STUDENT SUMMER INTERNSHIP TECHNICAL REPORT

Sustainable Remediation and Literature Review for Savannah River Site A/M Area Groundwater Remediation System

DOE-FIU SCIENCE & TECHNOLOGY WORKFORCE DEVELOPMENT PROGRAM

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Principal Investigators:

Natalia Duque (DOE Fellow Student)
Florida International University

Albes Gaona, Mentor
Physical Scientist, Office of D&D and Facility Engineering (EM-13)

Florida International University Program Director:

Leonel Lagos Ph.D., PMP®

Acknowledgements:
David Roelant, Ph.D., Assoc. Director of Research, Applied Research Center (ARC)
John De Gregory, General Engineer, Office of D&D Facility Engineering (EM-13)
Grover Chamberlain, Physical Scientist, Office of Soil and Groundwater Remediation (EM-12)

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FLORIDA INTERNATIONAL UNIVERSITY

ABSTRACT

During the summer of 2014, DOE Fellow Natalia Duque was given the opportunity to intern with the Office of Environmental Management (EM) at DOE Headquarters in downtown Washington D.C. Natalia's supervisor was Mr. Albes Gaona, lead sustainability specialist at the Office of Deactivation and Decommissioning and Facility Engineering (D&D/FE) (EM-13). The office's mission is to provide integration, planning and analysis for all EM D&D/FE including sustainability projects to ensure that these activities are completed efficiently and effectively, reducing significant risks and life cycle schedules and costs in the D&D program. The office also provides technical direction and/or assistance to resolve difficult technical problems associated with D&D.

During the internship, Natalia had the opportunity to work on different tasks that included further investigation of Green and Sustainable Remediation practices and tools; the development of a Sustainable Remediation Technologies Catalog; the development of the DOE's Sustainable Remediation Powerpedia page; and a literature review for Savannah River Site (SRS) A/M Area groundwater remediation system.

The analysis of the SRS A/M Area groundwater remediation system is the first step to develop an action plan to incorporate sustainability aspects into the project to improve overall performance, contaminant recovery, as well as a reduction in energy consumption to help lessen the environmental burden of the current treatment system.

ACRONYMS AND ABBREVIATIONS

AMSL	Above Mean Sea Level
CBAZ	Crouch Branch Aquifer Zone
CBUC	Crouch Branch Upper Clay
CBLC	Crouch Branch Lower Clay
CBMS	Crouch Branch Middle Sand
DNAPL	Dense Non-Aqueous Phase Liquid
DOE	Department of Energy
DUS	Dynamic Underground Stripping
D&D	Deactivation and Decommissioning
EM	Environmental Management
EPA	Environmental Protection Agency
GCCZ	Green Clay Confining Zone
GRS	Green and Sustainable Remediation
GW	Groundwater
ITRC	Interstate Technology and Regulatory Council
LCA	Life Cycle Assessment
LLAZ	Lost Lake Aquifer Zone
LLLAZ	Lower Lost Lake Aquifer Zone
MAAZ	M-Area Aquifer Zone
MNA	Monitored Natural Attenuation
O&M	Operation and Maintenance
PCE	Tetrachloroethylene
SCDHEC	South Carolina Department of Health & Environmental Control
SR	Sustainable Remediation
SRS	Savannah River Site
SVE	Soil Vapor Extraction
TCE	Trichloroethylene
ULLAZ	Upper Lost Lake Aquifer Zone

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1. INTRODUCTION

Sustainable remediation, also known as Green and Sustainable Remediation (GSR), is a relatively new concept, in which the main purpose is to achieve environmental cleanup in the safest and cleanest way possible, aiming for net environmental, social, and economical benefits. Traditionally, the main objective of remediation practices has been to protect human health and the environment, and technologies have been selected according to cost, efficacy, technical practicability, and regulatory acceptance, but the effect of such technologies on the environment are usually not considered. Some of the remedial actions that have been implemented consist of energy-intensive systems that release harmful emissions to the air, consume natural resources, and sometimes have negative impacts on local communities. During the past decade, there has been an increased interest in the use of sustainable remediation practices by the industry; this is partly due to information that suggests that the global climate change can be correlated with fossil fuel use and greenhouse gases release to the atmosphere.

The Department of Energy (DOE) Office of Environmental Management's (EM's) mission is the safe and successful cleanup of sites that were associated with nuclear materials and weapons production during the Cold War. The Office of Deactivation & Decommissioning and Facility Engineering (D&D/FE) (EM-13) provides information, planning and analysis for all EM D&D/FE activities including sustainability projects to ensure that the cleanup activities are completed efficiently and effectively, reducing the environmental, social and economic impacts associated with such activities.

The purpose of this document, in addition to report the work accomplished during the summer 2014 internship at DOE EM-13, is to provide a brief description of sustainable remediation practices. Definition, benefits, and application of SR are explained, as well as metrics and tools used for analysis, and the organization and regulatory drivers of sustainable practices. A technology catalog developed during the internship is also included in Appendix B, where some remediation methods that are considered sustainable are discussed.

A preliminary analysis of the groundwater remediation system at Savannah River Site's A/M Area is also included. This analysis will be further used to assist EM and ARC-FIU in the development of a set of actions to improve the overall performance of the system by including sustainable remediation concepts.

2. EXECUTIVE SUMMARY

This research work has been supported by the DOE-FIU Science & Technology Workforce Initiative, an innovative program developed by the US Department of Energy's Environmental Management (DOE-EM) and Florida International University's Applied Research Center (FIU-ARC). During the summer of 2014, a DOE Fellow intern, Natalia Duque, spent 10 weeks doing a summer internship at DOE Environmental Management Headquarters in downtown Washington, DC under the supervision and guidance of Mr. Albes Gaona, lead sustainability specialist at the Office of Deactivation and Decommissioning and Facility Engineering (EM-13). The intern's project was initiated on June 2, 2014, and continued through August 8, 2014. The internship's scope consisted of several interrelated tasks associated with sustainable remediation. The first task was to continue the investigation of tools and approaches used for remediation analysis. The second and third tasks were to help EM in the development of the sustainability and sustainable remediation Powerpedia pages, and the development of the final version of the Sustainable Remediation Technologies Catalog. The fourth and final task was to assist EM and ARC-FIU in the development of a set of actions to improve the overall system performance of the SRS A/M Area groundwater remediation system.

3. RESEARCH DESCRIPTION

Sustainable Remediation

Definition

"Sustainable Remediation", also known as "Green and Sustainable Remediation" or GSR, in a broad sense is a holistic approach to environmental remediation that takes into account the environmental, social, and economic effects of such remediation and tries to achieve a balance between these effects to attain an overall environmental, social, and economic net benefit.

Even though most of the organizations and federal agencies that are practicing the sustainable remediation concept agree on the previous (or similar) broad definition, no single, definite definition exists yet. Interstate Technology and Regulatory Council's (ITRC's) definition for GSR is one of the most cited, stating that:

> "[GSR] is a remedy or combination of remedies whose net benefit to human health and the environment is maximized through the judicious use of resources and the selection of remedies that consider how the community, global society, and the environment would benefit, or be adversely affected by, remedial investigation and corrective actions." (ITRC, May 2011)

The Sustainable Remediation Forum (SURF) goes further in its White Paper - Integrating Sustainable Principles, Practices, and Metrics Into Remediation Projects (SURF, 2009)-, stating that the various applications of the tern *sustainable* have resulted in numerous and inconsistent definitions, which has led to confusion. SURF also indicates that lawmakers and regulators are likely to resist the incorporation of this concept into legal authority. Therefore, a constant, uniform definition of sustainable remediation is most needed.

Environmental, Social, and Economic Benefits

When assessing the benefits of implementing sustainable remediation, the environmental benefits are the most noticeable. This may be because the actual driver for the development of such a concept was the fact that historical remediation practices have been implemented using energy-intensive remediation systems paying little to no attention to the detrimental effects of such practices on the environment.

Sustainable remediation practices aim for the use of energy-efficient systems that reduce the use of fossil fuels, as well as the release of carbon dioxide into the atmosphere. Such practices not only decrease the carbon footprint of the remediation, but also bring economic and social advantages. Economic benefits may come from the use of renewable sources of energy, job creation, and increased real estate values (The Horinko Group, February 2014). The minimization of material extraction and overall operation and maintenance (O&M) costs are also economic benefits associated with sustainable remediation. Social benefits include the improvement of health conditions, the possibility of land reuse for recreational facilities, and the integration of stakeholders into the decision-making process. APPENDIX A of this report includes a table developed by SURF where detailed benefits of SR are shown.

Application

The different stages of a typical site remediation include: (1) Investigation; (2) Remedy evaluation and selection; (3) Remedy design; (4) Remedy construction; (5) Operation, maintenance, and monitoring; (6) Remedy optimization; and (7) Closeout. Sustainable remediation may be applied at any stage of the remediation process. However, best results are seen when applied from the investigation stage.

Three levels of analysis and application of sustainable remediation exist (ITRC 2, November 2011) that can be applied depending on site complexity, purpose, budget, and time available. Levels go from the application of simple best management practices (BMPs) to a more complex and detailed evaluation in the following manner:

Level 1: Best Management Practices

This level of evaluation consists mainly of a series of common sense decisions that promote resource conservation and remediation efficiency. No quantitative analysis takes place at this level. Level 1 analysis is the easiest and less expensive approach.

Level 2: BMPs + Simple Evaluation

This level of analysis is considered semi-quantitative because basic calculations take place.

Level 3: BMPs + Advanced Evaluation

This level is considered the more complex because it requires special tools designed to calculate detailed quantities such as CO_2 emissions and water use. Level 3 is considered more expensive and requires a higher level of experience.

Metrics

One of the most important and decisive aspects of sustainable remediation is the selection of the appropriate metrics to evaluate. A metric is defined as a system or standard of measurement. When applied to sustainable remediation, metrics are indicators that measure the benefit or damage caused by implementing a particular remediation method.

There is a lack of consensus between the different agencies and organizations presently involved in the remediation industry and no commonly accepted set of metrics currently exists to measure the effects of implementing SR procedures,. Nonetheless, several organizations have developed their own guidelines of key metrics. NAVFAC (Naval Facilities Engineering Command) has developed a set of eight quantifiable and qualitative metrics, taking as a reference the core element of sustainability developed by the U.S. EPA and outlined in the Green Remediation Technology Primer: air, water, land and ecosystems, materials and waste, energy, and stewardship. The set of metrics developed by NAVFAC are:

- Energy Consumption
- Greenhouse gas (GHG) Emissions
- Criteria Pollutant Emissions
- Water Impacts
- Ecological Impacts
- Resource Consumption
- Worker Safety
- Community Impacts

Similarly, ITRC published a more comprehensive compilation of sustainability metrics in its Green and Sustainable Remediation: State of Science and Practice report, here each metric is identified with the applicable sustainability element it analyses (environmental, economic, and/or social), as well as a proposed unit of measure (if applicable), and a description of the metric.

Tools

Several tools are available to help in the remediation decision-making process and can be selected depending on the level of analysis and application. Before selecting a tool for analysis, it is important to consider site-specific characteristics and metrics to analyze, budget available, desired level of analysis, and type of remediation technologies to be used. Some tools require a higher level of detail, thus more data needs to be available. Following are some of the most used tools:

Level 1: for this level of analysis, tools available are usually guidance documents for the selection of appropriate BMPs that are useful for the remediation technology's footprint reduction. The following organizations have developed numerous such documents:

- *ASTM*
- *EPA*
- *SURF*
- *USACE*

Level 2: for this level of implementation, they consist of simple, qualitative in nature tools that do not require any specific training or understanding of advanced mathematical calculations. They are usually used to compare impacts of different remediation technologies where the result is typically a score or a ranking place.

- *Green Remediation Evaluation Matrix (GREM):* can be used to compare treatment alternatives in terms of their impact on different metrics

Level 3: at this level, tools are more advanced, quantitative in nature, and usually require previous training. As the detail of analysis is more complex, these tools require more data and site-specific detail acquisition.

- Carbon footprint calculators: tools used to calculate the reduction in GHG emissions associated with some decision or change in activity.
    - *Waste Reduction Model (WARM):* calculates GHG emissions associated with various waste management practices, including source reduction, recycling, composting, combustion, and landfilling.
- Remedy Footprint: quantify the environmental, social, and economic impacts of environmental remediation activities.
    - *SRT:* a Microsoft Excel–based tool that includes a series of modules to estimate green and sustainable impacts of eight commonly used technologies for soil and groundwater remediation. SRT is not currently available.
    - *SiteWise™*: assesses the remedy footprint of a remedial alternative/technology in terms of a consistent set of metrics.
- Life Cycle Analysis (LCA): used to comprehensively analyze a site and can be used for projects that are more complex in nature. LCA evaluates a systems throughout its life cycle.
    - *SimaPro*: can be used to calculate carbon footprint and other environmental impacts and identify key areas needing improvement.
    - *GaBi Software®*: offers functionality similar to SimaPro.
    - *Economic Input-Output Life Cycle Assessment (EIO-LCA):* estimates the materials and energy resources required, and the environmental emissions resulting from activities.
- *Net Environmental Benefit Analysis (NEBA):* examine alternatives for remediating ecologically sensitive sites, especially sites that have been contaminated with petroleum products.

Regulations

Regulations provide support for sustainable remediation practices and are often cited as a reason to implement such efforts. The following regulations are applicable to SR:

- **Executive Order 13514 - *Federal Leadership in Environmental, Energy, and Economic Performance***: This EO sets sustainability goals for Federal agencies and focuses on making improvements in their environmental, energy, and economic performance.

- **Executive Order 13423 - *Strengthening Federal Environmental, Energy, and Transportation Management:*** This EO requires Federal agencies to lead by example in advancing the nation's energy security and environmental performance by achieving energy efficiency, reduction of GHG emissions, purchasing of renewable power, higher building performance, reduction of water consumption, among others.

- **DOE Order 436**.1 **– *Departmental Sustainability*:** Requires that sustainability principles are integrated into DOE's Strategic Sustainability Performance Plans (SSPPs)

Organizations and Information Portals

The following organizations and portals provide useful information and guidance on how to incorporate sustainable remediation practices:

- ***Sustainable Remediation Forum (SURF):*** SURF is the first coalition dedicated specifically to sustainable remediation. It started in 2006 with a group of professionals that came together to contribute to this purpose
- ***EPA's Contaminated Site Clean-Up Information Web Site (CLU-IN):*** provides information about innovative treatment and site characterization technologies
- ***Interstate Technology Regulatory Council (ITRC):*** ITRC develops information resources and produces documents and training to expand technical knowledge in order to reduce compliance costs and maximize cleanup efficacy
- ***Federal Remediation Technologies Roundtable (FRTR):*** the FRTR works to build a collaborative atmosphere among Federal agencies involved in hazardous waste site cleanup
- ***ASTM International:*** ASTM is an international standards organization that develops and publishes voluntary consensus technical standards for a wide range of materials, products, systems, and services. ASTM recently developed two standard guides on sustainability

Guidance Documents

The following documents have been developed by federal and private agencies to provide information and guidance on the proper implementation of sustainable remediation:

- Sustainable Remediation Forum (SURF) White Paper – Integrating Sustainable Principles, Practices, and Metrics into Remediation Projects (SURF, 2009)
- Green and Sustainable Remediation: State of the Science and Practice (ITRC, May 2011)
- Green and Sustainable Remediation: A Practical Framework (ITRC 2, November 2011)
- Green Remediation: Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites (EPA, April 2008)

The Rise and Future of Green and Sustainable Remediation (The Horinko Group, February 2014)

4. RESULTS AND ANALYSIS

Sustainable Remediation Technologies Catalog

The Department of Energy (DOE) Office of Environmental Management's (EM's) mission is the safe and successful cleanup of sites that were associated with nuclear materials and weapons production during the Cold War. The Office of Deactivation & Decommissioning and Facility Engineering (D&D/FE) (EM-13) provides information, planning and analysis for all EM D&D/FE activities including sustainability projects to ensure that the cleanup activities are completed efficiently and effectively, reducing the environmental, social and economic impacts associated with such activities.

Traditionally, the main objective of remediation practices has been to protect human health and the environment. Remediation technologies have been selected according to cost, efficacy, technical practicability, and regulatory acceptance without necessarily considering the detrimental effects of such technologies on the environment, or their external social and economic effects.

The Sustainable Remediation Techniques & Technologies Catalog has been created to serve as a reference guide when selecting the appropriate action plan during environmental remediation activities. The techniques and technologies mentioned in the catalog have been considered to bring environmental, social, and/or economic benefits compared to other remediation methods. Some of the technologies are well known and have been repeatedly employed, and some are still in the pilot study stage.

All of the techniques and technologies mentioned are in-situ remediation methods. Treating contamination at the site does not require the extra energy consumption, cost, and resource use associated with the excavation and transportation of ex-situ remediation practices.

Biological, physical, and chemical techniques have been addressed. Biological processes are often implemented at low cost. Contaminants can be destroyed, and often little to no residual treatment is required; however, the process requires more time, and it is challenging to determine whether contaminants have been destroyed. Physical and chemical methods use the physical properties of the contaminants or the contaminated medium to destroy, separate, or contain the contamination; they are typically cost-effective and are usually not engineering or energy intensive.

The processes addressed in this catalog do not represent all the technologies available in the remediation industry and is only meant as a reference. Sustainable practices are becoming more important every day, and constant efforts are being applied to the development of new technologies.

The catalog has been included in Appendix B**.**

Powerpedia

Powerpedia is a DOE internal wiki established in early 2010 to help facilitate knowledge capture, collaboration, and increased efficiency. During the internship, one of the tasks was to help EM in the development of the "Sustainability at EM" and "Sustainable Remediation" Powerpedia pages. The content included in the wiki for "Sustainable Remediation" has been discussed in the "Research Description" section above. Following is the content added for "Sustainability at EM":

Sustainability at EM

Sustainability is the ability to maintain an activity for a long time. In the context of DOE Environmental Management Office, *sustainability* is related to the consideration of an activity's present and future implications on the environment, the society, and the economy, trying to achieve the correct balance that yields net benefits in all aspects.

Sustainability is about striking the appropriate balance between Social, Economic and Environmental priorities. (*Source: iSustainable.org)*

Background

The Department of Energy has worked diligently to manage its operations and facilities in a sustainable manner and tries to lead by example integrating sustainability into all aspects of its operations. At EM, sustainability is recognized as an organizational goal at the highest level of the office's management. To *Execute the EM Mission in a Sustainable Manner* is one of the goals in the EM *FY 2014 Annual Performance Agreement*.

Strategies to meet this goal include:

- Reduce energy intensity in agency buildings
- Identify means of reducing the overall EM carbon footprint

- Utilize the Department’s Energy Saving Performance Contract (if viable) or alternative data center optimization practices to reduce the Information Technology (IT) data center’s infrastructure footprint while providing state of the art services
- Identify activities that promote climate change adaptation and mitigation
- Work with local jurisdictions, as appropriate, to develop regional partnerships for climate change information sharing and collaboration

Structure and Coordination

The Office of Deactivation and Decomissioning (EM-13) provides integration, planning, and analysis for all EM D&D/FE including sustainability projects. The office coordinates EM's sustainability and energy management and efficiency related initiatives, and develops guidance and provides support on sustainability management and activities. The director of D&D and Facility Engineering (EM-13) is the primary interface with the Sustainability Performance Office and field sustainability point of contacts.

EM-13 staff participates in the EM Sustainability Working Group monthly conference call, and also hosts a Fleet Working Group. The Sustainable Remediation Workgroup provides assistance to the field in promoting and implementing sustainable remediation. The SR Workgroup consists of representatives from EM HQ, the EM Consolidated Business Center, site representatives, and DOE’s Office of Health, Safety, and Security (HSS). Additionally, EM regularly interfaces and works with the SPO, HSS, the Office of Management, and other DOE PSOs to promote sustainability and to benefit from other program’s efforts and developments.

Sustainability is considered throughout the EM program, which includes the mission areas of site restoration (soils and groundwater and D&D), tank waste/nuclear materials management, and waste management; as well as the mission support areas comprised of safety, security, and quality; acquisition and project management; program planning and budgeting; Green IT; and human capital and corporate services. EM has, and will continue to integrate formal sustainability goals into EM's management practices recognizing that this will require sustained culture change, education, measurement, and support from top leadership.

Strategic Sustainability Performance Plans and EM Goal Performance Overview

On October 5, 2009 President Obama signed Executive Order 13514 that focuses on Federal Leadership in Environmental, Energy, and Economic Performance. The EO called for all federal agencies to implement a Strategic Sustainability Performance Plan (SSPP) where the agency activities, policies, plans, and procedures towards the implementation of the EO are identified. The specific goals, schedules, milestones, and approaches for achieving the results are also outlined.

As a response to this and other EO (Executive Order 13423), DOE developed DOE Order 436.1 *Departmental Sustainability* that ensures the Department carries out its mission in a sustainable manner; implements a cultural change within DOE to include sustainability and GHG reductions into all DOE corporate management decisions; and ensures DOE achieves the sustainability goals established in its Strategic Sustainability Performance Plan (SSPP). The Sustainability Performance Office (SPO) has taken over the responsibility of producing the DOE SSPP each year.

Strategic Sustainability Performance Plan Goals

SSPP Goal #	DOE Goal	FY 2013 Status (relative to baseline, if applicable)	Risk of Goal Non-Attainment*
GOAL 1: Greenhouse Gas Reduction and Comprehensive Greenhouse Gas Inventory			
1.1	28% Scope 1 & 2 GHG reduction by FY 2020 relative to FY 2008 baseline	-54.8%	Goal met
1.2	13% Scope 3 GHG reduction by FY 2020 relative to FY 2008 baseline	-27.5%	Goal met
GOAL 2: Buildings, President's Performance Contracting Challenge, and Regional & Local Planning			
2.1	30% energy intensity (Btu per gross square foot) reduction by FY 2015 relative to FY 2003 baseline	-42.0%	Goal met
2.2	Energy Independence and Security Act, Section 432 energy and water evaluations (status as of January 2014)	87.7%	Low
2.3	Individual buildings metered for 90% of electricity (by October 1, 2012); for 90% of steam, natural gas, and chilled water (by October 1, 2015)[1]	Electricity: 16.3% ; Water: 0.0%; Steam: NA; Natural Gas: 0.0% ; Chilled Water: NA	High
2.4	Cool roofs, unless uneconomical, for roof replacements unless project already has CD-2 approval. New roofs must have thermal resistance of at least R-30[2]	429,661 sq ft	Low
2.5	15% of existing buildings greater than 5,000 gross square feet (GSF) are compliant with the Guiding Principles (GPs) of High Performance Sustainable Buildings (HPSB) (or equivalencies) by FY 2015[3]	0.4%	High
2.6	All new construction, major renovations, and alterations of buildings greater than 5,000 GSF must comply with the GPs[3]	Insufficient data, self-report as applicable	High
2.7	Implement alternatively financed projects to support the President's Performance Contracting Challenge	$0	NA
GOAL 3: Fleet Management			
3.1	159% increase in fleet alternative fuel consumption by FY 2015 relative to FY 2005 baseline	124.9%	Low
3.2	30% reduction in fleet petroleum consumption by FY 2020 relative to FY 2005 baseline	+40.6%	Medium
3.3	100% of light duty vehicle purchases must consist of alternative fuel vehicles (AFV) by FY 2015 and thereafter (75% FY 2000 - 2015)[4]	139.0%	Goal met

[1] Per NECPA (42 U.S.C. Section 8253) the term "buildings" includes industrial, process, or laboratory facilities

[2] Secretary of Energy Dr. Steven Chu, Installation of Cool Roofs on Department of Energy Buildings, Memorandum for Heads of Departmental Elements, June 1, 2010.

[3] DOE considers buildings meeting the following criteria as complying with GPs: Any building that achieves LEED-EB Silver or higher or LEED-NC Gold or higher; Any building that achieves a Green Globes-NC rating of four or a Green Globes CIEB rating of three; Any building that has been occupied for more than one year that achieves Living Status designation by the Living Building Challenge.

[4] EPAct 1992 goal updated per Presidential Memorandum on Federal Fleet Performance on May 24, 2011. http://www.whitehouse.gov/the-press-office/2011/05/24/presidential-memorandum-federal-fleet-performance

SSPP Goal #	DOE Goal	FY 2013 Status (relative to baseline, if applicable)	Risk of Goal Non-Attainment*
GOAL 4: Water Use Efficiency and Management			
4.1	26% potable water intensity (Gal per gross square foot) reduction by FY 2020 relative to FY 2007 baseline	-26.3%	Goal met
4.2	20% water consumption (Gal) reduction of industrial, landscaping, and agricultural (ILA) water by FY 2020 relative to FY 2010 baseline	-72.3%	Goal met
GOAL 5: Pollution Prevention and Waste Reduction			
5.1	Divert at least 50% of non-hazardous solid waste, excluding construction and demolition debris, by FY 2015	44.8%	Low
5.2	Divert at least 50% of construction and demolition materials and debris by FY 2015	15.9%	Medium
GOAL 6: Sustainable Acquisition			
6.1	Ensure 95% of new contract actions contain sustainable acquisition clauses, as applicable	97.4%	Goal met
6.2	Ensure new contract actions contain biobased clauses, as applicable; striving towards 95% compliance	Insufficient data, self-report as applicable	Medium
GOAL 7: Electronic Stewardship and Data Centers			
7.1	All data centers are metered to measure a monthly Power Utilization Effectiveness (PUE) of 100% by FY 2015	Data Center consolidation ESPC on hold; sites encouraged to use DOEGRIT energy efficiency assessment tool	Medium
7.2	Maximum annual weighted average PUE of 1.4 by FY 2015	Data Center consolidation ESPC on hold; sites encouraged to use DOEGRIT energy efficiency assessment tool	Medium
7.3	Electronic Stewardship - 100% of eligible PCs, laptops, and monitors with power management actively implemented and in use by FY 2012	98.8%	Low
7.4	Ensure applicable IT contracts include clauses for EPEAT, ENERGY STAR, or FEMP-designated products	99.6%*	Low
GOAL 8: Renewable Energy			
8.1	7.5% of annual electricity consumption from renewable sources by FY 2013 and thereafter	32.8%	Goal met
GOAL 9: Climate Change Adaptation			
9.1	Identify one priority facility, location, or region that would most benefit from a detailed climate vulnerability assessment pilot[5]	In progress	Low

[5] DOE Climate Change Adaptation Plan: http://www1.eere.energy.gov/sustainability/pdfs/doe_sspp_2012.pdf

Figure 1. EM 2013 Goal Performance Overview table. (*Source: EM 2014 Composite Sustainability Plan)*

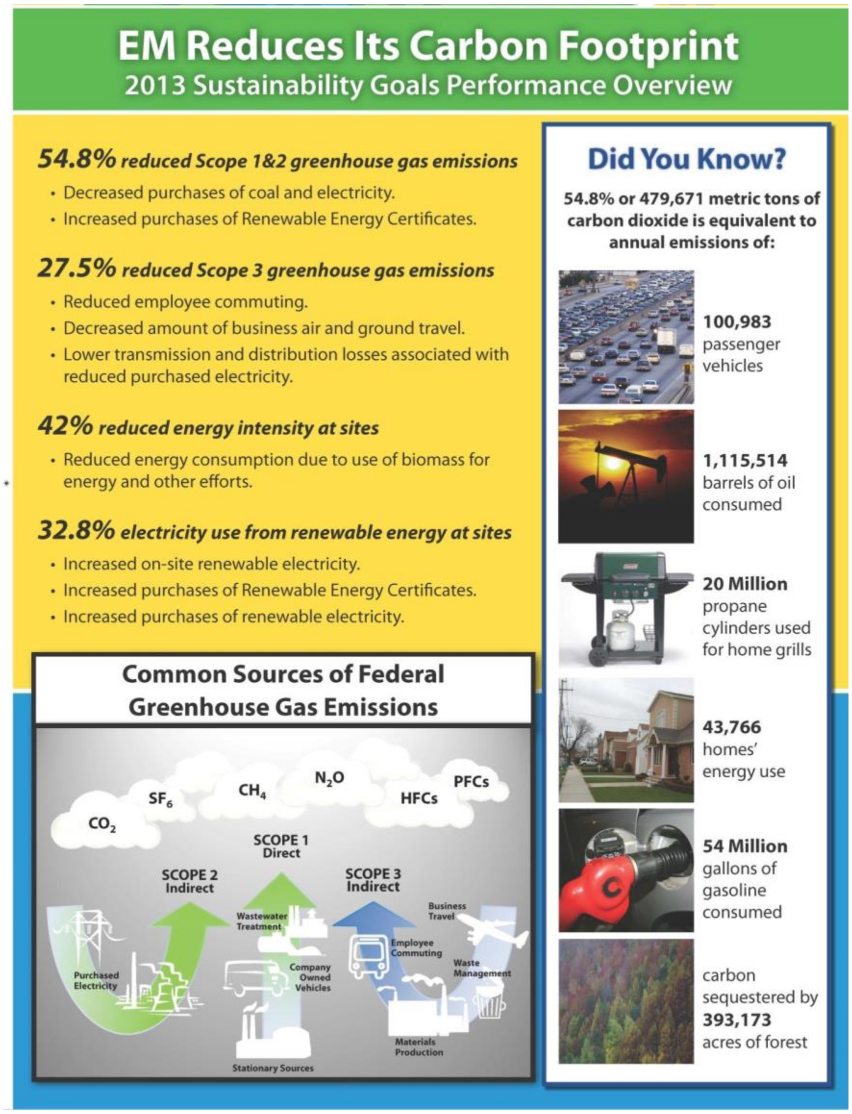

Figure 2. 2013 Sustainability Goals Performance Overview poster. (*Source: EM 2014 Composite Sustainability Plan)*

FY 2013 SSPP addresses the following goals for each of the Departments:

GOAL 1: Greenhouse Gas Reduction and Comprehensive Greenhouse Gas Inventory

GOAL 2: Buildings, ESPC Initiative Schedule, and Regional & Local Planning

GOAL 3: Fleet Management

GOAL 4: Water Use Efficiency and Management

GOAL 5: Pollution Prevention and Waste Reduction

GOAL 6: Sustainable Acquisition

GOAL 7: Electronic Stewardship and Data Centers

GOAL 8: Renewable Energy

GOAL 9: Climate Change Adaptation

EM 2013 Goal Performance Overview

The summary table above shows the EM 2013 Goal Performance Overview. Some of the actions taken by EM and the accomplishments of such actions are as follows:

- The Scope 1&2 GHG Emissions (Goal 1.1) were reduced 54.8% (479,671 MTCO2e) in FY 2013 from the FY 2008 baseline. This reduction was driven primarily by decreased emissions associated with purchased coal and electricity, and REC purchases.
- The Scope 3 GHG Emissions (Goal 1.2) were reduced 27.5% (38,837.3 MTCO2e) from the baseline. This was primarily driven by reductions associated with employee commuting (22,902.4 MTCO2e), business air and ground travel (4,271.4 MTCO2e), and savings realized through lower T&D losses associated with reduced purchased electricity (6,433.5 MTCO2e).
- Energy Intensity (Goal 2.1) 42% reduction from the baseline at EM complex was largely driven by the SRS biomass cogeneration plant. In FY 2013, SRS reduced energy intensity by 72.8% from the baseline due to the biomass plant and other efforts. Portsmouth and Hanford are EM's next largest energy consumers. Hanford reduced energy intensity by 35.2% from the baseline, while Portsmouth increased energy intensity by 19.6% in part due to a 26.3% decrease in goal subject square footage, hence, although the energy usage at Portsmouth was decreased but a higher footage reduction caused the energy intensity increase.
- Renewable electricity use (Goal 8.1) increased 32.8% by approximately 22% on-site renewable electricity use, 10.7% REC purchases, and 0.2% purchased renewable electricity.
- Alternative fuel consumption (Goal 3.1) increased by 124.9% relative to the FY 2005 baseline. Hanford increased alternative fuel use by 1621.2%, or 187,440 GGE, relative to the FY 2005 baseline. Fleet petroleum consumption (Goal 3.2) increased 40.6% (526,189 gasoline gallon equivalent (GGE)) relative to the baseline. SRS reduced petroleum use by 18.1% (58,727 GGE) between FY 2012 and FY 2013.
- Approximate 99% of eligible personal computers, laptops, and monitors have power management controls actively implemented and in use (Goal 7).

Award Winning Projects

In 2013, EM was the winner of five sustainability awards that recognize individual and group sustainability efforts across the DOE sites. All these projects, in conjunction to all of EM efforts, cut carbon emissions, lowered energy use, diverted construction and demolition debris, allowed for more efficient fleets, and provided overall cost savings.

The individual awards for Exceptional Service/Sustainability Champion were given to *David Wolfe*, Sustainability Program manager at SRS; and *Chuck Oldham*, IT infrastructure manager at URS | CH2M Oak Ridge. Wolfe received the award for his work on helping the site exceed its goals to expand renewable energy and reduce greenhouse gas emissions and energy intensity through the implementation of various Energy Savings Performance Contracts. Oldham contributed to Oak Ridge's success by purchasing energy friendly electronics products, recycling, and reducing power and cooling needs by consolidating a datacenter.

The awards for group sustainability efforts were given to *Portsmouth, Oak Ridge,* and *Savannah River* sites. The Portsmouth site achieved a 29-percent reduction in greenhouse gas emissions in fiscal year 2012 by creating a culture of energy saving and sustainability now incorporated into how the site performs daily activities. The Oak Ridge Environmental Management System program promotes opportunities to minimize waste, energy use, and greenhouse gases. The program also makes environmentally preferable purchases and finds opportunities to divert waste. The SRS green fleet management program supports sustainability goals by using alternative fuels and reducing petroleum use. Approximately 77 percent of vehicles in the light duty fleet, which includes vehicles that transport employees, use an ethanol fuel blend or are gasoline hybrids. SRS reduced its fleet petroleum use by approximately 19 percent and is on track to meet the overall goal requirement of 30 percent by fiscal year 2020.

Figure 3. EM Sustainability Award Winners poster. (*Source: EM 2014 Composite Sustainability Plan)*

SRS A/M Area Groundwater Remediation System

The Savannah River Site (SRS) is a 310 square mile complex that borders the Savannah River and is located in South Carolina. From the early 1950s to the early 1980s, SRS produced materials used in the production of nuclear weapons. Some of the facilities used for the manufacture of reactor fuel and target assemblies, administrative services, and laboratories are located in the A/M Area in the northern portion of the SRS. Some of the wastewater from the manufacturing operations containing various heavy metals and chlorinated degreasing solvents such as trichloroethylene (TCE) and tetrachloroethylene (PCE) flowed into Lost Lake and the M Area Settling Basin. Some of these contaminants were captured by the soil or evaporated; the remainder of the solvents seeped into the vadose zone and contaminated the groundwater.

In 1983, SRS started the A/M Area groundwater cleanup system by installing a groundwater pumping well and an experimental air stripper system. In 1985, a full-scale pump-and-treat system that consisted of eleven groundwater recovery wells and a 420-gpm air stripper was constructed. The M-1 air stripper and well network has operated continuously since that time at an average electrical load of 150 kW, representing an average of 1,314,000 kW-hr of electricity consumption per year. The TCE concentration has decreased exponentially from 25,000 µg/L in 1986 to 2,230 µg/L in 2012. The system TCE removal effectiveness decreased from 33,231 lbs of TCE removed during the first year of operation to only 2,092 lbs of TCE removed during 2011 with the same energy consumption and water pumping rate.

The purpose of this analysis and the consequent investigation is to develop an action plan to incorporate sustainability into the remediation system that bring improvements in system performance, contaminant recovery, and a decrease in resource consumption in order to lessen the environmental burden of the current treatment system.

A/M Area Characterization

The 350-acre A/M area is located within the northwestern portion of the Savannah River Site (SRS) as seen in Figure 4. The topographic elevation ranges from approximately 375 ft above mean sea level (AMSL) in the M Area to approximately 15 ft AMSL around the lower reaches of Tims Branch.

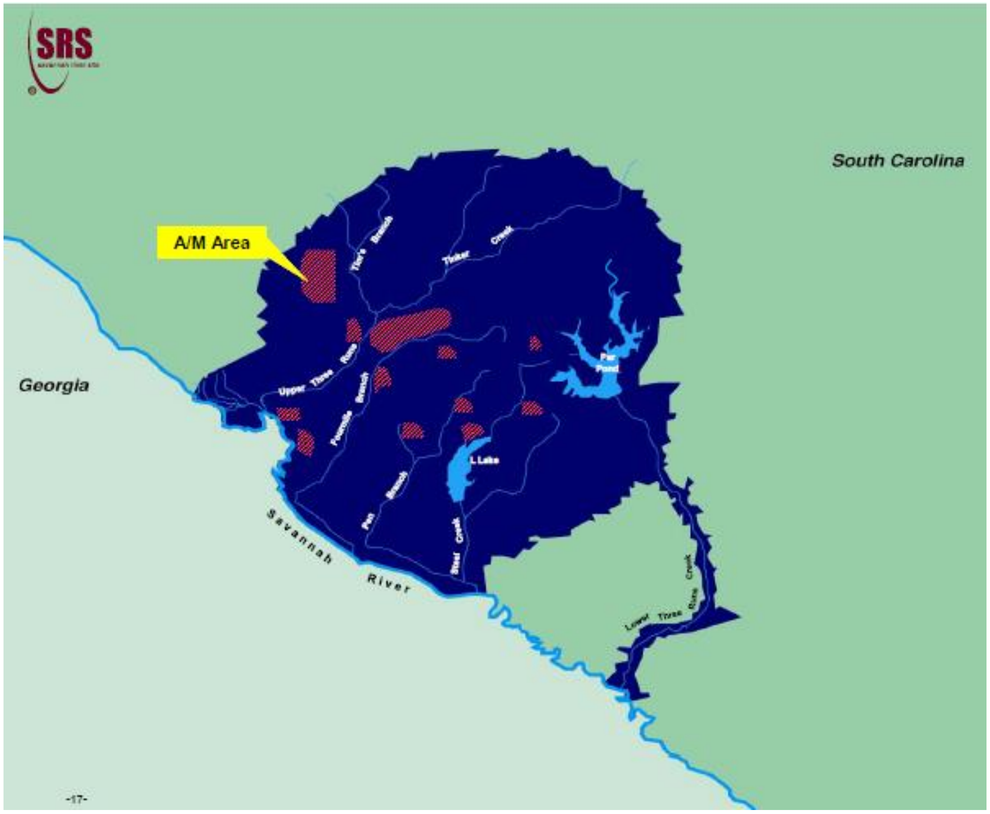

Figure 4. A/M Area location (Bergren, 2011).

The generalized **hydrostratigraphy** in the A/M Area shown in Figure 5 consists of aquifers of the Floridian-Midville Aquifer System, where the aquifers and the confining units are comprised of layers of sands, silts, and clays.

1. The M-Area Aquifer Zone (MAAZ);
2. The Green Clay Confining Zone (GCCZ) that outcrops along Tims Branch;
3. The Lost Lake Aquifer Zone (LLAZ), which is generally divided into the Upper Lost Lake Aquifer Zone (ULLAZ) and the Lower Lost Lake Aquifer Zone;
4. The Crouch Branch Upper Clay (CBUC);
5. And the Crouch Branch confining unit that is made up by the Crouch Branch Middle Sand (CBMS), the Crouch Branch Lower Clay (CBLC), and the Crouch Branch Aquifer Zone (CBAZ).

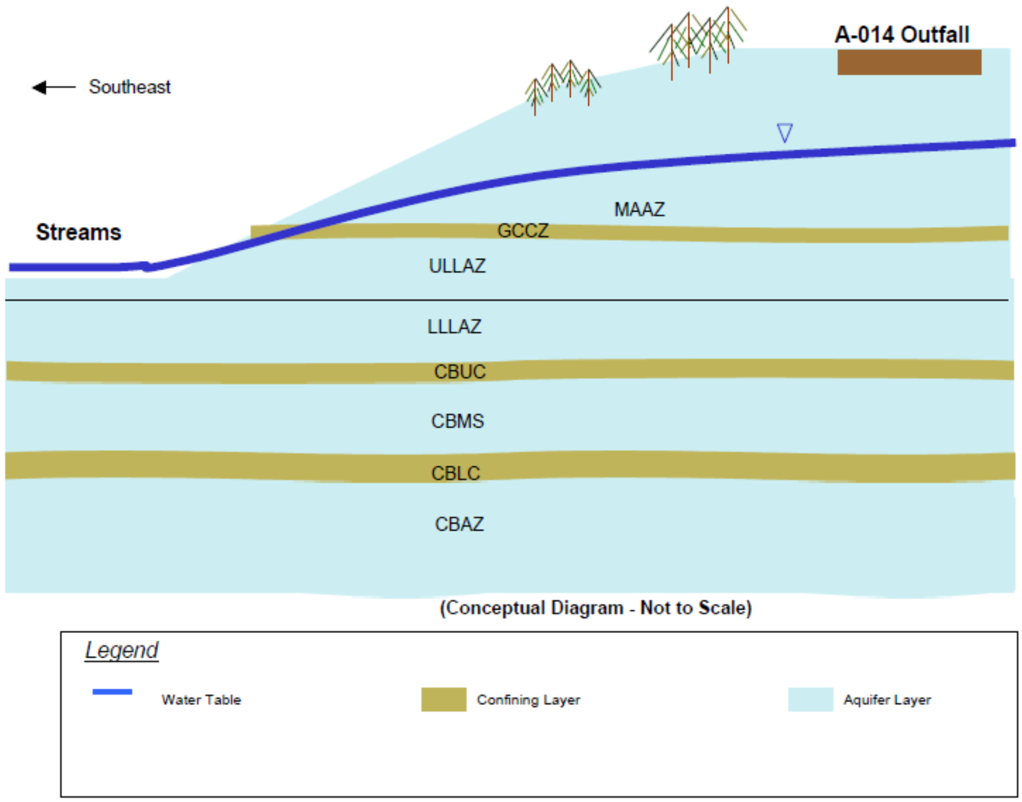

Figure 5. Modeled hydrostratigraphic layers.

Contaminant Source Description

The A/M Area consists of facilities that fabricated reactor fuel and target assemblies (M-Area), laboratory facilities (SRTC), and administrative and support facilities (A-Area). From the 1950's to the 1980's, operations from the A/M Area resulted in release of chlorinated solvents, primarily trichloroethylene (TCE), tetrachloroethylene (PCE) and 1,1,1-trichloroethane (1,1,1-TCA) due to their use to degrease tubes used in SRS reactors. Some of these solvents evaporated during operations. The remaining solvents (an estimated 3.5 million lbs) were discharged to the process sewer system, and some significant quantities were unintentionally spilled during handling and storage.

The waste effluent was piped underground to two primary locations: the A-014 Outfall and the M-Area Settling Basin, resulting in groundwater contamination by TCE and PCE. Approximately 1.3 million lbs of chlorinated solvents were discharged from A-014 Outfall to Tims Branch, and approximately 2.2 million lbs were sent to the M-Area unlined Settling Basin. A natural seepage area and Lost Lake received effluent from the basin. Discharges of waste solvents to the settling basin ceased in 1985 after the discovery of contamination near the settling basin in 1981, and consequent operation of a full-scale groundwater remediation system.

The majority of the solvent contaminant present is located within the M-Area Aquifer Zone (MAAZ), the Green Clay Confining Zone (GCCZ), and the Lost Lake Aquifer Zone (LLAZ), as shown in Figure 6 where the Southern sector of the A/M Area is depicted.

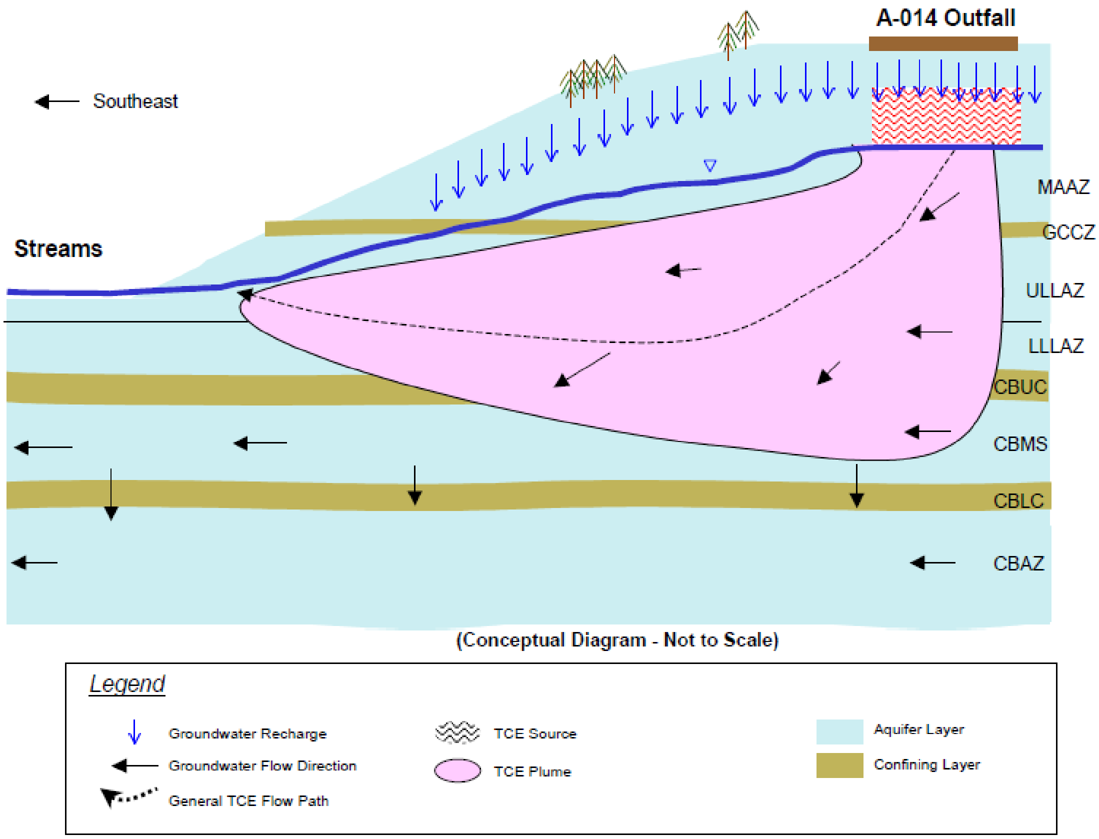

Figure 6. Hydrogeologic conceptual model for the southern sector of A/M Area.

A/M Area Sectors

In order to efficiently complete the remediation program in the A/M Area, the region has been divided into four sectors: the Northern, Central, Western, and Southern Sectors.

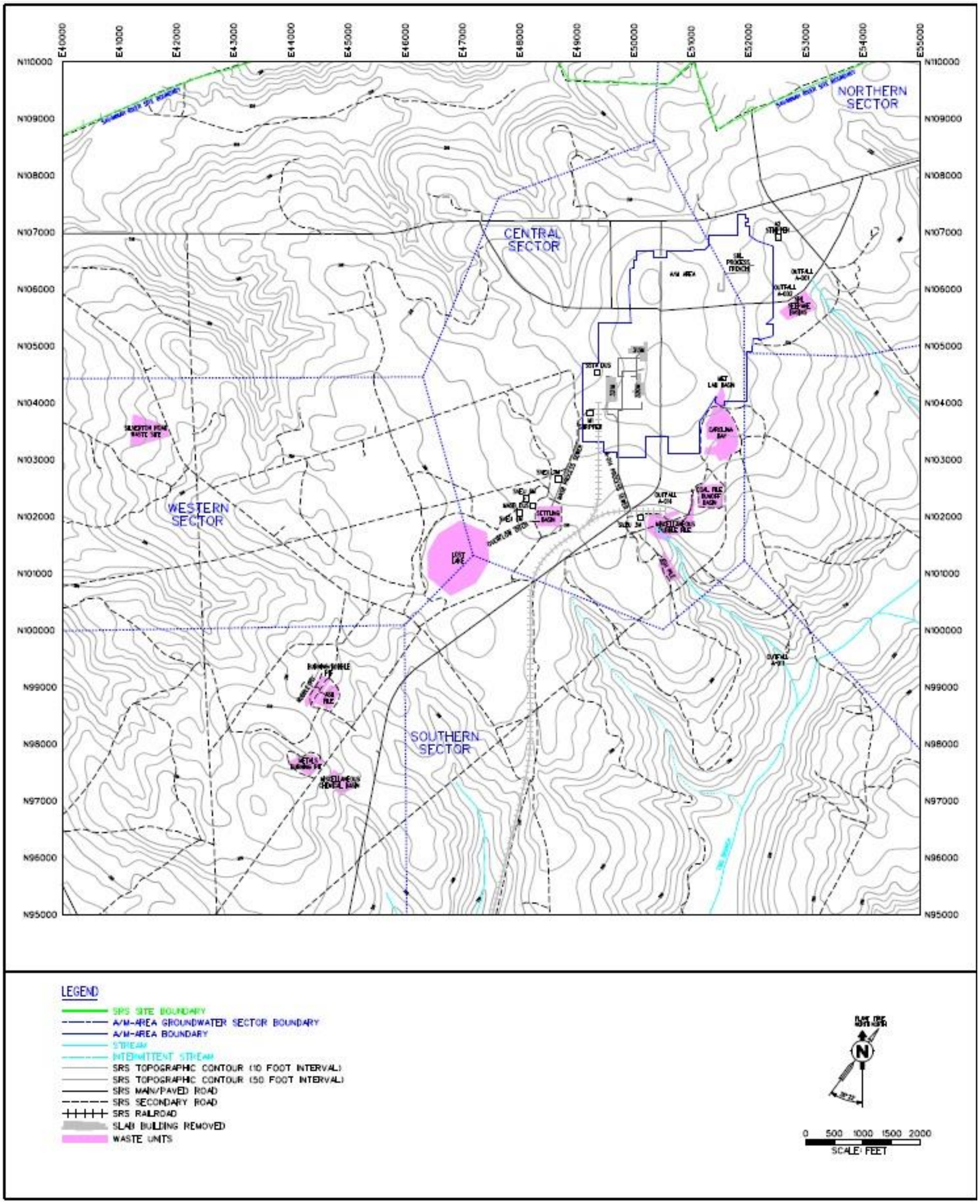

Figure 7. Location of Correction Action sectors. (SRNS, March 2012)

The contamination in the Central Sector is due to the direct release of solvents to the subsurface which migrate to the vadose zone and into the saturated zone. For the Western Sector, the source of contamination is from migration of DNAPL from the M-Area Settling Basin. The Southern Sector contamination is derived from advective transport from the source zones in the Central A/M Area; and the source of contamination for the Northern Sector is from direct release to the subsurface of small quantities of solvent which migrate through the vadose zone and into the saturated zone.

Groundwater Remediation System

The SRS groundwater (GW) strategy focuses on protection, remediation, and monitoring of contaminated groundwater.

Groundwater protection is accomplished through the implementation of Environmental Protection Agency (EPA) and South Carolina Department of Health & Environmental Control (SCDHEC) programs as well as the employment of methods to prevent future GW contamination which include specific activities such as the removal or immobilization of contaminant sources before they reach GW; the reduction of natural and artificial recharge in contaminated areas with water run-on/runoff control measures; and the continuous evaluation of wells to ensure they still serve a useful purpose.

Groundwater remediation is addressed using a graded approach. As shown in Figure 8, the area of the plume is categorized into Source Zone, Primary Groundwater/Vadose Zone Plume, and a Dilute Plume/Fringe, depending on the nature and mass of the source of contamination, contaminant concentration level, and subsurface characteristics.

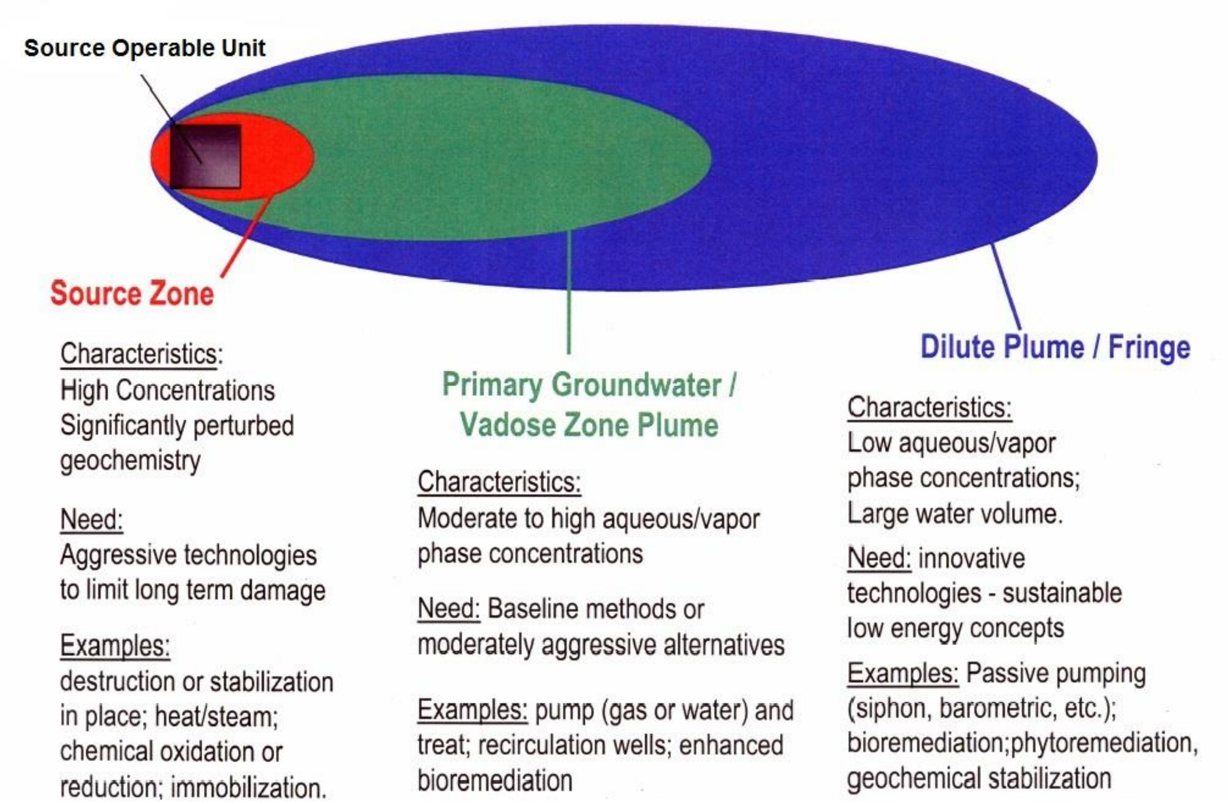

Figure 8. SRS graded approach to groundwater remediation (SRNS, February 2011).

The Source Zone contains the highest concentration of contaminants. It can contain materials such as undissolved organic liquids (oils, fuels, or solvent), strong acids or bases, high levels of radiation, and/or toxic chemicals or elements. The Primary Plume contains moderate levels of contamination in the aqueous or vapor phase that still represent a hazard and a long-term risk to humans and/or the environment. The Dilute Plume/Fringe contains low levels of contamination in large volumes of water.

The remediation technology selection for a specific area is based on its size, the contaminant type, concentration, and plume configuration. For Source Zone treatment, aggressive, active remediation systems are used such as in-situ chemical oxidation, excavation of contaminated soil, dynamic underground stripping (DUS), soil vapor extraction (SVE), and thermal technologies. For the Primary Zone, where contaminant concentration is moderate to high, both active and enhanced-passive treatments are used such as pump and treat, barrier walls, airlift recirculation wells, chemical oxidation injection, and nutrient injection. The dilute fringe zone can often be treated with passive techniques such as monitored natural attenuation (MNA), phytoremediation, and passive or solar powered soil vapor extraction.

As the remediation progresses and contaminant concentration decreases, active systems are replaced with passive and enhanced-passive technologies that have low energy consumption and a smaller carbon footprint.

Groundwater Remediation Implementation

M-Area Hazardous Waste Management Facility

Description

- Settling basin operated from 1958 to 1985, receiving wastewater that contained:
  - VOCs
  - Solvents used for metal degreasing
  - Depleted uranium
  - Other chemical constituents
- Wastewater overflowed periodically, traveling into the seepage area, and into Lost Lake.
- M-Area HWMF is subject to RCRA regulatory process and requirements.
- Closure cap for the basin completed between 1989 and 1991.
- Currently, the facility is maintained and operated under 2003 RCRA Permit Renewal.
- The corrective action program for the A/M Area addresses four sectors: Northern, Central, Western, and Southern sectors. Sectors are divided based on recovery well zones of capture (ZOCs), geography and subsurface conditions, and ongoing actions.

Corrective Action Systems

- Done by sectors.
- M-Area HWMF in Central and Northern Sectors.

Metallurgical Laboratory Hazardous Waste Management Facility

Description

- Met Lab HWMF is subject to RCRA regulatory process and requirements.
- The process sewer line was excavated and consolidated into the Met Lab Basin.
- The Met Lab Basin was closed through construction of a RCRA cap completed in 1992.
- Currently, the facility is maintained and operated under 2003 RCRA Permit Renewal.

Corrective Action Systems

- Done by sectors.
- Met Lab HWMF in Central Sector.

ABRP/MCB/MBP Operable Unit

Description

- Separate investigations under the FFA program found surface soil, vadose zone, and groundwater contamination.
- Elevated levels of VOCs in the MAAZ and LLAZ.

- ABRP Trench used in the 1950s for disposal and burning of construction debris and discarded solvents.
- ABRP closed in 1983.
- MCB received liquid chemical waste from c.1956 to c.1974.
- MBP is not a source of groundwater contamination.
- ABRP/MCB groundwater programs are part of the RCRA program since 2006.

Corrective Action Systems by Sectors

Central Sector Remediation

- Corrective action accomplished by pumping contaminated water using recovery wells (RWM series) to an aboveground air stripper, M-1, where VOCs are removed.
- The M-1 Air Stripper receives contaminated groundwater from thirteen RWM series wells (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 17B, and 17D).
- Remediation system was designed to hydraulically contain and capture the high concentration VOC plume in the LLAZ.
- The M-1 Air Stripper began operations in 1985.
- RWM 1 - 11 began operations in April 1985.
- RWM 17B and 17D began operations in July 2000.
- RWM 17D is currently not operating due to low VOC concentration and declining water levels.
- Dynamic Underground Stripping (DUS) was performed at the Solvent Storage Tank Area (SSTA) from September 2000 to September 2001. A total of approx. 70,000 lbs of VOCs were removed.
- At the MASB, a DUS operation started in August 2008, and by the end of 2011 had removed over 442,892 lbs of VOCs.
- Remediation complemented with SVEU operations in the vadose zone
- Six SVEU (782-3M, 782-4M, 782-5M, 782-6M, 782-7M, and 782-8M) have operated since 1990.
- SVEUs were connected to twelve vertical and/or horizontal SVE wells.
- Large SVEUs have been transitioned to passive SVE wells or smaller mobile units.
- Five SVEUs (782-3M, 782-4M, 782-6M, Mobile #3 and the M-1 Catalytic Blower unit) are currently in operating condition.
- SVEUs 782-4M, 782-6M, and the M-1 Catalytic Blower unit are used at the MASB DUS project.
- SVEUs 782-3M and Mobile #3 are addressing the area near A-014 Outfall.
- SVEUs 782-5M, 782-7M, and 782-8M reached active shutdown criteria and have been removed from service (782-5M) or dismantled (782-7M, and 782-8M). BaroBalls™ have been installed on extraction wells.
- Within the Met Lab area, 19 BaroBalls™ were installed in 1998, the majority of the contamination was removed in the first four years. From 1998 to 2011, the Met Lab remediation system has removed approx. 300 lbs of PCE and TCE.

- Within A/M Area, vadose zone remediation accomplished through the use of active soil vapor extraction (SVE) and innovative technologies such as dynamic underground stripping (DUS).

Northern Sector Remediation

- Corrective action accomplished by pumping contaminated water using recovery wells (RWM series) to an aboveground air stripper, A-2, where VOCs are removed.
- The A-2 Air Stripper receives contaminated groundwater from six recovery wells (RWM series wells: 12, 13B, 13C, 14B, 14C, 15B).
- The A-2 Air Stripper began operations in 1992.

Southern Sector Remediation

- In the southern sector plume, the VOC concentrations range from relatively dilute in the farthest portion of the plume to TCE concentrations exceeding 10,000 µg/L.
- The source of the plume was discharged from the A-014 Outfall.
- Remediation system initiated in 1996 with twelve in situ air stripping recirculation wells (ARWs) (SSR series: 001, 002, 003, 004, 005, 006, 007, 008, 009, 010, 011, 012) located as a “line” of ARWs south of A-014 Outfall.
- The GW remediation strategy of the Southern Sector plume is composed of two separate strategies. One strategy addresses the higher concentration in the primary groundwater plume (PGP), located between A-014 Outfall and the ARWs line. The second strategy addresses the dilute plume fringe area (DPFA) located between the line of ARWs and Tims Branch.
- Tims Branch is the predicted point of exposure (POE) of the dilute VOC plume.

Western Sector Remediation

- Analysis of results suggests that the primary source of the TCE/PCE contamination in the Western Sector is from the MASB and Lost Lake area.
- Additional characterization in 2008 showed a high concentration VOC plume potentially emanating from the MASB.
- VOCs observed west of the MASB are outside of the lateral and vertical boundaries of the DUS system being used at MASB.
- Any proposed GW remedial action within the ABRP/MCB/MBP OU has to consider the long-term impact of the M-Area plume due to its proximity.
- Remediation system initiated in 2002 with eleven in situ air stripping recirculation wells (ARWs) (MIS series: 001B, 002B, 003B, 004B, 005B, 006B, 007B, 008B, 009B, 010B, 011B).
- Since the system has treated the contamination in the designated area, in 2011 the ARW system was shut down and four sentinel wells would be monitored for 18 to 36 months to evaluate the system for possible permanent shutdown.

Wells Series

- **RWM** series: Recovery wells, M-Area and Met Lab, Central and Northern
- **SSR** series: In situ air stripping air-lift recirculation wells (ARWs), Southern Sector

- **MIS** series: In situ air stripping air-lift recirculation wells (ARWs), Western Sector

5. CONCLUSION

Environmental remediation often uses expensive, heavy engineered systems that consume resources and contribute to humankind's carbon footprint. The purpose of sustainable remediation practices is to lessen this burden on the environment and society while also reducing the cost associated with cleanup procedures.

SR can be applied at different level depending on site complexity and needs. The first and most important step when incorporating sustainability into a project is to use best management practices to help in the implementation of easy, and usually cost-effective procedures to obtain sustainable goals. Higher levels of analysis and implementation require more data and expertise, and can convey more tangible results.

The selection of appropriate metrics is site-specific and depends on site complexity, available budget and time, as well as existing data. Different tools for the analysis and implementation are also available depending on the site needs.

Most of the available technologies considered sustainable are in-situ remediation methods that treat contamination at the site and do not require the extra energy consumption, cost, and resource use associated with the excavation and transportation of ex-situ remediation practices.

Sustainable practices are becoming more important every day, and constant efforts are being applied to the development of new technologies.

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APPENDIX A.

Sustainable Remediation Practices and Objectives (SURF, 2009)

	Triple-Bottom-Line Element			Sub elements								
Sustainable Remediation Practices and Objectives	**Environmental**	**Economic**	**Social**	**Water Resources**	**Land and Ecosystems**	**Materials/Waste Minimization**	**Long-Term Stewardship**	**Atmospheric Emissions**	**Energy Efficiency**	**Life Cycle Costs**	**Environmental Justice**	**Human Health and Safety**
Minimize fresh water consumption	X			X								
Maximize water reuse	X			X		X						
Conserve groundwater resources	X			X			X					
Prevent runoff and negative impacts to surface water	X			X	X							X
Use native vegetation requiring little or no irrigation	X			X	X							
Minimize bioavailability of contaminants through source and plume control	X				X							
Maximize biodiversity	X				X		X					
Minimize soil and habitat disturbance	X				X		X					
Favor minimally invasive in situ technologies	X				X							
Favor low-energy technologies where possible	X				X			X	X			
Protect native ecosystems and avoid introduction of non-native species	X				X		X					
Minimize risk to ecological receptors	X				X		X					
Preserve natural resources	X			X	X		X					
Use telemetry or remote data collection when possible	X					X			X			
Use passive sampling devises where feasible	X					X		X	X			
Use or generate renewable energy to the extent possible	X						X	X	X			
Reduce emissions of greenhouse gases contributing to climate change	X						X	X				
Reduce emissions of criteria pollutants	X							X				
Prevent offsite migration of contaminant	X						X					
Integrate flexibility into long-term controls to allow for future efficiency and technology improvements	X	X					X			X		
Invest in carbon offsets	X	X								X		
Minimize material extraction and use	X	X				X				X		
Minimize waste	X	X				X				X		
Maximize material reuse	X	X				X				X		
Recycle or reuse project waste streams		X				X				X		

	Triple-Bottom-Line Element			Sub elements								
Sustainable Remediation Practices and Objectives	**Environmental**	**Economic**	**Social**	**Water Resources**	**Land and Ecosystems**	**Materials/Waste Minimization**	**Long-Term Stewardship**	**Atmospheric Emissions**	**Energy Efficiency**	**Life Cycle Costs**	**Environmental Justice**	**Human Health and Safety**
Use operations data to continually optimize and improve the remedy		X							X	X		
Consider the net economic result		X								X		
Consider cost of the "sustainability delta," if any		X								X		
Improve the tax base/economic value of the property/local community		X	X		X		X			X	X	
Maximize employment and educational opportunities		X	X				X				X	
Minimize O&M cost and effort		X	X				X			X		X
Minimize health and safety risk		X	X				X			X	X	X
Maximize acres of a site available for reuse		X	X				X				X	
Maximize number of sites available for reuse		X	X				X				X	
Use locally sourced materials	X	X	X			X						
Minimize noise, odor, and lighting disturbance	X		X				X				X	X
Favor technologies that permanently destroy contaminants	X		X		X		X					X
Avoid environmental and human health impacts in already disproportionately impacted communities			X		X		X				X	X
Consider net positive/negative impact of the remedy on local community			X				X				X	X
Assess current, potential, and perceived risks to human health, including contractors and public, over the remedy life cycle			X				X				X	X
Prevent cultural resource losses			X				X				X	
Integrate stakeholders into decision-making process			X				X				X	
Solicit community involvement to increase public acceptance and awareness of long-term activities and restrictions			X				X				X	
Maintain or improve public access to open space			X				X				x	
Create goodwill in the community through public outreach and open access to project information			X				X				X	
Consider future land uses during remedy selection and choose remedy appropriately			X				X			X	X	

APPENDIX B.

Sustainable Remediation Techniques and Technologies Catalog

Sustainable Remediation
Techniques & Technologies
Catalog

Sustainable Remediation Techniques & Technologies

Introduction

The Department of Energy (DOE) Office of Environmental Management's (EM's) mission is the safe and successful cleanup of sites that were associated with nuclear materials and weapons production during the Cold War. The Office of Deactivation & Decommissioning and Facility Engineering (EM-13) provides information, planning and analysis for all EM D&D/FE activities including sustainability projects to ensure that the cleanup activities are completed efficiently and effectively reducing the environmental, social and economic impacts associated with such activities.

Traditionally, the main objective of remediation practices has been to protect human health and the environment. Remediation technologies have been selected according to cost, efficacy, technical practicability, and regulatory acceptance without necessarily considering the detrimental effects of such technologies on the environment, or their external social and economic effects.

The Sustainable Remediation Techniques & Technologies Catalog has been created to serve as a reference guide when selecting the appropriate action plan during environmental remediation activities. The techniques and technologies mentioned in the catalog have been considered to bring environmental, social, and/or economic benefits compared to other remediation methods. Some of the technologies are well-known and have been repeatedly employed, and some are still in the pilot study stage.

All of the techniques and technologies mentioned are in-situ remediation methods. Treating contamination at the site does not require the extra energy consumption, cost, and resource use associated with the excavation and transportation of ex-situ remediation practices.

Biological, physical, and chemical techniques have been addressed. Biological processes are often implemented at low cost, contaminants can be destroyed, and often little to no residual treatment is required; however, the process requires more time, and it is challenging to determine whether contaminants have been destroyed. Physical and chemical methods use the physical properties of the contaminants or the contaminated medium to destroy, separate, or contain the contamination; they are typically cost-effective and are usually not engineering or energy intensive.

The processes addressed in this catalog do not represent all the technologies available in the remediation industry and is only meant as a reference. Sustainable practices are becoming more important every day, and constant efforts are being applied to the development of new technologies.

Sustainable Remediation Techniques & Technologies

Table of Contents

Enhanced Bioremediation

Enhanced bioremediation techniques use reagents to increase the rate of aerobic and anaerobic organic degradation, or to transform inorganic contaminants into less toxic forms.

Bioremediation is a process in which microorganisms, such as fungi or bacteria, are used to degrade or transform contaminants to non-toxic by-products. Enhanced bioremediation attempts to accelerate the process by the addition of reagents that release oxygen, if an aerobic environment is desired or, stimulate the removal of oxygen and the generation of hydrogen if an anaerobic environment is desired. This biodegradation is also enhanced by the addition of nutrients to the groundwater.

Commonly used reagents to promote aerobic bioremediation are calcium peroxide, magnesium peroxide, and hydrogen peroxide. To promote anaerobic conditions, molasses, and vegetable oil are commonly used. The addition of solubilized nitrate is used to provide an alternative electron acceptor to enhance degradation of organic contaminants.

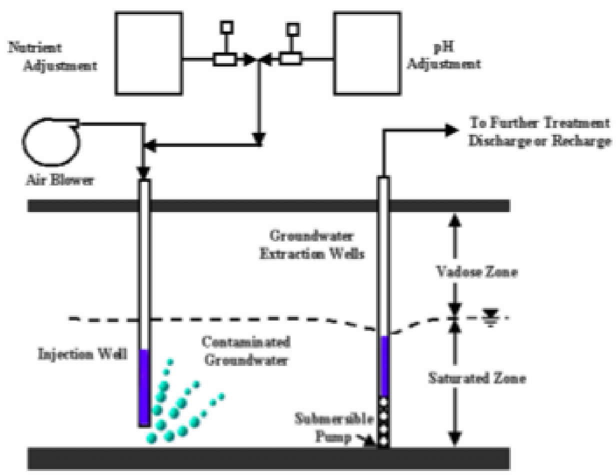


Figure 1: Typical Oxygen-Enhanced Bioremediation System with Air Sparging

Ground & Surface Water

Enhanced Bioremediation

Agricultural Oils

Technique: Enhanced bioremediation

Laboratory: Savannah River National Laboratory

Process: Biological, In-situ, Ex-situ

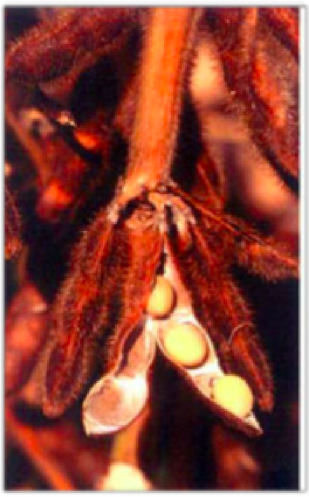
Media: Groundwater, wastewater, seepage, and/or surface water

Contaminants: Sulfate
Nitrate/nitrite
Perchlorate
Redox sensitive metals
Chlorinated solvents

Advantages:

- Energy resources are not consumed in the process
- No waste product is produced (organics are transformed into non-toxic end products)
- No above ground structure is required
- Length of time required for remediation is reduced by enhancing natural flow rates
- Ability to easily replenish the source in high quantities
- Source not being easily flushed out of the system
- Precipitate can be removed from the system without the removal of the substrate.

Technology Overview:



Savannah River Nuclear Solutions scientists have developed a groundwater treatment technique that employs agricultural oils to stimulate endogenous microbes which accelerates the cleanup.
The oils tested include canola oil, rapeseed oil, coconut oil, corn oil, cottonseed oil, olive oil, palm oil, palm kernel oil, peanut oil, safflower oil, soybean oil, sunflower oil, beef oil, cod-liver oil, tallow, candelilla oil, carnawba wax, beeswax, and palm tree wax.
This invention uses the physical and chemical properties of floating, separate phase, liquid organic substrates and system geometry to produce a passive treatment system for contaminated waters. The system utilizes a long-term, slow release, electron donor/carbon source for microorganisms. The electron donor/carbon source is fairly constant and is not subject to deactivation, plugging, and hydraulic failure

Contact: John Olschon
Commercialization Manager
Savannah River National Laboratory
Phone: 803-725-8125
E-mail: john.olschon@srnl.doe.gov

Ground & Surface Water

Enhanced Bioremediation

MicroCED
Microbial Based Chlorinated Ethene Destruction

Technique: Enhanced bioremediation

Laboratory: Savannah River National Laboratory

Process: Biological

Media: Subsurface environment

Contaminants: Polychlorinated ethenes
Halogenated ethanes

Advantages:

- Rapidly converts toxic substances
- Sensitive and efficient bio-process
- Process uses naturally occurring bacteria
- Cost effective and low maintenance

Technology Overview:

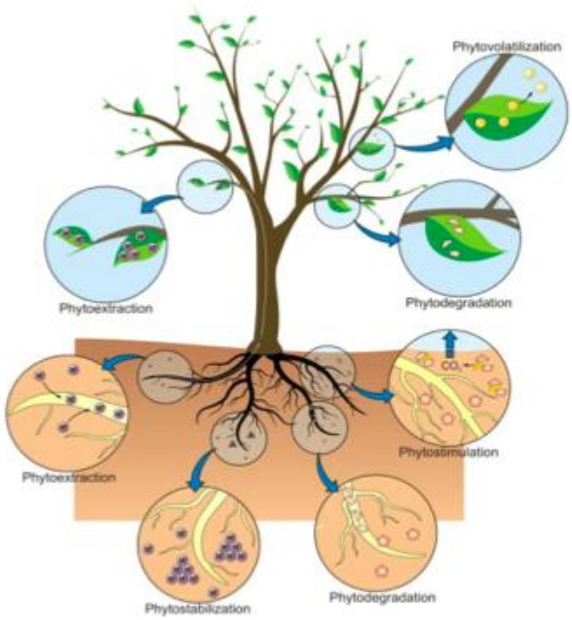
Microbiological-based Chlorinated Ethene Destruction (MicroCED), a mixed culture of Dehalococcoides species, rapidly and completely catalyzes the conversion of chlorinated ethenes (CE) to safe end products without production or accumulation of toxic by-products.
MicroCED consists of a unique mixture of naturally occurring bacteria that can completely transform lethal CEs to safe, nontoxic end products. The treatment process involves introducing MicroCED into a contaminated subsurface environment whereby the bacteria are nourished and grow through the process of detoxification and degradation of the CEs. The versatility of MicroCED allows for it to be used as a standalone bioremediation treatment for widespread, low level chloroethene contamination or in combination with aggressive source-zone treatment technologies.

Contact: Dale Haas, Commercialization Manager
Savannah River National Laboratory
Phone: 803-725-4185
E-mail: dale.haas@srnl.doe

Ground & Surface Water

Phytoremediation

Phytoremediation is a process that uses plants to remove, transfer, contain, stabilize, and destroy organic or inorganic contaminants. Phytoremediation of groundwater occurs via a number of mechanisms which include enhanced rhizosphere biodegradation, hydraulic control, phytodegradation, and phytovolatilization.



Enhanced rhizosphere biodegradation occurs in the zone of soil influenced by plant roots. The roots release nutrients that enhance the microorganism's ability to biodegrade organic contaminants. The presence of plant roots tends to pull water to the surface zone and dry the lower saturated zones.

Hydraulic control is achieved by some plants and trees that intercept, take up, and transpire the water, thus controlling the vertical or horizontal migration of water.

Phytodegradation is the metabolism of contaminants within plant tissues. Plants produce enzymes, such as dehalogenase and oxygenase that help catalyze degradation.

Phytovolatilization occurs as plants take up water containing organic contaminants and transpire then through their leaves.

Phytoremediation is normally used to treat organic contaminants such as petroleum hydrocarbons, gas condensates, crude oil, chlorinated compounds, pesticides, and explosive compounds, can be addressed using plant-based methods. Phytotechnologies also can be applied to typical inorganic contaminants, such as heavy metals, metalloids, radioactive materials, and salts.

Ground & Surface Water

Monitored Natural Attenuation

Natural attenuation relies on natural physical, chemical, and biological processes to attenuate the concentration, flux, or toxicity of contaminants in soil or groundwater. Some of the attenuation processes include dilution, volatilization, immobilization, adsorption, biodegradation, and chemical degradation.

Although not considered a technique per se, for monitored natural attenuation (MNA) to take place, there is a requirement to extensively characterize the site being managed and an evaluation of contaminant degradation rates and pathways that usually requires modeling. The primary objective of site modeling is to demonstrate that attenuation processes are occurring and will continue contaminant degradation below regulatory standards or risk-based levels.

Target contaminants for natural attenuation are VOCs, SVOCs, and fuel hydrocarbons; in some cases pesticides are also allowed to naturally attenuate.

Ground & Surface Water

Air Sparging

Air sparging consists in the injection of air into the saturated zone via wells to a point located below the target contamination area. The air moves vertically and horizontally producing contaminant removal by the partition of volatile contaminants as they move through the water, or by stimulating aerobic bacteria with the oxygen supply to biodegrade contaminants.

A vapor extraction system such as soil vapor extraction (SVE) is usually implemented in conjunction with air sparging as contaminants are transferred from the saturated to the unsaturated zone.

Air sparging has been found to be effective in reducing concentrations of VOCs, and is generally more applicable to light gasoline constituents such as benzene, ethylbenzene, toluene, and xylene (BTEX).

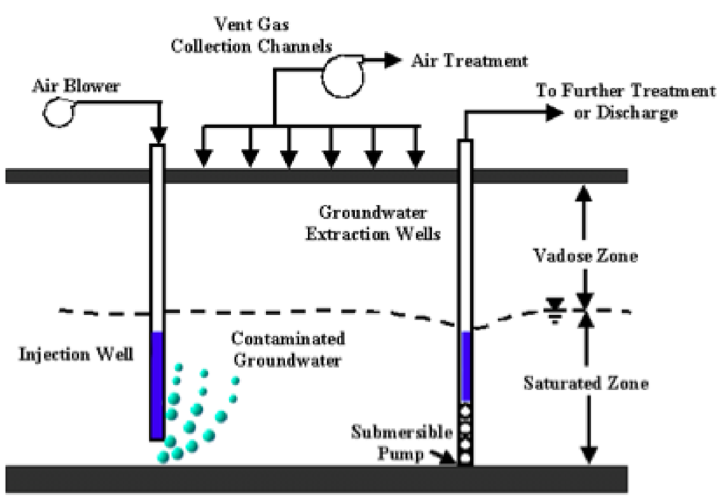


Figure 2: Typical Air Sparging System

Ground & Surface Water

Bioslurping

Bioslurping combines elements of bioventing and vacuum-enhanced dewatering technologies to recover free product that is lighter that water such as LNAPLs. This technique simultaneously recovers free product and bioremediated unsaturated soils.

Bioslurping can improve free-product recovery efficiency without extracting large quantities of ground water. Vacuum-enhanced pumping allows LNAPL to be lifted off the water table and released from the capillary fringe, minimizing changes in the water table elevation. Bioventing of unsaturated soils is achieved by drawing air into the soil due to withdrawing soil gas via the recovery well. The system is designed to minimize environmental discharge of ground water and soil gas. When free-product removal activities are completed, the bioslurping system is easily converted to a conventional bioventing system to complete the remediation.

Chemical Oxidation & Reduction

Chemical oxidation typically involves the injection of an oxidizing or a reductant compound in the subsurface to chemically convert hazardous contaminants to non-hazardous or less toxic, more stable compounds; to change their solubility; or increase their susceptibility to other forms of treatment. Reduction/oxidation (redox) reactions involve the transfer of electrons from one compound to another.

Typical *oxidants* include Fenton's catalyzed hydrogen peroxide, hydrogen peroxide, potassium permanganate, sodium permanganate, sodium persulfate, and ozone.

Typical *reductants* include zero valent iron (ZVI), ferrous iron, sodium dithionite, sulfide salts (calcium polysulfide), and hydrogen sulfide.

Chemical oxidation and reduction technique is applicable for DNAPLs contaminants such as halogenated VOCs, halogenated SVOCs, and PCBs. It is also applicable for non-halogenated VOCs and SVOCs.

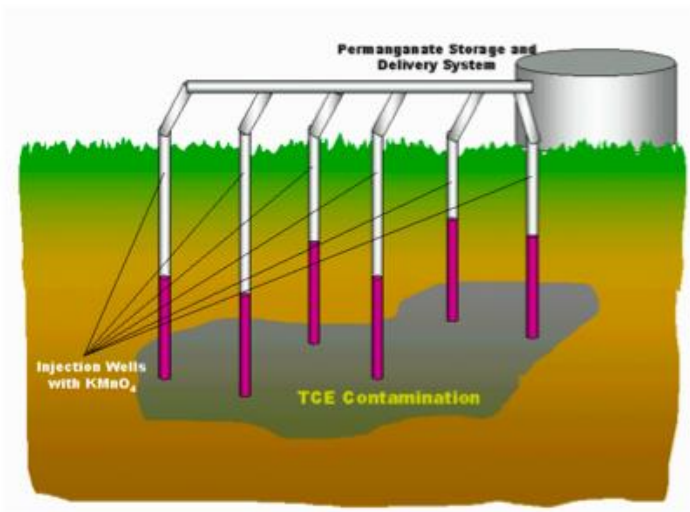


Figure 3: Typical Chemical Oxidation System

Ground & Surface Water

Chemical Oxidation & Reduction

RegenOX®

Technique: Chemical Oxidation

Laboratory: REGENESIS

Process: In situ, chemical

Media: Groundwater and soil

Contaminants: Chlorinated hydrocarbons
Polyaromatic hydrocarbons
Petroleum hydrocarbons

RegenOx™
CHEMICAL OXIDATION REDEFINED...

Advantages:

- Rapid and sustained oxidation of target compounds
- Generates minimal heat and pressure
- Compatible with underground infrastructure, conduits, piping and tanks
- Avoids detrimental impacts to groundwater
- Longevity - lasts up to 30 days on a single injection
- No Operations and Maintenance

Technology Overview:

RegenOx is an advanced chemical oxidation technology that destroys contaminants through powerful, yet controlled chemical reactions and not through biological means. This product maximizes in situ performance while using a solid alkaline oxidant that employs a sodium percarbonate complex with a multi-part catalytic formula. RegenOx directly oxidizes contaminants while its unique catalytic component generates a range of highly oxidizing free radicals that rapidly and effectively destroy a range of target contaminants including both petroleum hydrocarbons and chlorinated compounds.

A RegenOx application will remove significant amounts of contamination from the subsurface (both soil and groundwater) and is applied using direct-injection techniques or wells. The application process enables the two part product to be combined, then pressure injected into the zone of contamination and moved out into the aquifer media. Once in the subsurface, RegenOx produces a cascade of efficient oxidation reactions via a number of mechanisms including: surface mediated oxidation, direct oxidation and free radical oxidation. These reactions destroy a range of contaminants and can be propagated in the presence of RegenOx for periods of up to 30 days on a single injection.

Contact: **Corporate Office**
1011 Calle Sombra
San Clemente, CA 92673
Phone: (949) 366-8000

Ground & Surface Water

Chemical Oxidation & Reduction

Liquid Iron™

Technique: Chemical reduction

Laboratory: REGENESIS

Process: In situ, chemical

Media: Groundwater and soil

Contaminants: Chlorinated organic compounds

Advantages:

- Facilitates biogeochemical In-Situ Chemical Reduction (ISCR) of chlorinated contaminants
- Liquid iron form provides better distribution than can be achieved by directly injecting a solid iron material
- Seamless integration with anaerobic bioremediation
- Provides multiple pathways, both abiotic and biotic, for contaminant degradation in groundwater
- CRS is easy to apply with 3-D Microemulsion Factory Emulsified

Technology Overview:

CRS® (Chemical Reducing Solution) is an iron-based amendment for in situ chemical reduction (ISCR) of halogenated hydrocarbon contaminants such as chlorinated ethenes and ethanes. CRS is a pH neutral, liquid iron solution that is easily mixed with 3-D Microemulsion Factory Emulsified before injection into contaminated groundwater. CRS is a soluble, food-grade source of ferrous iron (Fe^{2}+), designed to precipitate reduced iron sulfides, oxides, and/or hydroxides. These Fe^{2}+ minerals are capable of destroying chlorinated solvents via chemical reduction pathways, thus improving the efficiency of the overall reductive dechlorination process by providing multiple pathways for contaminant degradation in groundwater.

The incorporation of iron as metallic particles or ferrous salts (Fe^{2}+) can enhance chlorinated contaminant remediation by enabling various chemical reduction pathways. The overall combination of biological and chemical processes displayed in equations 1 and 2 are referred to as "biogeochemical" reduction of contaminants. Biogeochemical reduction utilizes the biologically-generated reducing environment to create reduced iron precipitates that then go on to chemically reduce chlorinated solvents.

Contact: **Corporate Office**
1011 Calle Sombra
San Clemente, CA 92673
Phone: (949) 366-8000

Directional Wells

Directional wells are used as an enhancement for remediation. This technique is also referred to as directional drilling, and is used to position wells horizontally, or at an angle, to reach contaminants not accessible by vertical wells.

Remediation techniques that may be enhanced by directional wells are groundwater pumping, bioventing, soil vapor extraction, soil flushing, and in-well air stripping.

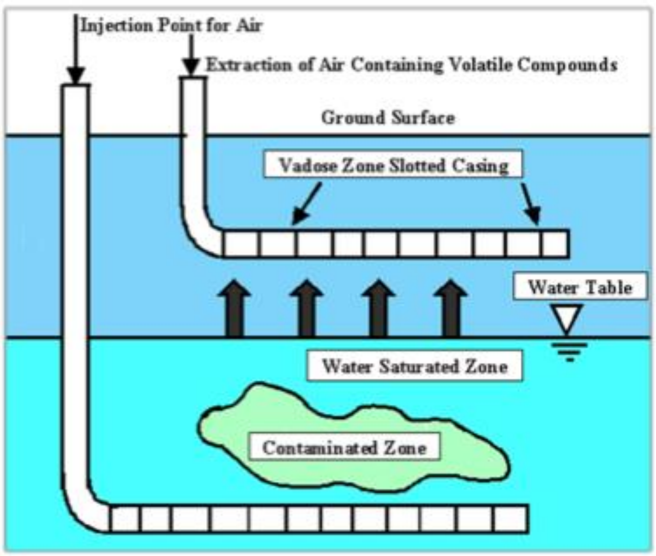
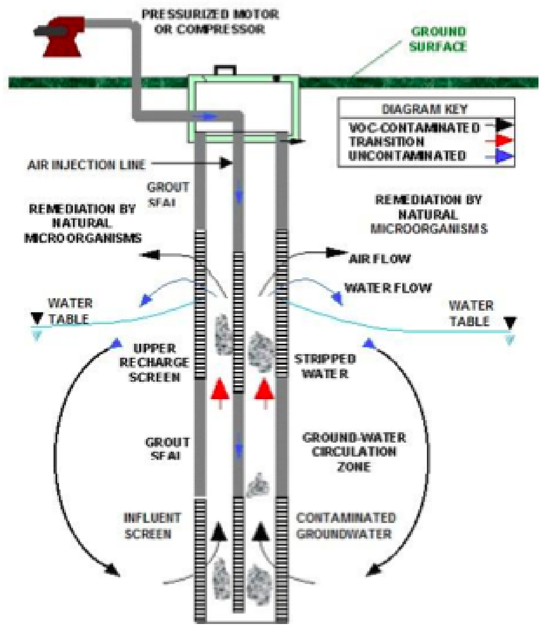


Figure 4: Typical In Sity Air Stripping with Horizontal Wells

Ground & Surface Water

In-Well Vapor Stripping

In-well vapor stripping is a technique that can continuously remove VOCs from groundwater without pumping the water to the surface or removing the water from the ground as in pump-and-treat systems.



This technique involves the creation of a groundwater circulation cell around a well through which contaminated groundwater is cycled. The air stripping well is a double-cased well ("well-within-a-well") with hydraulically separated upper and lower screened intervals within the same saturated zone. The lower screen, through which ground-water enters, is placed at or near the bottom of the contaminated aquifer and the upper screen, through which ground-water is discharged, is installed across or above the water table.

Pressurized air is injected into the well below the water table, aerating the water. The aerated water rises in the well and flows out of the system at the upper screen. Contaminated groundwater is drawn into the system at the lower screen. The VOCs vaporize within the well at the top of the water table, as the air bubbles out of the water. The vapors are drawn off by a soil vapor extraction system. The partially treated ground water is never brought to the surface; it is forced into the unsaturated zone, and the process is repeated as water follows a hydraulic circulation pattern or cell that allows continuous cycling of ground water. As ground water circulates through the treatment system, contaminant concentrations are gradually reduced.

Ground & Surface Water

In-Well Vapor Stripping

NoVOCs™

Technique: In-well vapor stripping

Laboratory: US DOE, Stanford University, EG&G Environmental, and Pacific Northwest National Laboratory

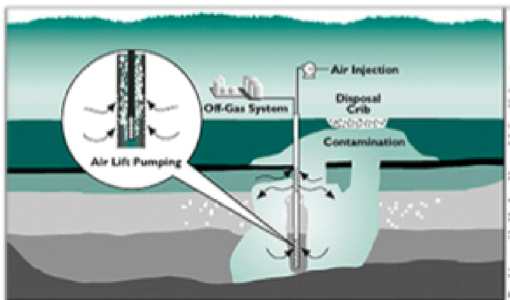
Process: In situ, physical/chemical

Media: Groundwater

Contaminants: Volatile organic compounds

Advantages:

- Cost effective
- Low risk level
- No need to handle contaminated water



Instead of sending water to the surface for treatment NoVOCs works inside extraction wells to capture VOCs as a vapor from contaminated ground water.

Technology Overview:

NoVOCs is an in-well vapor-stripping technology that offers numerous advantages over the pump-and-treat method of volatile organic compound removal.

NoVOCs works inside extraction wells to capture VOCs as a vapor from contaminated ground water. Ground water enters the bottom of the well through a screen. Air is injected at the base of the borehole, causing contaminated water to rise within the well as VOCs are stripped from the water. The contaminants are carried to the surface in a vapor stream, where they are fed to an off-gas treatment system. The VOC-free water continues to be air-lifted until it reaches a second screen where it flows out into the sediments above the aquifer before returning to the water table. The processes of extraction from the lower screen and return flow from the upper screen create a circulation cell within the aquifer. NoVOCs is, therefore, a continuous, in situ treatment.

Contact: **Joe Aiken**
MACTEC, Inc.
Phone: (303) 278-3100
www.mactec.com

Permeable Reactive Barriers

A permeable reactive barrier (PRB) is an engineered "wall" placed in the saturated zone, across the flow path of a contaminant plume, and remediates groundwater as it flows through. The barrier allows the passage of water while prohibiting the movement of contaminants.

The configuration of the PRB can be chosen depending on the contaminants to be treated and the layout of the area. The two basic types of PRBs are Funnel-and-gate and a continuous wall. In the funnel-and gate configuration, contaminated groundwater is directed to a permeable reactive zone by impermeable barriers such as cut-off walls. In the continuous wall configuration, a reactive treatment zone is placed in the subsurface across the complete flow path of the contaminated groundwater.

The reactive media to be used within the barriers could include zelo-valent metals, chelators (ligands selected for their specificity for a given metal), sorbents, microbes, and others.

Permeable reactive barriers are generally intended for long-term operation to control migration of contaminants in groundwater.

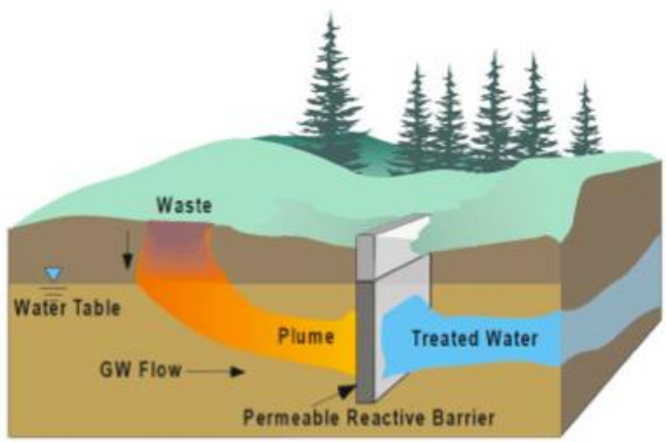


Figure 5: Typical Permeable Reactive Barrier System [1]

Ground & Surface Water

Permeable Reactive Barriers

GeoSiphon™

Technique: Permeable Reactive Barrier Enhancement

Laboratory: Savannah River National Laboratory

Process: Biological, In-situ

Media: Groundwater

Contaminants: Chlorinated volatile organic compounds (CVOCs) such as:
Trichloroethylene (TCE)
Carbon tetrachloride
Chloroform

Advantages:

- No external energy input
- Reduce clean-up time
- Low operating and monitoring costs

Technology Overview [1]:

A GeoSiphon™ groundwater remediation system is a passive system, which uses a siphon between two points of hydraulic head difference to drive contaminated ground water through a permeable treatment media. It uses natural forces to accelerate the flow of contaminated groundwater through the treatment media; therefore no external power input, pumps or compressors are required to produce the necessary water flow. (Pumping might be necessary only for priming to initiate flow)

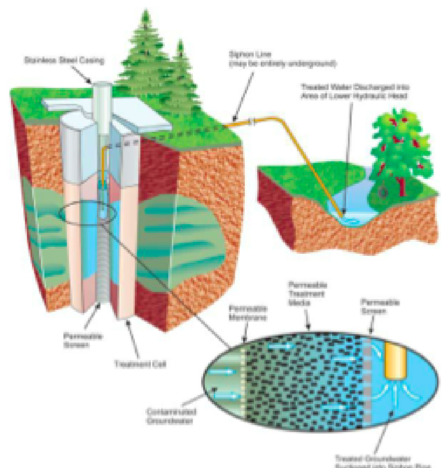


Image from SRNL techbriefs

The appropriate permeable treatment media is selected according to the contaminants associated with problem at hand, they can include materials such as: activated carbon, bimetallics, blast furnace slag, calcium peroxide, concrete, dolomite, fly ash, granular cast iron, ion exchange materials, iron, iron foam, lime, limestone, organic carbon, peat, phosphate rock, phosphates, pyrite, sodium carbonate, sulfur, and zeolites.
A test conducted at the Savannah River Site (SRS) showed that the technology is capable of sustaining flows of 8 gallons per minute and degrade 200 µg/L TCE to <5 µg/L.
More information on this technology and the results from the demonstrations, refer to Phifer, M. A., R. L. Nichols,F. C. Sappington, J. L. Steimke, and W. E. Jones. *GeoSiphon groundwater remediation system hydraulics*, and *Siphons for Geosiphon™ Treatment Systems.*

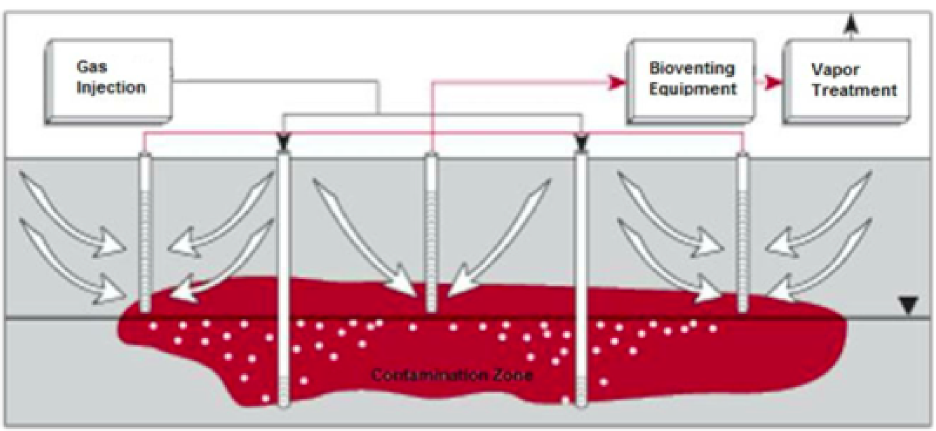
Contact: Dale Haas, Commercialization Manager
Savannah River National Laboratory
Phone: 803-725-4185
E-mail: dale.haas@srnl.doe

Bioventing

Bioventing involves the injection of a gas into the subsurface to enhance the biodegradation of a contaminant. The gas can be used to keep the subsurface aerobic or anaerobic.
Aerobic bioventing systems supply oxygen to contaminated unsaturated soils in order to maintain and maximize microbial biodegradation. Oxygen is typically introduced by air injection wells that should be designed considering soil gas permeability, contaminant diffusion and distribution, and environmental factors such as pH, temperature, and electron acceptor conditions. Aerobic bioventing could treat contaminants such as non-halogenated solvents, lightly halogenated solvents, and SVOCs.

Anaerobic bioventing systems supply nitrogen and electron donors, such as hydrogen and carbon dioxide, instead of oxygen. The nitrogen displaces the soil oxygen, and the electron donor gas facilitates microbial dechlorination. Volatile and semi-volatile organic compounds may be produced during anaerobic bioventing that are not anaerobically degradable. Volatile compounds may be aerobically degraded in the soil surrounding the treatment zone. Semi-volatile compounds may be treated by following anaerobic bioventing with aerobic bioventing. Since aerobic and anaerobic bioventing share similar gas delivery systems, the switch can be made by simply changing the injected gas. Anaerobic bioventing could treat highly chlorinated compounds such as PCE, TCE, some PCBs, and pesticides.

Bioventing is a medium to long-term technology. Cleanup ranges from a few months to several years.



Enhanced Bioremediation

Enhanced bioremediation techniques use reagents to increase the rate of aerobic and anaerobic organic degradation, or to transform inorganic contaminants into less toxic forms.

Bioremediation is a process in which microorganisms, such as fungi or bacteria, are used to degrade or transform contaminants to non-toxic by-products. Enhanced bioremediation attempts to accelerate the process by the addition of reagents that release oxygen, if an aerobic environment is desired or, stimulate the removal of oxygen and the generation of hydrogen if an anaerobic environment is desired. This biodegradation is also enhanced by the addition of nutrients to the soil.

Enhanced bioremediation of soil typically involves the percolation or injection of ground water or uncontaminated water mixed with nutrients and saturated with dissolved oxygen. Sometimes adapted microorganisms and/or another oxygen source such as hydrogen peroxide are also added. Spray irrigation is typically used for shallow contaminated soils, and injection wells are used for deeper contaminated soils.

Phytoremediation

Phytoremediation is a process that uses plants to remove, transfer, contain, stabilize, and destroy organic or inorganic contaminants. Phytoremediation of soils occurs via a number of mechanisms which include enhanced rhizosphere biodegradation, phytoaccumulation, phytodegradation, and phytostabilization.

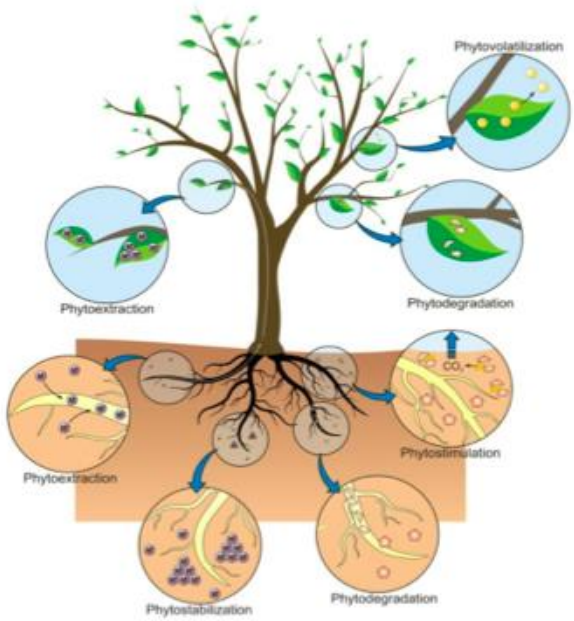
Enhanced rhizosphere biodegradation occurs in the zone of soil influenced by plant roots. The roots release nutrients that enhance the microorganism's ability to biodegrade organic contaminants. The presence of plant roots tends to pull water to the surface zone and dry the lower saturated zones.

Phytoaccumulation is the uptake of contaminants by plant roots and the accumulation of contaminants into plant shoots and leaves.

Phytodegradation is the metabolism of contaminants within plant tissues. Plants produce enzymes, such as dehalogenase and oxygenase that help catalyze degradation.

Phytostabilization is the phenomenon of production of chemical compounds by plant to immobilize contaminants at the interface of roots and soil.

Phytoremediation is normally used to metals, pesticides, solvents, explosives, crude oil, PAHs, and landfill leachates.



Chemical Oxidation & Reduction

Chemical oxidation typically involves the injection of an oxidizing or a reductant compound in the subsurface to chemically convert hazardous contaminants to non-hazardous or less toxic, more stable compounds; to change their solubility; or increase their susceptibility to other forms of treatment. Reduction/oxidation (redox) reactions involve the transfer of electrons from one compound to another.
Typical *oxidants* include Fenton's catalyzed hydrogen peroxide, hydrogen peroxide, potassium permanganate, sodium permanganate, sodium persulfate, and ozone.

Typical *reductants* include zero valent iron (ZVI), ferrous iron, sodium dithionite, sulfide salts (calcium polysulfide), and hydrogen sulfide.

Chemical oxidation and reduction technique is applicable for DNAPLs contaminants such as halogenated VOCs, halogenated SVOCs, and PCBs. It is also applicable for non-halogenated VOCs and SVOCs.

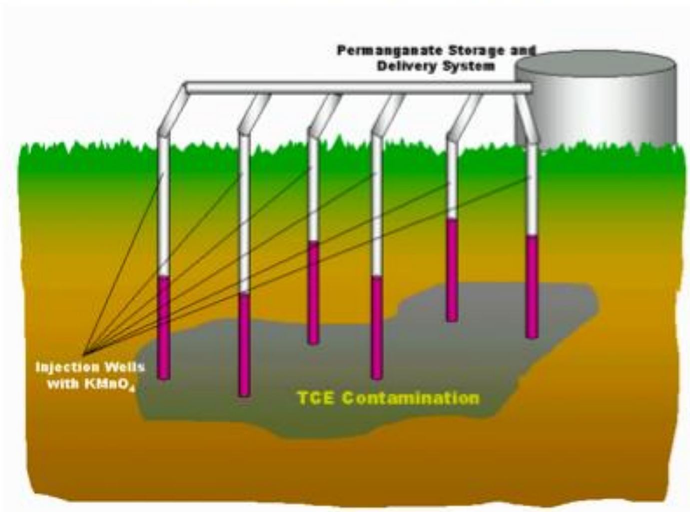


Figure 6: Typical Chemical Oxidation System

Soil

Chemical Oxidation & Reduction

S-ISCO®

Technique: Chemical Oxidation

Laboratory: VeruTEK Technologies

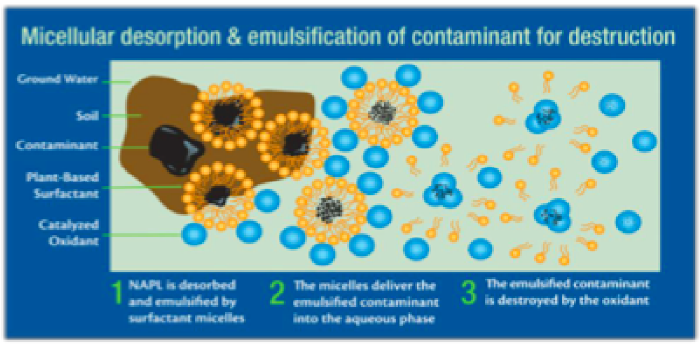
Process: Physical, in-situ

Media: Soil and groundwater

Contaminants: LNAPLs
DNAPLs
Chlorinated solvents
Polyaromatic hydrocarbons (PAHs)
Hydraulic fluid oil

Advantages:

- Source destruction through enhanced contact between oxidant & contaminants
- Permanent, safe and cost-competitive soil & groundwater remediation
- Remedial option for sites with roadways, utilities and structures
- Results achieved in weeks or months, providing faster, more complete remedies than competing alternatives that may take years.



Technology Overview:

During the S-ISCO process surfactants and oxidant systems are injected simultaneously to destroy contamination on site and in place, providing timely and permanent solutions to soil and free-phase contamination. At the foundation of this technology is the subsurface transport of surfactants and free radical oxidant systems in combination to increase the solubility of contaminants which normally exhibit low solubility, such as NAPLs, and make them available for oxidative destruction. S-ISCO incorporates the following four key elements:

- Biodegradable surfactant and co-solvent mixtures that emulsify NAPL-phase contaminants and desorb source zone contaminants;
- Catalysts and oxidants that generate powerful free-radical oxidant systems;
- Free radical oxidant systems that destroy solubilized contaminants;
- Reduced oxidant consumption through increased contaminant availability

Contact: Geeta Dahal
Phone: (860) 617 1572
E-mail: gdahal@verutek.com

Soil Flushing

In-situ soil flushing uses aqueous solutions to dissolve and recover contamination from the ground. The water or solution is injected or infiltrated into the contaminated area where the contaminants are mobilized by solubilization, formation of emulsions, or a chemical reaction with the flushing solution. The solution is then recovered, treated, and reused if appropriate.

Common flushing solutions include water, which will extract hydrophilic constituents; acidic solutions, which may remove metals or basic organic material; basic solutions, that may remove some metals such as zinc, tin, or lead, and some phenols; chelating agents, used to remove some metals; and surfactants, which can assist in the removal of hydrophobic organics.

Soil flushing has been proven effective for removing halogenated and non-halogenated VOCs and SVOCs, and some metals.

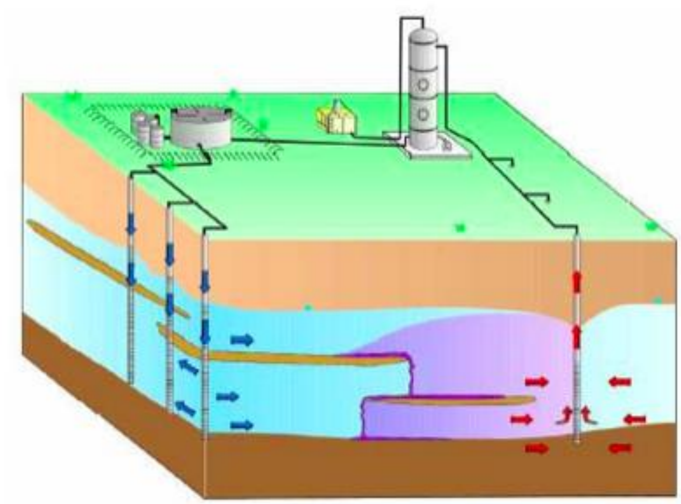


Figure 7: Conceptual Design of a Surfactant/Cosolvent Flushing System

Soil

Soil Flushing

SEPR™

Technique: Soil Flushing

Laboratory: VeruTEK Technologies

Process: Physical, in-situ

Media: Soil

Contaminants: NAPLs

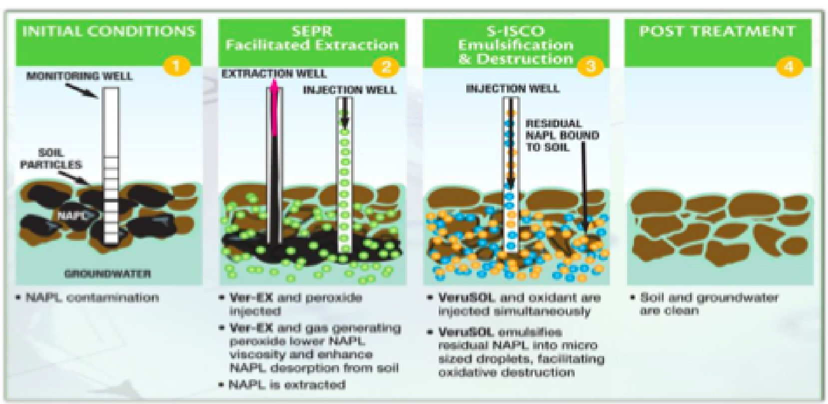
Advantages:

- Injection & extraction of the *SEPR* chemistry increases soil porosity around the well
- Plant-based & biodegradable surfactant and co-solvent mixtures
- *SEPR* increases the efficiency & cost-effectiveness of subsequent *S-ISCO* treatment at sites with heavy NAPL & free-product contamination

Technology Overview:

VeruTEK's Surfactant Enhanced Product Recovery (SEPR™) and Surfactant---enhanced In Situ Chemical Oxidation (S---ISCO®) technologies can be combined to provide an advanced and complete solution for NAPL contamination including DNAPL creosote and heavy---end hydrocarbon contamination and LNAPL fuel oil leaks. During the SEPR process Ver---EX, a powerful surfactant/cosolvent and oxidant solution reacts with NAPL, allowing the product to flow to recovery wells. After the SEPR process has removed the bulk of the NAPL contaminant mass, S---ISCO, which uses simultaneous injections of VeruSOL surfactants in combination with chemical oxidants, solubilizes and destroys residual contamination in place. Sequenced implementation of VeruTEK's SEPR and S---ISCO technologies eliminates or substantially reduces the need for excavation or long- term pump---and---treat remedies, resulting in significant cost savings and reduced treatment times.

Contact:
Geeta Dahal
Phone:
(860) 617 1572
E-mail:
gdahal@verutek.com



Soil

Passive Soil Vapor Extraction

Passive soil vapor extraction (PSVE) is an Enhance Attenuation technique used to remediate unsaturated (vadose) zone soil contaminated with volatile compounds. The process is driven by natural pressure gradients between the subsurface and atmosphere (Barometric Pumping), or by low-energy renewable resources of energy (Assisted PSVE).

Barometric Pumping

When the atmosphere and the subsurface environment are connected by a well, a natural flow of air occurs between the two zones due to difference in atmospheric and subsurface pressures. When the atmospheric pressure is higher than the subsurface pressure, the unsaturated zone inhales ambient air. When the atmospheric pressure is lower than the subsurface pressure, the unsaturated zone exhales soil gas.

Barometric pumping works by installing a one-way check valve in wells screened within the impacted soil layers that only allows soil gas to flow from the well into the atmosphere, and prevents the dilution of soil gas with ambient air in the unsaturated zone.

Assisted PSVE

Soil vapor extraction techniques have been conventionally used by applying a vacuum through extraction wells to induce the controlled flow of air between the subsurface and the atmosphere in order to remove volatile and some semi-volatile contaminants from the soil.

Assisted PSVE systems are similar in design to conventional active soil vapor extraction (ASVE) units, but are powered by renewable sources of energy such as solar and wind. With the use of these Assisted PSVE units, the need for an external power supply is eliminated.

PSVE technique is applicable for remediating sites with low levels of contamination and for transitioning sites from active source technologies such as active soil vapor extraction (ASVE) to natural attenuation.

Soil

Passive Soil Vapor Extraction

MicroBlower

Technique: Passive soil vapor extraction (Assisted PSVE)

Laboratory: Savannah River National Laboratory

Process: Physical, in-situ

Media: Soil

Contaminants: Volatile compounds

Advantages:

- Long operating life
- Solar powered
- Remediates shallow areas
- Remediates vadose zone
- Excellent for treatment polishing
- Offers significant cost savings

Technology Overview

MicroBlower uses a small, low power vacuum blower to extract or inject gases into the subsurface for characterization or remediation. Because the components of the system have a long operating life, the system is useful for long-term cleanup operations, particularly where mass transfer limits the rate of remediation.

The unit requires only between 20 to 40 watts of power which can be easily produces by small batteries, small photovoltaic panels, or wind generators.

The MicroBlower enables the use of simple, low-cost soil vapor extraction in shallower areas than previously considered possible. Perhaps the greatest potential for the MicroBlower is in treatment polishing of an area treated by an expensive, large blower system that still has residual contamination. Installation of an economical MicroBlower system to finish the cleanup at greatly reduced costs, allows the larger systems to be used where they can produce greater returns. The system also can remediate sites that are smaller than the capacity of typical, large blower systems.

Contact: Dale Haas, Commercialization Manager
Savannah River National Laboratory
Phone: 803-725-4185
E-mail: dale.haas@srnl.doe

Soil

Passive Soil Vapor Extraction

BaroBall™

Technique: Passive soil vapor extraction (Barometric Pumping)

Laboratory: Savannah River National Laboratory

Process: Physical, in-situ

Media: Soil

Contaminants: Volatile compounds

Advantages:

- Low-cost alternative treatment technique
- Simple design
- Easy to install
- Easy to maintain

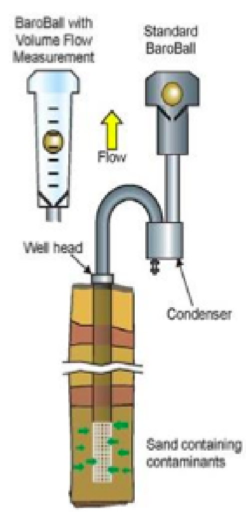
Technology Overview:

The BaroBall™ control valve increases the efficiency of barometric pumping and allows natural soil gas to flow out of an underground well, while restricting air flow from the surface into the well. Air flowing into the well from the surface will dilute and possibly spread contaminants still present in the subsurface.

The BaroBall™ control valve uses a ping-pong ball to provide low cracking pressure for outflow and to seal the well during inflow. The pressure required to open the valve (cracking pressure) is related to the weight of the ball and is approximately 1 mbar. The valve is a simple, inexpensive mechanical device requiring minimal maintenance.

An In-line condenser between the well and the valve prevents moisture condensation in the valve that could cause the valve to freeze in one position during cold weather. The condenser holds the condensed water that is produced when warmer, moist air from the subsurface is cooled in the valve tubing during cold weather. The condensate can be drained periodically with a valve in the bottom of the condenser.

A new design feature consists of a tapered column to measure the volume of air passing the valve. By periodically recording these flows along with vapor concentrations, the overall performance of the passive remediation system can be evaluated.



Contact: Dale Haas, Commercialization Manager
Savannah River National Laboratory
Phone: 803-725-4185
E-mail: dale.haas@srnl.doe

Soil

Solidification / Stabilization

Solidification and stabilization (S/S) refer to closely related technologies that use chemical and/or physical processes to treat radioactive, hazardous, and mixed wastes. Solidification technologies encapsulate the waste to form a solid material. The product of solidification may be a monolithic block, a clay-like material, a granular particulate, or some other physical form commonly considered solid.
Stabilization technologies reduce the hazard potential of a waste by converting the contaminants into less soluble, mobile, or toxic forms. The physical nature and handling characteristics of the waste are not necessarily changed by stabilization.

S/S technique is usually targeted to inorganic contaminants, including radionuclides.

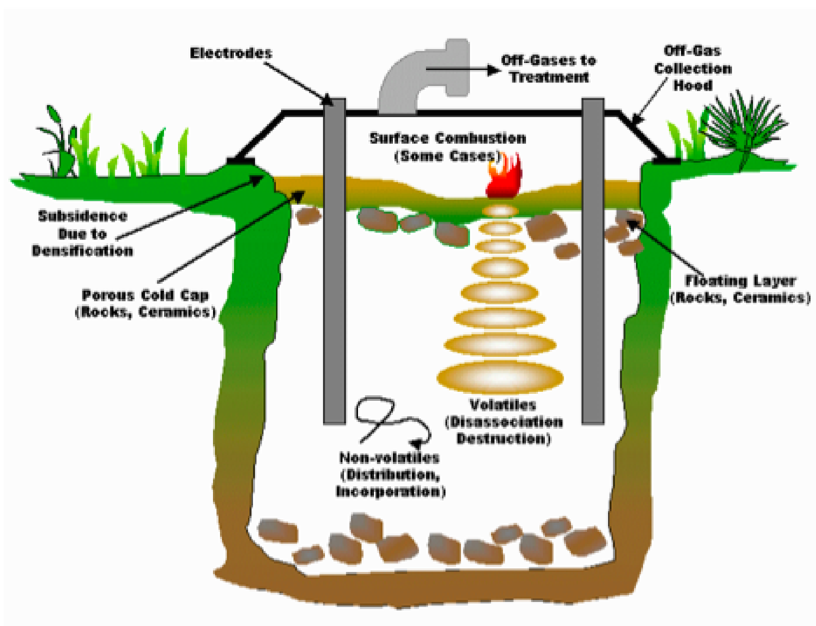


Figure 8: Typical In Situ Vitrification System

Soil & Groundwater Nanotechnology

Nanotechnology

Applications for Environmental Remediation

Nanoscale materials are increasingly being used with environmental remediation purposes. They are of special interest because of their high reactivity rate due to the large surface area to volume ratio and the presence of a larger number of reactive sites. Nanoscale materials may also reach small spaces in the subsurface.

The application of these materials in environmental remediation is site specific. The type of geology, as well as the type and distribution of contaminants will determine the type of material to be used and the method of injection.

Nanoscale materials could be applied using different remediation techniques. They could be applied using direct push technology, or via different types of wells; or used as the reactive materials in **Permeable Reactive Barriers**.

Soil & Groundwater Nanotechnology

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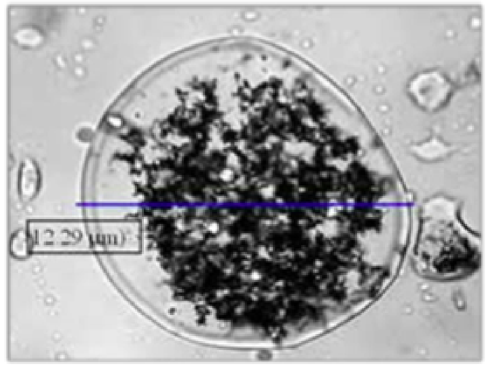
Emulsified Zero-Valent Iron (EZVI)



Technology: Nanotechnology

Manufacturer: Various

Process: In-situ, Physical/Chemical

Media: Groundwater, surface water

Contaminants: Chlorinated solvents
Nitroaromatics
Metals such as arsenic and chromium

Advantages:

- Variable specific gravity
- Can be manufactured with granular-, micro-, or nano-scale ZVI
- Small environmental footprint
- Reduce potential for contaminant rebound
- No heat generated during reaction
- No significant health and safety risks associated

Technology Overview:

EZVI consists of nano- or microscale ZVI surrounded by an emulsion membrane that facilitates treatment of chlorinated hydrocarbons. The exterior emulsion membrane is made from food-grade surfactant and biodegradable oil and the inside of the droplets contain water and the ZVI particles.

The exterior emulsion membranes are hydrophobic, similar to the properties of dense non-aqueous phase liquid (DNAPL) contaminants such as TCE. EZVI particles therefore mix directly with DNAPL. When the emulsion particles come into contact with TCE, TCE partitions into the oil membrane and then diffuses into the interior of the emulsion droplet, where it comes into contact with the ZVI and is degraded. A concentration gradient is established by migration of the TCE molecules into the interior aqueous phase of the emulsion droplet and by migration of the by-products out of the droplet and into the surrounding water phase, further driving the degradation reactions. The vegetable oil can also provide "food" (electron donors) to microorganisms and enhance biological activity, which in turn contributes to the destruction of the contaminant.

In addition, EZVI can be especially effective when DNAPL is present because DNAPL tends to be miscible in vegetable oil. When DNAPL contacts EZVI, the DNAPL can mix with the EZVI, after which the contaminants are in close proximity with the ZVI and can be effectively degraded.

Soil & Groundwater Nanotechnology

Nanotechnology

Nanoscale Zero-Valent Iron (nZVI)

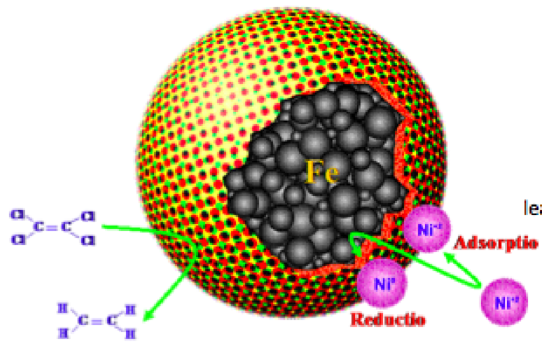
Technology: Nanotechnology

Manufacturer: Various

Process: In-situ, Physical/Chemical

Media: Groundwater, surface water

Contaminants: Chlorinated solvents
Nitroaromatics
Metals such as arsenic, chromium and lead
Legacy organohalogen pesticides



Advantages:

- High reactivity
- Cost-effective
- Small environmental footprint
- Degradation of a wide arrange of contaminants
- No health and safety risks identified

Technology Overview:

Particles of nZVI may range from 10 to 100 nanometers in diameter or slightly larger. Macroscale ZVI has been shown to be effective for treating groundwater contaminants within Permeable Reactive Barriers. Particles of nZVI provide the same environmental remediation benefits as macroscale ZVI but have larger surface areas per volume of material; this larger surface area provides more reactive sites allowing for more rapid degradation of contaminants when compared to macroscale ZVI. The nanoscale size of the iron particles also help to foster effective subsurface dispersion.

Soil & Groundwater Nanotechnology

Nanotechnology

Bimetallic Nanoscale Particles (BNP)

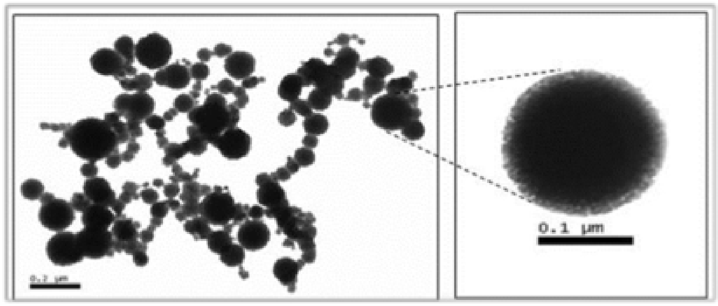
Technology: Nanotechnology

Manufacturer: Various

Process: In-situ
Physical/Chemical

Media: Soil and groundwater

Contaminants: DNAPLs
Heavy metals



Advantages:

- Cost-effective
- High reactivity due to large surface area
- High flexibility for remedial applications
- Exist ubiquitously in the natural environment
- No health and safety risks identified

Technology Overview:

BNPs consist of particles of elemental iron or other metals in conjunction with a metal catalyst, such as platinum, gold, nickel, and palladium. The combination of metals increases the kinetics of the oxidation-reduction (redox) reaction, thereby catalyzing the reaction. Palladium and iron BNPs are commercially available and currently the most common. In bench-scale tests, BNPs of iron combined with palladium achieved contaminant degradation two orders of magnitude greater than microscale iron particles alone: these particles were 99.9 percent iron and less than 0.1 percent palladium.

Palladium can catalyze the direct reduction of trichloroethene (TCE) to ethane without producing other intermediate by-products such as vinyl chloride. BNPs are generally incorporated into slurry for injection and can be injected by gravity or by pressure feed.

Soil & Groundwater Nanotechnology

Nanotechnology

Atomic Layer Deposition (ALD)

Preparation for Noble Gases Catalysts

Technology: Nanotechnology

Laboratory: University of Colorado – Technology Transfer Office

Process: In-situ, Physical/Chemical

Media: Groundwater, surface water and soil

Contaminants: Organic pollutants
Volatile organic compounds (VOCs)

Advantages:

- Increase the efficiency of photocatalyst TiO_2
- ALD method achieves the highly dispersed noble metal necessary to coat the TiO_2 particles, enabling it to be used as a photocatalyst to effectively break down toxic environmental contaminants.

Technology Overview:

Organic pollutants in wastewater streams and volatile organic compounds in the atmosphere have been increasing over the recent decades. Currently, semiconductor photocatalysts such as Titanium Oxide (TiO2), are used to minimize the effects of environmental pollution by detoxifying harmful organic materials. These photocatalysts are activated by UV light and break bonds in the contaminant to make it non-toxic. TiO2 provides many benefits in use, as it is low cost, non-toxic, and has the ability to degrade a broad range of pollutants. However, TiO2 is not used in environmental treatment because its low treatment efficiency prevents it from being used on a large scale.

At the University of Colorado, a research team led by Dr. Alan Weimer has developed a method of using Atomic Layer Deposition (ALD) to create noble metal nanoparticles on high surface area materials. The noble metal nanoparticles are of uniform size, and are evenly disbursed on the high surface area particle, as well as within in the pores of high surface area particles. This is a technical breakthrough considering that current methods have proven unsuccessful in reaching the inner pores of the mesoporous gel and have shown poor dispersion and distribution.

Contact: Lindsay Lennox
Assistant Director, Marketing/Communications
University of Colorado
Phone: 303-735-5518
E-mail: linday.lenox@cu.edu