 119, 69-79.
Badin, A., Broholm, M.M., Jacobsen, C.S., Palau, J., Dennis, P., Hunkeler, D., 2016. Identification of abiotic and biotic reductive dechlorination in a chlorinated ethene plume after thermal source remediation by means of isotopic and molecular biology tools. Journal of Contaminant Hydrology, Vol. 192, p. 1-19.
Murray, A., Ottosen, C.B., Maillard, J., Johansen, A., Zimmermann, J., Hunkeler, D., Broholm, M.M., 2018. A field-scale analysis of novel chlorinated ethene degraders in groundwater in Rødekro, Denmark. Manuscript in progress.
Ottosen, C.B., 2017. Assessment of biodegradation by stable isotope analysis and microbial techniques in a source zone and plume contaminated with chlorinated ethenes. MSc thesis, DTU Environment.
Tuxen, N.,2018. Tools and concepts for quantifying in situ degradation rates at contaminated sites. Nordrocs 2018 abstract and presentation.
Ottosen, C.B., Harrekilde, D., Hunkeler, D., Birnstingl, J., Tuxen, N., Broholm, M.M., 2019?. Project in progress.

Direct radiotracer rate measurements of groundwater contaminants in intact cores –method and first results on cis-DCE dechlorination

Rasmus Jakobsen, Ph.D., Senior Researcher
GEUS, mail: raj@geus.dk

Christian Nyrop Albers, Ph.D.,Senior Researcher, GEUS
Katerina Tsitonaki, M.Sc., Ph.D., Env. Eng. Orbicon A/S
Mette M. Broholm, Associate Professor, DTU Environment
Liselotte Clausen, Ph.D., Env. Eng., HOFOR
Ida Damgaard, M.Sc., Ph.D., Env. Eng. Capital Region Denmark
Nina Tuxen, M.Sc., Ph.D., Env. Eng. Capital Region Denmark

Background

Point source contaminations often lead to plumes moving with the groundwater towards water supply wells or vulnerable recipients, but is the plume a threat? This will depend on how fast the contaminant is degraded to harmless compounds. If we can determine the rate of degradation we have a much better basis for finding the most economical way of handling the contamination and in case we choose to actively treat it, we can monitor the efficiency. Radiotracers have been used for the determination of rates of several natural processes in intact cores from marine and freshwater environments, including groundwater. The rates previously determined in groundwater using radiotracers are: rates of sulfate reduction using 35S-sulfate, rates of methanogenesis using 14C labelled carbondioxide and acetate, and rates of methane oxidation using 14C labelled methane. The principle is that a known activity of the radiotracer is injected and distributed into a core with a syringe and a long needle, the core is then incubated at in-situ temperature for the amount of time needed to obtain a signal and then the core is frozen until it is processed. In the processing, the reaction product of the radiolabeled compound is separated from the unreacted part and the radioactivity of the reacted fraction is determined. It is assumed that the added radiotracer has reacted at the same rate as the compound being traced so the rate can be derived by multiplying the fraction of reacted tracer with the concentration of the compound in the core and dividing by the incubation time. This general methodology can be used: if an adequately pure radiolabeled compound can be obtained, if it is possible to separate the reaction product from the unreacted tracer when processing the core and if the concentration of the contaminant is high enough so the tracer does not change it excessively. Of course the rate also needs to be high enough for a detectable amount of reaction product to form during a reasonable incubation time.

Aim

The first method that we have developed has aimed at measuring the rate of degradation of one of the most common and most critical compounds in groundwater contaminant plumes namely cis-dichloroethene (cis DCE). Plume studies have shown that the rate of cis DCE degradation is most critical because degradation often stalls at cis DCE. The aim is to have a method where the use of radiolabeled compounds enables an improved and rapid determination of the extremely low rates of dechlorination at near natural conditions, compared to determinations derived from microcosm studies, demanding longer incubation times. As a local measurement it can supplement values averaged in time and space derived from observed changes in concentrations or stable isotope fractionation along a groundwater flowpath.

Conclusions

It is possible to obtain radiolabeled cis-DCE of very high purity. The injected cis-DCE can be separated from its degradation products during the extraction using a cooled sorbent. The reaction products can be trapped in Carbosorb after passing a catalyst so the radioactivity can be determined by scintillation counting. Tests of loss during incubation, and adsorption during extraction showed minor losses and extraction and oxidation efficiency were acceptable. During extraction of a sample with an incubation time of zero, only 0.5‰ of the injected activity shows up as reaction product, implying that very low rates can be determined. The first actual measurements, using 10 and 20 days of incubation, on samples from actual plumes have resulted in rates of the same order as rates obtained by analyzing stable isotope fractionation in the plume. With minor modifications, the methodology can give rates of vinyl chloride degradation. Using sorption, freezing, precipitation and other separation methods it should be possible to develop methods for many other contaminants such as pesticides.

Bacterial population dynamics in a groundwater plume from a heating oil spill quantified via 16 S rRNA gene amplicon sequencing

Poul Larsen, R&D Project Manager, Ph.D.
DMR A/S, Denmark, mail: pla@dmr.dk

Per Loll, Thomas Lehmann Hansen and Claus Larsen - DMR A/S, Denmark
Morten Nørgaard Christensen, Oliebranchens Miljøpulje, Denmark
Jeppe Lund Nielsen and Nadieh de Jonge, Aalborg University, Denmark

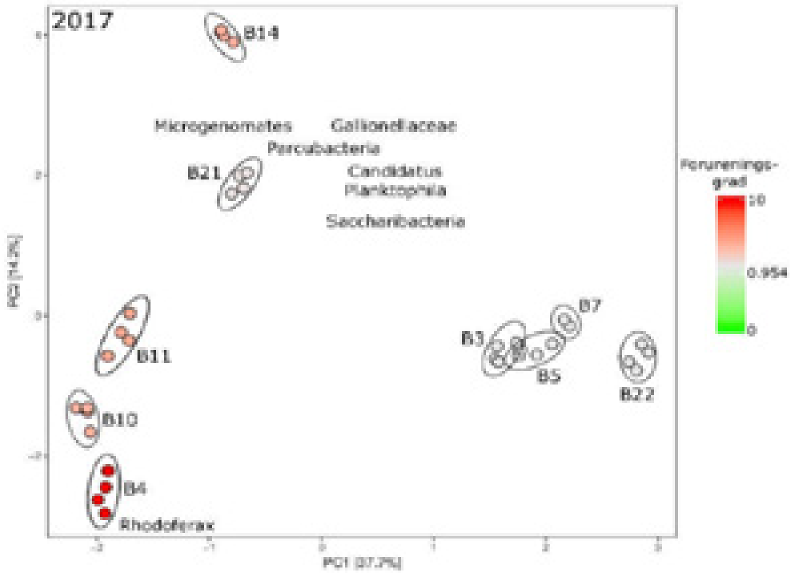
Background
For many hydrocarbons, it is well known, that natural degradation is occurring in most groundwater plumes. But for inclusion of degradation in a conservative risk assessment model, site specific documentation is needed. So far, indirect proof of natural degradation through decreasing concentrations, a shift in electron acceptors or isotopic composition, are the most commonly used indicator to document microbial activity, and degradation of pollutants. During the past 5 years, techniques for DNA-sequencing has improved dramatically and it is now possible to sequence (and data process) more than 50.000 bacteria for about 135 Euro per sample. This opens the possibility to use DNA-sequencing as a routine tool for a more direct assessment of the bacterial diversity, and of bacterial population response, at sites with groundwater contamination.

Aim
The aim of this pilot project was to test the potential of 16S rRNA gene amplicon sequencing as a tool for assessment of bacterial populations in contaminated groundwater. The protocol for sampling and handling was tested in a manner that can be inserted in the normal consultant procedure for groundwater sampling with a minimal amount of extra effort (both time and tools). The aim being to test the applicability of this type of analy¬sis to be performed as part of the normal toolbox in ground- and surface water risk assessment.

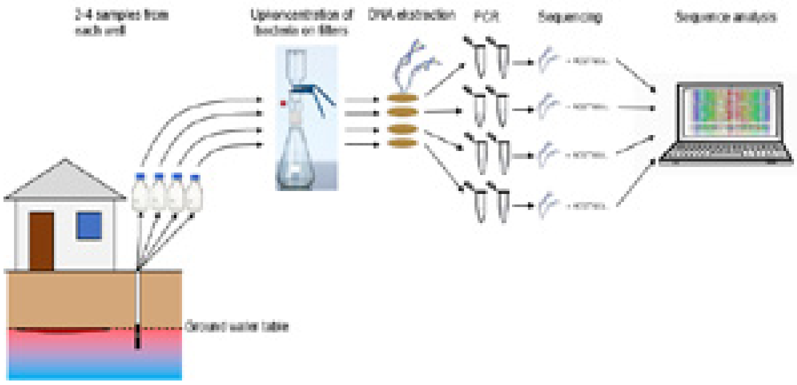
The test was performed at a site with a shallow groundwater table where the exact time of a heating oil spill was known. For testing the temporal changes of the bacterial community over time, samples were collected for characterization of the bacterial diversity only one month after the spill, and one year after the spill. 2-4 samples were collected from each of 9 wells to assess the procedural robustness and the need for replicates.

Conclusion
The test revealed a high similarity in bacterial composition between replicate samples, which is seen as a high tendency for grouping in the PCA-plot. Also, there was a clear tendency, that increased concentration of heating oil caused a shift in bacterial species composition. This pattern could be detected already one month after the spill – and

became more pronounced over time. Higher yield of extractable DNA in polluted samples substantiates, that the pattern was a result of bacterial growth/selection. The enriched species in the contaminated wells were primarily Rhodaferax, Acidovorax and Spirocaetaceae, some of which are known hydrocarbon degraders. These results showed, that bacterial degradation indeed took place at the test site, which add another dimension to the risk assessment, and substantiates other studies which has shown, that heating oil plumes in ground water is limited to an extent of about maximally 50 m.



The test proved to be highly robust, without the need for special equipment, as excellent replicate results were obtained, even under normal sample handling in a "dirty" consultant soil lab without cleanroom facilities.



An interesting result was, that even though there were many distinct species present, 50-60% of the biomass was comprised of less than 10-15 species in the polluted samples. This finding has interesting perspectives, as detailed site-specific knowledge of a few active bacterial species can become an important indicator and diagnostic tool for documenting naturally occurring degradation at other sites.

Notes

Notes

Session G

Contaminated Sediments – Risk Assessment and Remediation

Part I

Chair: *Paul Cappelen*
M.Sc., Geotechnical Institute, Norway

In-situ remediation of contaminated sediments:
Combining strong sorption with microbial dechlorination
Key note speaker Upal Ghosh
Professor, M.Sc. University of Maryland Baltimore County, USA

The Norwegian Management System of Risk Assessment
- contaminated Sediments
Hilde B. Keilen
M.Sc., Senior Adviser, Norwegian Environmental Agency, Norway

Dispersal pathways of contaminants from organic-rich sediments
– a field study of fibrous sediments in northern Sweden
Sarah Josefsson
Dr., SGU, Sweden

The Norwegian Management System of Risk Assessment - Contaminated Sediments

Hilde B. Keilen M.Sc.
Norwegian Environmental Agency, mail: hbk@miljodir.no.

Jeanette B. Beckius, M.Sc., Norwegian Environmental Agency
Harald Solberg, Norwegian Environmental Agency
Gijs Breedveld, Ph.D., NGI
Anne Kibsgaard, M.Sc. Director Environmental Engineering, NGI
Hans Peter Arp, Ph.D., NGI
Anders Ruus, Ph.D., NIVA
Torgeir Bakke, NIVA

Background

The Norwegian landscape with its mighty fjords and coastline is important for fishing, aquaculture and tourism. It is also important for recreation and leisure activities. A clean seabed, free from pollutants, is essential for a rich marine life.

Emissions from industrial activity and runoff from major cities and municipal wastewater have caused heavily polluted seabed in many Norwegian harbor and fjord areas. In Norway, much of the industrial activity is located in the inner part of the fjord. The fjords are also often deep, with a threshold that causes slow water exchange near the seabed. As a result, most of the pollutants have accumulated in the sediments in the inner part of the fjord. Even though measures of emission reduction have reduced the overall pollution today, pollutants from decades ago are still present in sediments. Ship and boat activity in harbor areas also contributes to spreading of the seabed contaminants to other areas and eventually to the marine food chain. Remediation of heavily contaminated sediments is therefore important to achieve a clean seabed with a rich marine flora and fauna.

Norwegian environmental authorities started a national work on mapping and remediation of contaminated seabed at the beginning of the 2000s. The work is anchored politically through the white paper no. 12 (2001-2002) Protecting the Riches of the Seas and no. 14 (2006-2007) Working together towards a non-toxic environment and a safer future — Norway's chemicals policy 2006-2007, which also describes the strategy and action plan for remediation of contaminated sediments.

The overall goal is that sediments contaminated with hazardous chemicals does not present a risk of serious adverse effects on plants, animals or humans. Remediation of the seabed is also an important measure in achieving the goal of the EU Water Framework Directive.

Aim
Because of this focus on remediation of contaminated sediment, The Norwegian Environment Agency, together with highly competent researchers and institutions, prepared the first issue of guidelines (2007) for environmental risk assessment of contaminated sediments. The guideline is based on risk of release of hazardous compounds from contaminated sediments, the impact on human health and on the ecosystem. The risk assessment system is a three level approach, with increased complexity and demand for local data. With an increasing amount of local data, the risk assessment becomes less conservative. These guidelines are regularly improved, latest in 2018, and harmonized with the system for classification of contaminated sediments and the Norwegian regulation of the Water Framework Directive.

Conclusion
The Environmental Agency will give a presentation of the main steps of the Norwegian Risk Assessment System related to sediment remediation projects.

Dispersal pathways of contaminants from organic-rich sediments – a field study of fibrous sediments in northern Sweden

Sarah Josefsson, Dr
Geological Survey of Sweden (SGU), mail: sarah.josefsson@sgu.se

Anna-Karin Dahlberg, Dr, Swedish University of Agricultural Sciences
Anna Apler, Ph.D- student, Geological Survey of Sweden
Paul Frogner-Kockum, Dr, Swedish Geotechnical Institute
Gunnel Göransson, Dr, Swedish Geotechnical Institute
Ian Snowball, Professor, Uppsala University
Karin Wiberg, Professor, Swedish University of Agricultural Sciences

Background

Several contaminated sediment areas with high organic matter content have been identified along the northern Baltic Sea coast of Sweden. These fibrous sediment deposits resulted from previously unrestricted discharges of wastewater by primarily the pulp & paper industry. The contaminant behaviour in this unusual sediment type is not certain. The high organic content of the fibrous sediment can on one hand enhance contaminant sorption, while on the other hand facilitate dispersal due to gas ebullition from organic matter degradation. The dispersal pathways of contaminants from fibrous sediments to the surrounding environ¬ment are investigated as part of the ongoing project TREASURE.

Aim

The aim of this study is to quantify potential important processes for the dispersal of organic contaminants from fibrous sediments. This includes diffusive/advective transport of dissolved contaminants, particle resuspension and uptake in benthic biota. Contrasting fibrous sediment areas in northern Sweden were investigated, and samples were taken in fiber¬banks (consisting almost entirely of fibers), fiber-rich sediment, and more minero¬genic natural sediment. Samples include sediment, sediment pore water, benthic biota, and passive samplers which quantify the sediment-to-water flux and concentrations in the water column. In addition, grab water samples were taken for resuspended sediment. The analysed contaminants were PCBs, DDTs and hexachlorobenzene.

Conclusion

Contaminant concentrations were highest in the fiberbanks, where also the content of organic carbon was highest, up to >35%. To evaluate sorption of contaminants to the sediment, KD values were calculated by relating the concentration in the sediment to the concentration in pore water (KD = CS/CPW). The sorption was highest in the fiberbanks, which was expected due to their high carbon content. Even so, pore water concentrations were still elevated in the fiberbanks due to high overall sediment concentrations.

The sediment-to-water flux, which was measured using passive samplers in flux chambers placed on the sediment, was connected to the pore water concentrations and significantly elevated at the fiberbanks compared to fiber-rich sediment and more minerogenic sediment. Interestingly, the sediment-to-water flux of PCBs was more than twice as high at one of the sampled sites (Väja, around 3 ng m-2 day-1) compared to the other site (Sandviken), despite similar concentrations in the pore water. One reason for this may be the higher gas content observed at Väja, probably related to differences in organic matter character (cellulose fibers vs. coarser wood fibers).

Benthic biota was not found in the fiberbanks due to anoxic conditions caused by organic matter degradation, only in fiber-rich sediment and more minerogenic sediment. Calculated biota-to-sediment accumulation factors (BSAFs) for the contaminants showed that bioaccumulation occurred in both analysed species. Contaminant levels were higher in the predator Saduria entomon than in the deposit feeder Marenzelleria spp., which indicates that biomagnification is occurring at the lower levels in the food web.

Overall, our study shows that both abiotic and biotic pathways are important for dispersal of contaminants from fibrous sediments. It demonstrates the need to further investigate and address fibrous sediments as point sources of contaminants to the aquatic environment, in the Baltic Sea as well as in other areas of the world where sediments impacted by fibers from the pulp, paper and board industry exist.

Notes

Session H

Investigation and monitoring of Soil and Groundwater

Part I

Chair: *Mette Broholm*
Associate Professor, DTU Environment, Technical University of Denmark

How groundwater velocity measurements can
strongly support aquifer characterisation studies
Keynote Speaker John Frederick Devlin
Professor, University of Kansas, USA

Multiple fluorescent dyes as a tool for understanding fate
and transport for large scale plumes
Nicklas Larsson
Project Director, NIRAS, Sweden

Porewater sampling in the unsaturated zone
– a novel technique for measuring seepage concentrations directly
Poul Larsen, R&D Project manager, Ph.D., DMR A/S

How groundwater velocity measurements can strongly support aquifer characterisation studies

Keynote Speaker John Frederick Devlin
Professor, University of Kansas, USA, mail: jfdevlin@ku.edu

Background

In the United States, the modern era of concentration-based contaminated site characterisation began in the mid- 1970s with the passing of the Resource Conservation and Recovery Act. Since at least the turn of the millennium, the engineering and hydrogeological communities concerned with groundwater restoration and risk assessment have been advocating a transition from concentration based decision making to one that is flux based – or at least flux informed. Such a change would shift emphasis from simple presence of pollutants at a location to consideration of pollutant movement, recognizing that substances that are not transported pose less risk than those that are. However, a possible limitation of the flux-based decision making approach is the uncertainty that accompanies flux measurements. Limited field experience, and modeling studies suggest that high sampling densities are required if flux estimates are obtained from control planes and multilevel sampling.

Aim

To review the strategies and concerns about flux-based site characterisation and discuss how direct velocity measurement could help overcome some of the limitations associated with the approach.

Conclusion

A primary concern about flux-based characterisation and decision making in contaminant hydrogeological investigations is the uncertainty that accompanies the values that ultimately control the decisions – fluxes are less certain than simple concentration measurements because they depend on multiple measurements and the associated propagated error, in addition to interpolation errors. Concentration data depend on error from single measurements, or averaged measurements, for which uncertainties can be relatively low. However, the direct measurement of groundwater velocity (or flux) may reduce uncertainty by eliminating hydraulic conductivity (a generally high source of error) from the calculations. Recent research has provided guidance, and tools for the most accurate estimations of flux across control planes so far.

In addition, a recent field case provides reason for optimism concerning flux-based characterisations in at least some cases.

Multiple fluorescent dyes as a tool for understanding fate and transport for large scale plumes

Nicklas Larsson, Project Director, NIRAS, mail: nla@niras.se

Gro Lilbaek, Project Manager, NIRAS
Anders G Christensen, Expertise Director, NIRAS
Sanna Börjesson, Project Manager, NIRAS
Benjamin Aske Hunner, Project Manager, NIRAS
Ulf Winnberg, Project Manager, Geological Survey of Sweden

Background
Protection of recipients, such as groundwater reservoirs and aquatic life, is of great concern across Scandinavia. At many contaminated sites, a fairly small distance between source area and recipient means that conventional methods can be used to clarify fate and transport of the contaminants. At some sites, however, large distances and/or multiple source areas may somewhat blur the image. Typically, this may be the case with chlorinated solvents and PFAS - two contaminants with the potential of generating large scale plumes.

At the Hagforstvätten site - located in central Sweden - two separate source areas with PCE DNAPL are responsible for discharge of large amounts of PCE into a nearby creek, where environmental quality standards are exceeded for most of the year. In the two source areas, PCE contamination occurs both at the "top" and "bottom" of the aquifer, approximately at 10 and 25 mbgl. respectively. It is unclear which of the two source areas that cause the largest discharge to the creek, and whether it is the pollutants at 10 or 25 mbgl. that pose the biggest problem. Since future remedial actions will be costly, it is vital that they are undertaken in (the right part of) the right source area.

Aim
A tracer test with four separate fluorescent dyes has been performed in order to quantify the contribution of PCE from the different parts of the two source areas.

Conclusion
Four different tracers have been injected in the "top" and "bottom" of each source area, followed by 15 months of monitoring in the aquifer, the creek and in a downstream river. The tracer test has verified some of the previously known pathways, but also revealed a number of unknown key informations. For instance, the study has revealed preferential flow paths acting as "highways" between source and recipient where previously hydraulic modeling has underestimated transport rates with an order of magnitude! These highways (10 m/day) are very important for mass discharge and - given the short retention time – they also limit the in situ-options in the source area. For instance, using ERD or ISCO in the source area could mean that potentially more toxic degradation products and active oxidants, respectively, would discharge into the

creek. Also, remediation efforts in the plume (i.e. Pump & Treat, PRB:s, etc.) will have to address the 10 m/day velocities!

The tracer test has also generated data to establish a mass balance and to determine actual dilution factors between groundwater and surface water. Hence, it is possible to establish future remedial goals for the different parts of the different source areas.

Finally, high resolution tracer sampling in the creek has revealed that PCE from the "top" and "bottom" of the source area discharges in one small (5 X 2 m) common discharge area. However, while tracer injected at the "top" is discharged along the north bank, tracer from the "bottom" is discharged along the opposite side. This underlines the complexity of groundwater/surface water interaction and implies that limited sampling in or near discharge areas may result in a quite wrongful understanding of mass discharge.

The presentation will address the above results and also describe how fluorescent dyes can be used as a tool to address different types of challenges. The presentation is believed to have great value for consultants, authorities and problem owners.

Porewater sampling in the unsaturated zone – a novel technique for measuring seepage concentrations directly

Poul Larsen, R&D Project manager, Ph.D.
DMR A/S, Denmark, mail: pla@dmr.dk

Per Loll, Andreas Houlberg Kristensen and Claus Larsen - DMR A/S
Hanne Kirk Østergaard - Region Nordjylland, Denmark

Background

The seepage concentration of soluble pollutants is a key parameter when assessing groundwater risk posed by hot-spots located above the groundwater table, in the unsaturated zone. Until now, direct measurement of seepage concentration of soluble volatiles has not been possible since techniques for porewater sampling is based on application of vacuum, which will strip volatiles, causing them underestimates of the true seepage concentration. Hence, risk assessments rely on estimating the seepage concentration from soil concentrations via (presumably) conservative equilibrium calculations – or via direct measurement in the groundwater if the source to groundwater transport time is sufficiently short relative to the spill time.

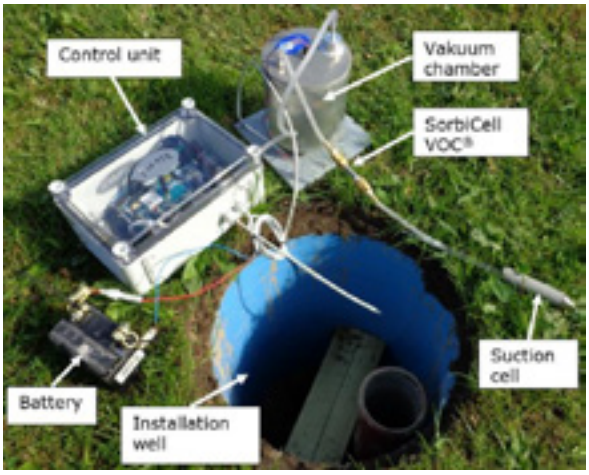
Aim

The aim was to develop a novel automated sampling technology that allows sampling and quantification of volatile organic compounds (VOCs) in pore water in the unsaturated zone. The technique should bypass the risk of stripping volatiles, reduce sampling costs and increase sampling stability which have been the main obstacles so far.

Conclusion

The presented equipment and methodology have been tested and allow for porewater sampling in the unsaturated zone for measurement of the seepage concentration directly in or below a hot-spot located above the groundwater table.

A novel sampling technology has been developed based on installation of a suction cell in the sampling point. Porewater is drawn from the unsaturated zone and passed through a SorbiCell®VOC where VOC's are adsorbed and conserved. The adsorption cell eliminates vapor stripping of VOCs during sampling, since the vacuum is applied to a vacuum chamber "downstream" of the SorbiCell. The amount of sampled porewater is monitored using a load cell, which enables the control unit to calculate flow and continuously regulate the vacuum setpoint if the flow exceeds flow limits for the Sorbi¬Cell. The vacuum is controlled by a small vacuum pump, and the installation can run on a standard auto battery for about 3 months. The control unit is equipped with a GSM modem which passes sampling data to an online spread sheet, making it possible to check the sampling status from the office and know when sampling is complete.



To the best of our knowledge, this is the first time sampling of volatiles has been possible in porewater. So far the technology has been successfully tested at depths of up to 7 meters, at sites polluted with chlorinated solvents, oil hydrocarbons and pesticides. At these sites the results allowed for a more realistic, but still conservative, risk assessment.

This enables us to base estimates of vertical flux of eg. chlorinated compounds to underlying groundwater aquifers, based on actual measurements of seepage concentrations rather than calculated equilibrium concentrations. The presentation will exemplify various applications and results of the technique and highlight practical applications.

Notes

Notes

Session I

Contaminated Sediments – Risk Assessment and Remediation

Part I

Chair: *Peter Harms-Ringdahl*
M.Sc., Environmental Consultant, EnviFix, Sweden

TREASURE: Novel and innovative methods used to characterize two of Sweden's contaminated fiberbank sediment sites
Ian Snowball
Professor, Uppsala University, Sweden

Remediation of Oskarshamn hamn: challenges and lessons learned from contractor point of view
Bart van Renterghem
Regional Manager, Envisan, Belgium

Quantification of microplastics in sediments from benthic and coastal environments
Heidi Knutsen
M.Sc., NGI, Norway

Nontarget analysis of sediment samples from Copenhagen, Denmark
Josephine Lübeck
Ph.D.-student, University of Copenhagen, Denmark

TREASURE: Novel and innovative methods used to characterize two of Sweden's contaminated fiberbank sediment sites

Ian Snowball, Professor
Uppsala University, Sweden, mail: ian.snowball@geo.uu.se

Anna Apler, PhD student, Geological Survey of Sweden
Anna-Karin Dahlberg, Dr, Swedish University of Agricultural Sciences
Paul Frogner-Kockum, Dr, Swedish Geotechnical Institute
Gunnel Göransson, Dr, Swedish Geotechnical Institute
Per Hall, Professor, University of Gothenburg, Sweden
Sarah Josefsson, Dr, Geological Survey of Sweden
Mikhail Kononets, University of Gothenburg, Sweden
Achim Kopf, Professor, University of Bremen
Hjördis Löfröth, Dr, Swedish Geotechnical Institute
Catherine Paul, Dr, Lund University, Sweden
Matt O'Regan, Dr, Stockholm University, Sweden
Karin Wiberg, Professor, Swedish University of Agricultural Sciences
Lovisa Zillén, Dr, Geological Survey of Sweden

Background
Prior to legislation in the second half of the 20th century, Sweden's paper and pulp factories discharged effluents and solid waste products directly into water bodies, most notably along Sweden's northern Baltic Sea coast. Marine geological surveys of 39 areas potentially impacted by the solid waste and its contaminants were contracted by county boards between 2010 and 2015. These surveys detected 19 sites where this waste exists today as relatively thick deposits of cellulose, which have been coined "fiberbanks". Some fiberbanks rest on relatively steep slopes in shallows waters, and in areas that are prone to land uplift and submarine slope failure. They contain elevated levels of legacy organic pollutants and trace metals, notably dioxins, DDTs, mercury and methylmercury but also, e.g., arsenic, chrome, nickel and cadmium.

Aim
The TREASURE* project contributes to a government initiative to expedite the remediation of contaminated sites. We aim to improve our knowledge of the physical and chemical properties of fiberbank sediments that are relevant to environmental risk assessment, which required development and application of novel methods to physically characterise them and quantify the physical and chemical mechanisms that can disperse contaminants to areas of bioaccumulation. The project, which is based on two pilot sites, is holistic and includes investigations of slope stability, contaminant transport and pollutant levels in benthic biota.

Conclusion
Fiberbanks are challenging to characterize and necessitate innovation. The deployment of purpose-built penetrometers enabled us to map the vertical and horizontal extent of

our chosen fiberbanks, which will provide better estimates of volume at sites where gas contents diffuse hydro-acoustic signals. We show that metal fluxes obtained from in-situ benthic flux chambers need to be considered in environmental risk assessment of areas affected by contaminated sediments in addition to total concentrations and/or flux model predictions, even if metals appear strongly bound to the fine grained organics in the reduced environment. Finally, persistent organic pollutants are taken up by benthic biota in adjacent fiber-rich sediments – a vector for transfer to organisms at higher trophic levels, such as fish and predator birds. This observation is perhaps the main motivation to design and implement proven methods to remediate these contaminated sediments.

* Targeting emerging contaminated sediments along the uplifting northern Baltic coast of Sweden for remediation

Remediation of Oskarshamn hamn: challenges and lessons learned from contractor point of view

Bart Van Renterghem, Regional Manager
Envisan NV, mail: Bart.vanrenterghem@envisan.com

Sofie Herman, Project Manage,r Envisan NV
Bert Crollet, Works Manager, Envisan NV

Background
Oskarshamn is a Swedish port city with a rich industrial history. In the past, a copper production site and battery factory discharged their contaminated waste water into the sea, as a result of which the whole harbour basin is now heavily contaminated and a source of heavy metals, dioxins, PCB,.... As the vessels continue to sail into and out of the port, the polluted sediments are also dispersed over the Baltic Sea. Envisan has been entrusted with the remediation works in what is currently the biggest environmental project ever executed in Sweden and financed with public funds.

The purpose of the whole project is to decontaminate the seabed in the harbour basin, a surface of 500,000 m2. Around 350,000 m3 of heavily contaminated sediments are dredged with a combination of hydraulic and mechanical dredging technologies, each of the technologies having its advantages and disadvantages. The dredged sediments are collected on-shore in a screen so as to separate all coarser material. Subsequently, the sediments are led to thickeners which, through a settling process, make a first separation between water and sediments. The water is pumped to the water treatment plant, the sediments to a silo for further dewatering. In the silo, lime milk is added to accelerate the dewatering process. The final step in the dewatering process is executed in filter presses, where the last amounts of water are pressed out of the sediments, leaving behind a hard cake. These cakes are transported with closed trucks to a licensed mono-landfill.

By adding polymer and flocculants to the water coming from the filter presses and thickeners, the remaining sediments in the wart start to congeal and settle. Through a laminated separator and sand filters, the final sediments are removed and pumped back into the starting point of the treatment plant. The purified water is partly re-used as process water for the plant, partly re-entered into the sea after a quality inspection.

Aim
In March 2016, Envisan started with the construction of the sediment dewatering and water treatment plant of which the design was entirely done in-house. The dredging and operation of the dewatering installation started in October 2016 and was stopped in November due to winter conditions. continued from April till November 2017.

Everything going according to plan, the remediation works should be finalized by November 2018.

Focus of the presentation will be on the challenges and lessons learned from contractor point of view as well as the achieved production rates and bottle necks

Conclusion
Dredging and operation of the dewatering plant will be on-going in the 6 to 8 months prior to Nordrocs 2018, making it too premature to draft already at this stage an overview of the challenges faced and lessons learned. One of the focus will be the advantages and disadvantages of the different dredging technologies applied.

Quantification of microplastics in sediments from benthic and coastal environments

Heidi Knutsen, M.Sc.
NGI, Oslo, Norway, mail: hkn@ngi.no

Hans Peter H. Arp (Prof.), NGI, Oslo, Norway and NTNU, Trondheim, Norway
Linn Merethe Brekke Olsen (M.Sc.), NGI, Oslo, Norway
Sabnam Mahat (M. Sc.), 2NMBU, Ås, Norway
Emma Jane Wade (B.Sc.), NGI, Oslo, Norway
Øyvind Lilleeng (M.Sc.), 2NMBU, Ås, Norway

Background
It has been estimated that there are orders of magnitude more microplastic on the sea floor than on the sea surface. Sediments in urban and industrial areas too are also likely polluted with microplastics. However, there is relatively little quantitative data to verify this in diverse environments, nor is there at present a universally accepted quantification method for microplastics in sediment.

Aim
The aim of the presentation is to present an overview of weathering and other processes that can lead to microplastic sinking. In addition, a novel, efficient method to quantify microplastics in sediments and benthic environments will be presented, along with surveying data of microplastic abundance from unique environments, including the Norwegian continental shelf, landfill sediments, and the coast of Havana.

Conclusion
The presented, novel method to quantify microplastics in sediments has shown to be efficient, and microplastics are found in sediment samples from various benthic and coastal environments. This method can be used to gain more insight into the emissions, fate and environmental consequences of microplastics.

Nontarget analysis of sediment samples from Copenhagen, Denmark

Josephine Lübeck, Ph.D.-student
Department of Plant and Environmental Sciences, University of Copenhagen,
mail: jsl@plen.ku.dk

Guilherme L. Alexandrino, Researcher, Department of Plant and Environmental Sciences, University of Copenhagen
Linus M. V. Malmquist, Lab manager, Department of Plant and Environmental Sciences, University of Copenhagen
Jan H. Christensen, Professor, Department of Plant and Environmental Sciences, University of Copenhagen

Background:
Sediments are sinks for various anthropogenic pollutants. Traditionally, gas chromatography-mass spectrometry (GC-MS) is employed for the identification of specific nonpolar contaminants in sediment samples. Yet, the analysis is limited in resolution and is better fit for the analysis of target analytes. A novel technique for sediment analysis is supercritical fluid chromatography (SFC)-MS which is comparable to normal phase liquid chromatography (NPLC) and has the potential to be used for hydrocarbon group-type separation, and for nontarget analysis of non- to slightly polar compounds.

Aim:
In this study, a comprehensive two-dimensional GC (GC×GC)-high-resolution (HR) MS method was developed for the characterization of pollution patterns and sources in sediment samples from Copenhagen waters. Additionally, a novel SFC-MS with electrospray ionization was employed for the analysis of the same samples and compared.

Conclusion:
The chemical fingerprints describing the samples were evaluated using pixels-based analysis and chemometrics. Initially, the raw base peak chromatograms were pre-processed to correct retention time shifts and concentration discrepancies among the samples due to the sample preparation. The most relevant compounds within their chemical fingerprints that distinguish the samples (nontargeted analysis) were obtained using Principal Component Analysis (PCA), in which tentative identifications of the aforementioned were done using MS-libraries. Oil components such as alkanes or alkylated-PAHs, halogenated organic compounds such as PCBs, fluorinated and brominated compounds but also natural contaminants such as terpenes were identified.

Notes

Session J

Investigation and monitoring of Soil and Groundwater

Part II

Chair: *Patrick van Hees*
Associate Professor, Eurofins, Sweden

High Resolution Site Characterization and 3D Geological Modelling Tools for Interpretation of Plume Migration in a Complex Geology
Bo Tegner Bay
M.Sc., COWI, Denmark

Development of an innovative methodology for monitoring of in situ remediation of chlorinated solvents – the MIRACHL-project
Haakan Rosqvist
Ph.D., Lund University and Tyréns, Sweden

Use of geostatistical modelling in investigation of soil contamination working toward a better definition of remedial mass and volume
Per Loll
R&D Manager, Ph.D., DMR, Denmark

Do we as practitioners have a general challenge with leaking wells causing cross-contamination to deeper aquifers ?
Swedish and Danish results and paths forward
Maria Heisterberg Hansen, Project Manager NIRAS, Denmark
Filip Nilsson, Environmental Consultant, NIRAS, Sweden

High Resolution Site Characterization and 3D Geological Modelling – Tools for Interpretation of Plume Migration in a Complex Geology

Bo Tegner Bay
M.Sc. geology, COWI A/S, mail: btba@cowi.com

Kirsten Rügge, M.Sc., chem., Ph.D., COWI A/S
Peder Johansen, Eng. and Helle Overgaard, M.Sc.,Capital Region of Denmark

Background
Moellevej in Denmark is an industrial site that hosted a large factory producing metal devices for gas cylinders in the years 1957-2000. TCE was used during this period for degreasing operations. The historical details of the site pointed out several known hot spots, but through the course of the investigations new hot spots have occurred.

The overall geology is extremely complicated and consists of an upper 10-15 m of boulder clay underlain by at least four different sand layers separated by boulder and marine clay. Underneath this geological sequence, a limestone layer situated at approx. 45-60 meters below ground surface serves as a groundwater aquifer, from which drinking water is extracted. Approximately 500 m downgradient of this site, a large well field with several drinking water abstraction wells is located, which is possibly influenced by the extensive contamination of TCE and its degradation products from the site.

A high-resolution site characterization was carried out to locate hot spots, delineate the plume, estimate the total mass and flux from the site, and evaluate the groundwater risk. A 3D-geological model as well as a 3D-groundwater model was also implemented for the risk assessment.

Aim and Conclusion
The aim for this presentation is 1) to show the many challenges you face when you are dealing with an extensive contamination in a complex geology with tilting of layers resulting in a flow direction completely different from what to expect, and 2) to broaden out how a comprehensive 3D geological model can help to solve the geological mysteries and thereby to understand the plume migration.

The investigation at the site included several different investigation methods such as soil vapor measurements, MiHpt-profiling, traditional boreholes for soil and groundwater sampling, level specific groundwater sampling as well as intact core sampling using the Geoprobe system. Due to the complex flow of the plume in small permeable layers a large number of deep boreholes with up to 7 multilevel filters in each borehole were installed. Groundwater samples were analyzed for the traditional chlorinated products as well as for degradation products and general groundwater chemistry to evaluate plume migration and possible degradation. In addition, specific stable isotope analysis were performed to support the delineation and degradation pattern in the plume.

The large amount of data was used to make a comprehensive 3D-model of the local geology in which the plume changed flow direction several times despite an overall dominant flow direction. The changing flow direction could have resulted in a closure of site investigations when the TCE-plume appeared to have a flow direction towards the sea, which would have been of no threat to the nearby abstraction wells. However, the complicated geology was elucidated by the 3D-model in combination with a 3D groundwater model and the risk towards the drinking water well field was evaluated.

When handling contamination in low permeability sites, the need for extensive data and a comprehensive geological model is essential. This extensive data volume can create new questions as well as frustration along the way, but in the end, this detail creates a better risk assessment and thereby greater value for the client and public health. A full overview of the results obtained in this investigation, and lessons learned, will be presented at the conference in September 2018.

Development of an innovative methodology for monitoring of in situ remediation of chlorinated solvents – the MIRACHL-project

Håkan Rosqvist, Ph.D./lecturer
Department of Geology, Lund University and Tyréns AB, mail hakan.rosqvist@tyrens.se

Charlotte Sparrenbom, Associate Professor, Department of Geology, Lund University.
Torleif Dahlin, Professor, Engineering Geology, Lund University.
Matteo Rossi, Post-doc, Engineering Geology, Lund University.
Mats Svensson, PhD, Business developer Geo, Tyréns AB.
Catherine Paul, Associate Professor, Water Resources Engineering and Applied Microbiology, Lund University.
Henry Holmstrand, Researcher, Department of Environmental Science and Analytical Chemistry, Stockholm University.

Background
Dense Non Aqueous Phase Liquids (DNAPL) such as chlorinated solvents are common pollutants stemming from different types of industries including dry cleaning facilities, and reports on cases showing serious risk to soil and ground water are frequent on a global scale. DNAPLs are especially problematic as they are denser than water and move down through the groundwater, not always following the groundwater flow but are mainly driven by gravitational forces. Difficulties associated with remediation activities of DNAPLs are many, especially delineation of the source plume, and understanding of the migration of contaminated groundwater in the underground. Therefore, the Swedish national environmental authority, (SEPA) has called for new and innovative in-situ remediation techniques.

The MIRACHL-project (monitoring of in situ remediation of chlorinated hydrocarbon contaminants - http://mirachl.com/) are focused on developing new and innovative methods for better understanding of the transport and fate of chlorinated solvents in soil and groundwater. The MIRACHL-project combine three methods; i)geoelectrical imaging by the geophysical method Direct Current resistivity and Induced Polarisation (DCIP), ii)Physical and BioGeochemical Characterisation (PBGC) and iii)the method Compound-specific isotope analysis (CSIA). The MIRACHL-project, based at the Engineering Geology at Lund University, is a collaborative project including several other universities and other relevant organizations, In particular, the collaboration on field sites with the Geological Survey of Sweden (SGU) is of great importance.

Aim
In the MIRACHL project we develop an integrated methodology based on three methods, i.e., Direct Current resistivity and Induced Polarisation (DCIP), Physical and BioGeochemical Characterisation (PBGC) and the method Compound-specific isotope analysis (CSIA), to better understand and map in situ remediation processes. A

combination of continuous geo-electrical observations during the decontamination, together with the analysis of biogeochemistry and isotope fractionation, provides opportunities to follow transport and fate of chlorinated solvents during different types of in-situ remediation processes.

The MIRACHL-project started in 2016 and will continue until 2022. In 2017, the MIRACHL methodology was established at two sites in collaboration with SGU, i.e., in Hagfors and Alingsås. At both site contaminations coming from dry cleaning facilities are in focus. The geology and hydrogeology is very different at these sites and the presentation will show the status in mapping and monitoring the ongoing remediation at the sites.

Conclusion
Initial studies performed at a site in Kristianstad (Färgaren 3) show the combination of DCIP, PBGC, and CSIA are promising methodology for mapping of transport and fate of chlorinated solvents. We will present on-going research on two sites where contamination from chlorinated solvents are in focus, i.e, contamination due to dry cleaning activities in Hagfors and Alingsås.
Max. 1 A4 page for this field

Use of geostatistical modelling in investigation of soil contamination – working toward a better definition of remedial mass and volume

Per Loll, R&D Manager, Ph.D.
DMR A/S, Denmark, mail: pl@dmr.dk

Theodora Tsitseli - DMR A/S, Denmark
Arne Rokkjær, Peder Johansen, Henrik Østergaard og Niels Døssing Overheu - Region Hovedstaden, Denmark
Hanne Østergaard – Region Nordjylland

Background

A lot of resources are spent on investigating and remediating contaminated sites that pose a groundwater risk. In Denmark, this is particularly true for sites contaminated with chlorinated solvents, since they often penetrate the subsurface to great depths. But dealing with the inherent inhomogeneity and uncertainty in geologic information and contaminant concentrations when estimating contaminant masses and placement, is no trivial matter. The data interpretation leading to mass estimates and subsurface contaminant delineation is often left to "expert interpretation", with little or no objective regard for the inherent uncertainties.

However, recent price drops in analytical prices and integrated use of database data storage gives us more data and better access to these data. Merge this with the emergence of commercially available geostatistical software packages with a simple user interface and excellent visualization capabilities, and we are offered with an opportunity to work with uncertainties in an informed and structured way.

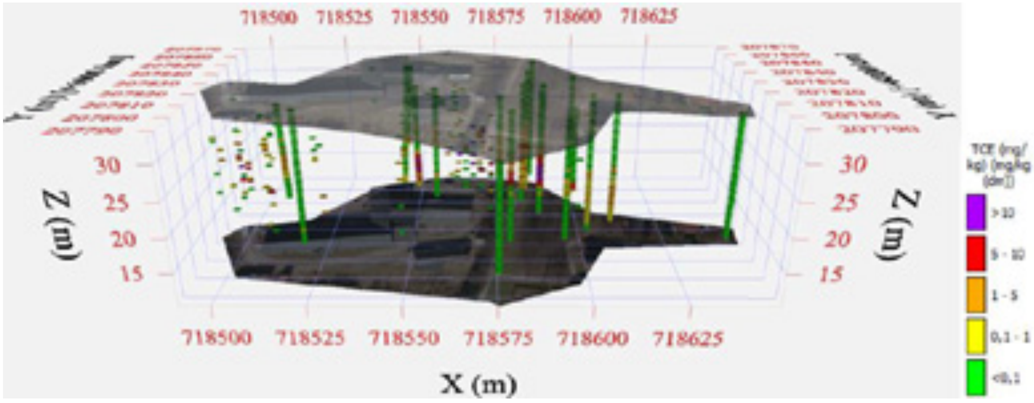
Aim

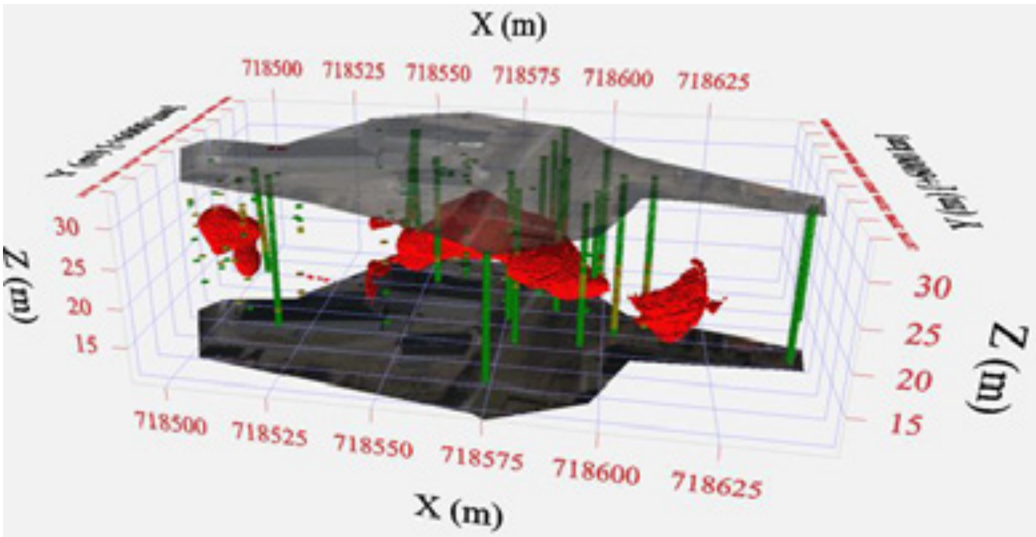
DMR has currently applied one geostatistical software package to nine projects with different aims. The applied software package allows for both kriging and conditional (Monte-Carlo) simulation of contaminant concentrations and masses. We would like to share the general results and lessons learned with the participants of the Nordrocs conference.

Conclusion

Geostatistical modelling allows us to extract more information from our data; uncertainties in particular. Mass estimates and contaminant volumes are obtained in a defensible manner and are easily updated given supplemental data. In addition, confidence intervals on estimated masses and volumes are obtained as an integral part of the modelling.

Intuitive 2D and 3D visualizations of volumes and masses can give a better knowledge transfer between consultant and client, and lead to a better understanding of the remedial volume. Geostatistical modelling also allows visualization of volumes with uncertain estimates. Hence, applying geostatistics allows us to better define volumes targeted for remediation, and to pin-point soil volumes with unacceptable uncertainty for possible further investigation/data collection. Also, working with uncertainty in this manner, on the first few projects, has led to a fresh view on sample selection procedures and required data density on other projects.





Do we as practitioners have a general challenge with leaking wells causing cross-contamination to deeper aquifers? Swedish and Danish results and paths forward.

Filip Nilsson, Environmental Consultant
NIRAS SE, mail: filip.nilsson@niras.se

Maria Heisterberg Hansen, M.Sc. Environment, NIRAS DK, mail: MHN@niras.dk
Peter Tyge, Geolog, NIRAS DK
Anders G. Christensen, Ekspertise Director, NIRAS DK
Susanne Rinette Pedersen, Project manager, Region Zealand
Helle Overgaard, M.Sc., Capital Region of Denmark
Ulf Winnberg, Project manager, Geological Survey of Sweden

Background
When environmental wells are established as part of an investigation of soil and ground water pollution, there is a risk that the well design can lead to cross-contamination between polluted and unpolluted depths. This risk has until now not been fully evaluated or investigated.

Recent focus on this topic has led to the understanding that materials used for sealing environmental wells (e.g. bentonite), are not always fulfilling the intended role of avoiding hydraulic contact between for example contaminated and non-contaminated aquifers. Furthermore, the joints of well casings have proven often not to be tight. This can, in combination with scarce sealing, allow dissolved contaminants or NAPLS to migrate into the casing and further down to the installed screen.

Several investigation techniques like borehole video inspection and geophysical borehole loggings exists and have been used to investigate if a well design might cause a cross contamination risk. But to proof that cross-contamination actually takes place in existing wells and to quantify the cross-contaminant flux is rarely done.

Without being aware of the cross-contamination risk caused by the well design, then water samples from an environmental well, will be interpreted as representing the groundwater from the depths of the screen. Further investigations and risk assessments will though be based on a false result in the case where cross-contamination is taking place.

Aim and Conclusion.
Field investigations have been carried out in several existing environmental wells in Denmark and Sweden; mostly at locations contaminated with chlorinated compounds. The aim has been to identify contaminant migration through the well materials as well as identifying if cross-contamination between two separate aquifers was taking place. The investigations included suitable borehole logging methods (i.e. gamma-logging and

video inspections, core sampling from the well sealing and finally tracer tests where one or two tracers were added to a shallow screen of the well and sampled in the deeper screen of the well. The sampling of tracer was done with passive activated carbon samplers in several depths of the water column in the deep screen while passive sampling of chlorinated compounds took place in the corresponding depths of the water column. Since the tracer was detected in the deeper screen, the investigations have proven that cross-contamination was taking place and that the detected contamination in the deeper screen therefore was entirely or partly caused by the well design and/or construction. Results from the other borehole investigations corresponded well to the tracer results and improved the understanding of the cause of cross-contamination.

The results from the field investigations will be presented and discussed in relation to how we can be aware of the cross-contamination risk and how to avoid letting results that are influenced by cross-contamination being the base of our further environmental investigations and risk assessments.

Notes

Session K

Management

Chair: *Anna Kruger*
Environmental Scientist, City of Vestarås, Sweden

Strategic decisions, while planning and implementing the challenging remediation project in the heavily polluted harbor in Oskarshamn, Sweden – the municipal perspective
Keynote Speaker *Bodil Liedberg Jönsson,*
Strategic Development Manager, Municipality of Oskarshamn, Sweden

Stakeholder engagement in strategic research agendas related to soil and land use management
Yvonne Ohlsson
Ph.D., Swedish Geotechnical Institute, Sweden

The Finnish Clean Soil Program. A national state-funded program to investigate and remediate sustainably the significant risks to human health and the environment due to land contamination
Jarno Laitinen
M.Sc., Project Manager, Centre for Economic Development-, Transport and the Environment, Finland

Strategic decisions, while planning and implementing the challenging remediation project in the heavily polluted harbor in Oskarshamn, Sweden – the municipal perspective

Keynote Speaker Bodil Liedberg Jönsson,
Strategic Development Manager, Municipality of Oskarshamn, Sweden, mail:
bodil.liedbergjonsson@oskarshamn.se

Fredrik Hansson, Project Manager, Empirikon
Ulrika Larson, Communication Advisor, Empirikon
Pär Elander, Technical Advisor, Elander

Background
The remediation of the Oskarshamn harbor started in September 2016. The harbor was contaminated with more than 1000 tons of heavy metals, emanating from industrial processes around the harbor since the beginning of the 20th century. In addition, the sediments contained 70 grams of dioxins of which 0.1-0.3 grams spread to the Baltic Sea every year. This should be compared with total discharge of dioxins from the Swedish Industry, estimated to about 2 grams/year.

The main part of the funding for the remediation project comes from the Swedish EPA, but also from Oskarshamn Municipality and a private company.

Oskarshamn municipality has thoroughly planned the remediation project in order to reach environmental-, financial- and knowledge based objectives.
It is a great challenge to carry out dredging activities of heavily polluted sediments within a harbor with ongoing commercial operations.

The project organization is put together to ensure high competence during planning and execution of the project but also to build knowledge and know-how for the future. The organization consists of a project group and a steering group as well as a group with external experts The competence in the project group is broad to cover several specialties like management, environment, geotechnique and law, and also deep to ensure good quality and high credibility.

Aim
The overall environmental objective is to reduce the discharge of heavy metals and dioxin from the harbor to the Baltic with at least 90 %.The environmental license limits both turbidity during dredging and the quality of the wastewater leaving the dewatering process. These factors are monitored on a daily basis.

The project organization keeps close track of the economic outcome of the project. The aim is to stay within the budget of 510 million Swedish crowns for the whole project, including the preparatory efforts preceding the execution as well as the follow up investigations after the remediation is finished.

This large project has also managed to reach the aim of producing different kinds of spin off effects. One example is that the Swedish Geotechnical Institute combined a TUFFO-seminar with a study visit on the site. Another is that Stockholm University and the project organization have been granted TUFFO funding for a study which will be carried out in the Oskarshamn harbor.

It has also been important to work in a transparent environment with information efforts focusing on both specialists and the public.

Conclusion

The project organization spent more than 20 years of planning and preparing for the execution of the remediation of the Oskarshamn Harbor. The preparations included a thorough mapping of the sediments, estimating the content of heavy metals and dioxin, licensing, procurement of a traditional contract and financing.

When the dredging works started in 2016 it soon became evident that it is difficult to predict all challenges that will occur during the dredging works and the construction of the landfill. Among other things it is evident that there is a need to develop techniques that can help provide better information about buried obstacles and techniques to handle such obstacles.

We find that it is helpful that the same organization that planned the remediation is also working during the execution. This provides possibilities to find quick and efficient solutions to problems that occur during the remediation.

Of course it is important to make note of what is experienced in this project and to communicate the result in a final report. We still have at least another year before the project can be wrapped up but we are already making plans for dissemination of what we now are learning.

Stakeholder engagement in strategic research agendas related to soil and land use management

Yvonne Ohlsson, Ph.D.
Swedish Geotechnical Institute, mail: Yvonne.ohlsson@swedgeo.se

Lisa van Well, PhD, Swedish Geotechnical Institute

Background
During 2015-2018 the Swedish Geotechnical Institute (SGI) was involved as project partners and national coordinators in two Horizon 2020 Coordination and Support (CSA) actions which use stakeholder engagement methods to influence national and EU strategic research agendas for sustainable societal development.

CIMULACT (Citizen and Multi-actor Consultation on Horizon 2020), engages citizens, experts and stakeholders in in 29 European countries to co-create research agendas based on the visions, needs and demands of society. CIMULACT will provide the European Commission with dozen suggestions for Horizon 2020 calls within in several Grand Societal Challenges the 2018-2020 period. INSPIRATION (Integrated Spatial Planning, Land Use and Soil Management Research Action), aims to adopt a funder and end-user demand-driven approach to adopt and promote a Strategic Research Agenda (SRA) for land use, land-use changes and soil management in light of current and future societal challenges. In both of these projects methods have been developed employed specifically to understand how stakeholder engagement can influence national and EU research agendas. Both projects deal with topics that are implicitly (CIMULACT) and explicitly (INSPIRATION) related to soil and land use management research, two areas where there are calls for further involvement of stakeholders and end-users on all levels.

Aim
This paper profiles the stakeholder engagement methods used by the CIMULACT and INSPIRATION projects to influence national and EU strategic research agendas. It compares the methods based on epistemic/expert user's knowledge used INSPIRATION with the methods based on consensual/citizen-based knowledge in used in CIMULACT, particularly in areas related to sustainable land use and soil management. In doing so the aims of the paper are two-fold:

- To demonstrate the challenges and opportunities of using stakeholder engagement as a tool for influencing national and EU soil and land use management research agendas.
- To provide lessons and recommendations for promoting soil and land use management research on strategic research agendas.

In addressing these aims we examine both the processes and outputs of CIMULACT and INSPIRATION at a pan-European perspective and within Sweden, and draw upon our experience as project partners and national coordinators of the projects.

Conclusions
The stakeholder engagement methods used in INSPIRATION and CIMULACT were both bottom-up of character, but with different approaches. But both presented some similar challenges, such as handling large amounts of qualitative data, maintaining active stakeholder involvement and accountability to stakeholders and translating visions and needs into research topics. Yet both showed that basing research agendas on these needs and visions can greatly increase the societal relevance of research on soil and land use.

The CIMULACT and INSPIRATION experience reifies the importance of profiling soil and land use research as an integral aspect of the greater societal challenges of sustainable land use. Yet putting soil research into a broader context may also risk losing some of its scientific depth. Thus, more efforts could be put into greater promoting of soil science as a basis for research topics such as sustainable food production or the bio-economy.

The Finnish Clean Soil Program
A national state-funded program to investigate and remediate sustainably the significant risks to human health and the environment due to land contamination.

Jarno Laitinen, M.Sc., Project Manager,
Centre for Economic Development-, Transport and the Environment,
mail: jarno.laitinen@gmail.com

Background
The Finnish National Soil Database System contains information on over 26,000 sites where harmful substances may have been released into the soil from a current or previous activity in the area. Over 15,000 sites are still not sufficiently investigated to define whether they are contaminated, and of these approximately 3,000 are located either in areas important for water supply or in the proximity of residential areas, thus requiring a more detailed analysis of the health and environmental risks, and if necessary, risk management measures.

Aim
The Ministry of the Environment published in 2015 The National Risk Management Strategy for Contaminated Land, which is based on a national vision of how the risk management and remediation of contaminated areas can be managed cost efficiently and sustainably in Finland, taking into account health and environmental protection in the best way possible. The main policy goal of the Strategy is to ensure that significant risks to human health and the environment due to land contamination will be managed in a sustainable way by 2040.

One of the most important implementing tool of the strategy is the Contaminated Sites Investigation and Remediation Program (Clean Soil Program, or CSP). It is a program having the objective of systematically identifying, investigating and if necessary remediating significant risks in contaminated sites. The CSP emphasizes health, areas with high conservation value and ground water protection. The implementation of the Clean Soil Program and the use of resources are guided by the Centre for Economic Development, Transport and the Environment.

The Clean Soil program is constructed from an "investigation program", "remediation program" and "demonstration program".

- In the investigation program, potentially contaminated orphan sites that are previously not sufficiently investigated are prioritized based on a multi-criteria model, that takes in account a number of parameters related to local land-use, human and economic activities, surface and groundwater resources and their use, conserved natural habitats and potential risk effect of the suspected contaminants.

- The remediation program is compiled based on the investigation program and is based on a health and environmental risks analysis, where the risks, their probability and effect are prioritized in a risk framework tool. Based on the analysis, most sustainable risk management strategy and remediation methods are selected in a stakeholder driven appraisal process.
- The demonstration program has the purpose of advocating sustainable contaminated land risk management and remediation practices and processes, advancing cleantech entrepreneurship and international co-operation. It functions by bringing together administration, different actors and technology vendors for specific pilot initiatives for developing innovative remediation.

Conclusions

In 2017, the first full operating year, the Clean Soil Program investigated 51 risk sites out of which 16 were prioritized in a high risk class, requiring further analysis or risk management measures. Remediation activities were initiated on 11 sites and a more thorough sustainability appraisal was done on 5 of the sites. Pilot initiatives were introduced through 7 Public-Private funded R&D&I projects, aiming at new method and technology development.

The ambition is, that by 2040, the Clean Soil Program has investigated and prioritized 1 900 potentially contaminated sites, remediated 1 100 contaminated sites and facilitated the development of cost- and resource efficient restoration methods that minimize adverse environmental impacts and promote circular economy globally. The expected costs of the program are 260 M€ and the annual investments of associated support works of approximately 2 M€ and 18 many years.

Notes

Session L

Surface Water Interaction from Soil, Sediment and Groundwater

Chair: *Marianne Olsen*
Research Manager, Norwegian Institute for Water Research, Norway

Contaminant response in a multistress environment
Keynote Speaker Katrine Borgå
Professor, University of Oslo, Norway

Bodø Airport – The story of PFAS' way from soil, through storm water to biota
Marianne Kvennås
Head of Section, NGI, Norway

Using temperature to assess interaction between
contaminated groundwater and surface water
Gro Lilbaek
Ph.D., Hydrogeologist, NIRAS, Denmark

Contaminant response in a multistress environment

Keynote Speaker Katrine Borgå
Professor, University of Oslo, Norway, mail: katrine.borga@ibv.uio.no

Contaminants are just one of challenges posed to the environment. Climate change, loss of biodiversity, habitat loss and changes in biogeochemical cycle, being some of the others. The risk posed by contaminants is usually assessed in a dose-response framework, where the response can be predicted from the exposure.

However, the state of the other challenges posed in an environment also affects the response of a contaminant, which is less predictable from the physicochemical parameters and mode of action of a toxicant. In addition, endpoint developed in laboratory tests to assess toxicity of various chemicals may not be relevant for organisms' nutritional ecology, growth, development and reproduction.

Most studies of multiple stress address a toxicant in combination with an abiotic driver, such as temperature or ocean acidification. Fewer studies address how biotic stressors or drivers affect the response when combined with exposure to a toxicant.

The presentation will give examples of studies on multiple stressors in the environment, in ecological relevant species from different ecosystems, ranging from benthic copepods, terrestrial collembola and pollinators to avian top predators.

Bodø Airport
The story of PFAS' way from soil, through storm water to biota

Marianne Kvennås, Head of Section
NGI, mail: mkv@ngi.no

Gijs Breedveld, Technical Expert, NGI
Åse Høisæter, PhD-student, NGI
Håkon Austad Langberg, PhD-student, NGI
Sigurbjørg Hjartardottir, MSc, NGI
Tore Joranger, Senior Adviser, The Norwegian Defence Estates Agency

Background
PFAS (Per- and polyfluorinated compunds) have been used in firefighting foam at Bodø Airport since in the 1960s. During the period 2014-2018, NGI has investigated PFAS at Bodø Airport on behalf of the Norwegian Defence Estates Agency.

Aim
Thorough investigations are carried out where historical information indicates extended use of PFAS. The investigations are carried out in 3 steps:
1. PFAS in soil and groundwater at 31 locations on land
2. PFAS in storm water that runs through the airport
3. PFAS in biota and sediments in the sea at nine different locations outside the airport (incl background area)

Conclusion
A general background-level of PFAS is detected in soil, ground water and storm water over large parts of the airport, also in areas where use of PFAS is not known. Concentrations are shown in table 1.

Table 1 Detected concentrations of PFAS in samples of soil, groundwater, storm water and sediments at Bodø airport.

		Soil (µg/kg)	Groundwater (ng/l)	Storm water (ng/l)	Sediment (µg/kg)
Amount of analyses		319	30	145	37
SUM PFAS	Average	335	1641	651	35
	Median	11	200	99	10
	Minimum	i.p.	<5	i.p.	2
	Maximum	33800	17700	12900	406

The amount of PFAS at the following four areas constitute 90% of all PFAS detected at Bodø airport (40 kg at 31 locations):

- Training area for firefighting
- Fire station
- House for air plane maintenance
- Workshop-area

Storm water that runs through these four areas also show higher concentrations of PFAS than compared to other areas.

There is a clear connection between elevated concentrations of PFAS found at the four locations on land, to PFAS found in storm water from these four locations, and elevated concentrations of PFAS found in biota where storm water with elevated concentrations of PFAS has its run off in the sea.

The biota investigations has covered biota in increasing trophic level (snail, shore crab and cod, both liver and whole fish). The exposure of PFAS seems to be through direct uptake in algae and snails from storm water, and not from seawater or sediments. The general runoff of PFAS from the airport does not seem to lead to a considerable load to marine biota, compared with other urbane areas. The exceptions are the runoff from the four source-areas, where remedial actions has to be considered.

Using temperature to assess interaction between contaminated groundwater and surface water

Gro Lilbæk, Ph.D., Hydrogeologist
NIRAS Denmark, mail: grli@niras.dk

Anders G Christensen, Expertise director, NIRAS Denmark
Nicklas Larsson, Project Director, NIRAS Sweden
Filip Nilsson, Quaternary Geologist, NIRAS Sweden
Ulf Winnberg, Geological Survey of Sweden
Helle Overgaard, Special Consultant, the Capital Region of Denmark
Anja Melvej, the Central Denmark Region, Denmark
Kristian Dragsbæk Raun, Region of Southern Denmark
Jens Aabling, Danish Environmental Protection Agency

Background

Discharge of groundwater to surface water may be of great significance in terms of the vulnerability of surface water to contamination from source areas. Contamination fluxes depend on the coincidence of the source's plume and areas of great groundwater discharge. In order to perform a risk assessment and/or remedial actions, detailed knowledge of the contaminated groundwater's flow path is needed. Hence, identification of discharge zones is essential in order to risk assess the impact of soil and groundwater contamination on aquatic environments as well as humans.

Groundwater discharge to surface water may vary both spatially and over time due to i.e. variations in the geology near the streambed in combination with the direction of the groundwater flow as well as the fluctuation in the level of the groundwater.

In the early 19th century the transfer of temperature as water flows through a porous media was observed. Consequently, heat can be used as a natural tracer to investigate the interaction between groundwater and surface water. The advantage of using the temperature as a tracer is to utilize natural differences in temperatures (temperature gradients). Thus, there is no need to add tracers to assess flow conditions and therefore no need for chemical analysis of water samples. Temperature is a robust parameter, that is easy to measure and monitor.

Aim

Using temperature as a natural tracer it is possible to identify and quantify the groundwater discharge to a stream. Distributed Temperature Sensing (DTS) and vertical sediment temperature profiles both utilizes the difference between the relatively constant temperature of the groundwater (8-10 °C) and the surface water's seasonally affected temperature.

Distributed Temperature Sensing (DTS) is a quick and efficient tool to map areas with significant groundwater discharge. Temperatures are measured along a fiber optic cable, which allows measurements with a high resolution and frequency. Combined with vertical sediment temperature profiles and groundwater samples it is possible to identify, map and quantify the groundwater discharge to the stream.

Conclusion
The presented methods are valuable when assessing the impact of soil and groundwater contamination on surface waters. The methods are not generally known, non-invasive and no chemical analyses are required. Investigations have been carried out at sites in both Sweden and Denmark. Results from these will be presented to illustrate the versatile use of the methods.

At a research site in Sweden, a dry cleaning facility leaked large amounts of PCE (>50 tons) into the ground, likely through the sewers, contaminating soil and groundwater significantly. Traditional investigation tools (i.e. geological characterization, soil and water samples, MIP-probing, and seismic exploration) conclude that the site comprises a highly complex geology and hydrogeological system. Hence, an extremely complex distribution of contaminants. Two source areas have been identified at the site; located approximately 150 m apart. Down gradient (ca. 120 m) estimates show that each year hundreds of kg PCE are discharged into a small groundwater fed creek, 'Örbäcken' (average Q= 260 l/s). The DTS method was applied in the creek to identify areas with significant groundwater discharge, such that remediation can become focused and thereby reduce costs.

In Denmark, temperature measurements have been applied at three sites as part of an investigation of suitable methods for assessing impacts from point source contamination on surface waters. Measurements were carried out twice at all locations in order to assess the seasonal variation in the areas impacting on the streams. These investigations were part of a large project in collaboration with the Danish Environmental Protection Agency and three of the Regions in Denmark.

Notes

Notes

Session M

Indoor Air

Chair: *Per Loll*
R&D Manager, Ph.D., DMR, Denmark

A detection dog, man's best friend during indoor air investigations
Mette Algreen, Project Leader, Ph.D., Orbicon A/S, Denmark

Vapor Intrusion Gas Source Investigation by use
of Stable Isotopes and Radiocarbon Dating
Katrine Moes Kristensen
Environmental Engineer, NIRAS, Denmark

Revisiting dry-cleaning sites -30 years of improving environmental
investigations from the perspective of a public authority
Sanne Skov Nielsen
Environmental Engineer, Ph.D., Region of Southern Denmark

Modelling of air flow in capillary break layers.
A new approach to determine governing mechanisms in balanced ventilation
systems preventing vapor intrusion of volatile pollutants
Jakob Washington Skovsgaard
Project Manager, Ramboll, Denmark

A detection dog, man's best friend during indoor air investigations

Mette Algreen, Project Leader, Ph.D., Orbicon A/S
Mail: meta@orbicon.dk

Ole Frimodt, Head of Department, Orbicon A/S
Preben Sørensen, Consultant, Danminar

Background
The use of dogs to detect substances such as illegal drugs or explosives is well known and accepted by the authorities. Detector dogs are also used for tracing accelerants, search for human bodies or blood, and more recently to detect medical conditions such as diabetes or cancer, or to point out mold and mildew in houses. With their noses, the detection dogs smell and point out the presence of specific chemicals quickly and with a minimum of impact. The purpose of use are diverse and the benefits which can be gained with a detector dog, are many.

Aim
The aim of this project was to train a detector dog to screen houses for vapor intrusion of chlorinated solvents (PCE and TCE). The dog should not only be able to quickly screen the houses for the presence of chlorinated solvents in the indoor air but also to locate the source or exposure pathways.

Conclusion
First, the detector dog learned to identify and point out the specific chemicals PCE and TCE in air, soil and water. Subsequently, the detector dog learned to locate exposure pathways, such as drains, installations, floor cracks or panels in houses. The dog marks its finding by sitting down and point out the hotbed with its nose and the handler notes the finding. Finally, the detector dog and the handler where tested and achieved certification by an ISO certified detector dog company.

The use of a detector dog have reduced the number of tests and sampling points when addressing indoor air quality problems. The team of a detector dog and a handler is a close companionship and a great resource for indoor air investigations.

Vapor Intrusion Gas Source Investigation by use of Stable Isotopes and Radiocarbon Dating

Katrine Moes Kristensen, Environmental Engineer
NIRAS Denmark, mail: KMS@NIRAS.DK

Anders G. Christensen, Expertise director, NIRAS Denmark
Monica Heintz, PhD, Project Geoscientist ARCADIS U.S.
Allan Horneman, PhD, Principal Geologist, ARCADIS U.S.
Anne Mette Granhøj Hansen, Environmental Engineer, the Capital Region of Denmark
Monica Sonne, Geologist, the Capital Region of Denmark

Background
In 1954-1959, the southern part of a pond near Copenhagen was used as a landfill, primarily for household waste. In 1975-1978 houses were constructed on top of and adjacent to the filling. Elevated concentrations of carbon dioxide (CO2, up to 38% volume) and other gasses, including methane (CH4, up to over 80% volume) have been documented in soil vapor in the area immediately surrounding the filled area, and have been attributed to degradation of the landfill waste. However, soil vapor samples collected in an area adjacent but not directly above the historic footprint of the former landfill also show elevated CO2 concentrations (up to 18 vol%), and as such this is an area of interest (AOI). In both the landfill area and the AIO, there are concerns associated with with high levels of CO2 intrusion into the indoor climate. The Capital Region of Denmark wish to know the source of the vapor intrusion gas in the AIO to be able to decide whether the region has an obligation towards the CO2 -content. To date, surveys of the landfill area and soil gas production have been extensive and have included, among other things: more than 100 soil gas measurements, continious vapor intrusion studies in 2 houses, camera inspection of the cavity beneath 4 houses, and tracer gas detection surveys in 7 houses.

There are multiple sources of organic carbon at and near the AOI that may degrade and contribute to CO2 in soil gas, including anthropogenic organic carbon sources. Organic carbon sources include, but are not limited to:

1. Landfill materials, including: Household waste (e.g., food and garden waste), building and demolition materials, and furniture;
2. Petroleum hydrocarbons detected in soil and groundwater in vicinity of the landfill;
3. Natural organic carbon in the form of peat (meadow mat) observed in soil cores.

Assessment of stable, and particularly radioactive carbon isotopes in CO2 has the potential to allow for distinction between the three identified potential sources of organic carbon that may contribute to CO2 in soil vapor.

Carbon-14 (14C) or radiocarbon is a radioactive isotope with a half-life (t1/2) of appr. 5,740 years. Atmospheric 14CO2 is incorporated into all living biomass through photo-synthesis and consumption of plants as a food source. Once incorporated in biomass, 14C will decay with the t1/2 listed above. Based on tree ring data, the Holocene atmospheric 14C concentrations are well understood and the content of 14C in organic materials allows for estimating the age of the material based on the amount of 14C remaining. Laboratory measured 14C activities (14C decays per unit time) are normalized to the international standard known as "modern carbon" and are reported as percent modern carbon (pMC).

For carbon age dating, the following apply:

1. Carbon in, and derived from, petroleum hydrocarbon products is typically millions of years - and will not contain measurable quantities of 14C (all 14C has decayed).
2. Carbon in, and derived from, naturally occurring organic carbon deposits (e.g., meadow matt and peat) in native soil may have a 14C that is less than 100 pMC with a corresponding age that is hundreds to thousands of years old.
3. Carbon in, and derived from degradation of, recently produced and deposited organic materials (e.g., household waste) is "young" and if the material was produced within the past approximately 65 years, the pMC may be greater than 100 percent.

Aim

The goal of this work is to determine if elevated concentrations of CO2 in soil vapor and indoor air are generally derived from natural organic rich soils, including meadow mat material, or organic rich waste associated with the nearby reclaimed landfill. The study is based on analysis of three soil gas samples from the landfill area, analysis of three soil gas samples from the AOI, and analysis of three soil samples from different depths at the AIO. Soil gas samples have been analyzed for: total gas composition (fixed gasses and light hydrocarbon gasses), petroleum hydrocarbons, stable carbon and hydrogen isotope composition of CH4, stable carbon and oxygen compositions of CO2, and radiocarbon ages of CO2 and CH4. Soil samples have been analyzed for: radiocarbon ages of organic material, soil pH, total inorganic and organic carbon and major ions. Together these analytical data will allow for distinguishing between potential sources of CO2 reaching the indoor climate in the AOI.

Conclusion

Although analytical results are still arriving, available data indicate that the organic matter in the AOI was deposited approximately 700-5,300 years ago, thus indicating, that CO2 sourced from this material will be distinguishable from CO2 sourced from landfill materials disposed of in the 1950s.

Revisiting dry-cleaning sites - 30 years of improving environmental investigations from the perspective of a public authority

Sanne Skov Nielsen, Environmental Engineer, Ph.D.
Region of Southern Denmark, mail: sanne.skov.nielsen@rsyd.dk

Susanne Roug Poniewozik, Geologist, Region of Southern Denmark
Jette Balslev Sørensen, Geologist, Region of Southern Denmark
Anita Hjørringgaard, Environmental Technician, Region of Southern Denmark
Rikke Sparsø Pedersen, Environmental Engineer, Region of Southern Denmark

Background

Investigations of soil and groundwater pollution have developed immensely from the early 1990ies, when chlorinated solvents emerged as a compound of concern for ground water resources. New and better techniques for investigation have been developed during the past 30 years and we have gained extensive knowledge in investigating those sites with the help of soil gas sampling and charcoal tubes. Now we know dry-cleaning facilities or laundromats and chlorinated solvents used there often cause indoor air problems by vapor intrusion or residuals in building material. This has led us to reopen cases, where risk assessment was performed on inadequate investigations compared to current industry standards.

Aim

The Region of Southern Denmark is a regional authority for public investigation and registration of soil pollution. In 2015 we started to reassess and revisit former dry cleaning facilities and perform up-to-date investigations of soil, groundwater and indoor air. The strategy was carried out in a two-step process:

1) A desktop study of previously investigated sites included for each site
- A short description of each site: Existing data, status, updated site use
- A communication plan
- A strategy for further investigations

2) An up-to-date investigation of selected sites
- Indoor air quality
- Soil air
- Ground water

Conclusion

So far 38 sites have been selected for desktop studies and of those 28 have undergone an up-to-date investigation. The project is ongoing and is scheduled to run until 2020. By then we will have performed desktop studies on more than 100 sites and revisited and investigated more than 50 sites.

In the talk we will present a few cases with results from their pre 2007 investigation and their complex up-to-date results. Many investigations from the 1990ies relied entirely on a few soil samples, and our investigations confirmed that indoor air quality in many cases has been overlooked and for some cases it is currently a major issue. Soil air is also the key to find previously overlooked hotspots of soil contamination in backyards and alleys. These are all well-known investigation strategies developed over the last 30 years, but coming back to the cases it is interesting how much more knowledge and complex investigation methods, we now have in our toolbox.

Due to their central urban location and architectural value, many former drycleaners have been repurposed to homes. Housing changes the risk assessment target and lead to stricter remediation goals. One of our most important issues during the process has been our communication strategy and dialogue with landowners. As cases are reopened, many questions need to be answered. One of our key findings is the importance of an open and honest dialogue with land owners and stake-holders on the implications of reopening soil pollution cases with a focus on indoor air quality.

Modelling of air flow in capillary break layers. A new approach to determine governing mechanisms in balanced ventilation systems preventing vapor intrusion of volatile pollutants

Jakob Washington Skovsgaard, Project Manager,
Rambøll Environment and Health (Denmark), mail: jvr@ramboll.dk

Hans Bengtsson, Senior Chief Consultant, Rambøll Environment and Health (Denmark)
Daniel, Plesner, Consultant, CFD Specialist, Rambøll (Denmark)

Background
Intrusion of hazardous, volatile pollutants represents a risk to indoor climate in buildings at many polluted sites. In Denmark, it is a widespread and commonly used practice to apply balanced ventilation systems in the capillary break layers in order to reduce air concentrations to a level that complies with the applicable threshold values.

Increasing building activity in former industrial areas/brownfields converting these areas into housing, institutions and commercial buildings is a consequence of urbanization in many cities. In these projects handling of polluted soil introduces additional costs to the building projects. But also the presence of volatile pollutants like chlorinated solvents, that are often not easily removed prior to the building process, has shown to be a challenge to indoor climate in buildings. Introduction of a sub-slab ventilated layer has together with other remedial measures been discussed through the last decades in response to the increase in applications put forward to the authorities. Controlling the air flow pattern in the ventilation layer and thereby the efficiency of the ventilation systems has however shown to be difficult in practice. There is therefore an increasing interest in developing methods to document the effect of sub-slab ventilation solutions.

Computational Fluid Dynamics (CFD) is a recognized tool for modelling air flow in buildings, tunnels etc. Through recent years attempts have been made to describe flow patterns in sub floor systems by using CFD modelling. In 2016 a project was performed to emulate the flow in compartments (e.g. crawl spaces) under floors. This project showed that increased pressure to the systems quickly entailed turbulent flow. This can easily introduce problems when the aim is to control the airflow and avoid non-ventilated areas beneath the floors of for instance new housing.

In 2017 a project was performed by the Capital Region of Denmark and Ramboll to assess whether CFD-modelling (and a freeware tool) could be applied to assess airflow in balanced ventilations systems in simple-geometric ventilation cells. This project clearly showed that CFD-modelling is a powerful and very useful tool in predicting and assessing the flow, pressure and the pollutant patterns in sub-slab flow cells with simple geometries.

Aim

In a new study from 2017 CFD modelling has been conducted to assess the influence of obstacles in the sub-slab ventilation system (elevator-foundations or chimney-foundations etc.) and to include more complex flow cell geometries that are often the case in modern building designs. This study was financed by the Danish Environmental Protection Agency.

Conclusion

The presentation will show the results of the projects from 2017 and give the audience insight into:

- Governing mechanisms when designing sub-slab ventilation systems
- How internal square foundations and skew angles as in a trapezoide and a parallelogram affect the distribution of air velocity and airflow in flow cells
- How it is possible to make adjustments to drain configurations in a way that improves the distribution of air flow using CFD-model analysis

Notes

Notes

Session N

PFAS

Chair: *Morten Jartun*
Ph.D., Norwegian Institute for Water Research, Norway

Immobilization of PFAS contaminated sandy soil
from a Norwegian firefighting training facility
Soil Hilmar T. Sævarsson
Director of Landfill and Contaminated, Lindum

PFAS Handbook: What, how and where to look,
what are the risks and can we be sure?
Jacqueline Falkenberg
Senior Consultant, NIRAS, Denmark

Mobility of PFAS: Do lysimeter results reflect
concentrations monitored in a groundwater plume?
Mikael Takala
Regional Manager, M.Sc., Vahanen Environment Oy, Finland

What is the total budget of PFAS in contaminated soil and
how does total oxidizable precursor (TOP) assay help comprehend the picture?
Patrick van Hees
Associate Professor, Eurofins, Sweden

Immobilization of PFAS contaminated sandy soil from a Norwegian firefighting training facility

Hilmar T. Sævarsson, Director of landfill and contaminated soil dpt.
Lindum AS, mail: hilmar.thor.saevarsson@lindum.no

Åse Høiseter, Ph.D.-student, Norwegian Geotechnical Institute (NGI).
Gorm E. Thune, R&D Manager, Lindum AS.
Andreas B. Smebye, Project consultant, Norwegian Geotechnical Institute (NGI).
Gudny Okkenhaug, Ph.D., Technical Lead, Landfills and Mining, Water and Resources, Norwegian Geotechnical Institute (NGI).

The use of aqueous film forming foams (AFFF) at firefighting training facilities at airports is an important source of per- and polyfluoroalkyl substances (PFAS) contamination to soil. Due to the high mobility of most PFAS, leaching from PFAS contaminated soil to groundwater and surface waters poses a threat to drinking water and the environment. There is ongoing work trying to develop efficient soil treatment solutions for PFAS contaminated soils. Landfilling PFAS contaminated soil does not solve the mobilization issue with PFAS, so there is a need for either immobilization of PFAS in the soil or removal of PFAS from the landfill leachate. In this study, we investigated if low cost industrial waste could be used as a sorbent to immobilize PFAS, especially perfluorooctane sulfonic acid (PFOS), in soil and removal of PFAS from landfill leachate. The sorbent investigated contains oxides of iron (Fe, 26%), aluminum (Al, 8%), calcium (Ca, 5%) and Carbon (6%). Total concentrations of sum PFAS and PFOS in the test soil were 2500 µg/kg and 2200 µg/kg, respectively. In the immobilization experiment, two different pathways were tested. Stabilizing PFAS/PFOS by mixing different amounts of sorbent into the test soil, and removing PFAS/PFOS in leachate water using the sorbent as a filter.

For the stabilization experiment, the sorbent was mixed into the test soil and batch tests with Liquid/Solid ratio of 10 where performed for 8 days. In the removal of PFAS/PFOS from leachate experiment, the sorbent was used as a filter to remove PFAS/PFOS from contaminated groundwater at a firefighting training facility. The retention effect of mixing 20% by volume of sorbent into the PFAS contaminated soil was shown to be approximately 75% for PFOS. When the sorbent is used as a filter, retention is about 99,9% for PFOS. The results indicated that this sorbent is working well and should be tested with a pilot field test. A pilot test cell for PFAS contaminated soil was built with the sorbent as a filter liner. Pore water and leachate sampling from the pilot test cell show good retention efficiencies for PFOS and several other PFAS. The pilot cell is an ongoing long term test.

Introduction

Per-and polyfluoroalkyl substances (PFAS) are manmade chemicals that have been used in numerous of industrial, commercial, and military applications, and the high mobility of these compounds has resulted in widespread distribution in the environment [1]. Remediation of these compounds is very challenging because of their high water solubility, hydrophobic properties and their toxicity potential in very low concentration. PFAS have strong C-F bounds which makes them extremely resistant to degradation, and perfluorooctane sulfonic acid (PFOS) and perfluorooctanoic acid (PFOA) are stable chemicals. The USEPA has revised its recommend-dation of PFOA and PFOS limits in drinking water. The limit was 0,4 µg/l and 0,2 µg/l in 2009. In 2016 the USEPA recommended that the sum of PFOA and PFOS is limited to 0,07 µg/l in drinking water [2]. Literature shows that treatment of PFOS contaminated soil is difficult, complex and even ineffective [3, 4, 5]. On the other hand, studies has also shown that there are positive correlations between iron oxide and PFOS sorption. Gao and Chorover (2012) stated that PFOS forms outer-sphere complexes and hydrogen-bounds at iron oxide in addition to electrostatic interaction [6,7]. Soil treatment is difficult, but treatment of PFOS/PFOA contaminated water is a well-known and less complex operation, and activated carbon (AC) filters are often used for water treatment [8]. One challenge with AC filters in the field is that organic compounds seals the filter and therefore reduces its capacity. Another side effect of DOC is that it often carries other pollutant as well, something that is both unwanted and might block PFAS from the active site in the filter. Firefighting training facilities at airports are an important source of PFOS/PFOA contamination. Several studies have shown that concentrations of PFAS in soil, groundwater and runoff water are above background concentrations in vicinity of airport firefighting training facilities. In Norway those sites have been targeted as Hot Spots for PFAS in need of remediation.

Lindum AS is a company specialized in treating contaminated soils. In cooperation, Lindum and NGI decided to develop a method to immobilize PFAS in contaminated soil prior to landfilling, and reducing the risk of contaminant transport to the environment. Lindum has earlier developed a method to stabilize heavily contaminated soils from shooting ranges [9]. In that case, both Pb and Sb needed to stabilize. Lindum did use industrial waste as a sorbent. The industrial waste is a by-product from the metal process industry, containing oxides of iron (Fe, 26%), aluminum (Al, 8%), calcium (Ca, 5%) and carbon (6%). Lindum learned that this sorbent did reduce DOC as well as both anions and cations, and could by useful dealing with PFOS/PFOA. Therefore, this study was designed to explore two different paths. One was to stabilize PFAS with sorbent mixed into the contaminated soil, and the other was to remove PFAS/PFOS from leachate, first in the lab, and then at a large scale field test site. In the latter case, the goal was to clean the water with a double filter; one filter made of industrial waste sorbent material to take out most of the DOC and PFAS, and the second one made of AC to take the rest of PFAS from the water.

Materials and Methods

First, the sandy test soil was tested in lab, with total PFAS and PFOS concentration in soil of 2500 µg/kg and 2200 µg/kg, respectively. In the experiment, the soil was mixed with different dosages of the sorbent in a batch test (L/S 10) lasting 8 days. The eluates were filtered (0.7 µm polyethersulfone membrane) prior to analysis. In addition, leachate collected at a PFAS polluted site was filtered with the same sorbent in lab. The column filtration experiment was carried out under saturated conditions in columns with 5 cm diameter. The leachate was fed into the columns using peristaltic pumps at a steady, low rate between 10.6 and 13.9 mL/hr until a L/S-ratio of 15 was reached. Based on the laboratory results, a large scale field experiment was carried out at one of Lindums Landfills.

Here approx. 16 650 tons of PFAS contaminated soil was placed in an isolated cell within the landfill, from September 2017 until April 2018. All the leachate from the cell was treated with a filter containing the same sorbent as used in the lab trials. The concentrations of PFAS, dissolved organic carbon, dissolved metals and pH in the leachate from the cell were determined at least monthly. In addition the pore water in the contaminated masses were sampled with suction lysimeteres (MacroRhizon, Rhizosphere Research Products, Wageningen, The Netherlands; 9-cm length, 4.5-mm outer diameter, pore size 0.12 to 0.18 μm) to determine the leaching of PFAS after deposition.

Table 1, Content of the industrial waste used as sorbent.

	pH	C	Ca g/kg	Fe g/kg	Al g/kg
Sorbent	11,2	6%	52± 0,3	277± 8,8	79± 2,8

Results

The results show clear differences between treated and untreated soil. (Figure 1). Comparatively, concentration in eluates decreased from 246 μg/l for PFOS to 51 μg/l with 20 % sorbent mixed with the soil during lab test. Using the sorbent material as a pre filter gave much better results. Keeping in mind the strict limit of PFOS/PFOA in drinking water, the filter solution was chosen for the large scale pilot test rather than mixing sorbent to the soil. Figure 2 shows the result of the pilot cell. Concentration of PFOS was measured to be approx. 70.000 μg/l in the pore water in the soil, in the large scale pilot test. After pore water has passed through the iron based filter in the large scale test cell, the PFOS concentration is now under the new limit of drinking water quality recommended of the EPA. The AC filter as step 4 in this treatment seem to take out rest of the PFAS.

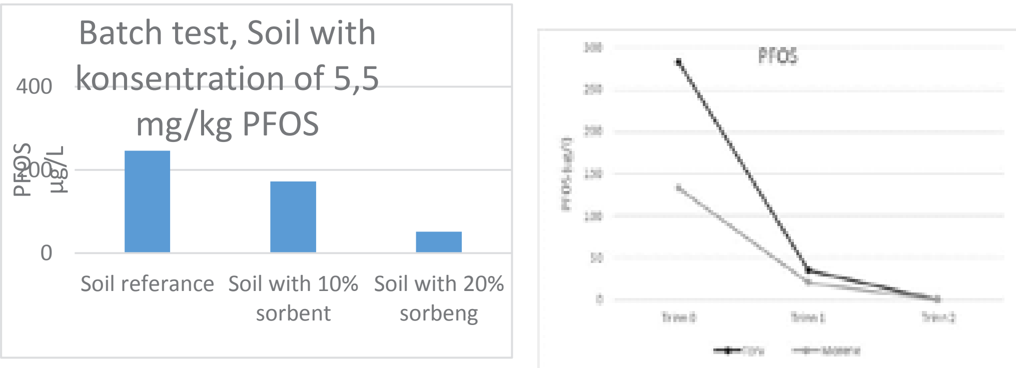
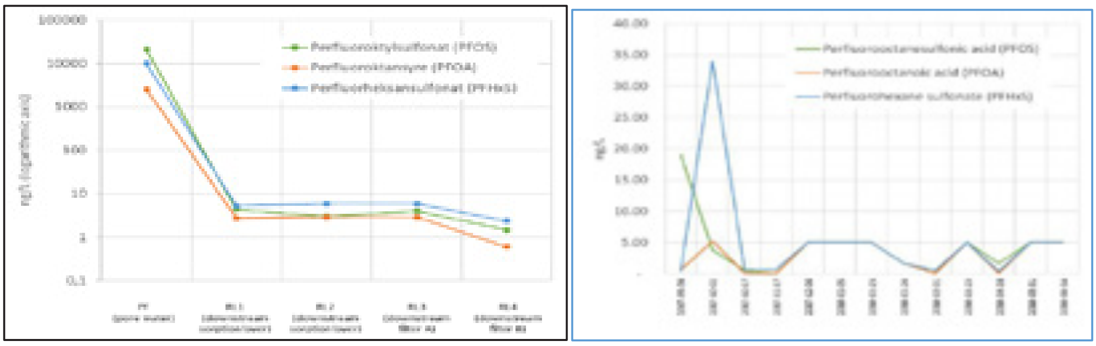


Figure 1a PFOS concentration from 10 days batch test with L/S10 PFAS contaminated soil was treated with iron based sorbent. Sorbent was added based on a volume. Fig 1b PFOS contaminated with water cleaned with 2 stesp filter system



Figur 2a shows concentration of PFOS/PFOA and PFHxS decrease as the water goes through the filter system of the pilot cell. Figur 2b shows time serie of the last testing point RL4 from the pilot test

The leached concentrations of sum PFAS and PFOS have been stable during the first 9 months of the experiment. The pilot cell has been open for all kind of weather to stress the filter system and try to test the limits of the filter. In normal operation of the landfill the PFAS cell would have been sealed to make sure no rain water could enter the PFAS contaminated soil, but in that case it wouldn't be possible to test the capacity of this solution. The total cumulative capacity of the sorbent filter to retain sum PFAS and PFOS, remains to be determined.

Conclusions

The batch tests showed that the mixing of 20% sorbent into the PFAS contaminated soils achived a retention effect of approx. 75 % for PFOS. However, the same sorbent bound 99% of the PFAS in a polluted leachate in a filtration test in lab. Filtration of the leachate from the large scale field experiment showed corresponding results as the filtration test in the lab. E.g. the PFOS concentrations in the leachate from the large scale field experiment were close to, or below, the detection limit (<10 ng/L). The promising results from using this low-cost sorbent material promotes full scale commercial use. Furthermore, it may be possible to use this material for in-situ remediation as well.

References

Environmental Protection Agency (USEPA), 2009a. Long-chain Perfluorinated Chemicals (PFCs) Action Plan. (December 30, 2009). U.S. Environmental Protection Agency, Washington, DC, https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/long-chain-perfluorinated-chemicals-pfcs-action-plan.

Environmental Protection Agency (EPA), 2016a. Drinking Water Health Advisory for Perfluorooctanoic Acid (PFOA). Available: https://www.epa.gov/sites/production/files/201605/documents/pfos_health_advisory_final_508.pdf. (Accessed 11 July 2018).

Giesy, J.P., Kannan, K., 2001. Global distribution of perfluorooctane sulfonate in wildlife. Environ. Sci. Technol. 35, 1339e1342.

Merino, N., Qu, Y., Deeb, R.A., Hawley, E.L., Hoffmann, M.R., Mahendra, S., 2016. Degradation and removal methods for perfluoroalkyl and polyfluoroalkyl substances inwater.,Environ. Eng. Sci. 33, 615–648.

Kucharzyk, K.H.,Darlington R., Benotti M.,Deeb, R.,Hawley, E.,2017. Novel treatment technologies for PFAS compounds: A critical review. Journal of Environmental Management 204, 757-564.

Gao, X., Chorover, J., 2012. Adsorption of perfluorooctanoic acid and perfluorooctanesulfonic acid to iron oxide surfaces as studied by flow-through ATRFTIR spectroscopy. Environ. Chem. 9, 148–157. http://dx.doi.org/10.1071/EN11119.

Wei, C., Song, X., Wang, Q., Hu, Z., 2017. Sorption kinetics, isotherms and mechanisms of PFOS on soil with different physicochemical properties. Ecotoxicology and Environmental Safety. 142,40-50.

Sævarsson,H.T., Frøsland, K., Okkenhaug, G., Almås, Å.R. Immobilization of Pb and Sb in Shooting Range Soil: Column experiment providing an Industrial waste Iron-based sorbent. Nordrocs 2016- 6th Joint Nordic Meeting on Remediation of Contaminated Site.

Appleman,T.D., Dickenson, E.R.V., Bellona, C., Higgins, C.P., 2013. Nanofiltration and granular activated carbon treatment of perfluoroalkyl acids. J. Hazard. Mater. 260, 740-746.

PFAS Handbook: What, how and where to look, what are the risks and can we be sure?

Jacqueline Anne Falkenberg, Senior Consultant
NIRAS A/S, Denmark, mail: jaf@niras.dk

Jette Kjøge Olsen, Senior Consultant, NIRAS A/S, Denmark
Dorte Harrekilde, Senior Consultant Ramboll, Denmark
Nanna Isbak Thomsen, M.Sc., ph.d. Danish Regions Environment and Resources

Background

The undesirable effects of PFAS substances on human health and wildlife has been acknowledged for nearly 2 decades, but the implementation of site investigations at point sources and monitoring of the diffuse loads in the environment is a more recent assignment for the environmental authorities. Investigations to date have clearly demonstrated that PFAS contamination is widespread, and - due to the low health-based criteria - is often present in problematic concentrations.

Aim

Sustainable risk management is dependent on an understanding of the consequences of soil and groundwater pollution and a methodical risk assessment. PFAS soil and groundwater pollution presents a new challenge for the Regional Danish Environmental Authorities as they need to initiate, plan, evaluate and risk assess site investigations and remediation activities for a group of chemicals with very different properties compared with the traditional pollutants. The Danish Regions Environment and Resources have therefore prepared a handbook on PFAS site investigations, so that the authorities can achieve a collective understanding of PFAS properties and management issues for this complex group of chemicals. The overall objective is to ensure that site investigations in Denmark are carried out in a competent manner avoiding obvious pitfalls, and that comparable results are obtained with a view to risk assessment and risk management.

Conclusions

The PFAS handbook is available in Danish via the website of the Danish Regions Environment and Resources (www.miljoeogressourcer.dk).

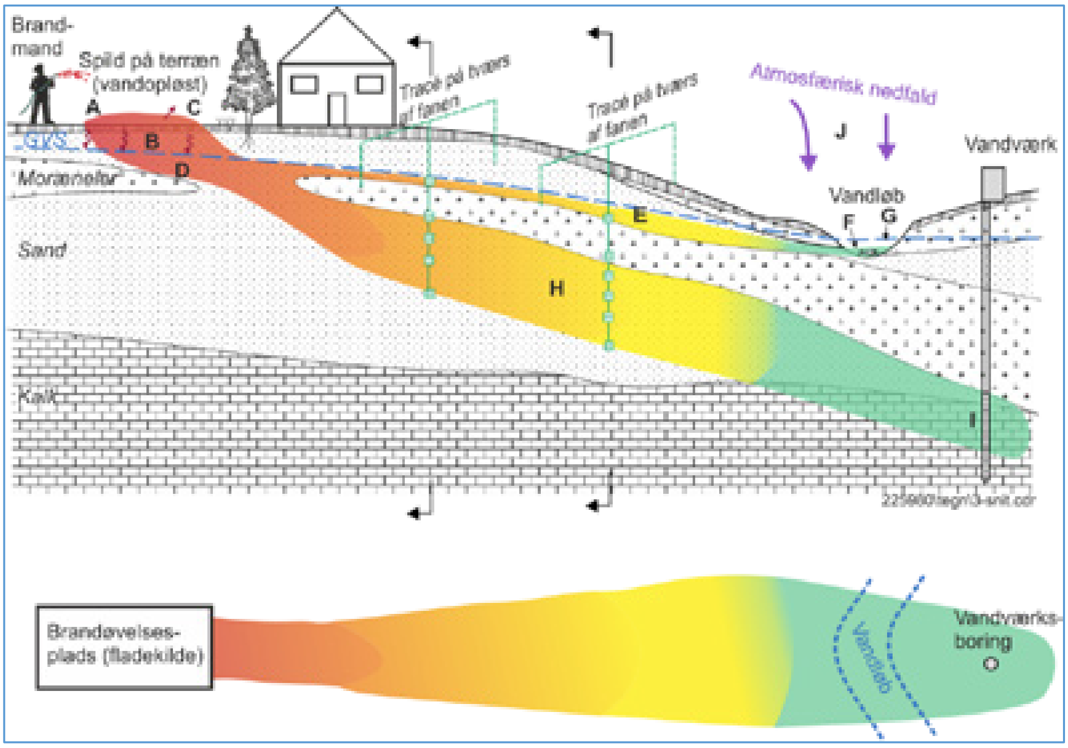
The PFAS handbook provides the environmental authorities and their consultants with information on PFAS nomenclature, historical and regulatory development as well as potential sources in the environment related to industrial usage in Denmark.

The physical-chemical properties and environmental fate and transport of PFAS substances are evaluated and related to conceptual site models for point sources, landfills and diffuse sources. These conceptual models form the basis for elaborating strategies for preliminary and supplementary site investigations as shown below. Note that the colour shading in the pollution plumes can indicate changes in PFAS fingerprint profiles.

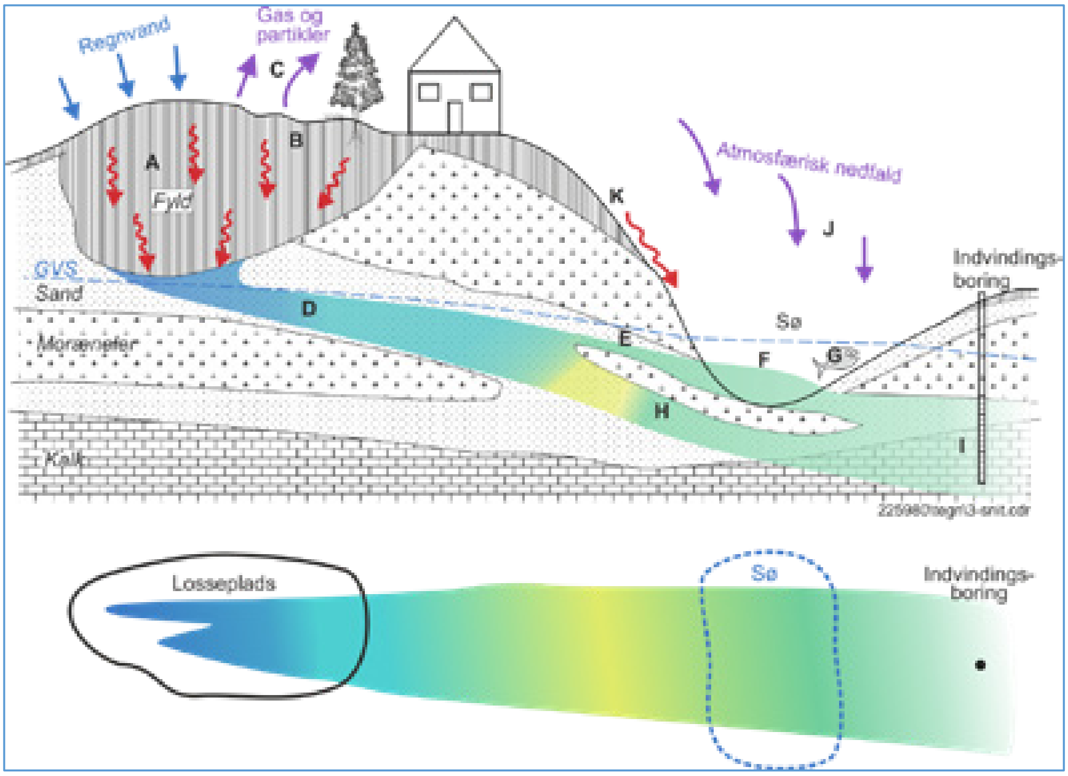
Sampling protocols and the available analytical techniques are reviewed and potential remediation methods are summarised. The guidelines are illustrated with examples and appendices, and a very detailed literature and reference list is provided.

Since most PFAS substances at point sources are applied as aqueous solutions, it is easier to identify potential pollution by screening of groundwater samples due to the low detections limits in water samples. However if precise historical information is available and the groundwater screening indicates the spill area, then soil sampling is invaluable to determine the residual PFAS mass present in the soil which is of importance with respect to sustainable remediation initiatives.

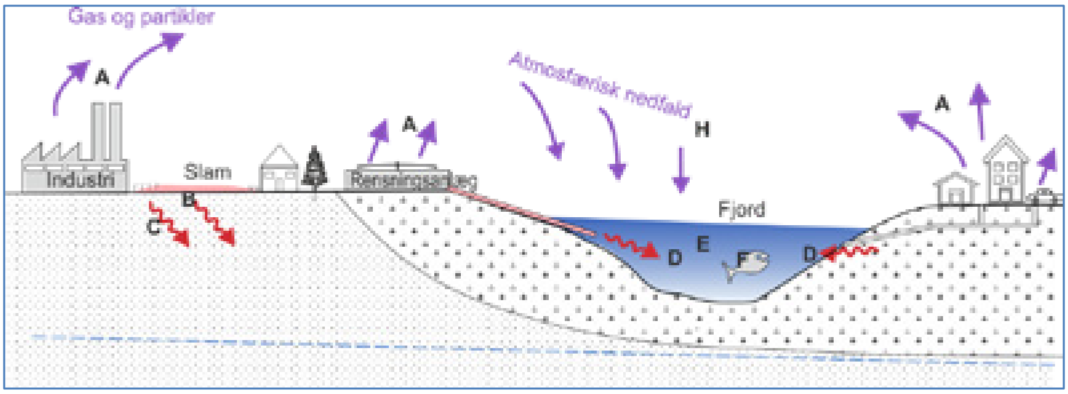
One aspect of major importance is the ability of unidentified PFAS compounds (precursors) to undergo transformation to PFAS compounds that are recalcitrant to biodegradation. Many of these transformation products are associated with health effects, e.g. PFOS and PFOA, and some are included in the Danish quality sum-criterion. In other words, the PFAS fingerprint may undergo changes within the pollution plume, but perhaps only a fraction of the PFAS substances present in the source area are identified by standard analysis. Increase in the measured levels of pollution downstream for the source might not be due to a decrease in source zones, but be caused by transformation within the plume. A detailed description of PFAS fingerprint profile in the residual soil pollution in the unsaturated zone as well as downstream the source in the groundwater zone is therefore recommended.



Conceptual Model for Point Sources



Conceptual model for Landfills



Conceptual Model for Diffuse Sources

Another challenge is that PFAS composition in products has changed greatly over the course of years leading to uncertainty in evaluating pollution plumes, risks and remediation needs.

Currently 32 PFAS compounds of interest are identified in the handbook including the 12 PFAS substances, which comprise the Danish quality criterion, but alternative analytical techniques to estimate precursors and total organic fluoride analytical are also emphasised, including the TOP-assay for oxidisable precursors. In the TOP-assay, a range of PFAS substances (as defined by the analytical suite) are analysed before and after oxidisation. In the oxidisation process, unidentified PFAS compounds (precursors) can be transformed to other PFAS substances, and if these are included in the analytical suite, they will be quantified resulting in an increase in concentration.

The preparation of the handbook and discussions with the steering committee identified a number of uncertainties about site investigations for PFAS substances. The handbook presents a status for knowledge in the spring of 2017, but new information is constantly being generated both nationally and internationally.

One of the main challenges is the need to look at a wider range of PFAS substances than defined by the Danish quality criterion for the sum of 12 PFAS substances. To-day we have very little information about which PFAS substances can constitute a problem because we cannot analyse for all PFAS substances. Nor do we know if these unidentified PFAS substances pose a health risk.

Is it the collective PFAS-loads in the environment that are our concern in risk assessments or just specific PFAS-substances?

Can we be sure that a PFAS pollution has been adequately investigated and identified so that some sites can be categorised as requiring no further investigation (Walk away)?

To gain more experience about groundwater contamination with PFAS substances, the Danish Regions have therefore initiated a program whereby selected water samples from point sources are analysed by a TOP-assay with quantification of 21 PFAS-substances.

Mobility of PFAS: Do lysimeter results reflect concentrations monitored in a groundwater plume?

Mikael Takala, Regional Manager, M.Sc
Vahanen Environment Oy, mail: mikael.takala@vahanen.com

Jussi Reinikainen, Senior Research Scientist, Finnish Environment Institute (SYKE)
Sirkku Tuominen, Senior Research Scientist, Finnish Environment Institute (SYKE)
Noora Perkola, Chemist, Ph.D., Finnish Environment Institute (SYKE)

Background

Per- and polyfluoroalkyl substances (PFAS) have been used widely in industry and products for seven decades. Since 1960s PFAS have been crucial ingredients in aqueous film forming foams (AFFFs), which are efficient in extinguishing flammable liquid fires. In Finland, AFFFs have been used by the military and fire departments to extinguish fires and for training in many locations. These sites are known to be contaminated with PFAS, especially PFOS.

This study is part of the "PFARA" project, which examined the occurrence, fate and transport of PFAS on four sites contaminated by firefighting training activities.

Aim

The aim of the study was to investigate how different short- and long-chain PFAS are mobilized from contaminated soils and transported through the vadose zone and further in the groundwater. The leaching/sorption behavior of 23 PFAS was studied using lysimeters and soil samples taken from three different training sites. Average soil concentrations of PFAS in the lysimeters, based on multi-increment samples, ranged from 2 mg/kg to 30 mg/kg. One set of lysimeters contained only PFAS contaminated soil, while the others also had layers of clean sand at the bottom of the lysimeter allowing for the quantification of sorption and retarded transport of the different compounds.

PFAS concentrations in the leachate samples, collected from periodic monitoring during one year, were then compared to concentrations in the groundwater samples in order to see if the lysimeter setup could be used to predict the fate and transport of PFAS in the subsurface.

Conclusions

The results from the lysimeter study confirmed the general perception that the short-chain PFAS are readily transported through the vadose zone and in the groundwater whereas the transport of the long-chain PFAS is slow; compounds with more than 12 carbon atoms being practically immobile.

Similar results were seen in the groundwater samples: near the PFAS source zone, even long-chain PFAS were present in the groundwater, but their concentrations rapidly declined under the detection limits downgradient of the source.

What is the total budget of PFAS in contaminated soil and how does total oxidizable precursor (TOP) assay help comprehend the picture?

Patrick van Hees, Eurofins, [1,2,]
patrickvanhees@eurofins.se

Marko Filipovic[3], Patrik Karlsson[4], Lydia Söderlund[4], Leo Yeung[2]
[1]Eurofins Environment Testing Sweden AB, Sjöhagsgatan 3, 531 17 Lidköping, Sweden
[2]Man-Technology-Environment (MTM) Research Centre, Örebro University, 701 82 Örebro, Sweden
[3]Niras Sweden AB, Fleminggatan 14, 112 26 Stockholm, Sweden
[4]Eurofins Food & Feed Testing Sweden AB, Sjöhagsgatan 3, 531 17 Lidköping, Sweden

Introduction
The problems of per/polyfluoroalkyl substances (PFAS) in the perspective of contamination of water and soil are of great concern. It is still common that only PFOS or a limited suite of PFAS are measured in sample. However, it has become increasingly evident that a broader evaluation, including so-called precursors, is necessary in research and risk assessment. Precursors are compounds of known or unknown identities, which have the potential to form perfluorinated carboxylic or sulfonic acids (PFCAs/PFSAs) upon degradation in natural systems. Similarly it is of interest to study the total composition of fluorine to be able to achieve a complete picture of organofluorine contamination.

The purpose of this project was to construct fluorine budgets in ten soil samples by measuring known PFAS and extractable organic F (EOF), and known PFAS in the same samples after subjected to total oxidizable precursor (TOP) assay. All samples were also analyzed for total fluorine (TF) and inorganic water extractable fluoride (IF). Another aim was to use TOP assay as a tool for "visualizing" precursors and yield information on their structures. Study of the increase/decrease of branched and linear isomers may also give insight to the original production method e.g. ECF (electrochemical fluorination) and fluorotelomerization.

Materials and Methods
Soils were sampled from five different locations at a site (in Sweden) where AFFFs are and have been historically used. Each sample was collected from three test pits within a 10x10m grid, where topsoil (0-0.5m) was collected in HDPE-bottles; these samples are denoted as Soil 1-10. Before analysis, soils were dried at 35°C, sieved <2mm and milled. All analytical results thus refer to dry sample. Extraction and analyses of PFAS (alkaline digestion followed by methanol extraction and SPE cleanup), EOF and TF followed Yeung et al. (2013). Levels of EOF and TF were measured using CIC (combustion ion chromatography) in the SPE extracts and whole soil, respectively. The procedure for TOP assay was slightly modified from Houtz et al. (2013). Thirty

PFAS originally present and after TOP assay were determined using UPLC-MS-MS. Branched and linear isomers of PFASs were separated and quantified. In the same sample, IF (fluoride) was extracted at L/S 5:1 ratio in water; IF in the extract was analyzed using IC (ion chromatography).

Results

Sum of PFAS ranged between 50-23000 ng/g. Anionic PFAS comprised >98% of the total PFAS except soil 3 (93%). The composition and concentrations of PFAS both before and after TOP varied among samples (Tables 1 and 2). The most commonly detected PFAS was PFOS, which dominated.

Table 1. Major PFAS concentrations before and after TOP assay (ng/g). L = linear, Br = Branched. PFCA, PFSA, FTSA refers to total no. of carbon atoms for each compound with the no. fully fluorinated carbon equaling n-1, n and n-2 for each class

sample id	PFBA	(TOP) PFBA	PFPeA	(TOP) PFPeA	PFHxA	(TOP) PFHxA	PFHpA	(TOP) PFHpA	L-PFOA	Br-PFOA	(TOP) L-PFOA	(TOP) Br-PFOA	PFNA	(TOP) PFNA
PFCA	C4	C4	C5	C5	C6	C6	C7	C7	C8	C8	C8	C8	C9	C9
Soil 1	4	222	14	353	5	173	2	177	9	<0,3	78	<1	2	56
Soil 2	10	2660	32	4240	14	2200	5	1860	10	<0,3	924	<1	7	618
Soil 3	13	338	46	469	16	379	11	301	42	3	736	99	9	87
Soil 4	10	544	31	860	83	1020	21	145	54	7	408	74	8	31
Soil 5	3	20	22	38	6	19	4	7	2	<0,3	7	1	1	<2
Soil 6	3	6	7	9	1	4	1	2	2	<0,3	4	<1	1	<2
Soil 7	6	162	20	279	6	106	2	55	3	<0,3	23	<1	4	12
Soil 8	2	5	11	13	7	7	3	3	1	<0,3	1	<1	<0,5	<2
Soil 9	1	<5	3	5	1	4	1	2	2	<0,3	4	<1	2	2
Soil 10	2	<5	2	2	1	2	<0,5	1	2	<0,3	2	<1	<0,5	<2

sample id	L-PFHxS	Br-PFHxS	(TOP) L-PFHxS	(TOP) Br-PFHxS	L-PFOS	Br-PFOS	(TOP) L-PFOS	Br-PFOS (TOP)	6:2 FTSA	(TOP) 6:2 FTSA	8:2 FTSA	(TOP) 8:2 FTSA
PFSA/ FTSA	C6	C6	C6	C6	C8	C8	C8	C8	C8	C8	C10	C10
Soil 1	1	<0,5	2	<1	20	2	21	4	12	2	11	<5
Soil 2	1	<0,5	2	<1	48	5	43	6	134	3	83	<5
Soil 3	30	3	34	3	3020	224	2260	133	35	<1	39	<5
Soil 4	1510	164	1450	166	16500	4165	15200	3290	192	<1	66	<5
Soil 5	12	1	11	1	150	35	130	23	7	<1	1	<5
Soil 6	2	<0,5	2	<1	43	5	35	3	1	<1	<0,5	<5
Soil 7	0,5	<0,5	1	<1	12	1	11	3	12	2	6	<5
Soil 8	1	<0,5	1	<1	23	2	15	2	1	<1	<0,5	<5
Soil 9	2	<0,5	3	<1	138	8	109	5	1	2	1	<5
Soil 10	7	<0,5	7	<1	164	28	129	15	<0,5	<1	<0,5	<5

in soils 3 and 4. In contrast, soil 2 had the greatest concentrations of 6:2 and 8:2 FTSAs. Other PFAS not shown in the table were either at relatively low concentrations or <LOQ.

Table 2. Fluorine budgets. Mean values (*n=2*). Relative standard deviation (RSD) mostly <10% for PFAS, TOP and IF and <20% for TF. See text for abbreviations.

Instrumentation	Types of Fluoride	Unit	sample ID Soil 1	Soil 2	Soil 3	Soil 4	Soil 5	Soil 6	Soil 7	Soil 8	Soil 9	Soil 10
CIC	TF	ng F/g	232000	202000	517000	296000	227000	256000	290000	371000	187000	331000
IC	dissolved IF	ng F/g	1620	1360	1170	873	2970	2790	1990	1600	1880	1780
CIC	EOF F1 (Neutral/cationic)	ng F/g	2710	22500	4490	5550	819	353	1990	265	288	78
LC-MS/MS	Neutral/Cationic PFAS	ng F/g	0,401	0,634	168	75,5	1,27	0,732	0,218	0,302	3,45	0,485
	Known neutral/EOF	%	0,015	0,003	3,75	1,36	0,15	0,21	0,01	0,11	1,20	0,62
CIC	EOF F2 (Anionic)	ng F/g	469	3170	3080	13700	724	314	590	285	304	287
LC-MS/MS	Anionic PFAS	ng F/g	56,4	226	2300	15400	163	43,6	47,8	34,3	108	137
	known anionic/EOF	%	12,0	7,1	74,7	112	22,5	13,9	8,1	12,0	35,4	47,9
CIC	Sum EOF	ng F/g	3179	25670	7570	19250	1543	667	2580	550	592	365
LC-MS/MS	Sum PFAS	ng F/g	57	227	2468	15480	164	44	48	35	111	138
LC-MS/MS	After TOP	ng F/g	769	8630	3250	15000	172	47	446	42	103	107
	Known PFAS/EOF	%	1,8	0,9	32,6	80,4	10,6	6,6	1,9	6,3	18,8	37,7
	TOP/EOF	%	24,2	33,6	42,9	77,9	11,1	7,1	17,3	7,6	17,3	29,2
	EOF/TF	%	1,4	12,7	1,5	6,5	0,7	0,3	0,9	0,1	0,3	0,1

Five soils (1-4, 7) showed substantial increases in PFCA (C4-C9) concentrations after TOP assay, with the greatest increases in soils 1, 2 and 7. After TOP assay, the PFAS sum of soil 2 became the second highest in the set (Table 3). Generally measurable precursors such as 6:2, 8:2 FTSAs and FOSA were reduced by 85% or more.

Levels of TF varied within a factor of three among samples (Table 2), and by large exceeded all of the other fractions measured. The concentrations of the neutral/cationic EOF fraction were greater than those of the anionic one with the exception of soil 4, dominated by PFOS. EOF could explain 0.1-13% of TF, while IF corresponded to 1.3% or less. Initial measurable PFAS could explain 1-80% and after TOP oxidation 7-78% of total EOF. As expected TOP assay raised the fraction explained for most soils, although the relative importance varied.

Table 3. Sums of known PFAS (ng/g) before and after TOP. Mean ± std dev (n=2)

sample id	PFAS	PFAS (TOP)
Soil 1	90 ± 5	1200 ± 65
Soil 2	370 ± 8	13100 ± 1400
Soil 3	3800 ± 320	4900 ± 160
Soil 4	23200 ± 800	23600 ± 1800
Soil 5	250 ± 15	270 ± 14
Soil 6	70 ± 2	74 ± 2
Soil 7	75 ± 3	680 ± 14
Soil 8	53 ± 2	56 ± 10
Soil 9	170 ± 9	160 ± 6
Soil 10	210 ± 11	170 ± 8

Discussion
The range and levels of known PFAS before TOP showed a large variation among the AFFF polluted soils, a finding in line with other observations (e.g. NV6709, 2016). After TOP assay, substantial increases were observed for C4-C6 PFCAs with the greatest level for PFPeA. This is consistent with the degradation pattern of 6:2 precursors (Houtz et al., 2012), and suggests 6:2 structures, the backbone of more modern AFFF, to be present in the contaminated soils (KEMI, 2015). In this study the identity of the precursors was further evidenced by the observation that no branched C4-C6 PFCAs were formed suggesting a telomer-based origin. In soil 1 and 2 raised levels of C7-C9 PFCAs were seen too, again linear substances only, indicating 8:2 besides 6:2 precursors. On the contrary, in soil 3 and 4 branched PFOA appeared after oxidation indicating a presence of ECF C8-sulfonamide precursors. This was also suggested by FOSA initially found in these soils (110-250 ng/g). The sum of PFAS after TOP varied from basically unchanged to about +3000% showing the importance of the nature of the precursors, e.g. for soils with, assumedly, 6:2 substances.
Similarly it is of interest to study the total composition of fluorine (F) to achieve a complete picture of PFAS present. The F budget showed that the EOF and IF could only account for a small part of TF. However, to what extent this is caused by non-soluble inorganic fluoride salts and minerals have not been investigated. The use of water instead of methanol as extractant is most likely not the cause for the difference between IF and TF since IC runs of methanol extracts showed values <5000 ng/g for all soils (not shown).

The PFAS/EOF quotient demonstrated that the degree of explanation is highly dependent upon the PFAS and precursor composition. The largest fraction explained was in soil 4, dominated by a high level of PFOS. The ratio is likely to be related to AFFF used but need to be further elucidated. TOP/EOF ratios were raised in accord with the PFAS increase seen for the particular soil, but a part of EOF could still not be explained. Presence of compounds that are not oxidized could be one cause. Also this observation deserves further attention, but to the best of our knowledge this is the first time these parameters have been reported for soil.

In conclusion, the initial PFAS composition across 10 soils reflected the site history and AFFF used. Oxidation in the TOP assay "visualized" unknown precursors to a varying extent in many of the samples. Patterns of PFCA formed indicated origin of the precursors e.g. 6:2 and 8:2 fluorotelomer-based and PreFOS. Origins of precursors were underpinned by measurement of branched and linear forms, providing another "line of evidence". TF was much larger than all other fractions, but inorganic F was, assumedly, not fully reflected by water extractions. Known initial PFAS and known PFAS after TOP could not fully account for the EOF determined (1-80%). The work demonstrates that analysis of a limited set of known PFAS is, in most cases, not sufficient to account for the total PFAS content of contaminated soil, and that consideration of precursors is necessary in overall risk assessment. At the same time more research is needed, not at least further characterization of EOF, both before and after TOP oxidation.

References
Houtz, E. F., Sedlak, D. L. 2012. Oxidative Conversion as a Means of Detecting Precursors to Perfluoroalkyl Acids in Urban Runoff. Environ. Sci. Technol., 46: 9342−9349

Houtz, E. F., Higgins, C. P., Field, J. A., Sedlak D. L. 2013. Persistence of Perfluoroalkyl Acid Precursors in AFFF-Impacted Groundwater and Soil. Environ. Sci. Technol., 47: 8187−8195
KEMI. 2015. PM 6/15, Chemical Analysis of Selected Fire-fighting Foams on the Swedish Market 2014. Stockholm
NV6709, 2016, Högfluorerade ämnen (PFAS) och bekämpningsmedel. En sammantagen bild av förekomsten i miljön. Redovisning av ett regeringsuppdrag. Naturvårdsverket, Stockholm
Yeung, L. W. Y., De Silva, A. O. Loi, E. I. H., Marvin, C. H., Taniyasu, S., Yamashita, N., Mabury, S. A., Muir, D. C. G., Lam, P. K. S. 2013. Perfluoroalkyl substances and extractable organic fluorine in surface sediments and cores from Lake Ontario. Environ. Int., 59: 389-397

Notes

Poster Abstracts

A low-cost largescale investigation of contamination with chlorinated solvents and evaluation of remedial pumping

Andreas Sahyoun Sørensen, B.Sc Eng & stud.polyt
Gladsaxe municipality, mail: Andreas_sahyoun@hotmail.com

Claus Frydenlund, B.Sc Eng. (hon), Gladsaxe municipality
Thomas Hauerberg Larsen, Ph.D, Orbicon A/S
Mette Martina Broholm, Ph.D, Associate professor at DTU
Klaus Mosthaf, Dr. Eng, Postdoc at DTU
Massimo Rolle, Ph.D, Associate professor at DTU

Background

Bagsværd is a large area located in the municipality of Gladsaxe. Bagsværd is registered as an area with special drinking water interests and has abstracted water since 1909. There are many possible sources to pollution in the area; most are located in the business district. Among the sources are auto repair shops, dry cleaning facilities and a gravel pit filled with chemicals and construction waste. The wellfield is placed 400 meters from the potential polluters and was first affected with chlorinated solvents in the 1980's. As contamination was found in the drinking water abstraction wells they were included in the remediation as remedial abstraction wells. There are remedial pumping from three locations, six pumps located around the gravel pit, one between the gravel pit and the wellfield and one at an old dry cleaning facility east for the gravel pit. In 2004 the waterworks had to install an active coal filter to ensure the continued operation.

Aim

As Bagsværd has a great history of water abstraction for drinking water it is in the municipalty of Gladsaxe's interest to make sure that the remedial pumping is placed optimally so the active carbon filter eventually can be uninstalled from the waterworks. The contamination is still reaching the drinking water abstraction wells with the current remedial pumping.

The municipality is economically challenged regarding a large-scale investigation therefore cheap methods such as reuse of historical data, reuse of existing wells, creation of isopotential maps, water samples, passive sampler, and tree core analysis are used.

Even though the Geological Survey of Denmark and Greenland holds a record of existing wells in the database known as Jupiter, there is a lack of updates on status and general information. During the project all registered wells in Bagsværd was located and updated. The most important wells was selected for water sampling.
With the use of the historical and newly obtained data, a graphical visualisation was done with the use of interpolation.

All results obtained for this project is further used to create a model for Bagsværd to evaluate the current remediation and check if an optimization is needed.

Conclusion

As many newly discovered wells were tested for the first time the results led to a new understanding of how and where the contamination spread. The contaminations found can be linked to areas with known activities.

Wells tested for the first time led to a new understanding of the spreading
A visualisation of the contamination history shows how the degradation occurs and how the transport changed.

Assessment of slope stability of contaminated fiberbank deposits

Hjördis Löfroth, Dr,
Swedish Geotechnical Institute, mail: Hjordis.lofroth@swedgeo.se

Jim Hedfors, Dr, Swedish Geotechnical Institute
Martin Holmén, Lic, Swedish Geotechnical Institute
Achim Kopf, Professor, University of Bremen, Germany
Timo Fleischmann, Bcc, University of Bremen, Germany
Matt O'Regan, Dr, Stockholm University, Sweden
Ian Snowball, Professor, Uppsala University, Sweden
Gunnel Göransson, Dr, Swedish Geotechnical Institute
Anna Apler, PhD student, Geological Survey of Sweden
Lovisa Zillén, Dr, Geological Survey of Sweden

Background

Along the northern Baltic Coast of Sweden highly contaminated fiberbanks from paper and pulp factories are deposited, many of them situated on relatively steep slopes in shallow waters, and on top of soft clays. Scars from submarine landslides have been identified in the area and some of those within the fiberbanks. Thus, it is likely that some of the strata underneath fiberbanks are instable and prone to landslides. Dispersion of particle bound contaminants on fibers due to landslides is one of several dispersion processes, such as chemical diffusion, and other advective mechanisms linked to ship traffic, currents and waves. Unlike the other processes, submarine landslides are extremely rare events, but they will instantaneously spread a large volume of contaminant sediment when they occur.

Aim

The aims of this part of the project TREASURE is to propose a methodology to identify the most unstable fiberbanks and proposal how to assess slope stability. To calculate the slope stability, it is necessary to determine the slope geometry, the soil (sediment) layering, and the density and the shear strength of the sediments and the fiberbank material. This is a rather difficult and costly process, especially when the slopes are submarine. For slope stability investigations (onshore) the Swedish guidelines for slope stability investigations propose a stepwise workflow for assessment of slope stability with successively increased detail. With this background, one aim was to develop an overview method to identify the fiberbank areas with the most prerequisites for landslides, based on data from the areas with fiberbanks in the county of Västernorrland mapped by Apler et al. (2014).

Following an overview survey of slopes susceptible to sliding, determination of the slope stability of a specific fiberbank must be done. However, several of the standard methods (used in Sweden) for determination of soil properties onshore are not appropriate for use in sediments at water depths where the fiberbanks are situated. In addition, the properties of the organic-rich fiberbank materials differ significantly from natural minerogenic sediments, especially by the content of long cellulose fibers and the very low density, which is close to that of water.

Conclusion

An outline of a method for identification of the prerequisites for submarine landslides has been developed. It is based on information presented in GIS maps, as soil (sediment) layers, slope inclination and landslide scars. It is based on the investigated fiberbank areas, limited to areas with soft sediment and sufficient background data. The number of landslide scars per kilometer is used as indicator of landslide susceptibility. Landslide scars were found in 18 out of 23 of these areas. As many of the prerequisites for landslides are present for several slopes, prioritization for remediation will still be a challenge.

To obtain information necessary for slope stability calculations, methods for determination of soil properties not commonly used in slope stability calculations (onshore) were tested and verified. Results from field measurements, such as geometry and soil layering were determined by hydro-acoustic methods, undrained shear strength was determined by free fall CPT and samples were retrieved by a Kullenberg piston corer. At the laboratory, the SHANSSEP method was used to verify the undrained shear strength from free fall CPT, while fall cone tests and direct shear tests were made on trimmed samples. The density was determined by a Multi Sensor Core Logger (MSCL) as well as on laboratory samples. To gain an understanding of the behavior of the fiber bank material a special "tipping box" was constructed and tested. The results from the tests on sediments could be used as input in slope stability calculations, but it will be more difficult to determine relevant properties of the fiberbank material.

PFAS in fire fighting foam

Jette Kjøge Olsen, MCs. Civil Engineering &
Morten R. Olesen, Senior Consultant
NIRAS, Denmark, mail: mno@niras.dk

Anne Mette Lindof, MCs. Geology Danish Ministry of
Defence Estate Agency (DMDEA)

Background
In collaboration with the Danish Ministry of Defence Estate Agency (DMDEA), NIRAS has carried out several investigations with focus on PFAS containing firefighting foams. The results have demonstrated that activities involving the handling of firefighting foams at Defence sites have resulted in PFAS contamination of groundwater and surface waters downstream of the firefighting training areas.

Aim
The focus for the investigation has been on the firefighting foams currently in use at Danish Defence sites. Due to the regulation of products containing PFOS and PFOA, the formulation of firefighting foams has changed over the years and especially during the latest 5 years. The aim of this study has been to illustrate whether the present use of firefighting foam affects the surface water quality and groundwater resources in the vicinity of firefighting training areas.

The investigation is based on the analysis of the PFAS composition in the firefighting foams in current use at Danish Defence sites in relation to environmental investigations of the impact on water quality. Groundwater contamination can impact drinking water resources and groundwater-fed streams and lakes. Furthermore contamination of surface water can occur due to direct discharge from sewers or drains associated with firefighting sites.

Conclusions
To evaluate the PFAS composition of the current firefighting foams and the impact on the environment the analysis of 21 PFAS compounds has been employed in conjunction with the TOP analysis (Total Oxidation of Precursors). The 21 PFAS compounds include different PFAS groups including potential precursors as well as the 12 PFAS compounds regulated in the Danish Groundwater Quality Criteria. The TOP-analysis measures the content of PFAS-compounds in the sample before and after oxidation and therefor predicts the potential transformation of PFAS precursors to persistent PFAS compounds. Although many perfluorinated PFAS compounds are recalcitrant to degradation, newer PFAS-formulations are often composed of fluorotelomer compounds which can partially degrade to the more persistent perfluorinated compounds. These fluorotelomer based compounds are seldom included in the analytical suites and therefore risk assessment of the potential impact on recipients cannot be performed. The TOP-analysis can illustrate the potential for degradation of precursors in a given media.

Using this method, a realistic picture of the potential impact in relation to the regulatory criteria for the PFAS-compounds of concern can be achieved.

The analysis results after the oxidation (TOP analysis) show an increase of the total content of PFAS compounds by a factor of up to 80.

The study has verified that there is a large difference in the PFAS content and composition in various firefighting foams. Furthermore, the study has revealed that the analysis of the foam liquid concentrate presents a number of analytical challenges to the analytical laboratory.

The study has also included analysis of firefighting foam used in connection with fire protection of buildings (sprinkler systems connected to liquid foam).

The study has verified that groundwater contamination with PFAS compounds as well as firefighting sites constructed with direct discharge to recipients via sewers affects the water quality in recipients located downstream of active firefighting sites.

Concerning surface water recipients, the only environmental quality standard for PFAS-compounds in surface water is the criteria for PFOS and derivatives as defined in the EU directive and implemented in the Danish legislation with effect from 22 December 2018. Is it sufficient to only have a criteria for PFOS and derivatives hereof in surface water, or should a secondary quality standard be derived to include all the 12 PFAS compounds defined in the Danish EPA groundwater quality criteria ensuring continuity in the risk assessment? Is it realistic to comply with the coming relatively low criteria for PFOS?

With respect to uncertainty in the potential PFAS loads in surface water recipients, consideration must also be given to a demand for the use of TOP analyses?

Evaluation of biodegradation capability of contaminated soil for *in situ* treatment

Marja Tuomela, PhD
Co-op Bionautit, mail: marja.tuomela@bionautit.fi

Leena Räsänen, PhD, Co-op Bionautit
Edina Rudner, PhD, Co-op Bionautit
German Jurgerns, PhD, Co-op Bionautit
Aura Nousiainen, PhD, Pöyry Finland Oy

Background

In situ technologies for contaminated soil treatment should be favoured according to principles of sustainable development. Excavation of contaminated soil and placement to landfill is still a common practice, although transportation of soil is costly despite the common agreement in the EU that landfilling in general should be greatly reduced. Furthermore, landfilling only transfers the problem elsewhere without solving it. Even if soil is excavated, on site treatment reduces remediation energy needs.

In situ and on site treatment technologies including (monitored) natural attenuation mostly rely on the microbiological processes in soil. Currently, no method exist for the evaluation of the biodegradation capability of the microbial population in soil only chemical methods for evaluating the nutritional status of soil. A procedure for testing the soil for status of microbiological degradation capacity would give a helpful tool when deciding for implementation of *in situ* or on site treatment.

Aim

Our recently started project creates a procedure for the microbiological evaluation of contaminated soil. The aim of the procedure is to answer questions: 1) does the soil have capability to degrade the contaminant, and 2) does the degradation require any nutrients, oxygen or moisture in order to be effective. Oil is used as a model contaminant. Various methods are tested, namely a presence of oil degrading genes, lipase activity, total microbial mass and soil toxicity. For total microbial mass and soil toxicity several methods are tested in order to find the most suitable one.

To test the relevance of selected methods we run an experiment with four types of oil contaminated soil and a control soil. Soils (appr. 10 kg for each replicate) have four types of treatments: 1) no treatment, 2) aeration 3) fertilization and 4) aeration and fertilization and they are incubated for four months. Samples are taken from the beginning of the experiment and three times during incubation. Soils are analysed for total petroleum hydrocarbons (C10 – C40) at the beginning and at the end of the experiment. Oil degradation in soils is compared with the microbiological evaluation tests selected for the project.

Conclusion

To our knowledge, currently no test is available on the market for evaluating the microbiological degradation capability of contaminated soil. Our test procedure will initially provide tools for oil contaminated soils, but our aim is to select as universal methods as possible in order to apply the procedure to other contaminants – possibly with some modifications – in future. The test procedure could also be used as background knowledge for environmental due diligence and risk assessment, and for evaluating if natural attenuation is a sufficient method for soil treatment.

Improvement of traditional investigations by prior geophysical measurements

Helle Blæsbjerg, M.Sc. Geology, Central Denmark Region,
mail: helle.blaesbjerg@ru.rm.dk

John Ryan Pedersen, M.Sc. Geology, Central Denmark Region
Anette Specht, M.Sc. Geography, Central Denmark Region
Rolf Johnsen, M.Sc. Geology, Central Denmark Region
Jesper Bjergsted Pedersen, M.Sc. Geology, Aarhus University

Geophysical investigation methods has frequently been utilised in Danish groundwater mapping. As contaminated sites often are situated in urban areas interference has ruled out the use of geophysical methods for this purpose. Also the resolution of the upper soil layers has been inadequate. Now improved and new geophysical methods are qualified for high resolution interpretation of the uppermost geology.

In this project we are testing the contribution of geophysical measurements to the traditional concept for investigations of contaminated sites. The project is part of the Interreg Topsoil project working on improvement of climate resilience by demonstrating and testing solutions for managing the top soil layers.

Traditionally, contaminated sites are investigated by drillings, soil and water samples and soil gas measurements. Sampling points are initially based on potential point sources collected in historical archives, by interviews etc. Based on the first results subsequent points are allocated in order to delineate hotspot and/or plume. This approach contains a substantial uncertainty especially in a heterogeneous geological setting, thus a solid risk assessment implies a large number of boreholes.

The objective is to clarify if expenses and/or time can be reduced by adding an areal dimension prior to the point approach. Beside cost efficiency we might be able to replace part of intrusive methods with non-intrusive methods, and also the 3D dimension will provide us with a higher amount of data for risk assessment. The final output should be recommendations and guidelines for a better integrated practice.

A traditional investigation draft is outlined and then compared to a draft based on geophysical interpretations. The aim is to analyze possible differences in the number and location of boreholes in a traditional investigation relative to an investigation with a prior geophysical mapping. This mapping is carried out with a TEM instrument towed after an ATV (tow-TEM). Depth of investigation with a proper resolution is 30 meters, and speed is 10-20 km/hour.

The trial has so far been carried out on a former landfill and an agricultural contractor, where pollution with leachate and pesticides has been proved. The geological setting is primarily quaternary sediments like clay tills and melt water sands. Preliminary results show limited success on the landfill due to high conductivity in the fill material causing low penetration depth. Also a complex geological setting in that area decreases the value of geophysical mapping.

At the agricultural contractor on the other hand, we have achieved promising results indeed showing a wide coherent mica clay layer which will assumingly reduce the need of boreholes substantially.

To strengthen the evidence in the project we expect to complete investigation drafts and geophysical mapping on two more locations during spring 2018. So at the NORDROCS conference in September we should be able to show results and preliminary conclusions from four different locations.

Investigation of possible contaminations from pesticide point sources

Lotte Banke, geologist
Denmark Central Region, mail: lotte.banke@ru.rm.dk

Kaspar Rüegg, civil engineer, Denmark Central Region

Background
Central Denmark Region is mapping locations with possible pesticide contaminations caused by activities on site. In a following step the Region determinates, through soil investigations, if the mapped activities have caused soil contaminations that may cause risks for the groundwater resource or the environment.

As pesticides for the most are very mobile, they almost solely are detected in water samples. Very often we detect pesticide in water samples taken a few meters below terrain, often from formations with very low permeability.

In preliminary investigations we seldom drill to greater depths than to secondary or upper primary groundwater resources because of cost. This leaves us with the question: Do we have a risk for a primary aquifer, if contaminations are detected a few meters below terrain in shallow, secondary aquifers or in water samples taken from small pockets of water in compact geological formations?

Aim
This presentation will discuss conceptual understanding of how contamination from different pesticide point sources spread. From this understanding the presentation will discuss potential strategies for investigation and their possible pitfalls.

On this background it will introduce a project Central Denmark Region recently has initiated and, if possible first results therefrom.

The project will in a 1st. phase look at data from preformed investigations and the findings and risk assessments therefrom. In a 2nd. phase it will look on theoretical flux to lower primary groundwater tables in 2 situations:

1. from a pulse like contamination in a sandy formation with high permeability, and
2. from a contamination embedded in a formation with low permeability .

Conclusion
Central Denmark Region often detects contaminations with pesticides in water samples when investigating possible point sources for contaminations with pesticides. However, it is difficult to determine, if those contents pose a threat for the groundwater resources in the areas. Studies of performed investigations and theoretic flux studies will hopefully help with the design of future investigations and risk assessment.

Novel passive sampling case study of Per- and Polyfluoroalkyl Compounds in groundwater and surfacewater.

Hubert de Jonge
Eurofins Environment, Denmark, mail: Hubertdejonge@eurofins.dk

Sarah E. Hale, Andreas Botnen Smebye, Åse Høisæter, Mona Cecilie Hansen, NGI, Norway
Kamilla Grotthing Moe, Julie Stene Krokstad: Avinor, Norway
Beate Sjøberg, Eurofins Environment, Norway

Background
Per- and Polyfluoroalkyl (PFAS) compounds have for several decades been applied at a large scale in a.o. fire extinguishing foams at airports. PFAS compounds are now recognized as priority contaminant of concern for recipient waters and the food chain because they are water soluble and mobile in soil and groundwater. At the same time these compounds are very persistent in the environment and have a potential for bioaccumulation. As PFAS compounds are still relatively new in a legislation context, effective means for monitoring these compounds in dynamic environments is a prerequisite for the future enforcement of environmental standards.

Aim
The motivation of the study is to develop and test a new passive sampling application for PFAS that has the advantage of representing accumulated time-weighted average (TWA) concentration without the need for expensive infrastructure. The specific purpose of the present study was to test a new passive sampler in a field scale application in both groundwater and surface water. The location of the study was in the close vicinity of Oslo airport. At the site, a plume of PFAS has been located and delineated downstream of a firefighting training facility. A newly designed passive sampler – Sorbicell for PFAS – was applied in consecutive installations in two groundwater wells and an adjacent surface water creek directly downstream of the contaminated aquifer. Water grab samples were taken as a reference for the performance of the passive sampler. Both sampling methods – grab samples and passive samplers – were analyzed for PFAS substances through LC-MS identification and quantification.

Results
Results showed highly varying content in groundwater both as a large variation of individual PFAS compounds fingerprint, as well as the levels found in groundwater and surface waters, with a variation over three orders of magnitude. A direct correlation of the two methods showed a good general agreement of the detectable compounds. There is a tendency of slightly higher levels measured with grab samples, while the analytical and temporal variation of the two methods was at a comparable level. This present study shows that the passive sampler is a suitable and potentially cost-saving sampling method for PFAS in surface water and groundwater, that is particularly effective in temporally dynamic waters.

Passive Flux Sampling in Groundwater: Guidelines and Demonstration Cases with iFLUX Samplers

Goedele Verreydt, Dr., Technical Director, iFLUX
mail: Goedele@ifluxsampling.com

Background

The monitoring and management of soil and groundwater is a challenge. Current methods for the determination of movement or flux of pollution in groundwater use no direct measurements but only simulations based on concentration measurements and Darcy velocity estimations. This entails large uncertainties which cause remediation failures and higher costs for contaminated site owners. On top of that, the lack of useful data makes it difficult to get approval for a risk-based management approach which avoids costly remedial actions. The iFLUX technology is a key development of Dr. Goedele Verreydt at the University of Antwerp and VITO. It is supported by the passive flux measurement technology as invented by Prof. Mike Annable and his team at the University of Florida. The principles of the iFLUX technology will be presented, together with the results and guidelines from Flemisch and French regulatory passive flux sampling demonstration projects.

Aim

The iFLUX technology includes an in situ measurement device for capturing dynamic groundwater quality and quantity, the iFLUX sampler, and an associated interpretation and visualization method.The iFLUX sampler is a modular passive sampler that provides simultaneous in situ point determinations of a time-averaged target compound mass flux and water flux. The sampler is typically installed in a monitoring well where it intercepts the groundwater flow and captures the compounds of interest. The sampler consists of permeable cartridges which are each packed with a specific sorbent matrix. The sorbent matrix of the water flux cartridge is impregnated with known amounts of water soluble resident tracers. These tracers are leached from the matrix at rates proportional to the groundwater flux. The measurements of the contaminants and the remaining resident tracer are used to determine groundwater and target compound fluxes. The modular design enables to sample several types of pollution at the same time. Exposure times range from 1 week to 6 months, depending on the expected concentration and groundwater flow velocity.

Conclusion

The iFLUX sampling technology has been tested and validated at multiple field projects on demand of the Flemish (OVAM, contaminant flux pilot study) and French (INERIS, Passiflux project) environmental regulators. The objectives of the demonstration projects for both regulators are to frame passive flux measurements in the context of contaminated site management, to test the passive flux sampling technology and to provide application guidelines. Various aspects are considered within these studies: various contaminant types and pollution levels, different hydrogeolocial conditions and different application objectives (e.g. characterization, remediation design, risk-based monitoring).

Determination of polyfluorinated compounds in soil and water

Václav Šístek, Ing., ALS Czech Republic
mail: vaclav.sistek@alsglobal.com

Eva Hudečková, Ing., ALS Czech Republic

Poly- and perfluorinated compounds have been produced since the 1950s. In the 1970s, fluorinated organic compounds have been found in the human body, and since then, the impact of these substances has been the subject of research by scientists. Since 1990s detection techniques have been sufficiently developed to find residues of poly- and perfluorinated substances in all types of environmental samples. Their high bioaccumulation potential and long half-life classify these substances among persistent organic pollutants (POPs).

Because of their unique properties (inert, hydrophobic, oleophobic, high temperature resistant) they have been used in many industries. They are used in the production of detergents, such as clothing protection, in pharmacy, food industry or as a fire-extinguishing additive. The most well-known perfluorinated polymer is Teflon used as a surface-inert material in many areas.

Nowadays about 600 different poly- and perfluorinated compounds are known. Perfluorooctanoic acid (PFOA) and Perfluorooctane sulfonate (PFOS) are the most well-known and most frequently studied. The occurrence of these substances is an indicator of the environmental burden because most fluorinated substances are degraded to these most stable representatives. Legislative requirements are set for PFOS in surface waters by Council and Parliament Directives 2013/39/EU.

ALS Czech Republic can determine 35 substances in water samples with routine quantification limits of 0.01 µg/L. We are also able to determine a low level concentration of about 0.3 ng/L by ultra-low limit method. This year, we have developed a method to determine the total content of poly- and perfluorinated substances in water sample by TOPA (Total Oxidazible Precursor Assay).

In case of soil samples we are able to determine 23 perfluorinated and polyfluorinated compounds with routine limits of 0.005 mg/kg DW.

Since 2015 about 10000 of samples have been analysed. Results and experience of PFC content in regular water and soil samples will be discussed and presented.

Diving plumes - Understanding the parameters that affect contaminant transport in sandy aquifers

Mads Møller, MSc. Eng.
Orbicon A/S Denmark, mail: msgm@orbicon.dk

Katerina Tsitonaki, MSc. Eng., PhD, Orbicon A/S
Thomas Larsen, MSc. Eng., PhD, Orbicon A/S
Mads Troldborg, MSc. PhD, The James Hutton Institute, Scotland
Lars Larsen, MSc. Geology ,Orbicon A/S
Sine Thorling Sørensen, MSc. Geology, Capital Region of Denmark
Nina Tuxen, MSc. Eng., PhD, Capital Region of Denmark
Jens Aabling, MSc. Eng. Danish EPA

Background
Sandy aquifers are often regarded as a homogeneous medium, where groundwater and contaminant transport take place in one direction. In reality, sandy aquifers are characterized by remarkable heterogeneity, which means that groundwater and contaminants flow in preferential horizons with shifting vertical and horizontal direction.

The motivation for this project is that in several of our site investigations we have observed contaminant plumes diving deeply into the sandy aquifer. We have experienced that there is a high risk that we will not detect the contaminant plume downgradient if we are not aware that the plume dives.

Aim
The primary objective is to improve the conceptual understanding of contaminant transport in sandy aquifers with a special focus on understanding the conditions and parameters that cause plume diving. A better understanding will eventually improve our strategies, documentation and risk assessment in our site investigations.

Conclusion
The project will result in three main products:

1. A new conceptual model for sandy aquifers.

   By setting up a simple analytical groundwater model we will simulate flow in a sandy aquifer and examine the influence of different parameters such as the location of source area, net infiltration, nearby pumpning wells, changes in hydraulic conductivity over depth etc.

   The new conceptual model will combine learnings from the analytical model and lessons learnt from site investigations where plume diving has been observed, regarding the conditions/parameters that have been significant for the diving plume

2. Description of different methods and tools that can be used to determine the different parameters that cause plume diving.

   An example is how different methods for determine hydraulic conductivity (slug tests, grain size analysis pumping tests etc.) yield different results. We will discuss the difference between the different measurements and the measurement uncertainty? Furthermore, we will discuss how data be interpreted as well as requirements for data density in order to obtain an adequate decision basis.

3. Recommendations for evaluating and predicting plume diving in sandy aquifers

   Based on steps one and two, the project will include recommendations on the following:

   - Checklist of critical conditions and parameters for predicting the risk of a diving plume at an early stage of a site investigation
   - Investigation strategy and tools for determining the critical parameters
   - Data processing and data density

The findings of the project by an improved conceptual understanding of diving plumes will result in a much higher security in terms of mapping and risk assessment of diving plumes in sandy aquifers and thereby a higher protection of the groundwater resource.

Electrokinetic in-situ remediation of a 75 tons xylene contamination in soil, bedrock and groundwater

Thomas Hougaard, M.Sc. et Sc., Senior Consultant
Golder Associates A/S, mail: thomas_hougaard@golder.com

Jonas Rose, M.Sc. Eng., Project Manager, Golder Associates A/S

Background
Golder has utilized applied in-situ electrokinetic ground improvements for more than half a century. This paper describes the site characteristics, development, and results of an on-going electrokinetic remediation of a severe xylene contamination caused by a former paint production facility.

The remediation addresses the contamination hotspot beneath a former tank farm covering ca. 1000 m2 to a depth of 25 m holding some 75 tons of xylene. The affected groundwater covers several hectares.

The geology consists of sandy clay overlaying calcareous bedrock at ca. 6 meters below grade. An unconfined groundwater table is situated ca. 20 m.b.g.

Golder designed and monitors an in-situ electrokinetic treatment system at the site.

Aim
The aim of the treatment is to lower the concentrations in soil, bedrock and groundwater to levels accepted by the authorities as safe for residents and environment. The remediation is divided in two. An initial 6 months demonstration period to sample data on mass conversion, groundwater concentrations etc. that allows for a realistic planning for the remediation of remaining product.

Setup
The system consists of central cathode and to anodes placed ca. 20 meters at each side of the cathode in a straight line. The electrodes, made of 160 mm mild steel pipes, are set to a depth of 30 m.b.g.

The electrodes are powered by a special power supply. The overall power consumption to operate the plant is ca. 1 kW.

The system was installed and started operating in late February 2018.
The first control samples were collected 2 months later. Two more sampling rounds are planned for.

Results
After two months of operation the following results were observed based on the analysis results from 21 initial and 24 control samples. Samples were sampled pairwise within ca. 1 meter from each other.

BTEX was reduced 42%, from 5.882 to 3.417 ppm
C_5-C_{10} was reduced 35%, from 9.650 to 6.257 ppm
C_{10}-C_{40} was reduced 74%, from 1.527 to 392 ppm
C_5-C_{40} was reduced 41%, from 11.177 to 6.649 ppm

Groundwater concentrations of BTEX and TPH have increased ca. 75%, from 207 to 356 and 332 to 596 ppm respectively, within the treatment area. 30 meters down-stream outside the treatment area concentrations have decreased some 15 %, from 60 to 50 and 81 to 63 ppm respectively.

Conclusion

EK has proved a viable, efficient and cost-effective method for remediation of xylenes in soil, water and bedrock. Costs, inconveniences for residents, and carbon footprint are lower compared to traditional in-situ and dig & dump methods. However, depending on clean up criteria, time requirements for full remediation can be a hindrance, and the use of EK in organic rich soils might cause settlements of soil and overlaying constructions due to mineralization of organic matter.

In-situ Thermal Desorption of Hydrocarbon-Impacted Soil

Haemers Jan, CEO
Haemers Technologies, mail: jan.haemers@haemers-tech.com

Hatem Saadaoui, Chief Scientist, Haemers Technologies
Patrick Vilette, Supervisor, Haemers Technologies
Aurélien Vandekerckhove, Project Engineer, Haemers Technologies

Background

Hydrocarbons products are highly toxic to human health and constitute a major environmental problem. This kind of contamination is relatively common because of its widespread use, its associated disposal and accidental spills.

In this context, a leak of domestic fuel oil from an underground tank led to the pollution of hydrocarbons in a residential area in the north of Copenhagen. As a result, unacceptable concentrations of hydrocarbons have been detected under the terrace of the private house, and mainly in the garden.

As result of the contamination and the risk of exceeding the drinking water standards in the Ground Water aquifer, In-Situ Thermal Desorption (ISTD) was applied to prevent propagation of this pollutant.

Aim

The proposed ISTD treatment (figure 1) is based on the principle of thermal desorption. First, heating pipes and perforated tubes placed throughout the ground (in a specific pattern) heat up the contaminated soil. This operation is aimed at vaporizing all the contaminants.

Figure 1. In-Situ Thermal Desorption of hydrocarbon-impacted soil in residential area.

Second, the soil is maintained under negative pressure thanks to extracting fan. The collected vapour from soil is extracted and reinjected into the burners, where they are recycled as fuel for the burners (reburn system).

The main expected mechanism of the treatment after recovering is a complete oxidative reaction. The combustion products are then sent toward the chimney.

Site description and ISTD treatment
The contaminated soil (target zone) is estimated at 5700 m3 with a lower treatment depth of 18 m below the ground level (bgl), with a total surface close to ca. 400 m². As most the groundwater is located below the contaminated zone, the groundwater has not been lowered. The average concentration of total hydrocarbons in soil is close to 1000 mg/kg (DM) with a maximum concentration of 22 000 mg/kg (DM) . The total mass of the pollutant into the soil was estimated to 12000 kg. For technical reasons, the contaminated zone was treated in two batches and the characteristics of the treatment are depicted below.

	Batch 1	**Batch 2**
Number of burners	57	69
Treatment surface (m²)	ca. 200	ca. 200
Contaminated depth (m)	12-18	12
Volume of batch (m³)	ca. 3000	ca. 2700
Treatment duration (days)	65	69
Average soil temperature at the end (°C)	242	302
Natural Gas Volume (Nm³)	180 203	202 629

Figure 2. Characteristics of the thermal desorption treatment of Vedbaek.

In this project, the concentrations of the hydrocarbons in the extracted vapour before reinjecting into the burners were taken as the validation parameter of the treatment with the target temperature (220°C – temperature to degrade/evaporate the hydrocarbons). The treatment is considered completed when the target temperature is reached and the vapour concentrations of collected hydrocarbons tend towards zero. The treatment is carried out respectively in 65 and 69 days for the batch 1 and 2. Haemers Technologies/Arkil accomplished the treatment without producing any environmental disturbance (atmospheric, dust, etc.) and in complete transparency. A process-related data was made available to all stakeholders on a daily basis to track changes in thermal desorption.

Conclusion
The ISTD treatment of residential site (ca. 10000 tons) contaminated with hydrocarbons has been successfully completed with 128 heating tubes in a few months for a surface of 400 m² at a depth between 12 and 18 m.

Mass discharge for vapor intrusion mitigation system analysis and vapor intrusion site assessment

Per Loll, R&D Manager, Ph.D.
DMR A/S, Denmark, mail: pl@dmr.dk

Martin Flyhn - DMR A/S, Denmark
Hanne Nielsen, Kristian Dragsbæk Raun, Kim Risom Thygesen and Klaus Bundgaard Mortensen - Region Syddanmark, Denmark
Niels Døssing Overheu and Sine Thorling Sørensen - Region Hovedstaden, Denmark

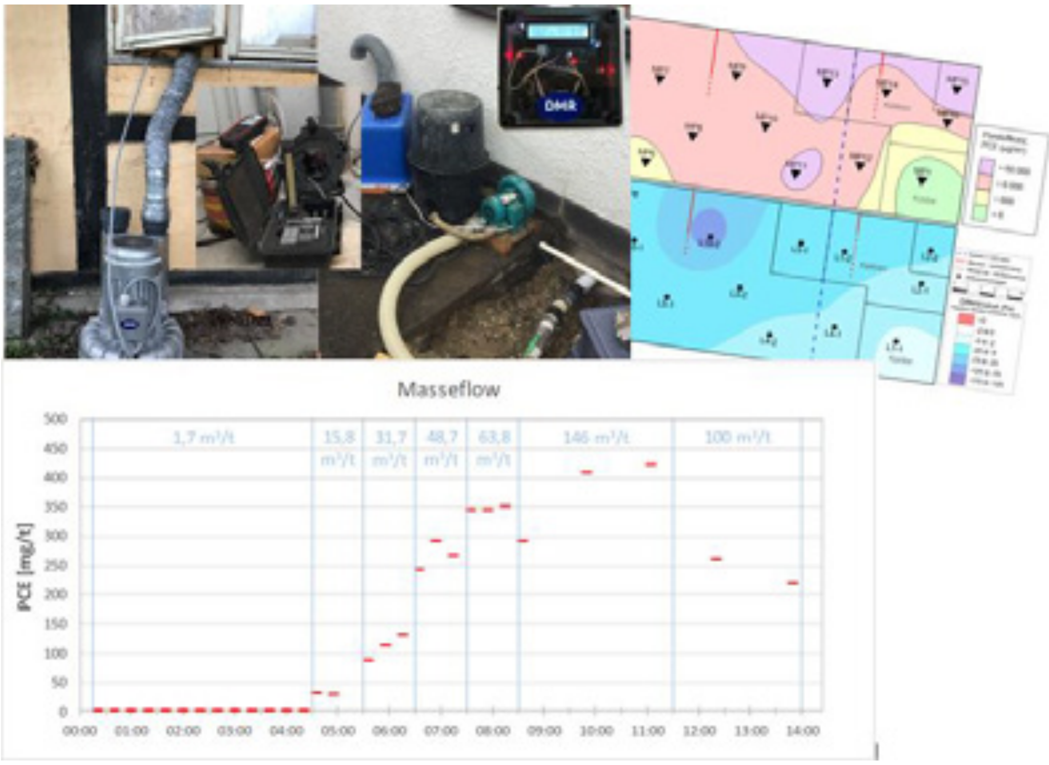
Background
In recent years, mass discharge tests have been applied as a useful tool in refining the Conceptual Site Model (CSM) in vapor intrusion studies, and it has been suggested that application of a mass discharge test procedure can be used for the determination of when a (passive) vapor mitigation system can be turned off.

The presentation will highlight the results of two separate projects where a mass discharge test has been carried out by application of a vacuum blower based sub-slab vacuum and measuring air flow (m3/h), concentration (µg/m3) and monitoring the differential pressure across the floor. At both sites, previous mitigation systems, one passive and one active, had failed.

Aim
The aim of the first project was to test a step-wise procedure for determination of mass discharge, and estimation of the necessary mitigation time frame at passive mitigation systems - and suggest a generally applicable procedure. This was carried out on a passive mitigation system for the Southern Region of Denmark (Obduktionsprojektet).

The second project was a pilot test for the Capital Region of Denmark (at Innovationsgaragen) for designing a blower driven sub-slab depressurization system (sub-slab vacuum). The aim was to design the most cost-effective number of vacuum points, their placement, and a vacuum that is just enough to create a robust downward pressure gradient over the concrete slab. Previous mitigation efforts, based on internal carbon air purifiers (Molly), were insufficient for reaching acceptable indoor concentrations.

Conclusion
It is easy and relatively cheap to perform a basic mass discharge test, and used at the right time it can provide critical information of a contaminated site.



At both test sites, previous site investigations left an impression of relatively well-established CSMs, with certain "blind spots". At both sites the mitigation systems had failed in reducing indoor concentrations to acceptable levels. Performing a mass discharge test at the sites gave valuable information for further development of the CSMs and gave unique new insight into the shortcomings of the mitigation systems.

Based on the results from the first case, a generally applicable test procedure for mass discharge tests at passive mitigation systems is proposed. At the second site, the test results have led to a hypothesis of contaminated building materials, and the design of a sub-slab mitigation system has been put on hold, pending new investigations.

Based on the results from the two sites, we propose that a mass discharge test can be a valuable tool, not only at sites with (passive) venting/depressurization mitigation systems, but also as a part of site investigations – to refine the Conceptual Site Model.

The two projects are finished and all results are available at the time of abstract submission.

Combination of enhanced reductive dechlorination and aquifer thermal energy storage – pilot test

Mette Christophersen, Head of Dept., ph.d., Contaminated Soil & Groundwater, Rambøll Denmark. Mail: metc@ramboll.dk

Lars Bennedsen, ph,d., Rambøll, Line Mørkebjerg Fischer, Msc., Anne Mette Granhøj Hansen, Msc., Ida Damgaard, ph.d., Capital Region of Denmark, Bas Godschalk, Msc., IF Technology, Maurice Henssen, Msc., Bioclear Earth, Nanne Hoekstra, Msc., Deltares and Tim Grotenhuis, dr.ir., Wageningen University

Background

Aquifer Thermal Energy Storage (ATES)-systems are highly effective energy-storage systems, and provide energy with low CO2-emmisions. There is an increasing interest in ATES systems, and the potential in Denmark is evaluated to be at least 400 ATES plants.

In urban and industrial areas there can be a large need for cooling and heating of buildings and industrial processes. However, in such areas, contaminated sites are often encountered and hampers urban development. Contamination with chlorinated solvents is one of the most frequently occurring contaminations. In addition, plumes of chlorinated solvents often occur in aquifers at approximately the same depths at which an ATES-plant would abstract and inject water. However, a new approach is to view the combination of ATES and remediation as an opportunity, as synergies and benefits are expected for the combination of ATES and bioremediation as the elevated groundwater temperature and flow is expected to increase the degradation rate for the chlorinated compounds.

The conclusions of a literature study conducted in 2016, were that laboratory results are promising, showed that there however still is a great need for practical experiences with the combination of ATES and enhanced reductive dechlorination (ERD) to demonstrate the proof of concept at field scale. Experiences are needed from sites in practice, in order to further explore and document the full potential of the combination of ATES and ERD. Based on the literature study it was decided to proceed with a pilot test.

Aim

The purpose with the pilot test is to investigate the synergy effects of combining ATES and ERD and thereby both improving the efficiency of ERD by the elevated groundwater temperature and higher flow and gain energy for heating/cooling of e.g. building at the same time.

Results

In March 2017 after a screening of several potential sites for a pilot test a suitable site was found in the Capital Region. In the summer 2017 pre-investigations were conducted at the site including groundwater sampling, pump test and groundwater modelling. The pre-investigations showed that the contamination with TCE is present in the upper 5 m of the saturated zone and that the upper app. 2 m of the saturated zone is oxic. In this part of the aquifer the groundwater model and the pump test showed that it should be possible to pump up to 5 m3/h, which is suitable for an ATES-system.

In late 2017 the HOT and the COLD well and 4 monitoring wells were installed at the site, and in the beginning of 2018 the base line monitoring at the site has been conducted. The recirculation of groundwater will start at the end of January 2018 and reductive dechlorination bacteria will be injected in March.

At the time of the Nordrocs conference app. 5 monitoring campaigns will have been conducted and the presentation will present the results from this monitoring together with an evaluation of the potential for this combination of remediation and energy production. The results will be compared with results from a similar pilot test conducted in the Netherlands (Utrecht) at the moment at lower concentrations of chlorinated compounds and different physical and chemical characteristics of the aquifer.

Ex-situ treatment techniques for PFOS contaminated soils

Adrien Kahn, Business Development Manager Nordic
SUEZ, mail: Adrien.Kahn@suez.com

Jeroen Vermeulen, Business Development, SUEZ
Tom Vermeiren, Account Manager, SUEZ

Background
PFOS substances have been used for a long time in the textile industry and in fire-fighting foams to name a few applications. PFOS are extremely persistent in the nature and are today restricted and classified under the Stockholm Convention as POP (Persistent Organic Pollutants). Several countries are paying particular attention to the remediation of PFOS contaminated sites, including Scandinavian countries, USA, Canada, Germany, The Netherlands and other countries are following.

Aim
Traditional ex-situ soil treatment techniques are tested to evaluate their feasibility and needed improvements or modifications to treat PFOS contaminated soils. Two techniques are selected: soil washing and thermal desorption.

Soil washing is a wet process and has the particularity to separate soil components in function of their size and density. As it is expected that PFOS adhere to the smallest soil fractions (clay and silt) and to organic matter and dissolve in the process water, the sand and gravel part can be re-used or recycled. Process water is successfully treated using activated carbon or specific resins.

Thermal desorption and not to be confused with incineration is a treatment that desorbs the organic contaminants in the gas phase, in our case PFOS. The gas phase is than oxidized at high temperature. In order to fully oxidize the PFOS into CO2 and H20, a temperature of close to 1.200°C needs to be reached. The fluor is cleaned from the gas phase using gas-washers. The treated soils can be re-used or recycled.

Conclusion
SUEZ has tested both techniques, first on laboratory scale, then on an industrial scale. Both techniques shows promising results. Soil washing allows a reduction of at least 80% of PFOS concentration in the sand and gravel parts of the soil. Thermal desorption allows a reduction of PFOS up to <1µg/kg d.m.

Both techniques can be applied on-site or off-site in dedicated treatment centers.

New process for the treatment of perchlorate contaminated water

Boris Devic-Bassaget, Technical Manager, SUEZ
mail: boris.devic-bassaget@suez.com

Jean-Yves Richard, R&D Manager, SUEZ

Background
Perchlorate (ClO_4^-) is used as a fuel in the form of ammonium perchlorate in the space and defense fields. Like all the anions, it is poorly retained by the soil and locally impacts groundwater, particularly in the fields of battle of the last two wars and various industrial sites where it is produced or used. Perchlorate poses health problems especially because it is suspected of being an endocrine disruptor. The threshold of 15 µg / l for water intended for human consumption in the USA is set at 15 µg / l.

The very low threshold, associated with a great persistence in the groundwater make that the treatment of groundwater impacted by the perchlorate becomes today a major environmental challenge. Perchlorate thus appears as an emerging pollutant in Europe.

Aim
The treatment of groundwater impacted by perchlorate is generally carried out by filtration on ion exchange resins. The resins used cannot be recycled and represent a significant cost. The saturated perchlorate resins must be treated by incineration and cannot be landfilled because of the perchlorate content making the resins explosive sensitive materials once saturated.

Biodegradation of perchlorate is possible under anoxic conditions where perchlorate is used as the terminal electron acceptor in place of oxygen. The bacteria involved are ubiquitous and often also able to "breathe" the nitrates.

SUEZ has developed a new biofiltration process capable of treating perchlorate-impacted groundwater. This extensive biofilter comprises a thin granular bed completely saturated with water. The contribution of a carbon source in the effluent and the presence of organic matter in the upper layer of the biofilter allow passage and maintenance in anoxic condition, a favorable condition for the desired biodegradation. A deep layer supports the purifying biomass.

The first tests in the laboratory validated the feasibility and the main operating parameters. A semi-industrial pilot (10m x 10m) was carried out on site to test the hydraulics of the system and the efficiency of the de-clogging device using reeds.

A first industrial application was conducted to treat heavily impacted groundwater in the source of contamination containing ammonium perchlorate.

Conclusion
The biofilter allowed biodegradation up to 15kg perchlorate per day. It can accept perchlorate concentrations higher than 100 mg / l and is capable of achieving under

optimal conditions a residual concentration of a few µg / L (ppb), ie a level under the threshold retained for distribution of water intended for human consumption.

In situ soil washing of pentachlorophenol - a pilot study on a former saw mill

Kristin Forsberg, project manager
Geological Survey of Sweden (SGU), mail: kristin.forsberg@sgu.se

Lijana Gottby, project manager, Geological Survey of Sweden

Background

The former saw mill in Hjortsberga village (active 1940-1981) is situated in the municipality of Alvesta. Pentachlorophenol (PCP) has been used for wood preservation. Former investigation has shown that the main contamination at the site in soil is from dioxins and the dominating contamination in the groundwater is PCP. The Geological Survey of Sweden (SGU) has the mandatorship for the actions at the site since 2011 and the contamination of dioxins was remediated by soil excavation already in 2013. An in situ treatment by chemical oxidation of the groundwater was initiated in 2014. Under 2017 a pilot field study has been carried out in order to design a system for soil washing in situ of PCP on the site. The project is partly financed by the Swedish Government (60 %) and (40 %) by the former owner of the saw mill.

Aim

The aim for this project is to find a strategy for remediating high concentration PCP that is bound to the soil particles in the saturated zone on the site. One of the key issues of the work has been to describe the conceptual site model to understand how PCP is spreading through the saturated zone in soil compartment and in the groundwater. The pilot field study was carried out in order to investigate possible remediation technique using in situ soil washing on the site in order to reduce the high levels of the particle bound contamination in the saturated zone of the soil compartment.

Conclusion

The results from the pilot field study confirmed that understanding the conceptual model of the specific contaminated site and how spreading is occurring in the saturated zone, is important when finding the final remedial strategy. The same pattern for spreading of PCP in the saturated zone can be seen at another saw mill close by with similar complexity of the contamination problem.

The solubility and spreading of PCP is highly dependent on pH and that is one reason why PCP doesn’t behave like other common chlorinated contaminants (i.e. PCE and TCE). Understanding its behaviour is the key finding a remediation strategy for saw mills contaminated by PCP.

The in situ treatment in 2014 included chemical oxidation method as the first stage of the treatment trains at the pollution source area. Reductive dechlorination was believed to be the second stage of the treatment trains. However, results from the chemical oxidation showed that level of PCP in the groundwater was increasing, instead of an expected decrease of concentration. The increase of contamination in the groundwater is believed to be a result of mobilisation of particle bound contamination. PCP was often used in dissolved phase in a base mixture, eg sodium hydroxide. The solute of PCP has been transported by gravity through the unsaturated zone down to the groundwater level. When reaching the groundwater level, the lower pH in the groundwater, most probably resulted in a precipitation of PCP creating particle bound contamination in the soil slowly diluting and spreading to the groundwater flow and further down in to the aquifer. That is mostly common behavior for like other chlorinated contamination with a higher density than water.

The pilot trail in 2017 was an attempt to perform in-situ soil washing using a technique that could be compared with an enhanced pump and threat in order to remove higher levels PCP from particle bound contamination in soil. The evaluation of the pilot study shows that this soil washing technique could be used as an effective remediation process in situ and has a high removal efficiency of the particle bound PCP contamination in the soil.

Remediating DDT-contaminated soil using zero-valent iron – a pilot study on a forest nursery site

Kristin Forsberg, project manager
Geological Survey of Sweden, mail: kristin.forsberg@sgu.se

Henning Persson, project manager, Geological Survey of Sweden
Sarah Josefsson, environmental chemist, Geological Survey of Sweden

Background
Old forest nursery sites are often contaminated with pesticides, and can cover large areas with low to average levels of contaminants in the surface soil. DDT is the most prevalent contaminant. The Geological Survey of Sweden (SGU) is responsible for sites where a former governmental organization has given rise to the contamination. Because of this, SGU are responsible for approximately 40 former forest nursery sites across Sweden. The soil at the nursery sites is generally sandy, as sandy soils are well suited for nurturing seedlings. The degradation rate in sandy soils is low and DDT is strongly adsorbed to the soil particles. There is therefore little change in the contamination levels in the soil due to transport and degradation over time. Due to the large number of sites and the large areas of most sites, there is a need to establish efficient remediation methods.

Aim
The main aim of this project is to investigate if it is possible to degrade DDT and its metabolites DDE and DDD by adding zero valent iron and a carbon source to soils from a forest nursery site at Kårehogen in western Sweden. A key issue is to investigate the potential formation of different degradation products, to ensure that ground and surface water resources are not put at risk.

Conclusion
SGU have carried out a pilot study in order to evaluate an on site treatment method with degradation of DDT through a combination of chemical reduction and biological oxidation. A carbon source and zero valent iron were added to containers with soil and reductive conditions were created by saturating the containers with water. The saturated conditions were maintained for two weeks (anaerobic phase), after which the soil was mixed to oxygenate it (aerobic phase). The sum of DDT, DDE and DDD in the soil before treatment was approximately 5 mg/kg dry weight and the treatment cycle was repeated five times.

In similar international remediation projects, reductions of DDT (and its metabolites DDE and DDD) concentrations with 30-70 % per cycle have been reported. At Kårehogen, degradation of DDT has occurred although not to the same extent as in previous international projects. A reason for this might have been the cold and rainy condition during the summer of 2017. There was no clear increase or decrease in the concentration of DDE and DDD during the experiment, which could be due to variations arising from sampling and laboratory uncertainties. However, when results were evaluated based on ratios between DDD and DDT, and between DDE and DDT, there were consistent increasing trends. This showed that degradation of DDT occurred. The metabolite formed during anoxic conditions, DDD, seemed to dominate. Analyses of subsequent degradation products demonstrated the presence of e.g. dicofol, DDMU, DDOH, DDA, DPM and DCBP. The concentrations of these often more water-soluble contaminants were substantially lower than concentrations of DDT, DDD or DDE.

There are a large number of potentially contaminated forest nursery sites in Sweden. Remediation through excavation and depositing the waste is costly and associated with an environmental impact. Furthermore, the land use requirements often place a demand on the quality of soils used for backfilling. There is therefore a large incentive for continuing to consider in situ/on site methods for remediation of DDT-contaminated soils

In-situ adsorption of per- and polyfluorinated alkyl substances (PFAS) for remediation of contaminated groundwater

Fritjof Fagerlund, Associate professor
Uppsala University, mail: fritjof.fagerlund@geo.uu.se

Lutz Ahrens, Associate professor, Swedish Agricultural University
Mattias Sörengård, PhD candidate, Swedish Agricultural University
Erik Östblom, MSc, Swedish Agricultural University
Dan Berggren Kleja, Professor, Swedish Agricultural University
Jonny Bergman, Research Director, RGS Nordic
Henning Persson, MSc, Swedish Geological Survey
Lijana Gottby, MSc, Swedish Geological Survey
Marko Filipovic, PhD, NIRAS
Johan Edvinsson, MSc, NIRAS

Background
Poly- and perfluoroalkyl substances (PFASs) are highly fluorinated compounds, many of which are widespread, extremely persistent in the environment, bioaccumulate, and are potentially toxic to wildlife and humans. Because conventional in-situ remediation methods for soil and groundwater are inefficient for most PFASs, there are currently no established methods for PFAS in-situ remediation. Instead, long-term pumping with treatment of contaminated water is common. Robust methods to remediate PFASs in situ and stop PFAS plumes in groundwater from reaching drinking water resources are urgently needed.

Aim
In this study, we present the newly started StopPFAS project and our preliminary results aimed at developing in-situ methods to efficiently sorb and immobilize PFASs in plumes in groundwater originating from hot spot areas. Different sorbents were tested in the laboratory for their ability to adsorb PFASs under various conditions relevant to field sites. In parallel, we work with a PFAS contaminated field site where a pilot test of an in-situ sorbent barrier for PFASs will be performed

Conclusion
Preliminary results from the laboratory indicate that activated carbon (AC) sorbents are promising candidates for in-situ adsorption of PFASs in groundwater. The site investigations indicate that local hydrological and geological conditions (e.g. soil characteristics) are important for the application of sorbents in the field and pose challenges for efficient implementation of sorbent-based, in-situ PFAS remediation.

PFAS Treatment – Comparison of Remediation Approaches

Jurgen Buhl, Cornelsen Umwelttechnologie GmbH.
mail: buhl@cornelsen-umwelt.de

Background
In August 2007, there had been a big fire on a site in Germany where shredders had been in operation as part of a recycling process. Shredding of wood and metal had been the main business of that company. During the process of unloading metal waste from a railway carriage a fire had started on the metal pile which covered an area of about 30000 m². Due to the structure of that pile it was very difficult to get that fire under control. It took more than four days and it had involved about 700 members of action forces to get that fire blown out. As water wasn't successful for getting the fire under control the head of the fire-fighting brigades had decided to use about 120 m³ of fire-fighting foam.

Years later, PFC (or PFAS) had been detectable in drink¬ing water wells some kilometres down¬gradient of that site. Further investigations have shown that the use of fire-fighting foams had caused the contamination in the groundwater on site and downgradient of the site.

Aim
Supported by public money the remediation approach should be able to answer the following questions referring the treatment of PFC contaminated water. Is it technically and economically more efficient to run a pre-treatment step before contaminated water enters the carbon vessels or not? Furthermore, it was of interest to identify which type of carbon (3 got tested) shows a better performance and which carbon is at the end the more economical one. An extended field test was performed on site from July until December 2016.

During that field test, contaminated groundwater was pumped through a treatment plant at a flow rate of about 540 L/hr. Starting at the groundwater well the water got split into two lines called line 1 and line 2 (ratio 50:50). At line 1 the water went through a sand filter and then it went through 3 different carbon vessels which were installed in parallel and were filled with carbon A, B, and C. At line 2 the water went through a pre-treatment unit first for generating flocs that contain some of the PFCs. Afterwards it went through a sand filter first for removing the particles that contain PFCs and then it went through three carbon vessels (A, B, C) as well. Samples got taken at the well, behind the filtration and behind the each of the three carbon vessels. The same three carbon qualities A, B, and C got used in both lines.

Conclusions
20 parameters of the PFC got measured in the lab. At the beginning of that test period the concentration of PFC had been at about 7 ppb. At the end of that test period about 2.4 ppb got measured. Main PFCs had been PFOS (start 60% and end 80%) and H4PFOS (10.5 and 5.3%).
In line 1 (GAC only) there had been no change detectable in the PFC concentration after the sand filter. In line 2 the pre-treatment, by generating flocs that contain a certain

part of the PFC, between 65 and 75% of the PFC got removed by this filtration process. At higher concentrations, the removal rate had been higher at that step. That resulted in an economical benefit for the approach in line 2 of about 15% compared to line 1 at that low concentration.

The order of performance of the three carbon qualities A, B, and C had been the same in both test scenarios. The differences had been less in the scenario with pre-treatment. Furthermore, the carbon lifetime was much longer in that scenario with line 2 which kept the effluent concentrations at a much lower level.

Remediation of chlorinated groundwater plumes in Denmark – a technology development project

Dorte Harrekilde,
Ramboll, Denmark, mail: doh@ramboll.dk

Ida Damgaard, The Capital Region of Denmark
Nina Tuxen, The Capital Region of Denmark
Lars Bennedsen, Ramboll, Denmark
Cecilie Bang Ottosen, Technical University of Denmark
Poul Bjerg, Technical University of Denmark
Gareth Leonard, Regenesis

Background/objectives.
Groundwater is the primary source of drinking water in Denmark – more than 99% of the supplied drinking water originates from groundwater. The groundwater beneath many of our larger Danish cities is threatened by chlorinated solvents from former dry cleaning and degreasing activities. Remediation of these plumes is often a very expensive and lengthy task involving many years of operation and maintenance. There is therefore a need to find and develop new remedial methods that are capable of reducing contaminant concentrations to acceptable levels in plumes. With this in mind the Capital Region of Denmark has initiated a technology development project to mitigate contaminated plumes.

The aim of the project is to test and document the effectiveness of a promising technology for in situ remediation of chlorinated solvents in groundwater plumes. The technology chosen is the use liquid activated carbonTM (PlumeStop®) combined with injections of a slow release electron donor and bacteria to create a treatment barrier intercepting the plume.

If successful, it could be a useful addition to the remediation options available to those looking to remediate groundwater plumes.

Approach.
An appropriate test site has been chosen with a saturated sandy aquifer beginning at 12 m bgl. and hydraulic conductivity at approx. 2-5*10-5 m/s. The groundwater plume downgradient from the source area contains chlorinated solvents (primarily TCE) at around 500 µg/l. PlumeStop®, donor (HRC®) and bacteria (BDI Plus) have been injected through 12 fixed screens in the aquifer to create a barrier, where the chlorinated solvents are expected to adsorb and be degraded by stimulated reductive dechlorination. The effect of the injection is followed in groundwater monitoring wells (65 screens) placed upgradient, in the barrier and downgradient.

The project focuses on documentation of the following aspects;

- The overall efficiency of the technology under realistic Danish field condition with a focus on documenting the dechlorination of sorbed chlorinated ethenes
- The distribution of injected PlumeStop in the soil matrix

- Obtaining practical experience with the method under typical Danish conditions and evaluating the potential of the method for treating groundwater plumes in Denmark

The project is performed in collaboration with the Technical University of Denmark (DTU) and Regenesis. The University of Copenhagen is also carrying out geophysical tests with the aim of determining the distribution of donor.

The documentation will be obtained from a comprehensive monitoring program (soil and groundwater) from the site supplemented by laboratory test performed at DTU. Besides standard parameters the groundwater monitoring includes analysis of compound specific isotopes (CSIA) and microbial communities (Quant array) to evaluate the degradation. Intact soil cores will be collected in different depths and distances from the injection points to evaluate the distribution of the injected carbon in the soil.

Results.
The barrier has been established in November/December 2017 and the results of the baseline monitoring and the first 3 monitoring rounds will be available in June 2018.

The presentation will focus on the results from the field test and give an overview of results obtained and discuss these results in relation to the above-mentioned focus areas.

Challenges in reusing clean soil

Dorte Harrekilde, Chief specialist
Ramboll, Denmark, mail: doh@ramboll.dk

Sidse Pedersen, Biologist, Municipality of Horsens, Denmark

Background and aim
The Municipality of Horsens was planning to reuse clean soil in connection with landscape modelling for recreational purposes in an area of special groundwater interest. Clean soil usually originates from construction works in urban areas and from road building in rural areas. According to Danish environmental legislation this type of soil must be checked for content of metals, PAHs and oil (TPH). The municipality however wished to evaluate whether or not there might be other pollutants in clean soil besides these components and whether such pollutants could pose a risk towards groundwater and surface water.

Approach
Initially it was assessed which types of pollutants would be expected in soil from urban and rural areas. Pollutants from gasworks and especially cyanide (as an indicator) were considered likely to be present in urban topsoil as was pesticides amongst others. For the pesticides the degradation product BAM (2,6-dichlorobenzamide) was chosen as an indicator as this compound has been used extensively in cities (up to 9% of urban areas were treated with BAM). BAM degrades slowly and is therefore still present in the soil where it may leach to the groundwater.

On this basis a risk assessment was carried out looking at the qualitative risk of groundwater pollution from these types of components in clean soil with special focus on TPH, cyanide and BAM. Risk calculations were carried out in RISC5 on a hypothetical site near Horsens, using hydraulic data from the national groundwater mapping.

Furthermore a quantitative risk assessment was conducted examining the effects on groundwater discharge in an area of 50.000 m2 that would in the future receive between 100.000 and 500.000 m3 of soil and therefore become more hilly than today.

Conclusion
It was concluded that content of BAM in typical Danish topsoil below the detection limit in soil could pose a risk towards the groundwater if extensive amounts of soil were placed in a large area. It was also concluded that PAHs could cause a risk towards surface waters due to the low EQS (Environmental quality standards). The risk assessment concludes that clean soil may not be as clean as we think and that possible effects on groundwater and surface water quality should be evaluated when reusing large amounts of clean soil in sensitive areas.

Side by Side Evaluation of BioGeoChemical, ISCR and ERD Reagents for Treatment of CVOCs

Josephine Molin, Technical Sales Manager
PeroxyChem, mail: josephine.molin@peroxychem.com

Mike Mueller, Business Development Manager, EMEA - PeroxyChem

Background.
Reactive iron sulfide minerals may be formed in situ under sulfate reducing conditions, and may be an important mechanism for chlorinated solvent removal during in situ chemical reduction (ISCR) and enhanced reductive dechlorination (ERD) treatments. This effect has been observed during the application of traditional ISCR and ERD substrates at sites with naturally high sulfate concentrations in groundwater, but may also be engineered by directly applying the needed building blocks. A potential key advantage of generating reactive minerals in situ, as opposed to directly applying minerals or zero-valent iron (ZVI) as solid particles, would be the potentially much greater surface area generated. Electron microprobe analyses performed on iron sulfide precipitation products collected one year after the application of an organic carbon substrate and ferrous iron to a high sulfate aquifer, showed that each 1.0 L of groundwater with sulfate at 3,000 mg/L generated about 0.11 m2 of very reactive FeS surface. Furthermore, high cVOC degradation rates and exceptionally long lasting results have been observed following the application of the EHC® ISCR reagent at sites with naturally high concentrations of sulfate, but without any controls to quantitatively measure the contribution from biogeochemical reactions at those sites.

Aim.
The goal of this bench study was to evaluate the effectiveness of engineered biogeochemical systems relative to organic carbon and ISCR substrates. Both liquid and solid biogeochemical reagent combinations were evaluated in a series of batch tests for the treatment of chlorinates ethenes. For each test, batch reactors were set up with cVOC impacted soil and groundwater, and amended with various substrate combinations composed of: micro-scale ZVI, organic carbon substrate, ferrous iron, and/or sulfate. Overall degradation rates achieved were compared to systems amended only with organic carbon substrate (emulsified lecithin substrate) and an ISCR reagent.

Conclusion.
Overall, the BioGeoChemical systems were found to support higher cVOC degradation rates compared to organic carbon substrate and ISCR alone. At the same dosage rates, a solid biogeochemical reagent composed of organic carbon, ZVI and sulfate exhibited a 67% higher removal rate relative to EHC for the treatment of 1,1-DCE. In another more comprehensive study, early results show 47% higher degradation rates in the solid biogeochemical system relative to organic carbon substrate, and 21% higher removal rates relative to the ISCR reagent for treatment of chlorinated ethenes (TCE and degradation products). The liquid biogeochemical reagent, combining soluble organic carbon substrate, ferrous iron and sulfate but without micro-scale ZVI, exhibited 35% higher removal rates compared to traditional ERD. The generation of daughter products

was at less than Stoichiometric amounts for both solid and liquid BioGeoChemical systems, indicating that an abiotic degradation pathway was promoted also without the direct addition of ZVI.

Thermal Remediation of large contamination from former drycleaners in Kristianstad, Sweden

Jesper Holm, Project Manager, Krüger-Veolia
mail: jsh@kruger.dk

Niels Ploug, Product Manager, Krüger-Veolia
Adis Dzafic, VA-Ingenjörerna-Veolia
Elin Remstam, Kristianstad Kommun
Peter Anderson, Kristianstad Kommun
Anders Bank, Structor Miljö Väst AB
Hanna Lindvall, Tyréns AB

Background

The site Färgaren 3 in Kristianstad (Skåne, Sweden) formerly housed a dye works and dry cleaners. Releases from these activities have created one of the most contaminated sites in Skåne. The site which sits on top of one the most valuable groundwater resources in Scandinavia. Therefore, this site has been prioritized for remediation funded by the Swedish EPA and headed by Kristianstad Kommun.

Aim

The aim of the remediation is to make the site available for all future land use and to protect the groundwater below the site. This is to be achieved through a combination of digging away the top 2,5 meters of soil on site and implementing thermal treatment from 2,5 meters below ground until 20 meters below ground inside a 900 m2 area. At the end of the digging operation, an extraction layer for the subsequent thermal remediation was installed from 2-2,5 meters below ground to be used for the thermal remediation.

The site is to be remediated down to an average concentration of chlorinated solvents of 1 mg/kg. It is estimated that the contaminant mass in the area for thermal treatment is 1.500 kg of chlorinated solvents, primarily PCE. The geology at the site is a combination of clay, sand and sandstone.

Conclusion

Thermal remediation in the form of ISTD was applied on the site. 92 heater elements were installed combined with an extraction and treatment system for treating the evaporated contaminants. Contaminated gas and steam was extracted through the gravel pack along the installed heaters and subsequently through the installed extraction layer.

Operation of the ISTD system commenced in September 2017 and verification sampling was conducted in January/February 2018. Results from this sampling campaign will be available at the time of the presentation.

An estimated contaminant mass of 1.500 kg of chlorinated solvents was extracted over the 4,5 months operating time. Maximum extraction rate was approximately 100 kg/day. Temperature development and extracted mass was monitored on-line over the duration of the remediation to help determine when verification samples should be performed.

During operation some challenges had to be met. The groundwater level in the area was unusually high during the time of operation, making it difficult to maintain the extraction layer free from water. The water extracted to maintain the extraction layer free for passage of the extracted steam and gas contained micron sized particles making filtration and cleaning of water before release challenging.

The presentation will focus on the design and implementation of the thermal remediation on the challenges met during operation and how they were met and present the results obtained during the remediation and at the end from the verification samples.

Treatment of 1,4-Dioxane Comingled with TCA and DCA Using Both Oxidative and Reductive Pathways

Mike Mueller, Business Development Manager, EMEA
PeroxyChem, mail: mike.mueller@peroxychem.com

Dr Brant Smith, Technical Applications Manager, ISCO - PeroxyChem

Background.
Explore the science behind creation of the oxidative and reductive pathways from an ISCO technology. Multiple studies showing the successful remediation of 1,4-dioxane comingled with TCA and/or DCA will be presented.

Aim.
In situ chemical oxidation (ISCO) has been applied at thousands of sites worldwide to treat a wide assortment of environmental contaminants of concern. Part of ISCO's broad appeal is based upon research showing that specific ISCO technologies, including catalyzed hydrogen peroxide (i.e. Fenton's reagent), and certain types of activated persulfate, will create both oxidative and reductive pathways. This has allowed these types of ISCO technologies to be able to treat contaminants including 1,1,1-trichloroethane (TCA) and carbon tetrachloride, in addition to compounds that are typically degraded using the oxidative pathway, such as BTEX, PAHs and chlorinated ethenes.

One so-called 'emerging contaminants' is the industrial additive 1,4-dioxane. It is an example of a compound that can be treated by ISCO, most effectively when using the oxidative pathway whereby either the hydroxyl and/or sulfate radical is generated. However, a common issue associated with treating 1,4-dioxane is that it is often comingled with compounds such as TCA, or daughter products including dichloroethanes (DCA), both of which are primarily degraded using the reductive pathway.

While sodium persulfate has been applied at thousands of sites, potassium persulfate is new to many practitioners in Europe. The main benefits of potassium persulfate revolved around its relatively low solubility, thus allowing for extended persistence in the subsurface (compared to sodium persulfate).

Activated potassium persulfate was selected for several studies, as it was intended to be used as a permeable reactive barrier (PRB) to treat dilute contaminant plumes containing 1,4-dioxane comingled with TCA or DCA at multiple sites. Longevity tests showed potassium persulfate persisted for 65 pore volumes at 20 C and 180 pore volumes at 4 C. The rate of release of potassium persulfate was linear for most of this duration, allowing prediction of PRB persistence of "months to years" depending upon aquifer temperature, and linear groundwater velocity.

Conclusion.
The data also shows treatment of 1,4-dioxane to below the detection limits with any of the activators used. However, the TCA and DCA daughter products were only treated to below the detection limits when the reductive degradation pathway was created. Multiple compounds were used to create these reductive conditions, including calcium peroxide and hydrated lime.

The science behind the creating of the oxidative and reductive pathways from an ISCO technology as multiple studies showing the successful remediation of 1,4-dioxane comingled with TCA and/or DCA will be presented.

Using Amendments to Control Geotechnical Characteristics following Soil Mixing with ISCO

Mike Mueller, Business Development Manager, EMEA
PeroxyChem, mail: Mike.Mueller@peroxychem.com

Dr Brant Smith, Technical Applications Manager, ISCO - PeroxyChem

Background.
Explore the use of reagents' relative impact on geotechnical characteristics of key parameters, following in situ soil mixing with activated sodium persulfate.

Aim.
In situ chemical oxidation (ISCO) technologies have been used to treat a wide assortment of environmental contaminants of concern around the world. For ISCO to be effective, it is important to establish contact between a sufficient dose of activated oxidant for the contaminant mass. In situ soil mixing is an increasingly popular application method for ISCO that helps establish this contact by mechanically blending the soils with the ISCO reagents. This is particularly beneficial for treatment of lower permeable soils, or thin lenses of non-aqueous phase liquid (NAPL).

Stabilization amendments can be added with ISCO reagents in low doses to help control post-application soil compressive strength, and to decrease hydraulic conductivity to the extent that the application effectively becomes a remedy combining ISCO and in situ stabilization (ISS).

The objective of this study was to determine the relative impact of increasing concentrations of the various amendments on key parameters following in situ soil mixing with activated sodium persulfate.

This study evaluated adding various doses of hydrated lime, bentonite, and Portland cement with activated persulfate on various types of soil. Each test condition consisted of soil, the same dose of activated persulfate, and increasing doses of the amendments. The reactors were thoroughly mixed to simulate the in situ mixing process and allowed to set up. The resulting compressive soil strength, hydraulic conductivity, and treatment efficacy were evaluated.

Conclusion.
The data show a trend of decreasing hydraulic conductivity with increasing dosages of amendments, and a trend of increasing soil strength with increasing amendment dose. Dose response curves and treatment efficacy will be presented.

An approach to estimate the risk of sediment and contaminant transport from marine fiberbank deposits

Gunnel Göransson, Dr,
Swedish Geotechnical Institute, mail: gunnel.goransson@swedgeo.se

Anna Apler, PhD student, Geological Survey of Sweden
Anna-Karin Dahlberg, Dr, Swedish University of Agricultural Sciences
Paul Frogner-Kockum, Dr, Swedish Geotechnical Institute
Sarah Josefsson, Dr, Geological Survey of Sweden
Achim Kopf, Professor, University of Bremen
Hjördis Löfroth, Dr, Swedish Geotechnical Institute
Catherine Paul, Dr, Lund University, Sweden
Matt O'Regan, Dr, Stockholm University, Sweden
Ian Snowball, Professor, Uppsala University, Sweden
Karin Wiberg, Professor, Swedish University of Agricultural Sciences
Lovisa Zillén, Dr, Geological Survey of Sweden

Background

To date, there is no Swedish guideline for the risk assessment of contaminated sediments, and there is no guideline, globally, that accounts for the specific characteristics that prevail for pulp mill solid waste, deposited as fiberbanks on seabed slopes that in some areas may fail. Chemical analyses on the fiberbank material, sediment, pore water and bottom water, show that these matrices contain toxicants (dioxins, PCBs, DDTs, PAHs, Hg and other metals). Physical analyses show that the deposits differ from natural minerogenic sediments by their extremely high organic content and low density, the anaerobic condition with low pH, the production of gas and absence of benthic fauna. Several fiberbank deposits are found near shore in areas where the hydrodynamic environment would not normally allow sedimentation. Fiber-rich sediments have also been found on the sea bed outside fiberbank areas, mixed with the natural sediments, indicating that dispersion does occur. There are also clear traces of submarine landslides in some of the deposits. Analysis of benthic biota from fiber-rich sediments indicates that the aquatic ecosystem is affected. The question is thus how stable these fiberbanks are – can they be considered stable as a landfill or unstable as a point source of pollution? Considering the difficulties and costs probably associated with the remediation of fiberbank deposits, such information will be important to know.

Aim

Inspired by Miljødirektoratet (2015) and their guideline for Trinn 2A, and the previous work by Göransson et al. (2014), we aim to develop an approach to estimate the importance of various contaminant dispersion pathways to the ecosystem that can support the assessment of harm to the aquatic life. We will consider the dispersion of contaminants and contaminated fibers from these fiberbank deposits through diffusion and advection. Five distinct mechanisms are considered; chemical diffusion and advection (re-suspension) triggered by ship traffic, currents, wind-generated waves, and submarine landslides. We consider diffusion to spread contaminants at a low but constant rate, while advective processes can release and spread contaminants at a higher rate, but only when the erosive forces are strong enough. A landslide will instantaneously spread a relatively large amount of contaminants, but is likely to be rare event. This will be described and assessed. The approach will then be applied to a case study.

Conclusion

We have developed a probabilistic approach to assess the likelihood for each of the dispersion processes to occur within a given time frame, and if so, the likelihood that each dispersion pathway will have the potential to cause contaminant fluxes at levels that potentially will cause, or possibly have caused, harm to the aquatic ecosystem. The approach will also allow for an estimation of the amount of contaminants that are/will be dispersed from the fiberbank by each dispersion pathway. The results can provide guidance in assessing the paths of dispersal that need to be closed or restricted to fulfill our national environmental goals. The approach is meant to be used as a part of a risk assessment and/or risk management method.

Biological side-effects from activated carbon used in contaminated sediment treatment: From the design & implementation perspective

Joe Jersak, Dr,
SAO Environmental Consulting AB, mail: joe@saoec.se

John Collins, Chief Operating Officer, AquaBlok, Ltd.
Tore Hjartland, Chairman, AquaBlok Norge.
John Hull, President, AquaBlok, Ltd.

Background

Abundant data published over the last 10+ years conclusively shows activated carbon (AC) is a highly effective sorbent of organic sediment contaminants. As a result, international use of AC as a reactive component in in-situ active isolation capping and in-situ treatment has grown dramatically, especially in the USA and Norway. Earlier in-situ treatment projects involved mechanically mixing AC into surface sediments, while later projects involved placing thin layers of AC-bearing material overtop sediment, then allowing benthic organisms to naturally mix it in over time; the thin-layer AC treatment mode currently dominates over the mechnically mixed-in mode, and will likely continue to do so, for multiple reasons. While AC's international reputation as a highly effective tool in sediment remediation has grown substantially, so too has the number of published studies reporting biological side-effects from AC when used in sediment treatment (both modes). Such results have prompted Norway's Miljødirektoratet to note in 2014 ”It is difficult to conclude if [AC] can be used in large contaminated areas”, and a 2017 study by Scandinavian researchers to state ”The promising remediation potential of AC has been brought into question based on the adverse effects of AC to certain benthic organisms”. There also seems to be a commonly held belief powdered AC (PAC) causes greater harm to benthic organisms than granular AC (GAC). While credible evidence of AC's biological side-effects cannot be denied or discounted, such results - including the often-broad conclusions being drawn from them - need to be critically reviewed and placed into context of the actual, practical designs and methods of implementation being applied and used today.

Aim

The lead-author reviewed 23 international studies published in reputable journals from 2005-17 in which AC effects on benthic organisms were evaluated and reported. Typically, the studies: were American and/or Scandinavian, were laboratory or field-based, involved either AC treatment mode, used PAC or GAC at different dosages (often < 5%), evaluated responses of selected benthic species or communities, and focused on specific ecological endpoints or community level responses.

Conclusion

This presentation summarizes available study results from the perspective of what conclusions can defensibly be drawn – or not – regarding biological side-effects from AC when used in in-situ treatment of contaminated sediments. Questions the review seeks to answer include:

- In general, are enough results available to say biological side-effects from AC outweigh AC's clearly demonstrated treatment benefits – especially when endpoint-specific and community responses are nearly always mixed (i.e. negative, no, or even positive effects)?
- For the thin-layer treatment mode, are the relatively few (and mixed) results enough to question AC's use in this increasingly popular treatment mode?
- Can results for the mixed-in treatment mode be used to adequately predict biological effects from AC when used in the thin-layer mode? Don't the two treatment modes represent entirely different levels of AC exposure, including over time?
- Are enough results available to conclude PAC is more damaging than GAC?
- Biological side-effects from AC appear to receive more focus and attention in Scandinavia than in the USA, perhaps to the point that AC's use in sediment treatment may be limited in Scandinavia. If so, why is that?

In summary, AC use in in-situ active isolation capping poses no risks at all to benthic organisms, given physical separation of AC from the organisms. In contrast, potential risks for biological side-effects clearly exist when AC is instead used in in-situ sediment treatment. The potential for such risks can be considerably reduced by proper design and implementation of treatment remedies, e.g. through incremental AC applications over time.

Advancements and Case Studies in the Application of Activated Carbon for Contaminated Sediment Remediation

Tore Hjartland, Chairman, AquaBlok Norge AS
Mail: tore.hjartland@aquablok.com

John Collins, COO, AquaBlok Ltd.
John Hull, President, AquaBlok Ltd
Joseph Jersak, Dr, SAOEC AB
Jantien Foekema, Applications & Development Manager,
Cabot Norit Nederland B.V.

Background

Sediments accumulated in a waterbody are known to be long-term reservoirs for contaminants and bio-accumulative chemicals that are transferred via the food chain to invertebrates and fish. Establishing effective methods to reduce the ecological and human health risks contaminated sediment poses has been a regulatory priority in both Norway and North America for over 20 years. Traditional remediation that has been considered convincing to most stakeholders involved using typical dredging and isolation capping (sand) approaches. However, more recently, issues with these approaches have been documented. Although traditional approaches will continue to be an integral part of sediment cleanup remedies, new approaches have been developed that can either supplement or provide alternatives to existing methods. The successful use of activated carbon for in-situ sediment treatment via contaminant sequestration and immobilization or the incorporation of activated carbon in reactive caps has been studied and demonstrated at dozens of sites world-wide.

Aim

This presentation will review the considerable advances in engineering approaches, discuss improved understanding of issues related to modeling and performance of activated carbon and summarize several field-scale applications performed to date. It will cover three aspects of the use/application of activated carbon for sediment remediation. First, an overview of impacts on performance related to the form of activated carbon (via modeling) will be provided. Second, an overview of a range of projects and applications will be presented to provide an expanded base of knowledge of the many sites and uses of activated carbon for remediation. Finally, selected detailed examples of field-scale applications will be reviewed.

Conclusion

Field results demonstrate that the appropriate material selection and application of powder activated carbon can provide significant reductions in pore water contaminant concentrations of PCBs, PAHs and other organic contaminants, and corresponding reductions in bioavailability as documented by contaminant up-take in target species. In addition, application methods are available that allow for the placement of active-treatment materials to the sediments in a manner that can be documented and provide results that support the design modeling assumptions.

Remediation of a former industrial landfill using a multifunctional active surface sealing

Kristof Thimm, Business Area Manager Environmental Engineering
HUESKER Synthetic GmbH, mail: thimm@huesker.de

Ole Syllwasschy, Expert Engineer, HUESKER Synthetic GmbH
Herbert Lassnig, Head of Sales Austria, HUESKER Synthetic GmbH,
Stephan Westhus, Sales Director EMEA, HUESKER Synthetic GmbH

Background
The K20 contaminated site, a former industrial landfill, is situated roughly one kilometer south of the town of Brückl in the lower part of the Gurktal valley in Austria. The landfill, which is not in operation anymore, is separated into two sections and was filled from 1926 until 1981 amongst others with calcium carbide as well as chlorinated hydrocarbons (CHC) and mercury contaminated wastes. The contained CHCs are mainly Tetra- and Trichloroethylene, Hexachlorobutadiene, Hexachloroethane and Hexachlorobenzene. The total amount of HCH is estimated to 100 – 1.000 t.

Since 1995 different remedial actions took place as well as continuous evidence securing measures. In 2000 a site risk assessment was conducted by the Austrian environmental protection agency. As a result of this the site was put on the list for contaminated sites that need remediation under the codename K20. Additional tests in 2003 ranked the site the highest priority level one.

In 2009, a notice was issued to remediate the K20 site through the complete removal of all waste material and utilising, treating or disposing thereof. During 2014, Hexachlorobenzene was detected – among other things, in locally produced food – nearby the cement plant assigned with the treatment of the polluted lime sludge. The clearance of the contaminated site was discontinued. The remaining waste material still left on site required a new remediation concept, since another pan-European tender for the treatment of the lime sludge ended unsuccessfully.

Solution:
In an option study for the remediation of the K20 site conducted 2008 the option of securing the material on site was addressed, too. This was identified as the next best option after the removal and treatment option. Due to the issues addressed above a new detailed security concept was published in July 2016 targeting to prevent emissions of the remaining materials.

The new physical safeguard measures included an innovative, multifunctional surface sealing system consisting of an 11 kg/m² calcium bentonite geosynthetic clay liner, an active geo-composite mat with 2 kg/m² activated carbon, a LDPE membrane with integrated aluminum layer and a drainage element. This system is a strong barrier for volatile CHCs. The activated carbon mat is installed below the membrane to reduce the CHC concentration at the interface of the membrane and by this reduce the driving force for diffusion. Additionally there are soil vapor extraction pipes installed below and above the sealing system to ensure continues monitoring.

Due to the special topography of the site and the requirement to interfere minimally with the existing landfill body, inclinations of 1:2 needed to be sealed. To enable a long term stability of the whole sealing system two layers of geogrids had to be installed to provide adequate stability against slip parallel to the slope. The required nominal strength was calculated according to Section 8 of the EBGEO ("Recommendations for Design and Analysis of Earth Structures using Geosynthetic Reinforcements", issued by the German Geotechnical Society, 2010) and the GDA (German Geotechnics of Landfills and Contaminated Sites) working group recommendation E2-7 (2015).

Conclusion

As there is no universal solution to the problems posed by contaminated sites, designers and engineers need a "toolkit" from which they can select the most suitable measures. The multifunctional active cover lining described in this paper, for use in the containment of contamination, represents a new tool in this kit. Specific site factors can be readily accommodated through the variation of materials or their quantities. The construction of the sealing system started in December 2016 and will be finished in December 2018.

Geotextile based solutions for treatment of contaminated subaquatic depositions

Kristof Thimm, Business Area Manager Environmental Engineering
HUESKER Synthetic GmbH, mail: thimm@huesker.de

Markus Wilke, Business Area Manager Hydraulics & Dewatering
HUESKER Synthetic GmbH
Stephan Westhus, Sales Director EMEA, HUESKER Synthetic GmbH

Background
Contaminated subaquatic sedimentary depositions are a far spread environmental issue due to the possible bioaccumulation which can affect the whole food chain. Significant sources include former industrial sites and harbours. The contaminants can infiltrate water bodies or sediments on different pathways, these include run-off water, accidents, and spillages as well as along with process water.

Many contaminants persist for years or decades because the contaminant does not degrade or degrades very slowly in the aquatic environment. Contaminants sorbed to sediment normally develop an equilibrium with the dissolved fraction in the pore water and in the overlying surface water to be taken up by fish and other aquatic organisms. Some bottom-dwelling organisms ingest contaminated sediment, and in shallow water environments, humans may also come into direct contact with contaminated sediment.

Aim
Today, different procedures are being applied to solve the problems originating from contaminated sediments. These include monitored natural recovery, in-situ capping and dredging and dewatering the contaminated sedimentsThe decision which method is used depends on the on-site situation, as well as possible environmental impacts and the degree of contamination.

In this paper two different remedial approaches under the utilisation of geosynthetics are highlighted. On the one hand active capping on the other dredging and dewatering using geotextile dewatering tubes.

Active capping is an in-situ remedial approach in which the contaminated sediments remain at their current location and are secured by above placed layers of geosynthetics, active materials and sand or clean sediment. Key for this application are active geo-composites which combine active materials and geosynthetics. While the geosynthetics act as a filter preventing the mixing of different cap layers and ensure stability of the cap the active materials bind the by upwelling contaminants for example by adsorption.

The other alternative consists in the hydraulic removal of the subaquatic disposals by means of e.g. a cutter suction dredger. Afterwards the liquefied material can be dewatered with the aid of geosynthetic dewatering tubes. Finally the residuals can be deposited. This method allows for an accelerated removal with a simultaneous dewatering operation.

Conclusion

Depending on on-site situations and an overall risk assessment and local regulations different approaches can be applied to remediate contaminated sediments. The key decision to make is to do in-situ or ex-situ treatment. For both solutions geosynthetics can be applied. In challenging projects also a combination of the different remediation methods can be applied.

Historical EDC contamination in groundwater assessed by comprehensive DQO process

Mikael Takala, Regional manager M.Sc.
Vahanen Environment Oy, mail: Mikael.takala@vahanen.com

Juha, Heijari, Environmental Specialist Ph.D, Neste Corp.
Maarit Luoranen, Environmental Engineer B.Eng, Vahanen Environment Oy.
Jussi Reinikainen, Senior Adviser, Finnish Environment Institute

Background

Considerable groundwater contamination by 1,2-dichloroethane (EDC) in a fractured bedrock at the Kilpilahti industrial site is a result from the operation of a former PVC plastic production facility in the 1970's. Several studies regarding the contamination have been carried out during the past decades in addition to continuous groundwater monitoring. Moreover, groundwater remediation by a pump & treat system from various locations has been running on the site since 1998 removing approximately 1000 kg of EDC from the groundwater annually, indicating no significant reduction in the EDC concentrations in the influent water of the treatment unit. Neste Corp. who took over the management of the property in 2008 after several business transactions decided to start a new research project at the site in 2017, in a co-operation with the Finnish Environment Institute, to gain more comprehensive understanding of the present EDC contamination.

Aim of the study

The aim of the project is to systematically gather data on the existing groundwater contamination at the Kilpilahti industrial site in order to assess the environmental and health risks of the EDC plume as well as the feasibility of the ongoing pump & treat system. The project focuses on the fate and transport of the EDC contaminated groundwater and the actual environmental impacts it may cause in the downgradient recipients, eventually the Baltic Sea. The main approach of the project is based on the USEPA's DQO (Data Quality Objectives) process that was modified to take into account national practices and requirements. The process began by identifying key stakeholders followed by defining the relevant research questions; i.e. formulating the "problem". The research questions were gathered and evaluated in several stakeholder working group meetings and formulated into a decision table. The decision table was then used to build-up a holistic data collection plan for the required site investigations that have been carried out during 2017-2018 allowing for the shut-down of the pump & treat system. The data from the new site investigations will be used in the forthcoming risk assessment and the sustainability appraisal of the pump & treat system in comparison with other risk management options.

Conclusions

Defining the project goals and research questions among many stakeholders with different backgrounds and viewpoints can be elaborate, but the outcome allows the project to be focused on the most relevant research questions improving also the commitment and knowledge of the people involved. In this case, for example, the DQO process gave the required confidence, both for the operator and the authorities, that the pump & treat system can be shut down (at least temporarily) despite the continuous yield of the EDC in the treatment unit. That confidence resulted from the findings during the project that the reduction of contaminant mass in the EDC source area (i.e. the groundwater treatment zone) was not proportional to the reduction of the EDC concentrations in the downgradient surface waters. In fact, some of the main research questions in the project have been related to the groundwater surface water interaction. Combining old information with the new project data regarding the EDC mass flux has helped the project team to better understand the key factors that influence the discharge of the EDC to the downgradient surface water streams. In addition, the DQO process has been useful in the identification of other potential risks providing also targeted data that can be eventually used to evaluate the most sustainable risk management options for this site.

Investigation on fibrous sediments in Sweden, an overview on objectives, geophysical method and results.

Johan Norrlin, Senior State Geologist
Geological Survey of Sweden, mail: Johan.norrlin@sgu.se

Lijana Gottby, Dr, Geological Survey of Sweden
Johan Nyberg, Dr, Geological Survey of Sweden
Anna Apler, PhD-student,Uppsala University and Geological Survey of Sweden
Olof Larsson, Senior state geologist, Geological Survey of Sweden
Sarah Josefsson, Dr, Geological Survey of Sweden
Lovisa Zillén, Dr, Geological Survey of Sweden

Background

In many regions in Sweden the forest industry was, and partly still is, very important. Unfortunately, the manufacturing of different types of wooden products, such as paper pulp and particle board, caused large amounts of fibrous material to be discharged with the wastewater in the late 19th and most of the 20th century. The fibres accumulated in calm aquatic environments in the near vicinity of the factories or further downstream in the catchment area. In addition, various chemicals were used or produced in the processes, and therefore, in many locations, the fibrous sediments contain large amounts of contaminants and are considered as environmental risks. Several natural and anthropogenic processes potentially cause a dispersal of hazardous contaminants from these sediments to the aquatic environment.

Aim

To get an overview of the spatial extent of fibrous sediments in Sweden, the Swedish Environmental Protection Agency and the Swedish Agency for Marine and Water Management have financed inventory surveys. This overview is a necessary basis for further assessment, monitoring and remediation of these contaminated sites.

In collaboration with the county of Västernorrland, which is situated at the northern part of the Bothnian Sea, the Geological Survey of Sweden (SGU) has developed a method for inventory of fibrous sediments. It is based on a combination of hydroacoustic (geophysical) measurements and sediment sampling. The method has now been applied in all counties in northern Sweden to investigate expected fibrous sediment areas, mostly in coastal areas but also in lakes and rivers. It is clear that these marine-geological tools, normally used in conventional bottom floor mapping, can be used to facilitate the mapping of contaminated fibrous sediments.

Conclusions

In total, 42 sites have so far been investigated by SGU, covering a total area of c. 212 km2.At these sites 45 fibrebanks, consisting almost entirely of cellulose fibres, have been identified and estimated to cover a total area of c. 2.6 km2. In addition, fibre-rich sediments, i.e. natural sediments displaying a pronounced content of fibres and/or wood and bark chips, have also been mapped and estimated to cover a total area of c. 27 km2. Further work on these deposits, in terms of e.g. risk classification and priorities for remediation, will need to be carried out by regional authorities in order to deal with the risk posed by this contaminated type of sediment.

An estimate from Swedish county boards shows that there are more than 300 sites in Sweden where soil contaminated from paper, pulp or fibreboard industries is or may be present. Since these industrial processes are very water-consuming, it is likely that they have discharged wastewater and potentially caused formation off fibrebanks or fibre-rich sediments.

The reported inventory method can be used for all types of fibrous sediments and can thus be applied to such deposits worldwide.

Remediation of contaminated sediments in Nordic countries: a review

Alizée P. Lehoux, Dr
Uppsala University, Sweden, mail: alizee.lehoux@geo.uu.se

Karina Petersen, Dr, NIVA, Norway
Morten Thorne Schaanning, Dr, NIVA, Norway
Matti Leppänen, Dr, SYKE, Finland
Ian Snowball, Professor, Uppsala University, Sweden
Marianne Olsen, Dr, NIVA, Norway

Background
In oceans, seas, and coastal zones worldwide, increased human activities have a negative impact on aquatic ecosystems. In particular, the contamination of sediments from regular and diffuse discharges leads to long-term disruption of the biosphere, and contaminants may enter the food web. Many of these pollutants are historical, due to industrial releases before regulations were applied to reduce pollution. Ignorance of chemical compounds present in discharges and their environmental impacts was often reason for the absence of regulations. Over the recent two-three decades, increased efforts to remediate historically contaminated sites have been made to restore them and obtain a better environmental quality.

Aim
In this study we assess the different types of contaminated sediments along the coasts of Norway, Sweden and Finland through a special collaboration between NIVA (Norwegian Institute for Water Research, Norway), UU (Uppsala University, Sweden) and SYKE (Finnish Environment Institute, Finland) funded by the Nordic Council of Ministers. These three countries have recently adopted similar political environmental strategies in order to achieve national environmental quality objectives and international sustainable development goals in the next few years.

Different sediment remediation techniques have been proposed, tested and applied worldwide; these include dredging, capping, application of active materials, and enhanced natural recovery. While dredging has been a commonly used method, many sites require alternative remediation technologies. Based on recently acquired experience, we review the strengths and weaknesses of each method, taking into account secondary effects, feasibility, cost and efficiency.

Conclusion
This review provides guidelines to ensure that the best remediation techniques are applied to future sites, and that all the aspects of management are taken into account to provide a sustainable, long-term remediation.

The challenges of capping fiberbank sediments in-situ

Alizée P. Lehoux, Dr,
Uppsala University, mail: alizee.lehoux@geo.uu.se

Joseph Jersak, Dr, SAO Environmental Consulting
Anna-Karin Dahlberg, Dr, Swedish University of Agricultural Sciences
Anastasija Isidorova, PhD student, Uppsala University
Karin Wiberg, Professor, Swedish University of Agricultural Sciences
Sarah Josefsson, Dr, Geological Survey of Sweden
Ian Snowball, Professor, Uppsala University

Background

In-situ capping is a sediment remediation technique that involves covering polluted sediments with one or more layers of clean material, often for the purposes of providing a physical and chemical barrier between the sediment and the overlying aquatic environment. Caps are often composed of non-reactive granular materials (such as natural sand or crushed stone), but can also include reactive materials (such as activated carbon) in their design. Sediment capping is typically less expensive than removal by dredging, which requires sediment treatment and disposal after its removal. Capping is an internationally recognized and accepted sediment remediation technology, and has been applied worldwide on many projects involving polluted minerogenic (mineral-rich) sediments. However, polluted sediment deposits resulting from long-term accumulation of waste historically discharged from paper and pulp industries have very different physical and chemical properties compared to common minerogenic sediments. Typically, these so-called “fiberbank” sediment deposits – which can be meters in thickness – are mainly composed of fine-sized cellulose or larger wood chips (depending on the process used by each factory), and thus have a very high organic content; very high gas production accompanies their high organic content. Furthermore, fiberbanks typically have low density (close to that of water) and are therefore geotechnically weak.

Aim

In the FIBREM project (FIBerbank REMediation), we identify the challenges of capping such unique sediments in-situ, and start addressing such challenges through laboratory-scale experiments. We show the sediment’s response to the cap load in terms of compression and changes in physical properties. The gas production is studied more closely in order to understand the gas’s role in the transport of contaminants, and potential physical disruption of the cap. This issue receives significant focus since gas production is a function of temperature, and most fiberbank sediments are located in shallow waters (which are especially prone to substantial temperature changes due to future land uplift and global warming). These factors need to be taken into account when designing and implementing caps for long-term remedial efficiency.

Conclusions

Our laboratory-scale experiments show that capping fiberbanks is possible in terms of physical properties. Further analyses are needed to evaluate the applicability and efficiency of this technology in providing an effective chemical barrier and significantly reducing contaminant transport over the long term.

Evaluating the current situation of PFAS in Lake Mälaren, Stockholm – distribution of PFAS in water column, surface sediment and sediment cores

A case study based on sediment cores as a tool for predicting the introduction in time of PFAS in the City of Stockholm

Marko Filipovic, PhD,
NIRAS Sweden AB, Stockholm, Sweden, mail: Marko.filipovic@niras.se

Anna, Kärrmann, PhD, Man-Technology-Environment (MTM) Research Centre, Örebro University, Sweden
Jonathan Benskin, PhD, Department of Environmental Science and Analytical Chemistry, Stockholm University, Sweden
Ian Cousins, PhD, Department of Environmental Science and Analytical Chemistry, Stockholm University, Sweden
Johan Edvinsson, MsC, NIRAS Sweden AB, Stockholm, Sweden
Emma Karlsson, PhD, NIRAS Sweden AB, Stockholm Sweden
Clara Neuschütz, PhD, NIRAS Sweden AB, Stockholm, Sweden
Sara Holmström, PhD, NIRAS Sweden AB, Stockholm, Sweden
Katrin Holmström, PhD, NIRAS Sweden AB, Stockholm, Sweden
Johan Temnerud, PhD, NIRAS Sweden AB, Stockholm, Sweden

Background
During the last decade the omnipresence of poly- and perfluoroalkyl substances (PFAS) in the environment have gained great attention from both the authorities and the media in Sweden, Norway and Denmark. PFAS unique properties make them suitable for a wide range of industrial applications and consumer products, impregnation of durable water repellent clothing, paints and aqueous film forming foam (AFFF) among others. Perfluoroalkyl acids (PFAAs), a class of PFASs, are highly persistent in the environment, and long chain PFAAs are bioaccumulative and toxic.

The Lake Mälaren is the most important fresh water body in Sweden surrounding the capital of Sweden, Stockholm, and is used for supplying 2 million people daily with potable water. The catchment of Lake Mälaren is highly populated and industrialized, it is thus important to identify potential point-sources of PFAS and ensure that the levels of the highly prioritized compounds do not exceed the European environmental quality standards (EQS) for PFOS. Further little or no information is available regarding PFAS concentrations in the sediments of Lake Mälaren, when the discharges of PFAS started and which are the what are the sources of PFAS within City of Stockholm.

Aim
Two scientific reports are included in this presentation, which aimed at increasing the general understanding of the fate of PFAAs in aquatic systems and sediment at a highly urbanized location, Stockholm, Sweden. This was achieved by planning and sampling of water and sediment, chemical trace analysis and source identification of PFAS using geographical information systems (GIS). The following topics were covered: (i) Mapping of known PFAS point sources within Stockholm city using GIS (ii) sampling of surface water and water columns in order to identify spatial distribution of of 16 PFASs in basins of Lake Mälaren and (iii) sampling of sediment in order to identify spatial distribution and historical deposition behaviors of 27 PFASs in sediment cores of Lake Mälaren. In both water and sediment, linear and branched PFAS isomers were measured for PFHxS, PFOS and FOSA.

As Lake Mälaren is a very sensitive yet important water body in Sweden, reducing environmental pollution with PFAS has therefore become a regulatory priority. In order to design successful measures to reduce the PFASs contamination requires an understanding of the sources, transport and fate of PFASs in the environment.

Conclusion
Using available data regarding PFAS point sources allowed us to create illustrative maps which could be used in order to plan sampling of water and sediments within the Lake Mälaren. PFAS were measured and detected in surface water, surface sediment and sediment cores of Lake Mälaren within the City of Stockholm.

Concentrations of the PFAS-16 in the surface water ranged from 13,1 ng/l to 37,4 ng/l. Concentrations of the PFAS-22 in the surface sediments (0-2 cm) ranged from 2,14 µg/kg dry weight (dw) to 7,63 µg/kg dw. Perfluorooctane sulfonic acid (PFOS) and perfluorooctanoic acid (PFOA) were predominant in the sediments, with an average of 2,16 µg/kg dw and 0,243 µg/kg dw, respectively. The distribution coefficients of PFASs in the water and sediment were analyzed (Kd), together with sediment characteristics such as organic carbon and metals will be further discussed.

The vertical PFOS concentrations profiles, in two sediment cores generally decreased with increasing depths, indicating that PFAS discharges from the technosphere has increased since the late 1970s and could be attributed to the development and urbanization of Stockholm. The increasing trends of PFOS in the surface sediment suggests that despite the ban of PFOS production and use in the European union in 2008, the concentrations in the Lake Mälaren are not declining, rather increasing. These findings point toward that there are active point sources and diffuse sources slowly leaching PFAS into to the Lake Mälaren. The delay of declining PFAS concentration in the environment in respect to regulatory actions taken will be discussed.

Unexpected contradiction between total metal contents and contaminant fluxes from marine fiberbank deposits

Paul Frogner-Kockum, Dr
Swedish Geotechnical Institute, mail: Paul.frogner-kockum@swedgeo.se

Anna Apler, PhD student, Geological Survey of Sweden
Mikhail Kononets, PhD student, University of Gothenburg, Sweden
Ian Snowball, Professor, Uppsala University, Sweden
Per Hall, Professor, University of Gothenburg, Sweden
Gunnel Göransson, Dr, Swedish Geotechnical Institute
Sarah Josefsson, Dr, Geological Survey of Sweden
Lovisa Zillén, Dr, Geological Survey of Sweden

Background

Environmental legacies of the pulp and paper industry are of global concern and include deposits of contaminated fibrous (cellulose) rich materials that exist in waterbodies and alter aquatic ecosystems. Historical activities of the pulp and paper industry lead to parts of the Swedish northern coastal zone to be covered by deposits of either pure so called fiberbank deposits, or fiber-rich sediments. Risk assessments of contaminated sediments usually are based on the total concentration of contaminants. Previous surveys of fiberbank deposits and fiber-rich sediments located at two pilot-study areas found concentrations of hazardous substances, such as PCB, DDT and several trace metals, that are above national background levels and contravene environmental quality objectives. Dispersion of contaminants from contaminated sediments have been previously assessed by diffusion flux models. These models are based on gradients between pore water concentrations and/or overlying bottom water. However, large uncertainties exist in using flux models, because the overall fluxes (a sum of diffusion, advection and bioturbation) from sediments might be greater than diffusion alone.

Aim

The study presented herein aims to test a relatively new in-situ method of studying fluxes of metals of environmental concern springing from fiberbank deposits as an initiative to develop a systematic risk assessment for similarly contaminated areas. The objectives are i) to test a benthic (BFC) lander system in the quantification of fluxes of metals of environmental concern in benthic waters originating from fiberbank deposits and fiber-rich sediments, ii) to compare the BFC measured metal fluxes with those of model predicted fluxes, and iii) to compare the BFC measured metal fluxes with the total content of metals in these materials.This study is part of a larger project (TREASURE – Targeting emerging contaminated sediment along the uplifting northern Baltic coast of Sweden for remediation) with the overall aim to develop new methods to assess the risk of dispersal of contaminant laden, cellulose rich fiberbanks.

Conclusions

We obtained fluxes for Co, Mo, Ni, V and Zn and were thus able to compare these fluxes with predicted ones. At one site even though Pb and Cr occur in very high concentration no fluxes of Pb and Cr were detected. These metals are thus likely strongly bound to the organic material in the fiberbank and may thus be transported downstream in particulate form. Consequently, there is an unexpected contradiction between total metal contents and their observed fluxes, and significant differences between observed metal fluxes and model predictions were found. We thus demonstrate that it is appropriate for risk assessment of contaminated sediments to complement total metal concentrations with in situ measurements. This approach creates a better understanding if different metals and their transport from the fiberbank deposits are in dissolved or particle bound form.

Finding ways to implement sustainability in remediation through procurement. Experiences from stakeholder engagement in a complex multisite 'design-build' tender for CHC contaminated urban groundwater remediation

Jarno Laitinen, MSc., Project Manager
Centre for Economic Development-, Transport and the Environment
mail: jarno.laitinen@gmail.com

Background
The Finnish Contaminated Land Demonstration Program is a part of the national Clean Soil Program, and one of the strategic priority projects of the Finnish Governments strategic reforms in 'circular economy and clean solutions' towards more sustainable resource management. Purpose of the Demonstration Program is to operate as an innovation platform for contaminated land risk management and remediation. To achieve this, the Demonstration Program facilitates various innovation and development activities within private and public sectors and executes site investigations and remediation projects at orphan sites, showcasing best-practice approaches.

A multisite 'design-build' procurement for CHC contaminated groundwater remediation was announced in January 2017 by the Demonstration Program. The tender consisted of five contaminated sites with a widespread groundwater CHC contamination (plumes > 1km) that had, or was currently threatening to, cause closure of the cities' municipal drinking water extraction as acute risk management. Many of the sites had been investigated for over a decade and a many had prior remediation history with varying success.

Aim
The procurement process had multiple intrinsic goals. Besides the environmental and health (risk) aspects and the political emphasis on GW resource management, the process was designed to 1) facilitate a stakeholder driven process for sustainable remediation design, 2) develop and disperse know how on managing complex brownfield sites throughout the stakeholders, 3) showcase opportunities and benefits of state-of-the-art in situ remediation methods and 4) enhance the national remediation market dynamics for futures benefit.

Conclusion
To achieve goals of the procurement, a number of negotiation rounds and workshops between the main stakeholders: client, municipalities, land owners, consultants, contractors, research institutes and regulators were arranged to define the technical, environmental, economic and social expectations of the remediation projects. These negotiations enabled to define the technical, environmental, social and economic feasibility and commercial availability of the solutions.

Parallel to the procurement, a collaborative regulatory group between the five municipalities and corresponding regional authorities was formed to ensure timely and coherent environmental remediation permit process. A thorough political decision process was conducted on the five regional municipalities supported by a detailed communication program to engage the decision makers and include the directly affected citizens to the process.

The presentation will focus on showcasing how the process was conducted and how it concluded in the selection of most sustainable remediation strategies and economically most advantageous solutions, while improving time and resource efficiency and quality of the related regulatory and political decision processes.

Thermal stripping as a method to remediation of PCB-contaminated tile and concrete prior to recycling in ground applications

Marlene Thorman, M.Sc. CEO Denmark
Golder Associates A/S, mail: marlene_thorman@golder.com

Thomas Hougaard, M.Sc. et Sc. Senior consultant, Golder Associates A/S
Charlotte Gudum, M.Sc.Eng., Ph.D., Senior Consultant, Golder Associates A/S

Background
PCB is a group of substances that were invented and produced in the United States from around 1950. PCBs that have many good technical features were widely used in the industrialized world. In Denmark, PCBs were used as additives in elastic joints and durable paints, until the fabric was prohibited from being produced and used in open use in 1976, due to unfortunate environmental impacts. Even PCB was not originally present in most building materials, low concentrations are found in almost all standing buildings. The PCB originates from use in elastic sealants, capacitors, paint, etc. from where it slowly evaporates to the air from where it condenses on other surfaces.

While indoor vapor concentrations might exceed local standards and cause an unhealthy indoor climate, it also settles on all surfaces and materials causing contents so high that PCB becomes a barrier for recycling the materials. Traditionally most Danish concrete and tile from demolished buildings are crushed and substitute natural raw materials. More than one million tons of materials annually has been recycled this way. However, the widespread occurrence of PCB constitutes a barrier for future recycling due to regulations prohibiting recycling of materials containing more than 2 mg PCBTotal/kg, peak value. Materials with PCB-concentration below 0.1 mg PCB Total/kg is considered as uncontaminated materials for free recycling. Materials containing between 0.1-2 mg PCB Total/kg in peak value can be reused after application to local authorities.

Concrete and tile in which concentrations of PCB exceeds the above-mentioned limits are either landfilled or, in case of concentrations exceeding 50 mg PCB/kg, destructed.

In buildings with unacceptable high indoor climate concentrations Golder has invented and developed a method that ensures a healthy indoor climate enabling the reuse of the building, instead of demolition; thereby increasing recycling and saving landfilling capacity

The method is called "thermal stripping" and utilizes that the PCBs evaporate from the surface when the material is heated, also at rather low temperatures; 50-60 oC. By circulating clean warm air over the surface with subsequent cleaning through carbon filters in a closed system, we can lower the indoor concentrations beneath the indoor criteria given by the Danish authorities (Sundhedsstyrelsen) without contaminating the surroundings and with a limited heat loss.

Aim
The poster presents the results and perspectives of thermal stripping as a method to remediate the indoor climate in PCB contaminated buildings, thus saving demolition and landfilling capacity.

Results
The experience from thermal stripping on hole buildings has shown, that heating and ventilating a building for 2-8 weeks at 50-55 °C, can lower the indoor concentration of PCB, to a no risk level, so the building can be reused instead of demolished. After thermal stripping of hole buildings, the building materials still contain PCB, often in concentrations exceeding the hazardous waste limit value, but the indoor climate problem is eliminated.

Discussion and Conclusion
The ideal way of recycling PCB-contaminated buildings, is to reuse the building itself after ensuring the indoor climate. In this case the standing building materials still contain some PCB, and the problem has, to some extend been postponed to the next generation.

When reuse of the building itself is not an option and demolition is decided, PCB-contaminated concrete and tile can be recycled after application of thermal stripping to clean the crushed materials to a level where the authorities allow reuse.

Thermal stripping has proved a viable, efficient and cost-effective method for lowering PCB levels in concrete and tile in both standing buildings, thus preventing demolishing, and in crushed concrete.

The test has shown, that with a grain size of 0-32 mm corresponding to stable gravel, all particles with concentrations up to 50 mg PCBTotal / kg can be expected to be purified down to a content of less than 2 mg PCBTotal / kg over a maximum of 3 to 5 hours, depending on the selected treatment temperature up to 200 °C. At higher treatment temperatures up to 600 °C, processing time may be significantly reduced provided sufficient air is supplied to prevent saturation in the gas phase, and to some extent it is possible to purified down to a content of less than 0.1 mg PCBTotal/kg. At higher temperatures the grains melts, and cannot be recycled, and cannot replace the gravel.

The test has also shown that the method is capable of purifying materials contaminated above the hazardous waste limit, i.e. 50 mg/kg typically secondary contaminated materials. However the presence of primary sources with high PCB content will have a strong negative effect on the process as the high concentrations will cause local saturation of the gas phase with especially heavier congener and the possibility of tertiary precipitation on other materials. It is therefore important that primary sources are removed, from materials subjected to thermal stripping.

Excavated soil reuse management in Central Denmark Region

Anette Specht, M.Sc. Geography
Central Denmark Region, mail: anespe@rm.dk

Morten Steen, M.Sc. Geology, Central Denmark Region
Rolf Johnsen, M.Sc. Geology, Central Denmark Region

In Central Denmark Region yearly 6 million tons of excavated soil are transported over shorter or longer distances – causing large economic and environmental consequences. Can we do better? There are many factors and actors to deal with, but we believe that it is possible to introduce more sustainability, if we work together across authorities, branches and stakeholders. Therefor the region has taken the lead on a two year project that aims towards more re- and upcycling. The project is driven by a steering group including representatives from the regional office as well as four municipalities in the region.

The project was started with a kick-off workshop in January 2018 for all 19 municipalities included in Central Denmark Region. The aim of this workshop was to clarify common challenges and needs as well as important stakeholders. Challenges and needs was not surprisingly many, and through a prioritization process two main objects was chosen to be transformed into actions and deliverables in the project: 1) A template to municipal strategies for excavated soil. 2) A stronger network and knowledge exchange in between all important stakeholders.

After a dialogue in the steering group the template has been extended to include: A) A forecast tool to predict the amount of soil excavated within a municipality over a period of 10-15 years B) A classic report template for use and inspiration when working on your own municipal strategy and C) A inspiration catalog including 20 existing soil reuse projects of different types and sizes. These products should be ready by the end of 2018, and on based on municipal data in the forecast tool we should be able to make a regional forecast by spring 2019.

The demand for finding solutions has been obvious. This is identified through the interest of the subject and the number of attendants to the workshops and meetings. Thus workshop 2 in June successfully gathered 70 people including municipalities, consultants, architects, contractors, soil receivers and utilities. It is also clear, that different stakeholders have different drivers, but the sustainable direction with a triple bottom line (economic, environmental and social) makes an inspiring an dynamic starting point towards the common goal. Besides introducing attendants to the template master plan other important subjects from kickoff workshop was eagerly debated like soil stock exchange, lime stabilization and local planning. Networking and knowledge exchange will be further developed by workshops every half year within the project period.

So far the project clearly confirmed that breakdown of boundaries across stakeholders and disciplines is a key word to success, and therefore the steering group is of course eager to here from anybody with a glance of curiosity and also we can only encourage to more networking on the subject.

Geophysical monitoring of bio-remediation using the Direct Current resistivity and time-domain Induced Polarization (DCIP) method

Aristeidis Nivorlis, Ph.D. student
Lund University, mail: aristeidis.nivorlis@tg.lth.se

Torleif Dahlin, Professor, Lund University
Matteo Rossi, Assistant Lecturer, Lund University
Sofia Åkesson, Ph.D. student, Lund University
Charlotte Sparrenbom, Senior Lecturer, Lund University

Background
Important work has been done in locating, characterizing and treating contaminated ground. Very often sampling techniques are performed which can provide very detailed and accurate data, however such information comes with low spatial distribution and high cost. Geophysical methods provide continuous models of the subsurface, and can be used as a tool to interpolate and extrapolate punctual data, and thereby increase the spatial distribution of the information. One method that is of particular interest in this context is Direct Current resistivity and time-domain Induced Polarization (DCIP). The combination has the potential to increase the reliability by reducing the risk of missing important zones, and at the same time reduce the cost.

In Alingsås, a dry-cleaning facility was operated for many years, and huge amounts of the solvent PCE was spilled into the ground. This contributed to an increasing concentration of PCE over the years until the use of PCE was stopped, resulting in the formation of a DNAPL plume beneath the building.

It is common that remediation takes place by excavating and moving the contaminated soil, but this only migrates the problem and is costly. Furthermore, in Alingsås this is not an option because of the amount of the contaminated mass and the fact that it is underneath the largest operating Swedish cleaning facility. In such cases, in situ remediation techniques appear as the only viable option. There are however concerns about how to control the result of the remediation and a need for new methods with spatial coverage.

Aim
A lot of studies have been done about the characterization of the subsurface, especially when it comes to the contaminants, however our main interest is the changes that take place due to the remediation. Can they be monitored by geophysical tools, and to which extent can geophysical tools provide reliable information about the level of success of in situ remediation techniques?

For that purpose, a fully autonomous and automatic monitoring system was installed in Alingsås, to perform frequent automated measurements and to provide information about the changes in the subsurface. Apart from the DCIP data the system has the potential to monitor several other parameters (soil temperature/moisture, rainfall, air temperature, groundwater level, water conductivity, redox potential, etc.) by using external sensors, to make it possible to obtain a better understanding about changes caused by other processes (i.e. rainfall) and how they can affect the measurements.

All those data are transferred daily on our server in Lund and are being processed to evaluate the data quality and extract useful information about changes into the subsurface. By evaluating the complimentary data, provided by the external sensors, we can take changes from external processes into account. The remaining events should then be compared with sampling data, such as isotope analysis, to verify our hypothesis.

Conclusion
It is expensive and time consuming to control the remediation result via sampling and analyses with high spatial resolution at regular intervals. With DCIP we can acquire dense data, in space and time, that hopefully can help following and better understand the changes due to the remediation.

The geophysical data should be ideally acquired, analyzed and verified with automated routines as part of a larger monitoring system. It is of great importance, especially in the early stage, to verify events that appear to show interesting changes with sampling data to evaluate the level of reliability of the system.

Geostatistics of public data on urban soil contamination in the City of Copenhagen

Nemanja Milosevic, Ph.D., project manager
MOE A/S, Denmark, mail: nmil@moe.dk

Peter Engelund, senior advisor, MOE A/S, Denmark
Torben Østergård, PhD, specialist in energy design, MOE A/S, Denmark
Martin Jakobsen, environmental chemist, The City of Copenhagen, Environmental Center, Denmark
Kristoffer Stensbo-Smidt, postdoc, University of Copenhagen, Department of Computer Science, Denmark
Marcos Antonio Vaz Salles, associate professor, University of Copenhagen, Department of Computer Science, Denmark

Background

Chemical data on urban soil and sediment contamination are characterized by high variety in analytical and spatial precision, which poses a challenge in data management and interpretation with respect to risk assessment on a city scale. The reason for varying data quality are complex urban field conditions and insufficient (or even a lack of) standards for soil sampling, chemical analysis and interpretation. Data of varying quality stored in one central system, such as ones in public offices for urban soil contamination, grow and become complex i.e. difficult to manage in a matter of years. The public offices are challenged in having a good overview of the past land use and collected, missing or incorrect chemical data in their jurisdiction areas.

We hypothesize that: 1) Soil and sediment contamination can be inferred from historical chemical data and descriptive data on industrial land use; 2) Techniques that exploit these data can be constructed by applying machine learning approaches.

Aim

We develop a spatial prediction for data obtained both with accredited (standard) and advanced (fingerprinting) chemical analytical methods. The process includes identification of relevant databases, retrieval, cleaning and storing of data, followed by algorithm development and visualization of statistical results. We use machine learning methods for algorithm development, where the model can automatically learn its parameters. As soil and sediment measurements are never evenly distributed, the algorithm can retrieve information from, e.g. local historical land use or properties of relevant chemical compounds, to help infer contamination.

Conclusion

We combined a pilot dataset on the City of Copenhagen soil contamination from 2012 to 2015 with an extensive dataset on historical land uses made in 1995. Standard analytical chemical data (6 metals, 4 hydrocarbon fractions and 2 PAH’s) were cleaned for geolocation both automatically and manually with a success rate of 80 %, providing a coverage of 16 % of parcels in the city. In addition, we combined a fingerprint analysis on sediment from Copenhagen’s Utterslevmose lake with data on local industrial activity.

We applied different statistical methods to two soil datasets (standard chemical parameters and land use types) and the sediment fingerprint dataset.

Using machine learning methods, we can automatically search for relations between land-use types and concentrations of chemicals. With sufficient data density and quality, maps of predicted concentrations and maps of prediction accuracy have a potential to reveal areas for further investigation i.e. prioritizing of data collection from databases or production of data in the field.

Using a semi-supervised machine learning approach, our model can combine contaminant concentrations from sites without land use data with sites with known land use. As the number of sites without knowledge on land use can be orders of magnitude larger than those with, this approach has the potential to significantly improve estimations by using all available information.

The decision-making process using maps of predicted concentration is conditioned by agreed cut-off values for accuracy of prediction. The cut-off values, however, make the approach useful both in areas with low and high accuracies, i.e. for optimizing sampling strategies and discarding the need for further sampling, respectively.

The main distinction from common risk assessment is that our approach is developed upon information from multiple sites with shared contamination sources and pathways. Thus, our approach is without the traditional focus on examination of processes within borders of individual contaminated sites.

Hydrocarbon background levels in Denmark in indoor and outdoor air

Børge Hvidberg, M. Sc.
Central Denmark Region, mail: boehvi@rm.dk

Per Loll, Ph.D., R&D Manager, Dansk Miljørådgivning A/S (DMR A/S)
Per Novrup, Environmental technician, Central Denmark Region

Background

Indoor and outdoor air typically contains volatile organic compounds (VOCs) from both outdoor and indoor sources. The VOC levels originating from such sources can be referred to as "background levels", when assessing the potential for vapor intrusion of VOCs from a subsurface contamination to the indoor air. When measuring VOCs directly in indoor air at contaminated sites, the resulting concentration will contain a contribution from background sources as well as a contribution from the subsurface contamination. When determining whether or not remediation of sub-slab contamination is warranted it is often important to know if the presence of volatile organic compounds (VOCs) in indoor air is primarily from background sources, or primarily from subsurface contamination.

Aim.

The primary study objective is to produce updated background hydrocarbon levels in both outdoor and indoor air, at non-contaminated Danish homes. Secondary purposes are to investigate if there are significant seasonal variations in the background levels in outdoor or indoor air, and if various factors are consequential in relation to the background levels; e.g. tobacco smoking, wood stove heating, rural/urban areas, town/city size, habits/methods of venting, traffic etc.
Approach/Activities. The investigation has been conducted by voluntarily engaged employees of the Central Denmark Region and DMR A/S, as well as their friends and family members. The methods included filling in of a questionnaire concerning all factors that might have an influence on background levels of VOC in indoor and outdoor air. Passive sampling by ORSA-tubes was conducted in a standardized manner in the outdoor and indoor air, and were analyzes by a professional laboratory (TVOC as C6-C35, BTEXN and C9/C10-aromatics). Two sampling rounds were conducted, in November 2015 (131 sites) and May 2016 (142 sites), respectively. Statistical analyses were carried out, identifying statistically significant trends in the collected data.

Conclusion.

In the Danish regulatory framework, the background levels of benzene and TVOC (C6-C35) are the compounds causing difficulties in relation to risk assessment at contaminated sites. More than 99% of all indoor and outdoor measurements of benzene are above the regulatory criteria of 0,13 µg/m3. For indoor air, the median values are: May: 0,44 µg/m³, Nov.: 0,66 µg/m³. For outdoor air the median values are: May: 0,28 µg/m³, Nov.: 0,50 µg/m³. 29% of all indoor measurements of TVOC (in un-contaminated Danish homes) are above the regulatory criteria of 100 µg/m3. Smoking and wood stove burning are identified as major contributors to high background benzene levels in residential areas. Surprisingly, benzene concentration in outdoor air are at the same level in rural and in urban areas.

Use of peat filtration to purify metals from runoff waters of a shooting range

Teija Hakalahti, Senior advisor
Vapo Clean Waters Ltd, mail: teija.hakalahti@vapo.fi

Background
There are about 2000 to 3000 shooting ranges in Finland that have been contaminated. About 1000 of these are in active use. Most shooting ranges have been set up before the existing environmental laws, which makes up to one third of them in risk areas, for example in or near groundwater areas.

The most significant environmental risk of shooting range operations is lead-containing runoff waters. In addition, zinc, copper, arsenic, antimony and sometimes nickel exists in the runoff waters. There are plenty of scientific research materials for the use of peat in the purification of metal containing waters, but there are no practical applications in Finland yet.

Aim
In this project Vapo Clean Waters Ltd tests and develops processed peat products and a peat filtering method for the removal of heavy metals in waters. The project performs laboratory tests for the needs of material development and tests the functionality of the method on the field. The piloting is implemented in a shooting range owned by the Finnish Defense Forces.

Conclusion
Column tests in the laboratory show that the peat holds well lead, copper, zinc from the runoff waters of the shooting range. Also soluble metals retained in the peat. There were no major differences between the peat products in the metal removal efficiency. Testing of peat products has continued under field conditions and the tests continue until summer 2018.

Results of 20 years of monitoring of heavy metals in surface water from military training and shooting areas in Norway

Kim Forchhammer, senior environmental consultant
Golder, mail: kim_forchhammer@golder.com

Eli Smette Laastad, senior environmental consultant, Golder.
Turid Winther-Larsen, senior environmental adviser
Norwegian Defence Estates Agency

Background
Norwegian Defence Estates Agency (NDEA) is responsible for the management of properties owned and used by the Norwegian Armed Forces. This includes a large number of military training and shooting areas where the use of ammunition has led to accumulation of heavy metals. Over time, the remains of the ammunition are subject to corrosion and weathering that can cause the release of heavy metals to soil, biota or water in the surroundings. For 30 years, NDEA has monitored heavy metal concentrations in surface water coming from shooting ranges. At the end of 2017, 81 500 analytical results had been collected from 7840 samples, from 820 sample points from 75 different military training and shooting areas.

Aim
The aim of the monitoring program is to control that the heavy metal concentrations in runoff from active military training and shooting areas does not increase, and that the effects are minimal in the larger recipients.

Conclusion
In general, it is difficult to measure any effect of the military training and shooting areas on the water quality in the runoff. In small streams or stagnant waters very close to the military training and shooting areas the concentrations of the heavy metals may be elevated, but in the larger streams any possible effects are normally masked by the uncertainties of the investigation. The main uncertainties are considered to be:

- Analytical uncertainty (normally 15-30 %)
- Temporal variation (most substances show a natural variation of at least a factor 2)
- Alternative sources (e.g. metal-rich minerals or stormwater from e.g. buildings and roads)
- Interaction with other substances

Elevated metal concentrations in larger streams are primarily found in waters where the calcium concentration is lower than 5 mg/l, and conversely all values are low when the calcium concentration is higher than 20 mg/l. For TOC and pH there is no such general relationship. For example, many of the highest heavy metal values are found in the normal range of pH (6-7.5). Some individual points have correlation between metal concentrations and pH or TOC.

In many sample points, there are large variations in the calcium concentration. Surface runoff and snowmelt in the spring will normally be low in calcium, whereas groundwater passing through soil may have high calcium concentrations. This difference is often reflected in the heavy metal concentrations. In some points, the metal concentration can vary a factor 10 between spring and autumn samples.

With a few exceptions, even the highest heavy metal concentrations found in this monitoring program, ongoing for 20 years, have been within the range normally encountered in stormwater in Norway.

Notes

Notes

Technical Tours Programs

Visit to practice range for fire fighting

Thursday September 6, 2018, kl. 09.00 – 13.30 (incl.lunch)

Bus – from Helsingør to Hedehusene, Danish Emergency Management Agency (DEMA) - Final destination: Copenhagen C (joint lunch)

Organised by:
Maren K. Hostrup, Civil Engineer/M.Sc., Danish Ministry of Defence Estate Agency
Anne Mette B. Lindof, Geologist, Danish Ministry of Defence Estate Agency
Basse Vængtoft, Captain, Danish Emergency Management Agency, Hedehusene

Subject
A technical tour to Danish Emergency Managements Agency, Hedehusene.

At this site firefighters have been educated and practicing for a number of years. One of the things practiced there is the use of foam to extinguish fires. In 2015 the Estate Agency did an investigation to see if the ground water under the practice range was contaminated with PFAS as a result of the use of foam and other fire extinguishers containing PFAS. Hedehusene is located in an area used for drinking water.

Today we are monitoring a PFAS plume in the primary ground water 13 m below surface. We have found PFAS as far as 1.200 m from the practice grounds. The tour will show the practice fields and where we will explain about the PFAS plume, monitoring, and other results.

DEMA has agreed to show the use of foam, as we believe that a lot of the participants in the NORDROCS conference know a lot about PFAS, but may never actually have experienced the foam that we talk about.

Program

09.00 Departure by bus from Helsingør

Tour at the practice range at Hedehusene
Fire fighters from DEMA will show the use of foam for fire extinguishing.
Opportunity to get a closer look at the compound before and after it is turned info foam.

Presentation of the environmental investigations concerning PFAS in the ground water beneath the practice grounds, and the PFAS plume downstream

Bus transport to Copenhagen C

13.00 Joint lunch

14.15 Bus - return to parking lot at Konventum - *Optional*

Innovation Garage, Skovlunde

Thursday September 6, 2018, kl. 09.00 – 13.30 (incl. lunch)

Bus tour – from Konventum, Helsingør
Final destination: Copenhagen C (joint lunch)

Organised by
Environmental Engineer Niels Døssing Overheu, Capital Region of Denmark
Special Consultant, hydrogeologist Hasse Milter, Region Zealand

Subject
The Danish regions operate nine contaminated test sites, which the regions and their partners use for test and demonstration of new technology for site investigation and remediation. This technical tour will visit the first establish test site, the Innovation Garage in the Copenhagen suburb of Skovlunde.

The Innovation Garage is a former dry-cleaning facility contaminated with chlorinated solvents, mainly PCE. The Capital Region purchased the site in 2012 to turn it into a living lab. A state-of-the-art pump-and-treat plant prevents the contamination from spreading from the site while we use it for testing. It is possible to divert part of the process water to test alternative water treatment methods.

The site has indoor and outdoor testing spaces, kitchen, meeting room, office, toilets and WiFi. More info on the site is available at http://danishsoil.org/testsites/testsite.php?id=1.

Program

09.00 Departure by bus from Konventum, Helsingør

09.30 Arrival at Innovation Garage, Skovlunde Byvej 96a, Skovlunde. Introduction to the Regions and their work on innovation, the test site network and the Innovation Garage
Niels Døssing Overheu, Environmental Engineer, Capital Region of Denmark

10.15 Tour of the site, including results of previous testing and interesting projects in the pipeline
Niels Døssing Overheu, Environmental Engineer, Capital Region of Denmark

Introduction to current projects at the Innovation Garage

Water treatment by membrane filtration and advanced oxidation
Special Consultant, hydrogeologist Hasse Milter, Region Zealand

Electrochemical groundwater remediation in a tank experiment
Bente Højlund Hyldegaard, Industrial Ph.D.-student, Danish Technical University/COWI

Investigation of contaminated building materials & vapor intrusion mitigation by sub-slab depressurization
R&D Manager Per Loll, DMR A/S

In situ remediation using nano-particles (The Metal Aid project)
Adrian Schiefler, Ph.D.-student, Capital Region/Copenhagen University

Hydraulic characterization of complex till deposits through advanced infiltration tests"
Knud Erik Strøyberg Klint, Senior Project Manager, M.Sc. Ph.D. Geology, Geo

Measurement of electrical potential as indicator of soil contamination
Lars Riis Damgaard, Ph.D., research specialist, Aarhus University, Department of Bioscience

12.00 Finish - Bus transport to Copenhagen C

13.00 Joint lunch

14.15 Bus - return to parking lot Konventum - *Optional*

Conference Sponsors

CONFERENCE SPONSORS

IFE is a Norwegian research institute based in Kjeller, near Oslo. Founded in 1948, the institute now employs about 600 scientists and engineers, developing sustainable technologies for a broad scope of energy applications and environmental topics.

IFE specializes in elemental and isotopic analysis of organic and inorganic gasses, fluids and solids using advanced mass-spectrometric instrumentation. Combined with in-house fluid flow modelling, these analyses have been used for a broad range of applications, from measuring and sourcing pollutants to studying sub-surface fluid flow patterns and compartmentalization in petroleum and groundwater reservoirs, as well as monitoring radioactive and hazardous waste to ensure safe containment. IFE has particularly long experience observing and controlling processes by monitoring natural isotope systems such as carbon, nitrogen, sulfur and strontium. In addition to natural isotope systems, the institute has advanced analytical tools that enable "fingerprinting" of organic pollutants as a parameter in process tracing. IFE has also decades of experience using artificial tracers to trace water, gas and oil fluid processes in porous media, and artificial tracers are currently used in an EUROSTARS project to detect Non-Aqueous Phase Liquid (NAPL) pollution in the ground close to an industry area.

IFE's combined expertise can deliver customized services to monitor the impact of waste deposits on the environment and on human life, and to develop new technologies to minimize these impacts. By determining the flow of gasses and liquids through leaking waste deposits, cost-efficient and effective measures can be determined and implemented to mitigate or prevent problems. With our tailor-made services we will find the best solutions for your environmental challenges.

COWIfonden is a commercial, independent Danish trust fund set up to develop the COWI Group in cooperation with its management and employees. COWIfonden was created in 1973, when the former partners transferred ownership to a private limited company with COWIfonden as the sole owner. In 2010, a new group structure was set up with COWI Holding A/S as the parent company. COWIfonden is the majority shareholder in the parent company, which in turn is the majority shareholder – either directly or indirectly – of all the companies in the COWI Group.

Apart from COWIfonden, only employees in COWI Group Companies can buy shares in COWI Holding A/S. According to its charter, COWIfonden is obliged to:

- Support and expand the COWI Group.
- Support relevant activities, primarily within areas related to the COWI Group's business and in particular within postgraduate studies and research.

Vision and mission
The COWI Group is a leading consultancy firm that offers its unique services in selected markets. The COWI Group is a profitable and competitive firm in Denmark as well as internationally. The COWI Group delivers consultancy services of the highest quality and professional standards and at the same time remains a desirable workplace. All units in the COWI Group conduct their business within the overall framework of the following set of values: Integrity, Respect, Independence, Professional capability, . reedom. The Foundation makes substantial donations to research and development projects at universities or research institutes that have a long-term effect and perspective inside the COWI Group's fields of activity. Please read more at www.cowifonden.com

RAMBOLL

Ramboll is a leading engineering, design and consultancy company founded in Denmark in 1945. The company employs 13,000 globally and has especially strong representation in the Nordics, UK, North America, Continental Europe, Middle East and Asia Pacific.
Global presence, local knowledge With more than 300 offices in 35 countries, Ramboll combines local experience with a global knowledgebase constantly striving to achieve inspiring and exacting solutions that make a genuine difference to our clients, the end-users, and society at large. Ramboll works across the markets: Buildings, Transport, Planning & Urban Design, Water, Environment & Health, Energy and Management Consulting.
Leading environmental & health consultancy As one of the world's leading environmental and health consultancies, we are trusted by clients to manage their most challenging environmental, health and social issues. We help clients understand and manage the impacts of their activities and products, so that they can respond to business, regulatory or legal challenges effectively and develop sound strategies for operating sustainably.
A sustainable approach to contaminated site investigations and remediation Ramboll engineers, geologists and scientists deliver value-added, site-specific solutions that address all aspects of the remediation process – from site investigation and feasibility studies to risk assessment, remedy selection, remedial design and construction management to site reuse. At the forefront of green and sustainable remediation, our innovative thinking and turnkey solutions have been applied successfully to thousands of industrial, mining, development and hazardous waste sites around the world. We have established an unsurpassed reputation with both public- and private-sector clients and regulators around the world for achieving cost-effective site closure. Ramboll's interdisciplinary approach to site remediation helps clients manage the complex and interrelated issues that drive remedial decisions. When engineering a solution, we consider ultimate site risk-reduction goals, risk management during implementation, management of long-term risk and future liabilities, and the short- and long-term costs of various alternatives. We have applied formal decision and probabilistic cost analysis techniques to consider the effects of uncertain cost components on the overall cost of alternative remedies. http://www.ramboll.com/services-and-sectors/environment-and-health

suez

Present on 5 continents, with its 90.000 employees, SUEZ is a group of services and industrial solutions specializing in the recovery and securing of resources. SUEZ has an extensive know-how in water treatment and waste recovery and offers solutions for the management and recovery of all types of waste to produce new resources (material, energy…).

Over the past 35 years SUEZ has supplied expertise and services to industries and authorities for the remediation and re-use of contaminated soils and groundwater. Trust in the expertise of SUEZ to perform your soil remediation projects. We provide proven and innovative treatment techniques for soil and groundwater, apply the appropriate combination of remediation techniques and manage the complete process on-site or with various ex-situ remediation options.

SUEZ provides a wide range of remediation services:

- In-situ (ISCO, ISCR, ERD…) and groundwater remediation services for all type of contaminants;
- On-site remediation services including biological treatment, soil washing, thermal desorption and stabilization / solidification. We design, build and operate mobile treatment units for soil and groundwater;
- Off-site treatment services with more than 20 soil treatment facilities in Europe;
- UXO clearance led by a former NATO officer;
- Site evaluation, risk assessments, engineering and design.

While carrying out soil remediation activities we take all necessary measures to mitigate environmental issues such as odors and nuisance caused by dust or air pollution. We take extreme care of the surrounding environment.

For over 18 years QM Environmental International is a supplier of bioaugmentation products used both in situ and ex situ soil and groundwater bioremediation projects in Europe. Products we offer are:

- EOS Remediation Emulsified Soybean Substrates for anaerobic bioremediation of chlorinated hydrocarbons, perchlorate, chromate, explosives, acid mine drainage, etc.. in aquifers.

- BAC family microbial cultures for stimulating both anaerobic and aerobic biodegradation of chlorinated hydrocarbons (PCE, TCE, DC, VC), chlorinated ethanes and methanes, BTEX, petroleum hydrocarbons, PAH's, 1,4-dioxane.

- MicroCat Microbial additives for soil and groundwater, and wastewater treatment.

We market innovative, sustainable, green remediation technologies for bioremediation and other soil and groundwater remediation. The complete family of groundwater remediation products supplied by QM Environmental International are supported by a team of engineers and scientists who assist in the design and implementation of a remediation project from bench scale laboratory biodegradability testing to on site pilot testing and full scale remediation.

Global strength and local service - SYNLAB is a winning partner when in need of environmental analyses! SYNLAB delivers service contributing to improve our environment and secure our health. We are represented in 35 countries on 4 continents and our 20 000 employees deliver 500 million analyses per year. This gives us global strength with local focus and a financial stability as partner as well as our co-workers and suppliers.

SYNLAB has 8 laboratories located in the Nordic countries. We deliver chemical and microbiological analyses to a great variety of businesses e.g. environmental consultants, construction, soil remediation, landfills and municipalities. We offer a wide range of analyses and have great experience of delivering high quality analyses in soil, water, sediments, waste, sludge, biota etc.

For situations requiring short turnaround times, we perform analyses overnight and deliver your results by 07.00 the next morning!

With its solid background in the environmental laboratory industry SYNLAB has gained a deep knowledge and understanding for different kind of problems that might show up in different customers every day work and what good value a close customer-supplier cooperation implies. We are dedicated to never stop developing our business. We keep our selves updated on the latest methods and techniques and are an active member in several standard committees.

We strive to digitalize unnecessary work to achieve a more effective and optimized mode of operations for our customers. One example is our popular web portal @mis and the SYNLAB Field Sampler that facilitates your ordering of analyses, saving precious time when working on contaminated sites! To learn more, please visit our exhibition stand or contact one of our sales representatives.

SYNLAB is accredited according to SS-EN ISO 17025 and environmental certificated according to ISO 14001. Read more about SYNLABs offer on www.synlab.se

Eurofins Scientific is the world leader in the field of environmental laboratory services with an international network of more than 400 laboratories across 44 countries in Europe, the USA, Asia-Pacific and South America. Eurofins has more than 38,000 employees and offers a portfolio of over 150,000 reliable analytical methods for evaluating contamination, safety, identity, composition, authenticity, origin and purity of biological substances and products.

Eurofins´ objective is to provide our customers with high-quality services, accurate results on time and expert advice. Focusing on the area of testing and analysis of environmental samples Eurofins is by far the largest provider in the Nordic region serving our customers with methods for both high volume standardized tests and specialized custom designed applications for both soil, water, indoor climate, and air matrices.

At NORDROCS 2018 Eurofins will present a number of innovative services and services of topical interest from the Nordic Region. This will include analysis for radon, PFAS and micro plastics, high-end sampling methods for indoor climate, innovative passive water sampling methods, chemical fingerprinting of contaminated soil samples, sampling of soil gas as well as geotechnical tests.

Meet us in the exhibition area on the common Nordic Eurofins boot where you will find Eurofins representatives from Norway, Sweden, Finland and Denmark.

REGENESIS Europe –Your Groundwater Remediation Partner
We are the European arm of Regenesis, the global leader in the development and supply of innovative solutions for cost-effective remediation of contaminated land and groundwater. Our patented, controlled-release technologies have revolutionised in situ groundwater restoration by providing lower cost, more environmentally sustainable and effective alternatives to traditional remediation solutions. Our multi award-willing technologies have been used on more than 26,000 sites to date, in 28 countries worldwide. They are currently being used every working day in Europe.

Our combined offer of innovative products and expert services ensures a high degree of certainty when it comes to meeting remediation objectives, and helps clients save valuable time and money on site.

From our offices in Ireland, UK, Italy and Belgium, we actively remediate sites across Europe. We offer an integrated suite of injectable reagents and specialist application services directly to the environmental industry. We provide accurate remedial solutions by identifying the optimal strategy and integration of remediation technologies for each individual site.

REGENESIS in Europe offers:

- Remediation design and technical support
- 14 innovative in situ remediation technologies
- Site application and project management
- Treatment of a wide range of contaminants, at all concentrations
- Minimisation of site disturbance and cost
- Pilot studies
- Performance-based solutions

Founded in 1986, Geovariances is a French independant software vendor with an international vocation. Our solutions, based on rigorous and innovative geostatistics, address our client issues related to mapping, resource estimation or risk analysis.

Geovariances has developed a real know-how and a professional expertise confirmed by more than 30 years experience in applying geostatistics to support contaminated site industries, nuclear dismantling, mine exploration and oil exploration .

Geovariances offers the most comprehensive solution based on geostatistics: software packages, consulting services, expertise and training.

The company develops and sells four software packages:

- ISATIS, comprehensive software solution for geostatistics;
- KARTOTRAK, dedicated software solution for contaminated site characterization;
- KARTOTRAK.ONE, fast characterization solution for all your remediation projects;
- MINESTIS, dedicated software solution for mineral resource estimation and geological domain modeling.

Key figures:
Number of employees: 35

- Headquarter in France
- 1 subsidiary office in Australia and 1 in Brazil
- Turnover: +4 M€
- +500 company customers over the world
- +3500 software users over the world

Multiconsult started out as a Norwegian firm of consulting engineers. With roots going back to 1908, the company has played an important role in Norway's development and economic growth. Over time, the company has grown into a group offering a range of services including multidisciplinary consultancy, design, architecture, project supervision, management, verification and inspection – in Norway and around the world. Including LINK arkitektur's architectural business, the Group now has 2.850 employees working in offices in Norway, Sweden, Denmark, the UK, Poland, Singapore, Tanzania and Uganda.

Bridging the past and the future
Multiconsult's vision is "Bridging the past and the future". Wherever humans travel, work and live, Multiconsult shall act as a bridge between what has been and what will be. The one common denominator in all of our projects is that they should, without exception, help to improve people's lives, generate growth and promote development.
Sustainability is important to us, and thanks to our specialist expertise in health, safety and the working environment, environmental management, risk assessment and BREEAM, we are able to help our customers to identify and implement environmental goals, in order to facilitate sustainable development. Our strategy also states that HSE shall always have priority over financial considerations.

Multiconsult's operations are split into seven different business areas:

- Buildings & Properties
- Industry
- Oil & Gas
- Transportation
- Renewable Energy
- Water & Environment
- Cities & Society

The business areas are where growth takes place, and they are also where we identify opportunities. Multiconsults business areas is Buildings & Properties and Transportation are the Group's two biggest business areas. Architecture is not defined as a separate business area, instead being integrated into the services offered by most of the defined areas. Read more at www.multiconsult.no

INNOVATION NETWORK FOR ENVIRONMENTAL TECHNOLOGY

Join the Innovation Network for Environmental Technologies' (Inno-MT)

- It's not just for Danes and it's free!

Innovation Network for Environmental Technologies' (Inno-MT) goal is to promote environmental technology innovation in the Danish environmental technology sector, with particular focus on increasing exports, growth and employment in Danish SMEs.

Inno-MT works to promote innovation of new solutions and services across our four focus areas:

- Soil resources and nutrient cycling
- Clean air technology
- Efficient resource use
- Water treatment and water supply

This is achieved through matchmaking, knowledge sharing, project generation, internationalization and entrepreneurship activities. We have over 360 members but we have room for many more who wants to work with us and each other to meet other innovative companies, engage in new projects and internationalize.

Visit our webpage: https://inno-mt.dk/ and sign up for membership at https://podio.com/webforms/14453058/968587
If you want to know more you can also contact network manager Simon Baagøe at +45 6071 1585 and sba@cleancluster.dk

The partners in Inno-MT are AgroTech, DHI, FORCE Technology, Danish Technological Institute, Aalborg University, Aarhus University, Denmark's Technical University

ARKIL MILJØ-TEKNIK

For more than 20 years, Arkil has acquired a high level of expertise in soil remediation through its division Arkil Miljøteknik, and we have significant experience working with several different clean-up techniques.

Arkil Miljøteknik masters state-of-the-art remediation techniques, including thermal and chemical methods and fixing/stabilization of contaminated soil. The company has a long and wide reference list, among others the waste landfills in Kærgaard Plantation and Cheminova / Høfde 42 - some of the most contaminated localities in Denmark.

Arkil Miljøteknik offers total solutions for soil- and groundwater pollution. We participate in all phases from feasibility studies, conceptual designs, cost estimates, pilot trials to execution, end treatment and end reporting to the authorities.

Come and see our posters in the exhibition area at NORDROCS 2018 where we focus on thermal remediation, i.e., remediation of contamination by heating and ventilating the soil using Smart Burners™ from Haemers Technologies. The technology is ideal for urban conditions as it can be used near or under buildings. We provide remediation of hydrocarbons, chlorinated solvents, mercury, PAH, PCB, dioxin etc. From small remediation projects caused by leaking from oil tanks near houses to large scale remediation of industrial plants and refineries.

Arkil's posters also feature the latest news on new techniques: During the summer of 2018 soil mixing was used as remediation technique on a gasworks site in Holte. A pilot test was followed by full scale remediation of 2.000 m3 soil to 15 meters below surface using a combination of soil mixing, stabilization and chemical oxidation with activated persulfate (ISS + ISCO remediation).
Arkil is one of Denmark's largest construction companies with more than 1.800 employees and a turn-over of approximately 3 bn DKK in Denmark and abroad.

The environment is our mission
In RGS Nordic we are working to pass on to our children a world in which resources are cleaned and recycled and

We specialise in

- treatment of contaminated soil and groundwater
- treatment of industrial wastewater
- reuse of demolition and contruction waste

A Nordic environmental company and market leader with

- more than 35 locations in the Nordic countries
- treatment facilities with strategic locations nearby larger cities and industrial parks
- head office in Copenhagen
- the largest wastewater treatment plant in the Nordics located at Stigsnæs
- approx. 250 dedicated employees

Each year we

- treat and remediate more than 1.5 million tonnes of soil
- purify 500,000 tonnes of industrial wastewater
- upcycle and reuse more than 1.7 million tonnes of demolition and contruction waste
- clean soil and groundwater in-situ. More than 300 remediation projects completed

The target is to create a good business for our customers through circular economy.
We clean soil in the biological and environmental proper way - Receipt, treatment and process of all types of soil at our treatment facilities or direct at the building site - Cleaning of contaminated soil and groundwater in-situ - Treatment of contaminated harbor sediments - Environmentally sound decontamination and closedown of gas stations

Notes

Notes

Notes