

# STUDENT SUMMER INTERNSHIP TECHNICAL REPORT

## **Development of Case Study Examples for ITRC Remediation of Complex Sites Subgroup – DOE EM Headquarters, Germantown, MD**

### DOE-FIU SCIENCE & TECHNOLOGY WORKFORCE DEVELOPMENT PROGRAM

Date submitted:

September 30, 2015

Principal Investigators:

Christine Wipfli (DOE Fellow Student)  
Florida International University

Skip Chamberlain, Carol Eddy-Dilek, Mentors  
DOE EM-12 Office of Soil and Groundwater

Contributing Authors: Brian B. Looney (SRNL), Carol Eddy-Dilek (SRS)

Florida International University Program Director:

Leonel Lagos, Ph.D., PMP®

Submitted to:

U.S. Department of Energy  
Office of Environmental Management  
Under Cooperative Agreement # DE-EM0000598



**Applied Research Center**  
FLORIDA INTERNATIONAL UNIVERSITY

### **DISCLAIMER**

This report was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor any agency thereof, nor any of their employees, nor any of its contractors, subcontractors, nor their employees makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe upon privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any other agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

## **ABSTRACT**

---

This technical report consists of three case studies that were developed in conjunction with technical representatives of the Department of Energy's Office of Environmental Management (DOE-EM) and the Interstate Technology and Regulatory Council (ITRC) for inclusion in the ITRC Remediation Management of Complex Sites Case Studies. The case studies pertain to the remediation strategies utilized across complex sites throughout the U.S. The objective of these reports is to serve as guidance documents for public, as well as private sector employees, public stakeholders, regulators, and policy makers on the innovative tools and technologies being applied to various sites that face unique remediation challenges that categorize the site's status as "complex". The goal with generating these guidance documents is to share valuable techniques and expertise that have proven successful in assisting individual sites reach closure status. Additionally, the objective is to provide examples of remediation techniques that if proven successful under certain circumstances at one site, may potentially prove to be successful under similar conditions at other sites.

In implementing these successful strategies and techniques at various contaminated sites, the goal of the ITRC, as well as the DOE, is to return useable soil and groundwater to its beneficial uses wherever possible, within a reasonable timeframe given the individual circumstances of the site.

## TABLE OF CONTENTS

---

ABSTRACT.....	iii
TABLE OF CONTENTS.....	iv
LIST OF FIGURES .....	v
1. INTRODUCTION .....	1
2. EXECUTIVE SUMMARY .....	3
3. CASE STUDIES.....	4
Lawrence Livermore National Laboratory Case Study .....	4
1.0 Background.....	4
2.0 Technical Basis for Remedial Action .....	4
3.0 Decision(s) .....	5
4.0 Remedial Approach .....	5
5.0 Monitoring/Optimization .....	6
6.0 Regulatory and Stakeholder Involvement.....	7
Paducah Gaseous Diffusion Plant (PGDP) Groundwater Case Study ....	<b>Error! Bookmark not defined.</b>
1.0 Background.....	<b>Error! Bookmark not defined.</b>
2.0 Technical Basis for Remedial Action .....	<b>Error! Bookmark not defined.</b>
3.0 Decision(s) .....	<b>Error! Bookmark not defined.</b>
4.0 Remedial Approach .....	<b>Error! Bookmark not defined.</b>
5.0 Monitoring/Optimization .....	<b>Error! Bookmark not defined.</b>
6.0 Regulatory and Stakeholder Involvement.....	<b>Error! Bookmark not defined.</b>
SRS F-Area Seepage Basins .....	17
1.0 Background.....	17
2.0 Technical Basis for Remedial Action .....	19
3.0 Decision(s) .....	20
4.0 Remedial Approach .....	20
5.0 Monitoring/Optimization .....	21
6.0 Regulatory and Stakeholder Involvement.....	22
4. CONCLUSIONS.....	24
5. REFERENCES .....	25

## LIST OF FIGURES

---

Figure 1. Simplified depiction of primary PGDP groundwater contaminant source (C-400 Building) showing the fine over coarse lithology, DNAPL, and the resulting slow-release challenge. ....	<b>Error! Bookmark not defined.</b>
Figure 2. TCE plumes with concentration levels at the Paducah Site. ....	<b>Error! Bookmark not defined.</b>
Figure 3. Location of the F-Area Seepage Basins at the Savannah River Site. ....	18
Figure 4. Map showing distribution of tritium in 2014 in relation to seepage basins, funnel and gate treatment system, seepline and receiving stream. ....	19
Figure 5. Schematic cross section of F- area groundwater plume. ....	20
Figure 6. Cross Sections showing Hydrogeologic Conceptual Model (left) and Funnel and Gate System (right). ....	21

## 1. INTRODUCTION

---

In 1989 the Department of Energy's Office of Environmental Management (DOE EM) was established to manage the task of cleaning up radioactive and hazardous waste from over 50 years of nuclear weapons production and energy research from the Cold War era. The consequence of that era includes millions of gallons of liquid radioactive waste, millions of cubic meters of solid radioactive waste, thousands of tons of spent nuclear fuel and special nuclear material, along with huge quantities of contaminated soil and groundwater. To help ensure the safety and well-being of the public, the Office of Environmental Management took responsibility for one of the largest and most technically complex environmental cleanup missions in the world.

Since the year of establishment EM focused on identifying the status of each contaminated site, addressing the most urgent risks, characterizing the soils, groundwater, facility contamination, and nuclear waste materials. The organization is also responsible for maintaining safety at each site, negotiating state and federal environmental compliance agreements, and developing the infrastructure to treat, transport, and dispose of the large quantities of radioactive and hazardous materials. The overall objective of the agency is to reduce the contamination footprint by effectively managing the nuclear waste at each site in order to leave it in a safe and sustainable manner.

Under the Department of Energy's Environmental Management branch, the Office of Soil and Groundwater Remediation leads an enormous effort of implementing remediation strategies at the contaminated sites across the country. This Office is focused specifically on delivering approaches and technologies from highly leveraged and strategic investments that maximize the impact to reduce risk and life-cycle cleanup costs. The research portion of the program consists of four elements of applied field research initiatives: Deep Vadose Zone; Attenuation-Based Remedies for the Subsurface; Remediation of Mercury and Industrial Contaminants; and Advanced Simulation Capability for Environmental Management. The intent of these initiatives is to develop a wide variety of remediation strategies to address contamination at DOE sites from active engineered systems to natural attenuation to address DOE contaminants. These approaches are being integrated into a systems-based, risk informed, endpoint remediation framework that applies strategically across the DOE EM complex.

An integral part of the development of these remediation technologies and strategies is the sharing of this valuable and specific expertise across the industry. DOE EM participates in numerous workshops, conferences, seminars, councils, and coalitions in both the national and international realm, with counterparts from both the public and private sector. The objective of this involvement varies by topic, but one of the underlining goals of the Agency is to transfer knowledge and industry expertise.

An example of this knowledge transfer is DOE's involvement with the Interstate Technology and Regulatory Council (ITRC). The ITRC is a coalition between the public and private sector, working to encourage the use of innovative environmental technologies and approaches so that compliance costs are reduced and cleanup efficacy is maximized. The goal of the ITRC is to protect human health and the environment via the production of documents and training that

broaden technical knowledge and expedite quality regulatory decision making. The ITRC provides a very diverse perspective comprising of individuals from all 50 states and the District of Columbia; members include both public and private sector employees, regulatory and compliance officials, and public stakeholders to name a few. To address each topic of concern the coalition divides itself into smaller teams of the diverse member base. These teams meet regularly to produce pieces of these informative documents to be later condensed into a consolidated report or guidance document that can be shared with others through various outlets. DOE specifically sponsors a sub-group within the ITRC pertaining to complex sites in order to consolidate successful remediation strategies that were proven effective at these types of sites.

Generally speaking, a complex site is one where certain conditions exist that require extensive remediation efforts. Often times these efforts are unable to achieve designated groundwater remedial action objectives within a realistic time frame. The term “complex” when referring to sites is not a strictly defined term, therefore it can often be subjective at times. Overall, a complex site consists of complicating factors that make the soil and groundwater remediation process especially challenging, where a single conventional cleanup approach would not suffice. Examples of complicating factors can range from unique geologic, hydro-geologic, and lithological characteristics, to the extent and size of the contamination plume, to certain contaminants that when comingled behave differently than existing solitarily. Due to the complex nature of these sites, the remediation strategies must also be thoroughly investigated and tested in order to identify successful strategies that prove efficient in managing these problematic contamination plumes. Once successful remediation strategies are identified, the aim is to share this expertise with other parties so that all may benefit from this key information. The case studies contained in this report are examples of these shared success stories. Although the overall process for managing complex sites is long and rigorous, the ITRC complex sites subgroup aspires to create guidance documents that can speed up these remediation processes in a safe and effective manner.

Contained in this report are three ITRC case studies pertaining to complex sites within the United States and under the management of the DOE EM. Each case study intimately describes the characteristics of the site that identify it as a complex site. It also describes the remediation strategies selected and the results obtained. As previously stated, the goal of generating these guidance documents is to share valuable techniques and expertise that have proven successful at assisting individual sites reach closure status. It is also desired to educate all interested parties on innovative approaches utilized at different sites, which may not have ever been previously considered. Additionally, providing examples of unique remediation techniques may potentially provide a solution to other complex sites that share similar conditions.

The complex site case studies contained in this report include the following: the Lawrence Livermore National Lab located in Livermore, CA; the Paducah site located in Paducah, Kentucky; and the Savannah River Site located near Aiken, South Carolina.

## **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 Office of Environmental Management (DOE-EM) and Florida International University's Applied Research Center (FIU-ARC). During the summer of 2015, a DOE Fellow intern, Christine Wipfli, spent 10 weeks doing a summer internship at the DOE EM Headquarters at the Office of Soil and Groundwater Remediation, under the supervision and guidance of Skip Chamberlain, Project Manager; Carol Eddy-Dilek, Lead SRNL Research Scientist; and Kurt Gerdes, Office Director. The intern's project was initiated on June 1, 2015, and continued through August 7, 2015 with the objective of gaining valuable insight into the daily operations of the Office of Soil and Groundwater Remediation and to assist in drafting case studies for the ITRC complex sites subgroup.



### 3. CASE STUDIES

---

-----LAWRENCE LIVERMORE NATIONAL LAB-----

## Lawrence Livermore National Laboratory Case Study

### 1.0 Background

**Lawrence Livermore National Laboratory (LLNL)** is a federal research facility located within Livermore, California, encompassing an area of one square mile. Currently the site is owned by the U.S. Department of Energy (DOE) and operated by Lawrence Livermore National Security, LLC, a partnership between the University of California, URS, Bechtel, Babcock & Wilcox and Battelle Memorial Institute.

The site was first used as a Naval Air Station in the 1940s; in the 1950s, it was converted to a nuclear weapons and magnetic fusion energy research facility operated by the U.S. Atomic Energy Commission. During this time, the research and operations at LLNL involved the generation and management of radioactive and hazardous materials. As a consequence of these activities, the surrounding soil and groundwater systems were exposed to hazardous and radioactive chemicals, resulting in contamination of the underlying groundwater with Volatile Organic Compounds (VOCs), chromium, lead, tritium and fuel hydrocarbons including benzene and ethylene dibromide. Excavated soil was found to contain solvents, radioactive wastes, heavy metals, polychlorinated biphenyls (PCBs), and fuel hydrocarbons. On-site soil contains VOCs, tritium, PCBs, fuel hydrocarbons, and inorganic substances.

LLNL was added to the National Priorities List (NPL) in 1987 and is addressed as a Federal Facility with DOE as the lead agency. The Environmental Protection Agency (EPA), California Department of Toxic Substances Control (DTSC) and San Francisco Bay Regional Water Quality Control Board (RWQCB) are signatories to the Federal Facility Agreement (FFA).

### 2.0 Technical Basis for Remedial Action

Investigative studies at the LLNL site and in the vicinity were initiated as early as 1979, and included geologic, seismologic, and hydrologic site characterization. Remedial Investigations (RI) have been completed at each of the LLNL waste sites to characterize the contamination at each potential source area and throughout the underlying groundwater. Quarterly groundwater quality assessments have been performed since 1983.

Volatile organic compounds are present at relatively low concentrations in diffuse plumes in the groundwater beneath about 85 percent of the 1.4 square mile LLNL site. The calculated volume of VOCs in the groundwater is estimated to be less than 200 gallons. In the saturated zone, although downward vertical gradients exist over much of the site, the lithological conditions significantly impact downward migration of volatile organic compounds.

The primary health threat at LLNL is contaminated drinking water to nearby residents. Approximately 50,000 people live within a 2 mile radius of the site. Two miles west of the site in downtown Livermore, the groundwater is used as a municipal drinking water source. There is a possible health risk for people ingesting or coming into direct contact with contaminated water or soil.

### **3.0 Decision(s)**

Due to plume migration, in 1984 the California Department of Health Services (CDHS) released an Order for Compliance for LLNL to provide alternative water supplies to residents whose wells were contaminated by hazardous substances.

To prevent further plume migration, in 2012 DOE constructed a pipeline to transport groundwater from an off-site location where the plume had migrated, to an on-site treatment facility in order to contain the remaining contamination.

Various approaches to treat groundwater and unsaturated sediment contamination were evaluated in the Feasibility Study (FS) and in the Proposed Remedial Action Plan (PRAP). DOE and LLNL evaluated several viable remedial options to meet EPA cleanup standards which were eventually implemented as either an initial action taken or part of an ongoing cleanup effort at the site. The initial action was to remove contaminated soil, and the ongoing action was to treat the remaining soil and groundwater.

In 2007 LLNL began an optimization phase for groundwater cleanup. Technologies are being evaluated to speed the cleanup of VOCs, augment the existing extraction and treatment facilities in-situ, including ethyl lactate, hydro-fracking and zero valent iron emplacement, as well as to isolate the tritium.

In 2008, DOE shut down or failed to repair 28 groundwater and soil vapor treatment facilities due to budget cuts. On Jan. 6, 2009 EPA took an enforcement action against DOE which was settled in March 2009. During 2009, DOE brought the shuttered facilities back into operational status. In 2010 DOE began a Focused Feasibility Study (ongoing) to determine the best way to treat and dispose of groundwater with both hazardous and radioactive contaminants (mixed waste). In summer 2012, DOE constructed a pipeline to transport groundwater from an offsite plume which is currently being captured back to a treatment facility onsite.

In 2014, DOE signed an Explanation of Significant Differences adding and implementing Institutional Controls to the remedy with respect to the off-site groundwater plumes. EPA concurred with the decision.

### **4.0 Remedial Approach**

The initial action taken to reduce soil and groundwater contamination levels was to remove 18,000 cubic yards of contaminated soil from waste disposal pits and relocate off-site to hazardous waste disposal facilities.

Soil and groundwater treatment systems were installed at 18 locations across the site, including source areas. Groundwater Extraction wells pump groundwater to above-ground treatment facilities where they effectively remove dissolved chemicals. At LLNL seven different water treatment facilities were built; four use ultraviolet light and oxidation as the primary treatment process and the other three use air stripping treatment systems. The pump and treat systems also provide hydraulic control of the groundwater plume thereby preventing or slowing the migration of contaminants to the site boundary. After treatment, the clean water is then pumped back into the subsurface. The initial FS estimated an expected timeframe of 50 years to reduce residual groundwater contaminants to below maximum contaminant levels (MCLs). The present-worth cost of this alternative was \$103 million.

A Soil Vapor Extraction (SVE) system was also installed on-site. SVE applies a vacuum to the unsaturated sediment zone through extraction wells in order to draw contaminated vapors toward the wells to be treated. Cleanup was estimated to take about 10 years to complete with a present-worth cost of \$1.84 million. Additional vadose zone modeling increased the rate at which contaminated vapors in the soil were treated in that system. Innovative technology has been used to focus and optimize remedial actions. Three dimensional characterizations of the subsurface and the use of Portable Treatment Units (PTUs) have allowed engineers to address water-bearing units for easier plume capture through targeted pump and treat. Advanced vadose zone modeling has helped improve mass removal rates of soil contamination by increasing the effectiveness of the SVE system. Catalytic Reductive Dehalogenation (CRD) was another technology used to treat VOCs in groundwater that is also contaminated with tritium. The tritiated groundwater remains in the subsurface and undergoes natural radioactive decay.

## **5.0 Monitoring/Optimization**

The removal of contaminated soil, the pump and treat systems, and the soil vapor extraction system significantly reduced potential exposure to contamination. All of the soil and groundwater treatment systems will continue to operate until cleanup target levels are achieved.

Additionally, in-ground (in-situ) treatments were investigated to increase the rate at which the existing extractions and treatment systems operate. The techniques being investigated include ethyl lactate, hydro fracking, and zero valent iron emplacement, in another effort to isolate tritium.

Nearby surface water bodies including lakes, ponds, streams, seeps, etc., located in and around the LLNL site will continue to be monitored under the environmental restoration and environmental protection monitoring programs. The samples collected from these surface water bodies are analyzed for gross alpha and beta radiation, tritium, and nonradioactive pollutants including various solvents, metals, and pesticides.

## 6.0 Regulatory and Stakeholder Involvement

The Department of Energy is the lead agency at LLNL, responsible for monitoring the status of the contamination on- and off-site, in addition to managing all of the remedial activities. Their work is overseen by the EPA and the state of California.

### -----PADUCAH SITE-----

## Paducah Gaseous Diffusion Plant (PGDP) Groundwater Case Study

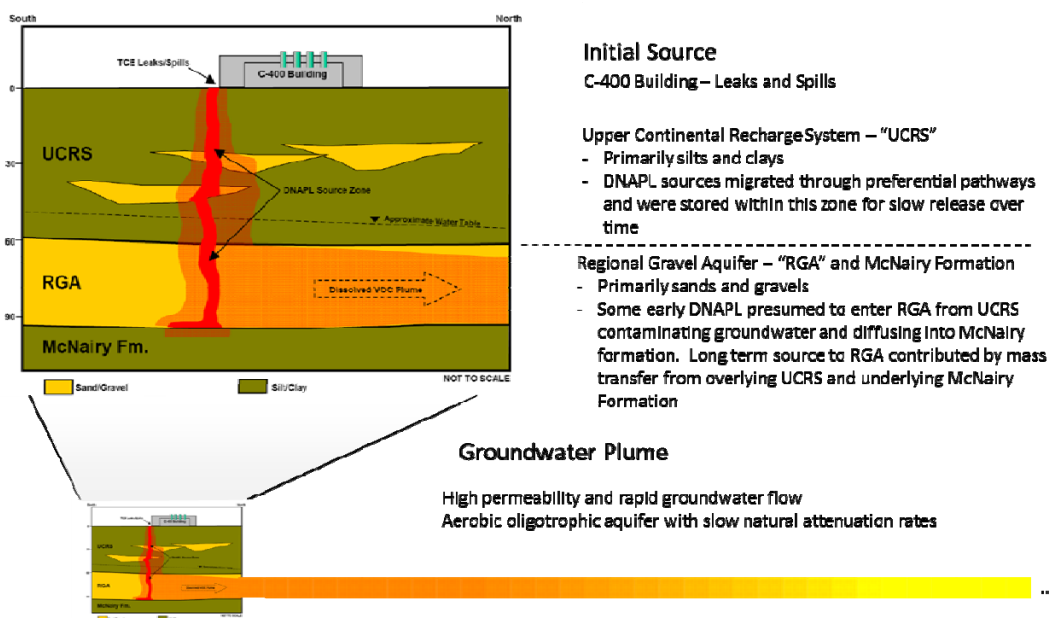
### 1.0 Background

The U.S Department of Energy's Paducah Site is located in McCracken County, Kentucky, approximately 10 miles west of the city of Paducah. Within the 3,556 acre site is the Paducah Gaseous Diffusion Plant (PGDP). The PGDP comprises over 500 facilities with 19 miles of roadway and 5 miles of fence. The Plant was constructed in the 1950s as a uranium enrichment facility for the fabrication of fuel assemblies to support commercial and military nuclear reactors, as well as weapons development. Four large cascade process buildings that enriched uranium by the gaseous diffusion process, served as the hub of PGDP until the termination of the commercial uranium enrichment process in 2013. A private company United States Enrichment Corporations (USEC) handled commercial operations until the cessation in 2013, after which the Department of Energy (DOE) has retained primary control of the facilities.

Environmental monitoring at the PGDP identified contaminant plumes in groundwater extending to off-site locations. These plumes are characterized by the volatile organic compound (VOC) trichloroethene (TCE) and the radionuclide technetium 99 (<sup>99</sup>Tc).

In general, PGDP groundwater meets a number of criteria for complex sites including: the extensive scale of the plume, multiple contaminants and contamination sources, heterogeneous geologic conditions, and contaminants that have migrated off-site. Of these criteria, the primary site-specific technical complexities are related to: a) strong source term (including dense non-aqueous phase liquids, DNAPLs), b) multiple contaminants (TCE and <sup>99</sup>Tc), and c) a challenging scenario of geological heterogeneity – the presence of lower permeability fine-grained sediments in the vadose zone and shallow groundwater overlying and high permeability aquifer (Figure 1). This particular geological scenario significantly impacts the performance of alternative remediation strategies and is representative of a number of contaminated sites throughout the US. At PGDP, the lower permeability Upper Continental Recharge System (UCRS) overlies the high permeability zone Regional Gravel Aquifer (RGA). Contamination moves downward through the UCRS and feeds into the RGA. Some contaminant migrates through relatively direct transport pathways and can enter the RGA in concentrated form. However, a significant amount of contaminant is held up in the UCRS, resulting in a long-term source as contaminants slowly

leach to the RGA. Once contaminants enter the RGA, the plume rapidly migrates laterally down gradient. Thus, the UCRS vadose zone acts as a reservoir for contaminants that discharge (similar to a capacitor or a battery) over an extended timeframe.



**Figure 1. Simplified depiction of primary PGDP groundwater contaminant source (C-400 Building) showing the fine over coarse lithology, DNAPL, and the resulting slow-release challenge**

A “groundwater project team” comprising the Department of Energy (DOE), the US Environmental Protection Agency (EPA) and the Commonwealth of Kentucky Department of Environmental Protection (KDEP), supported by technical resources from universities, national laboratories, and contractors, is working together to address the groundwater contamination. In response to the site specific complexities, a PGDP groundwater project team has emphasized a strategy that focuses on source removal from the UCRS (and RGA), hydraulic capture, and long term monitored natural attenuation. The resulting remedial activities include a groundwater pump and treat system, an interim action to implement thermally enhanced extraction, and research studies to quantify natural attenuation.

## 2.0 Technical Basis for Remedial Action

The groundwater underlying PGDP is contaminated by VOCs, principally TCE (Figure 3) and other constituents such as  $^{99}\text{Tc}$ . TCE was released as a DNAPL to the subsurface as a result of facility operations that began in 1952. Diffusion of the high-strength contamination into less permeable zones over the long contamination timeframe resulted in “loading” these zones, forming secondary sources that slowly “unload” after the primary contamination source is removed. As shown in Figure 2, the area that includes the C-400 Cleaning Building and nearby facilities such as the former cylinder drop test area, and burial grounds is coincident with the highest TCE concentrations and is the centroid of the groundwater plumes at PGDP. This locality represents a dominant historical and current source of TCE solvent contributing to the PGDP groundwater plume(s).

The subsurface in the vicinity of the C-400 Cleaning Building (Figure 2) has three relevant hydrogeologic zones: 1) the UCRS, about 0-65 feet deep; 2) the RGA, about 65-87 feet deep; and 3) the underlying McNairy Formation, greater than about 87 feet deep. Groundwater (the “water table”) is at a depth of about 34 feet and occurs within the lower UCRS. Near the C-400 Building, DNAPL has been identified both above and below the water table in the UCRS, in the RGA, and in the upper portion of the McNairy Formation (Figure 2). Following downward transfer of TCE from the source zone in the UCRS, the dissolved phase plume is transported laterally by groundwater flow primarily in the RGA, which is much more transmissive than the overlying UCRS or underlying McNairy Formation.

Consistent with the site specific conditions, the FFA core team recognized that a combination of technologies (a “combined remedy”) will be needed to most effectively and efficiently address the varying conditions within the plumes. These technologies include targeted actions to: interdict and provide hydraulic control for the dissolved plume down gradient of the source, remove the primary and secondary DNAPL source materials in the vicinity of Building C-400, and quantify natural attenuation and inform future groundwater-related environmental management decisions. Throughout the remediation period, a number of innovative/emerging technologies were tested to determine their applicability to overcome PGDP complexities. As appropriate, these technologies were deployed full scale and the resulting progress toward PGDP groundwater end-state goals has been supported by combining standard technologies and innovative technologies. The specific combination of technologies that were tested and selected/applied, as well as the measured performance of those technologies is described in the following sections.

### **3.0 Decision(s)**

The groundwater cleanup at PGDP is part of a larger environmental effort that also addresses contaminated soil, sediments, and former burial grounds. The process for managing these activities is governed by a Federal Facilities Agreement (FFA) negotiated between DOE, EPA, and the Commonwealth of Kentucky, created in 1996. The purpose of the FFA is to define a set of consistent requirements for achieving comprehensive site remediation in accordance with the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Under the FFA an outline was established to achieve cleanup targets and to work toward an agreed PGDP site end state. These targets and strategic goals are described in the annual Site Management Plan (SMP)<sup>5</sup>, End State Vision, and related documents.

Hydraulic Control - Early responses to identification of contaminated PGDP groundwater in 1988, focused on mitigating and eliminating potential exposure pathways. At that time, DOE placed affected areas on an alternate water supply, replacing contaminated drinking water wells. In 1993, DOE prepared two cleanup plans (RODs) to directly address contaminated ground water. A key early action in the RODs was to install a pump and treat system to provide hydraulic control on both of the major PGDP plumes, the Northwest Plume and the Northeast Plume. These systems were constructed and placed into operation in 1995 and 1997, respectively. The pump and treat systems have interdicted the Northwest and Northeast Plumes

and reduced the amount of contamination migrating down-gradient. Periodic adjustments have been made to optimize the pump and treat operations over time. For example, in August 2010, the NW Plume pump and treat system was modified (two new recovery wells were installed and two existing recovery wells were taken out of service) to refocus the recovery zone and to increase the contaminant mass removal – following optimization, the Northwest Plume pump and treat is projected to recover more than 90% of the mass discharging from the C-400 Building source area. A similar optimization effort for the Northeast Plume pump and treat system is ongoing. Operation and monitoring of the pump and treat systems continues under the oversight of the PGDP core team. Any future modifications to pump and treat operations/strategies (pumping rates, locations, collateral impacts, and criteria for turn-off) will be determined by the core team based on monitoring data and groundwater modeling.



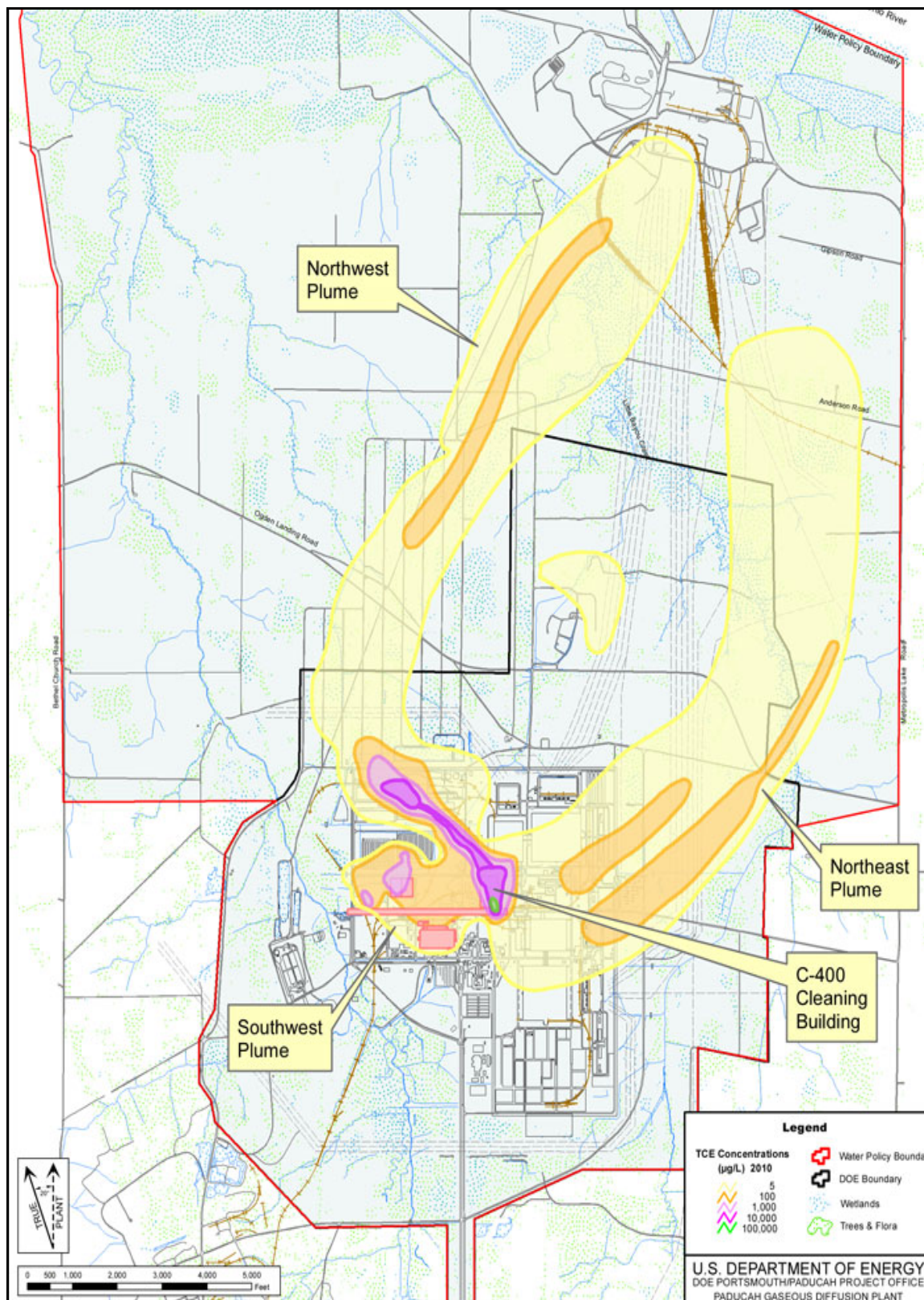


Figure 1. TCE plumes with concentration levels at the Paducah Site.



Implementation of innovative technologies related to hydraulic control of groundwater have generally been limited to system optimization efforts (pumping locations and strategies and improvements in the treatment processes), and improvement of characterization/monitoring and modeling/visualization approaches.

### Source Zone

Because of the site specific contaminant and challenging hydrologic conditions, removal of primary and secondary sources in the vicinity of the C-400 Cleaning Building has been a primary focus of DOE and the FFA core team. A number of innovative approaches were tested to determine which technology (or technologies) will effectively remove the contaminants from the lower permeability UCRS and from the most contaminated areas of the RGA and underlying McNairy Formation. Promising technologies were and deployed at pilot and production scale to reduce the source term. Electro-thermal and thermal enhanced removal techniques are of particular utility at PGDP to remove source contamination from the UCRS, thus limiting future mass discharge to the RGA.

In early technology testing (1990s), Monsanto, GE, and DuPont developed an electro-thermal remediation process (Lasagna), which exemplifies a class of technologies that applies electrical energy to the subsurface to accelerate contaminant removal and/or destruction. Lasagna creates an electric field underground via the installation of layered anode and cathode electrodes. The resulting electric currents create osmotic gradients and induce the movement of water through defined treatment zones containing a treatment material such as zero-valent iron. Another effect of the electric current is elevated soil temperature (due to resistive heating) which is beneficial in mobilizing contaminants for treatment or collection. Pilot studies for this technique were deployed in 1995 and 1996 at the Cylinder Drop Test Area (SWMU 91). The pilot studies demonstrated an average TCE cleanup effectiveness of 95%. The pilot studies also identified a number of advantages of the method: the infrastructure is left in place after the project is completed, there is minimal/no extraction equipment needed, and operations and maintenance costs are low. This system is installed using a sheet pile technique resulting in minimal waste generation during installation. Lasagna was selected as a full-scale remedy for source TCE at SWMU 91 and was the technology was deployed, operating from December 1999 through December 2001. The technology was applied to approximately 10,000 cu yds. of low permeability contaminated UCRS soil containing up to 1,500 mg/kg (DNAPL levels) of TCE. The pilot and full scale systems reduced the TCE soil concentration in the highest areas from 1,500 mg/kg to 4.5 mg/kg; average TCE soil concentrations were reduced from 84 mg/kg to 0.38 mg/kg. The full scale technique proved to be more than 90% effective in reducing source TCE, achieving regulatory objectives, and reducing costs by approximately 1/3 compared to the identified alternatives.

Similar to SWMU 91, an energy based remediation technology, Electrical resistive heating (ERH), was initially identified for remediating the primary and secondary source contamination directly associated with Building C-400. This technology heats the subsurface by applying an electric current between electrodes installed in the target volume. Heat is generated from the resistance to current flow increasing the vapor pressure and volatility of solvents such as TCE.

Volatilized contaminants are captured using soil vapor extraction (SVE) wells along with groundwater/steam extraction wells. In 2003, PGDP performed a small-scale pilot test of ERH and demonstrated that significant amounts of TCE mass could be removed from both the UCRS and the RGA near Building C-400; however, the high hydraulic conductivity in some portions of the RGA (i.e., about 425 feet/day) limited the ability to heat the base of the aquifer because of the inflow of water. The pilot test results highlighted the need to carefully design ERH for PGDP to make sure all parts of the RGA can be heated to target temperatures (especially the RGA-McNairy interface in locations where TCE penetrated to the bottom of the RGA and into the upper portion of the McNairy).

Based on the success of the pilot demonstration, the FFA Core Team identified ERH for the full-scale source removal at the C-400 Cleaning Building. The action is being performed as a Comprehensive Environmental Responsibility Compensation and Liability Act (CERCLA §121) Interim Action. The FFA Core Team has emphasized the C-400 CERCLA Interim Action to mitigate the dominant contaminant sources in the UCRS, RGA and McNairy; the CERCLA Interim Action is a crucial component and an early focus of PGDP groundwater activities. According to the Record of Decision (ROD), the C-400 CERCLA Interim Action has the following remediation goals and expectations:

- It will contribute to the final remediation of the Groundwater OU by removing a significant portion of the contaminant mass of TCE and other VOCs at the C-400 Cleaning Building.
- It will reduce the period of time that TCE concentration in groundwater remains above its Maximum Contaminant Level (MCL), and meets the statutory preference for attaining permanent solutions through treatment.
- It is not expected to meet the MCL in groundwater for TCE, but satisfies the requirements set forth in 40 *CFR* 300.430(f)(1)(ii) for interim measures that will become part of the total remedial action that will attain applicable requirements (ARARs).
- It will be cost-effective based upon the estimates available at the time of the ROD.
- It will permanently remove a significant portion of the TCE near the C-400 Cleaning Building area through treatment, but will result in hazardous substances, pollutants, or contaminants remaining on-site at levels precluding unlimited use and unrestricted exposure.
- It meets CERCLA's preference for remedies that employ treatment as a principal element of the remedy that permanently and significantly reduces toxicity, mobility, or volume of hazardous substances, pollutants, or contaminants.

To ensure optimum performance, the ERH interim action for the VOC source removal in the vicinity of the C400 Cleaning Building was performed in phases. Phases IA and IB heated the UCRS and RGA, respectively, adjacent to the southeast corner of the C-400 Cleaning Building. The Phase IA and IB ERH treatment was performed and completed in 2010. A post-operational review of the performance of Phase IA ERH indicated that the technology had effectively heated the UCRS and removed the associated source VOCs; however, the data from Phase IB in the RGA indicated that ERH underperformed in the highly permeable formation and did not heat to target temperatures in the lower part of the aquifer. Based on the Phase I data, the PGDP groundwater project team recommended proceeding with the ERH in the UCRS in the southwest

corner of the C-400 Cleaning Building (Phase IIA) and developing an alternative strategy to address the relatively significant RGA source in that area (Phase IIB). The Phase IIA ERH treatment in the UCRS was performed and completed in 2014 and 2015. Two alternative technologies are being considered for Phase IIB, in situ chemical oxidation (a chemical destruction method) and steam enhanced extraction (a thermal method that has the potential for improved performance in a permeable aquifer compared to ERH). Preliminary plans for both alternatives have been developed. A pilot test of steam injection to assess the viability of the technology for Phase IIB has been completed and results are being evaluated by the groundwater project team.

Finally, a separate CERCLA removal action is underway to remediate VOC sources associated with a 2.2-acre former oil landfarm area. The remedy for the landfarm area is deep soil mixing. The source removal/treatment makes use of an eight-foot in diameter auger to mix soil to a depth of roughly 60 feet in the cleanup area located in the southwestern part of the Site's fenced boundary. Steam will be injected through the auger to remove TCE which will be recovered at the surface and captured in a treatment system. The system is also capable of blending treatment reagents, such as reactive zero-valent iron particles with the soil to chemically break down any residual VOCs.

Based upon current information, the majority of the VOC source material will have been removed from PGDP soil and groundwater following completion of all of the phases of the interim action and related decontamination and decommissioning activities for the C400 Building, the Lasagna implementation at SWMU 91, and the soil mixing at former landfarm area.

#### Monitored Natural Attenuation

Coupled with hydraulic control and source removal, monitored natural attenuation is integral to effective long-term environmental management of the PGDP groundwater. In 2007, a TCE Fate and Transport project scoping team (including regulators, DOE, and technical support organizations) was assembled to coordinate a study of the migration of TCE and controlling processes in the groundwater at PGDP. This team focused on the important site-specific degradation and attenuation processes that impact the fate of TCE in PGDP plumes and TCE degradation rates for these processes.

Recent and emerging data from diverse sites across the U.S. (e.g., the Test Area North Site at the Idaho National Laboratory) suggest that co-metabolism can be a significant TCE degradation mechanism in aerobic oligotrophic (low nutrient) contaminant plumes such as PDGP. The PGDP aerobic co-metabolism assessment was conducted in the Northwest Plume. This assessment was based on enzyme activity probe (EAP) assays supplemented by multiple lines of supporting evidence, including molecular characterization techniques, stable carbon isotope analysis, and geochemical measurements for ten RGA wells that are located along the plume centerline and 2 control wells located outside the footprint of the Northwest Plume. The various EAP assays each provide a clear, definitive fluorescent signal if a particular "oxygenase" enzyme is active at the time of analysis. The assays test either for the enzyme that oxidizes methane (soluble methane mono-oxygenase, sMMO) or for one of a suite of enzymes that oxidize aromatic compounds

(e.g., toluene oxygenases). The specific enzymes that are targeted with EAPs are representative of those that have been documented to break down TCE. Such enzymes result in degradation and subsequent mineralization of TCE to end products such as carbon dioxide and chloride ions. If detected, the enzymes are active and capable of co-metabolic degradation of TCE.

For the tested wells: 80% showed significant presence of toluene oxidizers, 50% showed significant sMMO activity, and 90% showed at least one type of oxidizing capability. The data indicated that aerobic co-metabolic activity is occurring throughout the Northwest Plume at PGDP and is contributing to the attenuation of TCE. The positive EAP responses in the control wells from outside the plume suggest that there is a widespread potential for the aerobic degradation of TCE. The geochemistry throughout the PGDP Northwest Plume was spatially variable, but all of the wells had geochemical conditions that are generally consistent with those required for aerobic co-metabolism. Supplementary data confirmed that the groundwater sampled and analyzed for enzyme probe activity primarily represents the groundwater plume (i.e. formation water), rather than micro-communities present in specific and/or individual well casings, or biofilms present therein. In general, the MNA study indicated that:

- Bacteria capable of aerobically biodegrading TCE are present in the Northwest Plume at PGDP.
- The number and distribution of bacteria appear sufficient to contribute to the biodegradation of TCE in RGA groundwater.
- The microbial community appears to be stable and sustainable
- The previously-estimated degradation rates for PGDP are consistent with the published literature for aerobic co-metabolism in large aerobic plumes, with a half-life in the range of 9 to 25 years. A site specific study of degradation rates was recommended by the TCE Fate and Transport project scoping team.

#### **4.0 Assessment**

The overall objective of DOE and the groundwater project team is to remove/mitigate ongoing sources and to remediate the groundwater to target contaminant concentrations. Toward this end, DOE and the supporting contractors at Paducah have made extensive efforts to control contaminated groundwater and to identify, investigate and remediate sources of groundwater contamination. A successful strategy for PGDP groundwater, similar to other large complex sites, involves using a “Combined Remedy” that employs a number of synergistic technologies to most effectively achieve the remediation objectives. In the case of PGDP, the technologies focused on hydraulic control (groundwater pump and treat), source removal/destruction (Lasagna, six phase heating, chemical oxidation or steam enhanced extraction, and deep soil mixing), and natural attenuation. The remediation efforts to date have removed the major contaminant sources and partially mitigated the migration of the groundwater plumes. Efforts to understand and control the plumes continue. For example, a study of the potential vapor intrusion into nearby structures was recently completed; this study deemed that the vapor intrusion pathway is “not complete” due to the low permeability UCRS separating the groundwater plume from receptors. Additional studies of the down-gradient seep areas (along Little Bayou Creek) are planned to better understand the distal portions of the groundwater plumes. Finally, actions to stabilize remaining burial ground areas (continuing through the mid-

2020s) are planned. These activities will further reduce potential sources and impacts to PGDP groundwater.

The predominant contaminants of concern in PGDP groundwater are VOCs (primarily TCE). Table 1 provides an estimate of TCE mass removed by the various remediation actions through March 31, 2015.

**Table 1. Cumulative VOCs removed from subsurface plume and source areas through March 2015 (gal)\***

Northwest Plume Pump-and-Treat	3,339**
Northeast Plume Pump-and-Treat	292**
C-400 Six-Phase Treatability Study	1,900
C-400 Phase I	535
C-400 Phase IIa and Phase IIb	1,137
Dissolved-Phase Plume	N/A
Southwest Plume***	0
SWMU 4***	0
Other sources (i.e., SWMU 91, LASAGNA™)	246
-----	
Total	7,449

\*VOC values are primarily TCE and include liquid VOCs and VOCs on carbon.

\*\*Cumulative through December 31, 2014.

\*\*\*No remedial action tabulated to date.

## 5.0 Monitoring/Optimization

The cleanup of PGDP groundwater contamination involves a number of innovative and standard technologies that target the contaminant sources and the groundwater plume. Standard groundwater monitoring, supplemented by special studies, is used to identify technologies, design treatment systems, and monitor remedial progress.

The PGDP groundwater project team and DOE have focused on periodic optimization – for example making several adjustments to the ground water treatment system in the early 2000s to increase efficiency. Additional improvements to the existing hydraulic control (pump and treat systems) to better control the potential for offsite migration of groundwater contamination are in progress. In the case of ERH, a phased implementation was used to help determine if the technology could effectively treat the permeable RGA – based on the data collected during Phase IB, the treatment technology for Phase IIB is being modified to provide improved performance in the highly contaminated lower portion of the aquifer.

## 6.0 Summary of Alternatives

PGDP has employed a “Combined Remedy” strategy that provides hydraulic control, source removal and natural attenuation. The technologies selected for inclusion include both standard and innovative approaches. A key site-specific complexity that the selected technologies must

address is the geologic setting of a low permeability interval overlying a highly permeable regional aquifer. In some cases, this requires a different technology to be used for the near-field vadose zone and shallow groundwater versus the deeper regional groundwater. Based on these conditions, the PGDP groundwater project team has prioritized interim actions that focus on source removal to reduce the future reservoir of contamination feeding the RGA.

## **7.0 Regulatory and Stakeholder Involvement**

Since the initial discovery of site contamination, DOE, EPA and the Commonwealth have been working with the community to develop a long-term cleanup plan for the site. Outreach efforts have included public notices, interviews and public meetings. PGDP representatives have also held environmental workshops to inform the community of any upcoming public meetings about proposed future cleanup plans for the site. DOE also commissioned a Citizens Advisory Board (CAB) , which meets monthly to discuss cleanup activities and potential health issues associated with past operations and disposal activities at the site. The purpose of the organization is to keep local citizens up to date on site cleanup progress and related issues. Both EPA and KDEP participate in CAB activities.<sup>1</sup>

Through the Federal Facilities Agreement and groundwater project “core” team, DOE and their PGDP contractor/support organizations working with regulators and stakeholders to address soil and groundwater contamination, and to develop a risk-based end-state goal for the site (DOE, 2005).

-----SAVANNAH RIVER SITE-----

## **SRS F-Area Seepage Basins**

### **1.0 Background**

**The Savannah River Site (SRS)**, a 310 square mile (803 square kilometer) site, owned and operated by the Department of Energy, is located in South Carolina, southeast of Augusta, Georgia. The site was built during the 1950s to produce the basic materials used in the fabrication of nuclear weapons, primarily tritium and plutonium-239. Currently, a major focus at SRS is cleanup activities associated with the production of nuclear materials.

The F-Area Hazardous Waste Management Facility at SRS consisted of three unlined, earthen surface impoundments referred to as seepage basins (Figure ). From 1955 through 1988, the F-Area seepage basins (FASB) received approximately 1.8 billion gallons (7.1 billion liters) of low-level waste solutions originating from the processing of uranium slugs and irradiated fuel in the F-Area Separations Facility. The effluents were acidic (wastewater with nitric acid) and low activity waste solutions containing a wide variety of radionuclides and dissolved metals (Killian et al., 1987; Cummins et al., 1991). After entering the basin, the wastewater was allowed to evaporate and to seep into the underlying soil and layered Coastal Plain sediments. When the FASB were constructed, the conventional belief was that most of the radionuclides would be bound in the soils beneath the basins and would not pollute groundwater. Though the seepage

basins essentially functioned as designed, the acidic nature of the basin influent caused mobilization of some metals and radionuclides resulting in groundwater contaminant plumes. This was true for many radionuclides including plutonium isotopes and cesium-137 (Cs-137), but many such as strontium-90 (Sr-90), uranium isotopes, iodine-129 (I-129), technetium-99 (Tc-99), and tritium migrated to the groundwater. Currently, the main risk drivers for the groundwater are Sr-90, uranium isotopes, I-129, Tc-99, tritium, and nitrate. The pH of the groundwater within the plume is as low as 3.2 near the basins and increases to the background pH of 5.5–6 at the plume fringes and up-gradient of the basins. Figure shows the distribution of tritium in 2014 in relation to seepage basins, funnel and gate treatment system, seepage line and receiving stream.

The geochemical complexity of both the impacted zone and comingled plume constituents provide the greatest challenges to efficient and effective remediation activities. The low acidity of the impacted groundwater contributes significantly to increased mobility of metals and radionuclides. The diversity of the comingled radiologic, cationic and anionic species in the plume requires multiple remedial strategies to address the full range of contaminants.

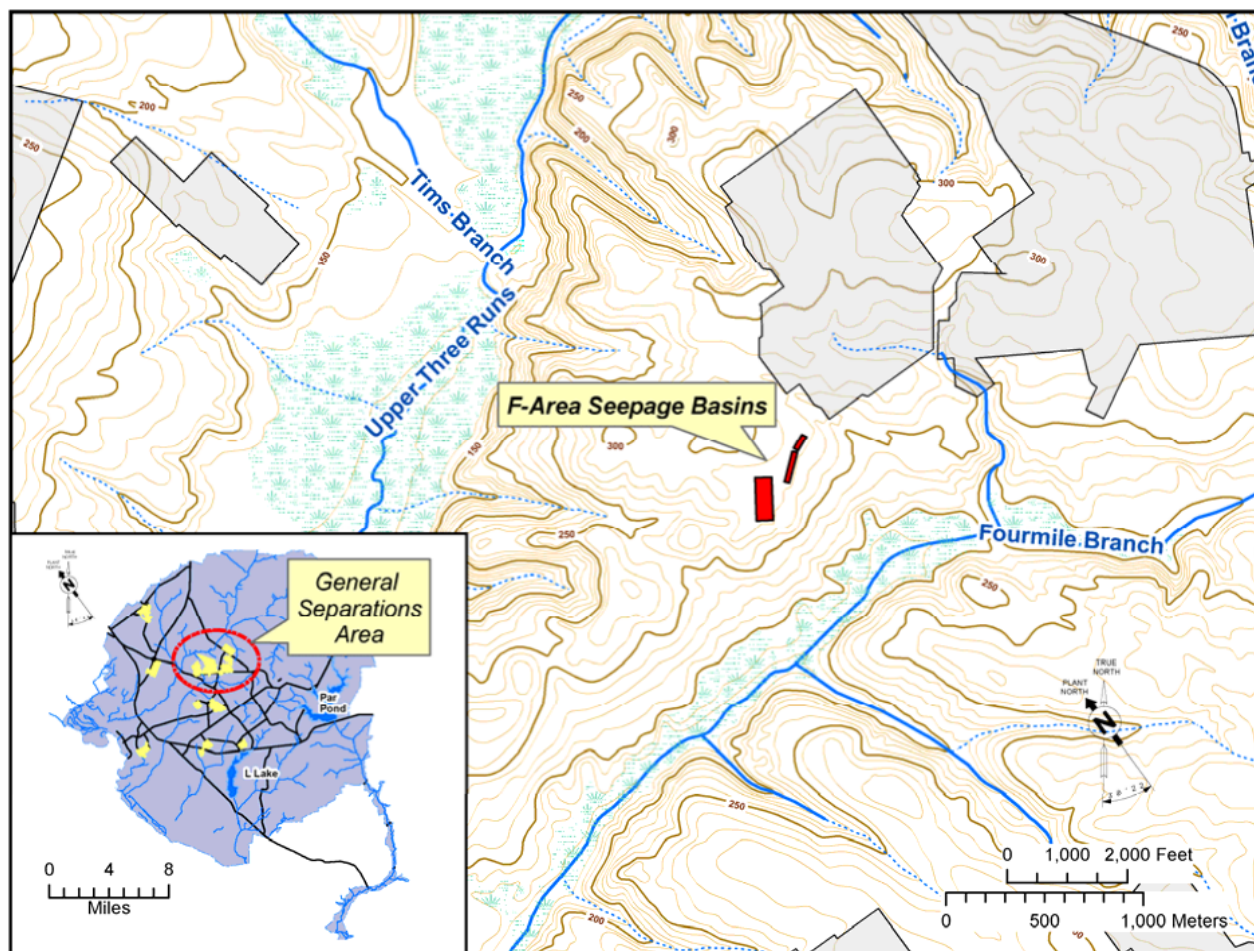
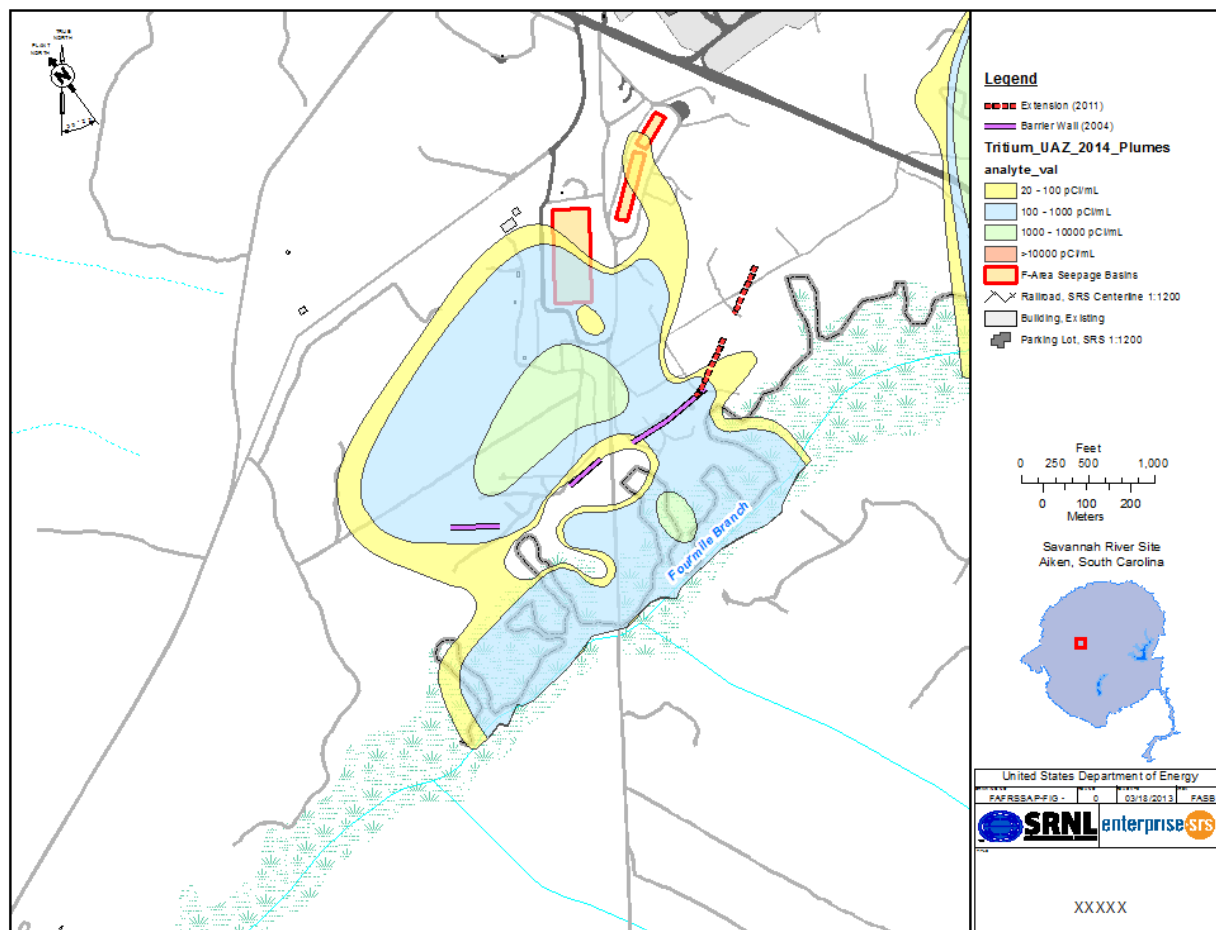


Figure 3. Location of the F-Area Seepage Basins at the Savannah River Site.



**Figure 4. Map showing distribution of tritium in 2014 in relation to seepage basins, funnel and gate treatment system, seepage line and receiving stream.**

## 2.0 Technical Basis for Remedial Action

Over seventy site investigations have been conducted in the vicinity of the basins since the 1960's. Monitoring of the groundwater collected from wells at the basins began in the late 1950s and has continued since that time. Over the years, various types and numbers of wells, seepage monitoring points, and surface water locations have been utilized for assessing impacts and remedial efforts associated with the FASB.

The geology of the site is heterogeneous, comprised of poorly consolidated quartz sands and clays typical of coastal plain deposits. The plume is stratified within the water-table aquifer (Figure ), moving mostly within a highly transmissive unit along the top of a clay layer that confines the aquifer below and cropping out at the seepage line along Four Mile Branch; a stream approximately 1,600 feet (500 meters) downgradient from the basins. The groundwater remains acidic, with pH as low as 3.2 near the basins and increasing to a pH of approximately 5 downgradient.



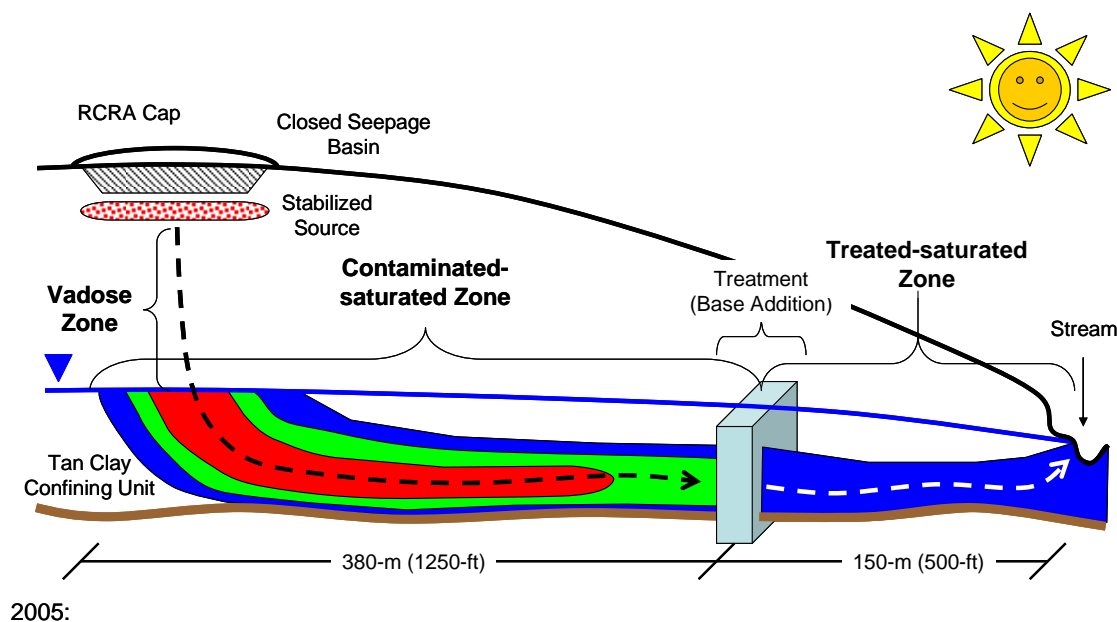


Figure 5. Schematic cross section of F- area groundwater plume.

### 3.0 Decision(s)

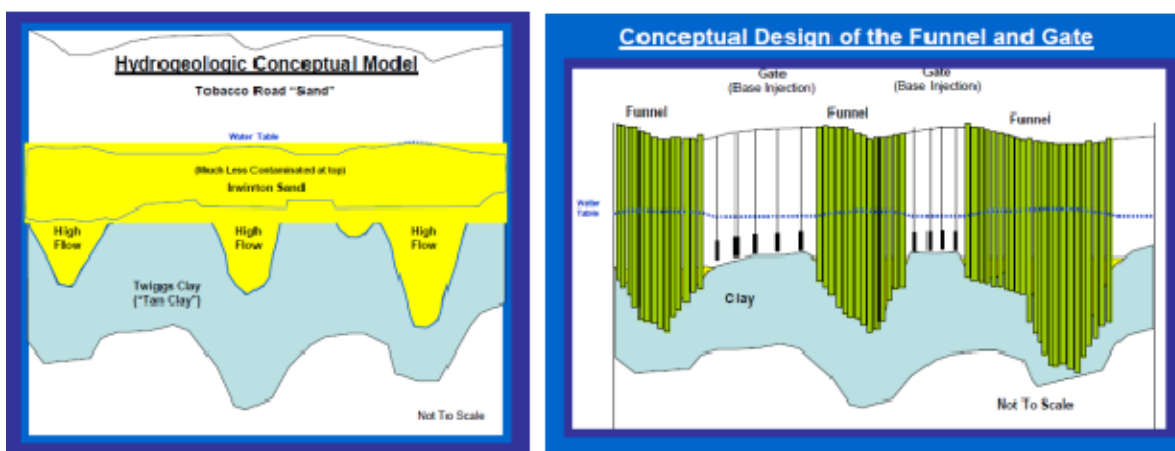
As early as 1962 it was known that some contaminants had migrated in groundwater from the basins. Later, visual signs of vegetative stress suggested the plume had reached the seepage line, and this fact was later confirmed by sampling. Extensive sampling and monitoring were completed to delineate the plume, which was found to have a footprint of approximately 0.38 square miles (1 square kilometer). In 1986, the determination was made that the basins should be regulated under the Resource Conservation and Recovery Act (RCRA) as hazardous waste disposal facilities, and closure plans were initiated. A lawsuit brought by the Natural Resources Defense Council against the Savannah River Site in 1988 accelerated treatment of this waste unit and associated groundwater under RCRA. In 1992, a permit was issued under RCRA that specifies the regulatory requirements for the groundwater corrective action program, as well as other appropriate local, state, and federal laws and regulations. This corrective action plan specifies a phased remediation approach designed to implement the basic remedial system followed by evaluation of the effectiveness of corrective action design and system components; this information is used to design and implement additional corrective action elements as necessary. The corrective assessment plan goals take into account technical practicability and economic feasibility considerations.

### 4.0 Remedial Approach

The basins were closed in 1991 by dewatering, physically and chemically stabilizing the remaining sludge, and covering them with a protective multilayer system to reduce rainwater infiltration. In 1997, SRS designed and installed a pump-treat-and-re-injection system with a water treatment unit designed to trap the untreatable tritium in a continuous loop by extracting groundwater from downgradient, removing contaminants other than tritium from the water, followed by reinjection of the treated water up gradient of the seepage basins. The treatment

system consisted of precipitation/flocculation, reverse osmosis, and ion exchange. Operation of the water treatment unit began in 1999 and was continued until 2003. The pump-and-treat system operated as designed, but had two significant drawbacks. It was very expensive to operate and generated large amounts of radioactive solid waste. Hence, SRS sought another more efficient way to treat the groundwater contaminant plume.

In 2004, the pump-and-treat system was replaced by a hybrid funnel-and-gate system (Figure ) that was installed about 1,000 feet (300 meters) up gradient from Four Mile Branch (WSRC, 2005; SRNS, 2012). The purpose of the funnel-and-gate is to slow migration of contaminated groundwater and to funnel it through in situ treatment zones at the gates. Extensive geologic characterization showed that much of the plume migrated along “troughs” at the top of the clay layer that confines the lower aquifer. The walls (or engineered subsurface barriers) were installed across these features to slow contaminant migration and force it through the gates (Figure ). The treatment zones at the gates attenuate migration of uranium, Sr-90, and I-129 by sorption or precipitation. Tritium migration is slowed by the walls and additional decrease in tritium concentrations is achieved when the stratified plume mixes with less contaminated groundwater as it migrates up through the gates.



**Figure 6. Cross Sections showing Hydrogeologic Conceptual Model (left) and Funnel and Gate System (right).**

Treatment zones for uranium and Sr-90 at the gates are maintained by neutralizing acidity of the groundwater and mineral surfaces with injections of an alkaline solution. This causes sorption of the contaminants and precipitation of uranium phases. Periodic injections are performed with the frequency at each gate dictated by sentry monitoring wells located down gradient.

## 5.0 Monitoring/Optimization

Monitoring of the performance of the funnel-and-gate with base injection over the past seven years indicates that it has functioned as planned. Analysis of subsurface cores collected down gradient of the middle gate shows that an elevated pH treatment zone has been established. Monitoring of groundwater indicates that tritium flux has been reduced to target levels and regulatory limits on concentrations of Sr-90 and uranium have been achieved downgradient of the treatment system.

In 2009, a pilot study was initiated to evaluate the removal of I-129 by the injection of particles of solid silver chloride (SRNS, 2012). Contaminant I-129 and natural iodine-127 react with the silver chloride to form insoluble silver iodide, removing I-129 from the groundwater. In 2011, a modification to the RCRA permit was approved to deploy silver chloride technology at the middle gate as part of the corrective action. The treatment zone extended from the top of the water table down to a local clay layer (25 to 50 feet [8 to 15 meter] below ground surface). Injection was performed starting at the bottom of the aquifer and proceeded upward pumping a specific volume of amendment into each zone at 2.5 foot (0.75 meter) intervals. Evaluation of the performance of the silver chloride treatment zones continues.

Implementation of long-lived attenuation-based remedies such as the funnel and gate system at the FASB will require adequate levels of monitoring to ensure that the remedies continue to be effective over very long periods of time. This monitoring will be required to demonstrate to regulators and stakeholders that attenuated contaminants are behaving as predicted by the site conceptual model and will not remobilize as the site evolves.

In FY14, a pilot field test was initiated to test an alternative paradigm for long term monitoring that should simultaneously improve the performance monitoring systems and lower costs. The new paradigm is focused on measurement of the controlling variables that are leading indications for changes in the stability of the plume that would be supplemented by a substantially reduced number of well measurements. The controlling variables include boundary conditions, master variables, and plume/contaminant variables. Boundary conditions are the overall driving forces that control plume movement and therefore provide leading indication to changes in plume stability. Master variables are the key variables that control the chemistry of the groundwater system, and include redox variables (ORP, DO, chemicals), pH, specific conductivity, biological community (breakdown/decay products), and temperature. A robust suite of tools is commercially available to measure these variables. Concentration measurements for all types of contaminants in groundwater are a lagging indicator of plume movement – significant changes indicate that contamination has already migrated. The new paradigm relies on leading indicators that conditions at the site are changing in ways that could lead to plume expansion.

## **6.0 Regulatory and Stakeholder Involvement**

Since 1993, SRS has managed regulatory compliance activities through a Federal Facility Agreement (FFA) with DOE, Environmental Protection Agency (EPA) Region 4, and South Carolina Department of Health and Environmental Control (SCDHEC). The FFA, which includes both EPA and the state of South Carolina, specifies how SRS will address contamination or potential contamination at waste units. SRS uses a Core Team process that was established in 1999, that was implemented to improve management of the regulatory and cleanup decision-making process at the site; core team members include DOE, EPA Region 4, and SCDHEC. The team operates on the following core principles:

- An effective Core Team is essential.
- Clear, concise and accurate problem definitions are critical.
- Early identification of likely response actions is possible, prudent, and necessary.
- Uncertainties are inherent and will always need to be managed.

The Core Team process greatly enhances communication and productivity to streamline the decision process and facilitates cleanup problem solving at an early stage. As a result, SRS has built a highly productive working relationship not only with its regulators but also with other public stakeholders such as the SRS Citizens Advisory Board (CAB). Once a waste unit has been fully characterized, cleanup alternatives evaluated, and a preferred method proposed, SRS solicits comments from the general public, which includes representatives from the media, legislators, educators, and other citizens. During the public comment period, SRS also seeks comments from the CAB. The CAB is an appointed advisory group of citizens that makes recommendations to the DOE, EPA Region 4, and SCDHEC regarding SRS cleanup. Once comments are received from stakeholders and considered, a Record of Decision is issued that documents the selected remedial alternative. DOE gives regular briefings to the SRS CAB committees on cleanup projects that are in progress, upcoming remedial decisions, and the programmatic and administrative matters that DOE, EPA Region 4, and SCDHEC are considering in carrying out SRS cleanup under the FFA and RCRA permits.

## **n4. CONCLUSIONS**

## 4. CONCLUSIONS

---

Complex sites pose a serious environmental concern due to the fact that traditional remediation strategies are not always effective. Reaching cleanup target levels for complex sites generally requires more time and inevitably higher cleanup costs. Overall they present an overwhelming challenge to the remediation industry, the regulatory world, nearby communities and tribes, as well as the parties that are liable and financially responsible for the cleanup efforts.

Presented were just a few examples of the remediation strategies that were implemented across complex sites. These case studies provide valuable insight into how to approach these sites, including the characterization efforts, remediation strategies utilized and the results obtained. By sharing this knowledge with industry professionals, other complex sites can be identified and characterized more efficiently.

The goal of the ITRC is to continue to provide these case studies and other trainings far into the future and across a variety of medias to insure that information pertaining to complex sites, and any other topic, is available for all to gain. Through this accessibility of information, the legacy of nuclear waste can be reduced leaving behind a cleaner and more sustainable environment.

## 5. REFERENCES

---

2013 Paducah Annual Site Environmental Report. (2013): n. pag. Oct. 2014. Web. <http://energy.gov/sites/prod/files/2014/12/f19/2013%20Paducah%20ASER.pdf>

Federal Facility Agreement for the Paducah Gaseous Diffusion Plant. (n.d.): n. pag. 1995. Web. <http://energy.gov/sites/prod/files/2014/12/f19/20141110-FFA-Controlled%20Copy-Complete.pdf>

Lee, M.H. et al. "Enzyme Activity Probe and Geochemical Assessment for Potential Aerobic Cometabolism of Trichloroethene in Groundwater of the Northwest Plume, Paducah Gaseous Diffusion Plant, Kentucky" / SciTech Connect. OSTI, 15 Aug. 2007. Web. 24 July 2015. <http://www.osti.gov/scitech/biblio/934526>

Looney, B. et al. "Independent Technical Review of the C-400 Interim Remedial Project Phase I Results, Paducah, Kentucky" | SciTech Connect. OSTI, 15 Aug. 2007. Web. 24 July 2015. <http://www.osti.gov/scitech/biblio/1043262>

Looney, B. et al. "Review Report: Building C-400 Thermal Treatment 90 Percent Remedial Design Report and Site Investigation, Pgdg, Paducah, Kentucky | SciTech Connect." OSTI, 15 Aug. 2007. Web. 24 July 2015. <http://www.osti.gov/scitech/biblio/913459>

Paducah Cleanup Progress. Paducah Cleanup Progress. Department of Energy (DOE), n.d. Web. 24 July 2015 <http://energy.gov/pppo/paducah-cleanup-progress>

Portsmouth Paducah Project Office." Portsmouth Paducah Project Office. Department of Energy (DOE), n.d. Web. 24 July 2015. <http://energy.gov/em/portsmouth-paducah-project-office>

Site Management Plan Paducah Gaseous Diffusion Plant Annual Revision. (n.d.): n. pag. Department of Energy (DOE), fy 2015. [http://energy.gov/sites/prod/files/2014/11/13%20D1%20FY%202015%20SMP%20REG%20Pub%20Docs\\_0.pdf](http://energy.gov/sites/prod/files/2014/11/13%20D1%20FY%202015%20SMP%20REG%20Pub%20Docs_0.pdf)

Swift, Barry, and Joseph Tarantino. Application of the Lasagna™ Soil Remediation Technology at the DOE Paducah Gaseous Diffusion Plant. WM'03 Conference (2003): n. pag. 27 Feb. 2003. Web <http://www.wmsym.org/archives/2003/pdfs/620.pdf>

U.S. DOE Gaseous Diffusion Plant. EPA. Environmental Protection Agency, 11 Mar. 2013. Web. 24 July 2015. <http://www.epa.gov/region04/superfund/sites/fedfac/pgasdifky.html>

Figure 1 - <http://wvp.greenwichmeantime.com/time-zone/usa/kentucky/map/>

Figure 2 - <http://energy.gov/pppo/paducah-site-description>

Figure 3 - <http://energy.gov/sites/prod/files/2014/12/f19/2013%20Paducah%20ASER.pdf>

Figure 4 - <http://energy.gov/pppo/paducah-cleanup-progress>