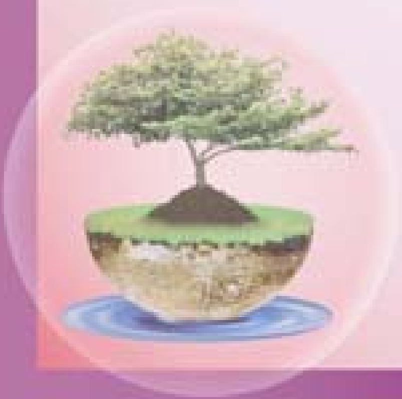
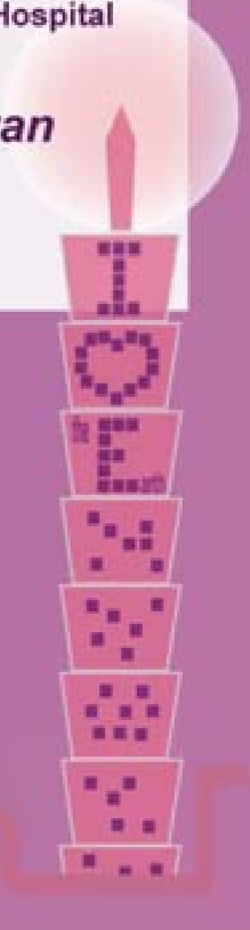
2012 Taipei International Conference on Remediation and Management of Soil and Groundwater Contaminated Sites

October 30-31, 2012

International Convention Center
National Taiwan University Hospital

Taipei, Taiwan





Proceedings

Program at a Glance

Time	October 30 (Tuesday)	
09:00-09:15	**Opening Ceremony of Exhibition** ***Room 201***	
09:25-09:50	**Opening Ceremony of Conference** ***Room 101***	
09:55-12:20	**S1: Two Keynote Speeches** ***Room 101***	
12:20-13:30	**Lunch at *Room 301 and 401* and Exhibition at *1st Floor and Room 201***	
	Room 301	***Room 401***
13:30-15:00	**S2: Sustainable Management (1)**	**S4: Bioremediation**
15:00-15:30	Coffee Break	Coffee Break
15:30-17:00	**S3: Remediation of Heavy Metals**	**S5: Remediation of Sediments (1)**

Time	October 31 (Wednesday)	
	Room 301	***Room 401***
09:00-10:00	**S6: Phytoremediation and Remediation Market**	**S8: Remediation and Communication**
10:00-10:30	Coffee Break	Coffee Break
10:30-12:00	**S7: Sustainable Management (2)**	**S9: Remediation of Sediments (2)**
12:00-13:30	**Lunch (Room 301 and 401) and Exhibition (Room 201)**	
13:30-15:30	**S10: Remediation Case Studies**	**S11: Chemical Remediation and other Challenges**
15:30-16:00	Coffee Break	Coffee Break
16:00-16:50	**S12: General Discussion**	
16:50-17:00	**S12: Closing Ceremony**	

Detailed Program

Day: October 30, 2012 (Tuesday)

09:00-09:15 Location: *Room 201*

Open ceremony of Soil and Groundwater Exhibition: opened by Minister Shen

09:25-13:30 Location: *Room 101*

Open ceremony of International Conference

09:25-09:30	Group photo with **Minister Dr. Shen, Stephen Shu-Hung** (Taiwan EPA)
09:30-09:35	Opening address by chairman, **Prof. Dr. Zueng-Sang Chen**
09:35-09:40	Opening address by **Minister Dr. Shen, Stephen Shu-Hung**
09:40-09:45	Opening address by **Mr. Christopher J. Marut** (**AIT**)
09:45-09:50	Opening address by **Mr. David Campbell** (**BTCO**)

Session 1: Plenary session

Location: ***Room 101***

Chairman: **Prof. Dr. Zueng-Sang Chen (陳尊賢)**, National Taiwan University/Taiwan

Time	Topics	Speaker
09:55-10:10	Realizing Sustainable Land Use through Soil and Groundwater Protection -The Vision of Taiwan EPA	**Dr. Shuenn-Chin Chang** (Taiwan EPA)
10:10-11:00	**Keynote Speech:** Advanced Site Remediation Technologies	**Prof. Dr. Ravi Naidu** (CRC CARE, Australia)
11:00-11:30	Coffee Break	
11:30-12:20	**Keynote Speech:** Regulation, Risk assessment and Management as Part of Sustainable Remediation	**Dr. Phillip Crowcroft** (CL:AIRE / ERM, UK)
12:20-13:00	Lunch at ***Room 301*** at 3rd Floor and ***Room 401*** at 4th Floor	
13:00-13:30	Soil and Groundwater Exhibition at ***1st Floor*** (Field operation)	

Session 2: Sustainable Management: part 1

Location: ***Room 301***

Chairman: **Prof. Dr. Chia-Shyun Chen (陳家洵)**, National Central University/Taiwan

Time	Topics	Speaker
13:30-14:00	Development of the SuRF-UK Framework for Sustainable Remediation in the UK	**Dr. Brian Bone** (BEC / CL:AIRE / SuRF, UK)
14:00-14:30	Risk Assessment as a Tool in Driving Sustainable Management of Contaminated Land Issues	**Mr. Neil Donaldson** (ERM, Australia)
14:30-15:00	Technologies and Approaches for Sustainable Sediment Management	**Mr. Mark Travers** (ENVIRON Holdings, USA)
15:00-15:30	Coffee Break	

Detailed Program

Day: October 30, 2012 (Tuesday)

Session 3: Remediation of Heavy Metals

Location: ***Room 301***

Chairman: **Prof. Dr. Chih-Jen Lu (盧至人)**, National Chung Hsing University/Taiwan

Time	Topics	Speaker
15:30-16:00	Two UK Remediation Case Studies: Combined In-Situ Treatment of Groundwater, & Stabilization of Heavy Metal Contaminated Sludge	**Dr. Jon Burton** (CL:AIRE / RAW Group, UK)
16:00-16:30	Reuse/disposal of Agricultural Drainage Water with High Levels of Salinity and Toxic Trace Elements in Central California	**Dr. Gary Stephan Bañuelos** (USDA-ARS, USA)
16:30-17:00	Assessing the Link between the Geochemistry of Soils and the Bioaccessibility of Arsenic, Chromium and Lead in the Urban Environment	**Dr. Joanna Wragg** (BARGE / BGS, UK)

Session 4: Bioremediation

Location: ***Room 401***

Chairman: **Prof. Dr. Colin S. Chen (陳士賢)**, National Kaohsiung Normal University/Taiwan

Time	Topics	Speaker
13:30-14:00	Microvi BioTechnologies	**Mr. John Darmody** (MWH, Australia)
14:00-14:30	Enhanced Biobarrier for a Mixed CVOC Plume	**Mr. William Pickens** (MWH, USA)
14:30-15:00	Electrokinetic-Enhanced Bioremediation (EK–BIO) - An Innovative Bioremediation Technology	**Dr. James Wang** (Geosyntec Consultants, USA)
15:00-15:30	Coffee Break	

Session 5: Remediation of Sediment: part 1

Location: ***Room 401***

Chairman: **Prof. Dr. Shian-Chee Wu (吳先琪)**, National Taiwan University/ Taiwan

Time	Topics	Speaker
15:30-16:00	Contaminated Sediment Remediation and Restoration: Comprehensive Approach	**Dr. Brian Mastin** (Southern Research Institute, Alabama, USA)
16:00-16:30	Historical Trends of Dioxin-like Compounds and Brominated Flame Retardants in Sediments Buried in Different Reservoir Systems in Taiwan	**Dr. Kai-Hsien Chi** (National Yang Ming University, Taiwan)
16:30-17:00	Innovative approaches to Dealing with Contaminated Sediments	**Mr. Jonathan Atkinson** (Environment Agency, UK)

Detailed Program

Day: October 31, 2012 (Wednesday)

Session 6: Phytoremediation and Risk assessment

Location: ***Room 301***

Chairman: **Prof. Dr. Min-Chao Wang (王敏昭)**, Chaoyang University of Technology/Taiwan

Time	Topics	Speaker
09:00-09:30	Use of Phytoremediation for both Managing Selenium and Producing Biofortified Plant Products and Biofuel under Adverse Soil Conditions	**Dr. Gary Stephan Bañuelos** (USDA-ARS, USA)
09:30-10:00	Risk Assessment of As in Soil and Groundwater for the Safety of Road Construction to Residents	**Prof. Dr. Jae E. Yang** (Kangwon National University, Korea)
10:00-10:30	Coffee Break	

Session 7: Sustainable Management: part 2

Location: ***Room 301***

Chairman: **Dr. Shih-Cheng Pan (潘時正)**, SINOTECH Environmental Technology LTD./Taiwan

Time	Topics	Speaker
10:30-11:00	Development, Validation and Application of a Harmonised BARGE Method	**Dr. Joanna Wragg** (BARGE / BGS, UK)
11:00-11:30	Self-Sustaining Treatment for Active Remediation (STAR): Overview and Case Study	**Dr. James Wang** (Geosyntec Consultants, USA)
11:30-12:00	On-site Remediation Technologies and Example of Remediation Sites	**Dr. Ryuzo Tazawa** (Shimizu Kensetsu, Japan)
12:00-13:30	Lunch at ***Room 301*** at 3rd Floor and ***Room 401*** at 4th Floor and Soil and Groundwater Exhibition at ***Room 201***	

Session 8: Remediation and Communication

Location: ***Room 401***

Chairman: **Prof. Dr. Hwong-Wen Ma (馬鴻文)**, National Taiwan University/ Taiwan

Time	Topics	Speaker
09:00-09:30	Remediation of the Lower Lea Valley and other Venues for the 2012 London Events and for a Lasting Legacy to the Local Communities	**Mr. Jonathan Atkinson** (Environment Agency, UK)
09:30-10:00	Outlook of Soil Contamination Countermeasures in Japan	**Dr. Ryuzo Tazawa** (Shimizu Kensetsu, Japan)
10:00-10:30	Coffee Break	

Detailed Program

Day: October 31, 2012 (Wednesday)

Session 9: Remediation of Sediments (2)

Location: ***Room 401***

Chairman: **Dr. Pei-Yao Wu (吳培堯)**, Industrial Technology Research Institute /Taiwan

Time	Topics	Speaker
10:30-11:00	Remediation of a Former Gasworks Using In-Situ Solidification Technology	**Mr. Bengt von Schwerin** (AECOM, Australia)
11:00-11:30	An-Shun Project Site: Sustainable Sediment Management	**Dr. Brian Mastin** (Southern Research Institute, Alabama, USA)
11:30-12:00	Management of Contaminated Sediments in Taiwan	**Dr. Meng-Der Fang** (Industrial Tech. Res. Insti., Taiwan)
12:00-13:30	Lunch at ***Room 301*** at 3rd Floor and ***Room 401*** at 4th Floor and Soil and Groundwater Exhibition at ***Room 201***	

Session 10: Remediation case studies

Location: ***Room 301***

Chairman: **Prof. Dr. Tsair-Fuh Lin (林財富)**, National Cheng Kong Univ/Taiwan

Time	Topics	Speaker
13:30-14:00	Review of UK Guidance on Permeable Reactive Barriers	**Dr. Brian Bone** (BEC / CL:AIRE / SuRF, UK)
14:00-14:30	Landfill Remediation under 'Emergency Management' Circumstances	**Mr. Bengt von Schwerin** (AECOM, Australia)
14:30-15:00	Programmatic Approaches to Management of Contaminated Land Liabilities on Large Portfolios	**Mr. Neil Donaldson** (ERM, Australia)
15:00-15:30	Current Status of the Classification System of Early Warning Management for Industrial Parks	**Dr. Chia-Hsin Li** (Taiwan EPA)
15:30-16:00	Coffee Break	

Detailed Program

Day: October 31, 2012 (Wednesday)

Session 11: Chemical remediation and other challenges

Location: ***Room 401***

Chairman: **Prof. Dr. Kuei-Jyum Yeh (葉桂君)**, National Pingtung University of Science and Technology/Taiwan

Time	Topics	Speaker
13:30-14:00	Lessons Learned from Implementation of In-situ Chemical Oxidation Remediation	**Mr. William Pickens** (MWH, USA)
14:00-14:30	Resin Capsules for Monitoring Soil and Groundwater Pollution	**Prof. Dr. Jae E. Yang** (Kangwon National University, Korea)
14:30-15:00	A Discussion On Project Procurement	**Mr. John Darmody** (MWH, Australia)
15:00-15:30	Remediation in the UK: Maintaining Innovation in a Challenging Market	**Dr. Jon Burton** (CL:AIRE / RAW Group, UK)
15:30-16:00	Coffee Break	

Session 12

Location: ***Room 301***

Time	Topics	Chairman
16:00-16:50	**General Discussion**	**Prof. Dr. Jimmy C.M. Kao (高志明)** National Sun Yat-Sen University/Taiwan
16:50-17:00	**Closing Ceremony**	**Prof. Dr. Zueng-Sang Chen (陳尊賢)** National Taiwan University/Taiwan

Content


Realizing Sustainable Land Use through Soil and Groundwater Protection
S.C, Chang
Associate Executive Secretary
Soil And Groundwater Remediation Fund Management Board
October 30, 2012
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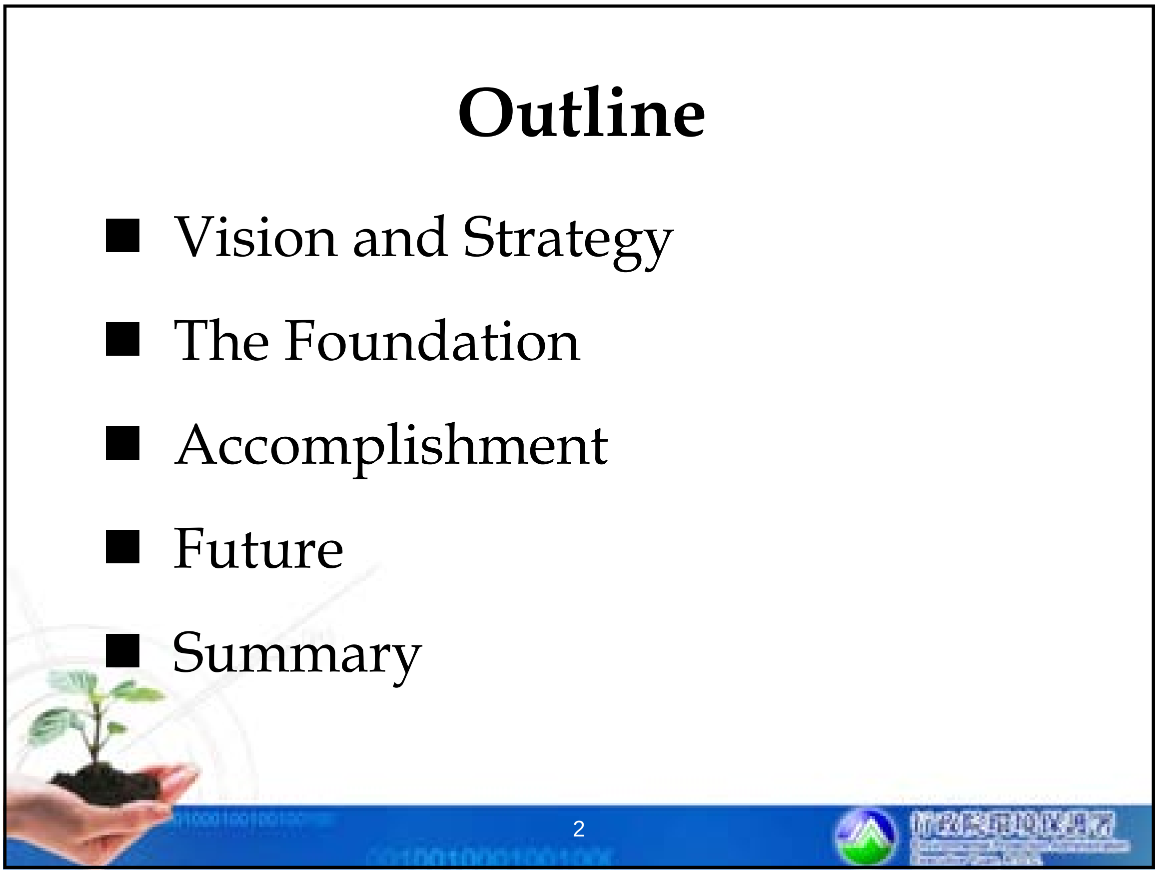
Outline
Vision and Strategy
The Foundation
Accomplishment
Future
Summary
2

Vision and Strategy

Initiation

- Over 3 decades of industrial development
- Soil as the final receptor of water, air, and waste generated
- Protection the health of public and environment from subsurface contamination has been recognized to be the major environmental issue

3

Vision and Strategy

Vision

- Protecting public from the harm of soil/subsurface contamination
- Restore the soil and ecological environment to its appropriate status
- Recover and reuse the contaminated land and reduce further impact to green field

4

Vision and Strategy

Strategy

5

The Foundation

Regulatory

- Legislation passed the Soil and Groundwater Pollution Remediation Act in January 2000
- The Act covers
  - Prevention
  - Investigation
  - Emergency Response
  - Remediation
  - Fine

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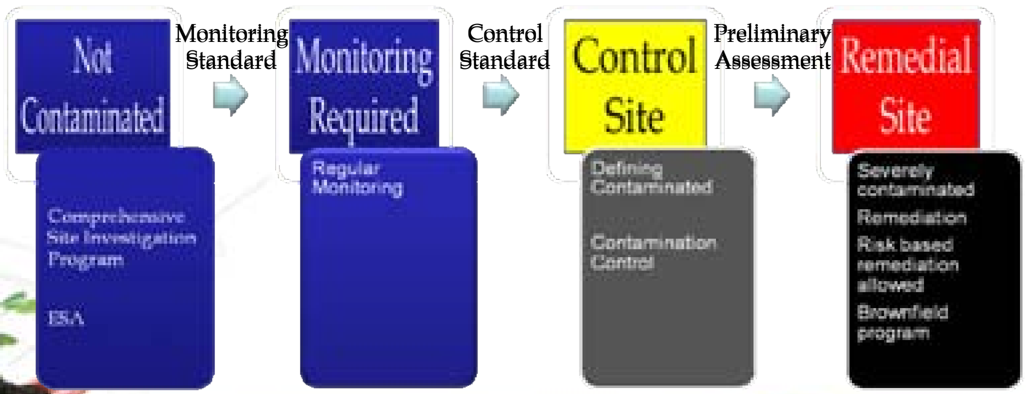
The Foundation

Site Management Framework

- Dual-Threshold
  - Control Site
  - Remedial Site



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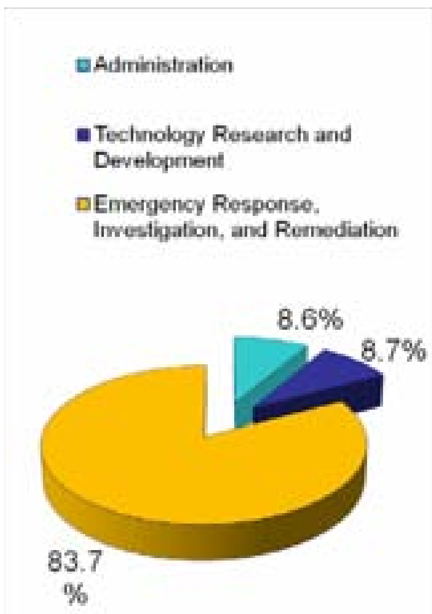
The Foundation

Resources

- Funding sources
  - Governmental budget
  - Soil and Groundwater Pollution Remediation Fund
- Remediation fee is collected from importers and manufacturers of potential contaminants
- As FY 2011, 6.7 billion NTD has been collected



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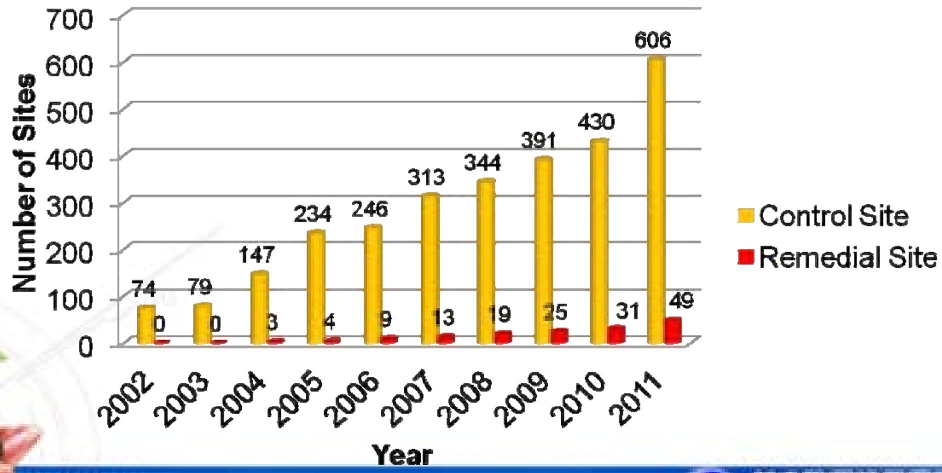
Accomplishment

Contaminated Sites

- Through comprehensive site investigation program



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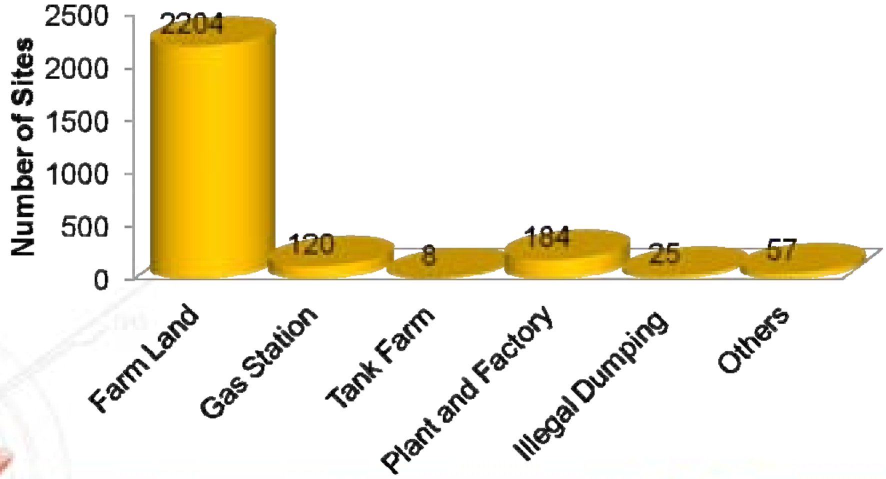
Accomplishment

Contaminated Sites

- Site categories



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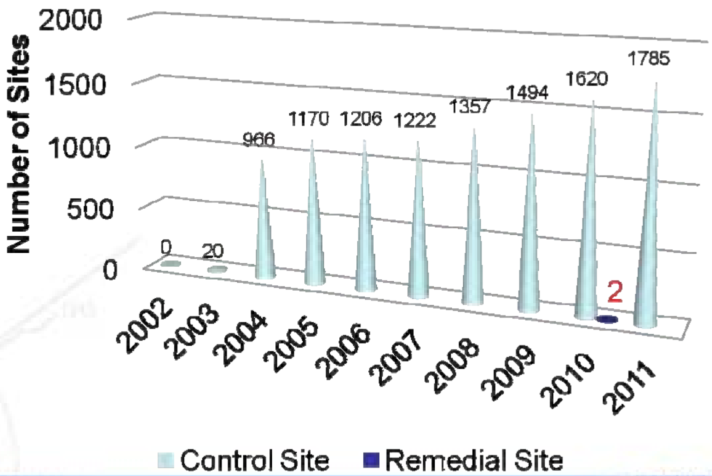
Accomplishment

Proactive Management

- Sites clean-up and delisted



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Accomplishment

Technology Innovation

- Related market growth leverages
  - Expedited site investigation
  - Diversified remediation application

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Accomplishment

Education and Collaboration

- Education for raising
  - Public awareness
  - Professional education
  - Knowledge diffusion

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Accomplishment

Education and Collaboration

- Collaboration to
  - Innovation acceleration
  - Better regional/global experiences sharing

14

Future

Site Management and Policy

- Continuing development of risk based site management framework
  - Human health
  - Ecological
- Sustainable remediation
- Brownfield program

15

Future

Leap with collective effort

- Establish platforms for regional partners to work together
- Continuing advocating the sustainable development of land at both domestic and regional scales
- Meet the demand and needs to regional partners and assist the continuous development

16

Summary

Summary

- Evolvement of soil and groundwater protection will continue at domestic and regional scales
- Learn and progress through collaboration among regional and global partners
- Create the sustainable future with collective efforts and wisdom
- Playing the responsible role as the citizen of the globe

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Thank you for your attention and participation

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Recent Advances in Contaminated Site Remediation

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1. Introduction

The recent poisoning of thousands of people through exposure to arsenic, asbestos (Naidu et al. 1996) and benzene has highlighted the massive challenge that contaminants pose for both human and environmental health. Globally, there are more than 3,000,000 potentially contaminated sites (Singh and Naidu 2012) which besides posing risks to the health and wellbeing of humans and the environment, also represent a large lost economic opportunity. Contamination is the legacy of industrialization, inadequate environmental laws and inconsistent and lacking enforcement. At the biennial International Committee on Contaminated Land, the World Bank reported that it had integrated contamination into its “Greening Development and Sustainable Urban Development” Agenda. Although site contamination has been recognised since the 1960s, less than a tenth of potentially contaminated sites globally have been remediated due to the complex and challenging nature of both surface and subsurface contamination. These challenges are further exacerbated by the cost and technical difficulty of dealing with contaminant mixtures, as well as recalcitrant and persistent pollutants. Common contaminants include petroleum hydrocarbons, chlorinated solvents, persistent organic pollutants, pesticides, inorganics, heavy metals and radioactive constituents. These contaminants can be found in a variety of sites such as oil and gas operations, service stations, mines, industrial complexes, landfills, waterways, harbours, and even in runoff from urban and residential settings.

In most countries, the scale of the problem is difficult to assess, as "contaminated land" or “site contamination” are often subjectively or poorly defined, even in statute. Very few efforts have been made to develop an inventory of contaminated sites in developing countries although industrial practices and the societal drive for economic growth continue to increase contamination of both land and water bodies. Although most developing countries have stringent regulatory guidelines, adherence to and policing of these remains a major problem. The rapid expansion of the urban fringe due to mass migration of people from rural into urban areas is causing substantial pressure on available land for residential and other uses including infrastructure, water and power distribution. As a result development is being driven into disused former industrial zones which are often contaminated. This has led to significant demand for remediation and protection from residual contaminants as well as cost effective and sustainable techniques for managing contamination to ensure the land is suitable for its new, more sensitive uses.

2. Remediation technologies

Contaminated site remediation technologies fall into two principal approaches: *in-situ* (soil and water are treated in the ground), or *ex-situ* (treatment is carried out above ground). While *in-situ* remediation deals with contamination without removing soil or water from the ground, *ex-situ* remediation requires the excavation of contaminated soil or abstraction of polluted water and/or soil vapour for treatment or disposal elsewhere. The techniques available for *in-situ* or *ex-situ* remediation can be prohibitively costly, resulting in poor rates of adoption in most countries unless there is a very large increase in the value of the remediated site. Many different *in-situ* and *ex-situ* technologies are used to remediate contaminated soils and ground water (Table 1). While many of these technologies are classed as *ex-situ,* the recent emphasis on minimisation of greenhouse gas emissions has ignited interest in *in-situ* technologies that do not require transport of contaminated soils to prescribed landfills. However, despite significant investment in the development of remediation technologies, especially in USA and Europe, contaminated site remediation remains a major challenge due to the complex nature of contaminants and their bioavailability, the presence of mixtures and the complexity of the local geology and hydrology. Readers are directed to an excellent publication by Davis (1997) on the pros and cons of disposal and *in-situ* and *ex-situ* remediation which provides a view of what we thought at that time.

3. Advances in *in situ* remediation technologies

For the last three decades, both soil and ground water remediation technologies have continued to evolve, however, the main advance has not been many brand new technologies but rather in the application of techniques once seen as novel (for example, *in-situ* thermal treatment of hydrocarbon contaminated soils, *etc*) and the development of novel uses of existing technologies (for example, *in-situ*-chemical oxidation, *etc)*. Some of these technologies are discussed in the following sections focussing on contaminated soil and ground water.

3.1. Contaminated soil

Unlike the manufacturing and sensor tools industries, progress in the development of new technologies for the remediation of contaminated soils has been slow. Conventional remediation technologies used for the remediation of contaminated soils include bioremediation using biopiles, bio-slurry reactors, thermal desorption, soil-washing, bioventing, bio-slurping and air-sparging (see Table 1). While most of these technologies work for hydrocarbons, their main problem with metal(loids) is their inability to degrade the metal although the treatment may result in changing the valence state of the metal resulting in either a more or less mobile, more or less toxic constituent depending on specific geochemical conditions. Also, when introduced into the soil environment metal(loid)s bind to colloidal matter forming matrices, from which the metal(loid)s can either leach down to the groundwater or be taken up by plants. Human exposure can occur via the food chain, water and soil or dust inhalation (example methyl mercury) and ingestion. The most common approach to dealing with metal(loid) contaminated soils has been excavation and transport to prescribed landfills. However, landfills are now seen to have intergenerational impacts and for this reason, some regulators in Australia have introduced additional legislation which increases landfill costs and thereby encourages *in-situ* management of contaminated material. Such an approach minimises greenhouse emissions from transport and at the same time forces the remediation industry to think laterally and develop new ways to manage and/or remediate metal contaminated soils. Recent advances over the last 15 years include the following technologies.

3.1.1. Electrokinetic remediation

The technique uses low-level direct current of the order of mA/cm^2 of cross-sectional area between the electrodes or an electric potential difference of the order of a few volts per centimetre across electrodes placed in the ground in an open flow arrangement. Moisture in the soil or groundwater in boreholes acts as the conductance medium. This is one of the few soil remediation technologies that has been developed during the past 20 years and is currently being extended from laboratory based studies to field remediation. This process results in significant change in pH which can be managed by using certain surfactants or buffer solutions (Yeung and Gu 2011). However, field scale remediation is still to be demonstrated from performance as well as cost perspective.

3.1.2. Thermal immobilization

This is not a new technology given its long use in Europe and relatively common consideration in North America. However it has evolved considerably over the last decade and is now being used for the remediation of both organic and inorganic contaminants. While organic contaminants degrade and/or volatilize at elevated temperatures, metals are immobilized thus minimizing their bioavailability and hence ability to leach or pose risk to humans (Singh et al. 2007; Gomez et al. 2009).

3.1.3. Risk Based Land Management

This approach to manage contaminated sites was introduced in 1990s following recognition of the prohibitively expensive cost of *ex-situ* and *in-situ* remediation. Risk based land management (RBLM) aims to manage the risks posed by historic contamination and to mitigate those risks deemed unacceptable. The decision of what level of risk is unacceptable has a socio-economic dimension but is based on robust scientific estimates of the level of risk. Together, these concepts form the basis of RBLM, which represents a mature, sustainable approach to the challenges of contamination (Ferguson et al. 1998; Nathanail and Smith 2007; Naidu et al. 2008a; Nathanail 2009). RBLM is a common and well developed consideration for contaminated site management in the United States.

To undertake RBLM, a chemical substance must be present in a form and at level that pose risks to possible receptors, including humans. Using this as the basis for management of contaminated sites, RBLM has often been employed to demonstrate ‘fit for purpose’ use of the contaminated land. Using this approach, when the site is found to have contaminant levels which exceed residential thresholds but fall within commercial/industrial guidelines, the site may be used for industrial but not for residential purposes. This approach has greatly expanded the availability of inner urban land for industrial or commercial purposes which was previously unused because of contamination.

However, risk based land management can be further refined to ensure *in-situ* management of contaminated sites by distinguishing between hazard and risk and, based on this distinction, minimising the risk by *in-situ* treatment of contaminated material. The presence of chemical substances in soils and groundwater (the hazard) is of concern, but for harm to result to the environment or human health they must be exposed. For there to be risk, pathways must exist which connect the sources of contamination to the receptors that can be harmed. The management of these risks posed by historically-released chemicals should drive remedial action; and secondly, the risk is a function of the dose-response relationship for each chemical substance (Naidu and Bolan 2008). This means that a chemical substance must be present in a form and at levels sufficient to pose a risk to the receptor. Contaminant bioavailability determines effective intake and hence the level of risk posed: this is a critical parameter that ought to be used in all cases of RBLM. Sites with high contaminant bioavailability may be managed with treatments that demonstrably reduce bioavailability in the long-term. An example is the immobilisation of metals to minimise their bioavailability. Immobilisation refers to the process of transferring an aqueous phase of highly mobile metals to a solid, stable phase that is locked within the soil. This phase transfer prevents the continued migration of contaminating metal plumes and can offer a permanent solution depending on the metal and site-specific geochemistry.

The most common mechanisms for *in-situ* metals immobilisation are metal adsorption to soil particles or the precipitation of metal solids that are chemically fixed to soil particles. Both of these mechanisms can permanently remove metals from the aqueous phase, restoring the aquifer and the desired usability of the water. CRC CARE has advanced this technology by developing a composite material known as MatCARE™ that immobilises both organic and metal contaminants permanently. This is a modern remediation technology for the *in-situ* treatment of both metals and hydrocarbon contaminated soils. The material is a composite mixture of a naturally occurring mineral that has been modified to increase its capacity to immobilise both metals and hydrocarbon contaminants. Field scale trials conducted in 2009 demonstrated the immobilisation of these contaminants was sustainable, with no observed leaching.

Rather than using the ‘fit for purpose’ approach, the demonstration of limited risk to humans and the environment following immobilisation of contaminants (no matter what changes occur in the environment) ought to be sufficient to permit human occupation and use of the land. However, this approach requires significant community participation in the process to allay public fears of perceived risk from exposure to bound substances.

3.2. Contaminated groundwater

With the exception of nano-technology, no major new groundwater remediation technology was developed during the first decade of the 21st century. However, major advances were made in existing technologies which have made the remediation process a lot more efficient. Table 1 presents a summary of existing technologies including those that may be considered innovative, emerging and developing. Rapidly advancing technologies include Permeable Reactive Barriers (PRBs), enhanced anaerobic dechlorination, especially for DNAPLs, anaerobic bioventing and *in-situ* co-metabolism with some new technologies including, bioaugmentation and bioengineering.

3.2.1. Permeable Reactive Barrier (PRB)

This technology is an underground barrier positioned to intercept a contaminated flow and charged with special substances that remove or degrade the contaminants. While the technology initially used zero valent iron as the reactive medium for the remediation of groundwater contaminated with chlorinated hydrocarbons (with the first field trials in the early 1990s and the first commercial deployment in late 1994), recently a range of materials for the remediation of other organics have been deployed (Warner et al., 1994). For example, investigators used saturated peat in a reactive barrier for the remediation of BTEX and inorganic contaminants (see Cohen et al. 1991 and Guerin et al. 2002) and polymer mat for the removal of ammonium-contaminated ground water (see Schipper and Vojvodić-Vuković 2001). Recent studies by our group demonstrated the use of Remat™ (a proprietary material) for the remediation of TCE in ground water. Remat™ was specially developed for the remediation of both chlorinated and petroleum hydrocarbons. These studies showed that zero valent iron (ZVI) was ineffective in alkaline water as it poisoned the ZVI surface with carbonate. In a further development, the team installed the PRB with wide diameter wells through which groundwater was extracted by solar pumping it through the barrier material after which the clean water was injected back into the aquifer (see Fig. 1). Recent reviews by Warner and Sorel (2003) and Thiruvenkatachari et al. (2008) present an excellent overview of PRBs and their application to organic and inorganic contaminant remediation in groundwater. Readers are also directed to additional reviews on PRBs by Warner (2011; 2012).

3.2.2. Bioremediation

In-situ bioremediation of contaminated ground water is seen as a cost effective and green technology. Often this involves the use of indigenous microbes and where *in-situ* bioremediation is slow, the process is enhanced via various techniques that range from biostimulation (the injection of growth substrates, co-substrates, and electron acceptors which are limiting the biodegradation reaction) to bioaugmentation (the injection of bacteria to increase the subsurface population). Biostimulation requires the bacterial species or consortia responsible to degrade dissolved phase contaminants are indigenous and it assumes that reactions are limited by population densities or by the absence of key electron acceptors. Much more still needs to be done in this field to enhance success rate especially for non-aqueous phase liquids and under challenging conditions such as fractured rocks.

3.2.3. Enhanced anaerobic dechlorination

Chlorinated solvents are sparingly-soluble, dense, non-aqueous phase liquids (DNAPL) that can contaminate groundwater in the long term due to their persistence in the aqueous environment. Many contaminated sites occur in areas within fractured sedimentary or bedrock systems (Chapman and Parker 2005), where the released DNAPLs penetrate into the flow pathways formed by the fractures and can then rapidly dissolve and diffuse from the fractures into the matrix (Falta 2005; Chambon et al. 2010). Even after the removal of the physical source from the site, the contaminant can re-diffuse back into the fracture network for hundreds of years, causing long-term contamination of an underlying aquifer (Harrison et al. 1992; Reynolds and Kueper 2002). Such contaminated sites have proved extremely challenging and expensive to remediate. Enhanced anaerobic biodegradation has shown to be effective for the treatment of chlorinated hydrocarbon contaminated ground water in some of these settings. The process includes adding an electron donor (hydrogen) to groundwater and/or soil to increase the number and vitality of indigenous microorganisms performing anaerobic bioremediation. A great hydrogen release material is ZVI – the hydrogen is released during the corrosion process and will continue to be released for decades and at fairly high levels depending on the amount of iron emplaced. This is another positive attribute to granular iron as a treatment material.While this approach to remediate DNAPL contamination has been successful,l at some sites, those with fractured rocks continue to pose significant problems in both delineating and remediating the contaminant.

3.2.4. Surfactant enhanced in-situ chemical oxidation

It is based on the ability of surfactants to increase the aqueous solubility of and/or displace non-aqueous phase liquids (NAPLs) from porous media including fractured rocks (Taylor et al. 2001; Abriola et al. 2005). Above the critical micelle concentration (CMC) surfactant molecules aggregate to form micelles that is able to solubilise organic contaminants. The displacement of NAPLs as free products may also occur if the interfacial tension between the organic liquid and the aqueous phase is reduced to such an extent that viscous and buoyancy forces exceed the capillary forces acting on the NAPL. The contaminant that is mobilised can then be chemically oxidised. This approach has proved quite successful in soils contaminated with chlorinated hydrocarbons, however, additional design issues include assuring that newly mobilized organic chemicals are fully captured and do not migrate outside the remediation area into zones not previously contaminated.

3.2.5. Anaerobic bioventing

It is often used for the treatment of chlorinated hydrocarbons in the vadose zone (Shah et al. 2001; Mihopoulos et al. 2002). *In-situ* remediation of vadose zone soils requires, among other factors, the establishment of highly reductive anaerobic conditions in the unsaturated subsurface. The process includes delivering an appropriate gas mixture into the subsurface (anaerobic bioventing) to create the conditions that enhance anaerobic biodegradation of contaminants. The gas mixture contains an electron donor for the reduction of these compounds.

3.2.6. Monitored natural attenuation (MNA)

Although MNA is a management strategy, it has been extensively adopted for the remediation of ground water in many countries. Natural attenuation includes both microbial degradation of contaminants and other processes (e.g. sorption, etc.) that either degrades or binds contaminants to sorbent (soil) (Sarkar et al. 2005; Naidu et al. 2010; 2012). For instance, in Australia, EPA Victoria has introduced CUTEP (Clean-up to the Extent Practicable) that recognises natural attenuation of the contaminant in ground water. Application of CUTEP requires regular monitoring of contaminants to demonstrate both attenuation as well as a steady decline in contaminant concentration in ground water. However, MNA and the application of CUTEP have posed significant challenge to the management and/or remediation of Light, Non Aqueous Phase liquids (LNAPLs). LNAPLs may consist of volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), non-volatile organic compounds and trace metals. When released into the subsurface, they can release dissolved contaminants to groundwater or VOCs into the subsurface atmosphere and potentially into indoor air for an extended period of time. In addition, sites which have complex or heterogeneous subsurface environments (such as low-permeability soils) pose particular difficulties in terms of characterisation and remediation of LNAPLs. No single technology has been identified as the best solution for all sites and all soil types contaminated with LNAPLs. LNAPL management in the subsurface is a particularly challenging problem in Australia given the wide range of soil types and hydrogeological conditions.

4. Challenges and conclusions

Although the potential impact of contaminants on the environment and human health was first recognised more than half a century ago, contaminated sites still pose major challenges in terms of site assessment and remediation. These challenges include:

(a) inadequacy in site characterisation and delineation of subsurface contamination including soil and ground water,

(b) lack of trialled and tested tools for estimating the mass flux of contaminants,

(c) cost of assessment and remediation, which is often hard to quantify,

(d) lack of advanced technologies for subsurface ground water remediation,

(e) inadequacy of policies supporting or defining end points for remediation, and

(f) fractured rocks and recalcitrant contaminants (such as DNAPLs) and their remedial endpoints.

To sum up, there needs to be a far more consistent and global effort to develop site characterisation and sustainable but green remedial technologies if humanity is to avoid the health and environmental wellbeing penalties of spreading contamination driven by the combination of world population and economic growth, which are likely to double our use of resources by the mid-21st century. Additionally, the continued stress on available water resources, in both developed and developing countries and communities require that we further isolate contaminated ground and surface water from potable water resources while we continue to develop reliable remediation methods.

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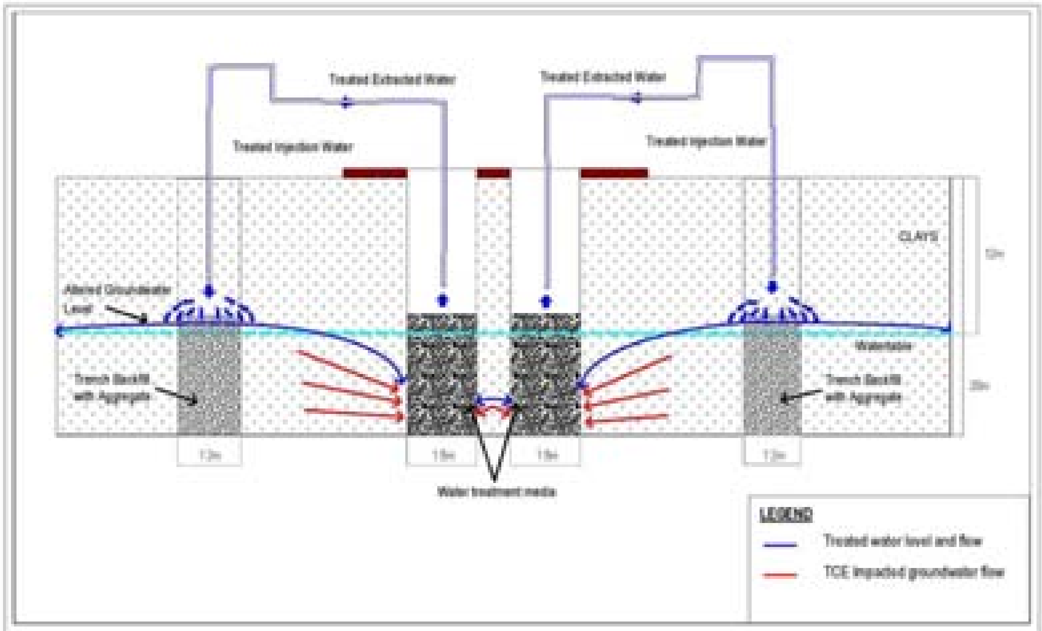

Fig. 1. Large permeable reactive barrier for the remediation of TCE contaminated ground water

Table 1: A summary of technologies for contaminated soil and groundwater remediation (http://www.epa.gov/superfund/remedytech/remed.htm; Naidu et al. 1996). Conventional technologies are those that are commonly used while developing technologies are those that are still being finetuned, emerging technologies that are now finding success.

Remediation technologies/ management strategies	Mode of operation	Technology type	References
Contaminated Soil			
Bioremediation	Microbial activity is optimised for degradation of contaminants especially hydrocarbons – often large volumes of soil are remediated using biopiles.	Conventional	Jørgensen et al. 2000; Bento et al. 2005; Megharaj et al. 2011; Rayu et al. 2012
Phytoremediation	Plants that accumulate toxic metals or biodegrade organics in their root zone.	Conventional	Cunningham et al. 1996; Pulford and Watson 2003; Gerhardt et al. 2009
Vapour-extraction	Techniques range from relatively simple designs for remediation of volatile hydrocarbons in permeable soil to high performance systems for treatment of lower permeability soils. They include thermal desorption plants that heat soil in a rotary kiln to a temperature at which target organic compounds are transferred to the gas phase.	Conventional	Frank and Barkley 1995; Zevenbergen et al. 1997; Soares et al. 2010; Chien 2012
Soil washing	A volume reduction method that uses chemicals to remove contaminants.	Conventional	Semer and Reddy 1996; Mulligan et al. 2001a; Dermont et al. 2008
Solidification-stabilisation	Application of a specially formulated (usually proprietary) additive mix to generate a low-hazard, low-leachability material usually for on-site re-use.	Conventional	Bolan and Duraisamy 2003; Kumpiene et al. 2006; Sarkar et al. 2012a
Electrokinetic	Application of a low intensity current that creates a gradient for ions to move from either cathode to anode or vice versa. A new technology being trialled in Europe and USA.	Developing technologies	Ottosen et al. 1997; Yeung 2006; Yeung and Gu 2011
Ultrasonic	Ultrasonic waves have been used to remediate hydrocarbon contaminated soils.	Innovative and emerging	Shrestha et al. 2009; Thangadivel et al. 2009; 2011
Thermal	Numerous *in situ and ex situ* thermal technologies are available for soil and ground water remediation.	Emerging Innovative	Mulligan et al., 2001b; Khan et al., 2004
Risk Based Land Management	Universally accepted as a cost effective strategy for implementing 'fit for purpose' use of contaminated land.		Ferguson et al. 1998; Naidu et al. 2008a; 2008b; Nathanail 2009; DTZ 2010

Ground water			
Pump and Treat	Operation requires pumping of contaminated water through a chemi- or bio-reactor that remediates contaminants. Cleansed water is then reinjected back into the aquifer.	Conventional	Mackay and Cherry 1989; Baú and Mayer 2008; Higgins and Olson 2009
In-situ chemical oxidation and reduction	Involves introduction of reactive materials into the subsurface to destroy organic contaminants. A variety of chemical oxidants and reductants makes this a useful technique where intensive source-zone treatment is required.	Conventional	Seol et al. 2003; Ferguson et al. 2004; Krembs et al. 2010
Bioremediation	Range from the relatively simple (e.g. placement of oxygen or nutrient-releasing agents to stimulate biodegradation activity) to the more complex process-based systems (e.g. for chlorinated solvent source areas) including enhanced anaerobic dechlorination, anaerobic bioventing, *in-situ* co-metabolism and bioaugmentation.	Conventional to emerging	Knapp and Faison 1997; Franzmann et al. 1999; 2000; Farhadian et al. 2008; Davis et al. 2009
Vapour extraction	Vapour-extraction techniques (soil vapour extraction, sparging and slurping) range from relatively simple designs for remediation of volatile hydrocarbons through complex multi-phase extraction systems capable of dealing with soil gas, groundwater and NAPL mixtures.	Conventional	USEPA 1989; Johnston et al. 1998; Johnston and Desvignes 2003; Patterson and Davis 2008
Permeable Reactive Barriers (PRBs)	PRBs offer potential for long-term, low-intensity treatment of groundwater plumes. PRBs comprise one or more zones of reactive material placed in the subsurface to degrade or sorb dissolved contaminants as the groundwater passes through.	Emerging to conventional	Patterson et al. 2002; 2004; Gibert et al. 2008; Thiruvenkatachari et al. 2008
Monitored Natural Attenuation (MNA)	MNA is a risk management approach for contaminated ground water plumes that evaluates and monitors the combined effect of natural processes (e.g. sorption, dilution, biodegradation, etc.).	Conventional	Davis et al. 1999; Franzmann et al. 1999; Prommer et al. 2002; Naidu et al. 2010; 2012
Nanotechnology-environmental remediation	A recent technology focuses on the *in-situ* use of nanomaterials for the degradation of contaminants.	Developing	Cundy et al. 2008; Karn et al. 2009; Grieger et al. 2010; Sunkara et al. 2010; Sarkar et al. 2012b
Risk Based Land Management	Universally accepted as a cost effective strategy for implementing 'fit for purpose' use of contaminated groundwater.	Innovative	Swartjes 1999; Davis and Johnston 2004

Recent Advances in Remediation Technologies

CRCCARE

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Uni of South Australia and CRC CARE

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Ravi Naidu

Outline

CRCCARE

- CRC CARE
- Background
  - Extent and severity of contamination
  - Cost implications
- Human health effects of contaminants
- Drivers for remediation
- Approach to managing contaminated sites
- Site remediation: recent advances
  - Soil
  - Groundwater
- Conclusion

Key messages

- Site contamination continues to be a major issue, and will be for the next 100 years and beyond.
- Last 50 years have seen less than 1% of sites being remediated.
- Most innovative technologies were developed during the past 30 years.
- Advancement has been the extension of existing technologies.
- Nano remediation technologies look promising, but need a lot more effort including an assessment of its behaviour and fate in the environment.

C **Cooperative**
R **Research**
C **Centre**

C **Contamination**
A **Assessment and**
R **Remediation of the**
E **Environment**

What is CRC CARE?

CRC CARE is a partnership of industry, government and scientific organisations

We devise new ways to overcome and prevent contamination of soil, water and air

Policy → Measurement → Risk assessment → Cleaning up

CRC CARE II: Partners
- $330 M of cash and in-kind contributions

- Site Owners
- Industry
- Consultants
- Government
- Researchers

Collaboration

- USEPA
- Purdue University, USA
- Hort Research, NZ
- ACLCA
- Defence Environment Panel
- Cranfield University, UK- RBLM
- Delaware University – Synchroton
- Chinese Academy of Sciences
- University of Roma
- Lancaster University
- Nottingham University
- British Geological
- TNAU, India
- M&P, Germany
- National University of Singapore
- HUST, China
- Zeijiang University, China
- MOST, Korea
- ETH, Switzerland
- Kansas State University, USA

Technology Demonstration in the field is a major feature of CRC CARE

- On-site demonstration of CRC research and technology
- On-site testing and validation of new techniques
- Current demonstration projects are co-sponsored by:
  - Department of Defence
  - BHP Billiton Iron Ore
  - Queensland Department of Natural Resources and Water
  - Australian Institute of Petroleum (AIP)
  - ExxonMobil

CRC CARE outputs

CRCCARE

- Solutions/ Technologi es
- Handbooks
- Guidance documents
- Law & policy online directory
- Training workshops
- Graduates

CRCCARE

Extent of Contamination

Extent of contamination

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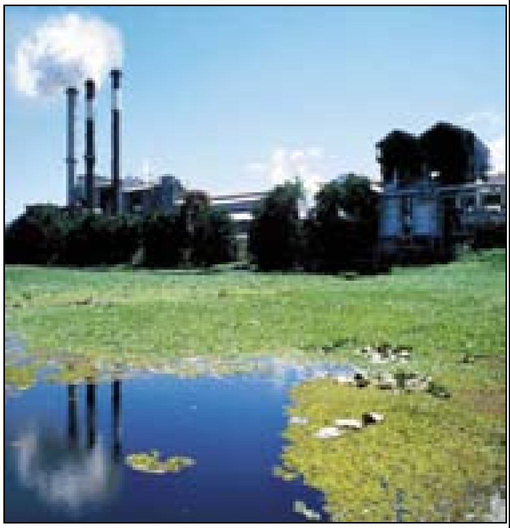
United States

- Number of contaminated sites: 450,000 - 500,000+
- Value of current market: $US 10 billion+ per year (1/3rd of global demand)
- Future potential: estimated at $650 billion over 30-35 years



Ref: Canadian Environment Industries (2005) Soil Remediation Technologies

Extent of contamination

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Western Europe

- Number of contaminated sites: 600,000+
- Value of current market: an estimated €50 billion, timeframe unspecified
- Future potential: 0.5-1.5% of GDP is likely to be spent per annum

Ref: Canadian Environment Industries (2005) Soil Remediation Technologies

The scale of the challenge - Australia

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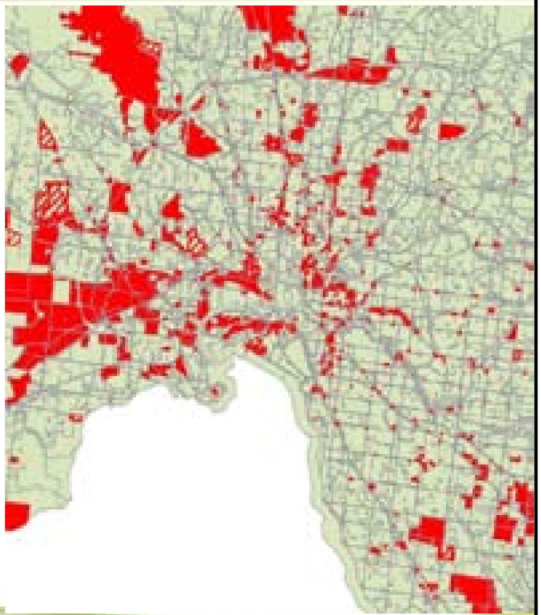
- *160,000 sites contaminated
- 60-80% within our cities, 30% government owned
- 75,000 toxic chemicals
- Complex mixtures
- Expenditure >$2 billion p.a.
- Need new solutions



*Ref: Canadian Environment Industries (2005) Soil Remediation Technologies

Health effects of contaminants: Arsenic

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What drives remediation in Australia?

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- Expanding urban population, hence expanding urban fringe
- Potential impacts to environmental and human health
- Intergenerational equity
- Highly informed citizens
- Societal perception
- Liability
- Legislation
- Sustainable environment

Approach to managing contamination

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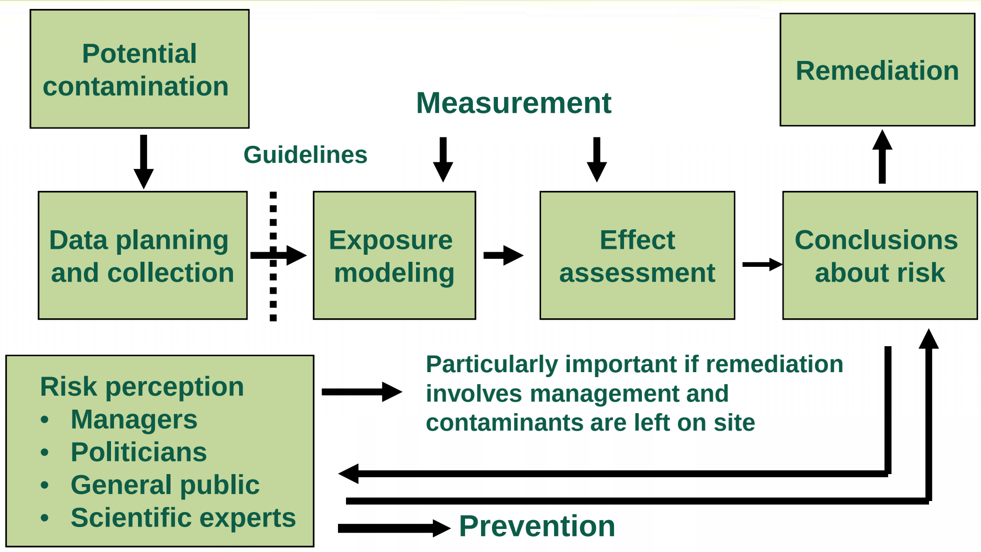
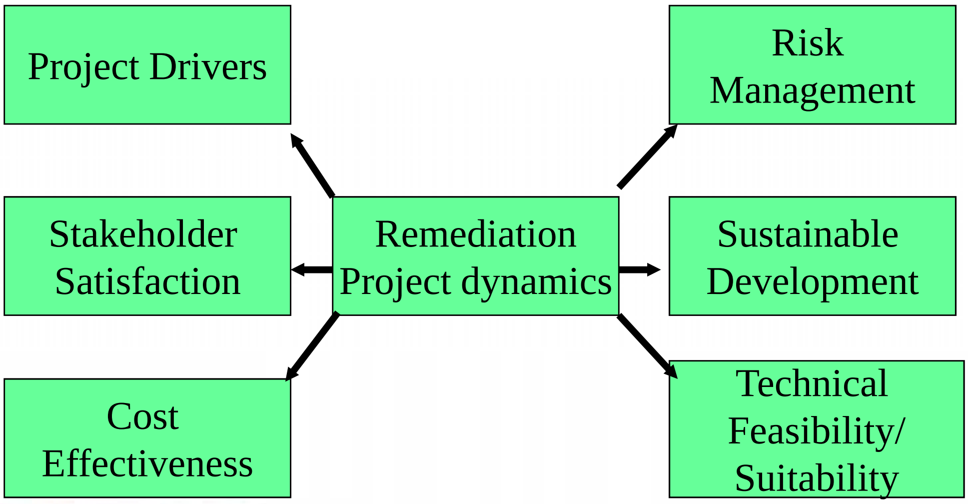


Selecting Remediation Technologies for Contaminated Sites



6 Key factors in decision making

Recent Advances in Site Remediation: I. Contaminated Soil

Soil remediation in Australia

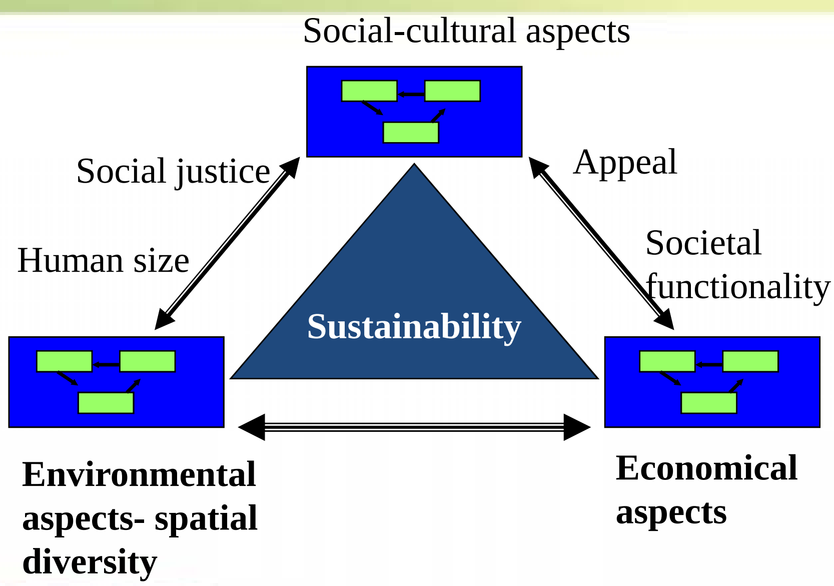
Technology	Type	Status
Landfill	Conventional / containment	Increased levy to discourage landfills
Solidification	Conventional	Still quite common
Dilution	Conventional	Now banned in Australia
Ex-situ soil washing	Conventional	Overly expensive
Ex-situ thermal	Emerging	Seen as suitable for highly re-calcitrants
Risk based	Conventional-emerging	Most preferred approach
Immobilization	Conventional to emerging	Technology on the rise
Bioremediation	Innovative	Green technology
Electro-kinetics	Innovative-emerging	Young technology- still not seen as attractive

Sustainable

Green

Sustainable Remediation Triangle

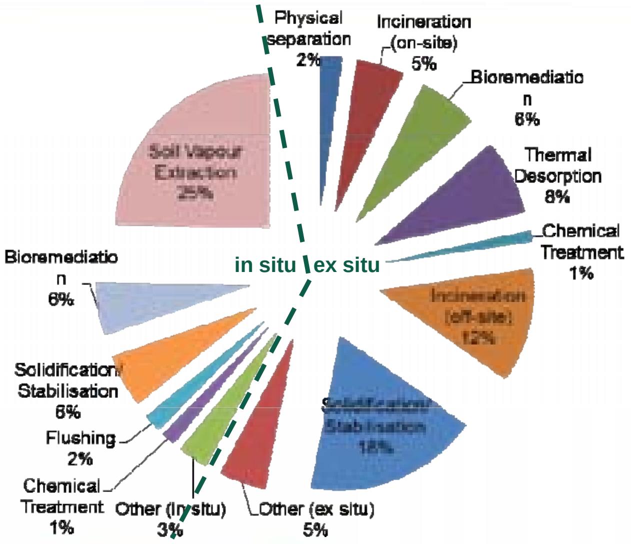
Clarinet, 2002



environmental decisions must be "socially-robust" and sustainable (Pollard et al. 2003)

Soil treatment technologies - relative use

CRCCARE



- Ex-situ methods (i.e. excavate and treat) more common than in-situ treatment
- Thermal methods most common
- Solidification / stabilisation next
- Separation and chemical treatment – very few

Superfund Remedial Actions: Source Control Treatment Projects (FY 1982-2002)

Source: US EPA, 2010

Current CRC CARE Research- soil remediation

CRCCARE

- Risk Based Approach to Managing Contaminated Sites
  - Fit for purpose
  - Minimising exposure and hence risk
    - Shooting range soils
- Electro-kinetics
- Bioremediation includes phyto
- Ultrasonic
- ISCO
- In situ thermal
- Nanoremediation

Current CRC CARE Research- soil remediation

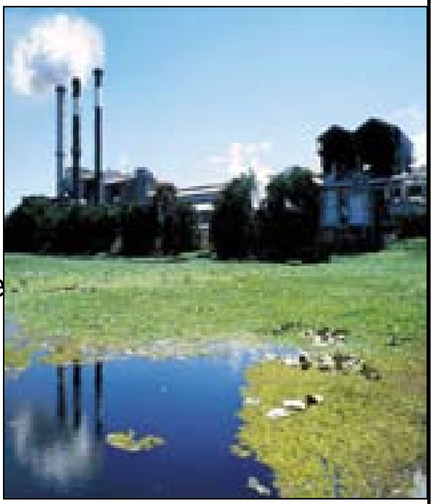
CRCCARE

- Risk Based Approach to Managing Contaminated Sites
  - Fit for purpose
  - Minimising exposure and hence risk
    - ✓Shooting range soils--
- ✓ Electrokinetics
- Bioremediation including phytoremediation
- ✓ Ultrasonic
- ISCO
- In situ thermal
- ✓ Nanoremediation
- ✓ Green remediation

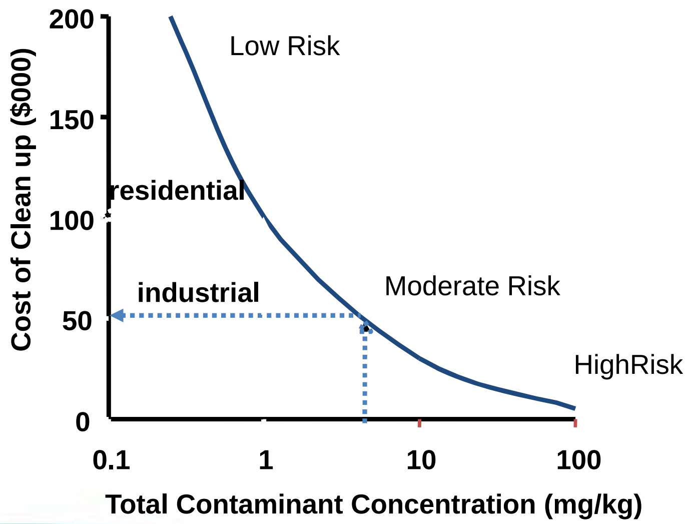
✓Soil remediation: Risk based approach

CRCCARE

- Fit for purpose approach to managing contamination
  - accepted in most countries
- Process includes:
  - Estimation of risks;
  - Mapping risk against different end use
  - Selecting end use where exposure is low- for example where risk is high – commercial or industrial activity may be more suitable than sensitive end use such as residential…



Can reduce cost by controlling land use



Risk based approach - recent advances

Fit for purpose- preferred method in 1990's

Current:

(a) minimise exposure via minimisation of the fraction of contaminant that poses risk;

(b) in place management of contaminated soil via immobilisation of contaminants which minimises bioavailable fraction and potential risk to receptors.

Scientific basis for risk based land management

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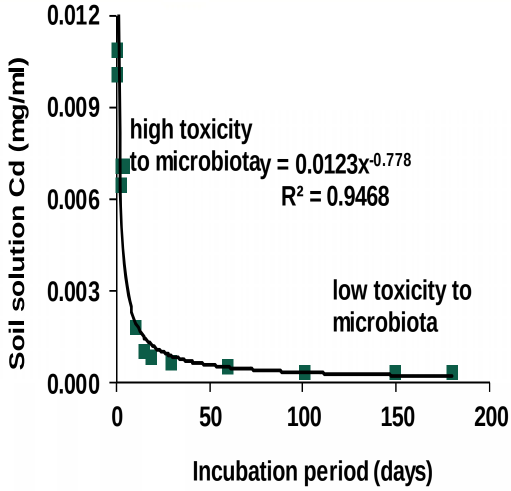
- Effect of aging
- Contaminant transformation
- Contaminant bioavailability and toxicity
- Community acceptance
- Ecosystem restoration factor
- Receptors and whether contaminants pose risk to these



Soil Remediation - Risk based approach

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Some case examples

- Shooting range soil remediation

- PFOS and PFOA remediation
- Subsurface As remediation

Shooting range soil remediation

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- Defence training sites for shooting
- Normal 200,000 rounds resulting in major contamination of the soils
- Total lead ranging from 7,000 to 35,000 mg/kg soil

Particulate Pb

Residue immobilised

Chemical immobilisation: In-situ remediation using phosphate

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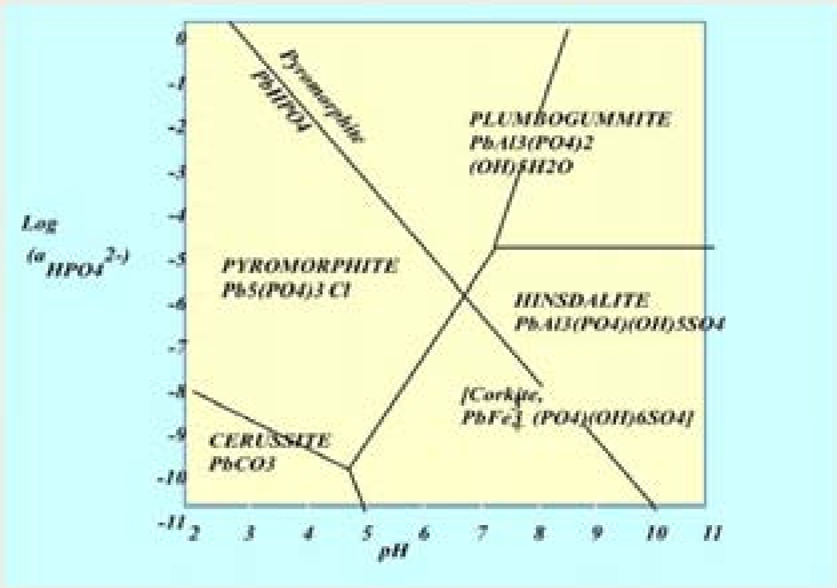
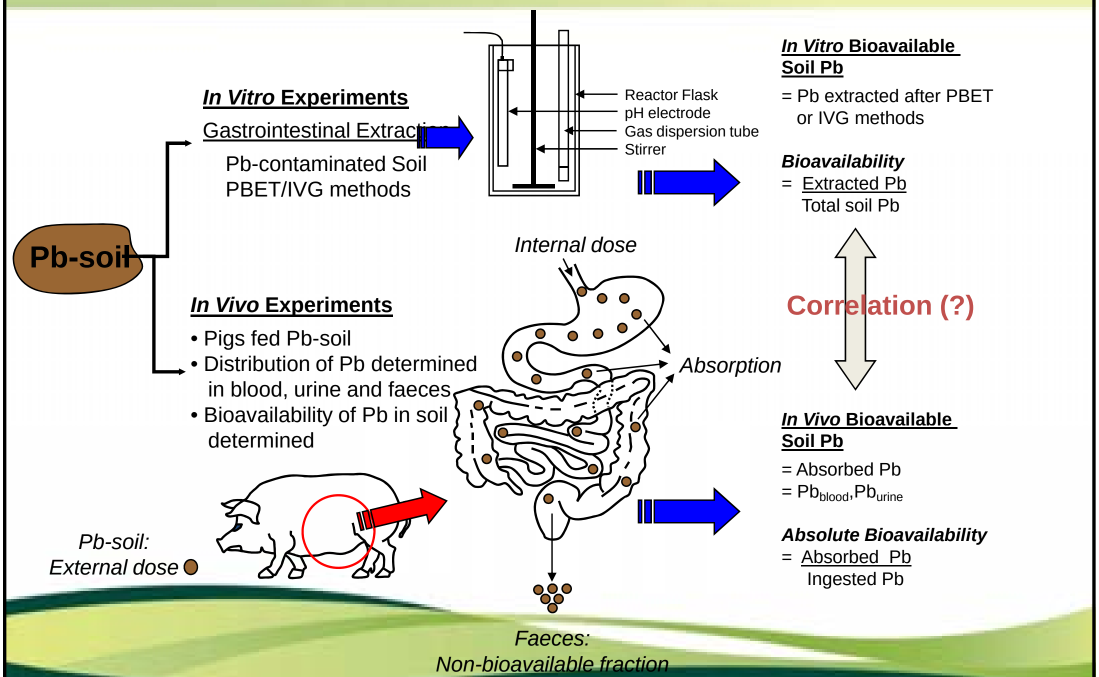
Solubility products (pKsp) of some Pb, Zn and Cd compounds

Mineral	Chemical formula	pK_{sp}
Tarbuttite	$Zn_2(PO_4)OH$	26.6
Hopeite	$Zn_3(PO_4)_2.4H_2O$	35.3
Cadmium phosphate	$Cd_3(PO_4)_3$	38.1
Fluoropyromorphite	$Pb_5(PO_4)_3F$	76.8
Hydroxypyromorphite	$Pb_5(PO_4)_3OH$	82.3
Plumbogummite	$PbAl_3(PO_4)_2(OH)_5.H_2O$	99.3
Corkite	$PbFe_3(PO_4)(OH)_6SO_4$	112.6

Stability phase diagram for Pb in the presence of phosphate and varying pH



In vitro and in vivo Pb Bioavailability



AFFF contaminated soils remediation

- Modified clays used in remediation of contaminated soils
- Inexpensive risk based approach

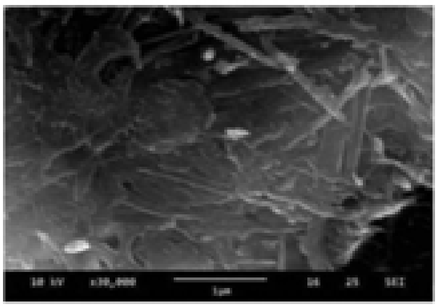
New materials developed → **$$$$$**

- ❑ **Efficient**
- ❑ **Durable**
- ❑ **Cheap raw materials**
- ❑ **Easy regeneration**
- ❑ **Value added product from natural materials**

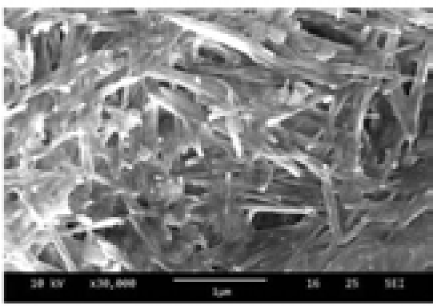
- ❑ **Clay/nano-material based remediation materials can effectively adsorb contaminants both in water and soil environments.**
- ❑ **Easy to develop catalysts.**
- ❑ **Potential to develop value added products from the natural clay resources.**

Material properties

Material	BET surface area (m²/g)	Cumulative pore volume (cm³/g)
Natural material	97	0.26
Modified material	24	0.18



Before modification



After modification

Sarkar, Naidu et al. 2011, *Appl Clay Sci,* 51 (3), 370-374.

AFFF contaminated soil remediation

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Field demonstration of AFFF contaminated soil remediation technology

Validation following remediation

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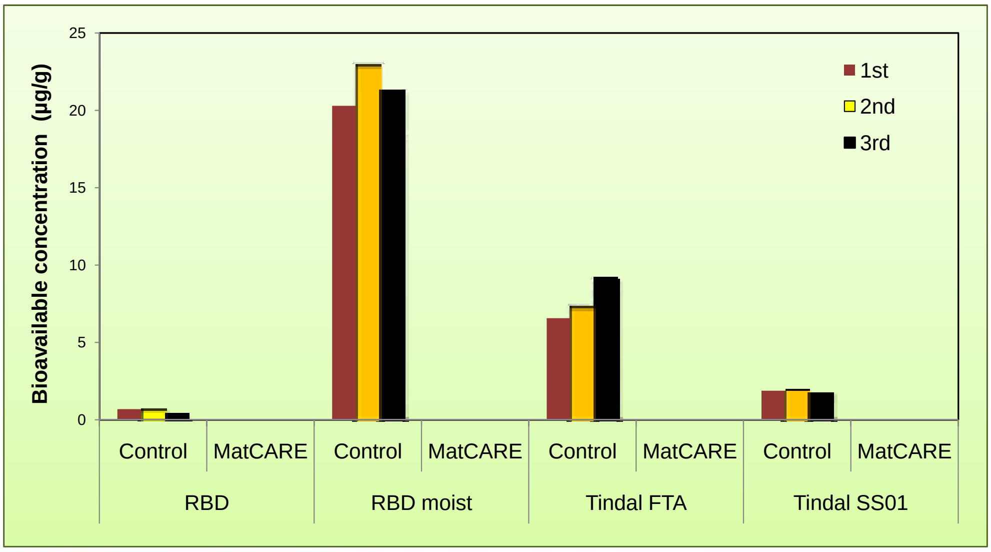

Soil Remediation: Electrokinetics

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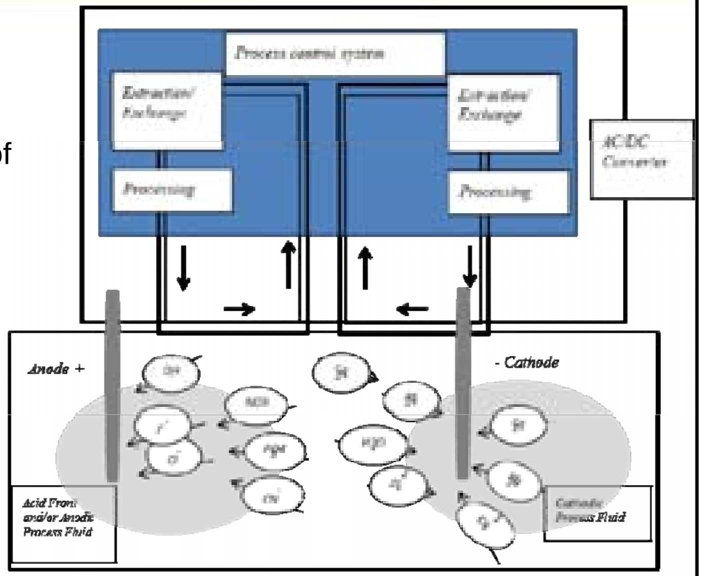
- An emerging technology
- Involves application of a low density direct current between electrodes placed in the soil to mobilise contaminants in the form of a charged species



Electrokinetic remediation

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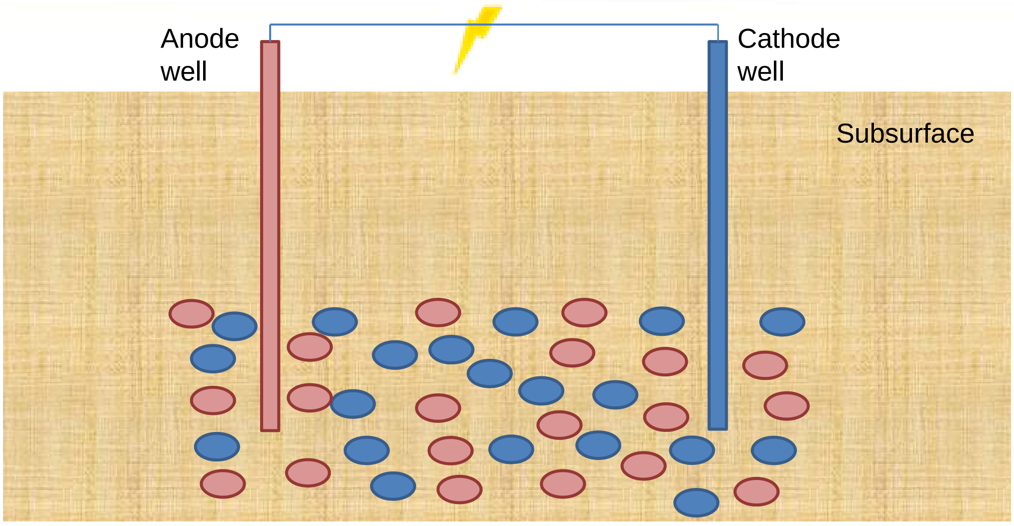
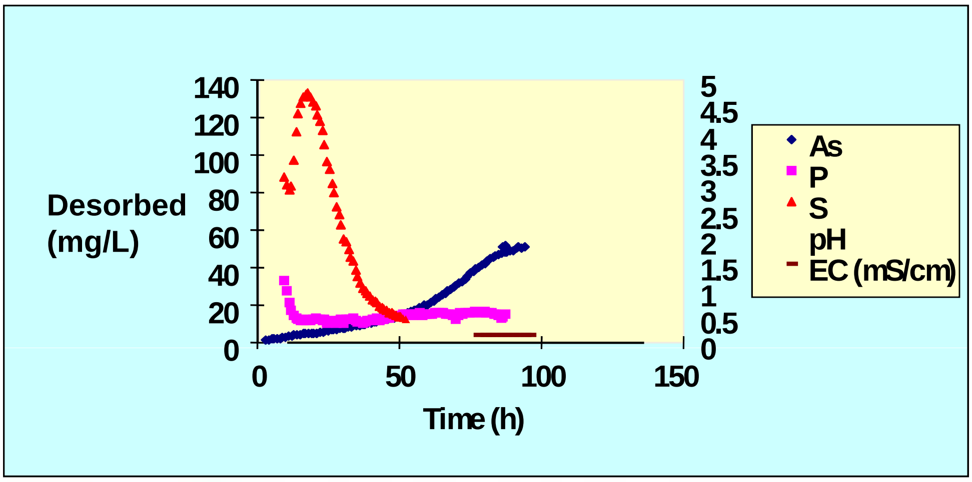
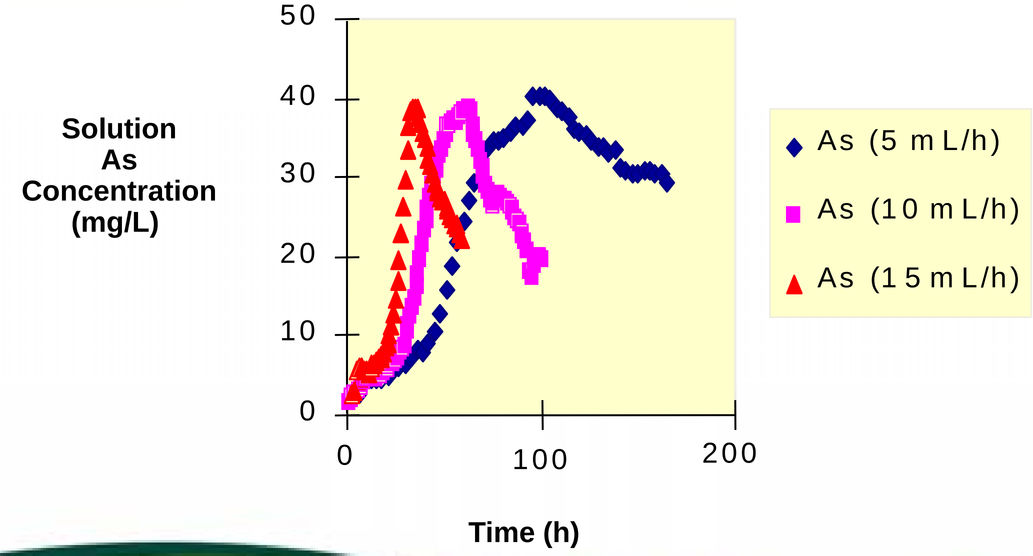


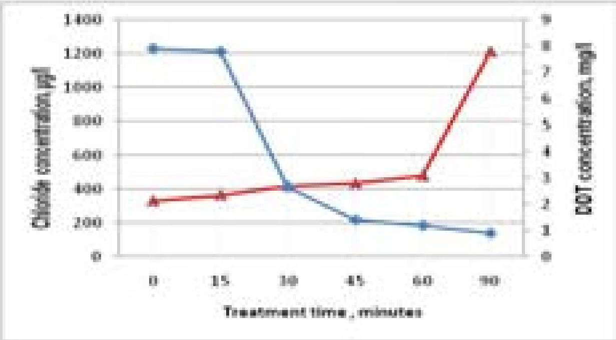
Electroremediation technology - (Naidu and E. Smith, unpublished)



Effect of flow rate on cumulative amount of As released



DDT Remediation using ultrasonic



(1.6MHz, 20 W) remediation of a 40 mL reactor with 8 mg/L of initial concentration of DDT in a zero percent slurry, (▲) Chloride and (♦) DDT respectively

90 % DDT removal in 90 min sonication, 150 W/L

Soil Remediation - Thermal

In Situ Thermal Remediation (ISTD)

- Steam-enhanced Extraction
- Electrical Resistance Heating
- Thermal Conduction Heating

Case examples include

- High temperature incineration of POPs-burns waste under controlled conditions

Technology is well accepted in Europe and USA but not so in many countries given the high energy intensive process

Soil Remediation - Thermal

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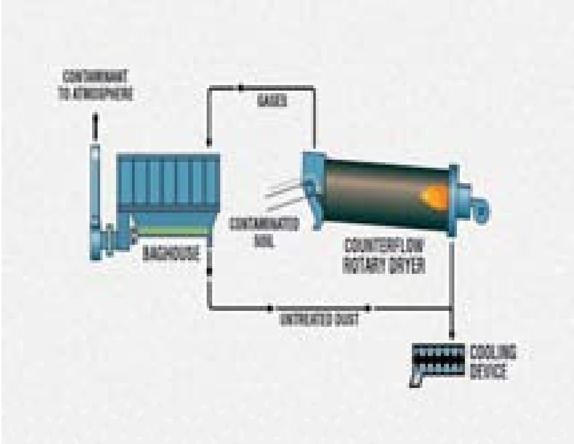
- Gasoline contaminated soils treated by drying and heating the soils to temperatures of 400-500°F.
- Heating drives off the contaminants by forcing them to evaporate, leaving the soils remediated
- **The gases discharged out of the exhaust**



Typical Asphalt Plant
Processing Contaminated Soil

Barriers to implementation of soil treatment technologies

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	Takes too long	Not understood by regulators	Costs too much	Policies prevent use	Not confident in technology
Excavation to landfill			X		
Monitored Natural Attenuation	X				
Soil Vapour Extraction	X		X		
Thermal Desorption			X		
Landfarming				X	
Biopiles	X		X		
Incineration			X		
Soil washing			X		
Bioventing	X				
Electrokinetics		X			X

Conclusion - Soil Remediation

- Excavation and transport to landfill still considered an easy option
- In situ remediation still a challenge
  - Technology;
  - Societal;
- Electrokinetics – a challenging new technology- still considered new;
- Thermal- seen to be an attractive technology;
- Mixtures; and
- Community acceptance of the remedial approach

Groundwater Remediation

Groundwater plumes

- What do they look like?
- Where are they going?
- What is the remediation target and risk drivers?

A typical service station

Source: LORAX/Shell, 2012

Groundwater plumes

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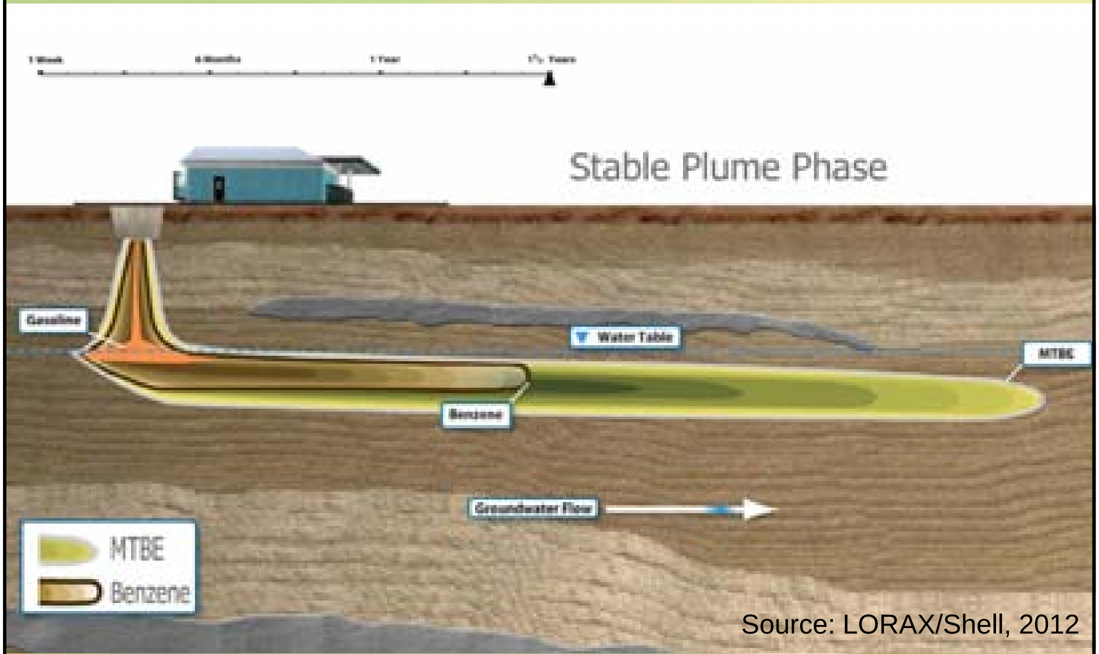

Source: LORAX/Shell, 2012

Fundamental Challenges - ground water remediation

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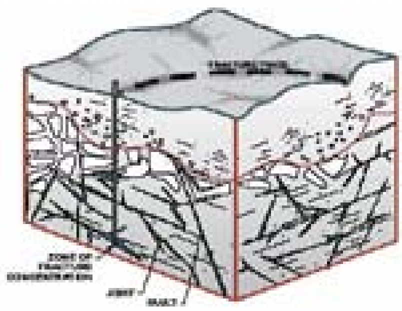
- Dynamic nature of ground water- helps distribute contaminants away from the source zone
- Subsurface vadose zone is extremely complex and heterogeneous,
- Fractured rocks- no single solution,
- In situ technologies irrespective of the type must deliver/distribute agents to where contaminants are.



Technologies for treating contaminants

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	Halogenated VOCs	Nonhalogenated VOCs	Halogenated SVOCs	Nonhalogenated SVOCs	Fuels	Metals and metalloids	Explosives
Air Sparging	G	G			G		
Bioremediation	S/G	S/G	S/G	S/G	S/G		S/G
Chemical Treatment	S/G	S/G	S/G	S/G	S/G	S/G	S/G
Electrokinetics	S/G	S/G	S/G	S/G		S/G	
Flushing	S/G	S/G	S/G	S/G	S/G	S/G	
In-Well Air Stripping	G	G					
Multi Phase Extraction	S/G	S/G	S/G	S/G	S/G		
Permeable Reactive Barrier	G	G	G	G	G	G	G
Phytoremediation	S/G	S/G	S/G	S/G	S/G	S/G	S/G
Pump and Treat	G	G	G	G	G	G	G
Thermal Treatment (in situ)	S/G	S/G	S/G	S/G	S/G		

S = Soils, sediments, and sludges
G = Groundwater, leachate, and surface water

Ref: USEPA, 2011

Groundwater remediation technologies

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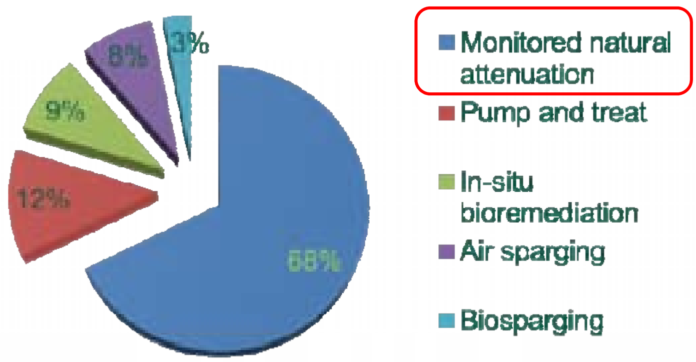

Typical groundwater remediation technologies in use for leaking underground storage tanks

Reference: Kostecki and Nascarella: *Survey of methods used for leaking underground storage tanks*, Con Soil Sed and Water, Jan/Feb 2003

Technology evolution

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Technology Progression		
Petroleum Hydrocarbons	**Conventional**	Landfill Pump and Treat Biopile/composting/landfarms/MNA Thermal desorption Bioslurry reactors Soil washing SVE Bioventing Bioslurping Air sparging/biosparging MNA
	Convention/ Innovative	Thermal ISCO Biobarriers
Chlorinated Hydrocarbons	**Emerging**	PRB Enhanced Anaerobic dechlorination Anaerobic bioventing In situ cometabolism
	Developing	Cometabolic air sparging Bioaugmentation Bioengineering

DNAPL/CVOCS

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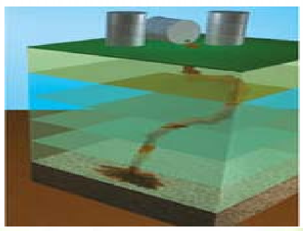
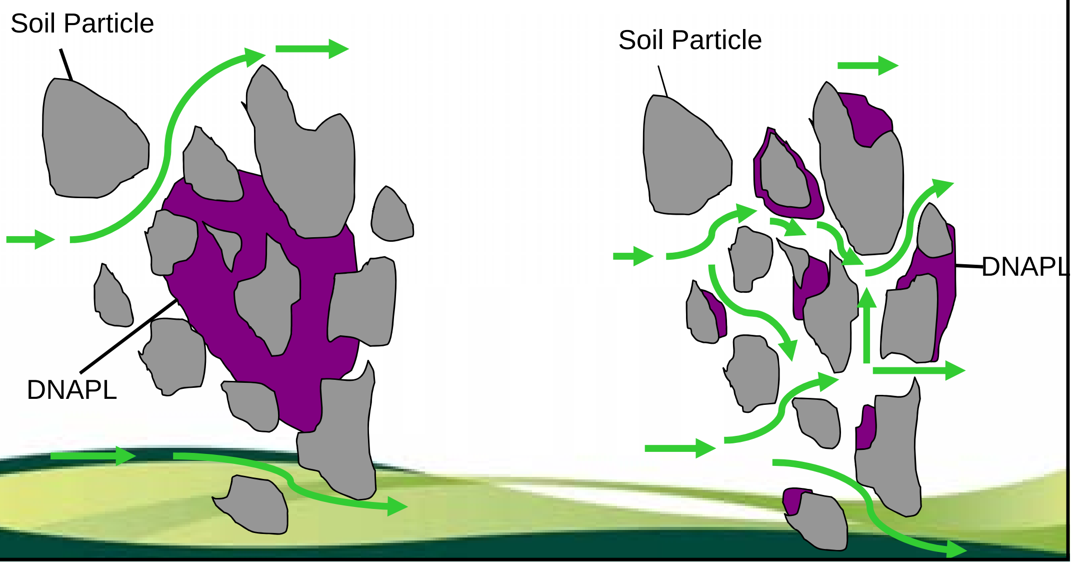
- More dense than water
- Low solubility/high volatility
- Varying lateral and vertical extent of contamination
- Hard to locate DNAPL pools and residues
- Fractured bedrock
- Costly to delineate source zones and plumes
- Costly to remediate
- Need innovative in situ solutions but must overcome in situ physics.



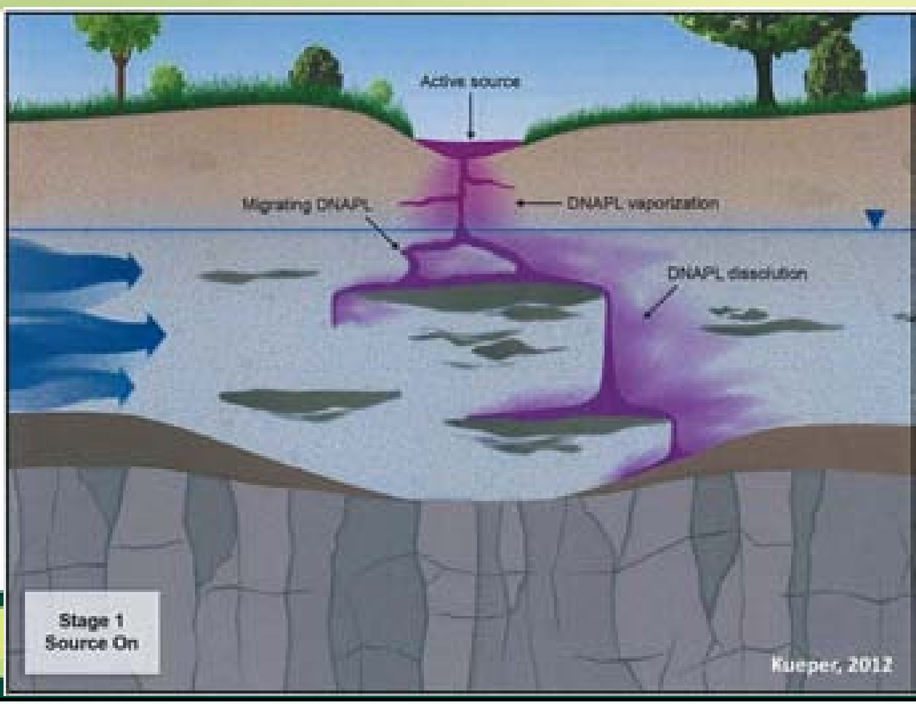
Finding / Treating DNAPL - A significant challenge

DNAPLs completely Filling in Pores

DNAPLs coating soil particles

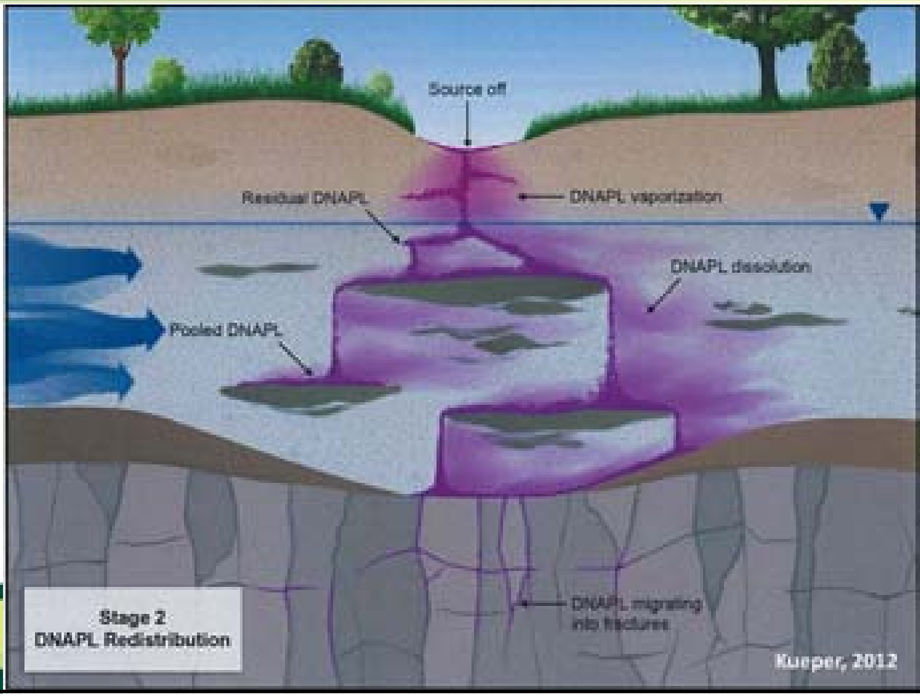


DNAPL behaviour in subsurface



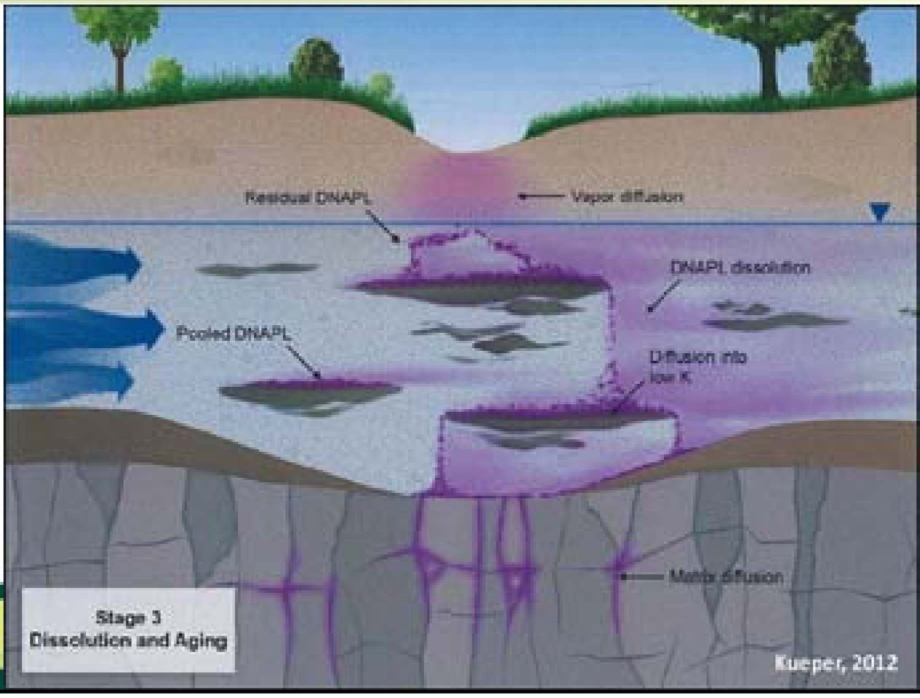
DNAPL behaviour in subsurface

CROCARE

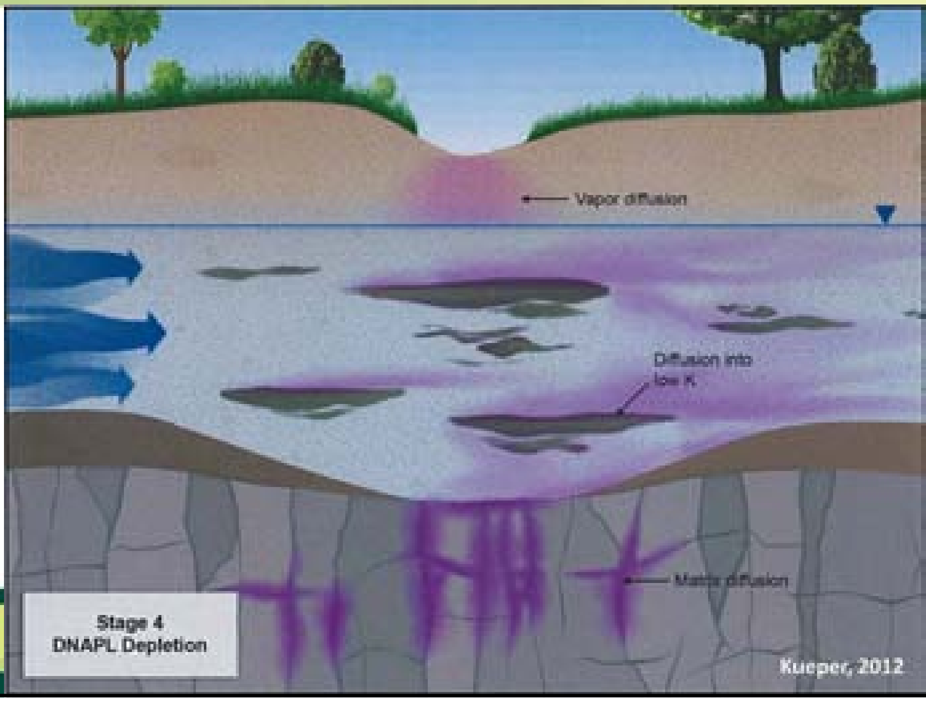


DNAPL behaviour in subsurface

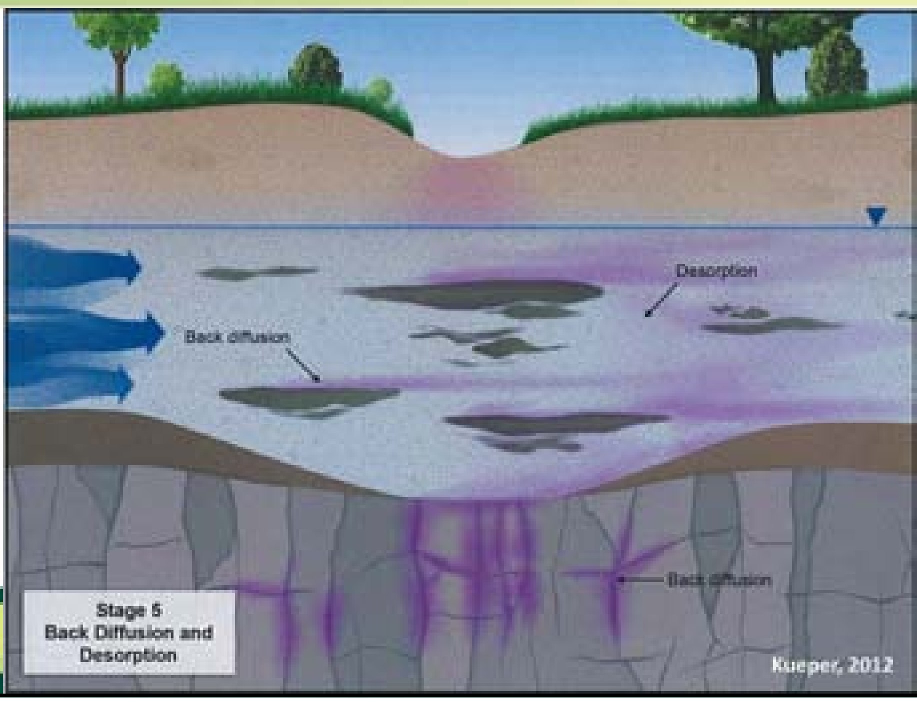
CROCARE



DNAPL behaviour in subsurface



DNAPL behaviour in subsurface



Challenges in NAPL remediation

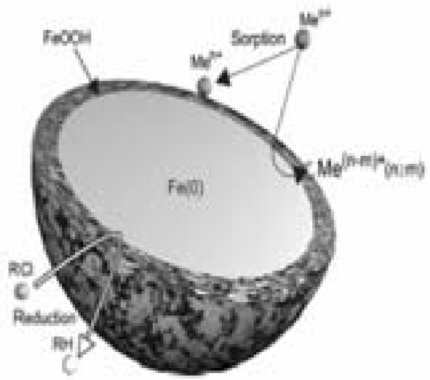
- Regulatory Framework
- Technical impracticability
- MNA
- HHRA
- Site characterisation
- Source removal vs Plume control
- Technology screening/selection

CRC CARE work

- Guidance documents on
  - NAPL behaviour in subsurface and fractured aquifers
  - Technical impracticability
  - NAPL remediation end points
  - NAPL remediation applications document
  - Predictive Model

Groundwater remediation technologies- recent advances

- PRB's--- traditional nZVI to other materials
- Biobarriers
- Bioremediation
- Surfactant enhanced in situ chemical oxidation (S-ISCO)
- Risk based
- Nano remediation technologies



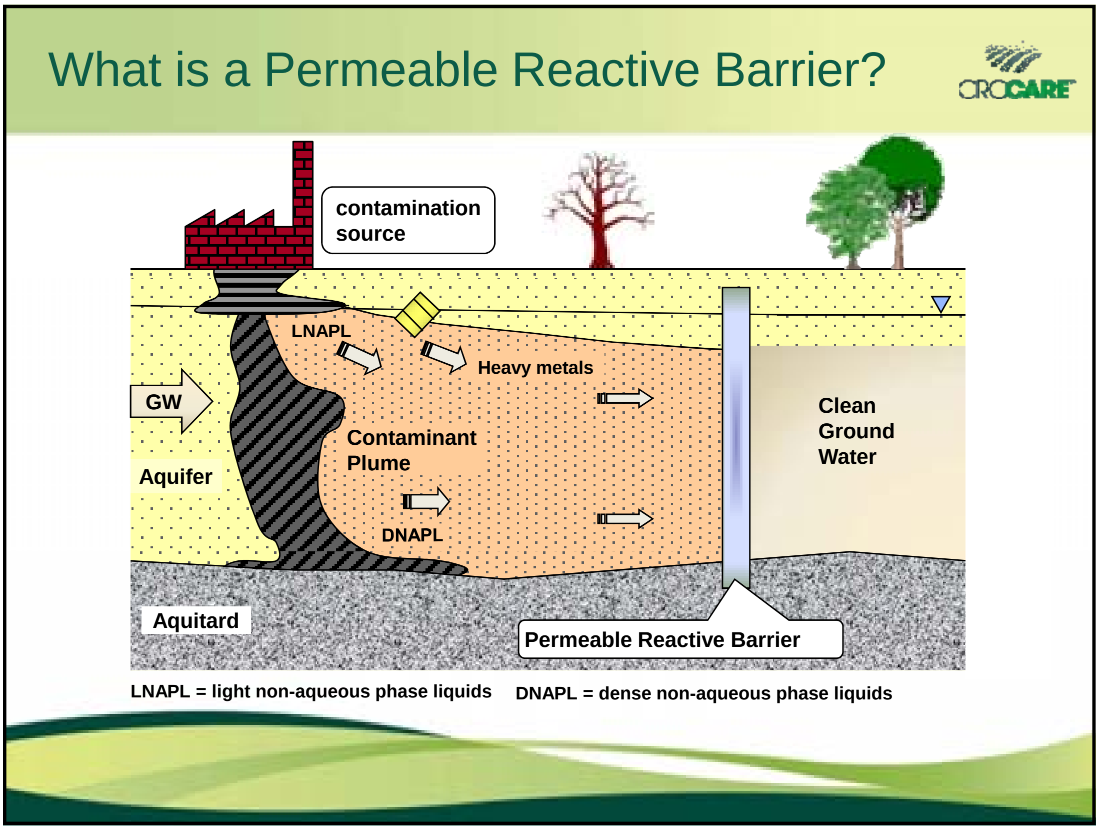
Current CRC CARE research

- Technology demonstration
- New model for Vapour intrusion
- LNAPL/DNAPL remediation
  - PRB- new material plus strategic research;
  - ENA;
  - Bioremediation;
  - Modelling end point;
- Flux based approach;
- Mixtures
  - DNAPL plus Cr(VI)…

Technologies evaluated at field scale

- Bioventing of diesel fuel in the vadose zone
- Biopiles and composting for hydrocarbon contaminated soil
- Air Sparging dissolved and non-aqueous phase liquid (NAPL) hydrocarbons in aquifers
- Phytoremediation for hydraulic control and bioremediation
- Monitored Natural Attenuation in groundwater and for hydrocarbon vapours in the vadose zone
- Multi-phase extraction of petroleum hydrocarbons
- Enhanced fracturing for NAPL recovery
- Bioclogging to hydraulically contain contaminants in groundwater
- Bioremediation and immobilisation strategies
- Permeable reactive barriers for contaminants in groundwater


Sparging
Fracturing
Multi Phase Extraction
NA – vapours
Phyto
NA – g/w
Biopiles
PRB
PRB - nutrients
Technology demonstration


What is a Permeable Reactive Barrier?
CRCCARE
contamination source
LNAPL
Heavy metals
GW
Contaminant Plume
Aquifer
DNAPL
Clean Ground Water
Aquitard
Permeable Reactive Barrier
LNAPL = light non-aqueous phase liquids
DNAPL = dense non-aqueous phase liquids

Criteria for selection of PRB Media

- High contaminant attenuation
- Fast reaction rates
- High hydraulic permeability
- Long-term stability
- Environmentally friendly/benign
- Sufficient availability in homogeneous quantity
- Cost-effectiveness

Treatment Mechanisms

- pH Control
- Chemical Precipitation
- Oxidation-Reduction Reactions
- Zero-Valent Metal Induced Dehalogenation
- Biological Degradation Reactions
- Sorption Reactions

Reactive Media Selection Guidance

CRCCARE

Treatment Material and Treatable Contaminants		
Treatment Material	**Target Contaminants**	**Status**
Zero-Valent Iron	Halocarbons, Reducible metals	In Practice
Reduced Metals	Halocarbons, Reducible Metals	Field Demonstration
Metals Couples	Halocarbons	Field Demonstration
Limestone	Metals, Acid Water	In Practice
Sorptive Agents	Metals, Organics	Field Demonstration, In Practice
Reducing Agents	Reducible Metals, Organics	Field Demonstration, In Practice
Biological Electron Acceptors	Petroleum Hydrocarbons	In Practice, Field Demo

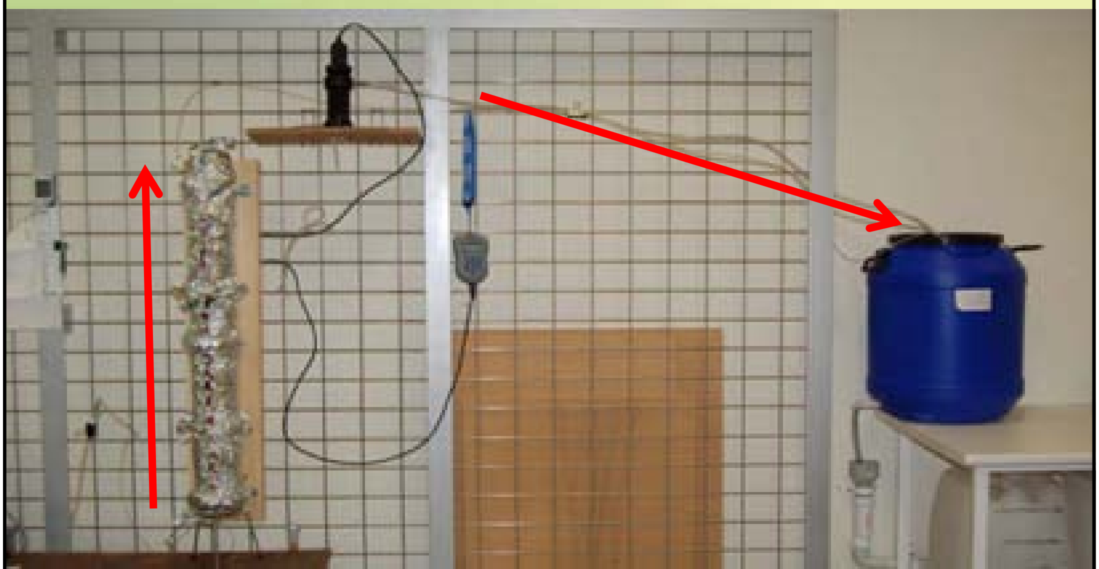
PRB - Case study

CRCCARE

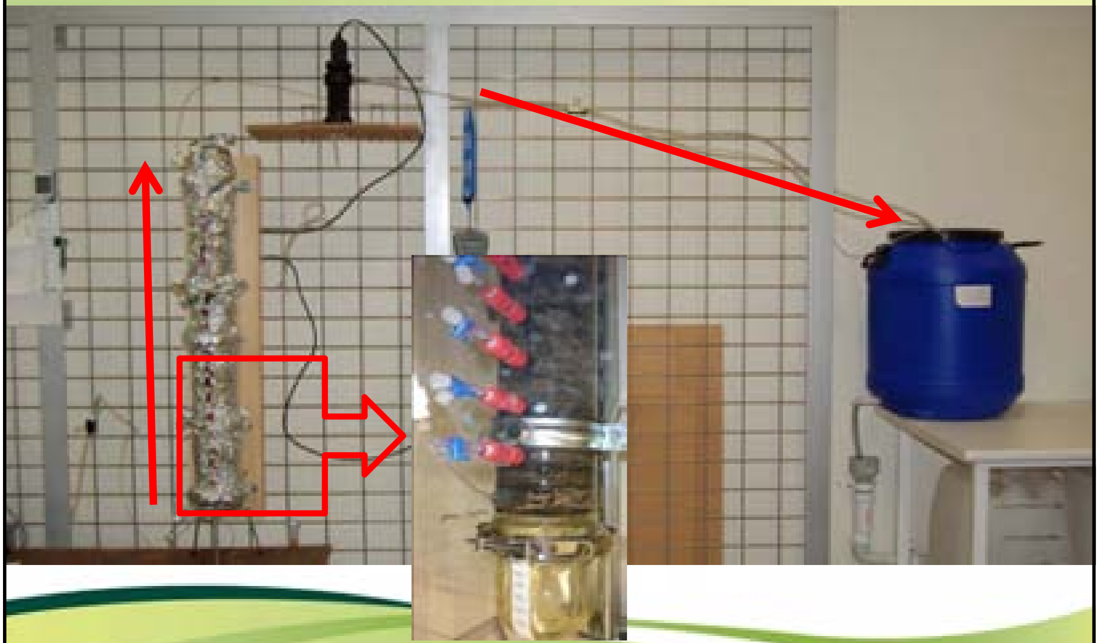
Parameter	Range
pH values for all wells	6.25 to 8.94
Electrical conductivity	0.985 to 9.38 mS/cm
Redox potential	-747 mV and 210 mV
Dissolved oxygen (DO)	1.4 to 8.55 μg/l
Cr(VI) concentrations	1 and 247 μg/l
Highest concentration of TCE	4161 μg/l

Short term treatability studies

Long term treatability study



Long term treatability study



Preliminary trial using ZVI

- Most commonly used material for PRB: ZVI;
- Treatability studies conducted in the laboratory using
  - synthetic water;
  - Ground water
- Column containing ZVI

- ZVI demonstrates excellent outcome with synthetic water;
- Efficiency drops to 20% with ground water

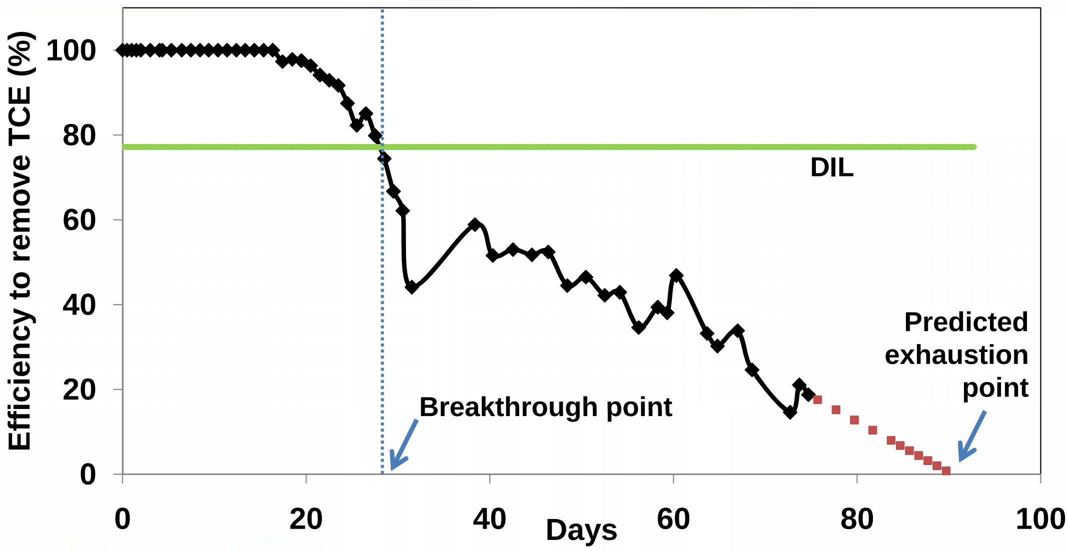
Failure attributed to the poisoning of ZVI surface

Treatability Study Parameters

	Area	Flow Rate*	Velocity*
	cm²	L/day	m/day
ReMat™	79	4.5	1.6
GAC	79	4.0	1.2

*Equivalent to maximum groundwater flow rate
VERY CONSERVATIVE

Short term treatability study: GAC



Treatment Capacity

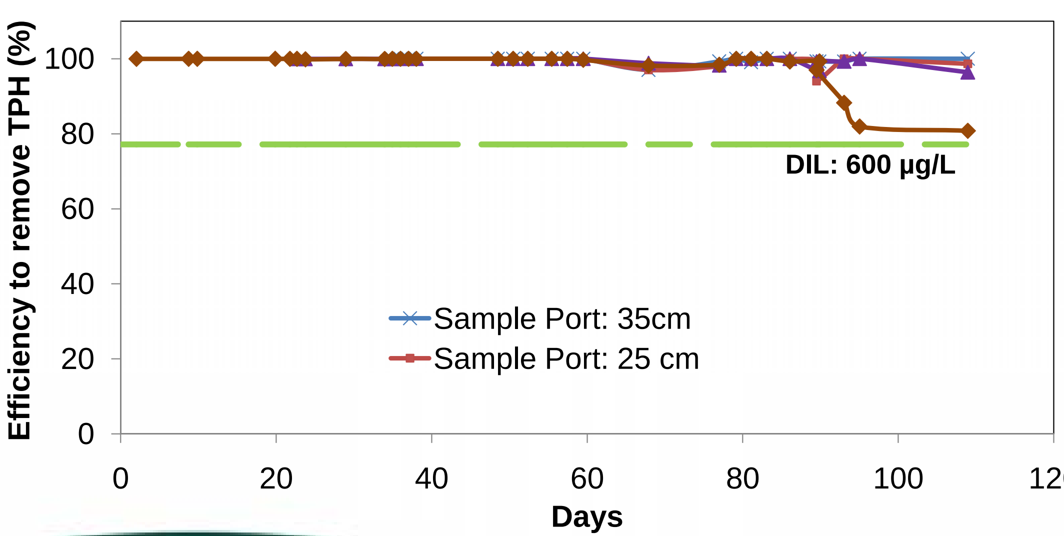
CRCCARE

	Total Volume of GW Treated (L)	TPH conc in GW (mg/L)	Total Mass of TPH (g)	Treatment Capacity* (g/L)
GAC	368	2.6	0.97	1.2
ReMat	436	2.6	1.14	1.5

*Treatment Capacity = Mass of hydrocarbon / Vol of Media (0.785 L)

Long term treatability study: ReMat

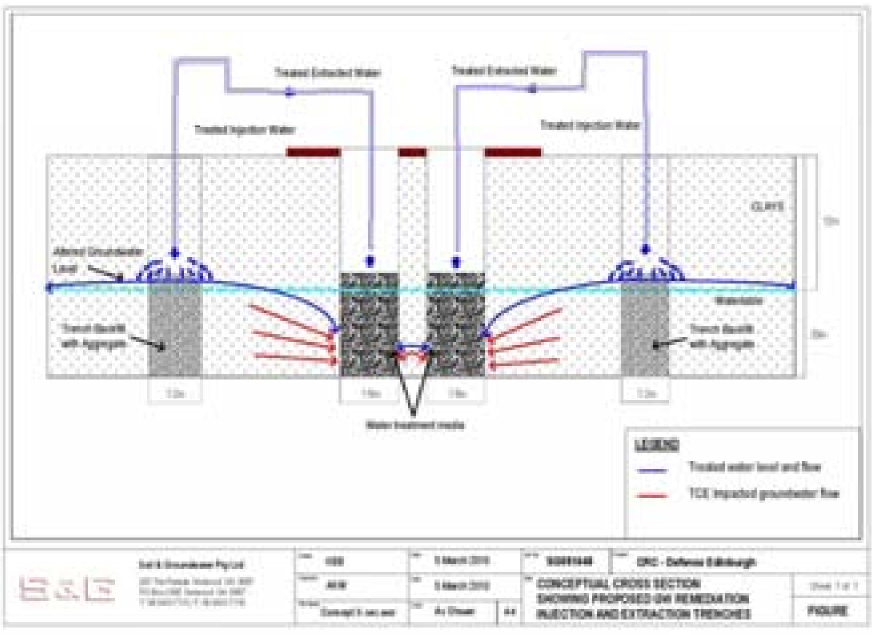
CRCCARE



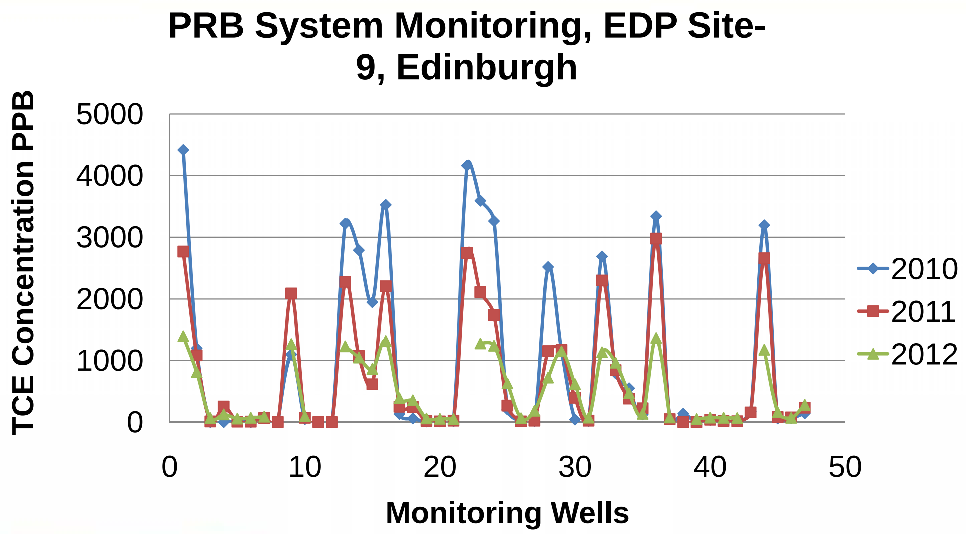
Long term treatability study: ReMat

- No breakthrough detected even after 109 days.
- Total treatment capacity of ReMat is in excess of 100 g/L, which is more than 67 times the initial treatment capacity (from short term treatability studies).

PRB Remediation System



TCE in groundwater post PRB



Surfactant enhanced *In-Situ* Chemical Oxidation (S-ISCO)

In situ technologies irrespective of the type must deliver/distribute agents to where contaminants are

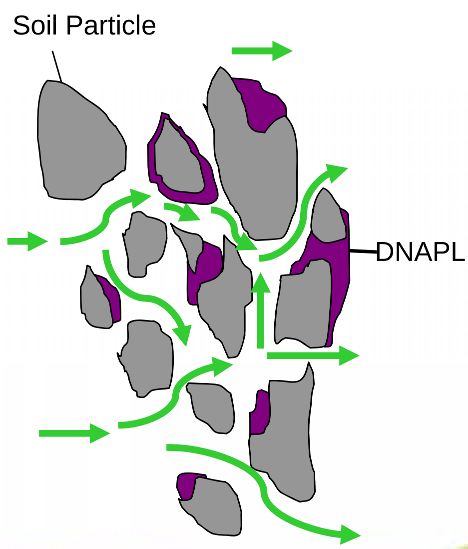


Image source: www.verutek.com

S-ISCO at Molecular Level

Surfactant enhanced *In-Situ* Chemical Oxidation (S-ISCO)

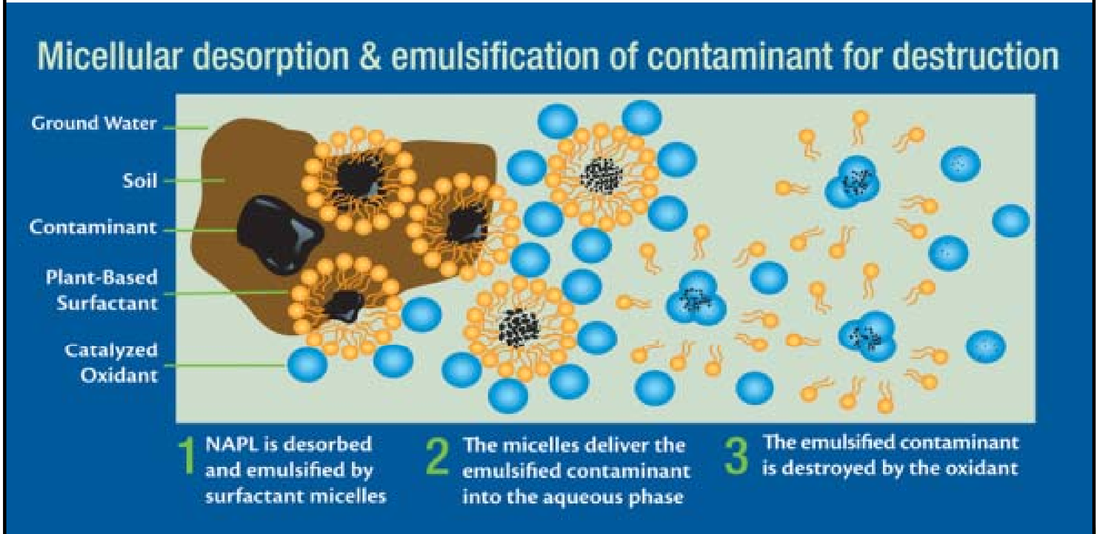


Image source: www.verutek.com

S-ISCO (Novel activator technology)

$S_2O_8^{2-}$ + activator → $2SO_4^{\bullet-}$ or ($SO_4^{\bullet-}$ + SO_4^{2-})   ($E°SO_4^{\bullet-}$ = 2.6V)

Novel activators

- Iron chelates (Fe-EDTA, Fe-EDDS, and other Fe-chelates)
- Green synthesised nano-scale iron
- Iron-TAML (tetra-amidomacrocyclic ligand)
- NaOH, H_2O_2, heat, UV light

S-ISCO Pilot Implementation

Injection solutions

- VeruSOL-3
- $Na_2S_2O_8$
- Alkaline

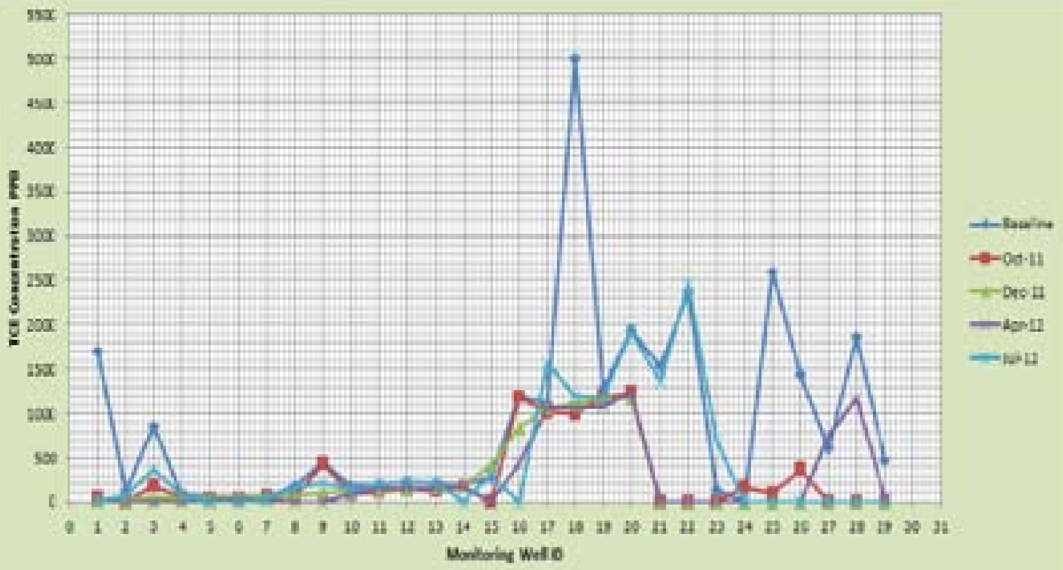
Pre & Post Injection Monitoring

23 wells, duplicate (46), blind and blank samples

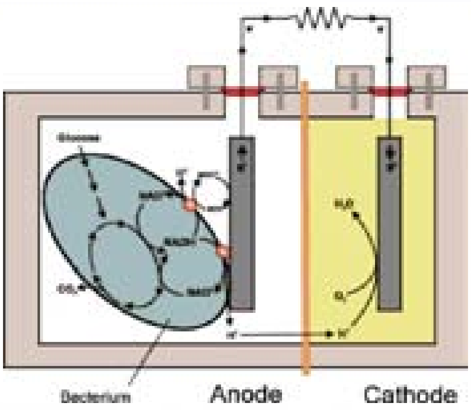
Daily monitoring

- Water quality parameters (pH, EC, ORP, DO, etc.)
- Interfacial Tension, $Na_2S_2O_8$
- TCE and daughter products
- Semi-Volatile organic compounds (SVOC)

Effect of S-ISCO on TCE



Microbial Fuel Cell



$C_6H_{12}O_6 + 6H_2O \rightarrow 6CO_2 + 24H^+ + 24e^-$

$6O_2 + 24H^+ + 24e^- \rightarrow 12H_2O$

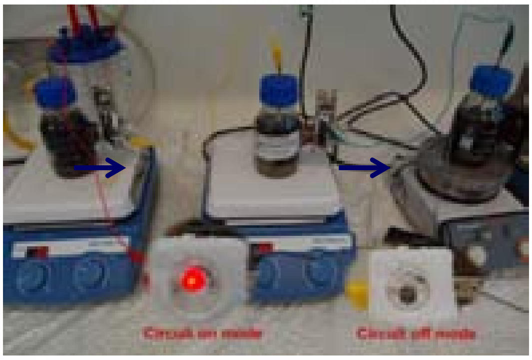
Highlights

CRCCARE

Lab-scale microbial fuel cell technology

Solution → **Opportunity**

Successfully **remediated petroleum hydrocarbon-** contaminated ground water with the removal of 93.5% of 8000 ppm (30days) with **simultaneous electricity generation**



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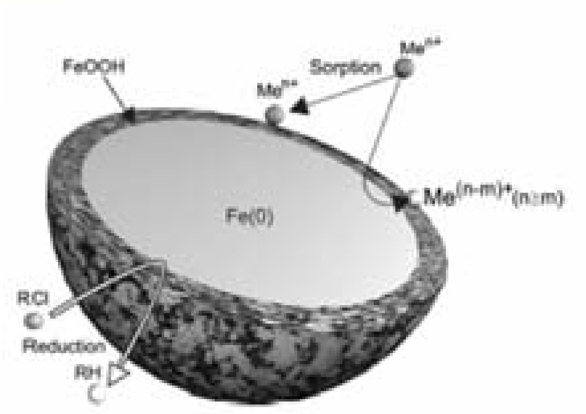
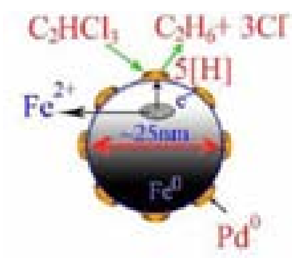
Nano remediation technologies

Some nanoparticles degrade contaminants



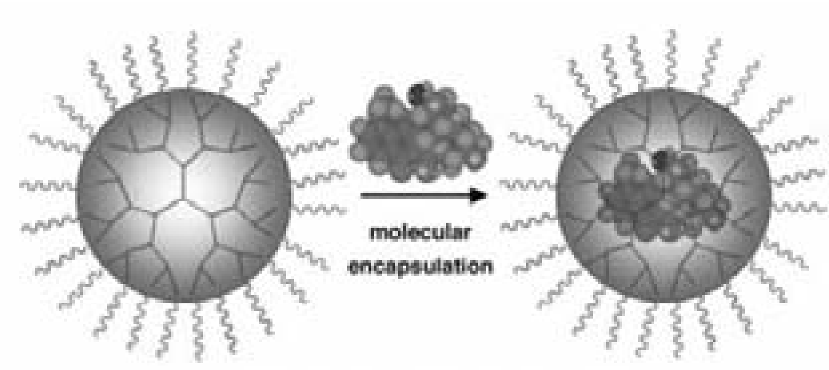


Zhang, J. Nanoparticle Res. 5, 323-332 (2003)

The core-shell model of zero-valent iron nanoparticles (nZVI).
The core consists of mainly metallic iron, whilst the shell consists mostly of iron oxides and hydroxides. Thus, iron nanoparticles exhibit characteristics of both iron oxides (e.g. as a sorbent) and metallic iron (e.g. as a reductant).

Theron et al. Critical Reviews in Microbiology. 34,43 – 69 (2008)

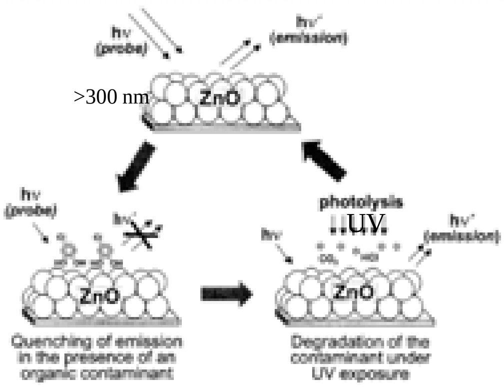
Some nanoparticles sequester them



Striba et al. Angwate. Chemie.Int. Ed., 41, 1329-1324, 2002

Some detect and destroy the pollutants

Dual role of ZnO semiconductor film as a sensor and photocatalyst



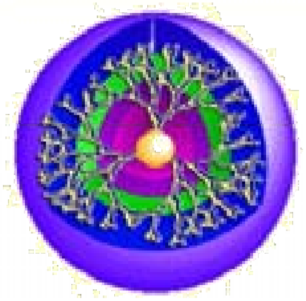
- Nanosized zinc oxide (ZnO) 'senses' organic pollutants indicated by change in visible emission signal.
- The ZnO 'shoots' the pollutants via photocatalytic oxidation to form more environmentally benign compounds.
- Sensing capability means that the energy-consuming oxidation stage only occurs when the pollutants present.
- Multifunctionality and 'smartness' is highly desirable for environmental applications.

Kamat, P.V, et al. J.Phys.Chem. B 2002, 106,788-794.

Common environmental contaminants that can be transformed by nanoscale iron particles

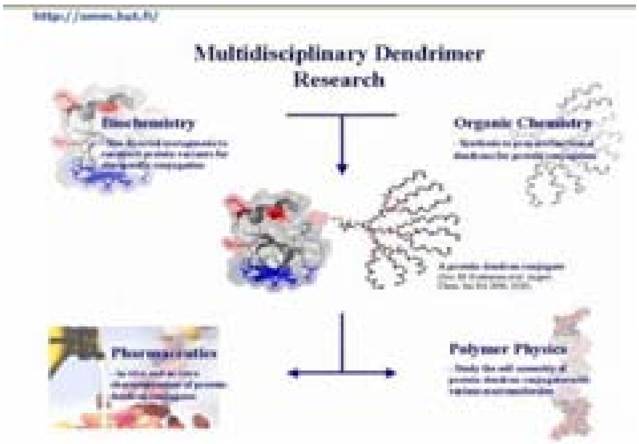
- Chlorinated methanes (CCl_4, $CHCl_3$, CH_2Cl_2, CH_3Cl)
- Trihalomethanes (CHBr3, $CHBr_2Cl$ etc)
- Chlorinated ethanes (C_2Cl_4, C_2HCl_3 etc)
- Chlorinated benzenes (C_6Cl6, C_6HCl_5, $C_6H_2Cl_4$ etc)
- Other polychlorinated hydrocarbons (PCBs, Dioxins etc)
- Pesticides (DDT, Lindane)
- Organic dyes (Orange II, Chrsoidine etc)
- Other organic contaminants (TNT etc)
- Heavy metal ions (Hg^{2+}, Ni^{2+}, Ag^{+}, Cd^{2+} etc)
- Inorganic anions (NO_3^-, AsO_4^{3-} etc)

Dendrimers

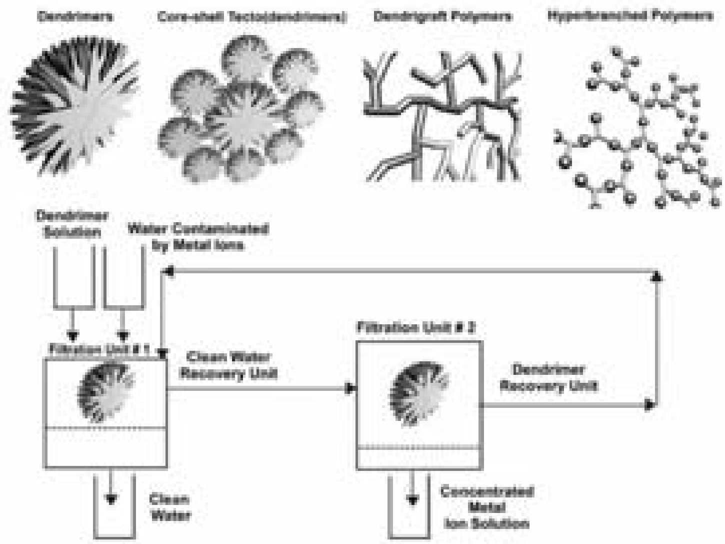


Dendrimers are a new class of polymeric materials. They are highly branched, monodisperse macromolecules.

DENDRIMERS: SYNTHESIS AND APPLICATION



Recovery of metal ions from aqueous solutions by dendrimer-enhanced filtration



Barriers to implementation

Barriers to implementation of groundwater treatment technologies

	Takes too long	Not understood by regulators	Costs too much	Policies prevent use	Not confident in technology
Dual phase extraction			X		
Monitored Natural Attenuation	X				
Pump and treat	X		X		
In-situ bioremediation	X				X
Air sparging			X		
Biosparging		X	X		

Reference: Kostecki and Nascarella: *Survey of methods used for leaking underground storage tanks*, Con Soil Sed and Water, Jan/Feb 2003

Conclusions

- Remediation technologies need to be demonstrated at field scale to bridge the gap between laboratory innovation and field application.
- Re-MAT more effective than GAC.
- It can be expensive to do field evaluations - but a DERT process offers the potential for substantial cost savings upon full application - industry savings are evident from application of outcomes of this research;
- Nano-remediation – great potential
- CRC CARE will be developing the DERT Program in 2012-2015 - collating these and other data and field evaluation studies

Key messages

- Site contamination continues to be a major issue, and will be for the next 100 years and beyond.
- Last 50 years have seen less than 1% of sites being remediated.
- Most innovative technologies were developed during the past 30 years.
- Advancement has been the extension of existing technologies.
- Nano remediation technologies look promising, but need a lot more effort including an assessment of its behaviour and fate in the environment.

CRC CARE Publications website

Technical reports

Fact sheets

available at:

www.crccare.com/publications/

Industry training

CleanUp 2013

5th International Contaminated Site Remediation Conference

15 – 19 September 2013, Melbourne

www.cleanupconference.com

Thank You

Questions?

Regulation, risk assessment and management as part of sustainable remediation

***Phil Crowcroft** and James Baldock,* (Environmental Resources Management, UK)

The remediation of contaminated land presents a range of challenges which have the potential to impact the overall cost of the works. The Regulatory Framework in which we operate has a fundamental effect on the degree to which risk assessment can influence the outcome of the works. Risk assessment itself is seen as a fundamental part of deciding what remediation is needed, but the risk assessment is only as good as the information it is based on. This paper describes the recent changes in approach to assessing land contamination in the UK. It goes on to consider the value of undertaking High Resolution Site Characterisation (HRSC) to deliver more sophisticated and accurate Conceptual Site Models, which in turn lead to more focussed and sustainable remediation solutions. Such solutions can generate large cost savings in remediation at relatively small additional costs for investigation and assessment. The process is illustrated by a case study, itself more detailed in Ref 1.

Changes in approach to regulation of land contamination in the UK

The UK has adopted a risk-based approach to land contamination and assessment for many years, but this approach has been tempered by a conservative approach to the risk assessment process. Typically, the key input parameters to risk assessments such as the toxicity of substances, or the duration of exposure of people to the substance have been set at the extreme conservative end of a range of possible values. This has led to delivery of very safe remediation schemes, but at a cost which has been potentially excessive and wasteful of resources. In the last year, a new approach has been developed in the UK, and there has been wide consultation with public and private sector about the changes. There has been some resistance to change, but the Government has driven through the changes, and these are now in place and operating.

The broad objectives of the contaminated land regulatory regime are:

- To identify and remove unacceptable risks to human health and the environment;
- To seek to ensure that contaminated land is made suitable for its current use;
- To ensure that the burdens faced by individuals, companies and society as a whole are proportionate, manageable and compatible with the principles of sustainable development;

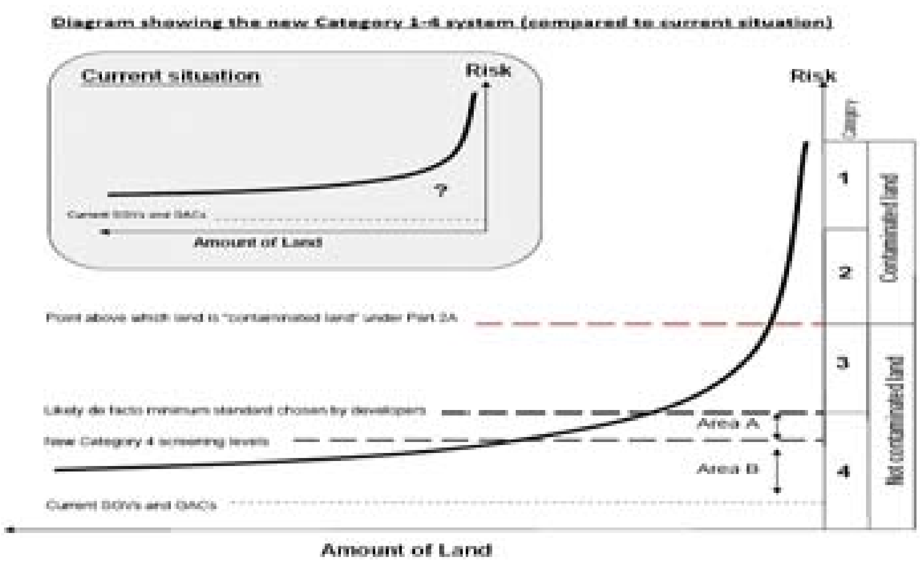
- The enforcing authority should take a precautionary approach to the risks raised by contamination, whilst avoiding a disproportionate approach given the circumstances of each case, in order to strike a reasonable balance between:
- Dealing with risks; and
- The potential impacts of regulatory intervention.

Government also encourages developers and landowners to deal with contamination as part of the redevelopment process, so that less land has to be dealt with by an enforcement process. Normal levels of contaminants in soil should not be considered to cause land to qualify as contaminated, unless there is a particular reason to consider otherwise. Examples of normal levels include:

- Natural – due to underlying geology / soil formation processes
- Anthropogenic - due to low level diffuse pollution

Determination as contaminated land can be made on one or more of four grounds:
- Significant harm is being caused (to human or non-human receptor)
- Significant possibility of significant harm (SPOSH)
- Significant pollution of controlled waters
- Significant possibility of significant pollution (of controlled waters)

In relation to SPOSH decisions, the risk assessment framework proposed in the SG is based on a four-category classification set out below:



Category 1 is definitely Contaminated Land, its sites where there is evidently contamination and receptors which create an unacceptable contaminant linkage (houses built on gasworks with in-situ tar wells, or serious pollution of an aquifer with a drinking water abstraction nearby, say).

Category 4 is definitely not Contaminated Land, its greenfield sites or brownfield sites with minimal levels of contaminants or industrial sites with contamination sealed below slabs over non-aquifers.

Categories 2 and 3 are the difficult area to define, and Detailed Quantitative Risk Assessment is used to determine whethere a site should be placed in Category 2 (contaminated land) or Category 3 (not contaminated land).

Local authorities may use Generic Assessment Criteria (GACs) and other technical tools to inform decisions provided:

- They understand how they were derived and how they can be used appropriately
- They have been produced in an objective, scientifically robust and expert manner by reputable organisations
- They are only used in accordance with the guidance regulatory guidance.

The Government is funding development of some further GACs which will define what is Category 4 (not contaminated land).

The enforcing authority may only require remediation action in a remediation notice if those actions are reasonable, having regard to:

- The practicability, effectiveness and durability of remediation;
- Health and environmental impacts of chosen remedial options;
- Financial cost likely to be involved;
- Benefits of remediation with regard to the seriousness of the harm or pollution in question.

In addition, Government is seting up a National Expert Panel – this will comprise an advisory group to help Local Authorities with decision-making using the revised Guidance, with a particular focus on sites near the Category 2/3 border.

The sites where the Expert Panel have made assessments and Local Authorities made decisions will be written up as case studies and disseminated to share best practice and ensure the revised Statutory Guidance is being applied in its intended way.

In conclusion, the UK has moved the approach to dealing with land contamination to concentrate more on only dealing with the sites which are really posing a problem. Marginal sites where risks are limited or more perceived than real will be assessed in detail if necessary, but remediation will be confined to only those sites where a very real risk to health or the environment can be shown.

High resolution site characterisation

The change in approach in the UK has thrown a focus on developing methods to understand the ground and the contaminant impacts in more detail. It has always been the case that the more detailed a site investigation in terms of number and spacing of boreholes, breadth of suite of laboratory testing and number of samples tested, the more likely we are to define the extent and nature of ground or groundwater contamination. However, conventional investigation techniques constrain our approach to data gathering and being able to understand what is happening in the ground. The main shortfalls are:

- Lack of sampling sophistication in conventional borings;
- Constraints in obtaining discrete water samples from precise depths;
- Time delays in obtaining test results;
- Challenges in understanding the behaviour of rock strata.

The Triad approach can been adopted to address these constraints, being based on the three principles of systematic planning, a dynamic work strategy and realtime data gathering. The approach is best demonstrated by reference to a recent project, where a conventional approach had led to a conventional solution at a very high cost, with little realistic prospect of close-out.

Case Study

Site Investigation and Risk Assessment

A programme of conventional intrusive investigation had identified the presence of soil and groundwater impact at an industrial facility from chlorinated solvents, and a remedial strategy based on pump and treat for a number of years was envisaged. This solution did not address a number of factors, not least that the investigation had failed to define the extent of the impact fully, and the proposed solution ignored many of the newer in-situ treatment solutions which can address pollution much more rapidly than pump and treat.

In preparation for site remediation and as part of a sustainability-led review of the site and remedial strategy, Environmental Resources Management (ERM) was retained to refine the existing conservative Conceptual Site Model (CSM) and define treatment zones. This Triad-style investigation comprised two phases of works using a combination of qualitative and real-time dynamic quantitative High Resolution Site Characterization (HRSC) techniques in near surface superficial alluvial deposits and underlying weathered and fractured shale bedrock.

The initial CSM theorized that the weathered shale would form a low permeability 'barrier' to vertical contaminant migration, however the results showed that contamination extended at least 5 m into the underlying bedrock and there was significant uncertainty as to the extent of the impact, corresponding mass distribution and the potential of this to act as a future source area.

The adoption of the HRSC approach was instrumental in refining and developing a rigorous CSM for the site and enabling the extent of sources zones, mass fluxes and risks to be evaluated. Subsequently the risks from the site were shown to be significantly reduced to those envisaged at the outset and the remedial strategy was revised from a long term containment and mass removal approach to one based on focused source reduction. The full scale remediation has been completed and comprised a combination of steam enhanced Dual Phase Vacuum Extraction (DPVE) for source zones and enhanced bioremediation for the plume.

The case study illustrates the benefit of the development of rigorous CSMs early in the life cycle of remediation projects in order that risks can be more clearly understood, the site characterization can be undertaken in a sustainable manner, and resources not be wasted through inefficient application of remediation technologies.

A programme of traditional site investigation (borehole drilling and installation of long screened monitoring wells (typically >5 m)) undertaken by others had previously determined that the site, an active manufacturing facility in the UK, was underlain by a geological sequence of fill (up to 2 m thickness), alluvial deposits (extending up to 5 m below ground level (bgl)) and fractured shale bedrock to an unproven depth. The lower margins of the alluvium and shale were thought to be in hydraulic continuity and be confined by the upper alluvial deposits, with the potentiometric head present at a depth of circa 1.5 m bgl.

Chemical analysis of soil samples collected during the site investigation identified the most significant impact to be from chlorinated solvents originating from the historical use and storage of trichloroethene (TCE). Impact to groundwater determined by collection of samples from the monitoring wells showed the main contaminants of concern to be the degradation compounds of TCE, namely cis 1,2 dichloroethene (cis 1,2-DCE) and vinyl chloride (VC), each at concentrations of up to 20 mg/l.

The initial CSM developed using the information previously obtained had postulated that impact would be mainly restricted to the alluvial deposits, given that the upper surface of the shale was known to be weathered and would therefore be expected to be limited in permeability, inhibiting downward migration of chlorinated solvents.

In order to develop the CSM and determine the need or otherwise for remediation, additional site investigation was proposed and undertaken using HRSC techniques to acquire collaborative data sets. This was to improve understanding of subsurface contaminant distribution such that whatever the remediation technique chosen resource efficiency would be optimised through targeted design.

The Sustainable Remediation Forum UK (SuRF UK) framework incorporates a two stage approach to apply to sustainable remediation decision making, either at the land use planning design stage and/or the remediation implementation phase (see Figure 1). A similar life cycle approach has been adopted for this project where sustainability has been an integral consideration from the initial review of the preliminary remedial strategy through to implementation of the site investigation and this paper examines the role of the HRSC within this context.

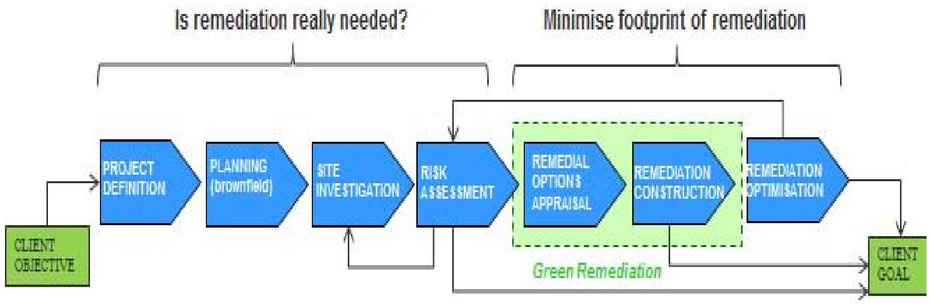


FIGURE 1. ERM's integrated sustainable site investigation and remediation.

The initial phase of works comprised assessment of the alluvial deposits using Gore Sorbers™ at 155 locations to carry out a passive soil gas survey to delineate contaminant source zones. Based on these findings and data collected during previous works, a groundwater assessment programme was then undertaken mainly within the lower alluvial deposits, but also into the weathered profile of the shale. This was completed using a Geoprobe™ to advance two Modified Waterloo Profilers (MWP) enabling collection of over 100 discrete interval groundwater samples (see Figure 2). These were analysed on-site for field geochemical parameters using handheld probes and Volatile Organic Compounds (VOCs) using a GC/MS.

FIGURE 2. Modified Waterloo Profiler Investigation, showing Geoprobe™ and field sampling equipment.

The second stage of the works comprised detailed assessment of the shale bedrock via the Core Discrete Fracture Network (DFN) approach and included collection of cores for geological logging, field screening (with a photoionisation detector) and on-site pore water extraction using Microwave Assisted Extraction (MAE) to obtain circa 450 crushed rock samples for on-site VOC analysis using a GC/MS; a process that takes only 45 minutes to complete extraction (compared to circa 5 weeks if this analysis was undertaken via traditional methods).

The use of the MAE equipment enabled the investigation to be completed using a dynamic Triad style approach and provided near real-time on-site analyses of bedrock matrix contamination data that was used to progressively refine the investigation scope. This approach also allowed accurate mass quantification in the shale to be determined, as it is known that a majority of contaminant mass in bedrock is typically present within low permeability rock matrix, rather than in the fractures.

In additional to the broad sustainability led context of these works, the opportunity was also undertaken to record the actual environmental footprint of the investigations. The metrics recorded during the HRSC works were travel to and from site, energy use, materials used, waste generation and disposal route, water use and details of wastewater production & disposal.

Results and discussion

The results of the HRSC study provided a refined and detailed CSM showing that, contrary to expectations, the contaminant plume is migrating laterally through the weathered shale profile and in this case the deeper, fresher fractured shale bedrock provides a 'barrier' to significant vertical contaminant migration. Geological logging noted that structures in the weathered-fresh transition are often recorded as being infilled with clays, which may be the cause for the contaminant distribution observed (see Figure 3). The depth of the shale was also ascertained as being circa 17 m bgl, which had not previously been determined.

The results indicated the presence of two TCE source zones (one originating via migration through the underlying aquifer, the other caused by preferential flow through drainage runs).

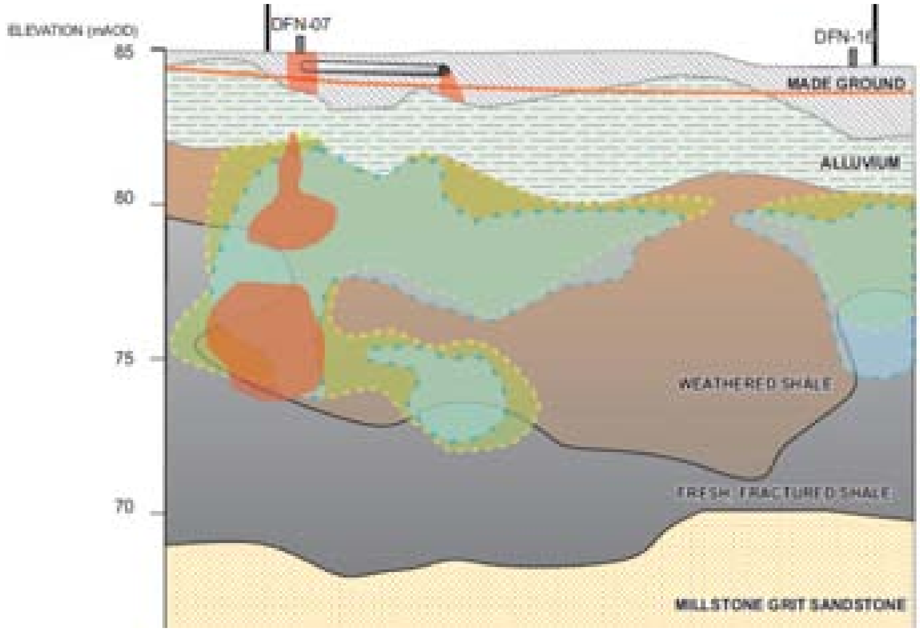


FIGURE 3. Geological cross section (scale: approximately 100 m from left to right). Of particular note is the correlation between presence of solvents within the matrix of the weathered shale and absence of solvents within the fresh fractured shale. The primary TCE source zone is shown near to investigation location DFN-07.

The results of the chemical analysis indicate that significantly greater contaminant concentrations are present within pore water samples (up to 1,620 mg/l (sum of cis 1,2-DCE and VC), than the dissolved phase concentrations detected in samples collected from monitoring wells had initially shown (up to 40 mg/l total VOCs), reflecting a typical mass distribution for fractured rock with the greatest concentrations present within the rock matrix.

The data collected also showed that the TCE migrated vertically and extensive dechlorination has occurred, possibly initiated by the reducing conditions caused by presence of localised peat lenses and petroleum hydrocarbons (toluene, ethylbenzene and xylenes) within the source areas. The resultant cis 1,2-DCE and VC plumes, which are broadly spatially coincident, have also been accurately mapped as the compounds attenuate downgradient through the shale. A significant decline in contaminant concentration in pore water and groundwater was observed within 20 m of primary source area.

From a technical perspective the use of the HRSC significantly enhanced the understanding of the site beyond that which was apparent from the conventional site investigation. The subsequent understanding of site geology, contaminant distribution and chemistry provided a sound, technically robust and defensible platform from which to refine the risk assessment and define remedial objectives and is considered a key element of the sustainability led approach shown in Figure 1 above.

Whilst HRSC has previously been successfully used to reduce time and project life cycle costs at other brownfield sites, an additional metric evaluated here was the environmental footprint of the programme. It is estimated that had the investigation been undertaken using conventional techniques to obtain a similar level of site characterisation detail, then this would have resulted in a carbon footprint of 33 tonnes CO_2e. This significantly exceeds the actual total emitted of 22.7 tonnes CO_2e. A majority of the resources used for the HRSC works were related to travel (45%), with accommodation (32%) and energy use (18%) the remaining significant contributors.

Additional benefits of undertaking the work using the HRSC approach at this site are:

- The VOC impact was delineated in a more systematic manner than would otherwise have been possible, with the number of intrusive locations decreasing with each step of the investigation. This decreased investigation time and hence overall project life cycle costs by optimising sample collection locations and reducing drilling meterage.
- Because the investigation was completed without the need for multiple phases of investigation that are typically associated with conventional approaches, the health & safety risks were lowered by spending less time on-site.
- The detailed CSM obtained from the work provided confidence to all stakeholders that the site conditions are fully understood via the technical defensibility of the data collected. This includes a more detailed understanding of the bulk attenuation factors than would typically be available using conventional site investigation approaches.
- The results provided a significantly less conservative but more realistic assessment of contaminant attenuation than typical half-life values obtained from literature would provide, with the HRSC dataset providing sufficient regulatory confidence that application of a site specific bulk attenuation rate was justified. This will ultimately reduce the remedial treatment area realising additional cost, time and sustainability benefits.

Given that chlorinated solvent distribution and mass has been clearly defined on the basis of a micro-scale understanding of the geological, hydrogeological and geochemical conditions beneath the site, remediation efforts are more focused using appropriate technologies to meet the remedial objectives, with the approach being to use a short-term relatively energy intensive technology in the source zones (thermally enhanced DPVE) in combination with a more passive approach in the remaining solvent impacted areas (biological substrate injection).

Remediation

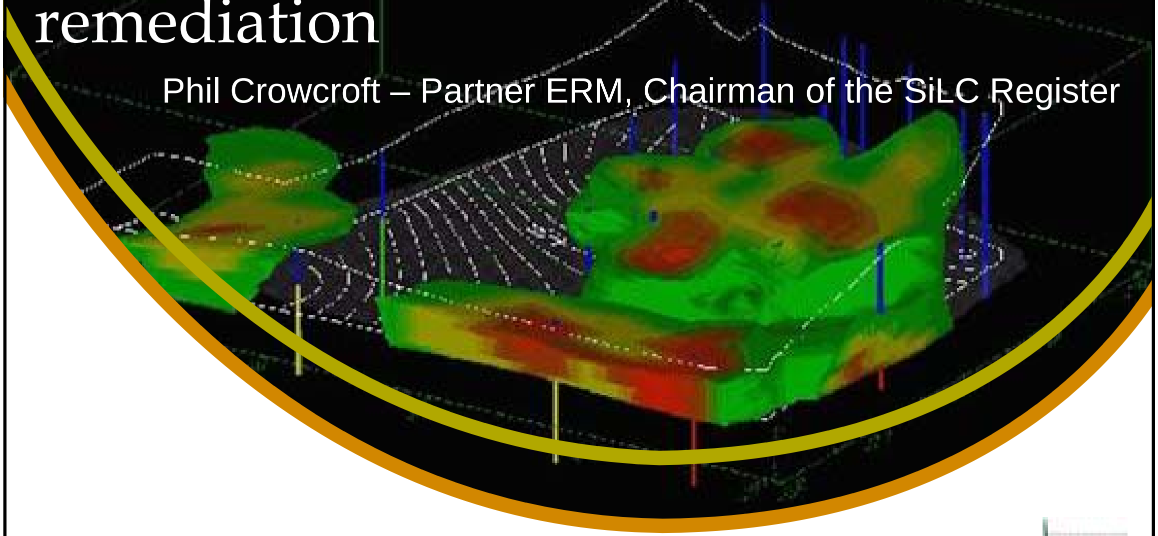
The approach to remediation using steam enhanced dual phase vacuum extraction, supported by subsequent injection of biological substrate was costed and delivered by ERM for approximately £2.5 million, compared to the quoted cost for pump and treat and long-term monitoring of £10 million. The whole approach to the work was focussed on obtaining high quality data which would cut out the wasted effort of treating ground which didn't need treating.

REFERENCES

1. Integrated use of a combination of high-resolution techniques to characterize a site impacted by Volatile Organic Compounds to develop a sustainability-led remedial strategy. Baldock, Sexton, Leahy, Thomas and Tillotson (Environmental Resources Management, UK) and Pitkin and Rossi (Stone Environmental Inc., USA)

Regulation, risk assessment and management as part of sustainable remediation

Phil Crowcroft – Partner ERM, Chairman of the SiLC Register



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Introduction

- Sustainable practice in dealing with land contamination
  - Starts with regulatory requirements
  - Site investigation is the basic tool for understanding what is there
  - Risk assessment is the tool used to define what is needed
  - Remediation then targets the problem
  - And we finish with regulatory sign-off
- This paper considers:
  - Changes in the UK approach to remediation of land contamination
  - The value of High Resolution Site Characterisation (HRSC)
  - How remediation solutions can be made more sustainable
  - A detailed case study

2

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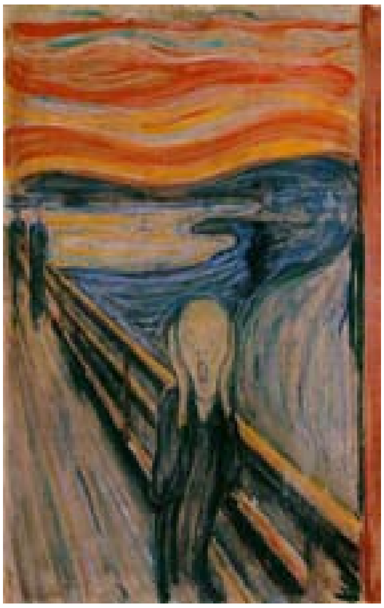
UK approach to contamination (Part 2A, EPA)

- Risk-based approach for many years
- Fundamentally conservative
- Detailed software packages used for assessment
- Input parameters set at low risk end of range
- Exposure durations set conservatively
- Has delivered very safe remediation
- Has been wasteful of resources and funding



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Example – Chatham Docks

- Generic remedial targets set to define what quality of ground would make site suitable for housing use
- Only relevant to top 2 metres of ground
- Excavation pursued to 15 metres to remove all impacted soil
- Original budget £18 million
- Out-turn cost £54 million
- Designer sued for cost over-run of £36 million, and was found liable for £19 million

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The 2012 approach in the UK

- The UK has changed its Statutory Guidance on land contamination
- Wide consultation with public and private sector
- Mixed responses, but has now been implemented
- Need for additional technical guidance on some issues
  - Naturally occurring substances and "normal" background
  - New screening levels (generic assessment criteria)

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Broad objectives of the regime (1)

- Planning legislation deals with making land suitable for new use
- Part 2A legislation deals with existing risks from land contamination
- Shorter and simpler Part 2A guidance
- Separation of Guidance into radioactive and non-radioactive contamination
- Under Part 2A, the starting point should be that land is not contaminated unless there is reason to consider otherwise
- Enforcing authorities should seek to use Part 2A where no appropriate alternative solution exists

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Broad objectives of the regime (2)

- To identify and remove unacceptable risks to human health and the environment
- To seek to ensure that contaminated land is made suitable for its current use
- To ensure that the burdens faced by individuals, companies and society as a whole are proportionate, manageable and compatible with the principles of sustainable development

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Broad objectives of the regime (3)

- The enforcing authority should take a precautionary approach to the risks raised by contamination, whilst avoiding a disproportionate approach given the circumstances of each case, in order to strike a reasonable balance between
- Dealing with risks, and
- The potential impacts of regulatory intervention

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Key issues

- Understand the risk (a combination of probability and severity of impact)
- Decide whether the risk is sufficiently high to justify regulatory intervention
- Primarily a matter of regulatory judgement being exercised by the Local Authority
- Regulators should strive as far as possible to ensure that specialist consultants are appropriately qualified and competent
- Decisions remain the sole responsibility of the Regulator

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"Normal" presence of contaminants

- Normal levels of contaminants in soil should not be considered to cause land to qualify as contaminated, unless there is a particular reason to consider otherwise
- Natural – due to underlying geology / soil formation processes
- Anthropogenic - due to low level diffuse pollution

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Generic Assessment Criteria (GAC)

- GACs are the standard numbers used by many jurisdictions to make decisions on the acceptability of contamination
- They are necessarily conservative, as they have to be safe for all circumstances
- They are often derived taking into account the specific circumstances of countries and their populations

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Generic Assessment Criteria (2)

- Regulators can use GACs and other technical tools to inform certain decisions provided
- They understand how they were derived and how they can be used appropriately
- They have been produced in an objective, scientifically robust and expert manner by reputable organisations
- They are only used in accordance with the underlying principles from which they were derived
- The UK has developed a four category system
- Significant Possibility of Significant Harm (SPOSH)

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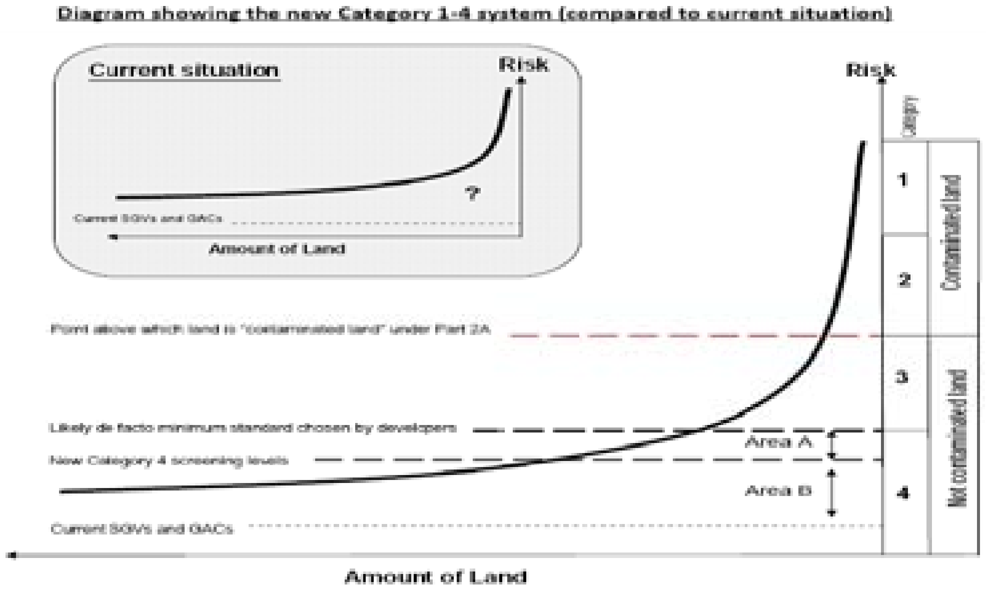
Summary of Category 1-4 system



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Meaning of categories

- Category 1 is definitely Contaminated Land, its sites where there is evidently contamination and receptors which create an unacceptable contaminant linkage (houses built on gasworks with in-situ tar wells, or serious pollution of an aquifer with a drinking water abstraction nearby, say).
- Category 4 is definitely not Contaminated Land, its greenfield sites or brownfield sites with minimal levels of contaminants or industrial sites with contamination sealed below slabs over non-aquifers.

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Meaning of categories (2)

- Categories 2 and 3 are the difficult area to define, and Detailed Quantitative Risk Assessment is used to determine whethere a site should be placed in Category 2 (contaminated land) or Category 3 (not contaminated land).
- In the UK, a GAC may be used to indicate when land is very unlikely to pose SPOSH to human health ie it can define Category 4.
- Detailed quantitative risk assessment will be needed for all other situations
- Regulatory decisions should be based on what is reasonably likely, not what is hypothetically possible

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Determining land as contaminated

- Significant harm is being caused (to human or non-human receptor)
- Significant possibility of significant harm
- Significant pollution of controlled waters
- Significant possibility of significant pollution (of controlled waters)

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Deciding land is not contaminated

- Lack of certainty should not stop the authority from deciding that land is not contaminated
- Where land is determined as not contaminated, a written statement should be issued (but may be qualified, e.g. relevant only to current use) and owners of land informed
- Regulator should keep a record of reasons

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Reasonableness of remediation

- The regulator may only require remediation action in a remediation notice if those actions are reasonable, having regard to:
- The practicability, effectiveness and durability of remediation
- Health and environmental impacts of chosen remedial options
- Financial cost likely to be involved
- Benefits of remediation with regard to the seriousness of the harm or pollution in question

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Next Steps

- National Expert Panel
- Advisory group to help LAs with decision-making using the revised Guidance, with a particular focus on sites near the Category 2/3 border
- Case Studies
- Decisions to be written up and disseminated to share best practice and ensure revised Statutory Guidance is being applied in its intended way
- Category 4 Screening Levels (C4SLs)
- Follows on from outputs of research project to determine normal / background levels of contaminants
- Aim is to establish levels below which local authorities can conclude that land is definitely not contaminated (i.e. within Category 4)

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Regulation and sustainability

- Better regulation focuses on ensuring real risks are addressed
- UK approach to land contamination is moving in this direction
- Marginal sites are unlikely to warrant action
- This ensures we target available budgets on dealing with the worst risks

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Sustainable approach to site investigation (1)

- The change in approach in the UK has thrown a focus on developing methods to understand the ground and the contaminant impacts in more detail.
- The more detailed a site investigation, the more likely we are to define the extent and nature of ground or groundwater contamination:
- number and spacing of boreholes;
- breadth of suite of laboratory testing: and
- number of samples tested.

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Sustainable approach to site investigation (2)

- But, conventional investigation techniques constrain our approach to data gathering and being able to understand what is happening in the ground. The main shortfalls are:
- Lack of sampling sophistication in conventional borings;
- Constraints in obtaining discrete water samples from precise depths;
- Time delays in obtaining test results;
- Challenges in understanding the behaviour of rock strata.

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Sustainable approach to site investigation (3)

- The Triad approach can been adopted to address these constraints;
- Based on the three principles of:
- systematic planning,
- dynamic work strategy and
- realtime data gathering.
- The approach is best demonstrated by reference to a recent project, where a conventional approach had led to a conventional solution at a very high cost, with little realistic prospect of close-out.

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Case Study Background - Introduction

- Site is a current manufacturing facility in the UK
- Extensive traditional site investigations (borehole drilling, limited monitoring well installation) conducted by another consultant, which produced an initial Conceptual Site Model (CSM) – investigation costs of £1m, estimated remedial costs of £10m – Total £11m. Investigation identified:
  - Geological sequence of Fill (1 m), Alluvium (3 m), shale (thickness unknown)
  - Significant impact to soil due to historical use of TCE. Presence of significant concentrations of degradation compounds cis 1,2-dichloroethene and VC in groundwater (both up to 20 mg/l)
  - Area of impact not fully defined either laterally or vertically
  - Anticipated that shale may form a low permeability barrier to inhibit vertical solvent migration, although fracture flow was not understood

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Background – Introduction (2)

- ERM approached by Client to evaluate remedial solutions.
- Geometry of the plume uncertain. A variety of HRSC techniques used, including Gore Sorbers, Modified Waterloo Profiler and Deep Fracture Network investigation
- HRSC approach carried out in accordance with Triad principles
- Following completion of HRSC, remedial solution agreed with regulators (steam injection and biological substrate injection): additional investigation and remedial solution delivered for £2.5m (£600,000 HRSC, 1.9m Remediation) on a fixed cost basis
- Sustainability a key focus at both site investigation and remediation stage (SuRF UK Framework)

What Is HRSC?

- A subsurface investigation that provides the degree of detail required to meet the project objectives:
  - Understand transport pathways (and injection pathways)
  - Understand exposure pathways
  - Understand processes affecting fate of contaminants
  - Understand the contaminant mass distribution
  - Understand how remedial measures will affect the problem
- An investigation in which the scale at which measurements are made is consistent with the scale of the variability of the measured property

Benefits of HRSC

- Better – significantly reduces uncertainty through generation of high resolution datasets
- Faster –typical takes around 30 - 50% less time than comparative traditional investigation scope
- Health and Safety risks reduced - less time on-site
- Cheaper SI Costs – about 50% lower cost than traditional investigations for equivalent data levels
- Reduces remediation costs by accurately refining treatment zones
- Certainty of remediation performance – the contaminant and subsurface conditions are fully understood
- Sustainable at both SI and remediation stages - more rapid and reduces SI or remediation extent/timeframe

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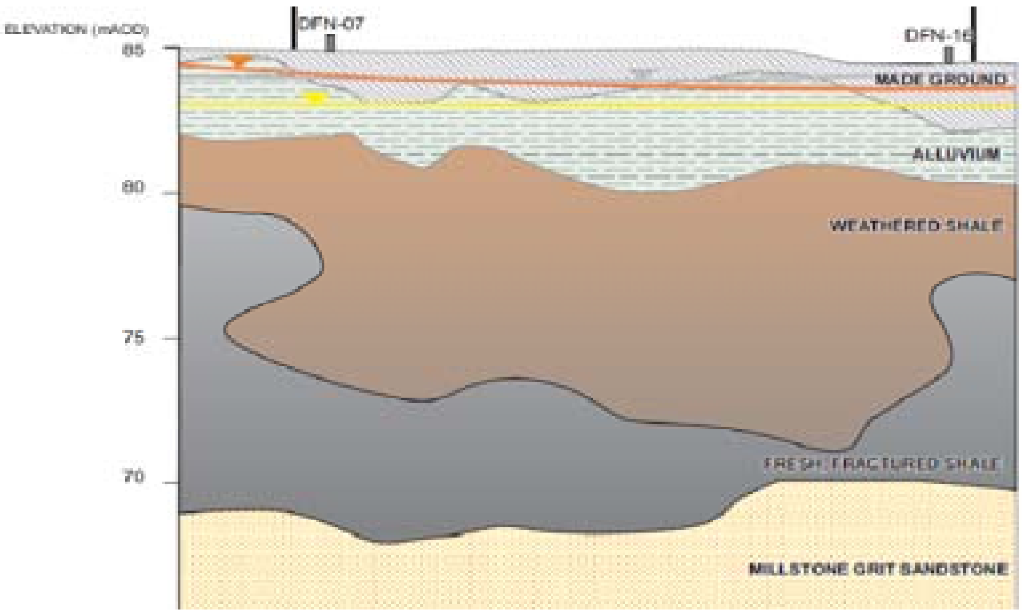
Geology



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Scope of investigation

- ERM were tasked with finding an immediate solution using treatment methods. A variety of HRSC techniques were deployed, including:
  - Gore Sorber™ Survey at 155 locations (largest survey of its type in the UK)
  - Modified Waterloo Profiler Investigation (Alluvium/shale) – 100+ groundwater VOC samples collected
- HRSC approach carried out in accordance with Triad principals to collect collaborative data set.
- Sustainability a key focus at both site investigation and remediation stage (SuRF UK Framework)

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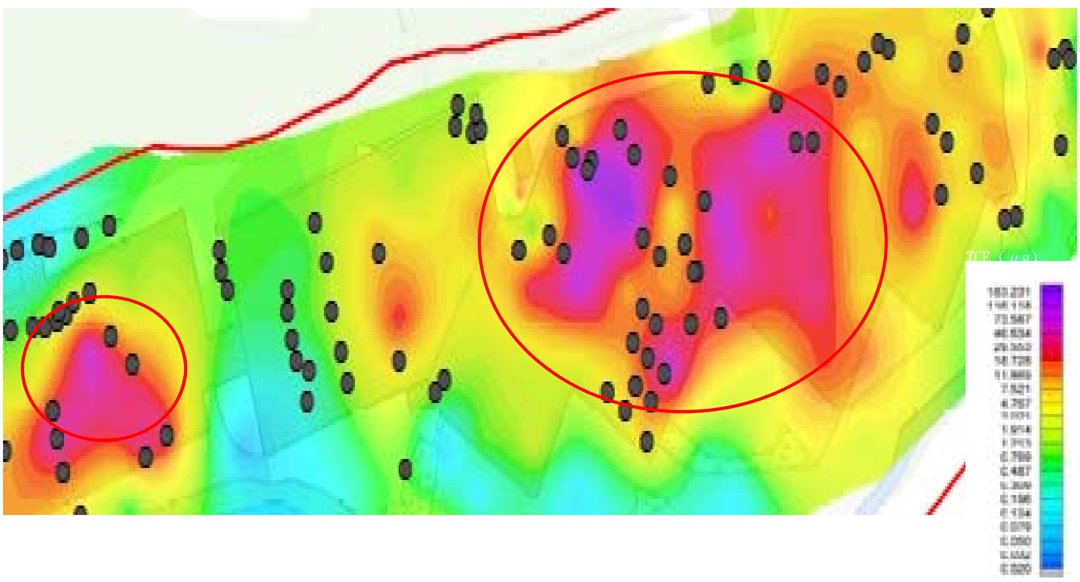
Gore Sorber™ Results



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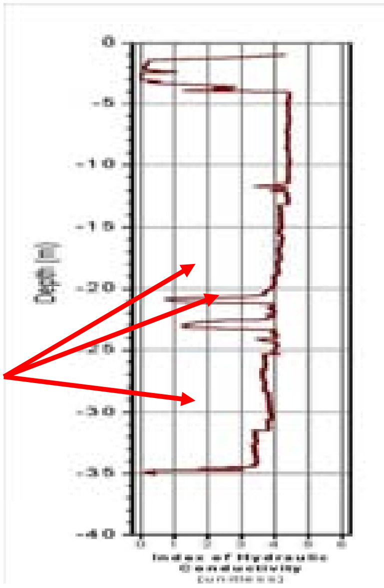
Modified Waterloo Profiler Investigation

Targeted DNAPL sampling above low K horizon



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Rock Core Investigation Rationale

- The investigation defined impact within the Alluvium and upper margins of the shale, but revealed that significant VOC impact was present within the weathered shale.
- Unknown how much VOC was in porewater, and how much in rock mass
- To assist with the remediation strategy development, ERM recommended additional detailed contaminant assessment of the bedrock matrix using a Discrete Fracture Network (DFN) investigation approach as developed by Beth Parker (University of Waterloo)

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Rock Core Investigation Scope

- Completion of 19 rock coring locations to a depth of between 11m bgl and 22m bgl. Total of circa 200m of rock core recovered
- All boreholes were photographed, structurally logged and selected samples screened with a Photoionisation Detector (PID))
- Samples tested on-site for VOCs and in off-site laboratory for physical property analysis (TOC, porosity, moisture content and bulk density)
- Wells installed into each borehole to enable assessment of groundwater flow direction and dissolved phase concentrations within the bedrock
- Initial locations selected based on areas of previously determined greatest groundwater impact. Subsequent locations and finally drilled depth based on progressive real-time assessment of the data during the field works

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Sample Collection Process

Above: shale core sampling

Above: shale core

Above and Left: Rock crushing, with decontamination equipment above

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On-site Laboratory Analysis

On-site laboratory analysis of pore water concentrations using Microwave Assisted Extraction

- MAE was then used to extract VOCs from the rock core into methanol
- Concentrations were measured in the methanol extract (by GC/MS)
- The entire process took <90 minutes (compared to circa 5 weeks if this analysis was undertaken via traditional methods)
- About 450 rock core samples were tested for VOCs in a period of 15 days

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On-site Laboratory

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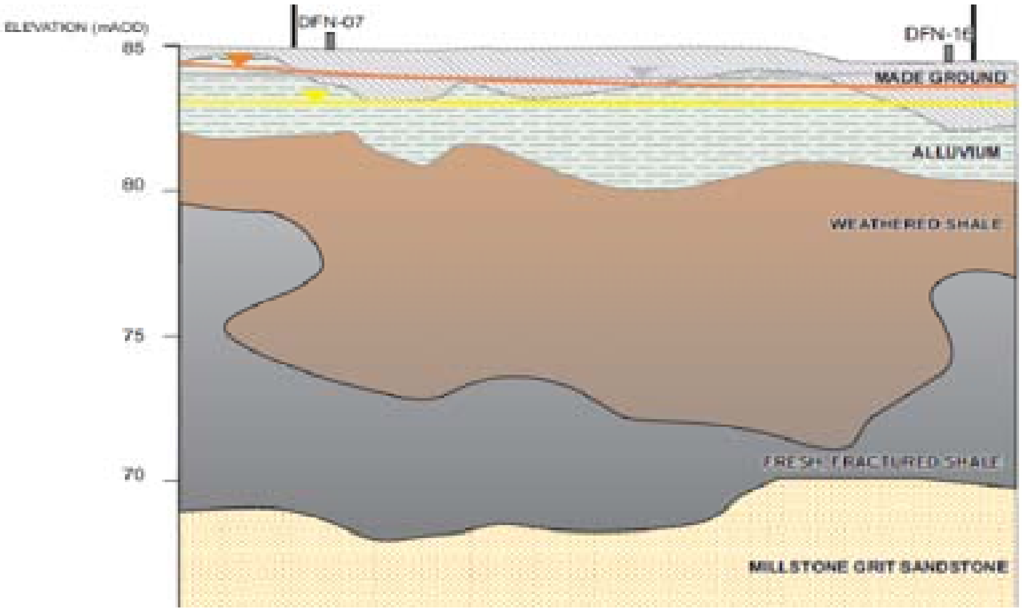
Geology



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Hydrogeology

- Groundwater flow direction confirmed in shale
- Both Alluvium and shale are in hydraulic continuity and form a confined aquifer beneath the site
- Permeability of shale is relatively high – up to 9.5m/d.
- Ecological receptors – nearby river (lateral) and sandstone aquifer at depth (vertical)

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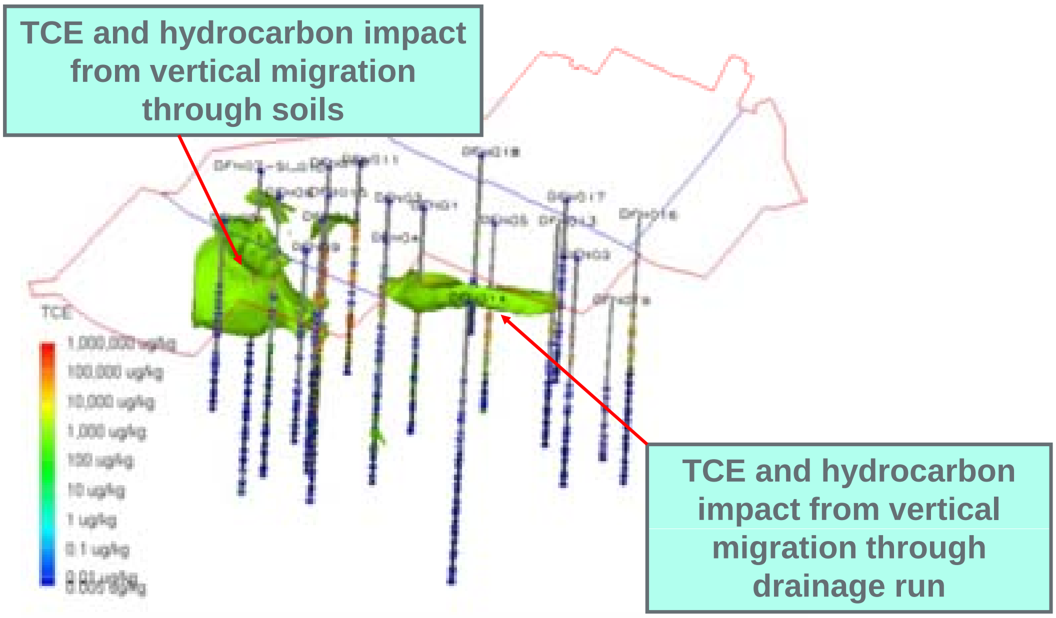
Pore Water Contaminant Distribution - TCE



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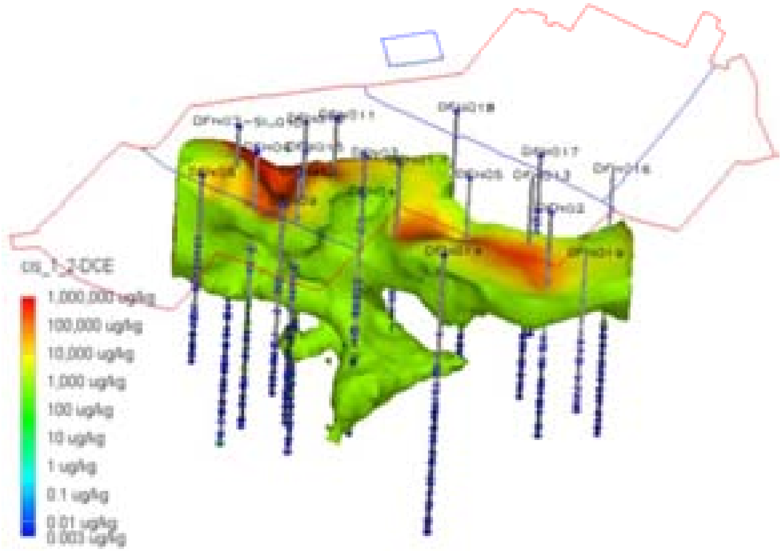
Pore Water Contaminant Distribution - Cis 1,2-DCE



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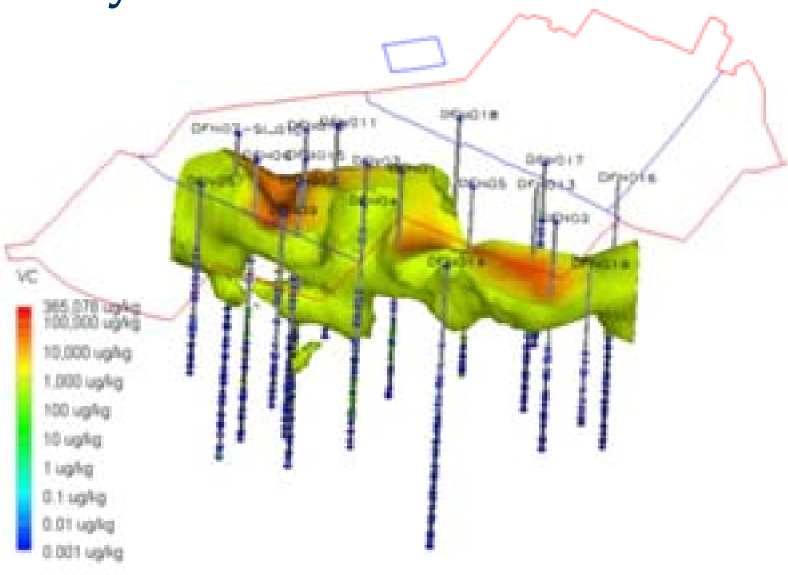
Pore Water Contaminant Distribution - Vinyl Chloride



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Groundwater sampling results

- Results showed a majority of the contaminant mass was sorbed within the rock matrix. This is a typical reflection of contaminant mass distribution within bedrock
- Groundwater concentrations significantly lower than in pore water (again typical for bedrock).
- Slow diffusion of impact from the rock matrix into dissolved phase likely to be on-going

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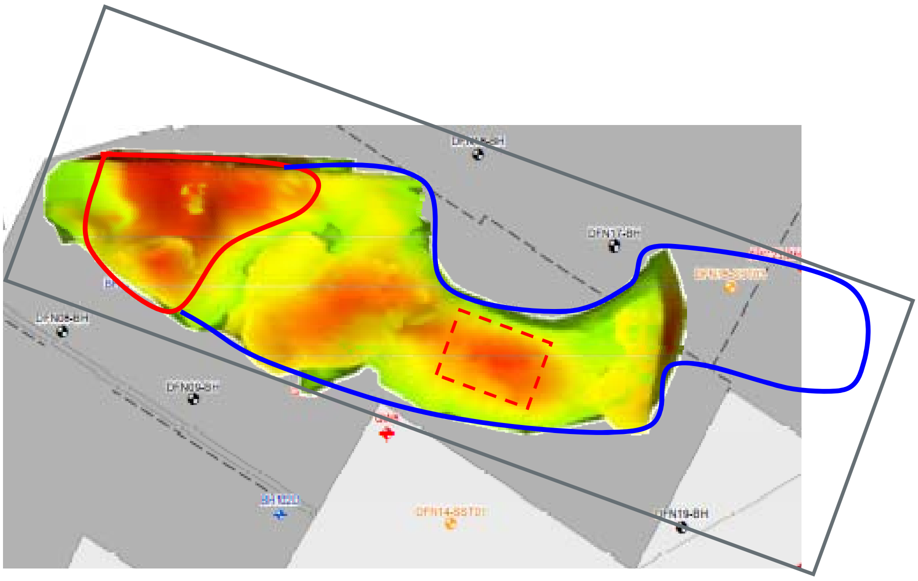
Summary of impact



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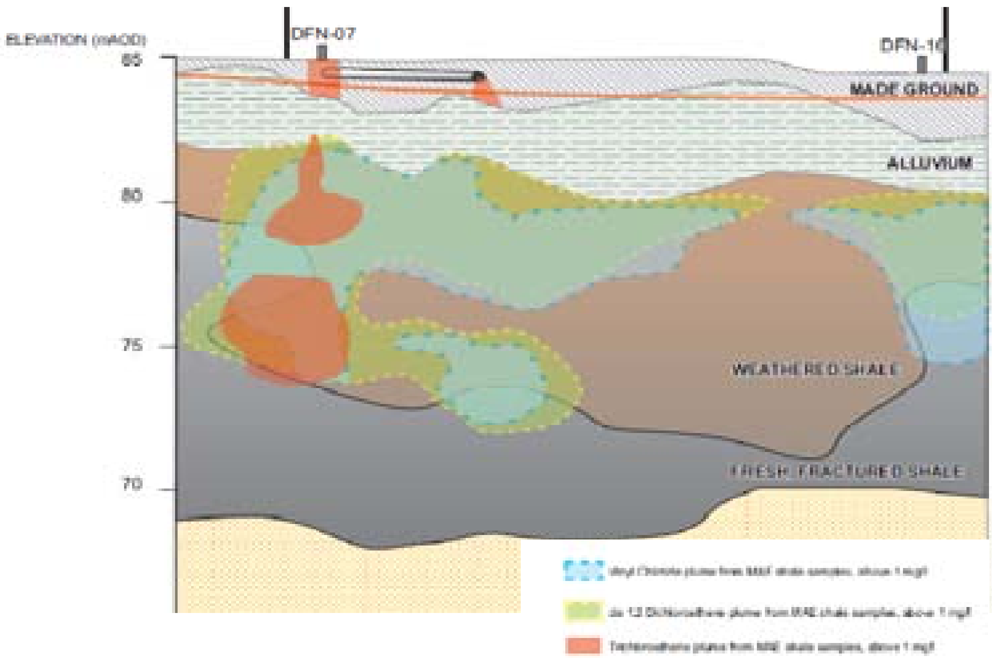
Refined Conceptual Site Model



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Sustainability Measurement Results

- To assess the impact of using innovative site characterisation approaches on the carbon footprint of the investigation, an estimate of the footprint that would have resulted with conventional techniques was calculated for comparative purposes
- Using conventional techniques to obtain a similar level of site characterisation detail would have potentially resulted in a carbon footprint of 33.1 tonnes CO_2e, This significantly exceeds the actual total emitted of 22.7 tonnes CO_2e.

Travel	19.9 t CO_2e	(60%)
Accommodation	6.0 t CO_2e	(18%)
On site energy use	4.7 t CO_2e	(14%)
Materials	2.3 t CO_2e	(7%)
Material Deliveries	0.1 t CO_2e	(0%)
Site wastes	0.0 t CO_2e	(0%)
Water	0.2 t CO_2e	(0%)
TOTAL	33.1 t CO_2e	

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Investigation Conclusion

- Three HRSC techniques (Gore Sorbers, MWP and Core DFN Investigation) applied on-site in both drift and solid rock deposits to collect a collaborative data set in accordance with Triad investigation principals. Shown to be an efficient process for developing robust conceptual site models
- Over 700 sample locations
- First application of the Core DFN rock core technique for bedrock in the UK
- More sustainable site investigation approach than traditional investigations, along with numerous other cost, time, safety and technical benefits. Also benefits at the remediation stage (performance certainty, reduced treatment zone and effort focused on greatest mass)

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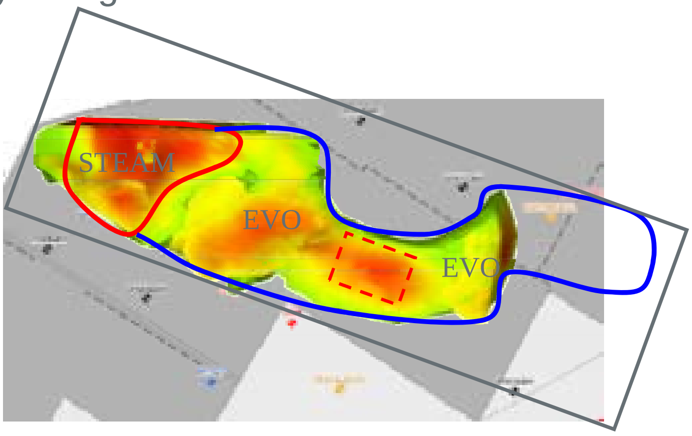
HRSC to define remedial treatment area/ technique

- Two areas of high impact
- Intervening areas of lower impact
- Vacuum extraction preferred, but problematic due to geology and groundwater



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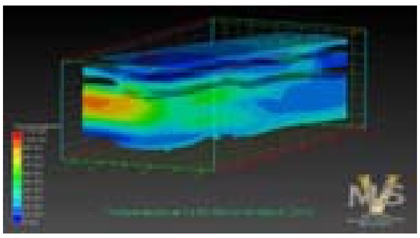
Innovation in Steam System Design

- Following field scale pilot trials, aquifer found to be highly transmissive and confined by clay, making traditional vapour recovery options technically unsuitable.
- Design of the remediation system was focussed upon
  - 1) heating the clay from beneath to increase its permeability
  - 2) development of a 'steam bubble' to allow vapour recovery through a zone created by boiling the groundwater.
- The steam injection process was monitored via a network of thermocouples to allow optimisation of heating within the remediation treatment zones.



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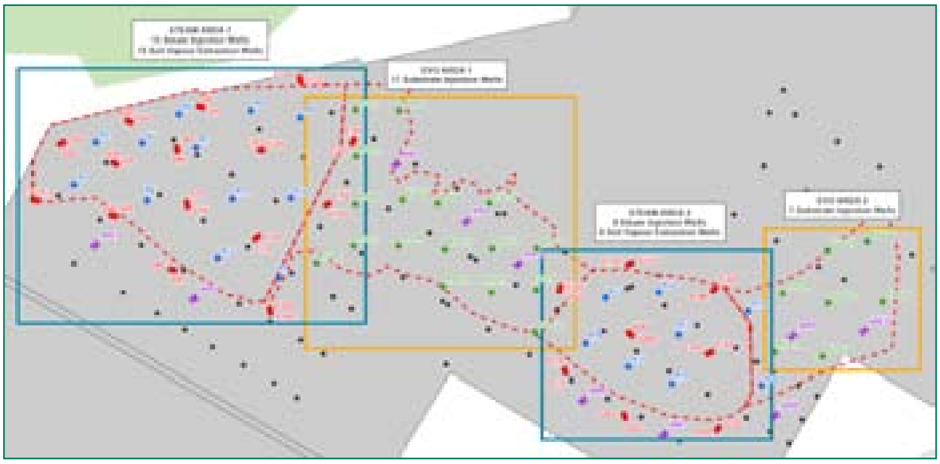
Below Ground Infrastructure Installation

- 23No. pairs of steam injection wells : 'S' Series
- 20No. DPVE recovery wells: 'R' Series
- 10No. monitoring wells: 'MW' Series
- Trenches with risers totalling approximately 70m: 'T' Series



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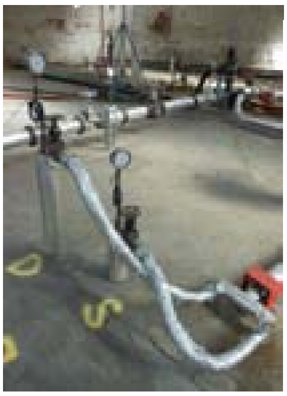
Well Head Infrastructure Connections



SHALLOW AND DEEP STEAM INJECTION WELLS WITH PRESSURE GAUGES

DUAL PHASE RECOVERY WELL: water abstraction via bottom-loading pneumatic pump and vapour extraction via connection to side channel blowers

TRENCH AND TRENCH RISER WITH CONNECTION TO RECOVERY SYSTEM

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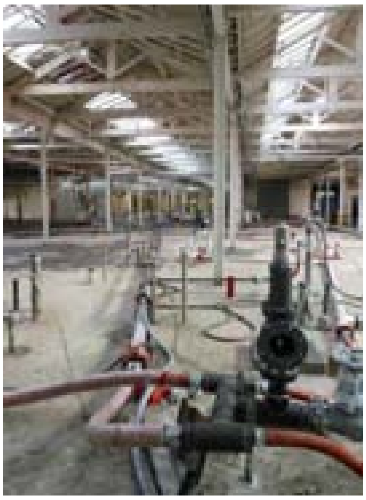
Steam injection and vapour recovery infrastructure



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Vapour Phase Treatment System

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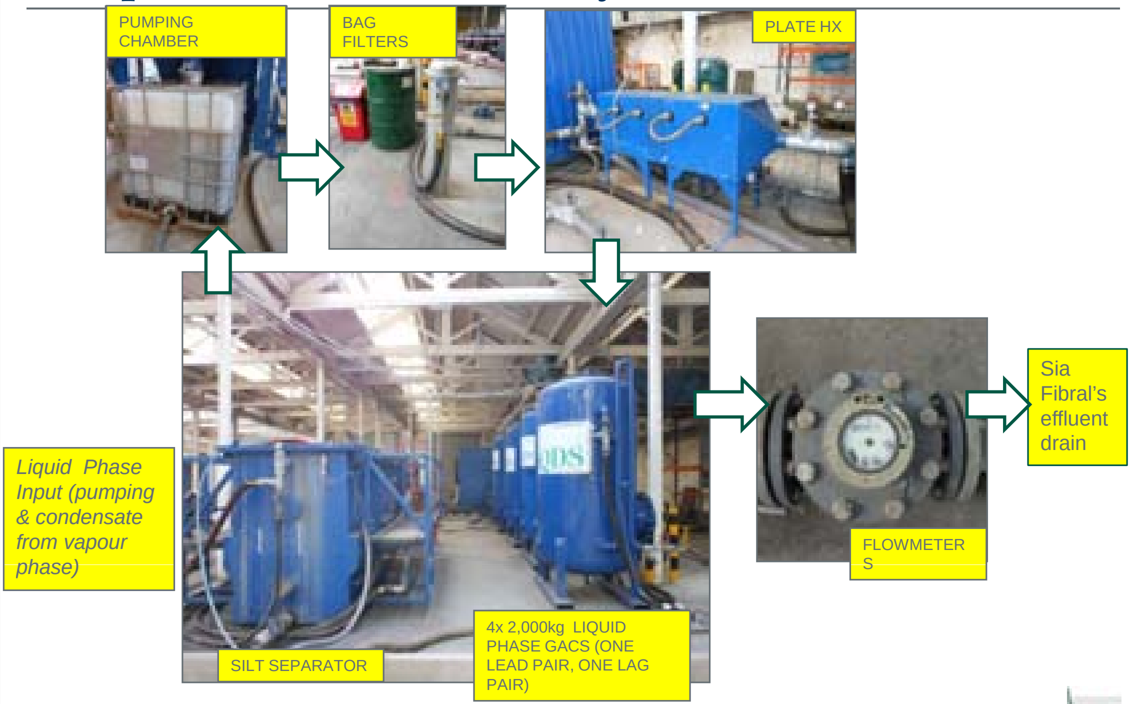
Liquid Phase Treatment System



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Steam/SVE System Performance

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Outcome

- More sustainable site investigation approach delivered than traditional investigations, along with numerous other cost, time, safety and technical benefits provided by HRSC
- Benefits at the remediation stage (performance certainty, reduced treatment zone and steam injection effort focused on areas of greatest contaminant mass)
- Design concept proven during system operation:
- Significant mass recovered in accordance with regulatory and client expectations
- Works delivered on time and budget.
- Regulatory 'approval' anticipated shortly
- Next Steps: carry out biological injection works and quantify carbon footprint of steam injection works
- Out turn cost £2.5 million including investigation, compared to previous work costed at £11 million

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Was it sustainable?

Three parts to sustainability

- Environmental
- rapid and effective removal of pollution
- lower carbon footprint than previous anticipated approach
- Social
- Minimal effect on neighbours – very few vehicle movements
- All odorous and toxic emissions captured using activated carbon
- Economic
- 25% of the cost of alternative approach

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Questions?

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Development of the SuRF-UK framework for sustainable remediation in the UK

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Abstract

Sustainable development has driven much European and UK policy over the last few decades, for example in land use planning, waste and contaminated land management. The three elements of sustainable development (environment, society and economy) can be considered when assessing the likely impacts and benefits of undertaking any scheme, including remediation. SuRF-UK was set up in 2007 to support the application of sustainability principles for remediation in the UK, and has produced a number of documents including the first formal framework for assessing the sustainability of remediation strategies. This paper provides an overview of the SuRF-UK initiative, its approach and the outputs derived from three phases of work.

Introduction

For over a decade, the management of historically contaminated land in the UK has been based on mitigation of unacceptable risks to human health and the environment to ensure that the land is suitable for its current or planned use. This risk-based approach was also considered as best practice by the pan-European project CLARINET (the Contaminated Land Rehabilitation Network for Environmental Technologies in Europe) (Vegter *et al*. 2002).

The "suitable for use" approach involves the assessment and mitigation of risks to human health and the environment associated with a particular use of the land, as opposed to the more stringent approach of making land suitable for **any** use. CLARINET considered that using a risk-based approach was consistent with the principles of sustainable development, but that not all remediation projects are intrinsically sustainable.

Sustainable development and sustainable remediation

Sustainable development was defined by the World Commission on Environment and Development (WCED) in 1987 as development that "meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987). The three pillars of sustainable development are society (people), environment (planet) and economy (profit), and can be considered when assessing the likely costs and benefits of undertaking any scheme, including remediation.

The UK government published its first sustainable development strategy in 1999 - *A better quality of life: A strategy for sustainable development for the UK* (DETR 1999) that has been subject to periodic review (e.g. HM Government 2005). This has underpinned much UK environmental policy and legislation over the last few decades.

Although the remediation of contaminated soil and groundwater is intended to reduce risks to human health and the environment associated with contamination, wider environmental, economic and social benefits and impacts may arise. A remediation strategy that provides the optimum overall balance of environmental, economic and social costs and benefits is considered to be sustainable. Where a remedy is poorly selected, the remediation activities may cause a negative impact that is equal to or greater than the impacts they seek to address. It is for this reason that interest in sustainable remediation has increased, both in the UK and overseas, in the past few years.

Drivers for sustainable remediation in the UK

Both European and UK legislation is underpinned by the concepts of sustainable development. European Directives promote sustainable practice, for example:

- The Waste Framework Directive (CD 2008/98/EC) provides a priority order in waste prevention and management legislation of prevention before re-use before recycling and other recovery before disposal.
- The Water Framework Directive (CD 2000/60/EC) considers that the preferred solution to achieving good water status is the best balance of social, economic and environmental costs.

- All previous drafts of the Soil Protection Framework (subject to high level discussion) have included text that requires the protection and use of land to be considered in a sustainable way.

In the UK, the Environment Act 1995 provides for the establishment of national environmental regulatory bodies; the Environment Agency (England and Wales) and Scottish Environment Protection Agency (SEPA). It places a principal aim on the Environment Agency to "contribute to the goal of achieving sustainable development" when undertaking its regulatory activities, and places a duty on SEPA to similarly have regard to social and economic needs. Both bodies are required to take account of likely costs and benefits in deciding how and when to exercise statutory powers.

The two principal regulatory regimes that apply to the management (including remediation) of land contamination are the planning regime and the contaminated land regime. Both environmental regulators have duties as statutory consultees on the former and with some regulatory duties for the latter. In addition, the remediation of contaminated soil and groundwater will usually fall under waste management legislation, with the EA and SEPA acting as primary regulators.

The UK approach to the management of historic soil and groundwater contamination is risk-based and founded on a 'suitable-for-use' philosophy under both regulatory regimes. The new National Planning Policy Framework was published in March 2012 (CLG 2012) and provides a presumption in favour of sustainable development, simplifies the planning system and strengthens local participation. However, the consultation draft released in July 2011 courted highly polarised views with particular regard to safeguarding the environment and included concern from the Environmental Audit Committee that the presumption is in favour of sustainable development, but without an adequate definition of what this means. Indeed, the Prime Minister was moved to write a letter to the National Trust to provide assurance that "appropriate protection" will be given to the countryside to prevent overdevelopment.

Revised Statutory Guidance on contaminated land was published in April 2012 for England only (Defra 2012) to ensure that

- Unacceptable risks to human health and the environment are identified and removed
- Contaminated land is made suitable for its current use.
- The burdens faced by individuals, companies and society as a whole are proportionate, manageable and compatible with the principles of sustainable development.

The revision was considered necessary following a regulatory review to ensure that high-risk sites are targeted, to reduce inconsistency of approach taken by local authorities (the lead regulator), to reduce the timescale for determination of whether land is contaminated, and to ensure that an unnecessary standard of remediation is not required.

Sustainable Remediation Forum United Kingdom (SuRF-UK)

The Sustainable Remediation Forum-UK (SuRF-UK) was established in 2007, under the co-ordination of CL:AIRE. This followed an Inaugural Meeting set up on 18th June 2007 to gauge the level of interest in sustainable remediation among an invited guest list of practitioners, academia, non-government organisations and government from the UK and overseas. The headline outcome from this meeting was that the measurement of sustainability of our actions, including remediation, is becoming increasingly important and that such assessment should become a material consideration in all development and remediation schemes.

SuRF-UK was initially established to "develop a framework to embed balanced decision-making in the selection of a remediation strategy to address land contamination, as an integral part of sustainable development". It is a collaborative, multi-stakeholder initiative with a Steering Group that incorporates members from government and regulatory bodies, industry, consultancy and academia (Annex 1).

The SuRF-UK Steering Group has taken an inclusive approach to developing guidance on sustainable remediation. This has included successful engagement with a wide range of stakeholders across a broad range of organisations working in contaminated land and brownfield management. Through its series of open forums and consultations it has ensured that a wide number of parties have had a chance to contribute to, the development of a UK framework. In addition, links have been established with overseas initiatives and a member of the Steering Group is also a member of SuRF (USA). The work has also led to a peer-reviewed publication (Bardos *et al*. 2011).

It was considered important that SuRF-UK does not "re-invent the wheel", but develops a framework that works alongside existing good practice guidance. Overarching technical guidance on managing risks at sites affected by land contamination is provided in "*Model Procedures for the Management of Land Contamination. Contaminated Land Report 11*" (CLR11, EA & Defra 2004). CLR11 refers to the need for sustainable solutions, but does not provide further guidance. The case for a framework that effectively integrates with CLR11 and supports the key regulatory regimes was therefore compelling.

SuRF UK framework guidance

While legislation and good practice guidance aim for remediation to contribute to sustainable development goals, no formal and authoritative framework has previously been published to help achieve this aim. The SuRF-UK framework (CL:AIRE 2010) has been designed to fit within, and complement, the phased approach to risk assessment and management described in CLR11 and to be used across a range of regulatory frameworks. In addition, the SuRF-UK framework enables sustainability to be taken into account when comparing different land uses for previously developed land, based on the wider impacts and benefits of their risk management requirements.

The SuRF-UK framework recognises two main stages where sustainable remediation decision-making can be applied (Figure 1):

- **Stage A**: The project/plan design stage when some of the most influential decisions about the remediation solution can be embedded into a wider sustainable project design
- **Stage B**: Remediation options appraisal and selection, when the decision is about selecting the optimum remediation strategy for a pre-defined plan.

Consideration of sustainable remediation requires an assessment of the environmental, social and economic aspects associated with the remediation project, in order to demonstrate that the benefits delivered by the optimum remediation strategy exceed the costs of undertaking remediation. It is strongly recommended that a tiered approach is taken to supporting the decision-making process (Figure 2). Assessors should starts using a simple, qualitative approach as long as the information it provides is seen as robust and acceptable by the various stakeholders involved in the decision-making process. The next tier, if satisfactory resolution cannot be achieved, would be a more analytical approach such as a semi-quantitative multi-criteria analysis, stepping up, only if necessary, to a more complex approach such as a fully monetised cost benefit analysis.

A number of questions must be answered, regardless of either stage or tier. These include (Figure 2):

- What management decision (objectives) does the assessment support?
- Which stakeholders need to be consulted?
- What are the boundaries of the assessment?
- What sustainability indicators should be used?
- What assessment method should be used?
- How certain is the result of the assessment, and what parameters is the outcome most sensitive to?

SuRF-UK Phase 2

The first phase of work included a review of indicator categories (CL:AIRE 2009). An indicator is defined as "a single characteristic that can be compared between options to evaluate their relative performance towards specific sustainable development concerns" (CL:AIRE 2010). They need to be measurable or comparable in some way that is sufficient to allow this evaluation. Achieving this has been the subject of much discussion within the Steering Group and wider participants. As a result, a second phase of work started in April 2010 to:

- Support the development of tools for sustainable remediation decision making (especially indicators)
- Develop case studies for sustainable remediation to demonstrate the use of the framework
- Ensure linkage with international initiatives.

The first two objectives led to a set of three workshops to explore the use of the framework with key stakeholder groups (consultant/contractor, regulator and land owner) and publication of an annex to the framework (CL:AIRE 2011), "Frequently Asked Questions" and a template for submitting case studies (download from www.claire.co.uk/surfuk).

Following road testing of the framework during the workshops, the initial 18 indicator categories were reduced to 15 (Table 1), and further information provided on how they can be used with the framework. This information included:

- Clarifying category descriptions to ensure consistent interpretation between practitioners
- Working to eliminate gross duplications (double-counting)and identify cross-referenced categories to avoid duplication
- Providing a clearer rationale for the social category (now taken to include all human related effects including health)
- Providing a platform with wider applicability than UK use alone (to support multi-national companies based in the UK and to ensure that indicators may satisfy current and developing EU Directives as well as UK regulatory needs).

Table 1 Indicator Sets (adapted from CL:AIRE 2011)

Environment	Social	Economic
Emissions to air	Human health & safety	Direct economic costs & benefits
Soil & ground conditions	Ethics & equality	Indirect economic costs & benefits
Groundwater & surface water	Neighbourhoods & locality	Employment & employment capital
Ecology	Communities & community involvement	Induced economic costs & benefits
Natural resources & waste	Uncertainty & evidence	Project lifespan & flexibility

A practical approach to indicator selection must also take into account the differing perspectives of the stakeholders who might be involved in the sustainability assessment. An iterative approach is suggested by SuRF-UK, beginning with a broad list of all the possible sustainability effects of interest to stakeholders, and what indicators might be used to represent these. Finally, transparent and robust reporting of the sustainability assessment, including the selection and use of indicators, is recommended in order to retain stakeholder confidence in the decision.

A number of SuRF-type initiatives exist, following on from the original SuRF that has operated in the USA since 2006. The chairs of international networks have recently agreed to meet on a quarterly basis. The meetings will be by teleconference, and aim to share progress and learning amongst the different networks and develop opportunities for more collaboration. The represented groups are currently: SuRF-UK, SURF (USA), SURF Canada, SURF Australia & New Zealand (ANZ), SURF Netherlands, SURF Italy, NICOLE (EU), SURF Brazil and SURF China.

SuRF-UK Phase 3

The focus on practical use of the SuRF-UK framework and supporting tools has continued into a third phase of work, started in August 2012, to:

- Develop and publish a series of illustrative case studies on sustainable remediation projects
- Develop guidance on generic 'best management practices' that can be applied to remediation projects to encourage use of more sustainable approaches
- Develop guidance for assessors on good practice for Tier 1 (qualitative) sustainability appraisals.

Again, the approach is one of participation, with a workshop planned to take on board stakeholder view before final publication of outputs. A webinar is also planned to disseminate good practice guidance on tiered assessment, with particular emphasis on tier 1. Final outputs are expected to be available after July 2013.

Conclusions

SuRF-UK was set up to develop a sustainable remediation framework that leads to better remediation strategies and options appraisal, which are more explicitly linked to the goals of sustainable development. It is a collaboration of regulators, industry, academics and consultants.

A number of outputs have been produced and are available from www.claire.co.uk/surf to promote sustainable thinking in the UK remediation sector.

Although a voluntary framework, the SuRF-UK guidance is well-placed to support the new regulatory landscape in the UK introduced by recent planning and contaminated land (Defra 2012) guidance. Use of the framework may help improve stakeholder confidence in the "presumption in favour of sustainable development" that underpins the new planning framework. In addition, under the new contaminatd land statutory guidance, the SuRF-UK framework may be used to support a decision on whether land is contaminated (a Stage A decision) and also support the selection of a sustainable, cost-effective remediation strategy.

Work continues on supporting the practical use of the SuRF-UK framework, including development of case studies and further guidance on good practice and Tier 1 (qualitative) assessment.

An international network of SuRF networks is now well-established, with quarterly teleconferences to exchange ideas and solutions. This network is likely to grow as sustainable thinking and practice becomes embedded in the global remediation sector.

Acknowledgement

The author would like to acknowledge the funding for SuRF-UK from the Homes and Communities Agency, Shell and National Grid and on the collective effort of the SuRF-UK Steering Group and participants in development of the framework. However, the views expressed are those of the author and not necessarily those of the Steering Group or their respective organisations.

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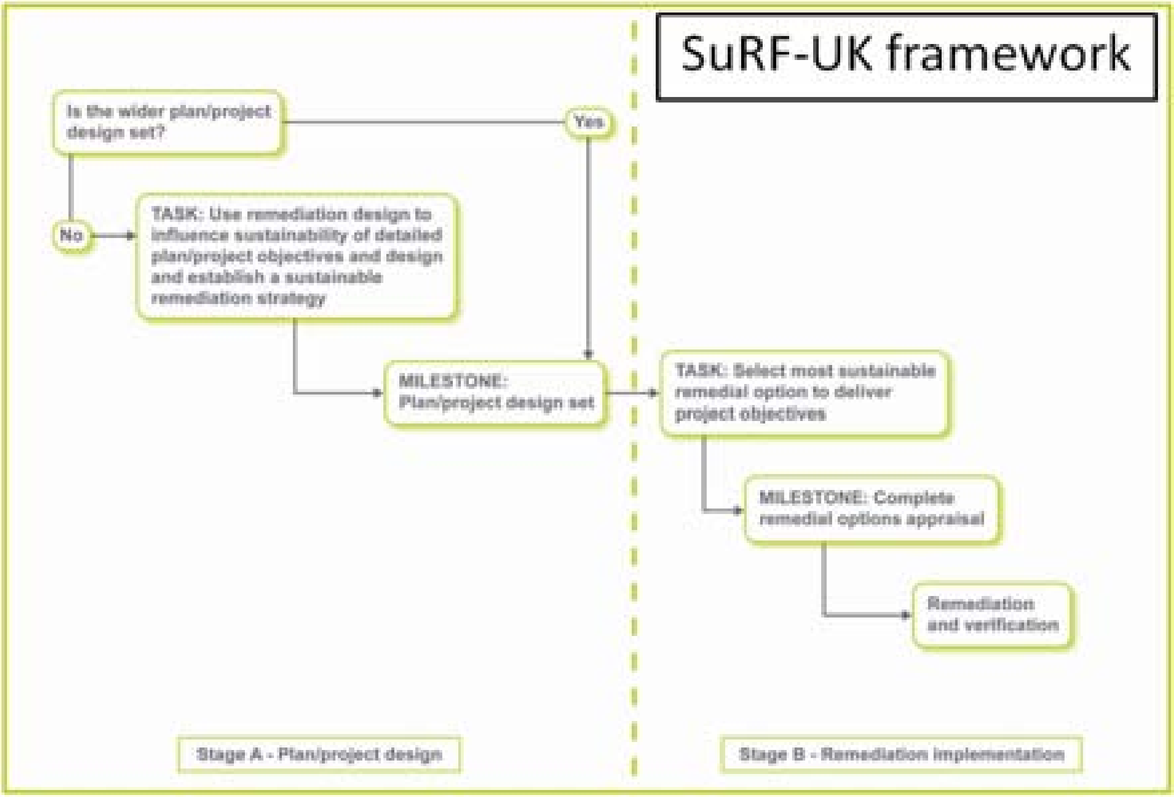

Figure 1 **The SuRF-UK Framework (CL:AIRE 2010)**

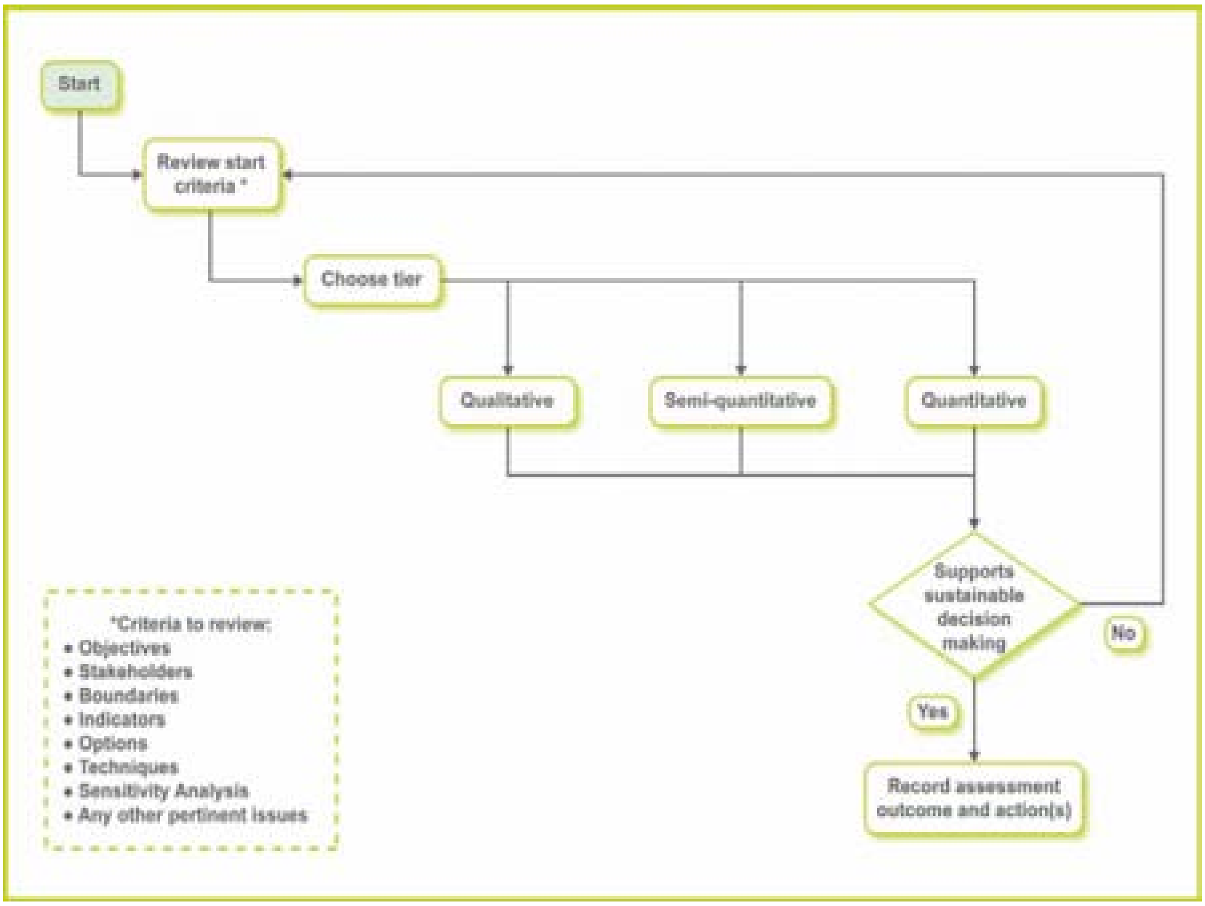

Figure 2 **Tiered approach to sustainability assessment**

Annex 1 SuRF-UK Steering Group Members

Paul Bardos, r3 environmental technologies

Brian Bone, Bone Environmental Consultant

Richard Boyle[#], Homes & Communities Agency

Dave Ellis, Du Pont (link with SuRF – USA)

Nicola Harries, CL:AIRE

Alison Hukin, Environment Agency

Naomi Regan[#], National Grid

Jonathan Smith[#], Shell

Former member:

Frank Evans, National Grid

[#] = also representing Soil & Groundwater Technologies Association (SAGTA)

Development of the SuRF-UK framework for sustainable remediation in the UK

Dr. Brian Bone, Bone Environmental Consultant Ltd.
Sustainable Remediation Forum-UK (SuRF UK)
Steering Group Member

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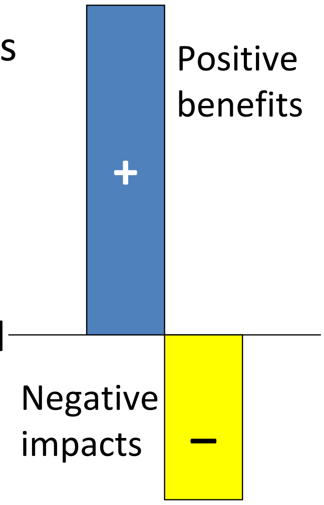
2012 Taipei International Conference on Remediation and Management of Soil and Groundwater Contaminated Sites and Taipei Soil and Groundwater Exhibition, Oct 29 – Nov 3, 2012

This presentation

- What is SuRF-UK?
- Drivers for sustainable remediation in UK
- The SuRF-UK approach and outputs
- Challenges and opportunities
- Summary

Sustainable Development

- Sustainable development
  - 'Development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (Report of the World Commission on Environment and Development 1987, the Brundtland report)
- Sustainable remediation
  - Application of the principles of sustainable development to remediation



.. a net benefit

SuRF-UK

- UK-based collaboration of industry, regulators, academics and consultants
- Established in 2007, following the lead of SuRF (USA)
- Independent co-ordination by CL:AIRE (www.claire.co.uk/surfuk)
- Secretariat has been funded by HCA, with in-kind support from industry
- **Aims**
- To produce a framework for assessing sustainable remediation that is effective, practical and meets regulatory and industry acceptance in the UK

Regulatory Drivers

- European Directives
  - Waste Framework Directive
    - Hierarchy to promote sustainable waste management
    - Escalating taxation on disposal
  - Water Framework Directive
    - Preferred solution (to achieve good status) … best balance of social, economic and environmental costs
  - Draft Soil Protection Framework
    - Deciding on remediation actions, Member States to consider … social, economic and environmental impacts, cost-effectiveness and technical feasibility of the actions envisaged

Regulatory Drivers

- UK legislation
  - Planning regime
    - Underpins sustainable development
    - National Planning Policy Framework
  - Environment Act 1995 requires environment agencies
    - To contribute to the goal of achieving sustainable development/have regard to social and economic needs
    - To take account of likely costs and benefits in considering how or whether to exercise statutory powers
  - Contaminated land regime
    - Balance of costs and benefits

Planning

- National Planning Policy Framework
  - For achieving sustainable development
  - Polarised consultation responses on draft:
    - PM promises "appropriate protection", "clearer definition of sustainable development", "simplify the system, strengthen local participation and secure sustainable development"
  - Published in March 2012
  - Presumption in favour of sustainable development
    - Development that is sustainable should go ahead, without delay – a presumption in favour of sustainable development that is the basis for every plan and every decision.

  - www.communities.gov.uk

Contaminated land regime

- Revised Statutory Guidance
    - Insufficient targeting of high-risk sites
    - Inconsistent approaches taken by local authorities
    - Determination process is too long
    - Remediation standard set too high
- Revised contaminated land guidance for England and Wales laid before Parliament on 7 Feb 2012 after consultation on draft (Dec 2010)
- Published in April 2012

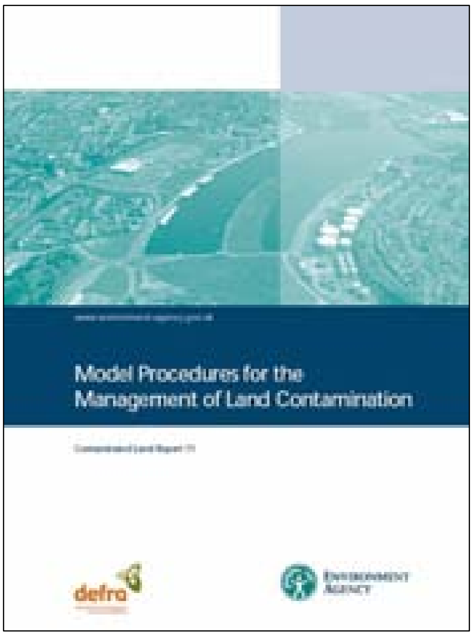
  - www.defra.gov.uk

Statutory Guidance and Sustainability?

- Objective of the regime includes:
  "To ensure that the burdens faced by individuals, companies and society as a whole are proportionate, manageable and compatible with the principles of sustainable development."
- Clause 1.6
  "… The authority should take a precautionary approach to the risks raised by contamination, whilst avoiding a disproportionate approach given the circumstances of each case. The aim should be to consider the various benefits and costs of taking action, with a view to ensuring that the regime produces net benefits, taking account of local circumstances."

Land contamination management framework

- Guidance CLR 11
- Risk-based
- Published 2004
- UK-wide
- All regulatory regimes
- Tiered approach
  - Risk assessment
  - Options Appraisal
  - Implementation of remediation



CLR 11 and sustainability?

- References in CLR 11
- 'The goal is to find solutions that identify and deal with risks from contamination in a **sustainable** way'
- '.. cost-benefit analysis is an inherent part of the management of environmental risks in a **sustainable** way'
- '**sustainability** of the strategy (i.e. how well it meets other environmental objectives, for example on the use of energy and other material resources, and avoids or minimises adverse environmental impacts in off-site locations, such as landfill, or on other environmental compartments, such as air and water)'

SuRF-UK Approach

- Inclusion
- Dissemination
- International

Key Principles

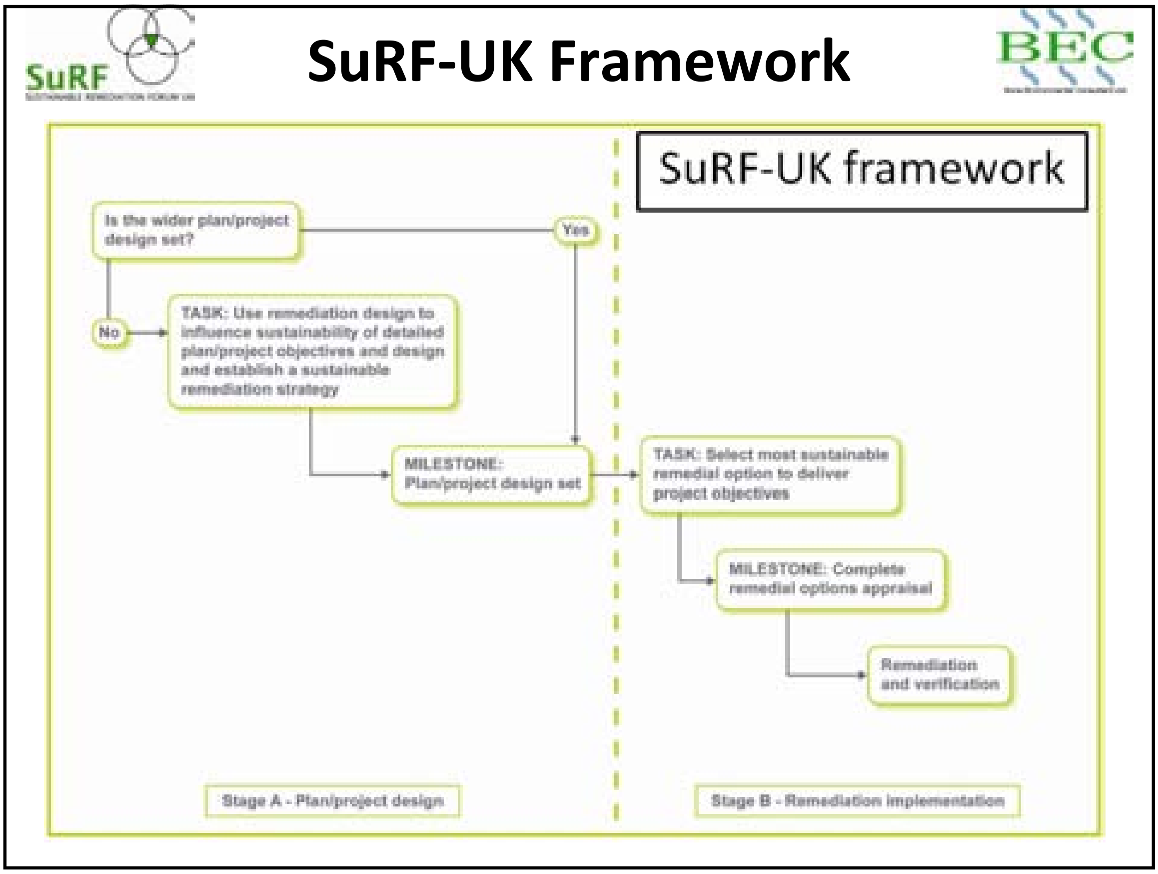
- Protection of human health and the environment
- Safe working practices (for workers & local communities)
- Consistent, clear and reproducible decision-making
- Record keeping and transparent reporting (including assumptions & uncertainties)
- Good governance and stakeholder involvement
- Sound science

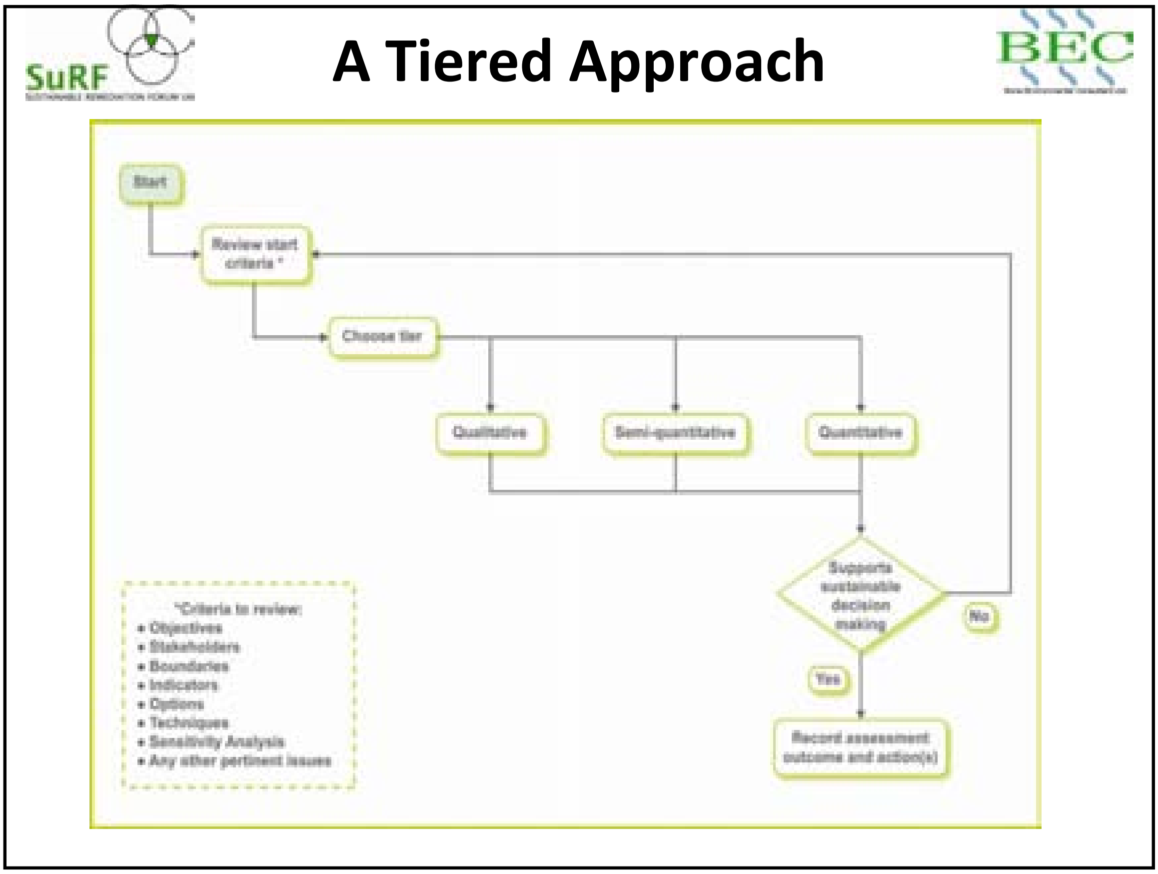
SuRF-UK framework

- Sustainable remediation

  ‘*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*’

March 2010

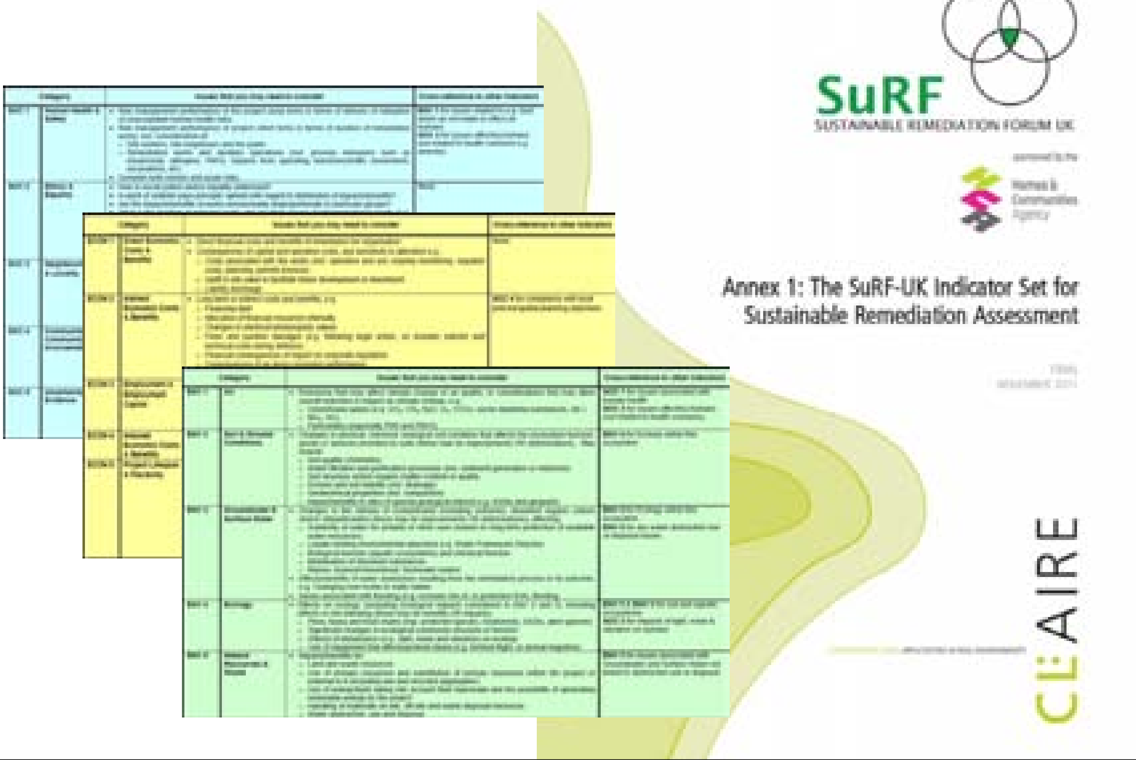

SuRF-UK Framework
SuRF-UK framework
Is the wider plan/project design set?
Yes
No
TASK: Use remediation design to influence sustainability of detailed plan/project objectives and design and establish a sustainable remediation strategy
MILESTONE: Plan/project design set
TASK: Select most sustainable remedial option to deliver project objectives
MILESTONE: Complete remedial options appraisal
Remediation and verification
Stage A - Plan/project design
Stage B - Remediation implementation


A Tiered Approach
Start
Review start criteria *
Choose tier
Qualitative
Semi-quantitative
Quantitative
Supports sustainable decision making
No
Yes
Record assessment outcome and action(s)
*Criteria to review:
• Objectives
• Stakeholders
• Boundaries
• Indicators
• Options
• Techniques
• Sensitivity Analysis
• Any other pertinent issues

SuRF-UK Phase 2

- Assess practical implementation of the framework
  – Road-tested in a series of 3 workshops
  – Developed case studies for syndicate exercises
  – Generic indicator lists for environmental, social and economic functions
- Functionality
  – Frequently asked questions
  – Case study template
- Revision of indicator lists
  – Clearer definitions and guidance on how to use
  – Publication of Annex 1 (Nov 2011)

Indicator Sets



Indicator Sets

Environment	Social	Economic
Emissions to Air	Human health & safety	Direct economic costs & benefits
Soil and ground conditions	Ethics & equity	Indirect economic costs & benefits
Groundwater & surface water	Neighbourhoods & locality	Employment & employment capital
Ecology	Communities & community involvement	Induced economic costs & benefits
Natural resources & waste	Uncertainty & evidence	Project lifespan & flexibility

Resources

- Framework document
- Review of Indicators report
- Annex 1 SuRF-UK indicator set
- Frequently Asked Questions
- Case Study template
- Workshop presentations
- Webinars/podcasts
- www.claire.co.uk/surfuk
- Ambassadors (industry, consultancies)

SuRF-UK Phase 3

- Started August 2012 (end July 2013)
- Develop and publish good practice UK case studies
- Develop guidance on generic "best management practices"
- Develop good practice guidance for assessors on Tier 1 (qualitative) sustainability appraisals
- Webinar

Summary of the Process

- Workshops were held to test and refine indicator sets using case studies
- Objectives, scope and meanings must be clear to all parties – a common understanding
- Boundaries to be set at outset – any assessment will not be unlimited
- Some confusion over the meaning of indicators
- Start simple, assessment should be proportionate to project scale and sensitivity
- The objective is to achieve a **balanced** decision

Challenges and Opportunities

- Promote voluntary use of the framework
  - Conferences/workshops
  - Ambassadors
- Feedback loop
  - Benefit of submitting case studies?
  - Is the framework fit for purpose?
  - Are stakeholders satisfied with outcomes?
- Encourage uptake through planning and contaminated land regimes
  – The stage is set to put the framework into practice

Lessons learned

- Definitions objectives, scope and meanings must be clear to all parties – a common understanding
- Boundaries – any assessment will not be unlimited
- Some confusion over the meaning of indicators
- Potential for “double-counting”
- Start simple, assessment should be proportionate to project scale and sensitivity
- Language of communication
- The objective is to achieve a **balanced** decision

Summary

- Balanced decision-making is a scary concept
- Recent consultation responses indicate a lack of trust
- Imperative that a clear, open and inclusive process is followed to reach and communicate a balanced decision of environmental, social and economic factors
- The SuRF UK frameworks is such a process
- Work is continuing, including:
    - Encourage the submission of case studies
    - Develop guidance on carrying out a first tier assessment
- Need to widen skill set
- Any other SuRFers out there?

SuRF-UK Steering Group

- Paul Bardos, r3 environmental technologies
- Brian Bone, Bone Environmental Consultant
- Richard Boyle#, Homes & Communities Agency
- Dave Ellis, Du Pont (link with SuRF – USA)
- Nicola Harries, CL:AIRE
- Alison Hukin, Environment Agency
- Naomi Regan#, National Grid
- Jonathan Smith#, Shell

Former member:

- Frank Evans, National Grid

also representing Soil & Groundwater Technologies Association (SAGTA)

Risk Assessment as a Tool in Driving Sustainable Management of Contaminated Land Issues

Neil Donaldson

In the Asia Pacific region the use of risk assessment has evolved rapidly in some jurisdictions over the past decade to become an effective tool at the disposal of consultant when developing coherent strategy to manage liability for clients. Maturing contaminated land legislation has been key to enabling this evolution in some jurisdictions however, is has also been necessary for proactive advocacy by industry bodies and contaminated land practitioners to drive the acceptance and understanding of risk assessment techniques, especially where the legislative tools are less prescriptive or absent.

Fundamentally, risk assessment assists in decision making on contaminated land issues by:

- Enabling informed discussion on health and ecological risk (quantification of the issues);
- Providing a transparent process that can be readily audited;
- Focusing decision making on the material issues by identifying the main drivers of risk;
- Supporting technology selection decision where active remediation of source areas is necessary; and
- Supporting investment or provisioning decisions.

Risk assessment can be a highly cost effective. In general terms, depending on the complexity and levels of risk assessment required, a typical health risk assessment can cost in the order of USD8, 000 to USD 100,000 whilst ecological risk assessment typically costs in the range of USD 20,000 to USD150,000. Typically the cost benefit of this investment is realised through:

- Defining site specific remediation targets which will generally reduce conservatism in design assumptions reducing extent of remediation required;
- Defensibly demonstrating that active remediation strategies are not required for a given site setting, end use and regulatory framework.
- Establishing ongoing management requirements which can allow for longer term cost effective investments in systems, processes and infrastructure to meet environmental obligations;
- Limit stakeholder outrage and potential reputational impacts by addressing community concerns; and

- Managing and / or limiting regulatory burden by ensuring regulatory concerns are proactively addressed through demonstrable programmes of compliance and governance.

The following paper presents a series of recent case from the Asia Pacific Region which illustrate the development and use of risk assessment techniques in supporting informed decision making on contaminated sites.

Updating of Australia's Health Based Soil Guidelines 2011

Environmental Resources Management Australia Pty Ltd (ERM) was commissioned by the National Health and Medical Research Council to update three Schedules of the National Environmental Protection (Assessment of Site Contamination) Measure (1999). This project was undertaken as part of the review and variation process undertaken in 2010.

The project was overseen by a steering committee with representatives from NEPC, Department of Health and Ageing, Queensland Health and the University of Queensland. ERM prepared revised versions for consultation of Schedule B(4*) Guideline on Health Risk Assessment Methodology* , Schedule B(7a) *Guideline on Health-Based Investigation Levels* and B(7b) *Guideline on Exposure Scenarios and Exposure Settings*.

Health-based investigation levels for soils were generated using ERM's in-house risk assessment model. Multiple pathways were included for four land-use scenarios (residential with gardens, residential without gardens, commercial/industrial and open space).

Over 50 chemicals were modelled. As part of the project, ERM reviewed the toxicology of all the modelled chemicals and selected toxicity data on the basis of an agreed hierarchy of preferred data sources.

The health-based investigation levels and exposure settings and scenarios were combined in a single revised Schedule B(7), which provides an internally consistent and transparent treatment of all the chemicals considered. The objective of this document was to permit contaminated sites practitioners to gain a full understanding of the assumptions inherent in the investigation levels, such that they will be able to derive site specific values using the same methodology.

The revised Schedule B(4) provides overarching guidance on the risk assessment methodology used in the development of the investigations levels and recommended for use in Australia. It also provides guidance on some issues that occur regularly in risk assessment work, such as speciation of metals, bioavailability, determining exposure from air, water and food, and dealing with mixtures.

Refinery (Confidential Client) – AP Region

The refinery was subject to a clean-up notice from the regulator; perception of the regulator was that petroleum products had escaped and were continuing to escape from the site into the adjacent bay in large quantities. The expectation was that sediments and the foreshore were significantly contaminated, and that an extensive remediation would be required. The notice set a deadline for submission of a clean-up plan explaining what action would be taken, and also required an ecological risk assessment.

ERM undertook a sediment and benthic macro invertebrate survey in the bay sediments, aimed at characterising contaminant levels in the sediment and pore water, and attempting to test whether macro invertebrate diversity was connected to contaminant levels. Sampling sites were chosen to represent near shore (within 100m) locations along the length of the refinery boundary, and background locations were also sampled. ERM also took water samples, sediment and pore water samples from along the beach and near foreshore, and analysed tissue samples from mussells to test for bioaccumulation.

The results showed that there were limited patches of LNAPL in the beach sediments in a small area at the south end of the beach, and traces of hydrocarbon contamination in the sediments further out but at much lower levels. There was no detectable contamination in the water, and no contamination in the mussel tissues. The rapid attenuation of the hydrocarbon was demonstrated using a series of transect samples with clusters of groundwater peizometers at 25m intervals at several places going down the beach into the water. Each cluster tested a number of different depths. The plume did not escape the low tide mark, and it appears that wave action is very effective at promoting attenuation – probably by a combination of dilution, dispersion and aerobic biodegradation.

Macroinvertebrate results showed that there was no correlation between species diversity and contamination levels. All the communities were disturbed to some extent, and were more dependent on the sediment type than on the hydrocarbon concentrations. There was no significant difference between the results for the contaminated areas and those for the background areas. On the basis of this study, ERM demonstrated that the ecological risk to bay was not significant, and that remediation was not necessary.

ERM also assessed health risks to users of the foreshore, centred on the possibility of people coming into contact with LNAPL whilst playing, or digging for bait. No significant risks were predicted, with the exception of the limited southern area where LNAPL was present close to the surface. The area was already difficult to access because the beach is stony at this point. The real value of the risk assessment in this case was to focus the attention of stakeholders on the significant issue – preventing contact with LNAPL. This enabled the agreement of a low-impact solution using landscaping to make access to the affected area more difficult, and preventing digging, without undertaking intrusive or ecologically damaging remediation measures. Both the refinery and the local stakeholders (beach users, fisheries, Council ecology and conservation officers, and Traditional owners) were pleased with this outcome, and it was agreed with the regulator.

Occupational health assessment supplemented the refinery's ongoing occupational monitoring for hydrocarbon exposure, using personal exposure badges and indoor air monitoring. The issue was potential for vapour intrusion into buildings from the underlying impacted groundwater. No evidence of a vapour intrusion risk was found, and personal exposures were well within acceptable levels. This assessment was required primarily to demonstrate to the regulator that no immediate health risk would result from the groundwater contamination, and this allowed agreement of a long term remediation approach for the on-site area. Gaining this time permitted a wider range of remedial options to be considered, and gave the refinery more flexibility to manage the situation (and undoubtedly saved a lot of money).

Retail Service Station – Australia

Concerns from residents arose when one of the owners of a neighbouring property installed a swimming pool and found hydrocarbon product in the groundwater seeping into the excavation. Early groundwater investigations provided limited plume delineation, and Council put a notice on the planning records of 7 properties stating that there was a potential risk to health. Understandably the community concerns were high and residents demanded action. ERM used soil vapour monitoring and quantitative risk assessment to model the air quality inside the affected properties to demonstrate that health risk was not significant. Indoor air sampling was carried out in one of the properties that included a child care centre. The results of this sampling at point of exposure validated the model.

Pesticide Manufacturer – New Zealand

NZ regulators require a permit if off-site migration of groundwater contaminants occurs above guideline values. No values exist for wide range of manufactured pesticides resulting uncertainty over compliance. The local community in the vicinity of this facility is very sensitive to the potential for product to enter the surrounding marine environment. Risk assessment of the products was required to ensure that the facility could demonstrate to the community that the license to operate did not present any risk to the local environment. license to operate should be maintained.

ERM generated marine water guideline values for 26 pesticides following approach and assumptions set out in available documentations ensuring full equivalence with NZ guidelines. The studies concluded that for the potential levels of product that could enter the environment a permit was not required. Without risk assessment to back this finding detailed monitoring and detection would have been required and the risk perception of the local community wold have continued to present ongoing reputational and operation risks to the facility.

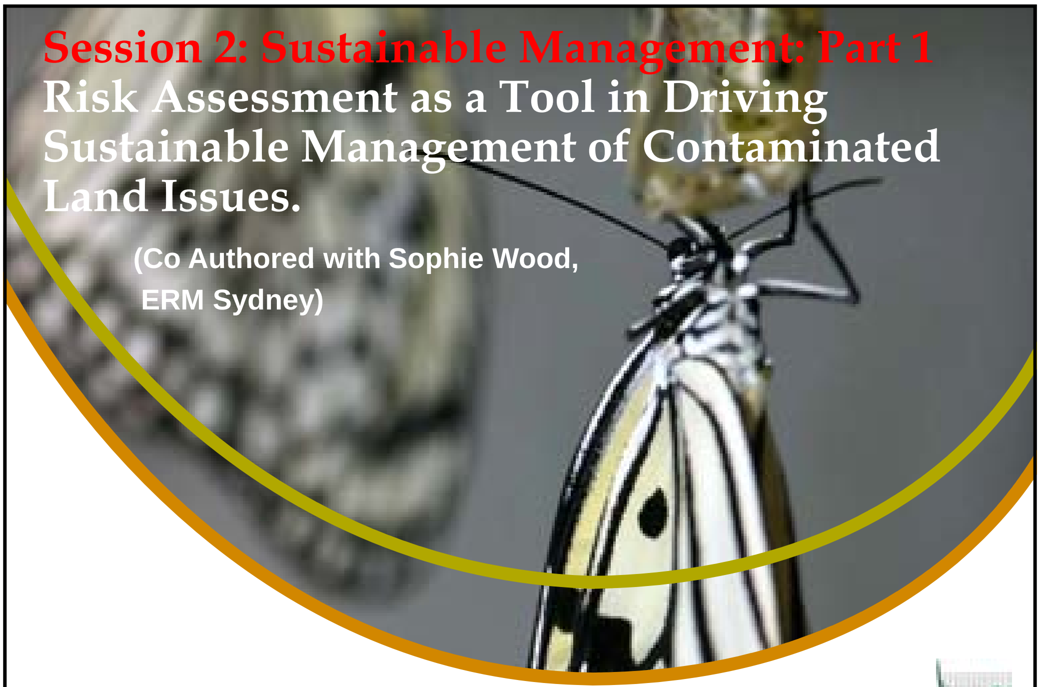
Air Conditioning Manufacturer – New Zealand

A chlorinated solvent plume was identified at the site of a former air conditioning manufacturer. Redevelopment was proposed at the site. The plume was attributed to legacy issues associated with historical operations at the site. Initial expectation by all stakeholders was that remediation would be required to address the source area and mitigate anticipated risks to allow redevelopment of the site to progress.

Based on a review of available data and development of a conceptual site model it was established that the primary risk driver to future site use was the vapour pathway. No off-site impacts were identified. On this basis vapour investigation and risk assessment was used to define:

- Types of development possible without remediation based on building size and layout
- Types of development requiring protection from vapour intrusion
- Monitoring criteria to maintain 'no risk' status both on and off site

Following the risk assessment, sensitivity analysis was used to derive building characteristics that gave a no risk prediction in the model, based on the same input vapour concentration. This approach allowed identification of an "envelope" around the development proposal within which the building designers could work, to make sure what they designed would not create a vapour risk. This is possible because the risk depends on floor construction, building volume and air exchange rate, all of which can be designed in. The advantage of this novel approach is that the designers can mitigate the risks in the building design avoiding the expense of incorporating vapour barriers of remediation design components which would, require ongoing maintenance and monitoring. This approach introduces the concet that the protection is intrinsic to the building design – based on the parameters established using the risk assessment.



Session 2: Sustainable Management: Part 1

Risk Assessment as a Tool in Driving Sustainable Management of Contaminated Land Issues.

(Co Authored with Sophie Wood, ERM Sydney)

Neil Donaldson, ERM Australia – Nov 2012

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Outline of Presentation

Aim: Highlight the significance of risk assessment in sustainable management of contaminated land.

- Outline current status of risk assessment in Asia Pacific region.
- Present series of brief case studies which:
  - demonstrate how approach can aid effective decision making;
  - provide means of effective stakeholder communication; and
  - Inform design of remediation schemes or other design mitigation measures.
- Provide practical example of "measuring" sustainability benefits of risk assessment.

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Current Status

- In the Asia Pacific region risk assessment has become an increasingly important and effective tool for managing contaminated land liabilities.
- Maturing contaminated land legislation has been key to enabling this evolution in some jurisdictions.
- Proactive advocacy by industry bodies and contaminated land practitioners is required to drive the acceptance and understanding of risk assessment techniques, especially where the legislative tools are less prescriptive or absent.
- Where applied, risk assessment techniques can deliver highly sustainable outcomes which can be a key selling point with regulators.
- But – in some jurisdictions the legislation and / or guidance has yet to gain full stakeholder acceptance and site specific risk based approaches to contaminated land assessment are not widely practiced or acknowledged.

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How does risk assessment help to make decisions?

- Enables informed discussion of health and ecological risks.
- Provides a means of communicating and managing risk perception of stakeholders.
- Transparent process – readily audited.
- Focuses decision making on the high risk areas.
- Can test effect of assumptions on different remediation scenarios.

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What does it cost/when is it value for money?

- Health risk assessment - $8k - $100k
- Ecological risk assessment $20k - $150k or more
- Risk assessments can assist with;
  - defining site remediation requirements;
  - establishing ongoing site management requirements;
  - addressing community concerns; and
  - fulfilling regulatory requirements.
- To provide this level of value typically considering "Tier 2" plus risk assessment. The derivation of site specific risk based standards or clean up criteria – NOT just comparison to published screening criteria.

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Australia's Health-Based Soil Guidelines 2011

- Model-generated soil assessment criteria for 50+ chemicals
- Guidance document for site specific risk assessment
- Technical document detailing soil guideline value derivation
- Drafts published Sept 2011, final imminent

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Refinery-Victoria, Australia

- Ecological Risk Assessment
  - contaminated sediment in Corio Bay
- Human Health Risk Assessment
  - off-site recreational users and school children
  - occupational health assessment for on-site employees
- Estimated >$10 million saved in off-site remediation costs.
- On-site remediation deferred based on assessment results

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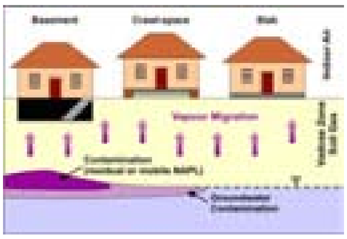
Retail Service Station - Sydney

Petroleum leak from a service station impacts properties of downgradient residents; intense concern over potential health risks from vapours and contaminated groundwater.

- Systematic soil vapour assessment over 2 years (ongoing).
- Health risk assessment for each individual property.
- Results used to demonstrate to regulators that residents health was not at risk.
- Study used to communicate with residents to help them understand, and reassure them.



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Pesticide Manufacturer, New Zealand

NZ regulators require a permit if off-site migration of groundwater contaminants occurs above guideline values.

No values exist for wide range of pesticides manufactured, and resulting uncertainty over compliance.

ERM generate marine water guideline values for 26 pesticides.

Full equivalence with NZ guidelines.

Resulting conclusion that a permit is not likely to be necessary.

Without risk assessment, detection would have required permit.

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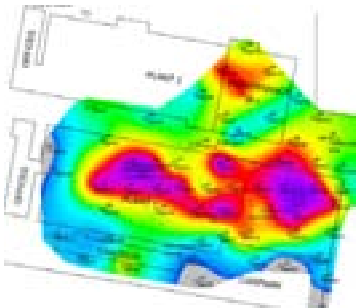
Air-conditioning Manufacturer

Chlorinated solvent plume from historic operations

Is remediation needed to redevelop site?

Vapour investigation and risk assessment used to define:

- Types of development possible without remediation based on building size and layout.
- Types of development requiring protection from vapour intrusion.
- Monitoring criteria to maintain 'no risk' status both on and off site.



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Measuring Sustainability At Portfolio Level

- Management of a portfolio of approx 150 sites.
- Cost savings a contract Key Performance Indicator (KPI)
- Classes of Cost Savings
  - Technical Innovation – typically result in reduction in resource.
  - Regulatory Advocacy – typically result in reduction in resource..
  - Commercial Efficiency – Usually a negotiated outcome without offset
- Register (log) of Cost Savings maintained as part of contract.
- Over 100 cost savings examples per year.
- Provided means of analysing and “ measuring” sustainability benefit in terms other than $.

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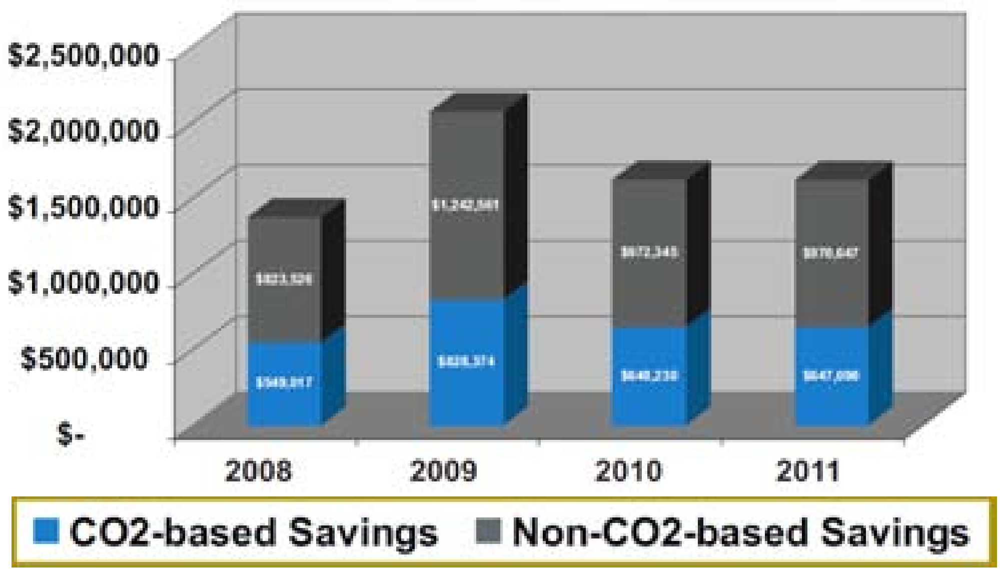
Cost Saving Summary



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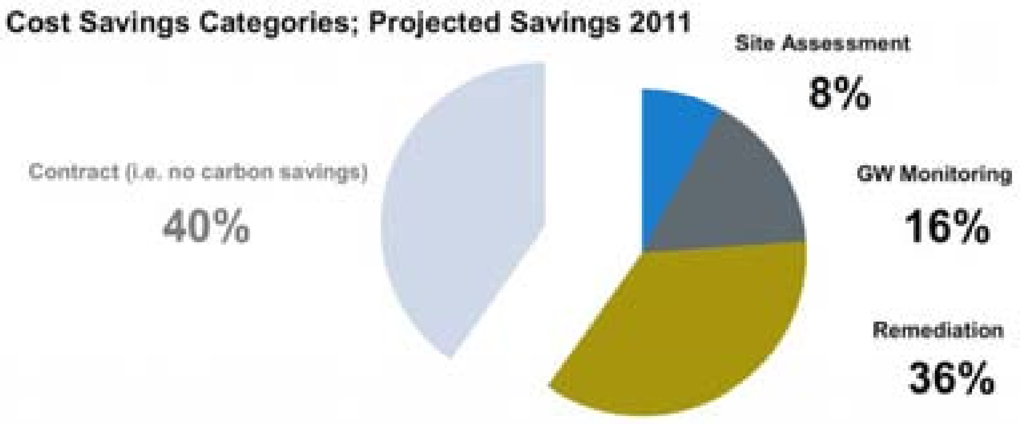

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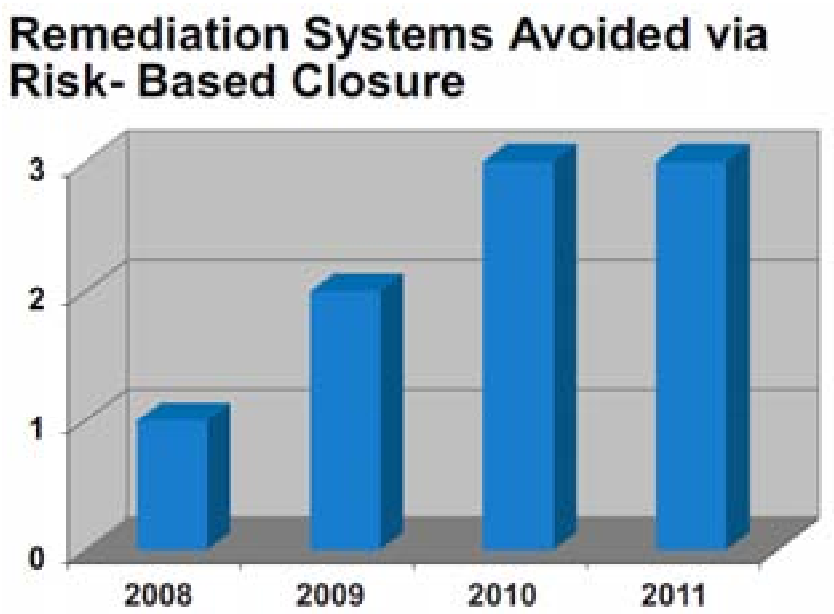

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Assumptions for CO2 –e Emissions Avoided

1. Typical Site Assessment saves 3.7 tonnes CO2-e
   a. 4 people on site for 4 days/3 nights
   b. Drill rig running 8 hrs/day for 4 days
   c. 300 km return for drill crew/rig
   d. 300 km return for ERM staff
   e. 2.4 tonnes non-hazardous soil disposal
   f. Typical Site Assessment = $35,000

2. Typical GW Monitoring Event saves 0.3 tonnes CO2-e
   a. 2 people on site for 3 days/2 nights
   b. 300 km return for ERM staff (diesel vehicle)
   c. Typical GME = $15,000

3. Typical Remediation saves 246 tonnes CO2-e
   a. Air Sparge/Soil Vapour Extraction
   b. Electric consumption = 505 KW/day
   c. System operating period = 548 days (1.5 year)
   d. Typical Remediation System = $200,000

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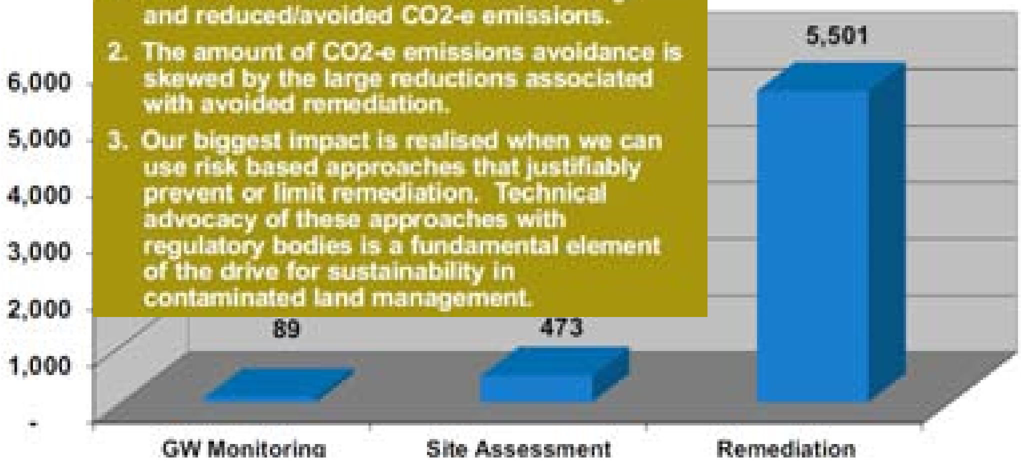
Savings in CO2-e Tonnes by Category 2008-2011

CONCLUSIONS

1. There is a clear link between cost savings and reduced/avoided CO2-e emissions.
2. The amount of CO2-e emissions avoidance is skewed by the large reductions associated with avoided remediation.
3. Our biggest impact is realised when we can use risk based approaches that justifiably prevent or limit remediation. Technical advocacy of these approaches with regulatory bodies is a fundamental element of the drive for sustainability in contaminated land management.



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Summary

Aim: Highlight the significance of risk assessment in sustainable management of contaminated land.

- Risk Assessment (Tier 1 plus) is an increasingly important tool for sustainable management of contaminated land
- Reduce, target or eliminate need for costly carbon intensive remediation measures.
- Advocacy by regulators, industry groups and technicians (consultants) is necessary to embed these approaches in statutory tools and grow acceptance.
- The Working Group on Remediation for Soil and Groundwater Pollution of Asian Countries (ReSAGPAC) is in an excellent position to inform and enable this process

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Technologies and Approaches for Sustainable Sediment Management

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Abstract

Sustainable sediment management is a comprehensive approach for addressing the long term management and conservation of sediments in a port or harbor, river or watershed. The goal is to maintain current and future economic and ecosystem-based services provided by the aquatic environment while balancing broader regional, environmental and societal needs.

Typically, sediments are managed on a project by project basis without the benefit of a comprehensive, sustainable strategy to reduce costs and improve environmental benefits. Several tools are emerging that attempt to evaluate sediment management practices that are sustainable such as practices that have either a net zero influence on the environment or enhance current conditions into the foreseeable future.

Net environmental benefit analysis (NEBA) is increasingly used to forecast different sediment management and remediation decisions. NEBA incorporates a set of specific quantified ecosystem service metrics in a framework that provides a scientific basis for balancing the investment costs and labour with the environmental and societal benefits imagined during decision-making. A NEBA identifies the breakpoints where costs become disproportionate to the benefits gained. By doing so sustainable sediment management activities can be identified that minimise impacts on ecological and human use services and maximise value to the public.

Resource footprinting is a tool that is much more focused on the evaluation of specific factors such as energy or land use, carbon and water. It is a framework for measuring the net change from baseline conditions or no-action to specific factors associated with the implementation of a sediment remedy. This paper summarises from an international perspective the existing and emerging technologies and tactics for developing a sustainable management strategy for sediments. The discussion draws from expertise and lessons learned in areas such as sediment transport, erosion control, flood control, dredging and dredged materials management, beneficial re-use, contaminated sediment treatment and management, ecology and habitat restoration, risk assessment and decision theory.

Introduction

Sediments are a sink for contaminants in the environment and accretion of sediments can negatively affect navigation, port and harbor operations and flood control. Each year approximately 1 billion cubic meters of sediment are removed from waterways throughout the world in support of navigation, waterborne commerce, environmental clean-up, habitat restoration, flood control and other purposes at a cost between US$15 to 30 billion.

Sediment management is costly and complex (eg human use and ecosystems closely interact, technologies vary and available financial resources are constrained considerably in the current economy) therefore social, regulatory and economic tradeoffs are inevitable. The key challenges including environmental licensing, contaminated sediment management, emergency and contingency plans for environmental disasters, sustainable port development, dredging impacts and global climate change are shared by most commercial ports around the world.

Based on years of experience in North America, Europe and elsewhere, the best approach to these difficult challenges is the design and implementation of a logical, technically defensible sediment management strategy that uses the appropriate technical tools to collect the appropriate data to identify appropriate sediment remedies.

Adding to the complexity of sediment management is an increasing desire by regulatory agencies and other stakeholders, particularly non-governmental organisations (NGOs), that the activities and results of sediment remediation are sustainable. In the context of addressing ship navigation requirements and contaminated sediments, sustainable remediation is broadly defined as a remedy or combination of remedies whose net benefit on human health and the environment is maximised through the judicious use of limited resources. The intent is to promote protection or enhancement of ecological habitat, energy efficiency, minimisation of toxics and waste, reduced emissions of air pollutants and greenhouse gases (GHGs), water conservation and water and air quality improvement. Other factors as yet to be defined as important by stakeholders may also be a metric for judging sustainability in the future. To the extent possible, these sediment remedies provide a net benefit to the environment if their implementation and results are demonstrated to as:

- Minimising or eliminating energy consumption or the consumption of other natural resources
- Reducing or eliminating releases to the environment, especially to the air
- Harnessing or mimicking natural processes
- Reusing or recycling of land or otherwise undesirable materials
- Encouraging the use of remedial technologies that permanently destroy contaminants

The Sustainable Remediation Forum (SURF[1]) defines sustainable remediation broadly as the implementation of a remedy or combination of remedies whose net benefit on human health and the environment is maximised through the judicious use of limited resources.

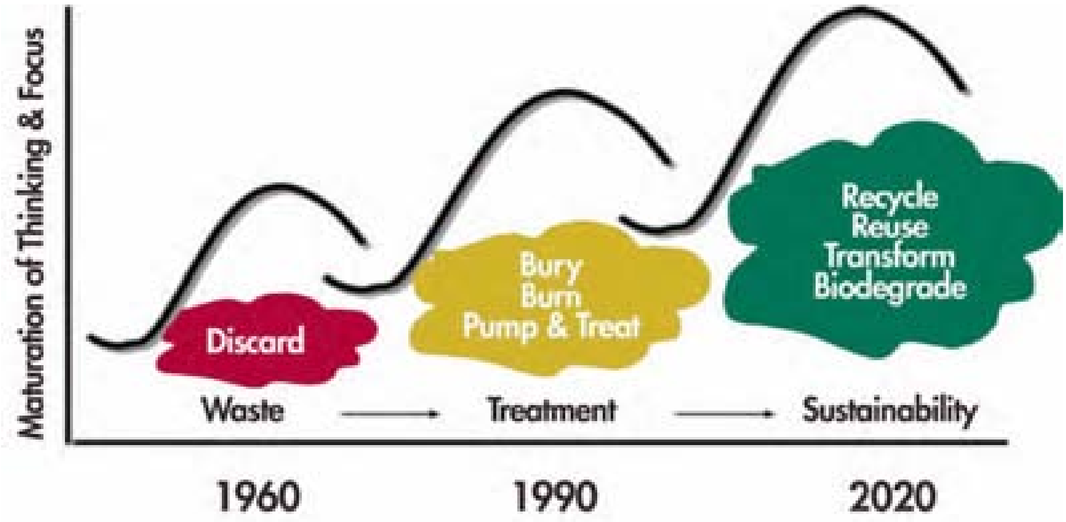

Figure 1. General evolution of the focus of environmental remediation from the 1960's to present day (Figure adapted from SURF, 2009)

A schematic illustrating the evolution of the environmental remediation industry is shown in Figure 1. As scientific understanding of biological, chemical and ecological processes in the environment has improved, the collective thinking of engineers, environmentalists, regulatory specialists, scientists and the general public have become more sophisticated about

[1] www.sustainableremediation.org

materials reuse and recycling, carbon footprinting, water scarcity, chemical hazards and the interconnectedness of human activity and the environment. According to SURF, this transformation of thinking has culminated in the maturation of environmental remediation. Sustainable remediation practices are not only those practices that reduce global impacts (eg GHG) but also those practices that reduce local atmospheric effects, potential impacts on worker and community safety and/or the consumption of natural energy resources (beyond fuel consumption) that might be attributable to remediation activities.

International finance and banking organisations are following suit (Schmidheiny and Zorraquín, 1998). Performance standards on social and environmental sustainability issued by the International Finance Corporation (IFC) require environmental projects to (a) integrate assessment to identify the social and environmental impacts, risks and opportunities of projects, (b) demonstrate effective community engagement through disclosure of project-related information and consultation with local communities on matters that directly affect them, and (c) manage social and environmental performances throughout the life of the project (Lowrance, 2008). The intent is to avoid, reduce, mitigate or compensate for impacts on people and the environment imposed by projects that include IFC financing.

Green Versus Sustainable Remediation

The US Environmental Protection Agency (USEPA) distinguishes between two seemingly indistinguishable remediation strategies. According to USEPA (2008), sustainable remediation is focussed on meeting the needs of the present without compromising the needs of future generations whilst minimising the overall burden on society. Green remediation on the other hand is defined by USEPA (2008) as the practice of considering all environmental effects of remedy implementation and incorporating options that minimise the environmental footprint of the contaminated site clean-up project. Regardless, the strategies for sustainable and green remediation are similar.

Environmental consideration	Stressors to focus on during remedy alternatives analysis
Air	Airborne NOx & Sox, chloro-fluorocarbon vapours, GHG emissions, airborne particulates/toxic vapours/gases/water vapour, temperature
Land	Solid waste production, soil quality changes, habitat changes, soil toxicity, bioavailability to terrestrial life, noise/odour/vibration/aesthetics, traffic
Water	Water use, water quality changes, bioconcentration in aquatic life, food web impacts, liquid waste production, water and sediment toxicity
Resource depletion/gain (recycling)	Petroleum (energy) consumption, mineral consumption, construction materials (soil/concrete/plastic), land use, biological resources (plants/trees/animals/microorganisms), species disappearance/changes to biodiversity

Table 1. Stressors in different environmental compartments to focus on during remedy alternatives analysis

Table 1 illustrates the stressors likely encountered during remediation that challenge the ability to implement a sustainable or green project. Until more recently identifying sustainability strategies and green remediation goals were poorly understood. The unresolved challenge was identifying performance metrics that could be reliable measured to ascertain specifically how goals and strategies were being met during the work or to predict the likely results.

What is Sustainable Sediment Remediation?

Applied to sediments, sustainable remediation is one component of a comprehensive sediment management strategy. Sustainable remediation provides a model to address the full extent of ecological services provided by environmental resources and the benefits and impacts of remedy alternatives while addressing the impacts of sediment contaminants. Sustainable remediation provides an opportunity to establish a more comprehensive view of aquatic resources which is not achieved by focussing solely on sediment contaminants.

During routine maintenance of navigation channels and ship berths at ports and marine terminals where sediments are likely to contain background levels of contaminants, sustainable sediment remediation strategies might focus on one or more beneficial uses that create either true monetary value or contribute to ecological value in the local environment (eg by creating bird or aquatic habitat, protecting shoreline property against flood damage or by stabilising or restoring shorelines after flooding). The sustainable navigation strategy, an initiative in Canada under the St Lawrence action plan phase III, is a good example of sustainable sediment management for navigation purposes (Environment Canada, 2004). The strategy intends to serve as a response to the needs and expectations expressed by various stakeholder groups concerning integrated management of dredging and sediments, contaminated site management, shoreline erosion, ballast water discharges and the environmental risks in case of spills.

When addressing industrial contamination similar sustainable sediment remediation strategies may apply however additional considerations are imposed by the presence of contaminants in the sediment that exceed regulatory limits or pose unacceptable human health and/or ecological risks. Committing to a contaminated sediment management strategy presents significant challenges (Burton and Johnston, 2010). These challenges involve identifying the contamination, understanding contaminant fate and behavior in the environment, assessing the nature and magnitude of human risks and ecological threats, selection of a remedy(s) to remove or isolate the contamination to mitigate the potential adverse effects and the technical issues associated with implementation of dredging, capping or monitored natural recovery (MNR) technologies and any materials and/or water treatment and disposal. Treatment and disposal of contaminated sediment will be even more important because in the future there are likely to be fewer available landfills and aquatic disposal sites (Magar and Wenning, 2006, Wenning *et al* 2006).

While case studies demonstrating the success of dredging continues to be the subject of debate (NRC, 2007) it is generally acknowledged to be energy intensive and to have potentially deleterious environmental side effects by generating waste and release of contaminants to other compartments (especially biota tissues and air) (USEPA, 2004). The primary advantage of dredging is its removal of mass from the environment however dredging alone rarely improves ecological services and habitat unless followed by capping and other restoration services. More favorable sustainable remediation approaches such as capping and MNR offer opportunities to exploit and enhance natural processes, minimise environmental side effects and improve natural habitat with more moderate energy use than associated with dredging (Magar and Wenning, 2006).

Using NEBA to Evaluate and Select Sustainable Remedy Strategies

In the context of site remediation, a NEBA is an approach that provides a formal quantification of the change in ecosystem service values (ecological and human use) that would be associated with the implementation of a remedial action and compares those changes to cost and predicted changes in risk (Efroymson *et al*, 2003). The concepts of ecosystem services have rapidly emerged as perhaps the best means for measuring and evaluating environmental sustainability for consumer products, business development practices, infrastructure construction and environmental remediation or restoration work. Since the goal of NEBA is to identify human activities (including sediment remedies) that maximise benefits to the public, NEBA can be an important tool for balancing sustainability goals with site risks and remedial costs for sediment management (Apitz, 2012).

This is important because to date there are few quantitative tools for evaluating and selecting sustainable practices. The majority of remedy decisions are based on an evaluation of remedial alternatives that rarely include a formal quantification of their effect on ecosystem service values (ecological and direct human use values). As a result, tangible metrics that can describe the benefits associated with the selection of remedial alternatives and subsequently overall site cleanup are lacking. Thus the potential exists for a remedial action to create more natural resource harm than that predicted by the risk assessment that drove the remedial action (ie create or increase natural resource liability) or provide marginal benefit compared to the effort expended.

NEBA is one of the most effective strategy tools for forecasting the result of different sediment management and remediation decisions. NEBA, incorporating a set of specific quantified ecosystem service metrics, provides a scientific basis for balancing the investment costs and labor with the environmental and societal benefits imagined during decision-making. The NEBA approach merges ecological and human health risk assessment with economic concepts regarding the estimation of the monetary value of ecological and human uses earned or lost as a consequence of environmental work.

Using a NEBA approach the likely impacts to the aquatic environment, local ecology, public health and land use, and sustainable remediation metrics such as water use, energy use and carbon footprints associated with each remedy option can be quantified. Some of the short and long term risks are summarised in Table 2. With the ability to quantify these impacts, the non-monetary aspects of different remedy options can be quantified, assigned monetary value (for some metrics) and compared alongside traditional project costs to ascertain the overall economic, environmental and social value of each remedy.

Ecological services	Human use services	Environmental risk	Human health risk
Short term impacts			
▪ Aquatic habitat disturbance during dredging ▪ Terrestrial habitat loss from staging area and roads ▪ Air quality decline from increased truck traffic ▪ Water quality decline through dewatering ▪ Habitat destruction to dig new channel	▪ Potential loss of access to river for recreational use during construction and dredging operations	▪ Risk of hazardous material spills during truck and barge transportation ▪ Increased bioavailability of contaminants in deep sediments	▪ Risk of traffic accidents during sediment transport ▪ Worker exposure to hazardous sediments throughout remediation process ▪ Increased exposure risk from perceived water quality improvements (eg more people fishing and eating fish)
Long term impacts			
▪ Aquatic habitat improved through removal of contaminants ▪ Terrestrial habitat improvement through landscaping and replanting ▪ Water quality improvement ▪ Terrestrial habitat improvement from use of dredge spoils and creation of habitat	▪ Boating, walking, fishing and other recreational opportunities ▪ Educational opportunities with improved habitat ▪ Improved navigation potential from dredging ▪ Reduced risk of damage	▪ Reduced risk of exposure to contaminants	▪ Reduced risk of exposure to contaminants

Table 2. Potential short and long term anticipated environmental risks and service benefits often (not in every case) associated with sediment remediation practices

The NEBA approach generally follows the 4 steps described in REMEDE (2007) and IMO/UNEP (2009). The 4 steps include:

- Collection of information on the physical characteristics, ecological characteristics and human use of the site
- Review of case histories and experimental results relevant to the area and response methods
- Prediction of the likely outcomes
- Comparison and weighing of the options

According to Wenning *et al* (2006), the success of environmental benefit–cost analysis approaches such as NEBA requires greater reliance on human health and ecological risk assessment in conjunction with the evolution of multivariate decision making methods such as multi-criteria decision analysis (MCDA) and comparative risk assessment (CRA). The extent to which benefits can be quantitatively included in an economic analysis is largely determined by the choice of risk assessment and field monitoring methods. Interdisciplinary collaboration between engineers, economists, regulatory specialists, community stakeholders and experts in risk assessment related disciplines is important to further development of objective, quantitative remedy alternatives analysis.

Other Tools for Developing Sustainability Strategies

Resource footprinting is a tool for evaluating remedy options that has the potential to become a standard component of remedy alternatives analysis. The focus is on supporting remediation decisions that have the most favorable footprint in terms of carbon, ecological impact, energy use, GHG emissions, land use, water use and raw materials. For example, ecological footprint analysis is increasingly used by NGOs and environmental planners as an indicator of environmental sustainability. The approach is under evaluation by USEPA (USEPA, 2011) and the approach has been included as a component of the feasibility study at one contaminated sediment site in the northwestern US (Newton and Fitzpatrick, 2012) and at various scales on upland projects. The footprint represents the amount of natural resources (eg water, land and materials) necessary to supply the resources necessary to support a particular human activity and to assimilate the associated waste generated by the activity. An approach to discerning the footprint of a sediment remedy is illustrated in Figure 2.

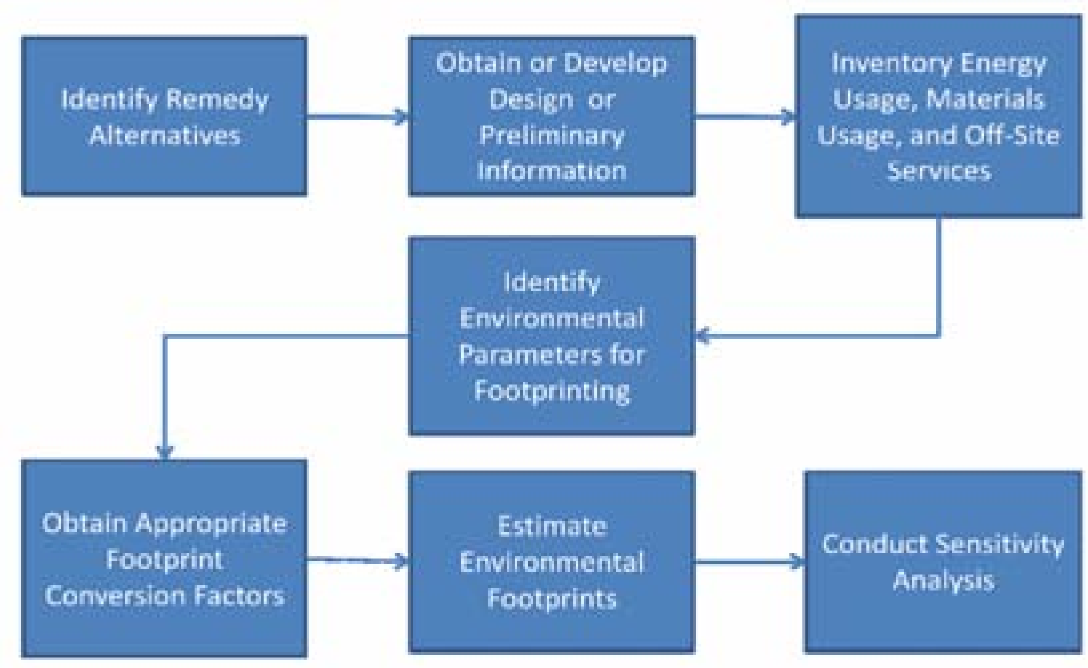

Figure 2. Determining a sediment remedy footprint

Incorporating Sustainability in Remedy Feasibility and Design Studies

According to Arevalo *et al* (2007) and Vistola (2009), sediment management should incorporate the elements of sustainability by focussing not only on the scale of the treatment process but also on the treatment chain (ie from planning and permitting to treatment, transport and disposal). Sustainability approaches are compatible with traditional remedy feasibility studies (such as those required under CERCLA in the US) because the approach strengthens overall protection of human health and the environment, addresses cost effectiveness and focusses on long term remedy success. For example within the last 10 years a growing body of information suggests that global climate change can be correlated with fossil fuel use and carbon dioxide releases into the atmosphere. Remediation experts are well aware of this concern and have firsthand knowledge of the potential contribution of energy intensive remediation systems to global climate change. At one remediation project in New Jersey, USA, it was estimated that the difference between two proposed site remedies could be as high as two percent of the annual GHG emissions for the entire state (Ellis and Hadley, 2009).

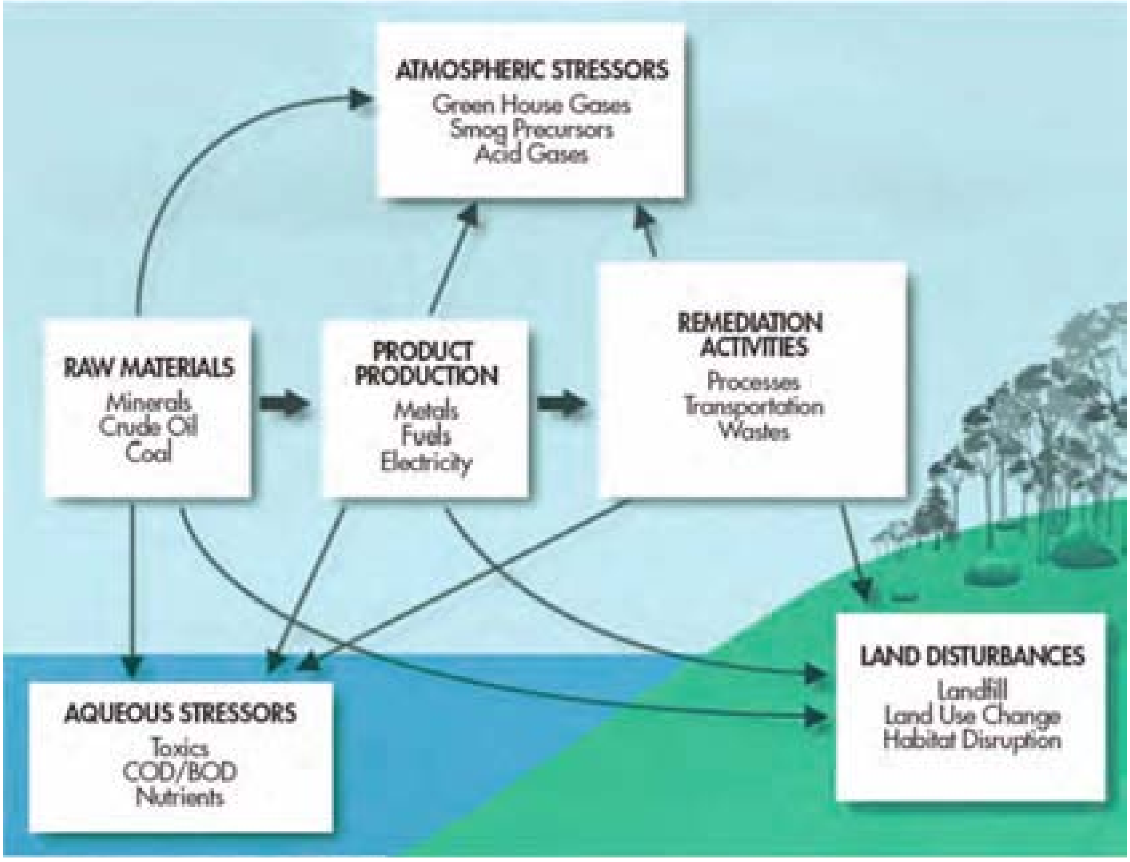

Figure 3. Sediment remedy lifecycle

Using NEBA together with traditional life cycle analysis (Figure 3), the environmental and human health impacts involved in sediment remediation can be predicted for the three key stages of remediation (raw materials extraction and processing, intermediate materials production and consumption, and processes and activities during cleanup). At the outset of a feasibility study or conducting a remedy alternatives analysis, a sustainability strategy can be developed that encompasses each of six environmental compartments. The elements of the strategy can be tied to specific performance metrics that can contribute to the understanding of the overall success of the sediment remedy (Figure 4). Technologies and monitoring tools are available.

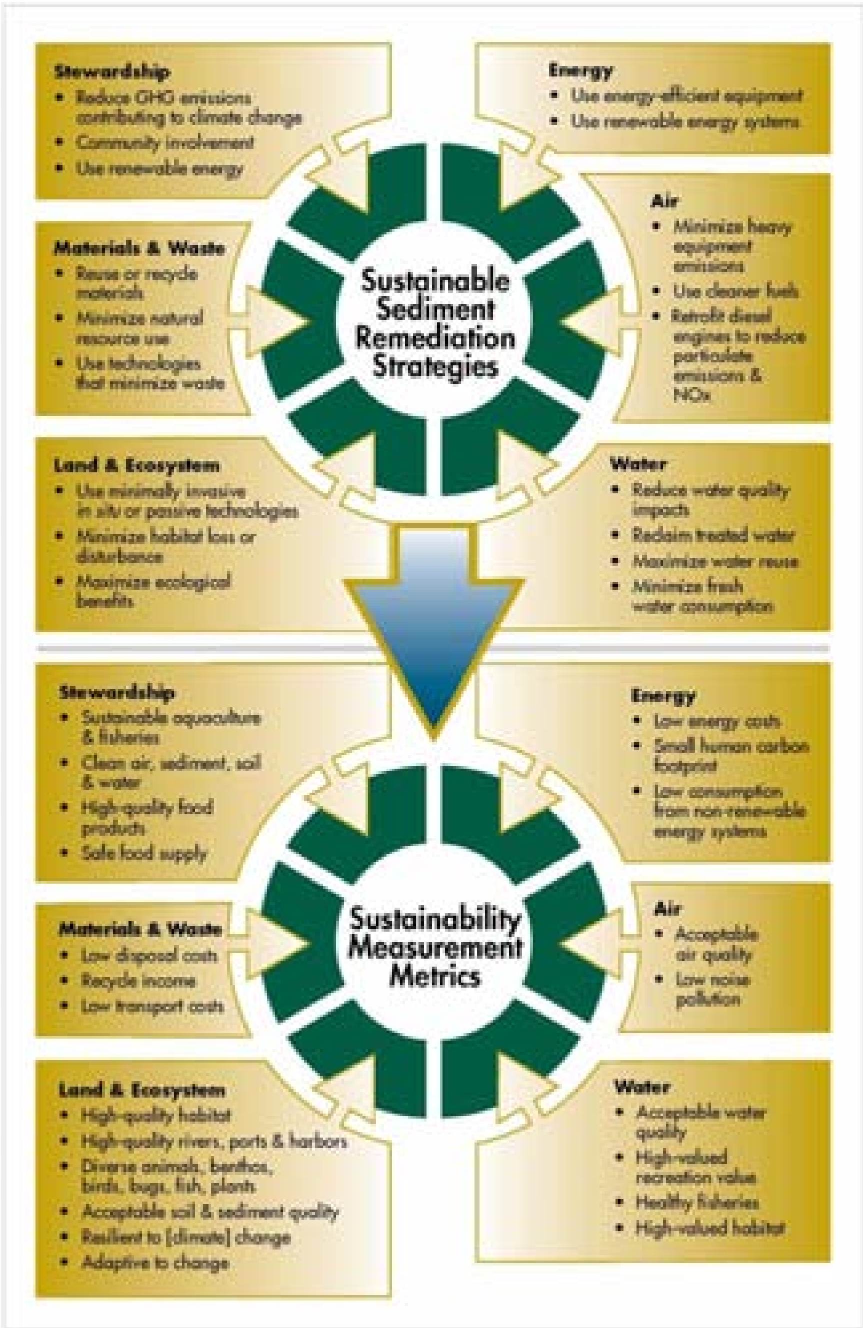

Figure 4. Matching sustainable sediment remediation strategies to performance metrics

Summary

New tools and technologies means a more reasonable balance can be achieved between environmental protection and mitigation of the collateral adverse impacts associated with the implementation of traditional remediation projects. Among the different tools that have emerged within the past five years, two tools are likely to be most important for developing a sustainability strategy for sediment remediation, net environmental (or ecosystem) services benefit analysis and footprinting (which may focus on any number of specific factors such as carbon, energy use or resource use). In the context of sustainable sediment remediation, long term success will be achieved when cleanup solutions are resilient to future changes by human activities, climate change and unexpected natural events.

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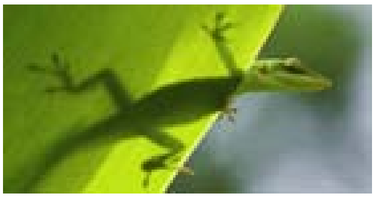
Taipei Taiwan, October 30 and 31, 2012



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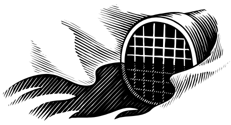
Challenges

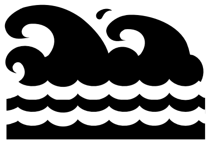

Stormwater

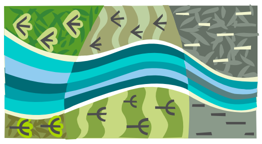

Industry


Municipal

Effluent control
Water quality
Sediment quality
Ecology
Recreation needs
Fishing
Land protection
Waste disposal
Sustainability
Economics
Money
Time
People
Society values
National security
Quality of life
Technology


Land


Sea


River

3

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SUSTAINABLE

Sediment Remediation

= perform the work EFFICENTLY

4

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Sustainable Sediment Remediation

- Remediation is typically blind, based on regulatory requirements
- What are real "sustainable" remedial actions on an ecosystem?

5

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It's All About Sustainability

IFC International Finance Corporation World Bank Group

Performance Standards on Social & Environmental Sustainability

i. Integrated assessment to identify the social and environmental impacts, risks, and opportunities of projects

ii. Effective community engagement

iii. Management of social and environmental performance throughout the life of the project

… avoid, reduce, mitigate or compensate for impacts on people and the environment

6

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Sustainable Remediation

"...implementation of a remedy or combination of remedies whose net benefit on human health and the environment is maximized through the judicious use of limited resources."

Sustainable Remediation Forum (SURF)

- Best management practices (BPMs)
- "Environmentally-friendly practices"

Promotes:

- Ecological habitat
- Energy efficiency
- Minimisation of toxics & waste
- Reduced emissions of air pollutants and greenhouse gases (GHGs)
- Water conservation
- Water and air quality improvement

7

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"Sustainable" or "Green"?

US Environmental Protection Agency (2008) distinguishes between two seemingly indistinguishable strategies:

- Sustainable remediation:
  - "... meeting the needs of the present without compromising the needs of future generations, and minimizing the overall burden on society."
- Green remediation:
  - "... the practice of considering all environmental effects of remedy implementation and incorporating options that minimize the environmental footprint of the clean-up."

8

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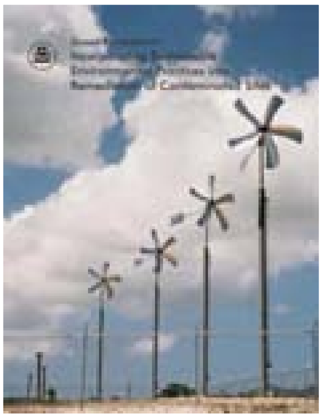
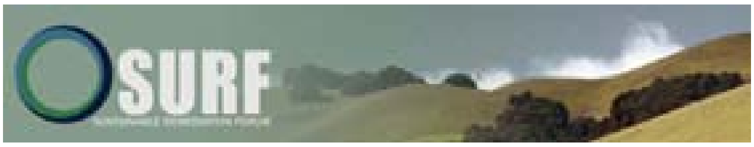
Guidelines and Tools



Region 2
Region 9
Region 10



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Sustainable Remediation Strategy

- Before the work, discuss long-term vision with stakeholders
- Combine remediation and restoration activities
- Focus on ecological recovery
- Target low energy and water consumption remedies
- Maintain small carbon footprint during and after the work
- Reduce long-term O&M costs

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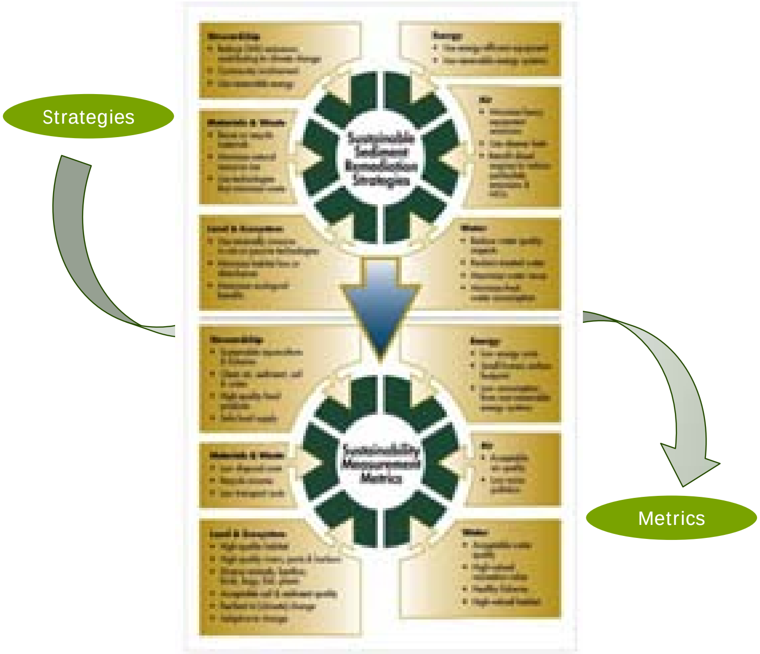
Linking Strategies to Metrics



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Metrics

Environmental consideration	Stressors to focus on during remedy alternatives analysis
Air	Airborne NOx & Sox, chloro-fluorocarbon vapors, GHG emissions, airborne particulates/toxic vapors/gases/water vapor, temperature
Land	Solid waste production, soil quality changes, habitat changes, soil toxicity, bioavailability to terrestrial life, noise/odor/vibration/aesthetics, traffic
Water	Water use, water quality changes, bioconcentration in aquatic life, food web impacts, liquid waste production, water and sediment toxicity
Resource depletion/gain (recycling)	Petroleum (energy) consumption, mineral consumption, construction materials (soil/concrete/plastic), land use, biological resources (plants/trees/animals/microorganisms), species disappearance/changes to biodiversity

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Footprint Tools

Tool	Developer	Energy use	Water	Air	Land	Ecology	Material & waste
Beneficial Reuse Model (BenReMod)	University of Toledo	√	√	√	√	√	√
Sustainable Remediation Tool™ (SRT)	Air Force Center for Engineering and the Environment (AFCEE)	√	(GW)	√	√	√	√
SiteWise™	US Navy, US Army, US Army Corps of Engineers, Battelle	√	√	√	--	--	√
Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET)	US DOE Argonne National Laboratory	√	--	√	--	--	√
GHG Protocol	World Resources Inst. (WRI) & World Bus. Council Sustain. Dvlopmt (WBCSD)	--	--	√	--	--	--

More tools are found at http://www.cluin.org/greenremediation/subtab_b3.cfm

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Carbon/GHG Footprinting

- Accounts for the impact of energy consuming processes (eg dredging, water and materials treatment and transportation)
  - Basis for understanding the overall contaminant mass reduction achieved by remediation
- In cases where the only practicable technologies are energy intensive, the only option may be the purchase of carbon credits to acknowledge the impacts of remediation

Project conception → Design → Construction plans & bids → Procurement → Construction & restoration → Monitoring

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Ecological Footprinting

A measure of materials costs in the context of resource and land use needed to satisfy those costs

Adopted from www.footprintnetwork.org

Project conception → Design → Construction plans & bids → Procurement → Construction & restoration → Monitoring

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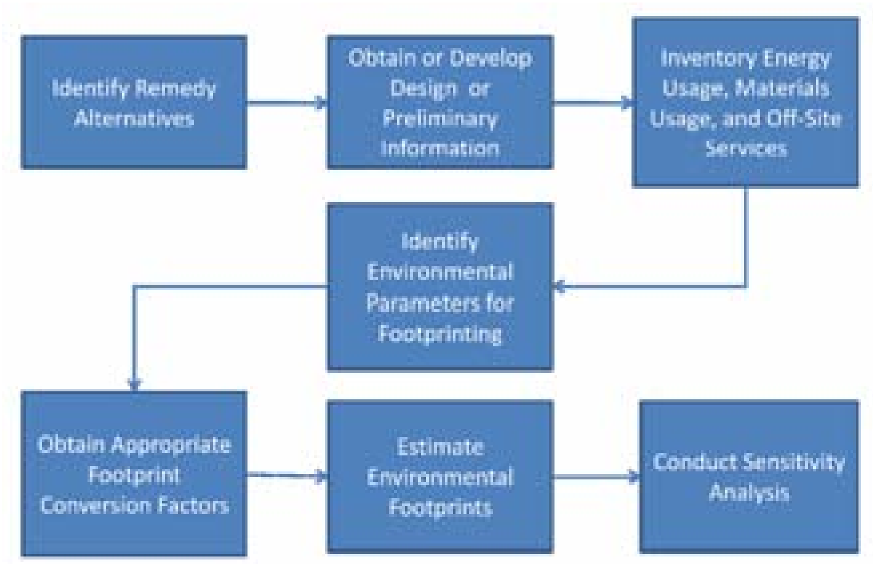
Environmental Footprinting



Approach used at a cleanup site pilot study - www.cluin.org/greenremediation

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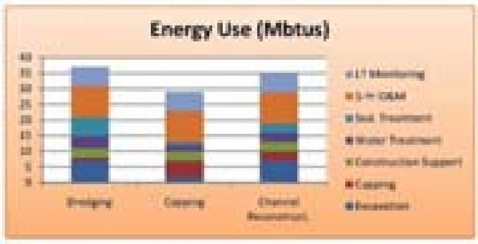
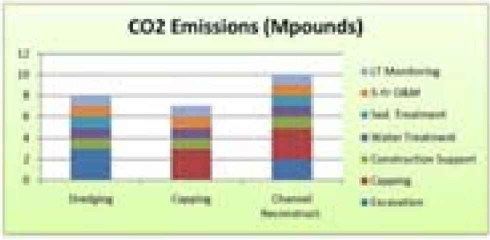
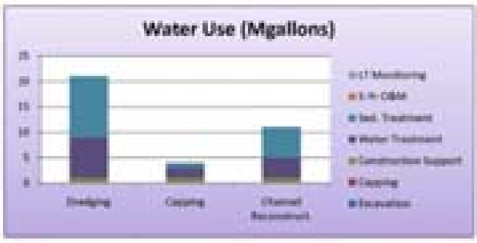
Footprints for 3 Remedy Options at a Freshwater Sediment Site

- Remedy alternatives analysis for a PAH-contaminated sediment site
- Dredging: 80,000 yd^3
- Capping: 3 acres, 6-inch sand
- Channel Reconstruction: 2 km







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Net Environmental Benefits Analysis

- Provides a balance sheet of the gains and losses in ecosystem services associated with a project, and helps to guide the identification of options that collectively will maximise the return on remediation costs
- Gain or loss of resource use (services) as a result of remediation are measured and compared with risk reduction and costs

Improvement in ecological services resulting from a remedy, as compared to baseline condition, is viewed as the net service benefit of the remedy

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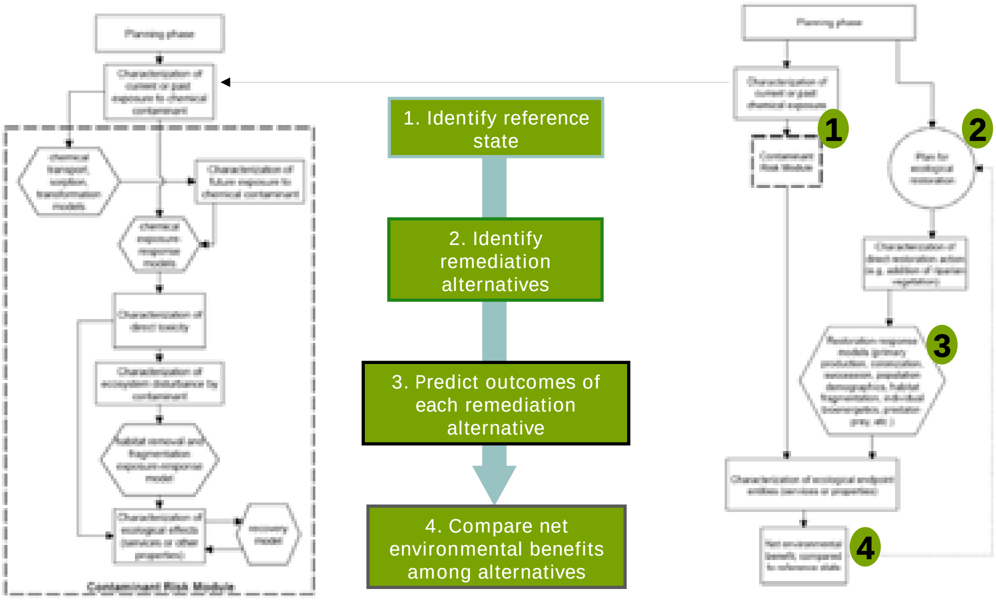
NEBA Assessment Framework



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Case Study: Pallanza Bay and River Toce

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Steps

- Identify plausible remedial alternatives
- Quantify ecological service loss and gain associated with implementation of each remedial alternative
- Quantify human use services value associated with implementation of each remedial alternative
- Evaluate how human health and ecological risk profiles might change theoretically as a result of the implementation of each remedial alternative.
- Develop order-of-magnitude cost, estimates for each remedial alternative

Remedial Action	Ecological Services (dSHYs)	Human Use Value (monetary)	Human Risk Profile	Ecological Risk Profile	Cost (monetary)
Alternative 1					
Alternative 2					
Alternative 3					
Alternative 4					

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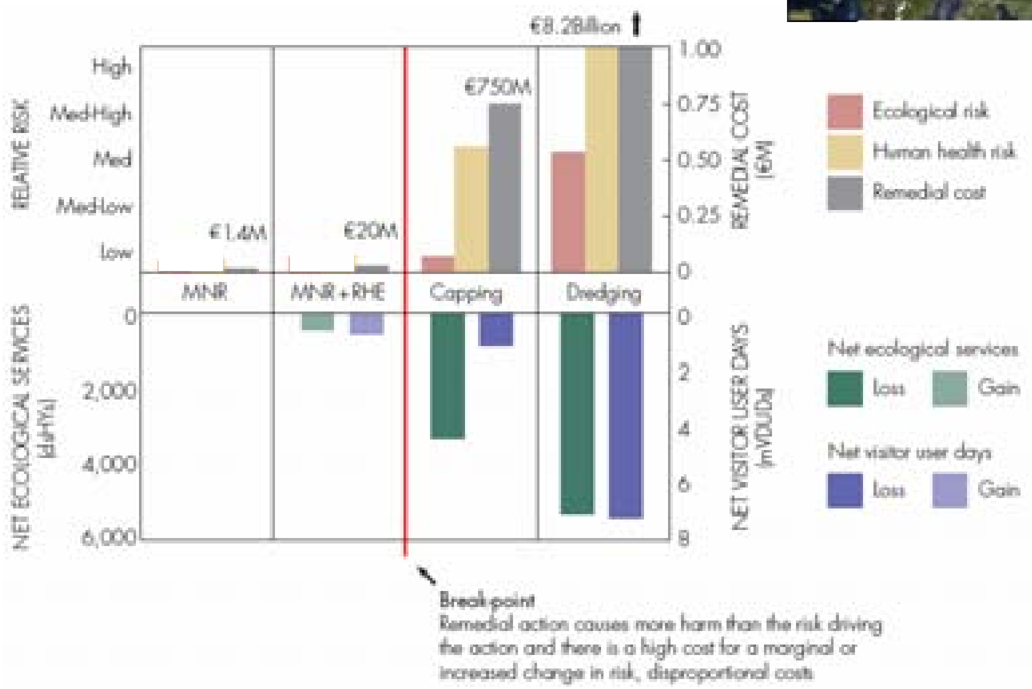
Results



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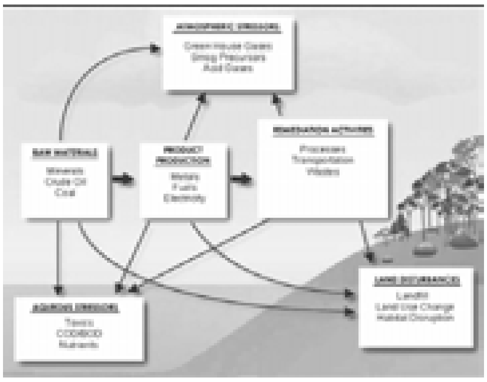
LCA for Sediment Projects

Evaluates each stage of the project:

- Raw materials extraction and processing
- Intermediate materials production and consumption
- Processes and activities during cleanup



Sediment life-cycle framework

Project conception → **Design** → **Construction plans & bids** → **Procurement** → **Construction & restoration** → **Monitoring**

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Dredging Sustainability Analysis

Background Dredging

Description	Units	Value
Emission factor for CO_2	lb/hp	1.15
Emission factor for CO	lb/hp	0.00668
Emission factor for NOx	lb/hp	0.031
Emission factor for SOx	lb/hp	0.00205
Emission factor for CO_2	lb/gal	26.835
Emission factor for CO	lb/gal	0.154438
Emission factor for NOx	lb/gal	0.716916
Emission factor for SOx	lb/gal	0.04140509
Load factor for boat	-	0.20
Work accidents rate for inland water freight transportation	Accidents/ worker/year	0.03600
Deadly work accidents rate for water transportation	Accidents/ worker/year	0.00030
Work accidents rate for heavy and civil engineering construction	Accidents/ worker/year	0.51000
Deadly work accidents rate for operating engineers and other construction equipment operators	Accidents/ worker/year	0.00107
Energy content of diesel fuel	MJ/gal	139.9625
Average break-specific fuel consumption	gal/hp h	0.04257

Dredging Input

Description	Equipment	Units	Alt 2	Alt 5
Volume placed under water level	Barge-mounted derrick crane	Cubic yard	571,710	2,013,785
	Barge-mounted backhoe	Cubic yard	122,509	431,525
Volume placed above the water level	Barge-mounted backhoe	Cubic yard	122,509	431,525
Fuel consumption	Barge-mounted derrick crane	Gallons/hour	25	25
	Barge-mounted backhoe	Gallons/hour	10.6	10.6
	Survey boat	Gallons/hour	8	8
power rating	Barge-mounted derrick crane	hp	1,890	1,890
	Barge-mounted backhoe	hp	532	532
	Survey boat	hp	250	250
dreadging rate (>0)	Barge-mounted derrick crane	Cubic yard/hour	60	60
	Barge-mounted backhoe	Cubic yard/hour	60	60
total time required for survey operation	Survey boat	Hour	710	2,310
number of water equipment operators	-	Worker	3	3
number of construction equipment operators	-	Worker	3	3
OTHER CATEGORIES	-	Worker	0	0
OTHER CATEGORIES	-	Worker	0	0
dredging area over water level	Barge-mounted backhoe	Acres	5.4	21.6

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US Air Force Sustainable Remediation Tool

Estimates sustainability metrics for specific technologies (eg excavation, soil vapor extraction, pump-and-treat, and *in situ* biodegradation)

- Tier 1 calculations = industry rules of thumb
- Tier 2 calculations = detailed, site-specific evaluation of input, technology, and output factors

Air Force Center for Engineering and the Environment (AFCEE)

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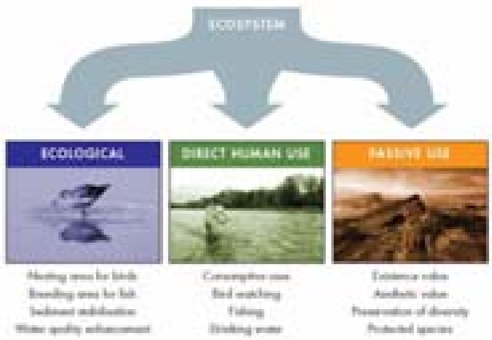
It's All About Ecosystem Services...



- Use tools that help stakeholders understand decisions regarding the level and amount of remediation that is compatible with ecology, technology, costs, and societal needs
- Make decisions that demonstrate a balance for the environment and stakeholders
- Use a systematic, consistent and defensible process that earns regulatory and public support for environmental decisions

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… and performing the work:

EFFICENTLY,

WISELY, and

Sensibly.

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… and our "Footprint" after Remediation

- Footprinting will emerge as a standard component of feasibility studies and remedy alternatives analysis
- It's about more than just <u>removing</u> contamination
- Focus is making remediation decisions that have a favorable 'footprint' in terms of carbon, ecology, energy use, GHG emissions, land use, & water and raw material consumption

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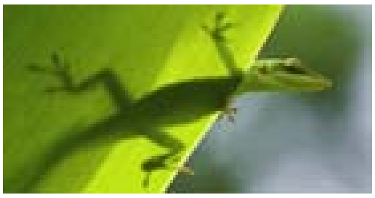
Thank You



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Two UK Remediation Case Studies: Combined *In-Situ* Treatment of Groundwater, & Stabilization of Heavy Metal Contaminated Sludge

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Case Study 1: Combined *In-Situ* Treatment Of Diesel Oil Threatening A Regionally Important Public Groundwater Supply

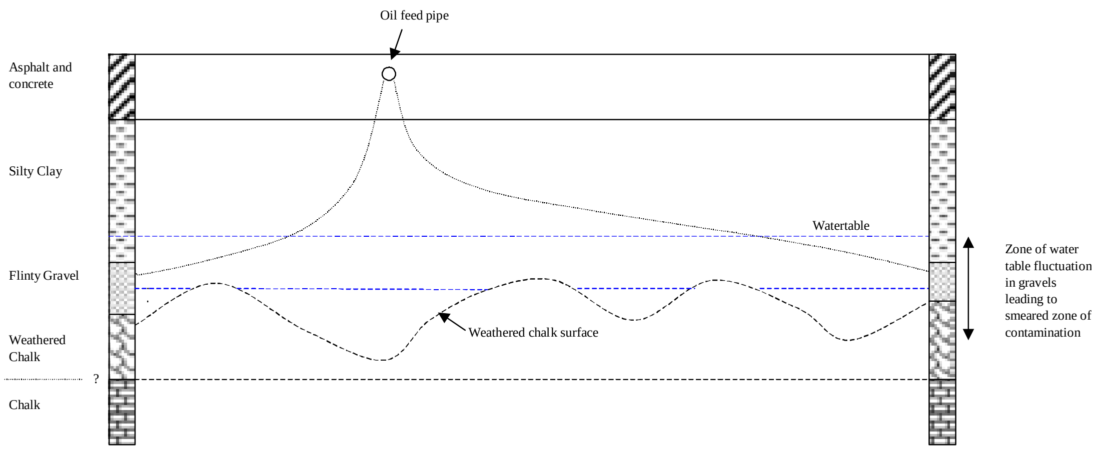
This case study discusses the performance of combined remediation techniques including product recovery, *in-situ* bioremediation and monitored natural attenuation (MNA) to treat a diesel oil spill on a highly environmentally sensitive site. The diesel contamination was threatening a water supply abstraction from a chalk aquifer that provided 16 Ml/day of public drinking water.

Background

Prior to January 2003, approximately 3,400 – 5,700 litres of diesel had escaped from a fractured oil-feed pipe that ran below ground adjacent to the pump house. Site investigation identified a plume of light non-aqueous phase liquid (LNAPL) and a much larger plume of dissolved phase hydrocarbons extending over 40 m from the area of the leak.

Site investigation identified that the vast majority of the diesel was prevented from contaminating the main chalk aquifer by the presence of a layer of "putty" chalk (chalk weathered to a low permeability clay - see Figure 1 below). However, the presence of vertical migration pathways could not be ruled out and the presence of the LNAPL and dissolved phase hydrocarbons remained a risk to the aquifer and the public water supply abstraction. Therefore remediation was required.

Figure 1: Conceptual Model of Geology and Contaminant Distribution



Remediation Works

Active remediation was performed in two stages. The first stage was carried out as emergency response with the objectives of recovering available LNAPL and prevention of further migration. A recovery system was installed that operated by recovering LNAPL and diesel contaminated water from wells, sumps and trenches for 9 months. A period of 5 months of subsequent monitoring showed no significant LNAPL and mass balance indicated that around 40% of the total spill volume had been recovered - the majority of the remaining contamination was considered to remain adsorbed to the sediments in the zone of water table fluctuation and detailed investigation revealed daily fluctuations in response to the changing pumping regime from the 4 no. abstraction boreholes on site and longer seasonal fluctuations (Figure 2).

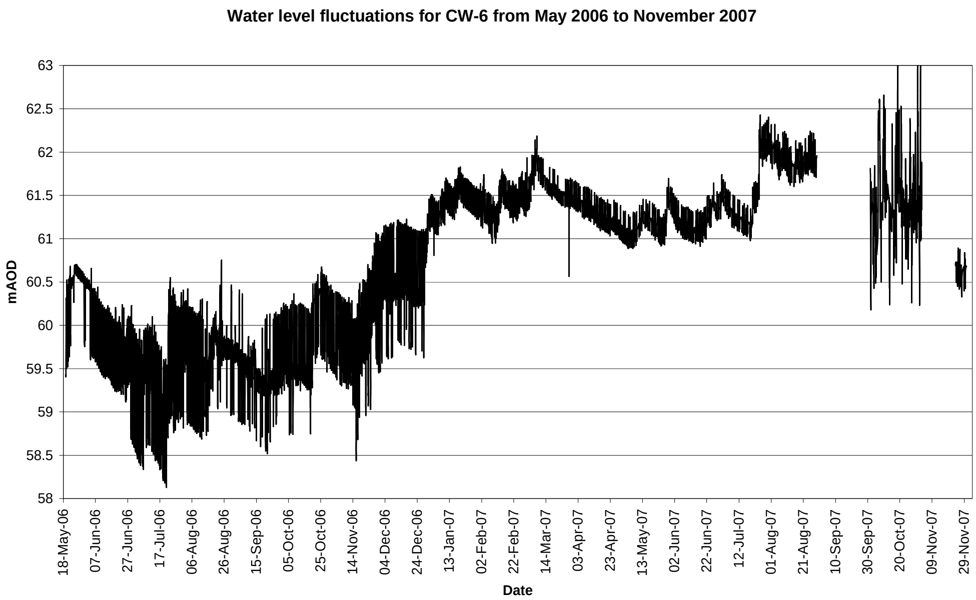


Figure 2: Daily and seasonal fluctuations in groundwater levels from May 2006 – November 2007.

Remediation Target Derivation and Options Assessment

Following the LNAPL recovery, further assessment was undertaken including a quantitative risk assessment to derive remediation targets based on the remaining contaminant distribution. This used a methodology recommended by the Environment Agency for England and Wales for contaminant fate and transport modelling, developed specifically to enable the derivation of site specific remedial targets (Carey, 2006). The risk assessment showed that concentrations of dissolved phase hydrocarbons remaining at the site exceeded the remedial targets and further remediation was required as shown in Table 1 below.

Table 1: Remedial Targets and Contaminant Concentrations

Contaminant of Concern	Remedial Target for Groundwater ($\mu g\ l^{-1}$)	Maximum Recorded Concentration ($\mu g\ l^{-1}$)
Total petroleum hydrocarbons (TPH)	266	18,000
Benzene	430	0.74
Xylene	34	24.6

A remediation options assessment was carried out which compared a number of different remediation treatments. This considered remediation outcome, physical restrictions and costs.

The chosen remediation strategy for the second stage of remediation included the continuation of pumping contaminated groundwater from two sumps as well as an *in-situ* bioremediation scheme injecting oxygen into the groundwater by direct diffusion (using iSOC^{TM} gas diffusion units). The continuation of the pump and treat was proposed so that the groundwater gradient could be maintained and controlled to encourage the migration of oxygenated groundwater away from the oxygen injection wells as well as providing a mechanism for direct removal of additional dissolved phase contaminant mass.

In-situ **Bioremediation**

An array of nine wells was used for a pilot scale implementation using gas diffusion units in each well for one month. The pilot was successful and a full scale gas diffusion system was installed for a further 12 months. Contaminant concentrations, dissolved oxygen (DO), oxidation reduction potential (ORP), electrical conductivity and water level, were monitored both inside the treatment area and outside during and following the treatment period. The system maintained DO concentrations up to a maximum of 48 mg l^{-1} in monitoring wells, exceeding saturation (11 mg l^{-1} in H_2O at 10°C).

Sampling of groundwater showed rapid shrinkage of the contaminant plume in comparison with the extent of that recorded prior to the treatment which was attributed to the oxygen diffusion remediation system. The results show that the highest concentration of TPH contamination remained near the original leak and had not migrated away from this area. Examples of the reduction of TPH concentrations over the period of remediation are shown in Figures 3 and 4.

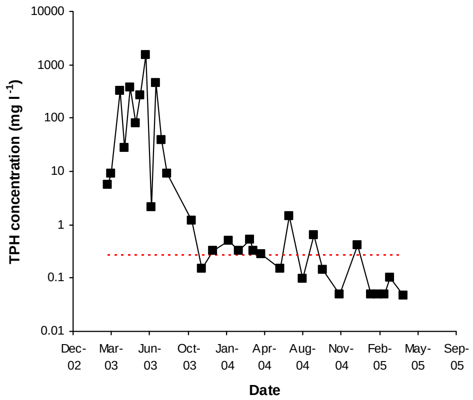


Figure 3: TPH Concentrations in MW-20

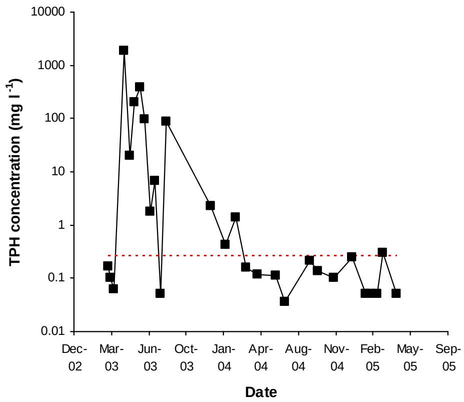


Figure 4: TPH Concentrations in MW-21

Intermittent increases in TPH or "spiking" occurred in monitoring wells closest to the area of highest concentration which are likely to have been caused by periodic leaching of adsorbed free product from residual contamination entrained in the zone of water table fluctuation, illustrating the difficulty of assessing the condition of the groundwater in the proximity of the contaminant source.

Site Closure

After 13 months of *in-situ* bioremediation using the oxygen diffusion technique, the following conclusions were drawn:

1. The remediation strategy of combining pump and treat with the oxygen injection system prevented the wider migration of diesel contamination and reduced the size of the contaminant plume;
2. The oxygen injection system showed evidence of reducing the dissolved phase contaminant concentrations in groundwater;
3. The oxygen injection system could not address the problem of intermittent leaching of LNAPL near the source of the leak; and
4. Oxygen was not the limiting factor for the rate of biodegradation in groundwater.

The cost benefit of continued source treatment against monitored natural attenuation (MNA) was assessed. The lines of evidence described above were presented to the Environment Agency along with a remedial options assessment, and an on-going strategy of MNA was chosen as the most pragmatic. MNA was carried out until 2011 when the remedial targets were exceeded only occasionally in 2 of the 51 monitoring boreholes installed at the site. It was agreed by the Environment Agency that the remaining limited contamination was of low risk and did not justify further expenditure on remediation or monitoring.

The project represented a successful implementation of a strategy of combined remediation techniques as well as regulatory pragmatism which was assisted by the provision of high quality data collected during the remediation process.

Case Study 2: Stabilisation of Steel Refinery Waste in the UK and China

Background

Steel refining has a long history in the UK and as a consequence there are very large stockpiles of refinery waste that need to be treated so that the land can be reused. UK steel works facilities might store over 1 million m^3 of refinery waste, taking up a considerable amount of land that is often required for redevelopment. Likewise, the waste contains heavy metals at concentrations that can pose a risk to health and the environment.

We provide a review of quality data collected from refinery facilities in the UK where waste has been produced and compare with data collected from steel works waste in China. Treatability trials have been completed to assess stabilisation reagents and the treatment process to reduce the risk of harm to human health or the environment in accordance with national legislation. Summary data is presented which indicates that these wastes can often be treated to allow reuse in the steel production process or as general civil engineering fill materials with minimal environmental risk.

Stabilisation/solidification is an established treatment technique for inorganic contaminants in the UK, the rest of Europe and the US. However, it is a complex process that is not fully understood. The Environment Agency of England and Wales has published a comprehensive review of the science of stabilisation/solidification (Bone, *et al.*, 2004a) as well as guidance on the use of stabilisation/solidification as a remediation treatment (Bone, *et al*., 2004b).

The choice of reagent is critical to the success of the process, and is determined by the type of contamination, the type and chemistry of the soil or sludge being treated, and the proposed long term use of the treated material (Bone, *et al*., 2004b). There are a number of stabilisation processes but the importance of each is thought to vary for different contaminants so treatability testing is a key part of the assessment process. Fixation mechanisms include a combination of:

- Adsorption to the reagent and soil matrix;
- pH controlled precipitation
- Reduction/oxidation controlled precipitation of insoluble compounds;
- Absorption/encapsulation into and onto nano-porous reagent gel;
- Incorporation into crystalline components of the reagent matrix; and
- Formation of a low permeability matrix to minimize water ingress.

Waste Composition

Composite samples of waste from the steel works were analysed. The samples included both aged and fresh waste materials from different processes within the steelworks so the composition was expected to vary. The material was tested for a suite of contaminants but was determined to contain a range of heavy metals at concentrations resulting in their classification as Hazardous Wastes and exceeding leachability criteria for surface water. This was the case for materials from both the UK and China.

The results of the total contaminant analysis, shown in Table 2 below, indicate some similarity in general composition but there is local variation particularly in relation to chromium and nickel content between the wastes produced in the UK and China.

Table 2: Steel Works Wastes Metal Content mg/kg

	UK Waste Samples			China Steelworks Waste	
Sample Ref	A	B	C	1	2
Zinc	58	77	77	75.4	67
Manganese	893	1525	1610	2960	2700
Cadmium	10	8	8	7.8	<1
Lead	113	94	71	15.5	23
Chromium	120	230	221	22700	33000
Nickel	76	106	100	2240	2400
Copper	131	136	128	976	1000

Treatment

Table 3 below shows the results of treatment on samples of the steel works refinery waste. The testing for leachates was carried out using Tank Tests (Environment Agency Standard EA NEN7375: 2004) which are appropriate for stabilised monolithic soils and approved by the Environment Agency for testing of stabilised soils. The results of treatment generally comply with the strictest available standards in each country.

Table 3: Steel Works Wastes - Stabilised (mg/l)

	UK Steelworks Waste		China Steelworks Waste	
	Pre treatment	Post treatment	Pre treatment	Post treatment
Zinc	0.065	0.0071	0.40	<0.1
Arsenic	0.030	<0.001	0.80	<0.1
Cadmium	0.225	<0.00008	<0.1	<0.1
Lead	0.125	<0.001	<0.1	<0.1
Chromium	0.630	0.029	0.20	<0.1
Nickel	0.010	0.0097	0.92	<0.1
Copper	0.040	<0.001	0.57	<0.1

Assessment of Treatment Curing Time

Table 4 below shows the reduction in leachate concentrations of the contaminants from the UK steel works waste after treatment for up to 4 days. The leachate concentrations continue to reduce after 4 days but a reducing trend is demonstrated which provided sufficient information to allow the Environment Agency to approve the treatment process.

Table 4: Stabilisation Curing Results for UK Steel Works Waste (μg/l)

	Pre treatment	**0.25 Day**	**1 Day**	**2.25 Days**	**4 Days**	**UK DWS Standard**
Arsenic	30	38.4	18.75	11.04	10.23	10
Cadmium	225	2	1.4	0.58	0.40	5
Chromium	630	39.2	31.05	24	24.35	50

Summary

The results of the analysis of steel works wastes from the UK and China show some similarities but also marked contrasts in composition. These contrasts require serious consideration when planning treatment.

Treatment trials for stabilisation/solidification of the wastes have been successful and indicate that appropriately designed stabilisation reagent formulations are able to reduce contaminant leaching to very low levels, below for example strict UK Environmental Quality Standards and Drinking Water Standards (DWS) and Chinese surface water discharge regulations.

References

Carey M.A., Marsland P.A. & Smith J.W.N. (2006) Remedial Targets Methodology. Hydrogeological Risk Assessment for Land Contamination. Environment Agency.

Bone B. D. Barnard L. H. & Hills C. D. (2004a) Review of Scientific Literature on the use of stabilisation/solidification for the treatment of contaminated soil, soilid waste and sludges' Science Report: SC980003/SR2. November 2004

Bone B. D. Barnard L. H. & Hills C. D. (2004b) Guidance on the Use of Stabilisation/Solidification for the Treatment of Contaminated Soil' Science Report: SC980003/SR1. Environment Agency

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Two UK Remediation Case Studies: Combined In-situ Treatment of Hydrocarbons in Groundwater, and Stabilisation of Heavy Metal Contaminated Sludge

Dr. Jon Burton
Technical Director
RAW Group
on behalf of CL:AIRE

CL:AIRE

RAW

Who are RAW?

- Pollution Response & Remediation specialists, est. in 1998
- >100 staff across UK, Ireland and China
- Specialise in investigation and remediation of contaminated environment (air, soil, water)
- National and international project experience

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Remediation at work: examples

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Two Case Studies

1. Combined In-situ Treatment of Diesel contaminated groundwater on a Public Groundwater Supply Site

2. Stabilisation of Steel Refinery Waste

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Case Study 1:

Combined In-situ Treatment of Diesel contaminated groundwater on a Public Groundwater Supply Site

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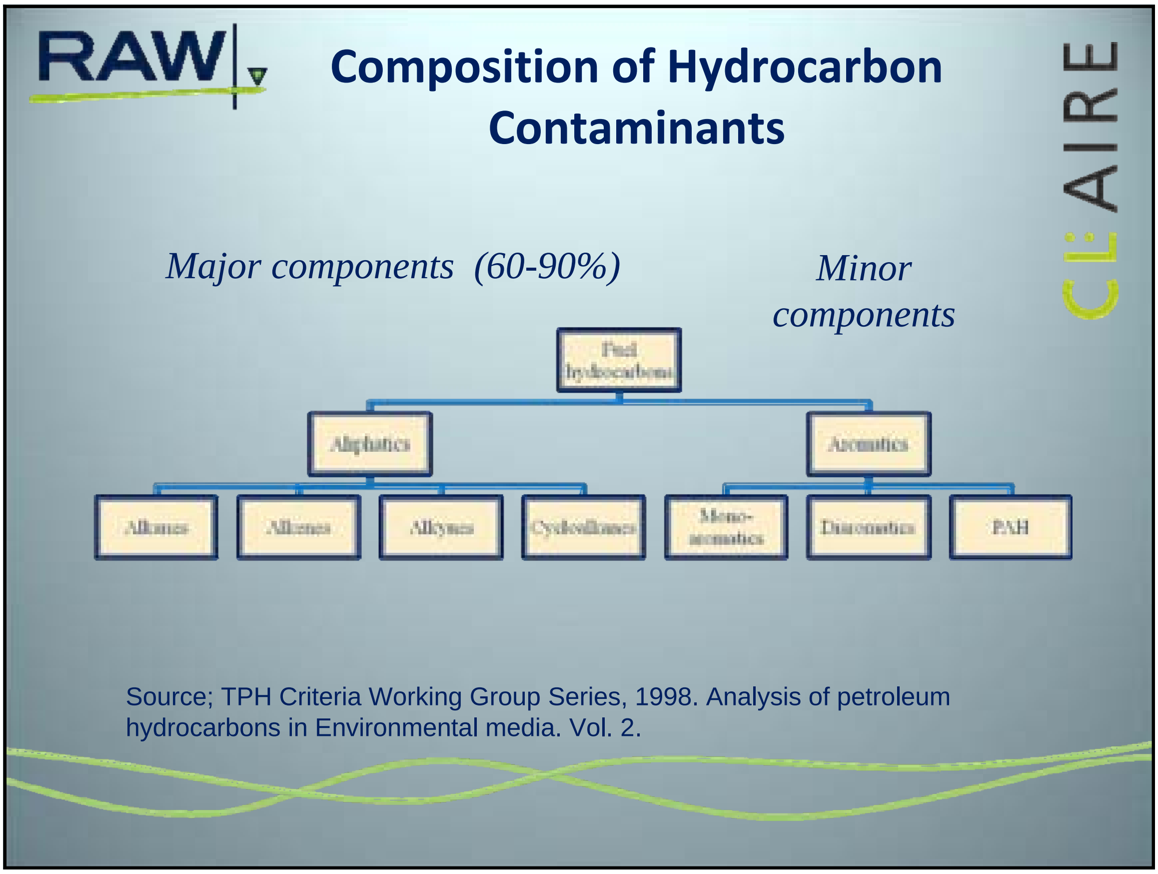
Case study 1:

- Highly sensitive commercial site abstracting 16 ML/day
- Principal aquifer used as a drinking water supply
- Oil feed pipe fractured during building works
- Estimated loss of 3,400 – 5,700 litres red diesel


RAW
Composition of Hydrocarbon Contaminants
Major components (60-90%)
Minor components
Fuel hydrocarbons
Aliphatics
Aromatics
Alkanes
Alkenes
Alkynes
Cycloalkanes
Mono-aromatics
Diaromatics
PAH
Source; TPH Criteria Working Group Series, 1998. Analysis of petroleum hydrocarbons in Environmental media. Vol. 2.
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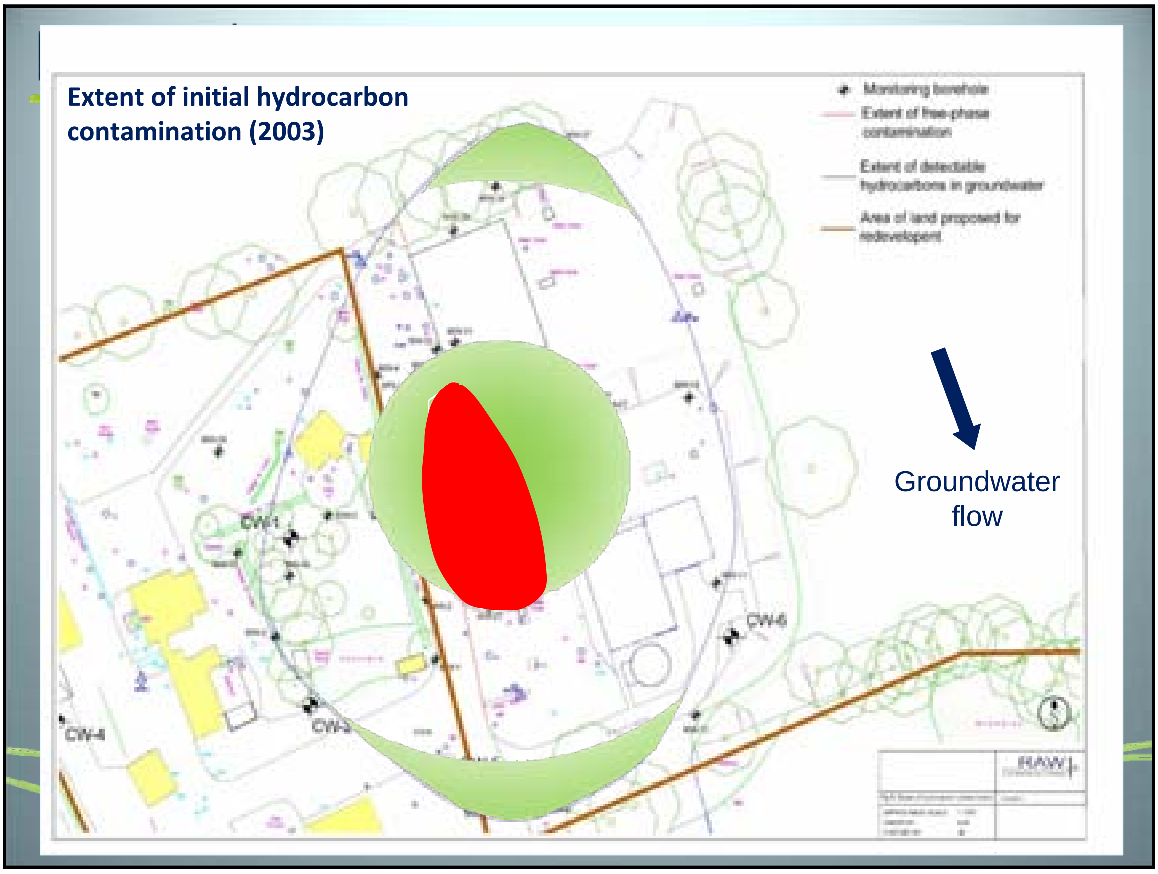
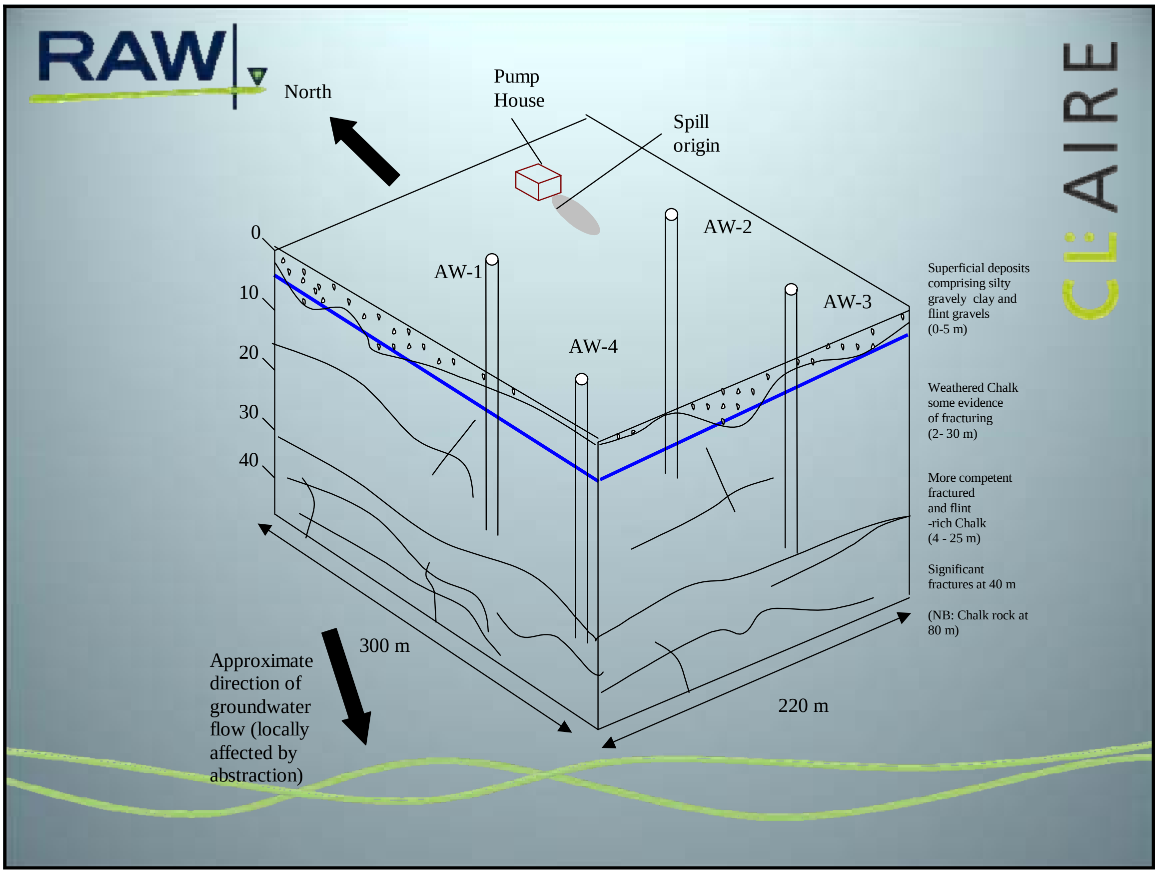
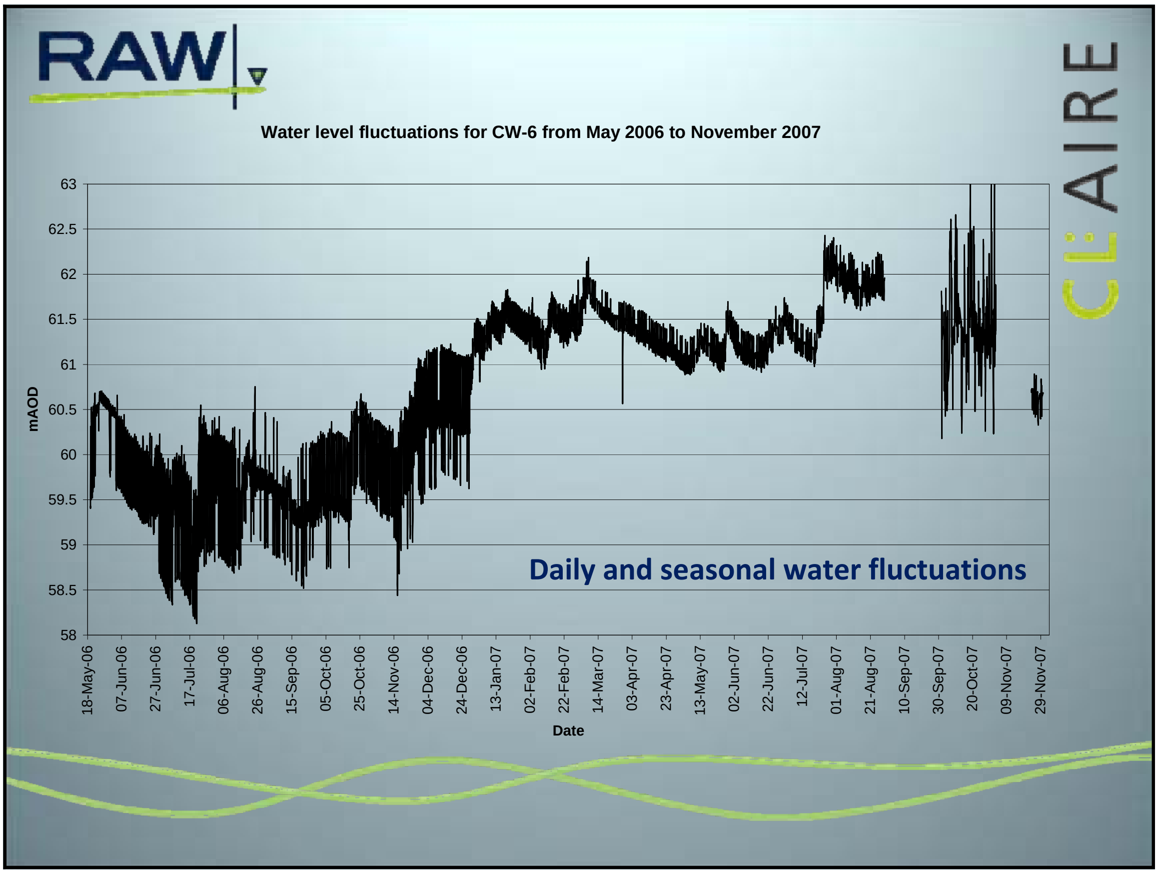
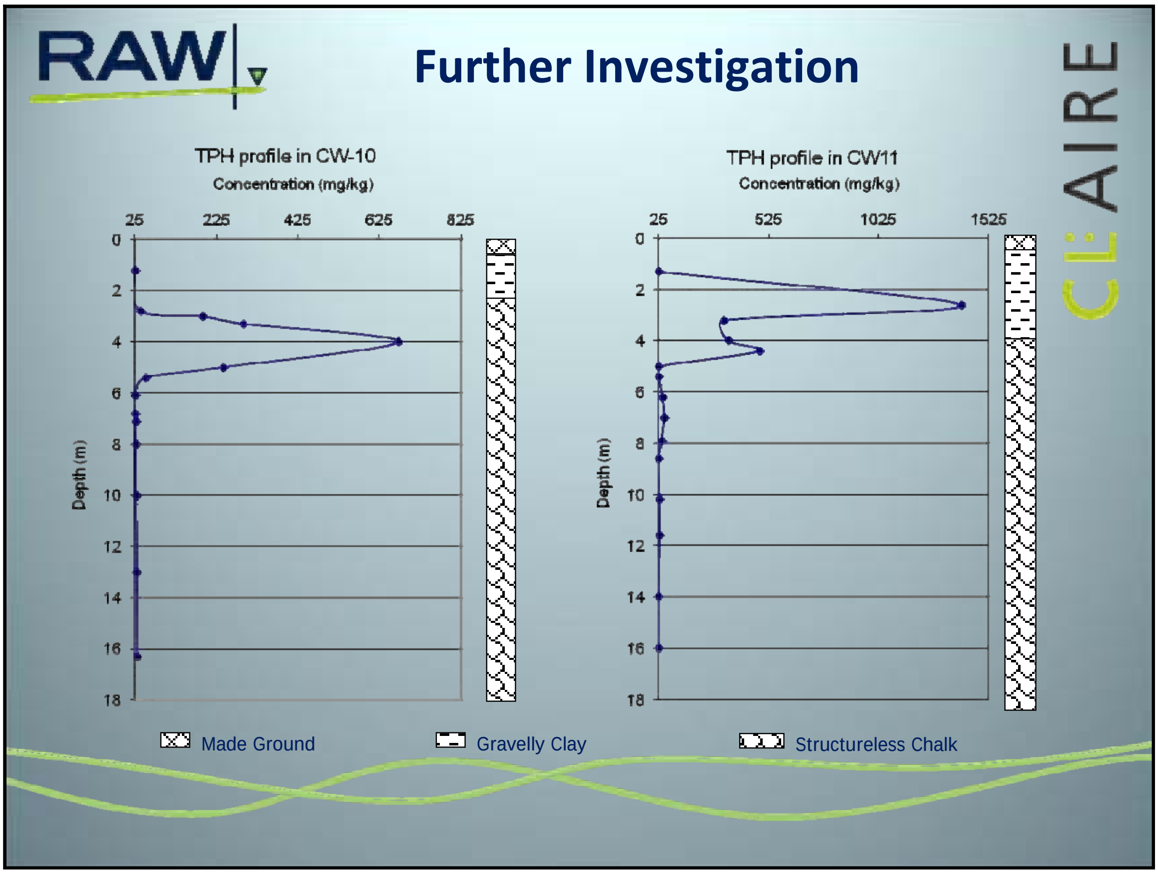
Detailed Intrusive Investigation
• Trial trenches
• 40 shallow boreholes to 5m
• 11 deep boreholes 15-20 m
WS-28
CL:AIRE

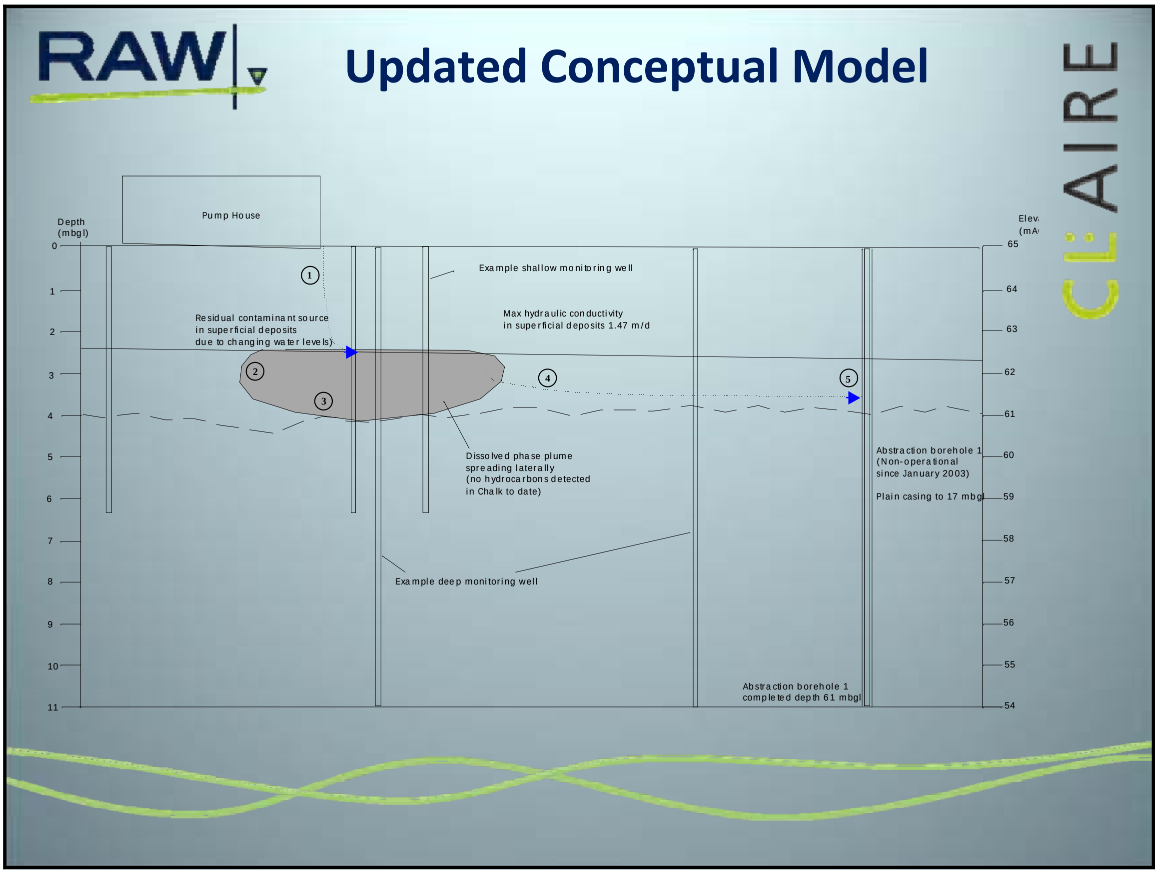

RAW
Detailed Logs
CL:AIRE


Extent of initial hydrocarbon contamination (2003)
Monitoring borehole
Extent of free-phase contamination
Extent of detectable hydrocarbons in groundwater
Area of land proposed for redevelopment
Groundwater flow
CW-1
CW-3
CW-4
CW-6
RAW


RAW
North
Pump House
Spill origin
0
10
20
30
40
AW-1
AW-2
AW-3
AW-4
300 m
220 m
Approximate direction of groundwater flow (locally affected by abstraction)
Superficial deposits comprising silty gravely clay and flint gravels (0-5 m)
Weathered Chalk some evidence of fracturing (2- 30 m)
More competent fractured and flint -rich Chalk (4 - 25 m)
Significant fractures at 40 m
(NB: Chalk rock at 80 m)
CL:AIRE


RAW
Water level fluctuations for CW-6 from May 2006 to November 2007
mAOD
63
62.5
62
61.5
61
60.5
60
59.5
59
58.5
58
18-May-06
07-Jun-06
27-Jun-06
17-Jul-06
06-Aug-06
26-Aug-06
15-Sep-06
05-Oct-06
25-Oct-06
14-Nov-06
04-Dec-06
24-Dec-06
13-Jan-07
02-Feb-07
22-Feb-07
14-Mar-07
03-Apr-07
23-Apr-07
13-May-07
02-Jun-07
22-Jun-07
12-Jul-07
01-Aug-07
21-Aug-07
10-Sep-07
30-Sep-07
20-Oct-07
09-Nov-07
29-Nov-07
Date
Daily and seasonal water fluctuations
CL:AIRE


RAW
Further Investigation
CL:AIRE
TPH profile in CW-10
Concentration (mg/kg)
25 225 425 625 825
Depth (m)
0 2 4 6 8 10 12 14 16 18
TPH profile in CW11
Concentration (mg/kg)
25 525 1025 1525
Depth (m)
0 2 4 6 8 10 12 14 16 18
Made Ground
Gravelly Clay
Structureless Chalk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Updated Conceptual Model
CL:AIRE
Pump House
Depth (mbgl)
0 1 2 3 4 5 6 7 8 9 10 11
65 64 63 62 61 60 59 58 57 56 55 54
Example shallow monitoring well
Residual contaminant source in superficial deposits due to changing water levels)
Max hydraulic conductivity in superficial deposits 1.47 m/d
1
2
3
4
5
Dissolved phase plume spreading laterally (no hydrocarbons detected in Chalk to date)
Abstraction borehole 1 (Non-operational since January 2003)
Plain casing to 17 mbgl
Example deep monitoring well
Abstraction borehole 1 completed depth 61 mbgl

Remediation

- Two stages
  - Stage I: Emergency Free product removal
  - Stage 2: Dissolved phase contamination treatment
- Remediation by pump and treat only, estimated to take >100 years. An alternative solution was required
- Secondary treatment constrained by:
  - Number of services on site
  - Cost
  - Site shut-down not an option
- Innovative remedial solution required → bioremediation

Stage 1: Pump And Treat Product Recovery System

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Stage 2: Bioremediation

- Site chemistry suitable for bioremediation (pH, nutrients etc)
- BUT oxygen limiting in contaminated regions
- Oxygen (gas) infusion sited at heart of dissolved plume using gas diffusion technology

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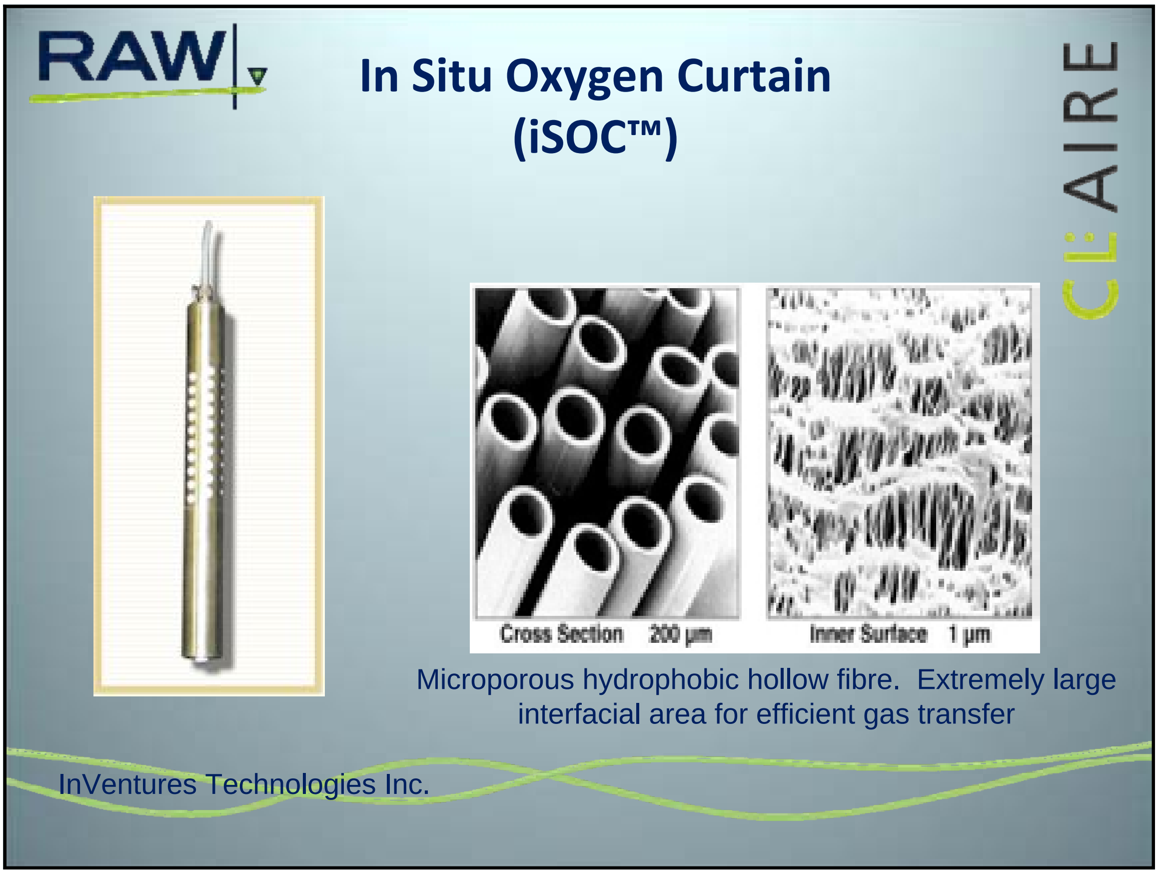
What is Oxygen Diffusion Technology?

- Method for increasing dissolved oxygen in groundwater
- Increases / supplies oxygen required for aerobic bioremediation
- Ensures cost effective saturation of water with oxygen (bubble-less).
  - Other methods waste energy and gas, bubbles to surface, poor transport of O_2
  - Reported super-saturation of 70 mg l-1 (non-equilibrium)
- System can also infuse other gases (e.g. methane or propane for chlorinated solvents (co-metabolism)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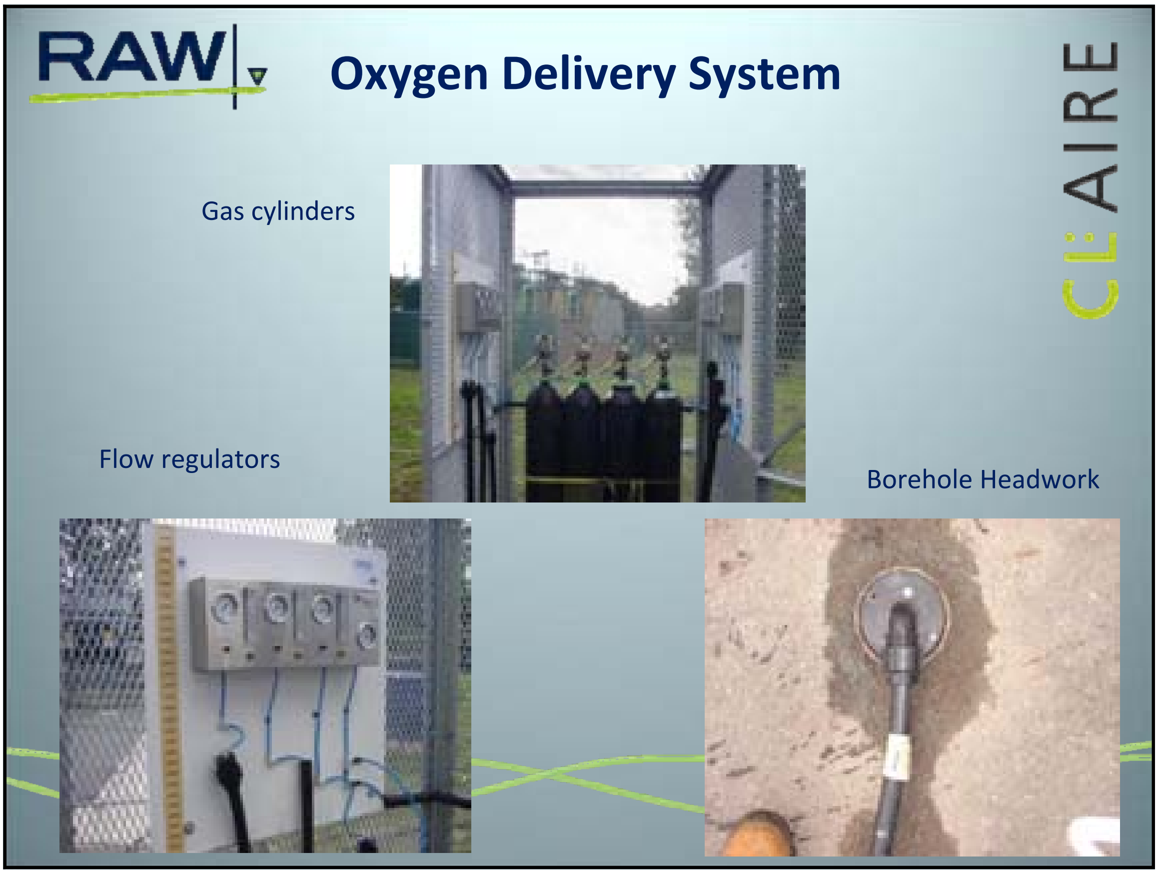
In Situ Oxygen Curtain
(iSOC™)
CL:AIRE
Cross Section 200 µm
Inner Surface 1 µm
Microporous hydrophobic hollow fibre. Extremely large interfacial area for efficient gas transfer
InVentures Technologies Inc.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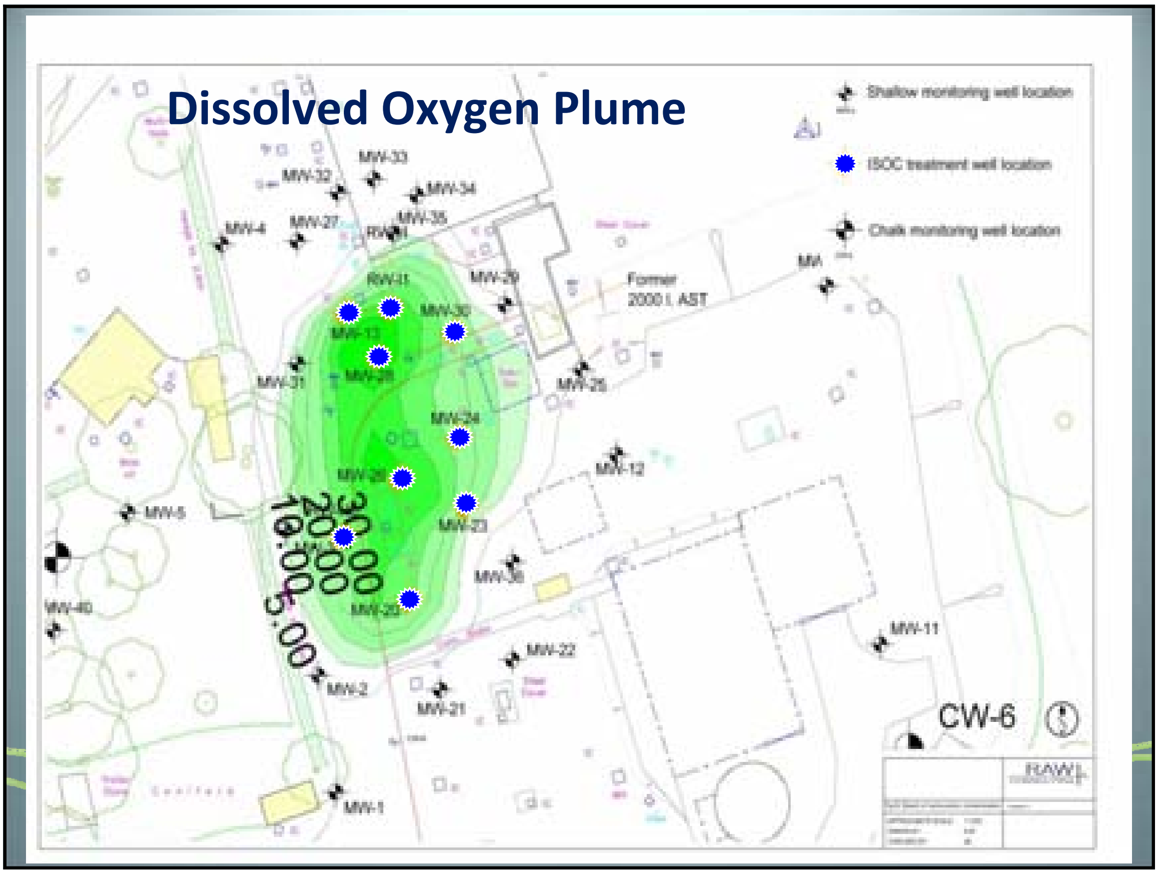
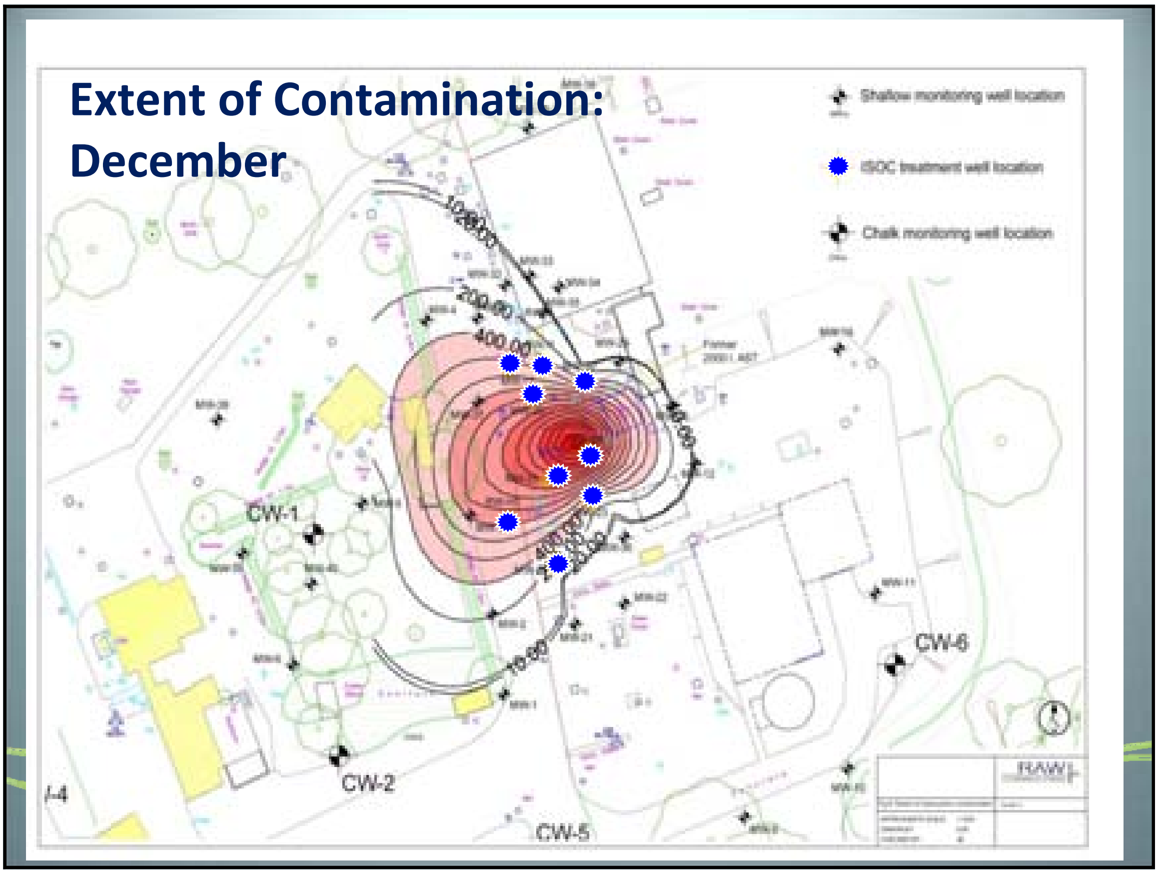
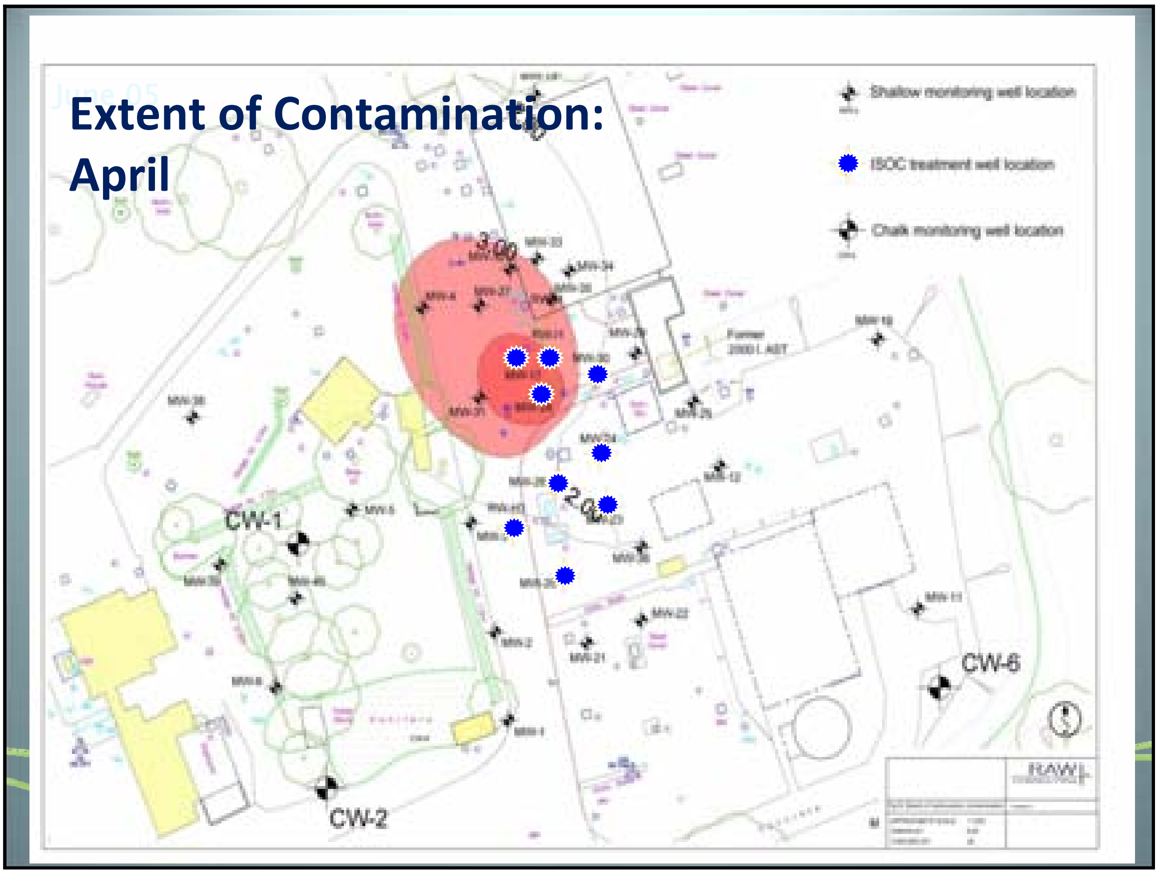
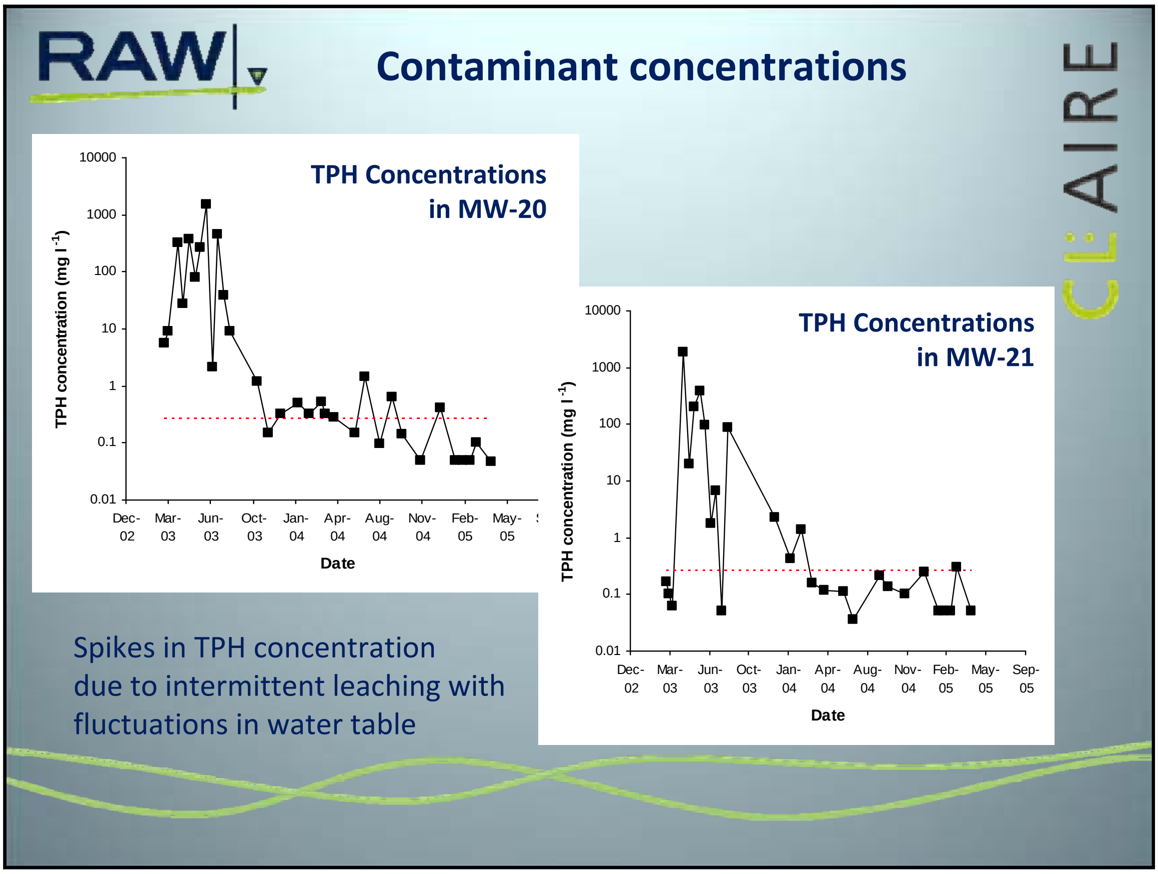
Oxygen Delivery System
CL:AIRE
Gas cylinders
Flow regulators
Borehole Headwork


Dissolved Oxygen Plume
Shallow monitoring well location
ISOC treatment well location
Chalk monitoring well location
Former 2000 L AST
CW-6


Extent of Contamination: December
Shallow monitoring well location
ISOC treatment well location
Chalk monitoring well location
CW-1
CW-2
CW-5
CW-6


Extent of Contamination: April
Shallow monitoring well location
ISOC treatment well location
Chalk monitoring well location
CW-1
CW-2
CW-6
RAW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Contaminant concentrations
CL:AIRE
TPH Concentrations in MW-20
TPH concentration (mg l-1)
10000
1000
100
10
1
0.1
0.01
Dec-02
Mar-03
Jun-03
Oct-03
Jan-04
Apr-04
Aug-04
Nov-04
Feb-05
May-05
Date
TPH Concentrations in MW-21
Sep-05
Spikes in TPH concentration due to intermittent leaching with fluctuations in water table

Case study 1: Summary

Positives

- Gas infusion created a plume of DO at concentrations exceeding saturation (max. 51 mg l^{-1}) ensuring sufficient oxygen
- Diesel range hydrocarbons intermittently leached as a result of water table fluctuations
- Contaminant plume considerably reduced in 6 months but further MNA required to close project with regulators

Lessons

- Iron precipitation on ISOC units can result in clogging
- Efficacy temporarily hindered by low water levels (driest period for 3 years) and subsequent contaminant leaching

Case Study 2:

Stabilisation of Steel Refinery Waste

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What is Stabilisation/Solidification?

- Widely accepted remediation technology
- Contaminated soils, wastes & sludges
- UK & US regulatory guidance
- Combines chemical and physical fixation processes
- Specific processes vary depending on contaminants
- In-situ & ex-situ treatment possible

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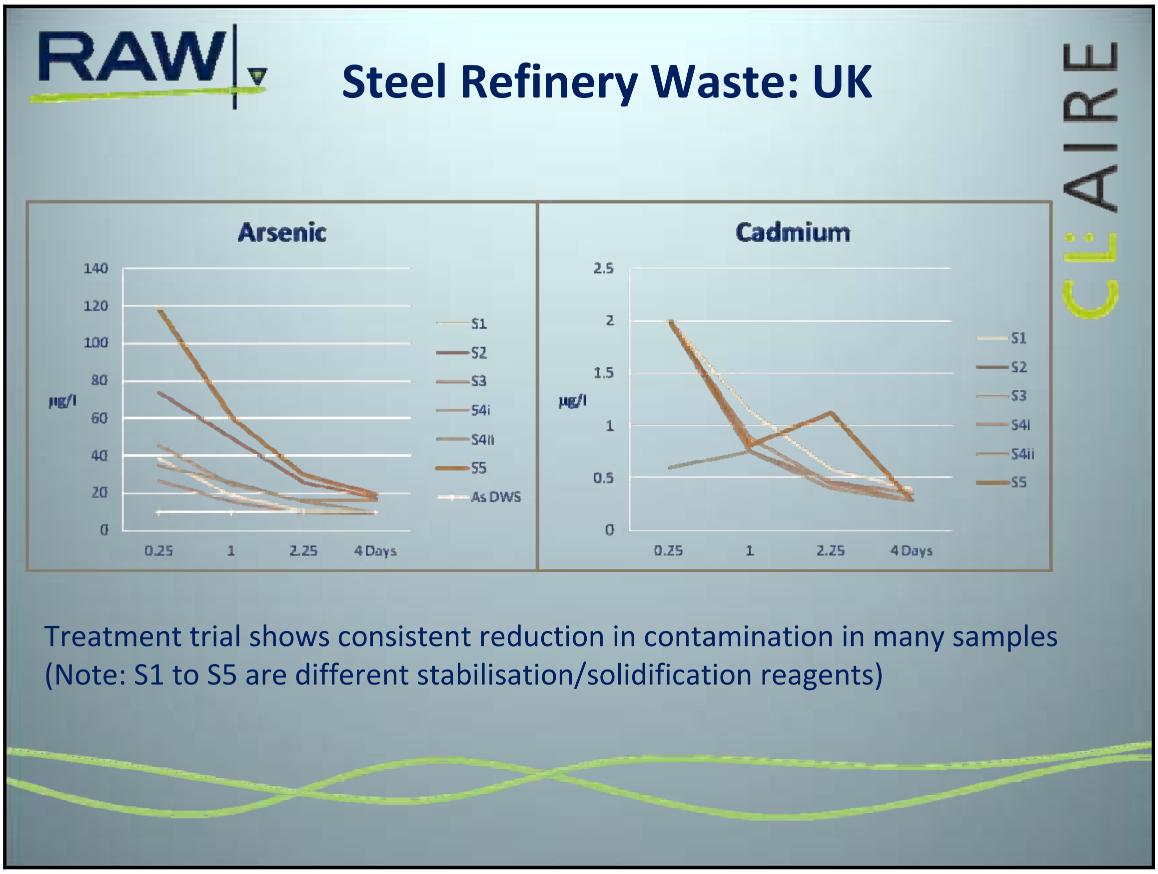
Steel Refinery Waste: UK

- Scale & dust produced as waste by the refinery
- Scale, dust and filter cake wastes
- 1 million tonnes of waste stored
- Little prospect of re-use
- Environmental risk
- Heavy metals contaminants in the waste:

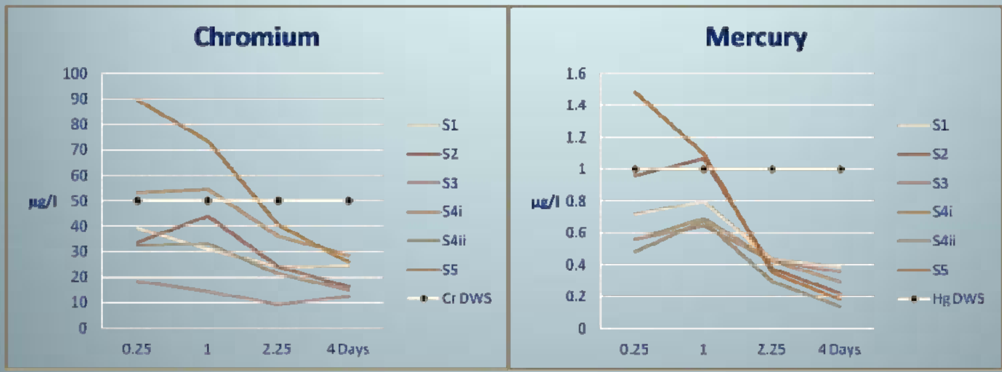
  As, Cd, Cr, Pb


RAW
Steel Refinery Waste: UK
CL:AIRE
Treatability Trial
• Objectives: Meet water quality standards
• Laboratory trial testing selected reagents
• Proves treatment concept
• Refine design if necessary
• Authority approval for site trial


RAW
Steel Refinery Waste: UK
CL:AIRE
Arsenic
140
120
100
80
60
40
20
0
µg/l
0.25
1
2.25
4 Days
S1
S2
S3
S4i
S4ii
S5
As DWS
Cadmium
2.5
2
1.5
1
0.5
0
µg/l
0.25
1
2.25
4 Days
S1
S2
S3
S4i
S4ii
S5
Treatment trial shows consistent reduction in contamination in many samples
(Note: S1 to S5 are different stabilisation/solidification reagents)

RAW CL:AIRE

Steel Refinery Waste: UK



Treatment trial shows consistent reduction in contamination in many samples (Note: S1 to S5 are different stabilisation/solidification reagents)

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Steel Refinery Waste: UK

- Results of treatment trial exceeds expectations
- Leachability generally below drinking water standards
- Achieves regulatory approval
- Client has budgetary constraints – full scale treatment not started yet

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Steel Refinery Waste: China

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- Scale, dust and acid sludge waste produced by the refinery
- Scale, dust and filter cake wastes
- Over 100,000 tonnes per year produced
- Hazardous waste – cannot be legally landfilled
- Limited use in brick manufacture
- Heavy metals contaminants in the waste:

  As, Cd, Cr, Pb, Ni

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Steel Refinery Waste: China

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Treatment Trial

Stage 1: Laboratory Trial
•Samples of material and background data provided
•Laboratory analysis to confirm composition and hazard
•Outline treatment and reagent design
•Laboratory treatability trial by third party consultant
•Objective: reduce classification to non-hazardous to allow landfill disposal
•Trial exceeds success criteria

Stage 2: Site Trial
•Objective changed: treatment for reuse within production furnace due to success of laboratory trial
•3,000 tonnes to be treated on site
•Due to commence shortly
•Dedicated treatment centre under construction

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Steel Refinery Waste: China

Treatment Trial

•Laboratory analysis of sample;

•Sample contents:
- ~60% water
- ~20% non hazardous organic matter
- ~12% iron (Fe)
- ~3% chromium (Cr)
- ~1.5% nickel (Ni)
- ~2% manganese (Mn), copper (Cu), molybdenum (Mb), zinc (Zn), lead (Pb) and others

•Trial bespoke reagents to identify most suitable

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Steel Refinery Waste: China

Treatment Trial Results

Treatment trial uses method from UK Environment Agency document: *Guidance on the Use of Stabilisation/Solidification for the Treatment of Contaminated Soil* Science Report: SC980003/SR2 Environment Agency September 2004.

	UK Steelworks Waste (mg/l)		China Steelworks Waste (mg/l)	
	Pre treatment	Post treatment	Pre treatment	Post treatment
Zinc	0.065	0.0071	0.40	<0.1
Arsenic	0.030	<0.001	0.80	<0.1
Cadmium	0.225	<0.00008	<0.1	<0.1
Lead	0.125	<0.001	<0.1	<0.1
Chromium	0.630	0.029	0.20	<0.1
Nickel	0.010	0.0097	0.92	<0.1
Copper	0.040	<0.001	0.57	<0.1

Sample of treated material

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Steel Refinery Waste: China

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Stage 3: Planning Full Scale Treatment

- Client requirements change so treatment design must be flexible to match
- Dedicated waste treatment centre under construction
- Design treatment works:
  - RAW VL - 400 tonnes per hour
  - Treated soil suitable for reuse in refinery furnace or disposal as non-hazardous waste
  - Bespoke design of treatment reagents
  - Treatment process monitoring and validation testing programme

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Stabilisation: Treatment Equipment

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- **Large volumes**
- **Specialist plant required**
  - Continuous mixing
  - Computer controlled
  - Reagent silo
  - Mobile plant
- **Up to 400 tonnes per hour throughput**
- **Treated soil suitable for many uses**

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Stabilisation: Treatable Contaminants

- **Heavy Metals**
  - As
  - Cd
  - Cr
  - Cu
  - Ni
  - Pb
  - Hg
  - Zn
- **Organic contaminants**
  - CN
  - PAHs
  - TPH
  - Heavy oil & tars

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Stabilisation: Selecting & Designing Reagents

- **Heavy metals**
  - Chemical binding reagents
  - Soil drying
  - pH adjusting
- **Organic contaminants**
  - Chemical oxidisers
  - Activators for oxidisers
  - Chemical binders
  - Soil drying reagents


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Reuse/disposal of agricultural drainage water with high levels of salinity and toxic trace elements in central California

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ABSTRACT

Agricultural drainage waters in the western San Joaquin Valley of Central California contained high levels of salts, boron (B) and selenium (Se). To investigate the plausibility of using plants as recipients for disposing of poor-quality drainage-waters, multi-year field studies were conducted to reuse drainage water on plants that are salt and B tolerant, and accumulate soluble Se from the drainage water.

INTRODUCTION

Extensive volcanic eruptions during Cretaceous times are thought to be the primary source of selenium (Se) and other trace elements that had submerged in the western United States. Over time, Se was incorporated in sediments that were then uplifted and exposed to weathering and erosion. Weathering of reduced shale (oxidation of pyrite, FeS2) was largely a reversal of the chemistry of the early diageneses of the shale (i.e. reduction of sulphate). Because of its similar chemical and physical properties, Se substituted for sulphur in pyrite in sedimentary rock at high concentrations (Berner 1984). Agricultural practices in such soils, e.g., in the Westside of central California, require intensive irrigation and subsurface drainage to prevent salt accumulation in the surface soils. The application of excessive irrigation water causes leaching of soil salts, and increases Se and B concentrations in the groundwater, as well as in drainage waters. Management of large volumes of agricultural drainage water produced in this part of California can be a major environmental challenge, because wildlife's susceptibility to Se toxicity (Ong et al. 1997). Therefore, it is important to substantially reduce the volume of drainage water resulting from agricultural production in central California. One possible strategy is the reuse of this poor quality drainage.

Reusing poor-quality water for irrigation can serve two purposes – one is to dispose of drainage water that would otherwise be costly to be treated, and the other is to utilize poor-quality drainage water as a new water resource for growing crops that have economic value. The concept of reusing and disposing of salt-and Se-laden drainage water in agricultural systems was originally expanded upon by Cervinka et al. (1999) as the Integrated on-Farm Drainage Management (IFDM) system (formerly also termed the 'agroforestry system'). The IFDM system involved the use of freshwater (i.e. with low salinity and Se concentration) to grow salt-sensitive crops, and the use of the resulting drainage water to irrigate salt-tolerant crops (Lin et al. 2000). Drainage water produced from the irrigation of salt-tolerant trees or grasses was, in turn, used to irrigate highly salt-tolerant halophytic plants. By this means, the volume of drainage water was substantially reduced by evapo-transpiration, and the remaining drainage water was eventually disposed of via sprinklers into a lined solar evaporator (Lin et al. 2002; Cervinka et al. 1999).

The sustainability and success of a drainage-water reuse strategy is dependent on managing the ever-increasing accumulation of salts and using the appropriate plant species for the varied quality waters and soils. In central California, suitable plants must be salt- and

B-tolerant, and be fairly low-maintenance to grow (see Benes et al. 2004). Maas and Grattan (1999) have reviewed the effects of salinity on the yields of different crops, and clearly indicated that crop yields are a function of interactions between salinity and various soil, water and climatic conditions. When possible, the economic viability of selected crops and a low field maintenance requirement should be considered as two important criteria for the selection.

The objective of this review was to illustrate a plant-based agricultural drainage-water reuse system in the Westside of central California, with an emphasis on the role of soil and vegetation in operating a water reuse system in an environment having high levels of salt, B and Se.

MATERIALS AND METHODS

The drainage-water reuse field project was initially established in 1994 on a commercial farm (Red Rock Ranch) in Five Points, California, and was comprised of reuse components A through E (see Fig. 1 for the field layout); more detail was described by Bañuelos and (Lin 2007). Based upon reported salt and B tolerances of different plant species (Maas and Grattan 1999), the plant species exhibited in Figure 1 were specifically selected for the respective drainage reuse components. During the experimental periods, data were collected from sampling sites located on the following components: (A) 195 ha of salt-sensitive crops, such as lettuce (*Lactuca sativa*) and tomatoes (*Lycopersicon esculentum*); (B) 52 ha of salt-tolerant crops, including cotton (*Gossypium hirsutum*), alfalfa (*Medicago sativa L.*), canola (*Brassica napus*), sunflower (*Helianthus anuus L.*), and safflower (*Carthamus tinctorius*); (C) 5 ha of salt-tolerant eucalyptus trees; (D) 2 ha of halophytic plants: pickleweed (*Salicornia bigelovii* Torr.), saltgrass (*Distichlis spicata* L.), saltbush (*Atriplex lentiformis* L.), and cordgrass (*Spartina gracilis* Trin.), and (E) 0.73 ha of a lined solar evaporator. The total ground surface area of the last three components C (salt-tolerant grasses), D (halophytes) and E (solar evaporator) comprised only a small portion (~3%) of the whole water reuse system. A subsurface drainage system was installed to a depth of 1.65–2.13 m below the soil surface, and all drains consisted of perforated polyethylene pipes placed on a gravel ﬁ3%) (Lin et al. 2002). The collected drainage water was pumped from a drainage sump and routed through a central distribution manifold. The grower followed typical furrow irrigation practices when using available drainage water. Irrigation scheduling was primarily based on the weather data provided by the local California Irrigation Management Information System.

The soil on the field site was predominantly classified as ciervo clay (fine, Semitic, thermic, vertic haplocambid). Collected soil samples were dried at 65 °C, thoroughly mixed and sieved through a 2-mm screen. Water-soluble Se and B, and electrical conductivity (EC) were determined in a soil water extract of 1:1. The different harvested plant organs (leaves, stems and roots) were washed with de-ionized water, dried at 50 °C for seven days. Plant samples were acid-digested with concentrated HNO3, H_2O_2, and HCl. Selenium in soil and plant tissues was analysed by an atomic absorption spectrophotometer with an automatic vapour accessory, and B concentrations were determined by an inductively coupled plasma spectrometer. Volatile Se was also collected at limited sites by a sampling chamber system that was described in detail by Lin et al. (2000, 2002).

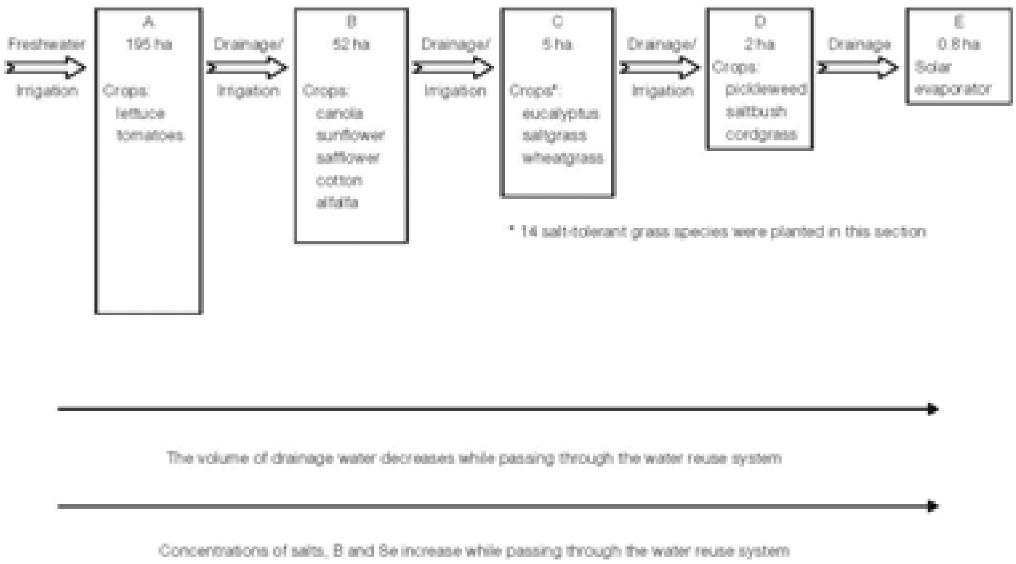

Figure 1. Schematic illustration of a plant-based drainage-water reuse system at Red Rock Ranch, Five Points, California (Bañuelos and Lin 2007).

RESULTS

Irrigation with different quality waters

Irrigation of salt-sensitive crop species with good-quality water (designated as component A) produced the first drainage water that would subsequently be reused on selected vegetation in component B (Fig. 1). The quality of water used for irrigation in the following components – B, C and D, decreased with each subsequent use. For example, qualitative differences were clearly observed in water used for irrigation in component A as compared to component D, as follows: water salinity (EC) increased from 0.7 dS m^{-1} to 15.1 dS m^{-1}; soluble B concentrations increased from 0.7 to 21.2 mg L^{-1}; and soluble Se concentrations increased from <1 µg L^{-1} (in good quality water) to 1.3 mg L^{-1}. The quality of the drainage waters produced from these two components A and B decreased to the greatest extent among all the components: EC increased from 4.5 to 15.2 dS m^{-1}, soluble B increased from 3.4 to 14.5 mg L^{-1}, and soluble Se increased from 0.08 to 0.12 mg L^{-1}. There was no substantial increase in EC and B concentrations in drainage waters produced from components C to D. In general, while volumes of drainage water decreased due to evapo-transpiration along the path of drainage-water reuse, concentrations of salts, B and Se increased in the drainage waters.

Accumulation of salts, B and Se in irrigated soil

The reuse of drainage water resulted in an increased accumulation of salts, B, and Se in the soil from 0 to 90 cm at harvest of each year for all reuse components of the drainage reuse system, showing a descending pattern as follows: D > C > B > A (soil data not presented). Significant increases and downward movement of soluble salts, B and Se were also observed at the deepest depth (60–90 cm) at post-harvest for each of the water reuse components (A through D). These changes are clearly illustrated in the mean comparison from 0 to 90 cm soil layers between component A (pre-planting) and component D (post-harvesting) as follows: soil EC levels increased from 1.6 to 30 dS m^{-1}, soil-extractable Se concentrations increased from <14 µg L^{-1} to 1.3 mg L^{-1}, and extractable B concentrations increased from 1.5 to 31 mg L^{-1}.

Plant tolerance in water reuse systems

Stand establishment for the selected crops for each respective component was generally good during the study time period. Typical plant yields are shown in Table 1 for each drainage reuse component. Careful monitoring and salt management practices of some sort will, however, be absolutely necessary for the soil to sustain the observed plant growth over long-term use of components C and D. Symptoms of leaf burn/necrosis from excessive salt or B buildup in the soil were only observed in canola growing near the ends of furrows, where there was an obvious excessive accumulation of salts on the soil surface (i.e. salt hot spots). Mean tissue B concentrations were greatest in canola at 226 mg kg^{-1} DM, and generally under 100 mg kg^{-1} DM (except for cotton and eucalyptus at 118 and 165 mg kg^{-1}, respectively). The low accumulation of plant B indicates that B was not causing plant damage, despite the high concentrations available within the reuse system.

Removal of excessive Se in the drainage reuse system

Selenium can be removed through phytoextraction (Bañuelos 2002) and volatilization (Lin et al. 2002). The amount of Se remaining after irrigation with drainage water was determined at selected sites under field conditions, although this drainage-water reuse system was not designed and established with a primary focus on Se removal from soil. In the different components, the plant Se concentrations ranged from a low of 0.1 mg kg^{-1} in lettuce to a high of 13 mg Se kg^{-1} DM in pickleweed shoots (Table 1). The estimated amounts of Se mass removed by phytoextraction (or plant uptake) are shown in Table 1, based upon plant concentrations of Se and yields (or biomass) per ha per growing season for annual crops in components A and B, and on an annual basis for perennial crops grown in components C and D.

Rates of Se volatilization for some plant species were also determined in this study. The mass of Se removed by volatilization was estimated for selected plant species, with the respective growing season (in days) for each of the species (Table 1). The greatest mass of Se removed by biological volatilization was 620 g ha^{-1} $year^{-1}$ in the pickleweed field, compared with the lowest observed in the cotton field at 20 g ha^{-1} per year.

Final disposal of drainage in the solar evaporator

The drainage water collected from component D was discharged by sprinklers into the solar evaporator, and its discharge was programmed according to daily evaporation rates, to prevent excessive saline water ponding in the solar evaporator for bird protection. Because the solar evaporator was lined with a plastic sheet, there were no output pathways of salts, B and Se from the system, except for Se volatilization.

DISCUSSION

In these studies, the grower selected a part of the farm to use ‘good quality water’ on salt-sensitive crops and use a much smaller part of the land for growing more-tolerant crops with poor-quality drainage waters. Segregating the farm into areas growing salt-sensitive and salt-tolerant crops entailed less operational complications. Reusing drainage water produced from salt-sensitive crops, e.g. from component A, grown in these Westside soils in central California, will eventually increase soil salinity and trace-element levels on the same farm in component B if without having a salt management strategy. In order to address this environmental problem at the earlier stage in the drainage-water reuse system, we annually moved our field site within ‘component B’ (consisting of moderately salt tolerant plants, e.g. mustard, canola, sunflowers), to different locations on the farm. Mustard/canola and sunflower were preferred plants for component B, because of canola/mustard’s ability to accumulate and volatilize Se (Bañuelos 2002), and sunflower’s ability to both tolerate high-B/saline conditions and to be used in rotation with canola. All crops can produce viable economical products, e.g. biofuel, Se-enriched animal forage (Bañuelos et al. 2010). Moreover, mustard/canola can be sometimes grown as rain-fed cover crops in the winter raining season, and hence require fewer applications of drainage water containing salt, B and

Se. Vegetation selected and grown in component B will be of great importance in the demonstrated reuse program, because viable economic products are required by growers who accept or attempt this water reuse concept.

The latter stages of the drainage-water reuse strategy, e.g. reuse components C and D, are very much dependent on the long-term ability of selected plants, e.g. saltgrass, cordgrass, pickleweed, to tolerate the high levels or concentrations of sulfate-salinity and B from the irrigation drainage water, and especially in the soil. In addition, if plant transpiration rates are eventually reduced by saline-or B-induced stress, less water will be taken up by the plant species in components C and D and water-logging could occur and result in a low redox potential in the root zone. Clearly, growing crops successfully in components C and D requires more information on both irrigation production practices and on salt-management strategies that will be essential for growers using a drainage-water reuse system (Benes et al. 2004; Suyama et al. 2007).

With continual application of poor-quality water on the farm, the gradual deterioration of the soil's structure and the formation of a surface seal may occur over time, which will result in decreases in the infiltration rate (IR) of a soil. The IR is more sensitive to exchangeable Na, EC and pH than hydraulic conductivity. Drainage from soils where water is reused must be adequate, so that the salts, including exchangeable Na and B, are removed from the root zone. Boron is more difficult to leach than other salts, because it is adsorbed on to clay materials – hydroxyl oxides of Al, Fe and Mg (Keren & Bingham 1985). Other constituents of drainage water, particularly arsenic, chromium, molybdenum and dissolved solids, can also create problems associated with disposing/reusing such poor quality waters (Ong et al. 1997).

In addition to salinity, the potential phytotoxicity of B may become a major limitation to long-term reuse of drainage water containing high B concentrations of >5 mg L^{-1} (Letey et al. 2001). Although B did not appear to exert any noticeable effects on the selected plant species used in this drainage-reuse system, its increasing concentrations over time will need to be managed because of its relative immobility in the root zone and boron's interaction with salinity. If leaching is used as a management tool for extractable soil-B concentrations in the root zone, at least three times more water will be needed to leach B than that amount of water necessary to leach salts from the soil root-zone (Oster et al. 1999).

Unique to the drainage-water reuse strategy in central California is the presence of Se in the drainage waters used for agricultural irrigation. Because Se is potentially a toxicant of concern at excessive levels to wildlife, extended research was needed for the removal of Se from the drainage reuse system (Bañuelos and Lin 2007). In this study, removing Se via biological volatilization was observed only at some sites with selected plant species (Table 1). Among the species tested, pickleweed (*Salicornia bigelovi*), a salt-tolerant vascular plant species, volatilized the greatest amount of Se, followed by cordgrass and saltbush. Identifying key plant species for Se volatilization may represent a contributing technology for the bioremediation of Se contaminated waters and soils, because Se is volatilized from the ground surface and passes harmlessly into the atmosphere (Terry et al. 1992; Frankenberger & Karlson 1994; Terry et al. 2000). Vegetation is generally important to Se volatilization, not only because plants volatilize Se directly, but also because plants create rhizosphere environments that support specific soil micro-organisms that also contribute significantly to Se volatilization (Azaizeh et al. 1997).

Plant utilization will always be the most important consideration for the growers when adapting such a drainage-water reuse system. Bañuelos and Mayland (2000) have harvested Se-enriched plants grown under saline soil conditions, and have used them as part of a feed ration for sheep and dairy cows (Bañuelos et al. 2010). Selenium is an essential trace element for animals, and Se deficiencies are generally a far greater problem than Se toxicities in animals in many other regions in the world (Mayland 1994). While excess Se caused ecologists to be concerned about the safety of wildlife in the western San Joaquin Valley, Se deficiency in the diets of cattle is more of a problem in eastern California. Harvesting Se-enriched crops (such as canola produces products, including Se-enriched feed and oil for biofuel) is of potential economic importance for growers who plan to reuse drainage water as an additional source of irrigation water in central California (Bañuelos et al. 2010). Importantly, Se-enriched food and feed products could be beneficial for Se-deficient regions in China, UK, Australia, or New Zealand, especially since Tan et al. (2002) reported that up to 15% of the world population experience Se deficiencies.

CONCLUSIONS

Irrigation management is essentially the most important strategy for reducing the volume of fresh water applied and drainage water produced in many agricultural regions worldwide. Since salts are imported from the central California soils with irrigation water, a means of ultimately isolating salts from productive agricultural soils is required for sustainability. Otherwise, salts will accumulate in soil root zone. When, however, drainage water is produced, re-using drainage water for irrigation on salt and B tolerant crops can not only dispose of drainage water that would otherwise be costly to discharge and but also reduce the requirement for good-quality irrigation water. Producing products of economical value from poor quality waters enhances the long-term, acceptance of this water reuse strategy.

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Table 1. Above-ground yields and leaf Se and B concentrations and volatile Se produced from different plants grown within the respective components of the plant-based drainage-water reuse system*

			Plant concentrations of:			Mass of Se removed by:	
Reuse component	Plant species	DM Yield Mg ha^{-1}	Se mg kg^{-1} DM	B mg kg^{-1} DM	Volatile Se mg Se m^{-2} d^{-1}	Uptake g ha^{-1}	Volatilization† g ha^{-1} year
A	Lettuce	39.2 (5)‡	0.1 (0.01)	38 (6)	ND§	0.39 (0.01)	BD§
A	Tomatoes	31.4 (4)‡	0.2 (0.01)	45 (7)	ND§	0.31 (0.01)	BD§
B	Canola	14.2 (3)	5.8 (1.1)	226 (28)	35 (5)	82 (9)	56 (8)
B	Sunflower	12.6 (2)	1.1 (0.01)	47 (8)	NA¶	14 (2)	NA¶
B	Safflower	3.3 (0.07)	1.3 (0.01)	49 (10)	NA¶	4 (0.09)	NA¶
B	Alfalfa	25.0 (5)	1.3 (0.01)	85 (9)	21 (3)	33 (5)	56 (7)
B	Cotton lint	1.5 (0.09)	0.6 (0.01)	118 (9)	12 (3)	1 (0.01)	20 (5)
C	Eucalyptus	Replaced	3.6 (0.9)	165 (31)	25 (5)	NA¶	BD§
D	Pickleweed	8.1 (1.0)	12.9 (2.0)	78 (11)	155 (25)	105 (10)	620 (124)
D	Saltgrass	13.1 (0.2)	2.5 (0.2)	48 (9)	18 (8)	34 (4)	48 (6)
D	Saltbush	4.5 (2.0)	2.8 (0.3)	89 (10)	40 (12)‡‡	13 (2)	125 (19)
D	Cordgrass	9.1 (1.5)	5.3 (1.1)	52 (7)	48 (14)‡‡	48 (7)	152 (22)

* Values presented are means and one standard error given in parentheses.

† Values were calculated based upon the average rate of Se volatilization and the number of days for their growth season: pickleweed and saltgrass: 365 d; cordgrass, saltbush and alfalfa: 300 d; canola and cotton: 160 d; and bare soil (component D) with an average rate of 167 g ha^{-1}: 365 d.

‡ Fresh weight yields.

§ ND: not detected.

¶ NA: not analyzed.

‡‡ Observed during the summer.

ASSESSING THE LINK BETWEEN THE GEOCHEMISTRY OF SOILS AND THE BIOACESSIBILITY OF POTENTIALLY HARMFUL ELEMENTS IN AN URBAN ENVIRONMENT

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Abstract:
The newly validated BioAccessibility Research Group of Europe (BARGE) unified BARGE method (UBM) has been applied to a small set of soils from the Northampton urban are of the United Kingdom (UK), with the aim of predicting potentially harmful element (PHE) bioaccessibility across the urban conurbation. In addition to predicting the PHE bioaccessibility, this study has begun to identify the source bioaccessibility inputs and mapped the spatial distribution of predicted PHE across the Northampton urban area.

Introduction:
In the UK, there are large areas of land that have relatively high concentrations of naturally occurring potentially harmful elements (PHE) such as arsenic (As), chromium (Cr) and lead (Pb) in the soil (Ander *et al.*, 2012). A recently published British Geological Survey (BGS) geochemical soil atlas of England and Wales (Rawlins *et al.*, 2012) using soil samples collected for the National Soil Inventory (NSI), highlighted the extent to which the soil guideline value (SGV) of 32 mg kg^{-1} for residential land use for one of these PHE, As, was exceeded.

The county town of Northampton, in the Midlands region of the UK (Figure 1), has a population of circa. 200,000, is served by busy rail and road links and is located on the Jurassic ironstones (Northampton Sand Formation and Frodingham ironstone). The industrial development of Northamptonshire, and the growth of Northampton, was supported by open cast quarrying of the abundance of iron ore in the middle of the 19^{th} century (Cave *et al.*, 2003) and the ease of access to two major railways (the London & North Western and the Midland Railways). There were also considerable currying and tanning works, breweries, iron foundries, and brick and tile works across the area. It is, however, the shoemaking industry, which was very large, at one time employing 75% of the population of the county that is more often associated with Northampton. A geochemical survey of the urban soils of Northampton, carried out by the BGS geochemical baseline (G-BASE) project, showed that 45% of the 275 soils sampled contained total As concentrations exceeding the Environment Agency soil SGV.

One of the principal pathways for PHE in soil to enter the human body is through ingestion. Since these PHE are toxic to humans there is a potential risk to human health. Importantly, when a soil is ingested, only a fraction of the PHE in the soil is mobilised in the human gut (the bioaccessible fraction) and passes into the body (the bioavailable fraction). Therefore, it is the bioavailable fraction of a PHE in the soil that is required to assess the risk to human health. However, because *in vivo* studies that use animal or human studies are required to provide bioavailability data, it is unlikely that this will be possible on a site specific or large scale because of the time and monetary constraints and even less likely because of ethical issues related to the use of animals. As such, many researchers have developed *in vitro* methodologies to simulate the gastro-intestinal environment to determine contaminant bioaccessibility as a surrogate of bioavailability data in human health risk assessment and associated studies. Such groups include the BioAccessibility Group of Europe (BARGE) who have developed the unified BARGE method (UBM), which has been recently validated against a swine model for As, Cd and Pb (Denys *et al.*, 2012). Since the validation of the UBM, research in the area of bioaccessibility has moved towards the application of this useful tool. Recently, several studies have used an environmetrics approach to measurement, mapping and modelling of bioaccessibility in both rural and urban environments and on regional and national scales (Appleton *et al.*, 2012; Cave *et al.*, 2012).

Figure 1. Location of Northampton in the UK

Materials and Methods:

As part of the BGS G-BASE urban geochemical surveying programme, a total of 281 <2mm topsoils were collected (5 – 20 cm depth) from a 500 m grid, at a density of approximately of 4 samples per km^2, from open ground and as close as possible to the centre of each 500 m grid cell. Each sample was a composite of 5 sub-samples, taken from the centre and four corners of a 20 m square. Samples were stored in uniquely labelled kraft bags and dried in a fan assisted oven, set at 35 ± 2ºC, for at least 12 hours or until visually dried. Prior to sieving to <2mm, the dried samples were gently disaggregated to ensure the breakage of aggregates but retention of clasts.

X-ray Flurescence spectroscopy (XRFS) was used to determine the elemental content of a suite of circa 40 major and trace elements of each soil as described by Johnson et al., (2011). The resulting geochemical data set was subjected to hierarchical clustering in order to reduce the total number of soil samples to 50 samples because of time and cost constraints. The clustering allowed the reduced sample batch to stay representative of the different geochemical groupings in the Northampton urban area as a whole. The sub-set of 50 samples was then subjected to bioaccessibility testing for As, Cr and Pb, using the UBM methodology (Figure 2) (Wragg *et al.*, 2011) with subsequent Inductively Coupled Plasma Mass Spectrometry (ICP-MS) analysis of the resulting solutions.

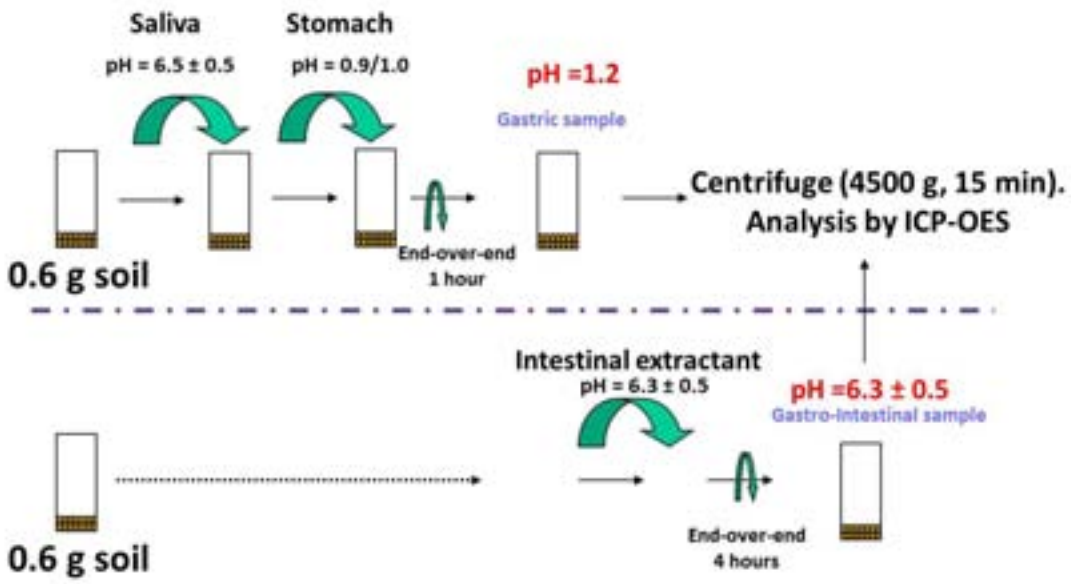

Figure 2. Schematic of the UBM extraction methodology

Using the R programming language, PHE (As, Cr and Pb) bioaccessibility for the whole of the Northampton urban area was modelled, based on the major element (Na, Mg, Al, P, Mn, Fe), pH and PHE data for the 50 test soils using multiple linear regression (MLR) modelling. The MLR model was then used to predict PHE bioaccessibility in the 281 soils across the whole of Northampton urban area.

Predicted bioaccessible PHE concentrations were mapped onto Google earth © satellite images of the Northampton conurbation with and without the underlying geology to investigate bioaccessibility associations with parent geology and anthropogenic influences.

Results:

Comparison of the total and bioaccessible PHE in the 50 test soils indicated that PHE bioaccessibility was not proportional to the total amount of PHE in the Northampton urban soils. Analysis of the PHE bioaccessibility data inferred the presence of hotspots, possibly related to the presence of anthropogenic inputs such as sewage treatment works. The results of the MLR modelling are summarised in Table 1.

The MLR model for As bioaccessibility indicates Mg, P and total As are positive controls on As bioaccessibility i.e. the higher the concentration of these elements in the soil the higher the As bioaccessibility. In contrast, the higher the Mn and Fe soil content, the lower the As bioaccessibility, as a result of the unavailability of As from the strong Fe-oxide association. The positive coefficients for As, pH and P composition can be explained as follows:

- As – it is reasonable to suggest that the bioaccessible fraction is dependent on the total As in the soil.
- P – phosphate adsorbs strongly to Fe oxides and displaces oxo-arsenic anions from Fe oxide surfaces (Cornell and Schwertmann, 1996); therefore higher concentrations of P would point to the As being more mobile.

- pH – If As is mostly held on Fe oxides the adsorbtion Kd increases with increasing pH (Cornell and Schwertmann, 1996), again leading to the As being more mobile at higher pH

Similarly, Cr bioaccessibility appears to be related soil pH and the amount of geogenic Cr/Fe present in the soil. Thease associations are thought to be the same as those described above. However, in Northampton there is also a potential anthropogenic source of Cr, which is related to the significant Na and Al coefficients (both of these elements were used in the tanning of leather). In comparison, Table 2 indicates that the only significant contribution to the bioaccessible Pb concentration is the total Pb soil concentration.

Table 1. Coefficients for the optimum MLR model for bioaccessible PHE prediction. All coefficients are significant at the 99% confidence interval.

	As	Cr	Pb
Soil pH	5.26e-01	3.55e-01	n/a
Na	n/a	1.22e-03	n/a
Mg	2.66e-04	n/a	n/a
Al	n/a	-1.23e-05	n/a
P	8.13e-04	n/a	n/a
Mn	-1.15e-03	n/a	n/a
Fe	-2.66e-05	-2.04e-05	n/a
As	6.97e-02	n/a	n/a
Cr	n/a	2.35e-02	n/a
Pb	n/a	n/a	0.581

Figures 3 and 4 show examples of a predicted As bioaccessibility map for the Northampton, using the MLR model. Figure 3 shows predicted As bioaccessibility overlain on a Google earth satallite image and Figure 4 shows the same prediction map overlain onto the geology of Northampton.

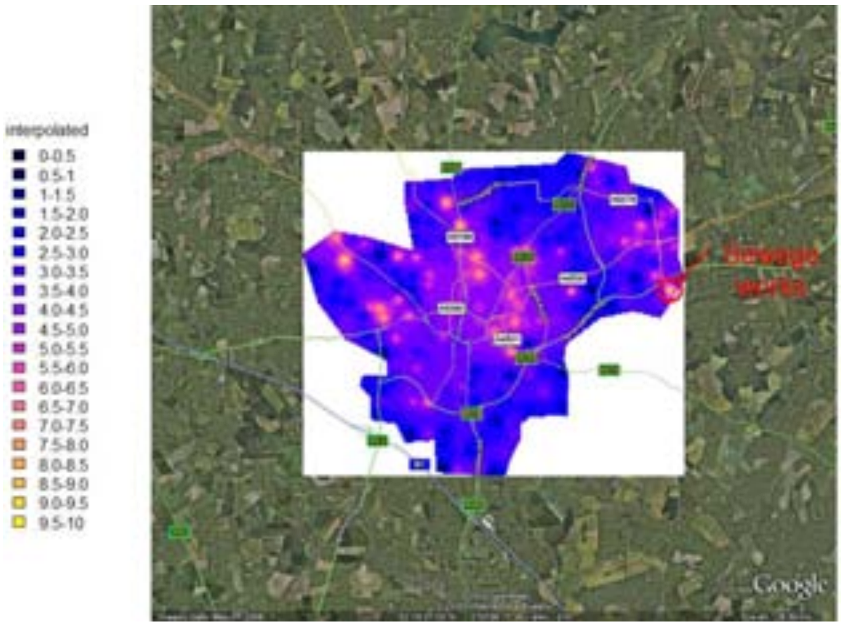

Figure 3. Example of PHE bioaccessibility map for As in the Northampton urban area

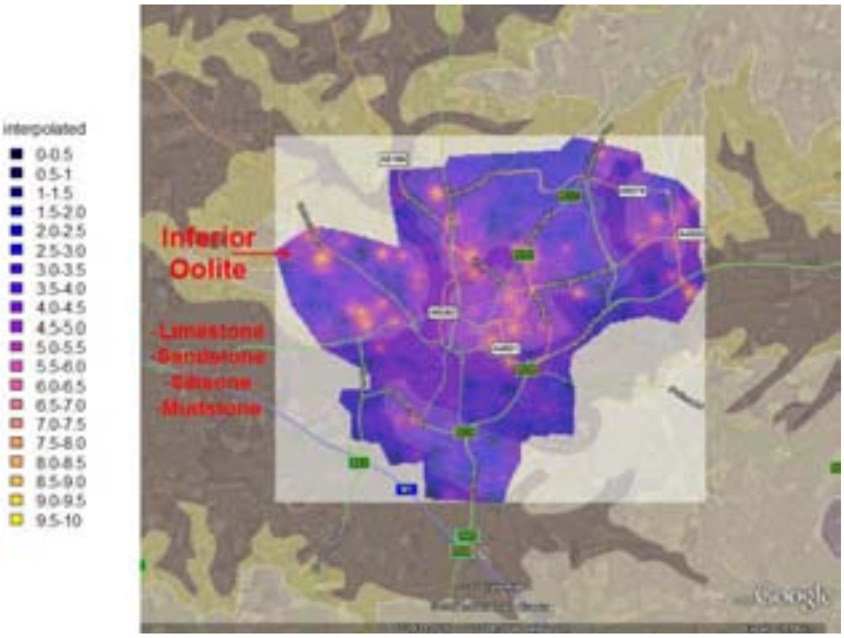

Figure 4. Example of PHE bioaccessibility map for As, showing As bioaccessibility overlaying the underlying geology in Northampton

Discussion:

Mapping of predicted bioaccessibility shows a clear anthropogenic input from a sewage works for all PHE of interest (Figure 3). Inclusion of a geology layer into the mapping process (Figure 4) indicated a clear relationship between parent geology and PHE bioaccessibility for As and Cr. The main geological influence was the inferior oolite. For Cr, in addition to the geological influence, the previous industrial heritage of the location (the ironworks, shoemaking and tanneries) may be influencing the bioaccessibility results. Lead bioaccessibility appears to be related to anthropogenic inputs alone, as inputs from the roads and sewage works appear to be the main influences.

The MLR methodology is a useful tool for identifying the controls on PHE bioaccessibility.

In conjunction with mapping information bioaccessibility prediction techniques allow for the identification of any anthropogenic inputs, the spatial distribution of PHE bioaccessibility and more importantly the identification of areas of potential concern.

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British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Applied geoscience for our changing Earth

Assessing the link between the Geochemistry of Soils and the Bioaccessibility of Arsenic, Chromium and Lead in the Urban Environment

Joanna Wragg and Mark Cave

29th June 2010

Northampton

- Large Market town in central England
  - Population of c. 200,000
  - Busy Road and Rail links
- Primary industrial activities were shoe making and other leather industries
  - Now a hub for finance and distribution industries

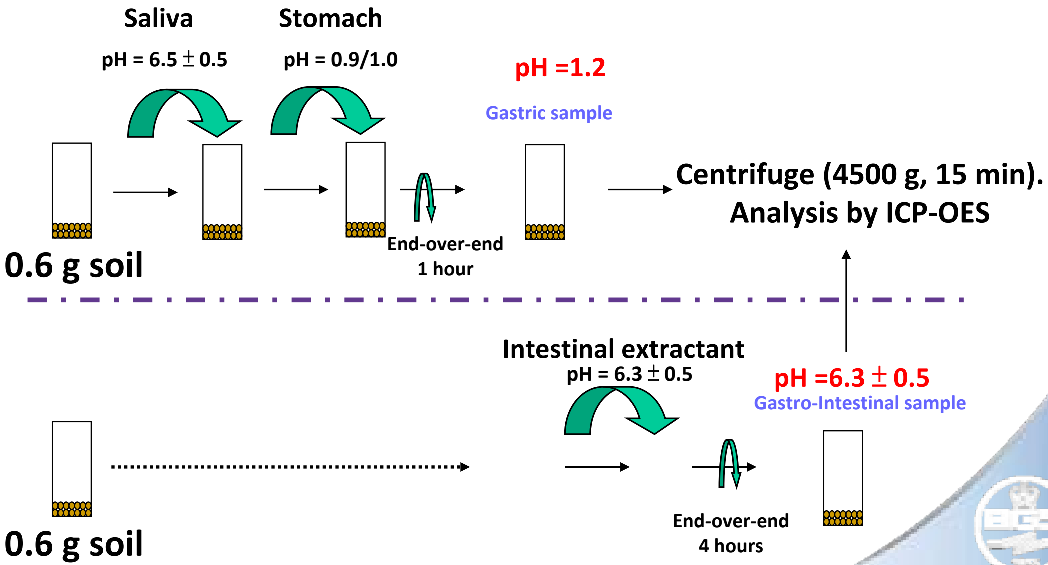
- BGS surveyed the area as part of the G-BASE programme
- Ironstone soils, naturally elevated in arsenic
- 45% of the soils have As concentrations above the residential SGV of 32 mg mg^{-1}

What have we done?

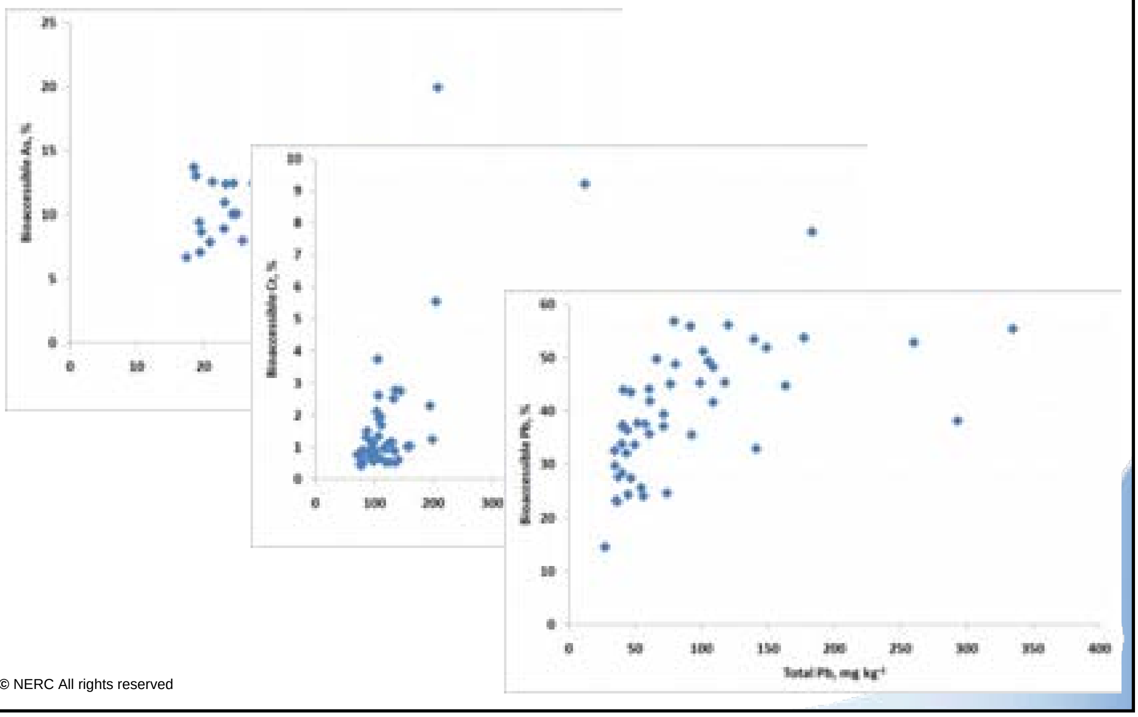
- 275 Surface soils (G-BASE Urban sampling program)
  - Composite samples
  - 5 auger flights at a depth of 10-20cm from the centre and corners of a 20 x 20m square
  - Collected from unbuilt ground every kilometre square
- XRF analysis of major and trace elements
  - All samples
- Bioaccessibility
  - Subset of 50 samples
  - Using the newly validated BARGE UBM method

Bioaccessibility

- Primary exposure route
  - Adults – 20 to 100 mg day^{-1}
  - Children – 80 to 400 mg day^{-1}



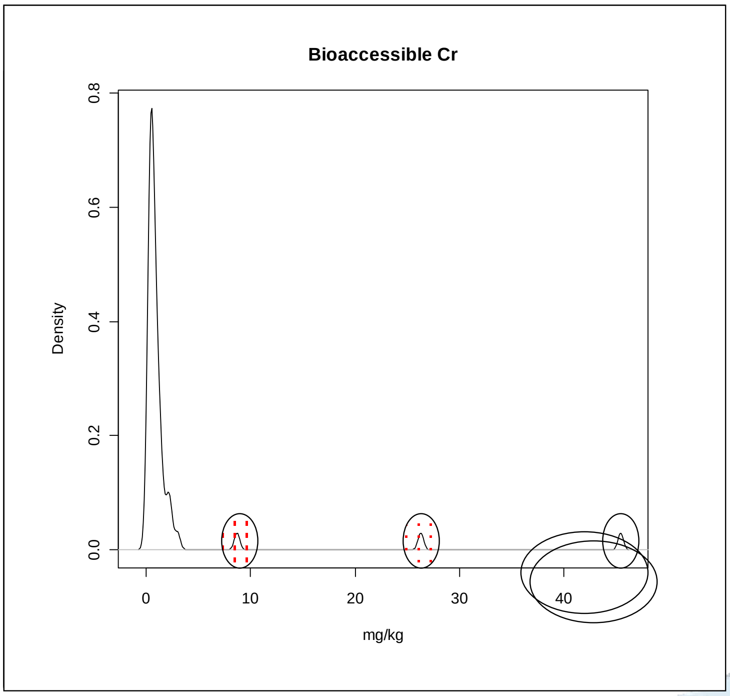
Total vs Bioaccessible PHEs



Data modelling

- Predict the bioaccessibility of PHEs using the major element geochemical data
- R
  - Density plots to identify populations in data
  - Identify and remove hotspots from the model
    - Background bioaccessibility prediction

Density plots



Data modelling

- Predict the bioaccessibility of PHEs using the major element geochemical data
- R
  - Density plots to identify populations in data
  - Identify and remove hotspots from the model
    - Background bioaccessibility prediction
  - Linear regression model based on the major element concentrations and PHE in the soils

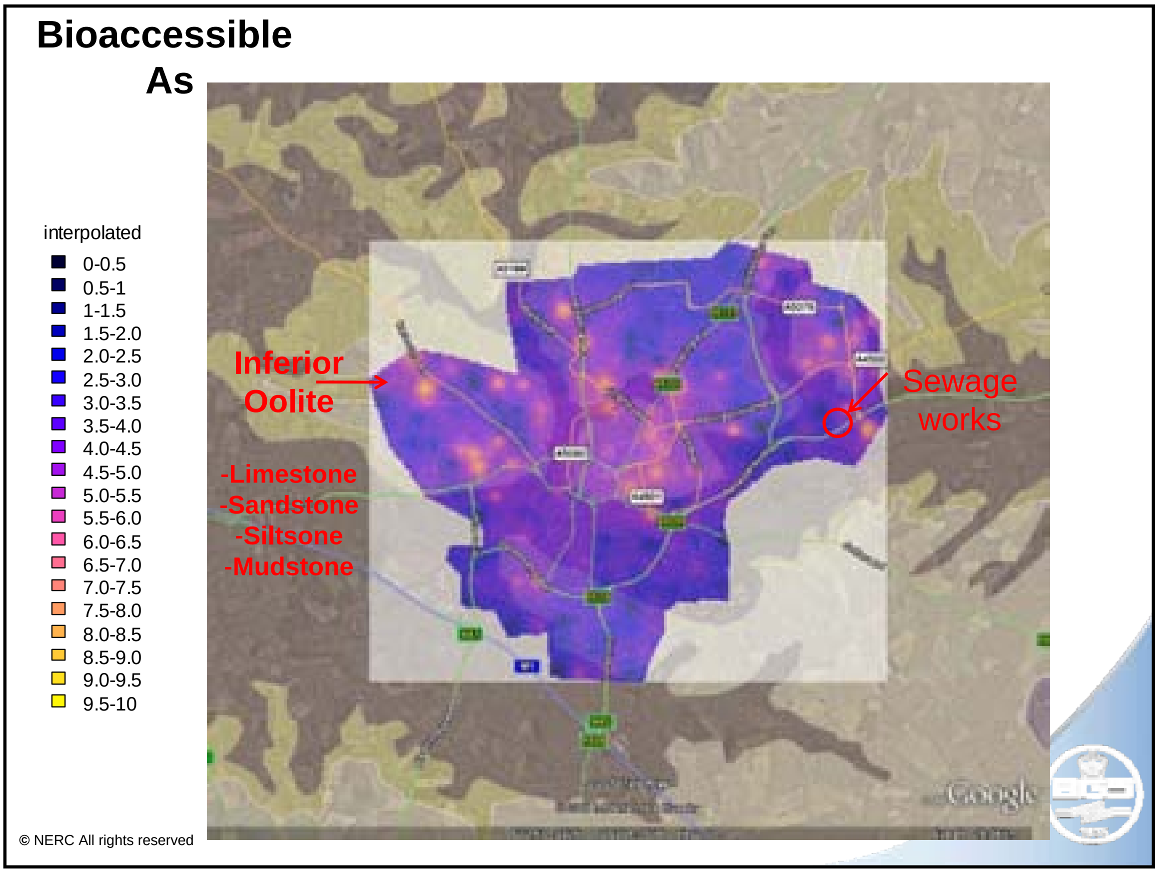
Optimum models

	As	Cr	Pb
Intercept	-3.036	-3.506	-11.1
Soil pH	5.26E-01	3.55E-01	n/a
Na	n/a	1.22E-03	n/a
Mg	2.66E-04	n/a	n/a
Al	n/a	-1.23E-05	n/a
P	8.13E-04	n/a	n/a
Mn	-1.15E-03	n/a	n/a
Fe	-2.66E-05	-2.04E-05	n/a
As	6.97E-02	n/a	n/a
Cr	n/a	2.35E-02	n/a
Pb	n/a	n/a	0.581

* All coefficients significant at the 99% CI min

Data modelling

- Predict the bioaccessibility of PHEs using the major element geochemical data
- R
  - Density plots to identify populations in data
  - Identify and remove hotspots from the model
    - Background bioaccessibility prediction
  - Linear Regression model based on the major element concentrations and PHE in the soils
  - Predict the background bioaccessibility of the whole area
  - Mapping of background bioaccessibility, even for removed hotspots (limitation)
    - As a layer in Google Earth


Bioaccessible
As
interpolated
0-0.5
0.5-1
1-1.5
1.5-2.0
2.0-2.5
2.5-3.0
3.0-3.5
3.5-4.0
4.0-4.5
4.5-5.0
5.0-5.5
5.5-6.0
6.0-6.5
6.5-7.0
7.0-7.5
7.5-8.0
8.0-8.5
8.5-9.0
9.0-9.5
9.5-10
Inferior
Oolite
-Limestone
-Sandstone
-Siltsone
-Mudstone
Sewage
works
Google
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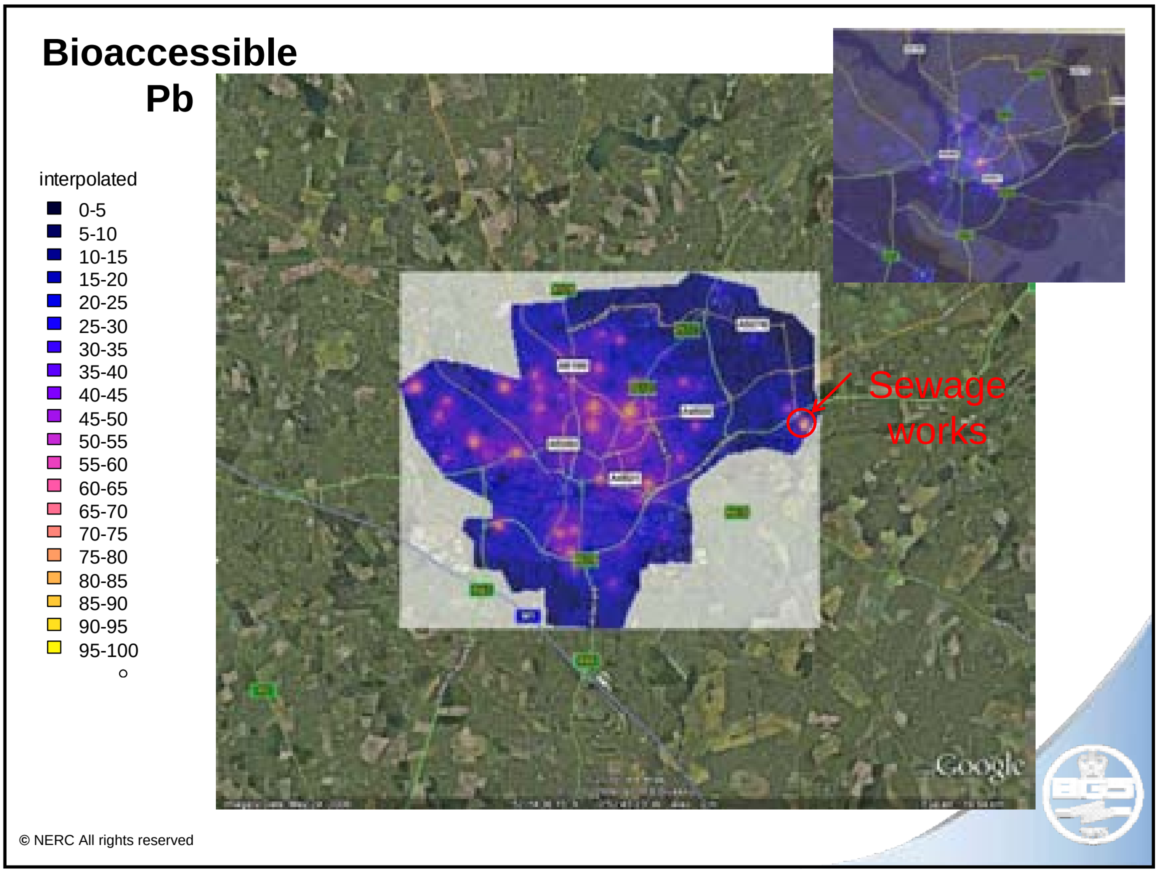
Bioaccessible
Pb
interpolated
0-5
5-10
10-15
15-20
20-25
25-30
30-35
35-40
40-45
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50-55
55-60
60-65
65-70
70-75
75-80
80-85
85-90
90-95
95-100
Sewage
works
Google
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Bioaccessible Cr

interpolated

- 0-0.5
- 0.5-1
- 1-1.5
- 1.5-2.0
- 2.0-2.5
- 2.5-3.0
- 3.0-3.5
- 3.5-4.0
- 4.0-4.5
- 4.5-5.0
- 5.0-5.5
- 5.5-6.0
- 6.0-6.5
- 6.5-7.0
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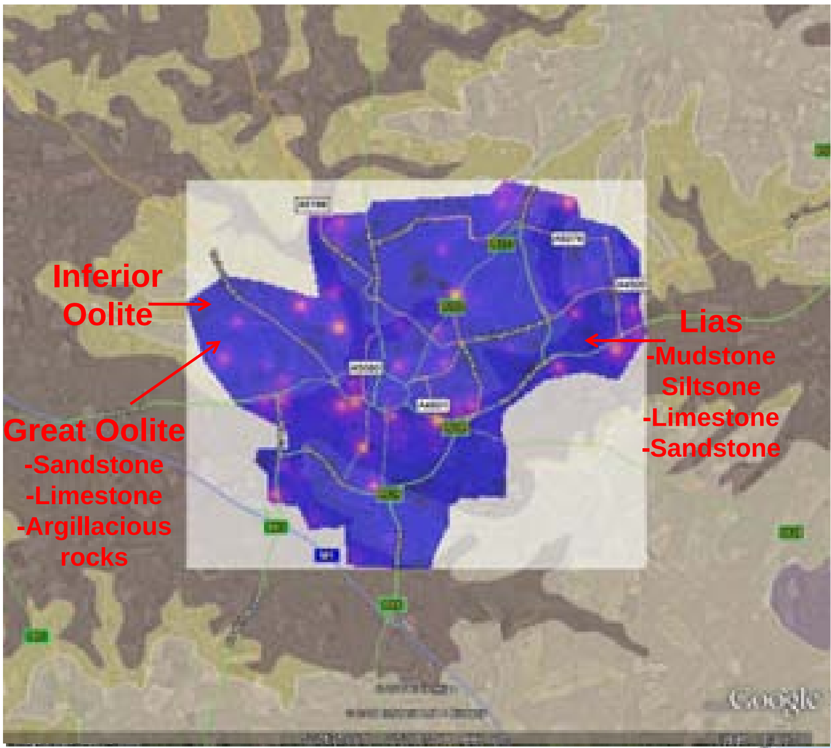
- 8.0-8.5
- 8.5-9.0
- 9.0-9.5
- 9.5-10



Conclusions

- Possible both geogenic and anthropogenic influences on bioaccessibility of PHEs
  - As – mainly influenced by soil geochemistry – inferior oolite
  - Cr – mixed influences, background geology and possibly the previous industrial heritage of Northampton (shoemaking and tannaries)
  - Pb – see the input from the urban environment, roads, sewage works
- Looking forward
  - We have a large NIR dataset to investigate
  - Need to investigate methods to separate the geochemical controls from the anthropogenic inputs

Thankyou!

Microvi
BIOTECHNOLOGIES INC

MWH
BUILDING A BETTER WORLD

A clean, low-cost, comprehensive and sustainable solution to water treatment

Issues with conventional treatments

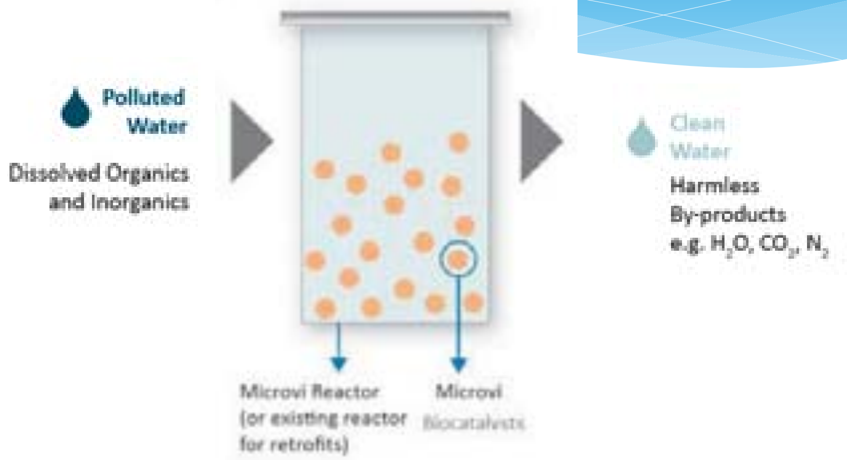
Evolutionary Technologies			
Biological	Physical e.g. Nanofiltration	Chemical e.g. Ion Exchange	Membrane Bioreactor
• Unreliable microbial activity • Microogranism loss • Sludge production • Large footprint	• Secondary waste streams • N/A for all contaminants • High energy usage • Large footprint	• Expensive consumables • Secondary waste streams • N/A for all contaminants • Post treatment needed	• Frequent fouling (short lifespan) • Microorganism loss • Sludge production • N/A for all contaminants

← HIGH LIFECYCLE COST →



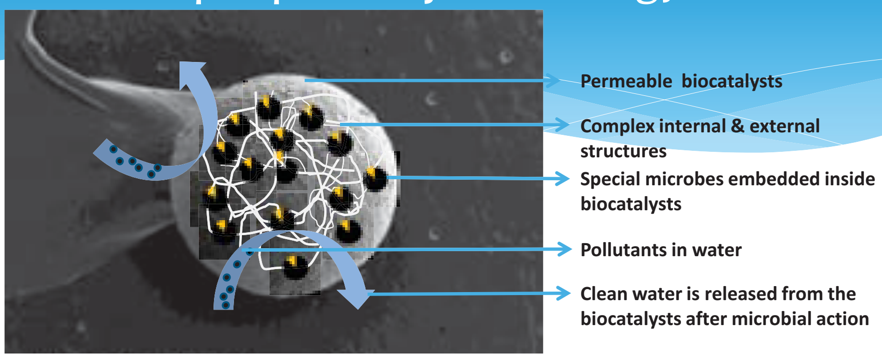

2

Microvi addresses challenges of current technologies for organic and nitrogen removal…



3

……through simple, yet elegant proprietary technology



4

Microvi Technologies & Applications

5

Perchlorate Treatment Processes

Purpose:

Microvi MB-P Technology can effectively remove perchlorate without producing any waste stream. Various concentrations of perchlorate can be treated to non-detect.

Performance:

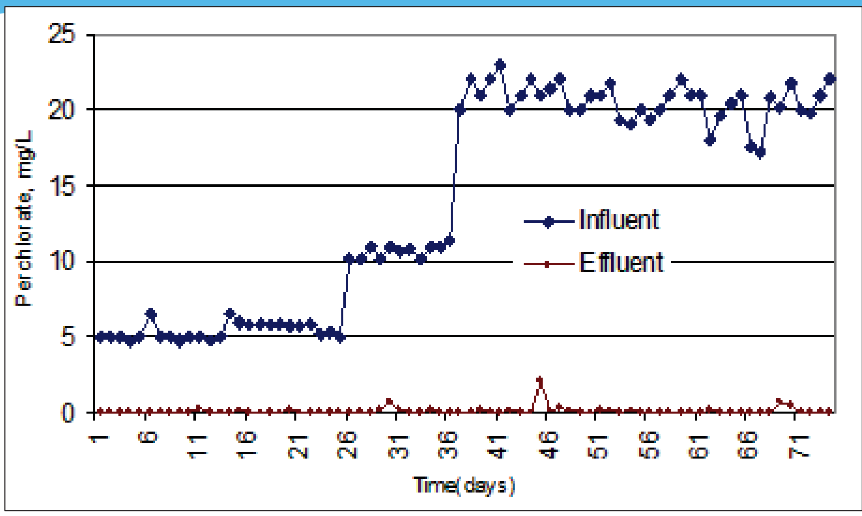
Removal rates of up to 99.99% of perchlorate at various concentrations (10ppb – 100 ppb)

Features:

- Low retention time (minutes)
- Stable process and short start up period
- Bio-reactor capacity 30% to 50% of conventional methods
- Cost reduction of around 50%

6

Treatment of perchlorate



7

TCE Treatment Processes

Purpose:

Microvi MB-CS Technology can effectively remove Trichloroethylene (TCE) the need to add any secondary pollutants and without producing any waste stream. Various concentrations of perchlorate can be treated to non-detect.

Performance:

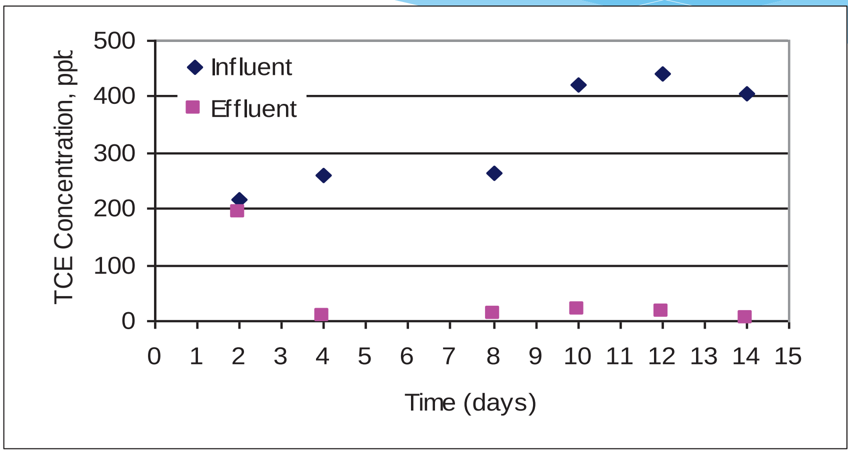
Removal rates of up to 99.99% of perchlorate at various concentrations (10ppb – 15 ppm)

Features:

- Low retention time (minutes)
- Stable process and short start up period
- Bio-reactor capacity 30% to 50% of conventional methods
- Cost reduction of around 50%

8

Treatment of Trichloroethylene



9

Nitrate Treatment Processes

Purpose:

Microvi MB-N2 Technology can effectively remove nitrate without producing any waste stream. Greatly enhanced through intensified degradation of nitrate to nitrogen gas.

Performance:

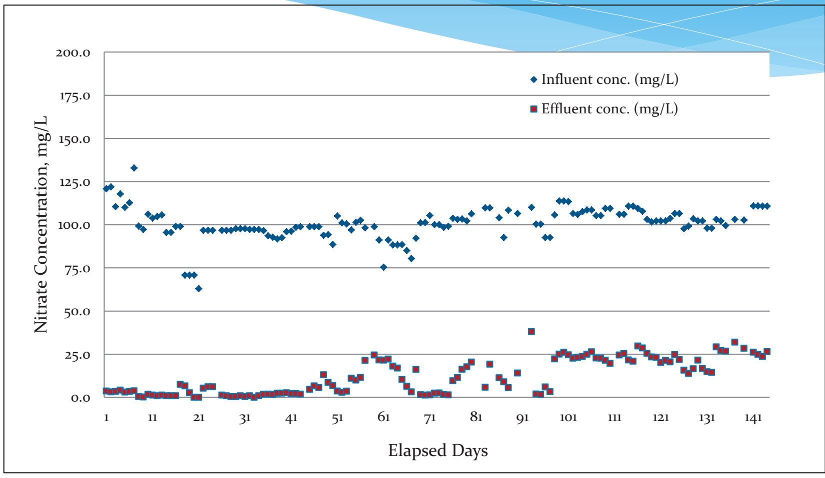
Removal rates of up to 99% of nitrate at various concentrations (10 ppm – 1000 ppm)

Features:

- Low retention time (minutes)
- Stable process and short start up period without generating nitrite
- Bio-reactor capacity 30% to 50% of conventional methods
- Cost reduction of around 50%

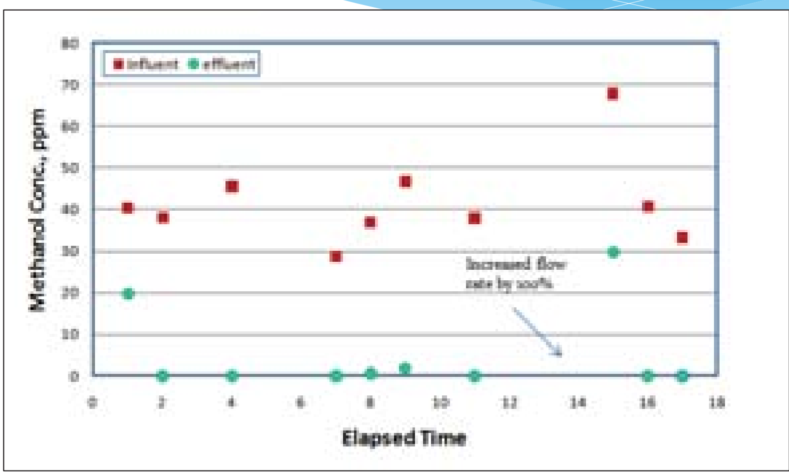
10

Treatment of Nitrate



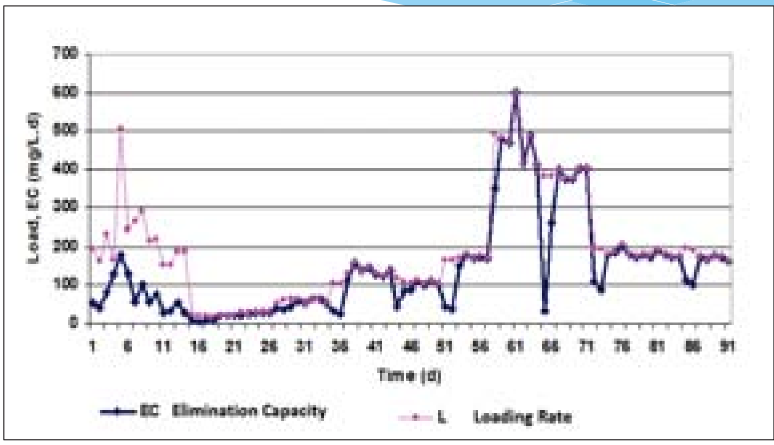
11

Treatment of methanol & hydrocarbons by MB-HAB Technology



12

Treatment of oxygenated compounds ($MTBE$ - $C_5H_{12}O$)



13

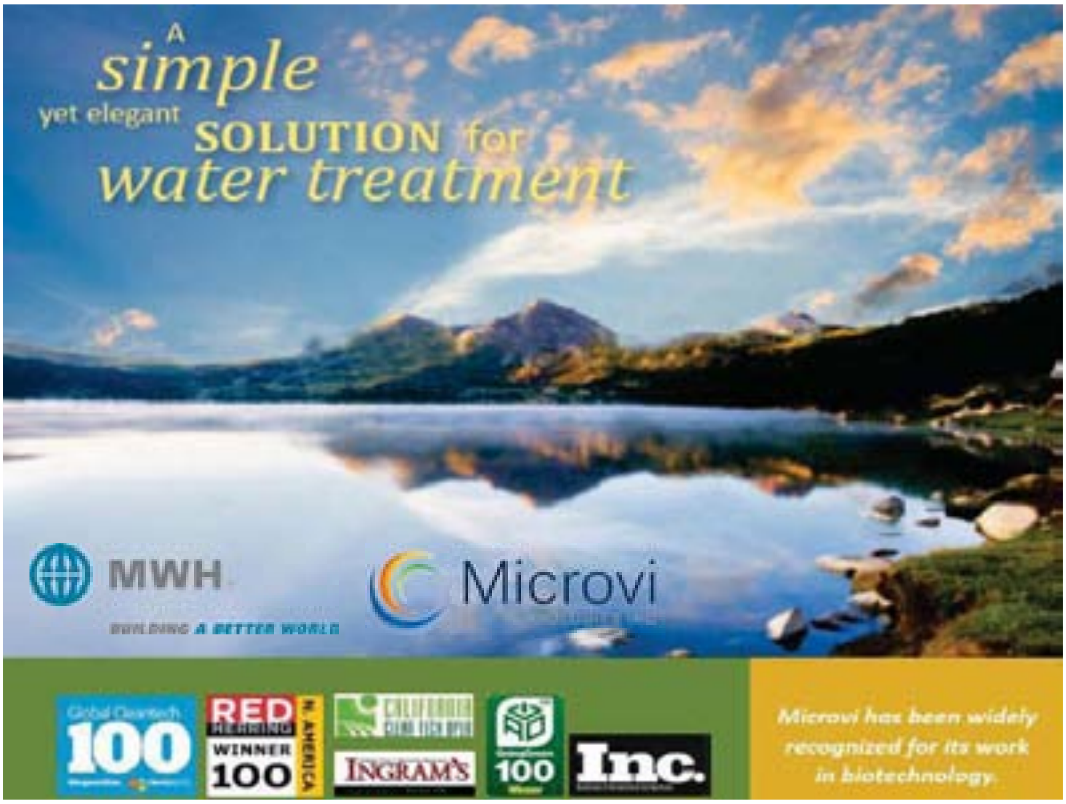
Microvi's Technology Disrupts Existing Opex and Capex Economics in Treatment of Various Pollutants in Water

- Very high cell density
- Very high process stability and toxicity tolerance
- Cellular focus shifts from biomass production to biochemical conversion
- Low sludge and waste stream productions
- Low chemical addition, high effluent quality, and simple process

CAPEX and OPEX impacts

- Smaller footprint
- Drastically reducing pre and post treatment
- Elimination of major post treatment
- High reaction rate, highly stable process
- Significantly shorter retention times
- Lower electricity and heat consumption, lower oxygen demand (aerobic), and lower chemical addition (anoxic)
- Significantly reduced waste stream and sludge
- Fast recovery from fluctuations in operating conditions

14


A simple yet elegant SOLUTION for water treatment
MWH
BUILDING A BETTER WORLD
Microvi
Global Cleantech 100
RED HERRING WINNER 100 N. AMERICA
INGRAM'S
100
Inc.
Microvi has been widely recognized for its work in biotechnology.

Enhanced Biobarrier for a Mixed CVOC Plume

Cassandra Shoup, William J. Pepe, Richard A. Sellen, and William E. Pickens

Background

A biobarrier was installed at the downgradient boundary of a confidential industrial facility in Pennsylvania to prevent the off-site migration of chlorinated volatile organic compounds (CVOCs) in groundwater. The facility was used for the manufacture of various electrical components and equipment from 1924 to 2002. Operations during this time resulted in the contamination of soils and groundwater by a variety of CVOCs. The primary constituents of concern at the site are the CVOCs trichloroethylene (TCE) and tetrachloroethylene (PCE).

A Human Health Risk Assessment (HHRA) was conducted and site specific standards (SSS) were developed for the CVOCs that were detected at the site. TCE (maximum concentration in groundwater at the site was 3,500 µg/L) was the only CVOC detected at a concentration in groundwater above the SSS. TCE was also found to have migrated off-site at concentrations greater than the SSS. Therefore, a boundary control measure was determined to be necessary to prevent additional off-site migration of CVOCs.

A biological barrier (biobarrier) was selected as the most viable option to prevent off-site migration from the facility. The objective of the biobarrier was to decrease groundwater concentrations to below the SSS before they reached the property boundary by degrading the dissolved phase CVOCs through reductive dechlorination.

Enhanced Anaerobic Biodegradation Summary

Enhanced anaerobic biodegradation of chlorinated solvents represents a reasonable remedial option when natural attenuation processes alone are not sufficient to mitigate risk to human health and the environment. Enhanced biodegradation involves the addition of sources of carbon and nutrients to the subsurface in order to stimulate anaerobic bacteria capable of reductively dechlorinating chlorinated solvents to innocuous by-products like ethene and ethane. Reductive dechlorination involves the step-wise replacement of individual chlorine atoms with hydrogen atoms, such that:

$$\text{TCE} \rightarrow \text{cDCE} \rightarrow \text{VC} \rightarrow \text{Ethene}$$

where cDCE and VC are cis-1,2-dichloroethene and vinyl chloride, respectively.

In these processes, the chlorinated compounds act as an electron acceptor, while an electron donor is required to provide energy (McCarty, 1994). Hydrogen is generally considered to be the direct electron donor for reductive dechlorination, but it is typically produced from the anaerobic fermentation of other carbon substrates, such as sugars, organic acids, or alcohols (Maymo-Gatell, et al, 1995). There are many carbon sources suitable for promoting reductive dechlorination of chlorinated aliphatics by anaerobic bacteria. Water insoluble carbon sources have seen increasing application in enhanced biodegradation. These carbon sources biodegrade slowly over time and include substances like lactic acid polymers, emulsified vegetable oil (EVO), chitin, and wood chips. Bacteria also require basic nutrients like nitrogen and phosphorus in order to grow. These nutrients are often present in sufficient quantities in soil and groundwater, but can be limiting in some cases. In the same way, dechlorinating bacteria are generally present in the environment, particularly those capable of dechlorinating TCE to cDCE. However, the bacteria responsible for dechlorinating cDCE and

VC to ethene are more sensitive to environmental conditions, and are not present at all sites. In this case, they can be added via bioaugmentation and will grow and proliferate in the subsurface under favorable conditions (Ellis, et al, 2000).

Successful implementation of enhanced bioremediation requires careful decision-making during the design phase. Among these decisions are choice of electron donor, evaluation of the need for bioaugmentation, calculation of donor loading, well-spacing, delivery fluid requirements, and attention to pH issues. Reductive dechlorination is an effective bioremediation method for treating CVOCs and daughter compounds. Common techniques of stimulating reductive dechlorination involve the injection of soluble electron donors into the contaminated plume.

Different microorganisms compete for food sources. For example, both dechlorinators and methanogens can use hydrogen released from food sources as an electron donor (Redox Tech, LLC, 2010). At low hydrogen partial pressure, dechlorinators will outcompete methanogens. Whereas at high hydrogen partial pressure, most of the hydrogen is wasted by methanogens and dechlorinators cannot thrive (Fennell et al., 1997; Smatlak et al., 1996; Yang and McCarty, 1998). It is, therefore, important to deliver a food source to the subsurface such that a low hydrogen partial pressure can be maintained to impart a competitive advantage to dechlorinators. One of the most effective food sources for dechlorinators is fatty acids, such as sodium lactate or ethyl lactate. Vegetable oil is an inexpensive alternative for use as an electron donor.

Biobarrier Concept Evaluation

The biobarrier approach was chosen as a first step to reduce dissolved phase concentrations while treatment of the onsite source areas could be planned and implemented. The aquifer is largely composed of a 32 feet thick, coarse-grained alluvium overlying a weathered schist, with an average depth to groundwater of 17 feet below ground surface (bgs). The average linear groundwater velocity ranges between 42 and 60 feet per year.

A laboratory microcosm study was performed to evaluate whether the complete reductive dechlorination of TCE, trichloroethane (TCA), and 1,1-dichloroethene (11-DCE) could be stimulated in the soil and groundwater collected from the southwestern property boundary of the facility. The most active treatment in the study received sodium lactate, supplemental nutrients, and KB-1® Plus (a product produced by SiREM that containing *Dehalococcoides* and *Dehalobacter*, cultured bacteria that have successfully stimulated reductive dechlorination of the CVOCs present at the Site). This treatment was able to dechlorinate all of the TCE, TCA, and 11-DCE to chloroethane and ethene in 111 days. Another active treatment in the study was emulsified vegetable oil (EVO), supplemental nutrients, and KB-1® Plus. This treatment was also able to dechlorinate all of the TCE, TCA, and 11-DCE by the 111th day; although at the end of the study some of the degradation products were still present. It was concluded that these products would have been completely degraded if the study was extended longer. Lactate and EVO were both shown to be acceptable electron donors. For this pilot test, EVO was chosen as the preferred electron donor due to its persistence and mobility in the subsurface.

Bioaugmentation with KB-1® Plus had the largest impact on the dechlorination rate. EOS® 598-B12 (EVO + nutrients), a product of EOS Remediation, LLC that combines a high concentration of soybean oil with lactic acid and vitamin B-12, and KB-1® Plus was chosen for the biobarrier application. Since the microcosm study revealed that lactate outperformed the EVO in this geological environment, additional lactate was added to supplement the 4% solution provided by EOS®. The lactate provided a quick acting boost to achieve a reducing environment. The food additives and vitamin B-12 provided the supplemental nutrients that promoted the growth of dechlorinating bacteria. The manufacturer of EOS® recommended a target concentration of EOS® between 0.1 % and 0.4%, or 0.001 to 0.004 kilograms (kg) EOS® per kg of saturated soil to be treated. Based on the dosing during the bench scale test (0.3 % in two 0.15% doses) and the experience of MWH, a target concentration of 0.2 % EOS® was chosen for the pilot test.

Biobarrier Implementation

The injection and performance well network consisted of 13 permanent injection wells and 6 performance monitoring wells. The injection wells were spaced 11 feet apart in two staggered rows. Each injection well was screened across the saturated alluvium above the weathered schist. The wells were installed to a depth of approximately 30 feet bgs and were constructed of 2-inch diameter polyvinyl chloride (PVC) risers with 10 to 15 feet of 0.020-inch slotted screen (injection wells) or 0.010-inch slotted screen (performance monitoring wells).

The blended mixture of EOS®, additional sodium lactate, and water was injected between 15 and 30 feet bgs. The estimated radius of influence (ROI) for the EOS® solution was 10 feet. The injection wells were located on a 15 foot spacing interval to allow for overlap in the ROI. Injections were completed from the outside of the barrier inwards and by alternating sides to allow for the injection solution to distribute throughout the subsurface. Approximately 1,748 gallons of water and EOS® were blended and injected at each location. Injection of the blended solution was followed by 2,382 gallons of chase water. The total injected fluids represent approximately 75% of the pore volume within the estimated 10 foot ROI. After the injection of EOS® created anaerobic conditions in the subsurface, bioaugmentation was conducted by adding KB-1® Plus at injection locations. KB-1® Plus is a bacterial culture that contained equal parts of ACT-3® and KB-1®, both of which are mixed cultures of Dehalococcoides/Dehalobacter that are known to degrade CVOCs.

Approximately 7,650 pounds of EOS® and 970 pounds of lactate were injected into the barrier. Approximately 50,000 gallons of dilution and chase water were used to distribute the donor. Baseline sampling in the injection wells indicated that the pH had fallen to 4.9. Therefore, 40 gallons of EOS® activator (alkaline solids) were injected with the chase water to increase the pH to a level more suitable for bioaugmentation. Bioaugmention with KB-1® Plus occurred 8 weeks later, when anaerobic conditions were established and a higher pH was measured in the aquifer.

Performance Monitoring

In order to properly evaluate the performance of the pilot test, two baseline sampling events were conducted. The first baseline sampling event was conducted a minimum of two weeks after the injection wells and performance monitoring wells had been installed. A second baseline sampling event was conducted prior to the start of injections. Performance monitoring, including laboratory samples and water level readings from performance monitoring locations began approximately 1 month after the initial injection and was conducted monthly for 6 months after the injection. Performance monitoring was then conducted quarterly for an additional year. Bromide analysis was included in samples from select wells during the events to identify the presence of the bromide tracer that was injected with the EOS®. All monitoring wells were either within or downgradient of the treatment area and provided information about residence time effects during the pilot study implementation.

Five rounds of monthly performance monitoring have been completed to date. Results indicate that the aquifer in the vicinity of the barrier is now reducing and the average pH has moderated to 6.7. TCE concentrations have been reduced by 97+% in all barrier monitoring wells. With one exception, 111-TCA has been reduced by 94+% in the same wells. Daughter product and ethene production are widespread, such that total VOC concentrations were reduced by 76-95%. A monitoring well located 19 feet downgradient of the performance monitoring wells showed a 40+% reduction in VOC concentration to date. The slower response in this well is a function of both groundwater travel time and desorption of contaminants off the aquifer solids. Performance monitoring is continuing on a quarterly basis in order to establish the donor life in the barrier.

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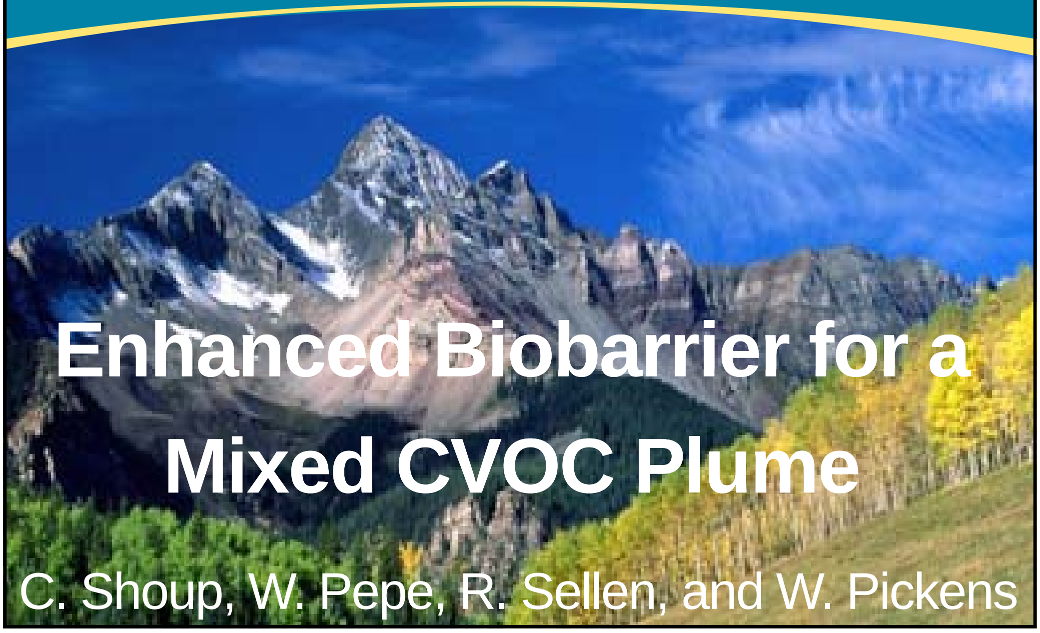
Yang, Y.R. and McCarty, P.L., 1998. Competition for Hydrogen within a Chlorinated Solvent Dehalogenating Anaerobic Mixed Culture. *Environmental Science & Technology*, 32(22): 3591-3597.

MWH.

BUILDING A BETTER WORLD



Enhanced Biobarrier for a Mixed CVOC Plume

C. Shoup, W. Pepe, R. Sellen, and W. Pickens

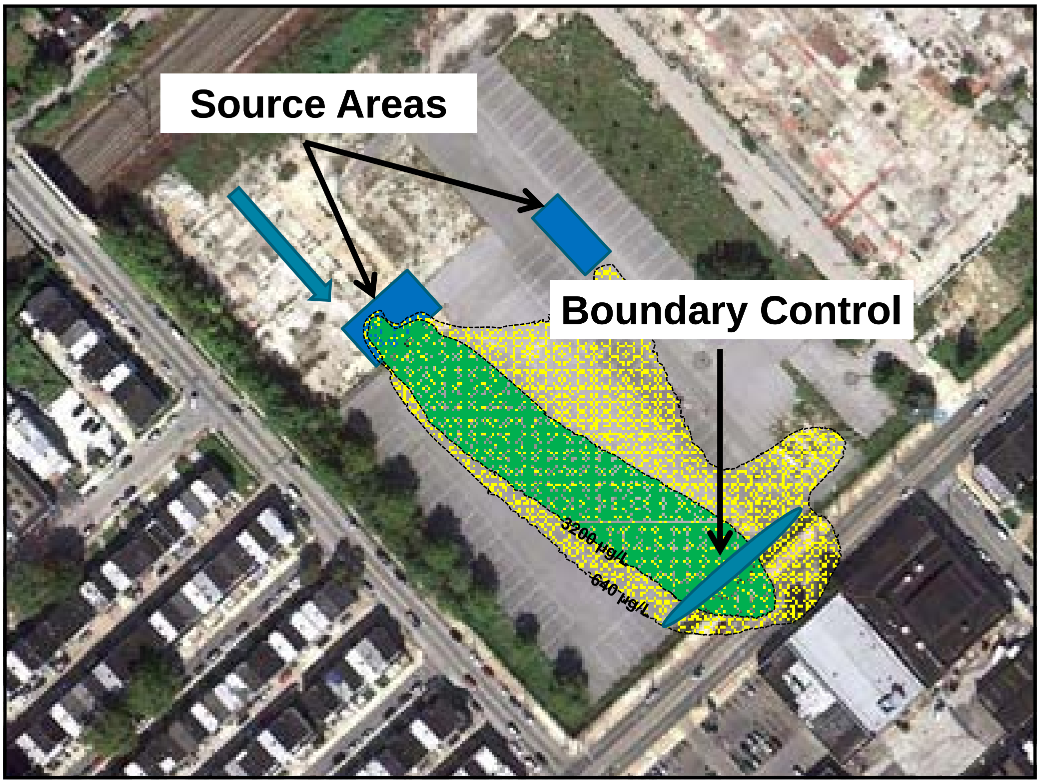
Case History

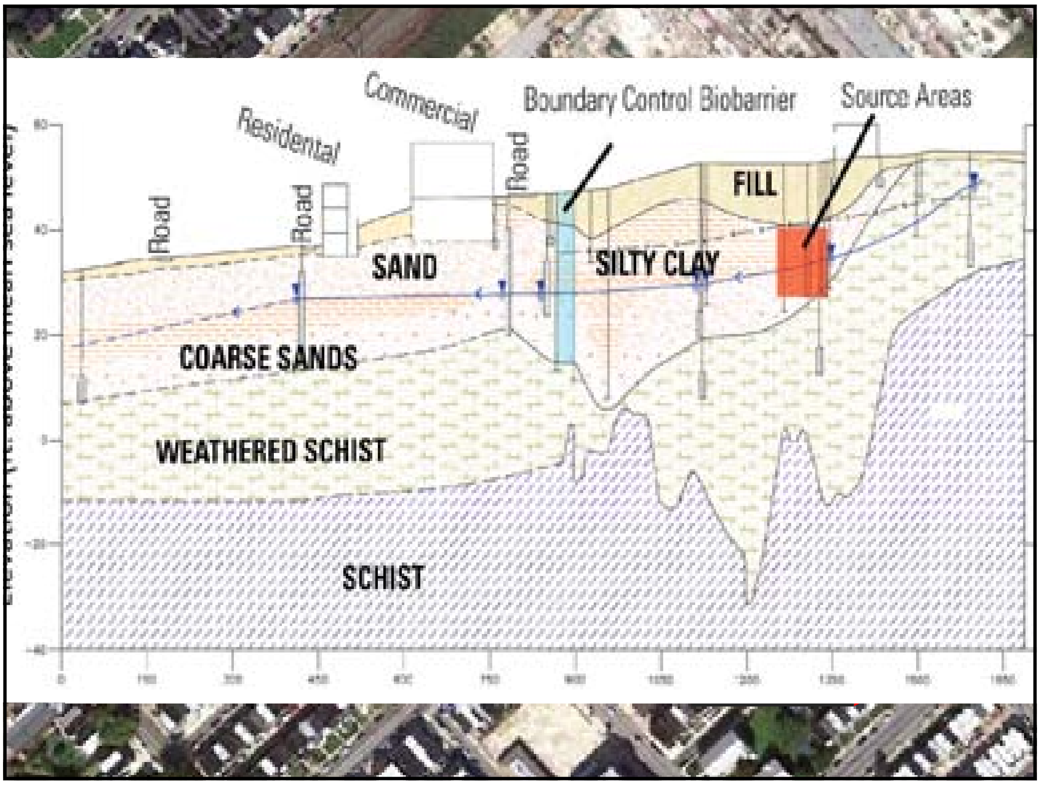
- Biobarrier pilot study conducted at the downgradient boundary of an industrial facility in Pennsylvania.
- The facility was used for the manufacture of various electrical components and equipment from 1924 to 2002.
- Operations resulted in the contamination of soils and groundwater by a variety of CVOCs (primarily TCE).
- Human Health Risk Assessment: TCE was the only CVOC greater than the health-based site-specific standard.
- A biological barrier (biobarrier) was selected as the most viable option to prevent off-site migration from the facility.

RMBU 2012


Site Location


Project Location


Source Areas
Boundary Control
3200 µg/L
640 µg/L


Commercial
Residental
Boundary Control Biobarrier
Source Areas
Road
Road
Road
FILL
SAND
SILTY CLAY
COARSE SANDS
WEATHERED SCHIST
SCHIST

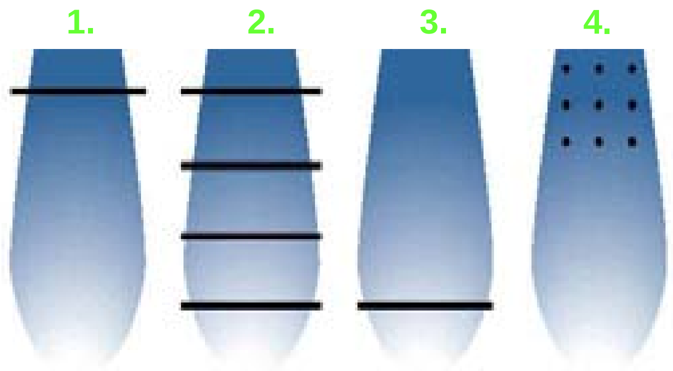
TYPES OF IN-SITU TREATMENT AVAILABLE

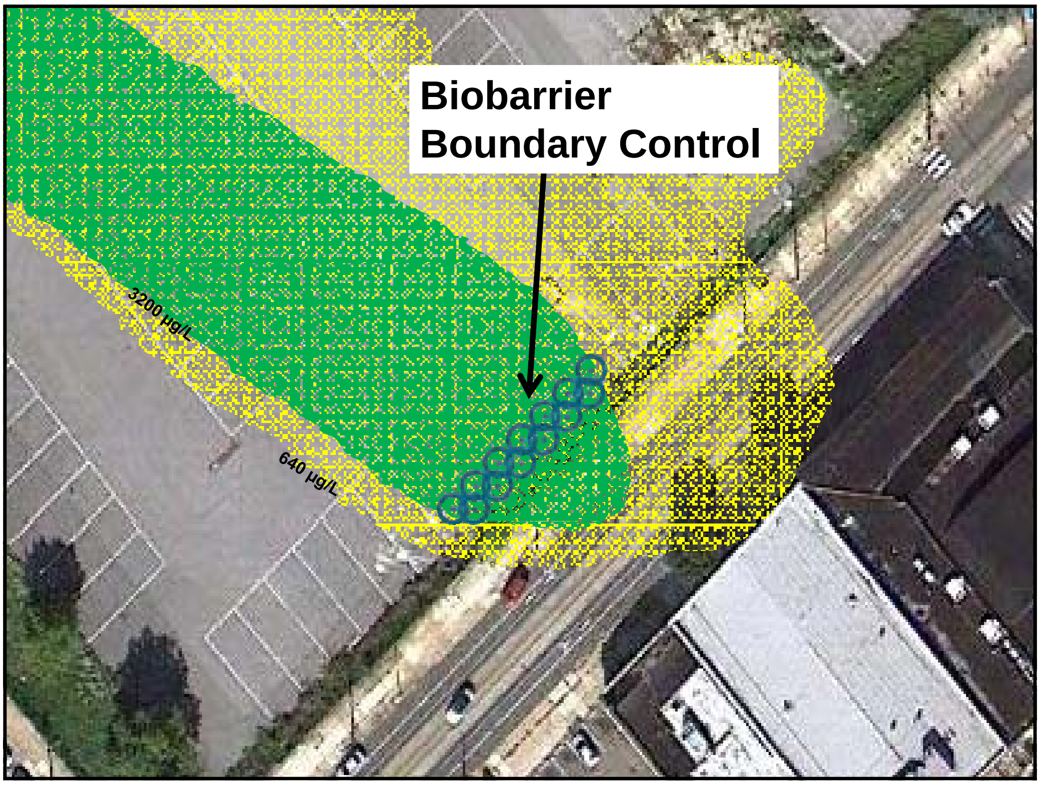
DESIGNS FOR BARRIERS

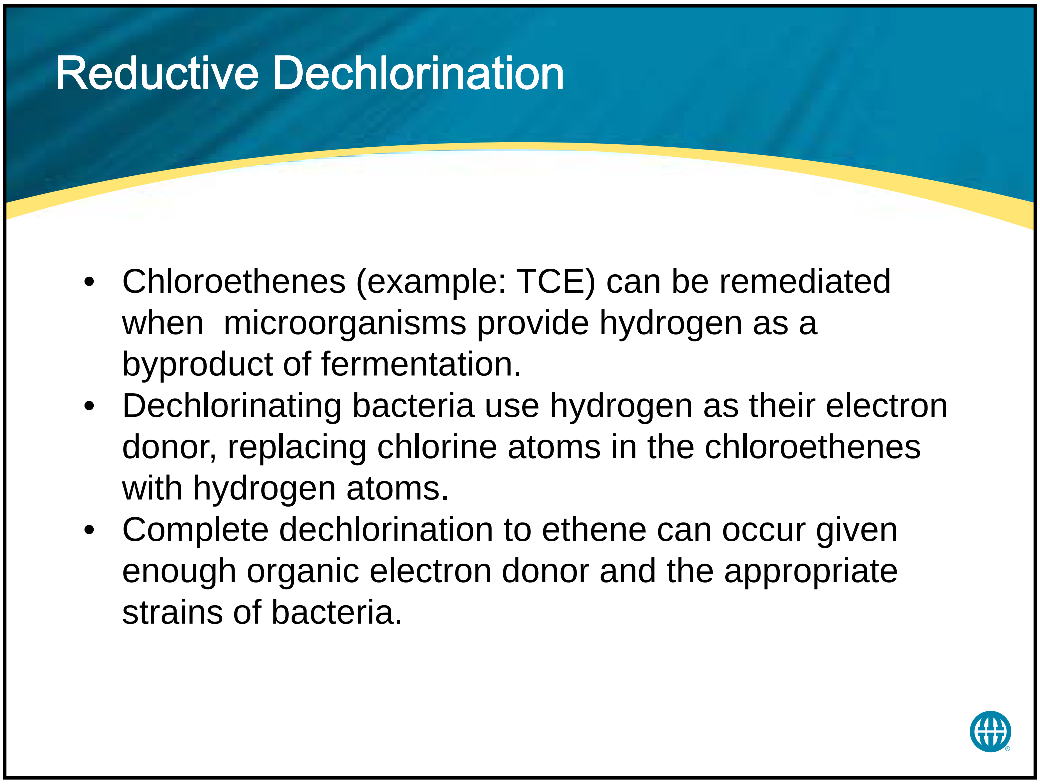
1. UPGRADIENT BARRIER
2. SERIES OF BARRIERS
3. DOWNGRADIENT BARRIER
4. “GRID” OF INJECTION POINTS (AQUIFER-WIDE)

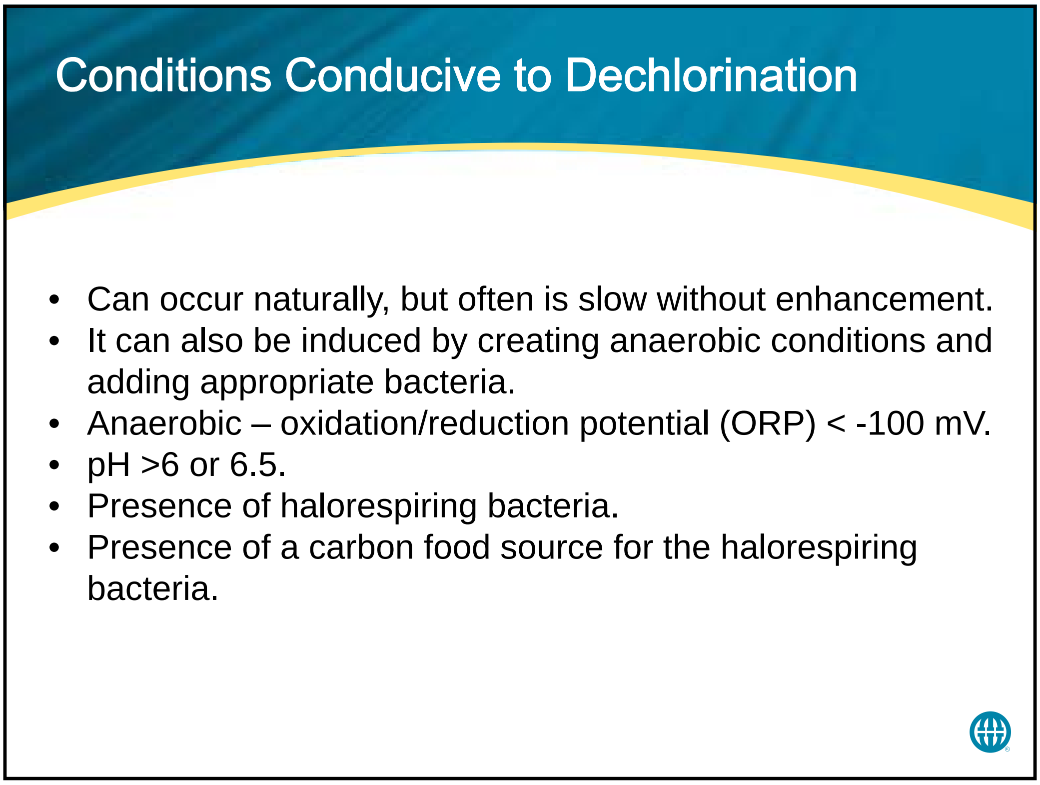
CONSIDERATIONS

- TIME
- COST
- REGULATORY ACCEPTANCE



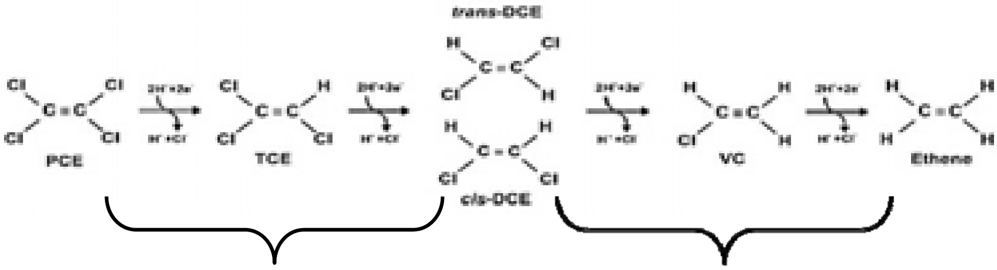



Reductive Dechlorination
• Chloroethenes (example: TCE) can be remediated when microorganisms provide hydrogen as a byproduct of fermentation.
• Dechlorinating bacteria use hydrogen as their electron donor, replacing chlorine atoms in the chloroethenes with hydrogen atoms.
• Complete dechlorination to ethene can occur given enough organic electron donor and the appropriate strains of bacteria.


Conditions Conducive to Dechlorination
• Can occur naturally, but often is slow without enhancement.
• It can also be induced by creating anaerobic conditions and adding appropriate bacteria.
• Anaerobic – oxidation/reduction potential (ORP) < -100 mV.
• pH >6 or 6.5.
• Presence of halorespiring bacteria.
• Presence of a carbon food source for the halorespiring bacteria.

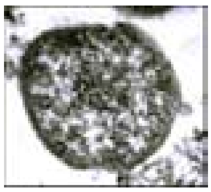
Biological Dechlorination

Can accumulate if DHC is absent



Dehalobacter
Dehalospirillum
Desulfitobacterium
Desulfuromonas
Dehalococcoides

Primarily Dehalococcoides (DHC)

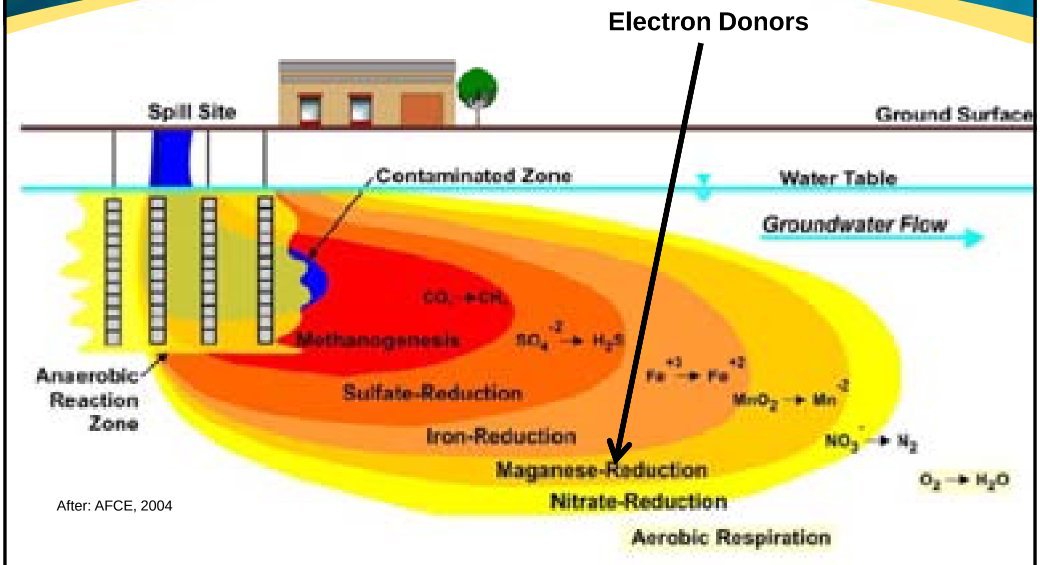


References: AFCEE, 2004,
http://www.genomenewsnetwork.org/articles/2004/04/02/toxic_microbe.php

Enhancing Reductive Dechlorination

- Can enhance natural biodegradation processes by adding carbon substrate (food), nutrients, and Dehalococcoide organisms.
- Many types of carbon substrates have been used:
  - o Methanol and ethanol
  - o Molasses, corn syrup, and lactate
  - o Cheese whey
  - o Emulsified soybean oil
- Dehalococcoides bacterial cultures can be purchased commercially.

Reducing Zones Downgradient of Substrate Injection



After: AFCE, 2004

BENCH/PILOT SCALE TESTS BY MWH CONFIRMED FEASIBILITY OF TECHNOLOGY

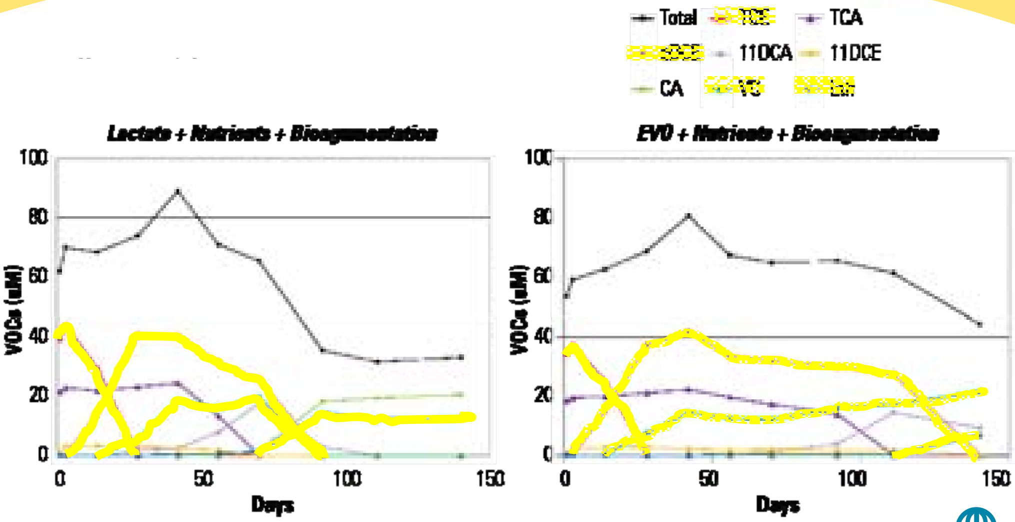
20 Bottle Study-Spiked with TCE/TCA

- Donors: Lactate and EVO
- Bioaugmentation (KB-1® Plus by SiREM)
- Additional Nutrients

Results

- Lactate and EVO both achieved complete degradation of TCE and TCA
- Lactate performed best, EVO-some degradation products after 150 days

Treatability Study



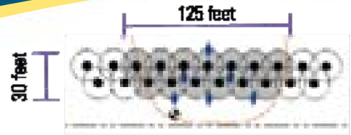
Products Chosen for Implementation

- **EOS® 598B42** – Includes nutrients and lactate, provides longevity of carbon source in subsurface
- **Sodium Lactate** – Provides initial boost to degradation activity
- **EOS® Activator** – Added to raise pH in treatment area
- **SiREM KB-1® Plus** – Ability to degrade mix of VOCs

Target Donor Concentration
0.002 kg EVO / kg saturated soil

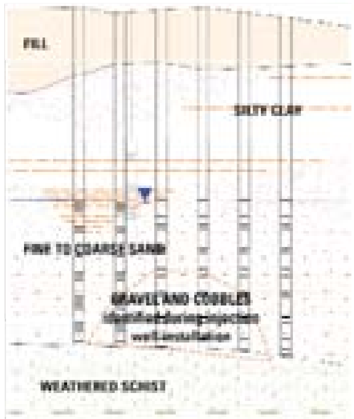
75% of Pore Volume Replaced with Donor Solution and Chase Water

Pilot Test Design



- Performance Monitoring Well Location
- Injection Well Location
- Pilot Test Location
- Proposed Full-Scale Design Location

Design Radius of Influence = 10 feet
Injection Well Spacing = 15 feet

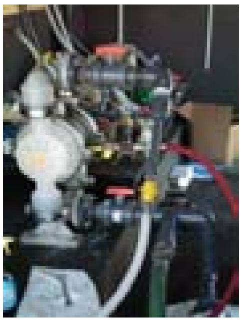


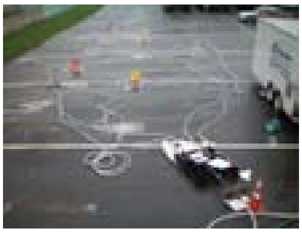
Injection Well Depth = 30-33 feet
Screened Interval = 15 feet

Injection Fluids

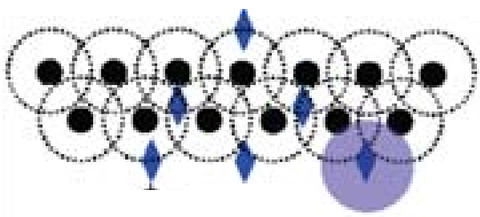
Day 0-5 ***Donor Solution*** 1,700 gal/location	=	**EOS® 598B42** 75 gal/location	+	**Sodium Lactate** 7 gal/location	+	**Mixing Water** from city hydrant
Day 6-8 ***pH Adjustment Solution and Chase Water*** 2,300 gal/location	=	**EOS® Activator** 3 gal/location	+	**Chase Water** from city hydrant	+	Mixing water from city hydrant
Day 69 ***Bioaugmentation*** 10 gal/location	=	**SIREM KB-1® Plus** 3 gal/location	+	**Anaerobic Chase Water** Groundwater extracted from treatment area		

Pilot Study Implementation

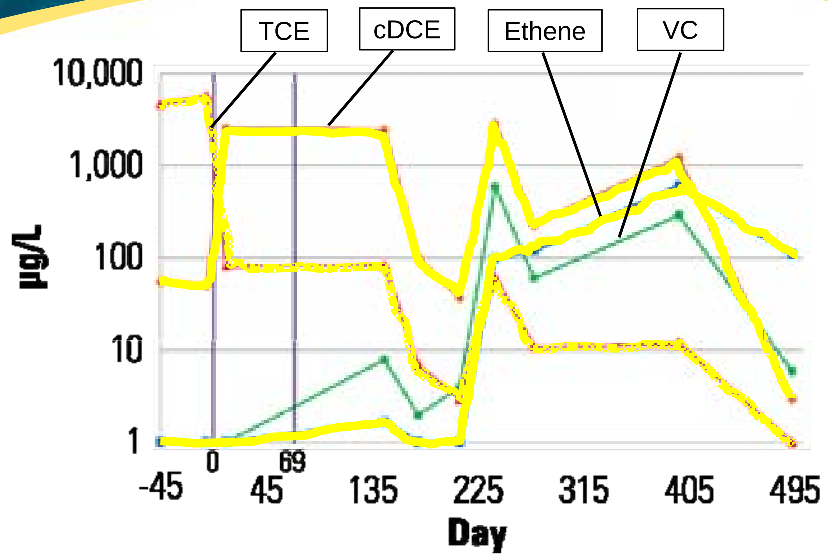




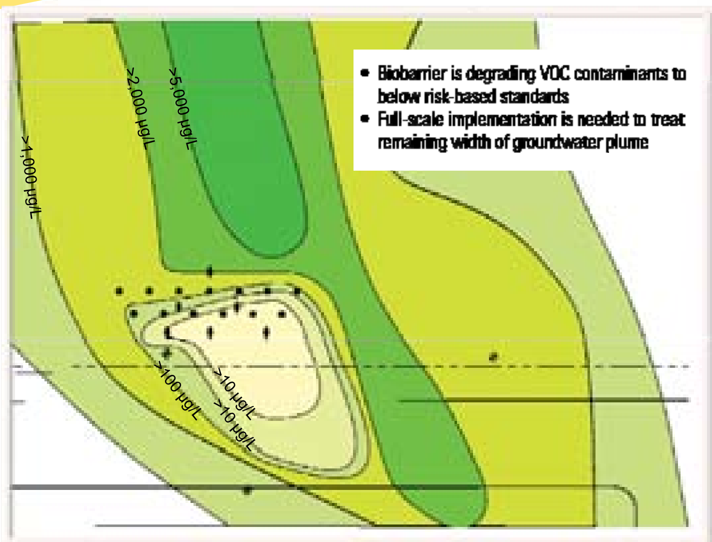
Pilot Test Results



Pilot Test Results

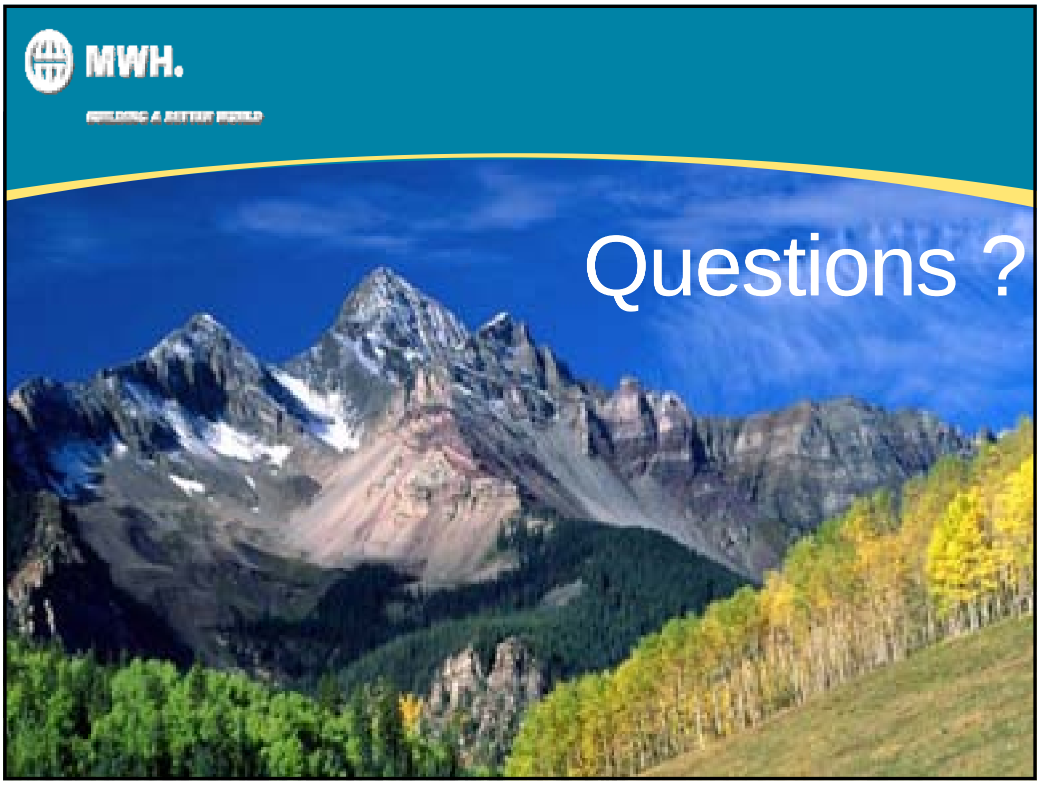


Pilot Test Results (495 Days After Treatment)



Expanded Implementation 2012

- Pilot test expanded to 42 injection wells
- Carbon donor injection was completed in September 2012.
- Bioaugmentation planned for November 2012.
- Pre-second phase baseline sampling indicated:
  - o Microbial population decreased by one order of magnitude ($3x10^7$ Dhc from > to $3x10^8$ Dhc).
  - o Microbial population still meets minimum size for complete dechlorination (> 10^4).
  - o Degradation of TCE occurring. Some buildup of breakdown products (cis-DCE, VC, etc.).
  - o ORP remains slightly negative around -30 mv) and DO remains <1.



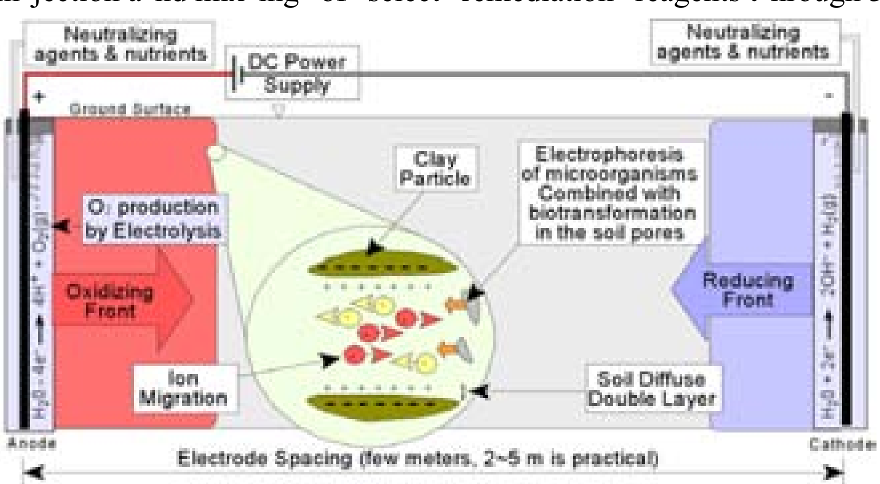
Electrokinetic-Enhanced Bioremediation (EK-BIO) - An Innovative Bioremediation Technology

James Wang (jwang@geosyntec.com), Evan Cox (Geosyntec Consultants, USA)
Charlotte Riis (NIRAS A/S, Denmark)
Mads Terkelsen (Capital Region, Denmark)
David Gent (US Army ERDC, USA)

ABSTRACT: Effective delivery of remediation reagents is a critical component for successful implementations of various in-situ remediation technologies. Traditional injection methods are generally based on hydraulic advection mechanisms and often faced with limitations at site with low-permeability materials and/or highly heterogeneous geology. The transport of ionic substances, such as lactate, in an electric field in subsurface is relatively independent of hydraulic conductivity of the formation. Therefore, effective delivery can be achieved in areas where advective flow is limited. This presentation introduces a new technology (EK-BIO), which uses direct current (DC) electric fields to facilitate the subsurface transport of reagents. For a site in Skuldelev, Denmak, EK-BIO was evaluated and subsequently demonstrated as an innovative strategy for distributing electron donors and dechlorinating microorganisms (*Dehalococcoides*) in PCE-contaminated, low-permeability aquifer.

INTRODUCTION

EK-BIO technology is intended to distribute bioremediation reagents throughout low permeability materials through the establishment of an electrical field in the subsurface that promotes electron donor migration. The electrical field is established in the subsurface by applying a low-voltage direct current (DC) to electrodes installed through the targeted subsurface materials. The established subsurface DC electric field facilitates efficient injection and mixing of select remediation reagents through 3 transport

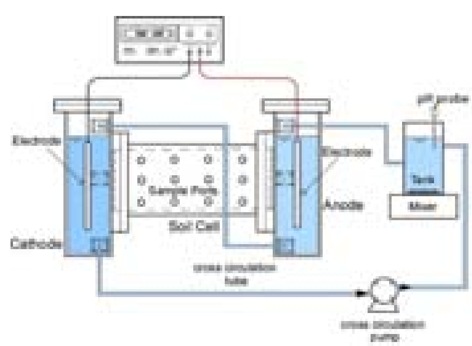


mechanisms: electroosmotic advection (electroosmosis), ion migration, and electrophoresis, as depicted in the figure above. Electroosmosis is bulk transport of the pore fluid in the soil; usually the flow direction is from the anode toward the cathode. Ion migration refers to the movement of anions (negative ions) and cations (positive ions) to the anode and cathode, respectively. Electrophoresis describes the transport of charged particles, such as clay particles or bacteria, under the applied electric field to the electrodes of opposite polarity. Typically, electrophoresis is expected to contribute less to contaminant transport in the subsurface because soil tends to act as a filter to retard the movement of solid particles. In this EK-BIO evaluation project, electroosmosis and ion migration are considered the two primary mechanisms for delivery of bioremediation reagents.

Substrates (organic acid anions), such as lactate and butyrate, will migrate into and across low permeability zones along the electric field lines that are established between the electrodes. Because the transport occurs in the form of ion migration, soil pore size and porosity will have little effect on transport rates. This migration will be relatively independent of the hydraulic conductivity and flow. A comparison of typical transport rates in clay and sand under hydraulic and electric gradients shows that although hydraulic transport rates in sands can be orders of magnitude higher than in clays, transport rates by ion migration are relatively similar in clays and sands. This is a major advantage in heterogeneous deposit where hydraulic delivery techniques are limited by the preferential flow through the high permeability areas (bypassing low permeability zones), while EK transport will result in much more uniform delivery of substrates.

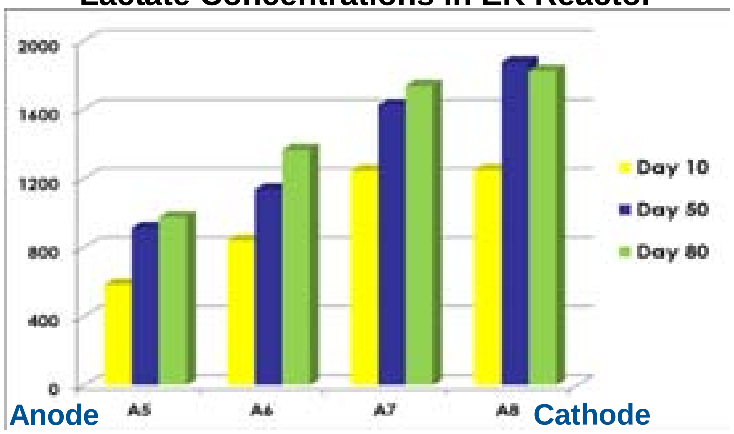
BENCH-SCALE EK-BIO EVALUATION

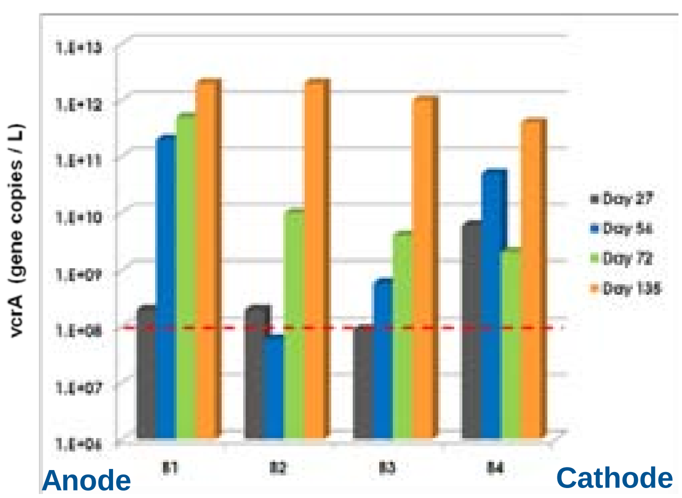
A bench-scale treatability test was designed to evaluate the potential application of EK-BIO at a site in Denmark (the Site), where tetrachloroethene (PCE) impact was identified. The Site geology generally consists of 2 to 3 meters (m) of topsoil and sand, overlying a thick sequence (> 5 m) of clay till containing frequent, discontinuous, lenses and stringers of sand. A previous laboratory treatability study indicated that indigenous bacteria present at the Site could achieve partial dechlorination of PCE to cDCE. The soils used for the bench-test were collected from 3.5 to 6.5 m bgs with PCE concentrations between 142 and 464 mg/Kg dry soil and Total Organic Carbon (TOC) at approximately 450 mg/Kg dry soil. The test was conducted in EK reactors shown below.



The EK-BIO bench test included three stages of operation: (1) the initial delivery of lactate under EK conditions, (2) transport and distribution of augmented *Dehalococcoides (Dh*c) under EK conditions, and (3) post-EK (no electricity) monitoring for the continuing biotreatment established by stages 1 and 2 operations. For EK operation, a constant current, which resulted in a target current density of 5 A/m^2 with respect to the soil cell cross-sectional area, was applied to the soil cell through two graphite electrodes. The peristaltic pump was used to cross-circulate between anolyte and catholyte reservoirs at a flowrate of approximately 25 mL/min. The liquid levels in both electrode compartments were always maintained at the same level so that no hydraulic gradient across the soil cell was created. To bioaugment the EK reactor, KB-1® culture (SiREM Laboratory, Guelph, Ontario, Canada) was added to the electrode compartments (5 mL each compartment) and to the central supply well (1 mL).

Lactate Concentrations in EK Reactor





Biomarker for *Dhc* in EK Reactor

Based on the results of this bench-scale test shown above, the following conclusions and recommendations were made to support the further development of EK-BIO applications at the Site:

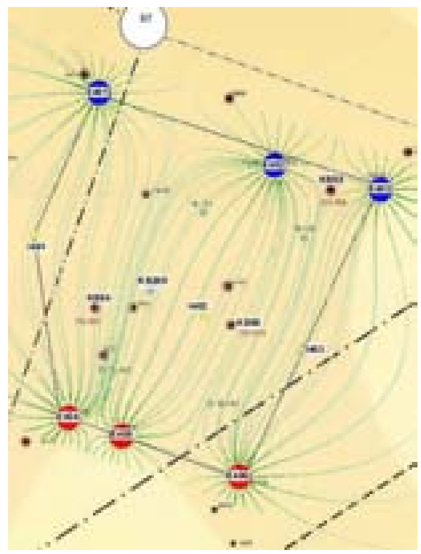
- The current density applied in this test (5 A/m^2) was adequate to establish the desired electric field across the soil matrix;

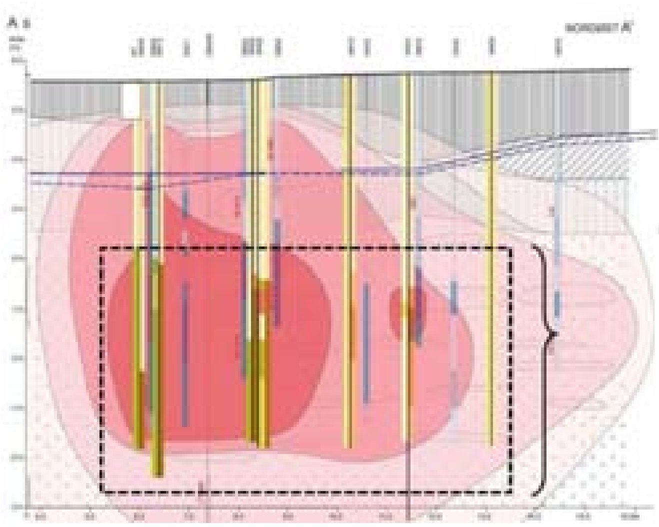
- EK with an electrolyte cross-circulation component can be engineered to maintain neutral pH during EK operation;
- Effective lactate transport (approximately 3.2 cm/day) was achieved in the soil under the EK conditions tested in this study;
- The bioaugmented *Dhc* appeared to be effectively transported through the soils under the EK conditions tested; and
- The added *Dhc* could survive, grow, and achieve effective PCE dechlorination to ethene.

FIELD-SCALE EK-BIO PILOT TEST

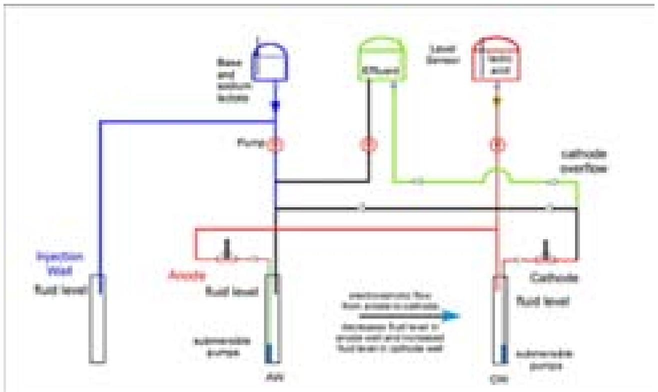
In 2011, an EK-BIO pilot test was conducted at a site in Denmark. A PCE DNAPL contamination is present in interbedded glacial deposits of sand and clay till. Highest concentrations (up to 21,000 mg PCE/kg DM) have been observed in clay till between 3 and 7 meters bgs. The EK-BIO pilot test was performed and designed with the objective to demonstrate effective transport of lactate, the viability and migration of augmented *Dehalococcoides*, and PCE dechlorination in the test area achieved within the timeframe of the pilot test.

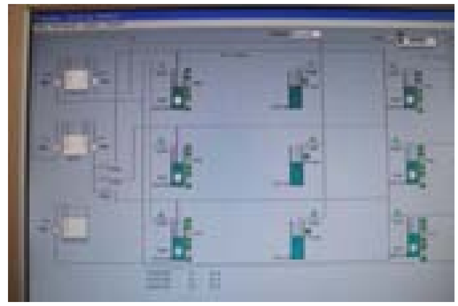
The pilot test design was an array configuration of the well network covering an area of approximately 3 meters by 3 meters. The design included 3 pairs of anodes and cathodes, and 3 amendment supply wells along with 4 monitoring wells, and 4 multilevel well systems to allow for detailed performance monitoring. The well network was designed with screen intervals targeting a treatment interval of 3 to 8 meters bgs.





EK-BIO Pilot Test Area



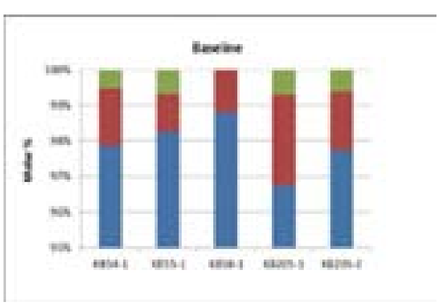


EK-BIO Pilot Test System Process Flow and Control

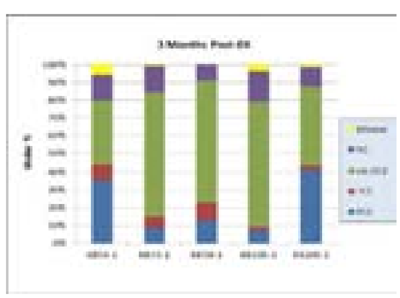
The system was designed with cross-circulation between anodes and cathodes for the purpose of pH control. A SCADA system was designed and installed to continuously collect various system operational data such as voltages and currents to electrodes as well as water levels and pH in the wells. Active EK operation was maintained for 74 days. The current settings were in the range of 5A to 8A to each electrode. The power supplied to the system was relatively consistent. The overall total energy supplied to the EK system throughout this pilot test was calculated to be 1,943 kW-hour.

Monitoring of the geochemical parameters showed that the pH in the groundwater remained relatively neutral throughout the test. The oxidation-reduction potential (ORP) became negative (approximately -100 mV) within the first 30 days of operation, and thus optimal for reductive dechlorination. A slight increase in temperature (~5 ^{o}C) was observed during the operation period, but the temperature returned to baseline conditions at the monitoring campaign 3 months after end of operation. This slight increase of temperature in fact may be beneficial in promoting in situ microbial activities.

Based on groundwater sampling data, a lactate transport rate of ~ 2.5 to 5 cm/day was estimated, which corresponded well to the lactate transport rate of 3.2 cm/day found in the bench-scale treatability test. The monitoring data of groundwater chlorinated volatile organic compounds (CVOCs) shown below clearly indicated reductive dechlorination of PCE and trichloroethene (TCE) originally present in the target treatment area.



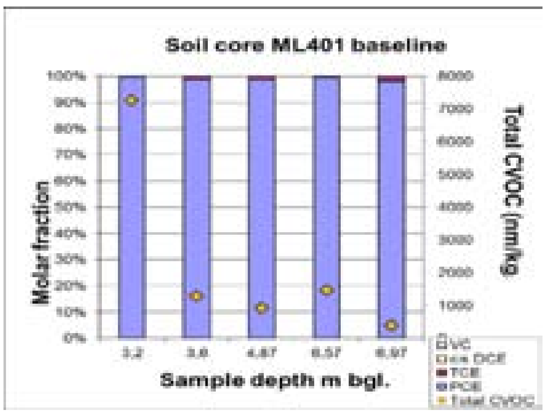
Baseline Groundwater Quality



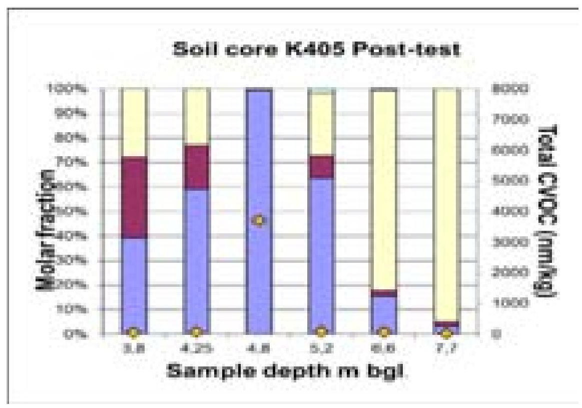
3 Months after EK Test

A key observation was the complete dechlorination of PCE to ethene. A previous laboratory treatability study indicated that indigenous bacteria present at the Site could achieve partial dechlorination of PCE to c DCE. Therefore, the observed complete dechlorination across the target treatment area within 3 months following EK test suggested the distribution of augmented dechlorinating *Dhc* bacteria.

In addition to groundwater monitoring data, soil core sampling data further confirmed the development of reductive dechlorination capacity within the pilot test area. Soil core sampling was performed to specifically collect clayey materials from various locations within the pilot test area. Analytical results of clayey samples collected during baseline event and post-test events again showed evident reductive dechlorination of PCE. These soil sampling data provided strong evidence that EK operation had established active reductive-dechlorination microbial populations in the clays within the pilot test area.



Baseline Soil Quality



Post-Test Soil Quality

CONCLUSIONS

Based on the results of both bench-scale evaluation and field-scale pilot test, it has been demonstrated that EK-BIO can facilitate the transport of amendments (lactate and KB-1®) through clay soils. Concentrations of biomarkers increased significantly across the pilot test area compared to baseline levels. Significant reductive dechlorination of PCE to cis-1,2-DCE was achieved within the short pilot test duration, and complete dechlorination to ethene was observed in post-test monitoring. The total power supply used in the pilot test (1,900 kW-hr) was equivalent of the energy needed for approximately ten 100-watt light bulbs operated for the same duration. This project demonstrated that EK-BIO can be engineered and applied cost-effectively at sites with low-permeability materials. This innovative technology offers an important remediation alternative at sites where in-situ remediation may face significant challenges.

Geosyntec consultants

Electrokinetic-Enhanced Bioremediation (EK–BIO)

An Innovative Bioremediation Technology

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Charlotte Riis – NIRAS A/S, Denmark
David Gent – US Army ERDC

Geosyntec.com

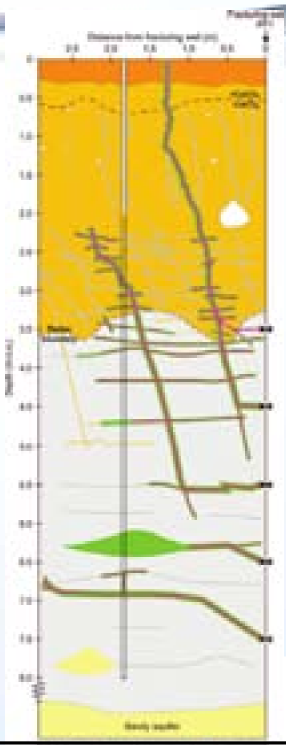
Geosyntec consultants

Delivery ! Delivery ! Delivery !

EISB can be cost-effective, **BUT ...**

- A key challenge for EISB is **effective delivery** of remediation reagents
- Conventional hydraulic flow-based injection becomes limited in **low permeability soils and heterogeneous subsurface**

Can EK overcome fundamental limitations of low-K materials?



Christiansen et al., ES&T 2008

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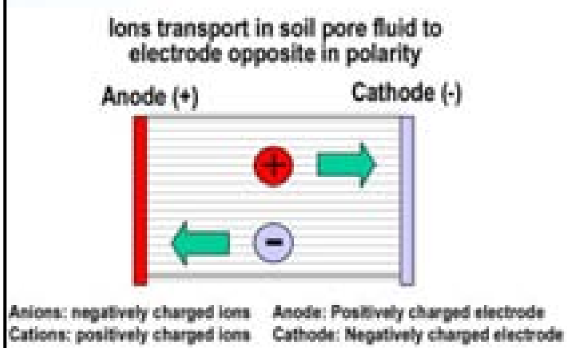
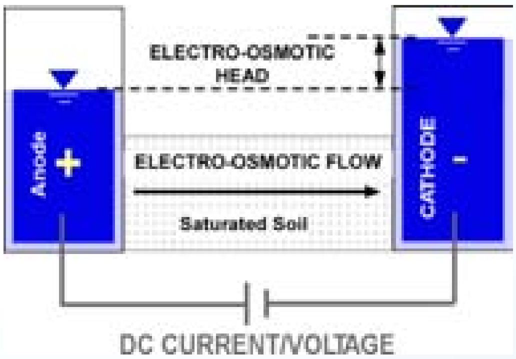
EK for Subsurface Transport





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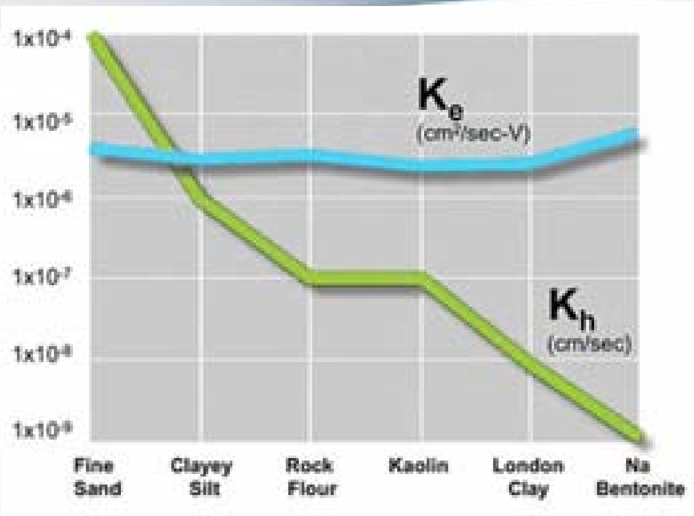
EK vs. Conventional Hydraulic Delivery



As Kh decreases, EK becomes the most efficient delivery method

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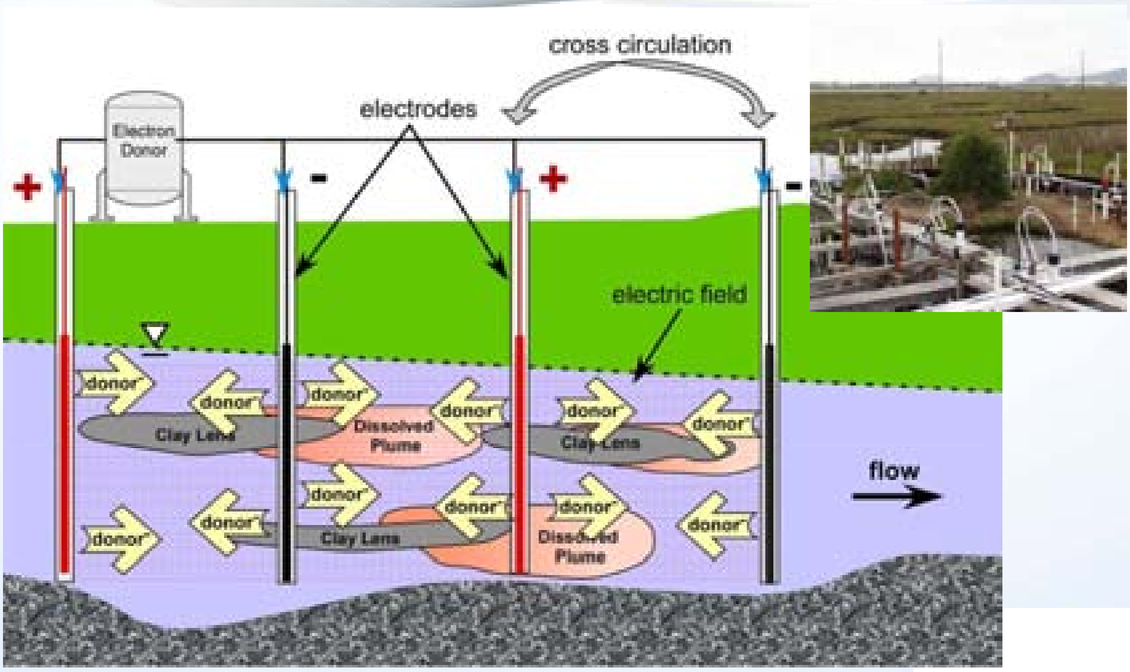
EK Field Implementation



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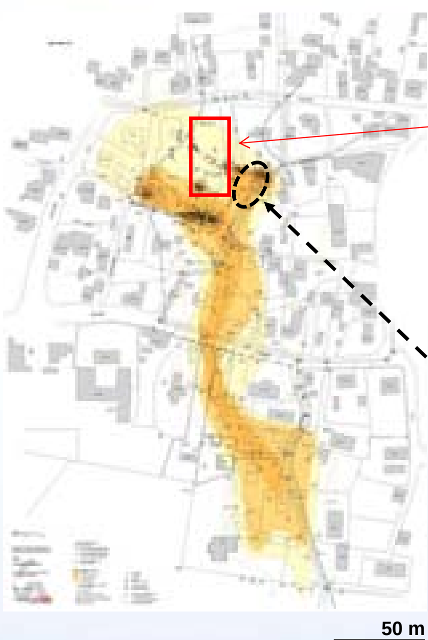
EK-BIO Test Site – Skuldelev, Denmark

- 1969-1983 industrial facility
- PCE used for degreasing
- 7 PCE DNAPL hot spots
- 300 m long plume in sand layer 2 - 6 m bgs



Test Site: Hot Spot IV

- PCE DNAPL
- 10,000-100,000 µg CVOC/L
- 1,000-10,000 µg CVOC/L
- 100-1,000 µg CVOC/L

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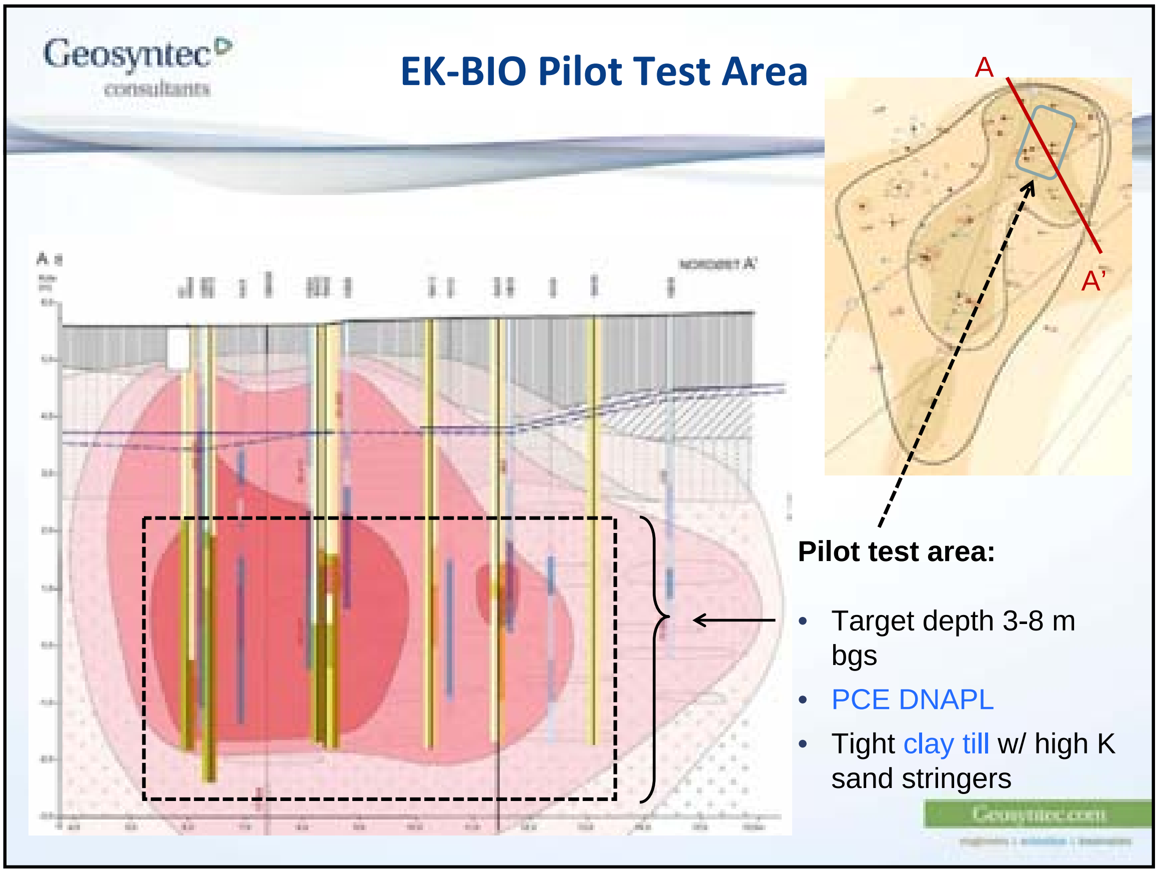
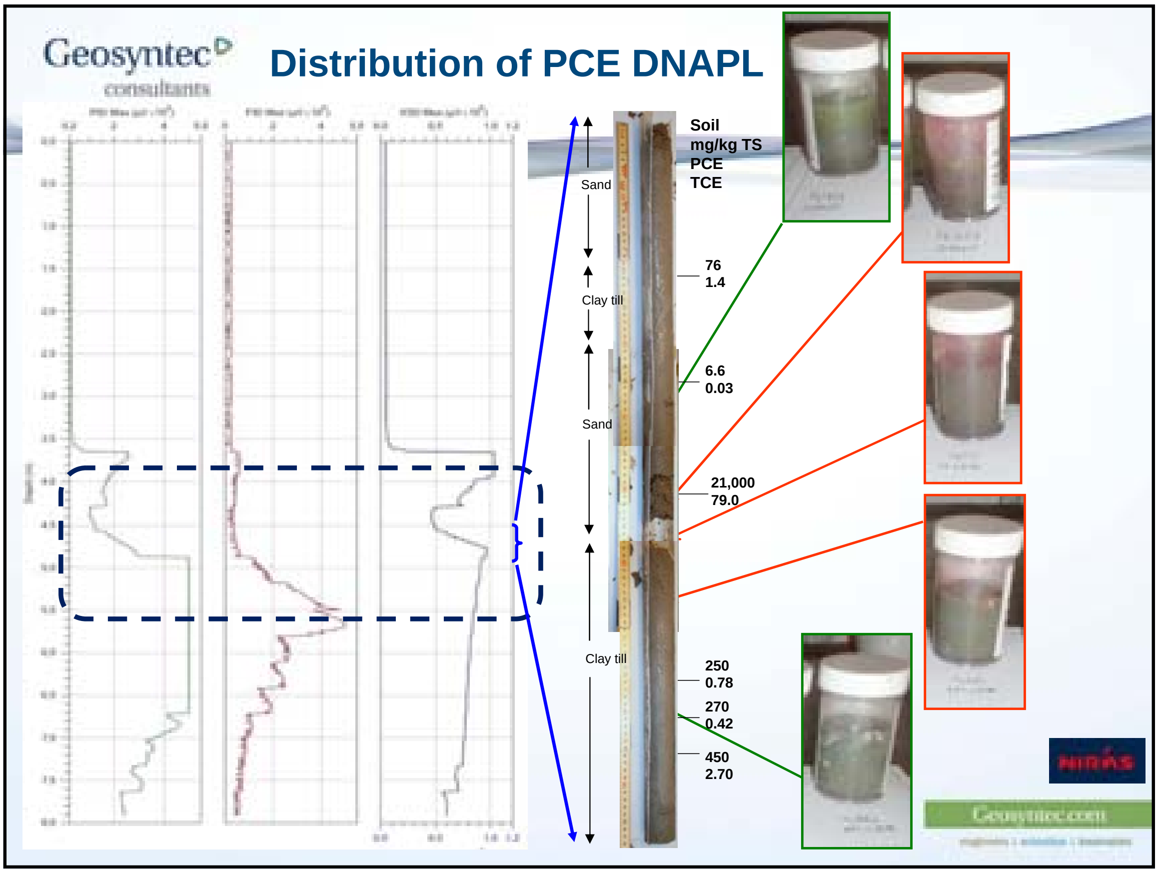

Geosyntec consultants
EK-BIO Pilot Test Area
A
A'
Pilot test area:
• Target depth 3-8 m bgs
• PCE DNAPL
• Tight clay till w/ high K sand stringers
Geosyntec.com


Geosyntec consultants
Distribution of PCE DNAPL
Soil
mg/kg TS
PCE
TCE
Sand
Clay till
Sand
Clay till
76
1.4
6.6
0.03
21,000
79.0
250
0.78
270
0.42
450
2.70
Geosyntec.com

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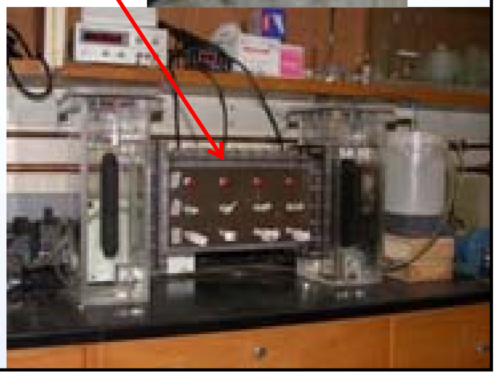
Bench-Scale EK-BIO Testing

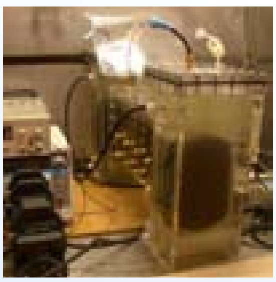
- Bench Scale EK Reactor (40 cm x 15 cm x 5 cm test cell)
- Two 5-Liter electrode chambers; with cross-circulation & gas vent
- Electrodes : graphite plates
- DC power supply and control
- Compaction during setup
- A central "supply well"



Geosyntec consultants

Bench-Scale EK-BIO Test Design

- Site soil – Duplicate EK (A&B) & Control Reactor (no electricity)
- Electrolyte solution (lactate)
- Constant current (380 mA; ~ 5 A/m^2); Zero Hydraulic Gradient



Chemicals	Concentration (g/L)
$NaC_3H_5O_3$ (sodium lactate)	10
KH_2PO_4	0.05
K_2HPO_4	0.08
NH_4Cl	0.6
NH_4CH_3COO	0.6

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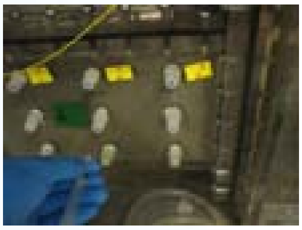
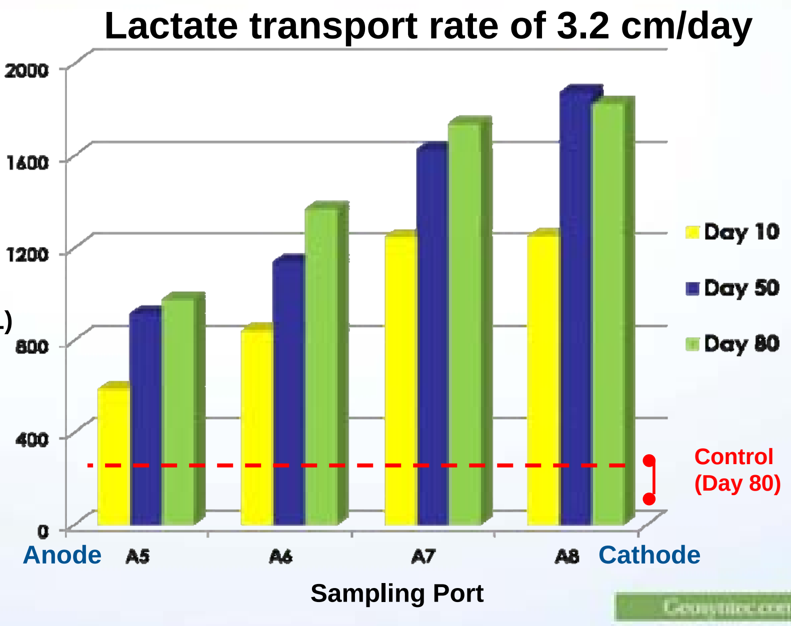
EK Transport of Lactate





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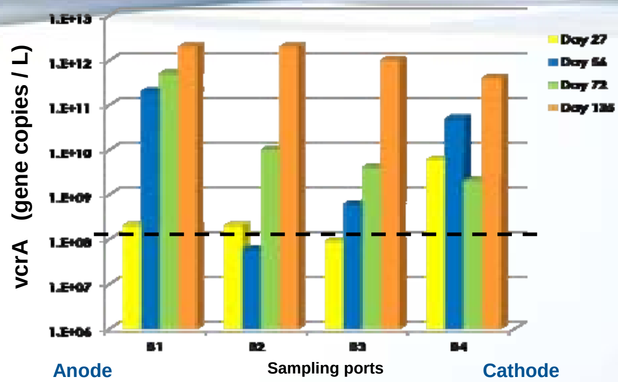
Bench-Scale EK-BIO Test Results



Site Soil Samples : 2.E+04 gene copies / gram

- ✓ Electrolyte cross-circulation ⇒ effective pH control
- ✓ Electric current density of 5 A/m² ⇒ lactate transport of 3.2 cm/day
- ✓ Biomarker data → increases of *Dehalococcoides* across EK reactors (EO likely transport mechanism)
- ✓ Complete dechlorination of PCE to ethene observed and consistent with active *Dhc* population (biomarker data)

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EK-BIO Pilot Test – Objectives

1. Evaluate and demonstrate applicability of EK-BIO
2. Evaluate lactate transport rate
3. Evaluate viability and transport of *Dhc* in clay materials
4. Evaluate degradation of PCE w/in timeframe of pilot test
5. Gather site-specific field data and operational data for full-scale EK-BIO design

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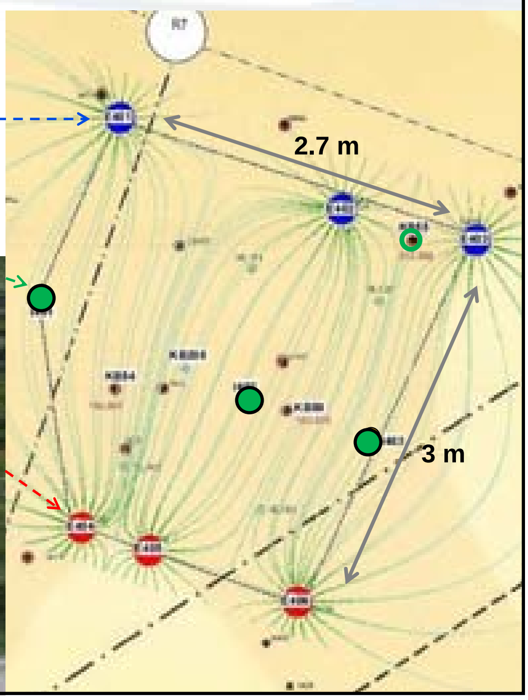
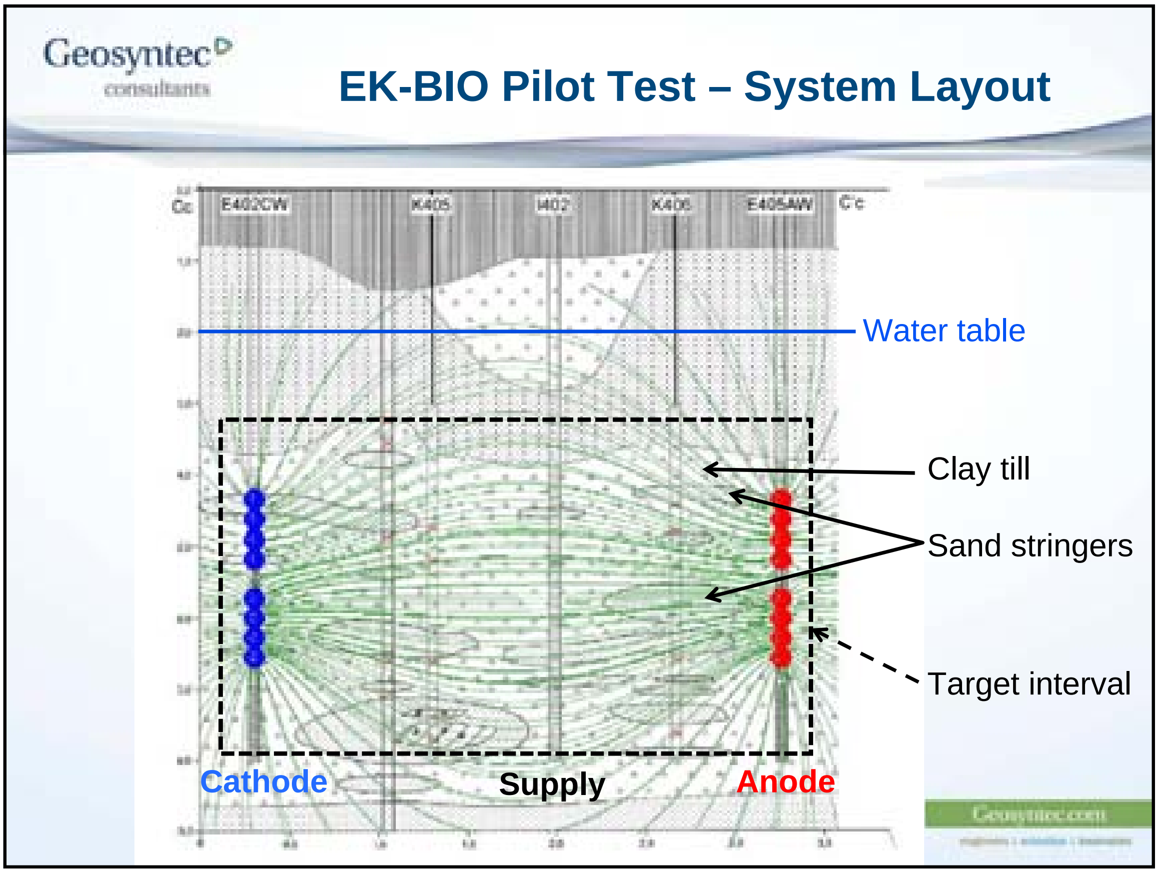
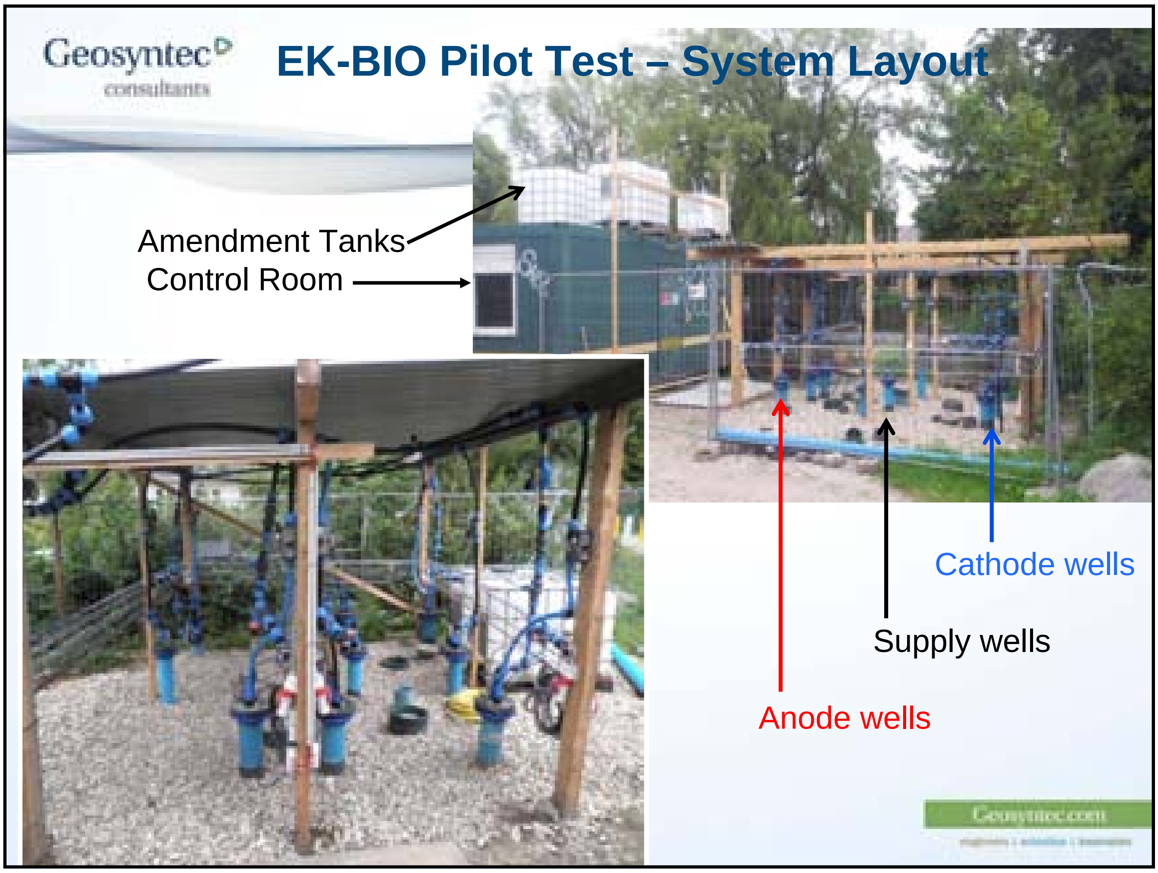
EK-BIO Pilot Test – System Layout

- Pilot test area ~ 3 x 3 m
- Pilot test infrastructure
  - 3 cathode wells
  - 3 supply wells
  - 3 anode wells




Geosyntec consultants
EK-BIO Pilot Test – System Layout
E402CW
K405
I402
K406
E405AW
Water table
Clay till
Sand stringers
Target interval
Cathode
Supply
Anode
Geosyntec.com


Geosyntec consultants
EK-BIO Pilot Test – System Layout
Amendment Tanks
Control Room
Cathode wells
Supply wells
Anode wells
Geosyntec.com

EK-BIO Pilot Test – System Power Supply and Operational Control

EK-BIO Pilot Test – Operational Parameters

- Periodic, short-cycle circulations between cathode wells and anode wells for pH control
- Power supply settings : ~ 3 to 6 A to each electrode well (required ~ 90 to 100 V)
- Chemical amendment over 60 days of testing :
  - Supply wells and anode wells:
    - Lactate ~ 5,900 liters total
    - NaOH ~ 1,100 liters total
  - Cathode wells:
    - Lactic acid ~ 250 liters total
- All wells:
    - Bioaugmented with *Dhc* culture KB-1®: ~ 21 liters total

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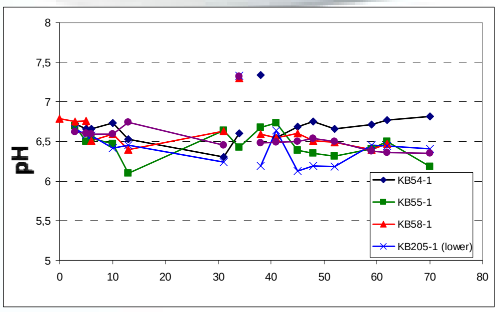
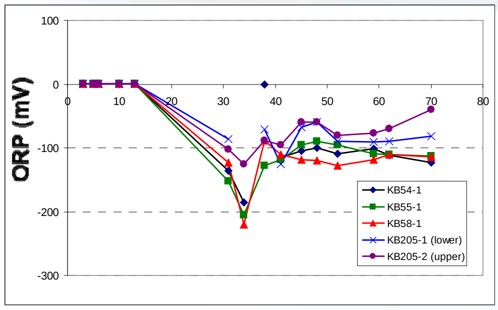
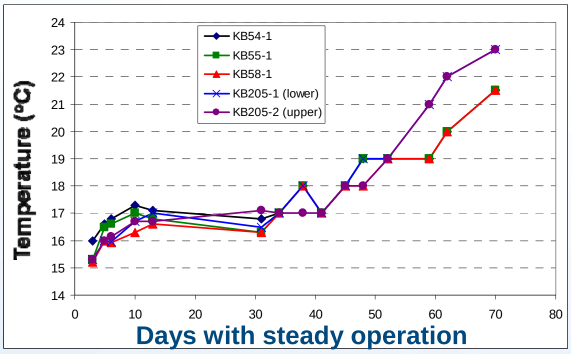
EK-BIO Pilot Test – Geochemistry







Monitoring showed:

- ✓ Neutral pH
- ✓ Negative ORP
- ✓ Slight increase in temperature (~5 ºC), which may benefit biological activities

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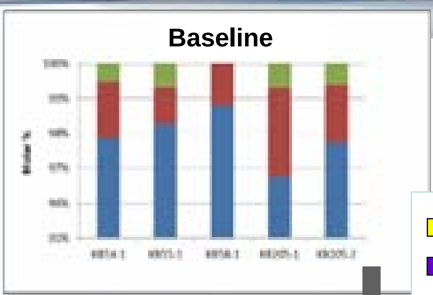
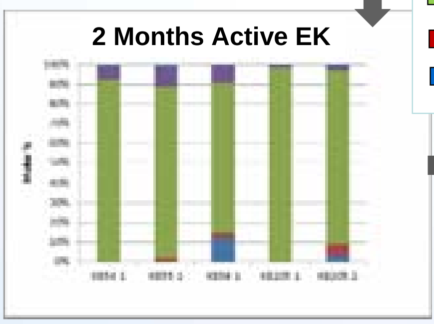
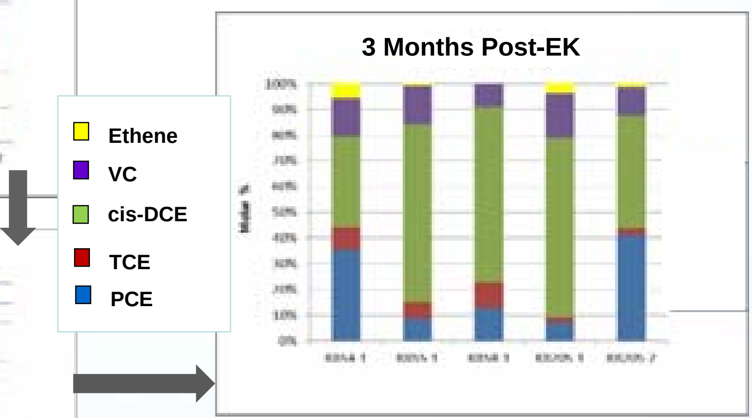
EK-BIO Pilot Test – Groundwater Data







✓ Increase in ethene post-EK operation up to 3,700 µg/L

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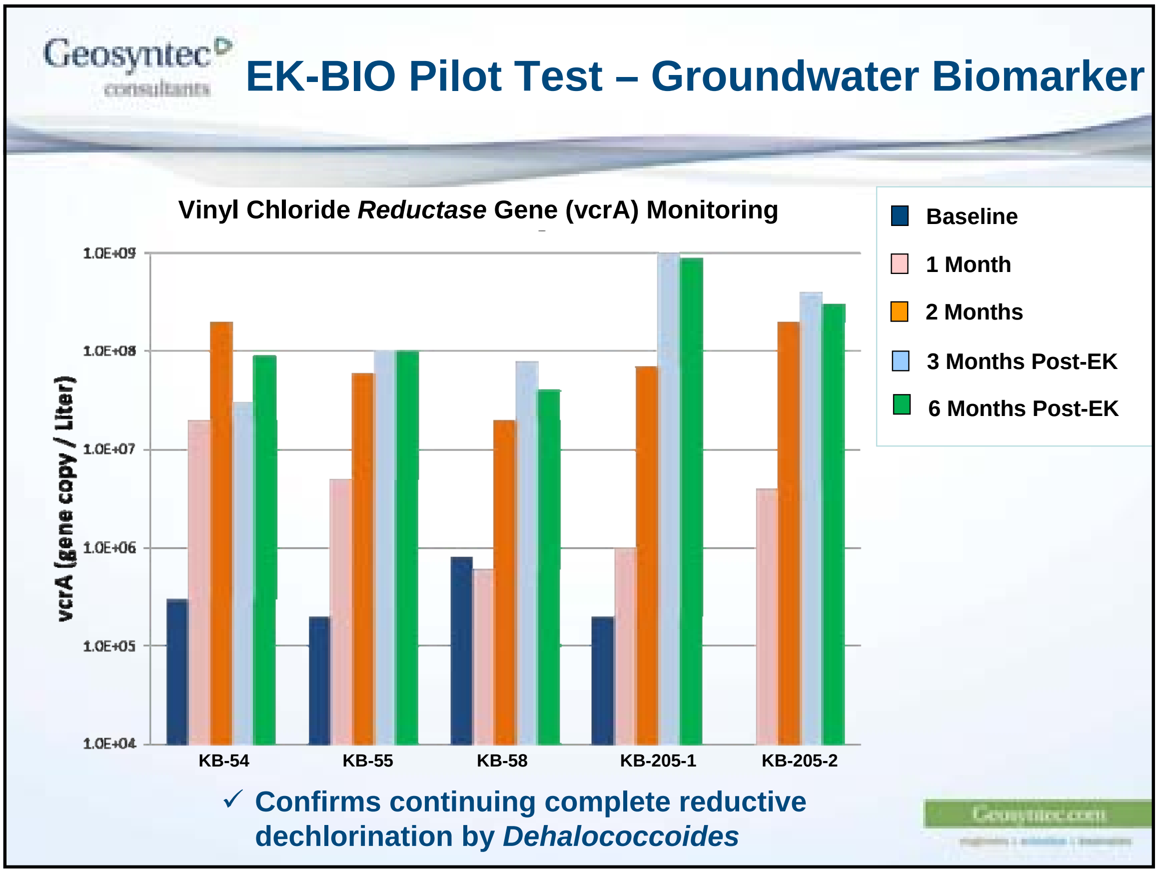
Geosyntec consultants
EK-BIO Pilot Test – Groundwater Biomarker
Vinyl Chloride Reductase Gene (vcrA) Monitoring
vcrA (gene copy / Liter)
1.0E+09
1.0E+08
1.0E+07
1.0E+06
1.0E+05
1.0E+04
KB-54
KB-55
KB-58
KB-205-1
KB-205-2
Baseline
1 Month
2 Months
3 Months Post-EK
6 Months Post-EK
✓ Confirms continuing complete reductive dechlorination by Dehalococcoides
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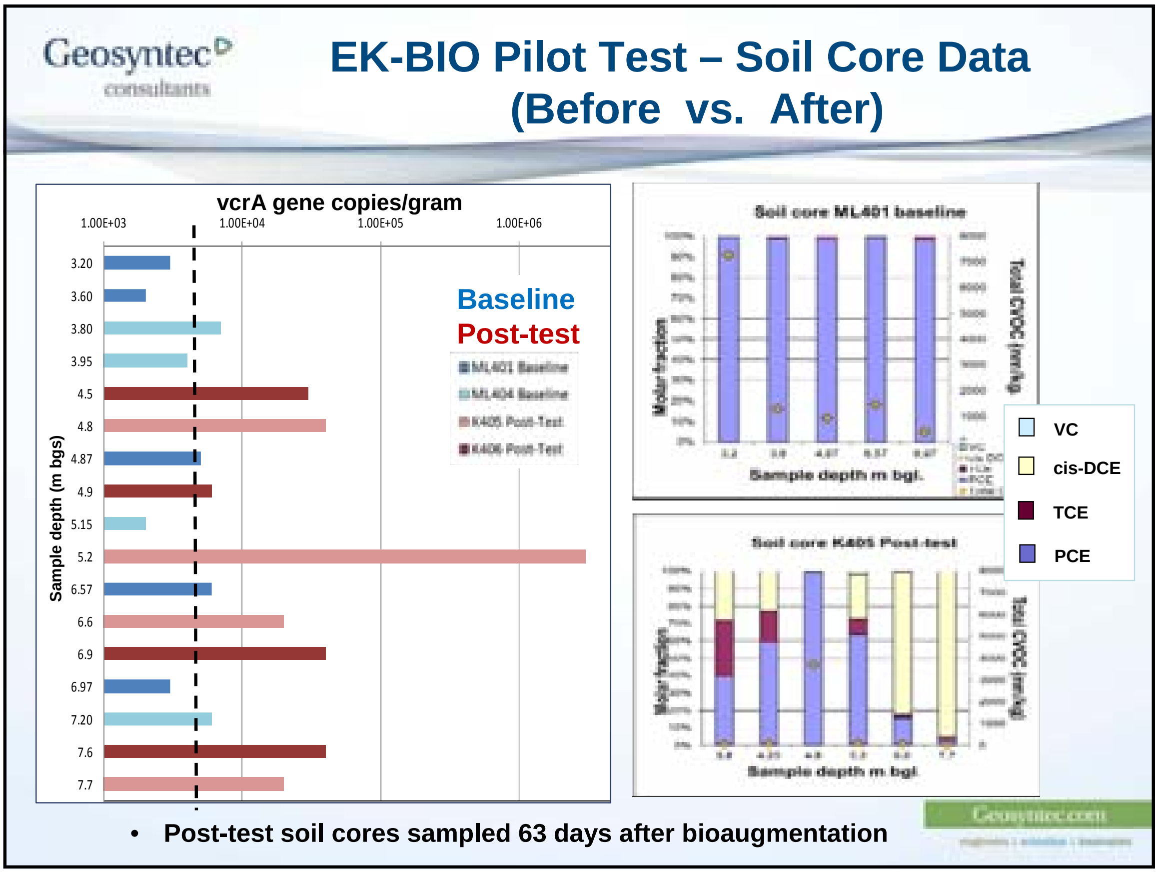
Geosyntec consultants
EK-BIO Pilot Test – Soil Core Data (Before vs. After)
vcrA gene copies/gram
1.00E+03
1.00E+04
1.00E+05
1.00E+06
Sample depth (m bgs)
3.20
3.60
3.80
3.95
4.5
4.8
4.87
4.9
5.15
5.2
6.57
6.6
6.9
6.97
7.20
7.6
7.7
Baseline
Post-test
ML401 Baseline
ML404 Baseline
K405 Post-Test
K406 Post-Test
Soil core ML401 baseline
Molar fraction
Total CVOC (mg/kg)
Sample depth m bgl
Soil core K405 Post-test
VC
cis-DCE
TCE
PCE
• Post-test soil cores sampled 63 days after bioaugmentation
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EK-BIO Pilot Test – Key Conclusions

1. EK-BIO works!
2. EK transport of lactate through clay till ~ 2.5 to 5 cm/day
3. Evident increases of *Dehalococcoides* and *vcrA* in groundwater and clay till matrix within pilot test area
4. Groundwater and soil core data show PCE dechlorination to vinyl chloride and ethene :
   - Increasing dissolved PCE concentrations ⇔ dissolution/desorption of PCE DNAPL
   - Increasing ethene concentrations and *Dhc/vcrA* numbers ⇔ sustained Enhanced Reductive Dechlorination
5. Stabile electric system - energy usage ~29 kW-hr/m^3

EK-BIO is an effective method for delivering substrate and bacteria across clayey materials for the purpose of enhancing PCE dechlorination!

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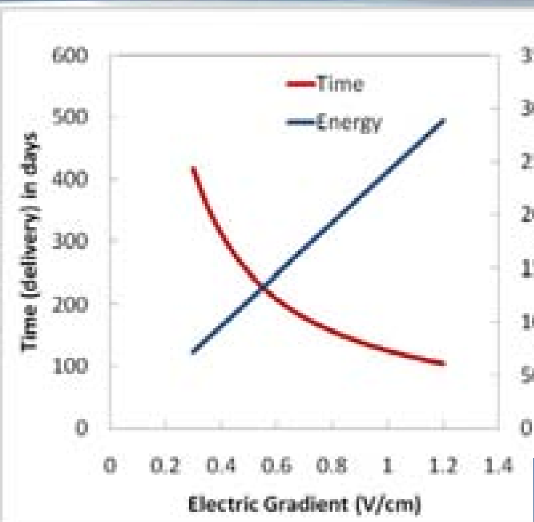
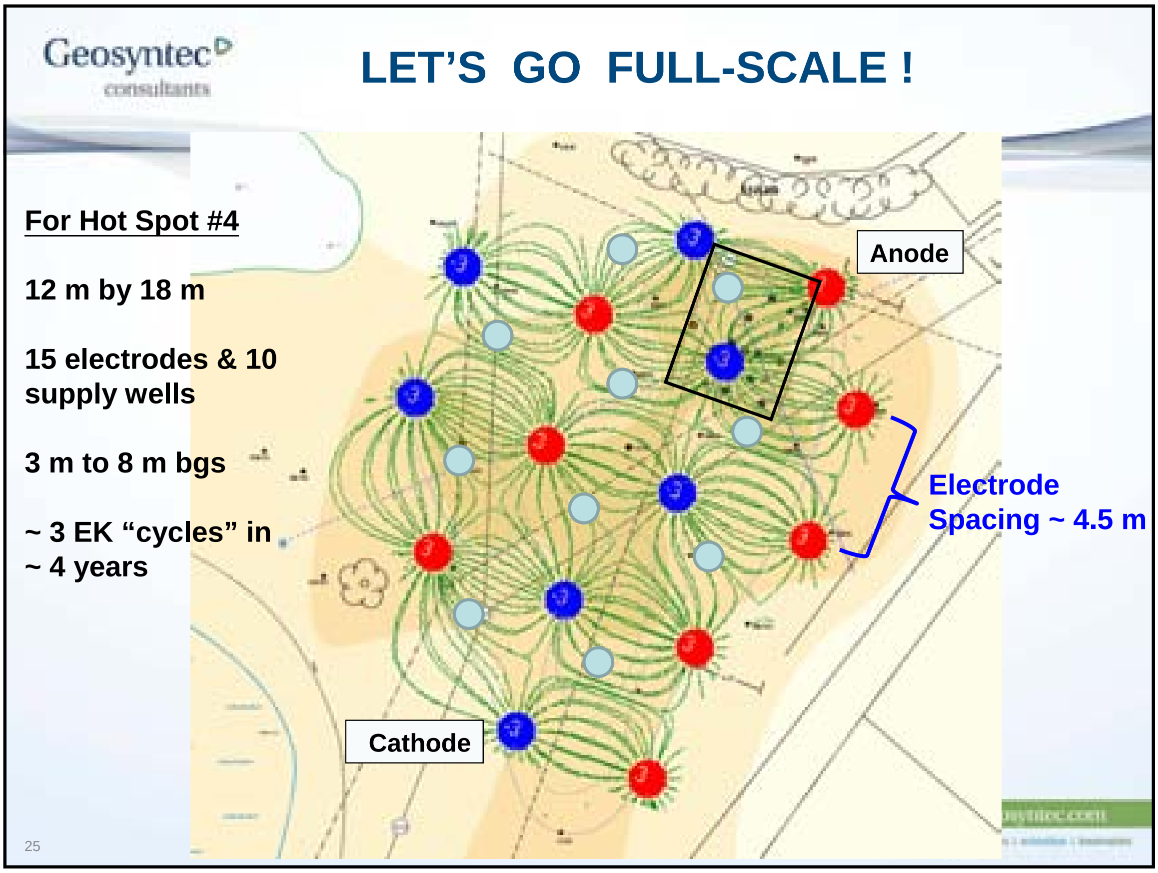
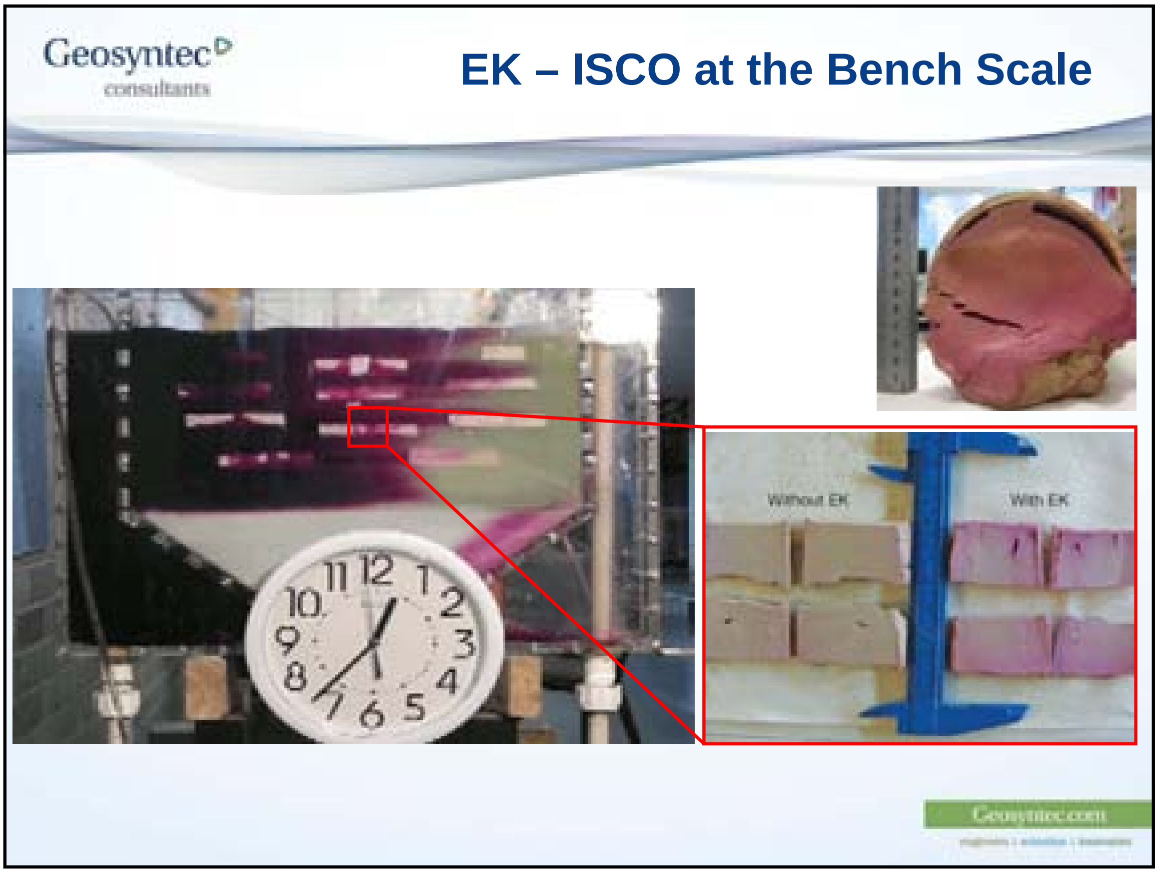
EK-BIO Engineering



- 1,900 kW-hr was the total power applied to the aquifer for the ~ 65-day demonstration.
- The power used is equivalent to less than 10x 100-watt light bulbs operating 24/7 for the same duration.


Geosyntec consultants
LET'S GO FULL-SCALE !
For Hot Spot #4
12 m by 18 m
15 electrodes & 10 supply wells
3 m to 8 m bgs
~ 3 EK "cycles" in ~ 4 years
Anode
Cathode
Electrode Spacing ~ 4.5 m
25


Geosyntec consultants
EK – ISCO at the Bench Scale
Without EK
With EK
Geosyntec.com

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Questions / Comments ?

Thank You !

James Wang – Geosyntec Consultants

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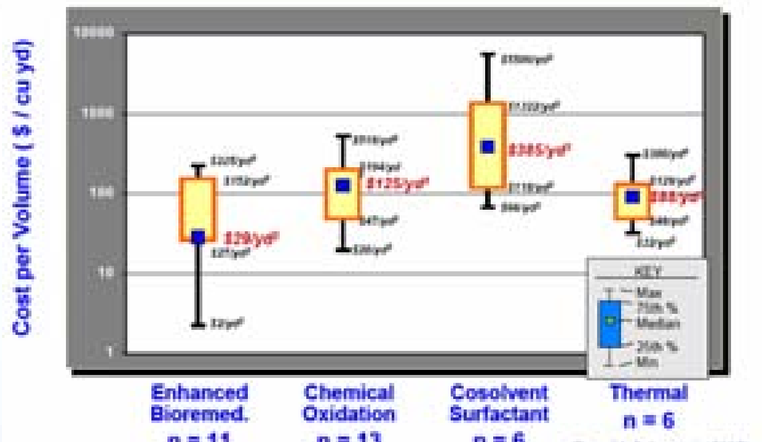
Cost Considerations



From McCabe et al. (2005)

- For the Danish pilot test (beyond EISB costs):
  - Electricity costs ~ $7/m^3$
  - Infrastructure costs ~ $40,000
  - Additional non-capital costs ~ $500/day

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Pilot Test - EK-BIO for Aerobic Bioremediaiton

- Delivery of oxygen supersaturated water via EO to chlorobenzene-contaminated silts at depth of 5 m.
- Nitrate addition via EM (in opposite direction) concurrent with oxygen addition.
- Radial electrode well configuration.

EK for Subsurface Transport