Savannah River
NUCLEAR SOLUTIONS℠

Savannah River Site Groundwater Management Strategy and Implementation Plan (U)

Aiken, South Carolina

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LIST OF ABBREVIATIONS AND ACRONYMS

ac	acre
ACL	alternate concentration limit
ABRP	A-Area Burning/Rubble Pits and Rubble Pit
AMRP	A-Area Miscellaneous Rubble Pile
BGC	Burial Ground Complex
CAGW	C-Area Groundwater
CBRP	C-Area Burning/Rubble Pit
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CMP Pits	Chemicals, Metals, and Pesticides Pits
CSGW	Central Shops Groundwater
DAGW	D-Area Groundwater
DOSB	D-Area Oil Seepage Basin
DNAPL	dense non-aqueous phase liquid
DUS	Dynamic Underground Stripping
EC&ACP	Environmental Compliance and Area Completion Projects
ERH	Electrical Resistance Heating
FFA	Federal Facility Agreement
FMB	Fourmile Branch
FSB	F-Area Seepage Basin
FY	Fiscal Year
GSA	General Separations Area
GSACU	General Separations Area Consolidated Unit
GW	groundwater
ha	hectare
HSB	H-Area Seepage Basin
HWMF	Hazardous Waste Management Facility
IOU	Integrator Operable Unit
KAGW	K-Area Groundwater
km	kilometer
km^2	square kilometer
KBRP	K-Area Burning/Rubble Pit
L	liter
LANG	L-Area Northern Groundwater
LASG	L-Area Southern Groundwater
LBRP	L-Area Burning/Rubble Pit
LLRWDF	Low-Level Radioactive Waste Disposal Facility
LTR	Lower Three Runs
LUCs	Land Use Controls
MACO	M-Area Chemical Oxidation
MAML	M-Area and Met Lab
MAOU	M-Area Operable Unit
MAPSL	M-Area Abandoned Process Sewer Line
MASB	M-Area Settling Basin

LIST OF ABBREVIATIONS AND ACRONYMS *(Continued/End)*

MBP	Metals Burning Pit
MCB	Miscellaneous Chemical Basin
MCL	maximum contaminant level
Met Lab	Metallurgical Laboratory
mi	miles
mi^2	square miles
MIPSL	M-Area Interactive Process Sewer Lines to Manhole 1 (081-M)
MNA	Monitored Natural Attenuation
MWMF	Mixed Waste Management Facility
PBRP	P-Area Burning/Rubble Pit
PCB	polychlorinated biphenyl
PCE	perchloroethylene (tetrachloroethylene)
PFAS	Per- and Polyfluoroalkyl Substances
RAGW	R-Area Groundwater
RAOU	R-Area Operable Unit
RCRA	Resource Conservation and Recovery Act
RG	remedial goal
ROD	Record of Decision
RRSB	R-Area Reactor Seepage Basin
SCDHEC	South Carolina Department of Health and Environmental Control
SE	Southeast
SLF	Sanitary Landfill
SRFS	Savannah River and Floodplain Swamp
SRNL	Savannah River National Laboratory
SRS	Savannah River Site
SSTA	Solvent Storage Tank Area
SVE	soil vapor extraction
SVEU	soil vapor extraction unit
SW	Southwest
TCE	trichloroethylene
USDOE	U.S. Department of Energy
USEPA	U.S. Environmental Protection Agency
UTR	Upper Three Runs
VOC	volatile organic compound

1.0 INTRODUCTION AND BACKGROUND

Environmental Compliance and Area Completion Projects (EC&ACP) is responsible for the remediation of operable units (OUs) and the decontamination and decommissioning of excess facilities at the Savannah River Site (SRS). This document describes the SRS groundwater protection, remediation, and monitoring strategy for groundwater and the vadose zone.

SRS groundwater management is guided by Federal and South Carolina regulations, primarily those implementing the Resource Conservation and Recovery Act (RCRA); the Safe Drinking Water Act; and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). As a result of historical operations, soils, surface water, and groundwater have been contaminated by releases of hazardous substances. These areas of contamination are identified as OUs warranting investigation and possibly remediation. Groundwater contamination areas may be addressed as separate units or as part of larger units. A map of the SRS groundwater contamination areas is shown in Figure 1, including the contaminants of concern.

This groundwater strategy and implementation plan guides field activities at SRS and facilitates negotiations with the United States Environmental Protection Agency (USEPA) and the South Carolina Department of Health and Environmental Control (SCDHEC). Detailed groundwater activities and implementation are described in Appendix A, Implementation Plan.

2.0 OBJECTIVES

This groundwater strategy and implementation plan describes the remediation of groundwater and the associated source units. The objectives include:

- Mitigate potential human exposure to contaminated groundwater,
- Minimize contaminated groundwater from impacting surface water above regulatory standards,
- Control contaminated groundwater growth and migration to the extent practicable,

- Take actions to return aquifers to their intended beneficial use,
- Meet regulatory requirements,
- Reduce long-term costs of groundwater remediation and land use controls (LUCs) (including monitoring), and
- Minimize carbon emissions and waste generation from remedial activities.
- These objectives will be achieved by:
- Focusing on source and vadose zone treatment and control to prevent further impact to groundwater and to reduce cleanup time;
- Developing new technologies and using existing technologies to effectively remediate groundwater and the vadose zone;
- Maintaining LUCs (i.e., institutional controls and engineering controls) to minimize human exposure to contaminated groundwater;
- Transitioning active groundwater remedies to enhanced attenuation remedies or monitored natural attenuation (MNA);
- Optimizing remediation and long-term monitoring;
- Streamlining remediation efforts by integrating actions required for multiple OUs; and
- Practicing a “green” approach to remediation.

3.0 REGULATION OF GROUNDWATER ACTIVITIES

EC&ACP groundwater activities are regulated by the SRS RCRA Permit Renewal and the SRS Federal Facility Agreement (FFA). The SRS RCRA Permit Renewal is issued and overseen by SCDHEC. The FFA is a tri-party agreement between the U.S. Department of Energy (USDOE), USEPA, and SCDHEC. All three parties are responsible for ensuring groundwater cleanup activities are conducted in accordance with the applicable regulations for the protection of human health and the environment. These three parties form the Core Team, which provides input, technical support, and decisions at various stages of the remediation processes. Groundwater activities associated with on-site landfills are regulated under SCDHEC's Solid Waste Management: Solid Waste Landfills and Structural Fills regulation and are not discussed in detail as part of this plan.

3.1 RCRA Groundwater and Vadose Zone Activities

RCRA groundwater characterization, monitoring, reporting, corrective action, and post-closure care are conducted for contaminated plumes associated with RCRA hazardous waste management facilities (HWMFs). These activities are regulated by SCDHEC. Groundwater and vadose zone corrective action at RCRA facilities are conducted in accordance with applicable regulations under the jurisdiction of the SRS RCRA Permit. Corrective action activities are proposed in RCRA Permit Renewal Applications, which are revised as needed, and associated Corrective Action Plans. All activities conducted under the RCRA Permit require SCDHEC approval and must be conducted in accordance with permit conditions. Field treatability studies of innovative technologies and standard corrective actions can be implemented under temporary authorizations that have received SCDHEC approval. If the studies or actions will extend beyond 180 days, then a RCRA Permit Renewal Application revision must be submitted to SCDHEC prior to the end of the 180 days for the activity to continue.

3.2 FFA Groundwater and Vadose Zone Activities

Groundwater contamination areas not associated with closed RCRA HWMFs are addressed under CERCLA as specified in the FFA. Remedial decision-making for these areas follows the CERCLA regulatory process. The CERCLA process requires documentation that must be approved by USEPA and SCDHEC, including a work plan or sampling analysis plan, OU characterization, and a comparison of contaminant concentrations to appropriate standards or risk screening levels. A Feasibility Study or Corrective Measures Study/Feasibility Study is prepared to evaluate potential remedial alternatives, and the selected remedy is made available for public comment in a Proposed Plan or Statement of Basis/Proposed Plan. The selected remedy is documented and institutionalized in a Record of Decision (ROD). Some early groundwater actions may be implemented under the removal action administrative process, which streamlines the documentation process.

Groundwater units have been established to allow separate characterization and remediation of the source of contamination and contaminated groundwater. This approach allows remediation of the source areas to be achieved on a relatively expedited schedule. Associated contaminated groundwater generally requires extensive characterization and evaluation before the remedy can be selected, and implementation of the remedy is often a lengthy process conducted in phases. This approach of segregating groundwater units also allows for multiple contaminated groundwater areas to be addressed holistically. Under CERCLA, innovative technologies can be field-tested as Treatability Studies, which are approved by the USEPA and SCDHEC.

4.0 ELEMENTS OF THE GROUNDWATER STRATEGY

The SRS groundwater strategy focuses on protection, remediation, and monitoring of contaminated groundwater. Strategic elements for each of these areas are presented in the following sections.

4.1 Groundwater Protection

In addition to USEPA and SCDHEC programs that are designed to protect groundwater (e.g., underground storage tank program, underground injection control program, wellhead protection program, and waste disposal program), prevention of future groundwater contamination and the disposition of contamination sources are the primary ways by which SRS groundwater is protected. Key activities include removing or immobilizing contaminant sources before contamination can reach groundwater, reducing natural and artificial recharge in contaminated areas, and eliminating the opportunity for contaminants to reach groundwater along unsealed well casings or through wells that are no longer needed. Considerable progress has been made at numerous SRS OUs in this respect through capping, *in situ* stabilization, and volatile organic compound (VOC) treatment technologies.

Reducing natural and artificial recharge in contaminated areas protects groundwater by reducing the transport of contaminants through the vadose zone into the unconfined aquifer. Water run-on/runoff control measures have been implemented in and around SRS OUs.

Wells that no longer serve a useful purpose at SRS potentially provide a pathway for contaminant migration to the vadose zone, the unconfined aquifer, or deeper zones. These wells fall into three broad categories:

- Older wells that are noncompliant with the current SRS well specifications;
- Wells that no longer serve an investigative, assessment or regulatory purpose; and
- Wells with open screens across confining zones.

To aid in protecting the aquifer from mobile contamination, wells must be evaluated to ensure that they still serve a useful purpose. Wells that are not necessary or cannot be used will be abandoned in accordance with SCDHEC regulations and SRS procedures. Wells are prioritized for abandonment based on the threat they pose to groundwater resources. The factors examined in characterizing the threat include proximity to contamination, depth, well construction method, casing material, and installation age.

4.2 Groundwater Remediation

The goal of groundwater remediation is to take actions to restore contaminated groundwater to its intended beneficial use and to protect human health and the environment. Groundwater remediation is underway at SRS. The benefits are already apparent and are reflected by:

- Reduction of risk;
- Evaluation and development of alternative corrective actions/remediation technologies;
- Continued implementation of early actions to control plume expansion, minimize surface water impacts, reduce contaminant mass, and better characterize aquifer response to corrective/remedial actions; and

- Use of alternate concentration limits and monitored natural attenuation when demonstrating source control and attenuating plumes.

SRS uses a graded approach to groundwater remediation. The selection of groundwater remediation technologies for a specific contamination area is based on the size, contaminant type, contaminant concentration, and configuration of the plume. These attributes are the result of the nature and mass of the source of contamination and the subsurface characteristics in the area of the plume. A schematic diagram of a generic plume is shown in Figure 2. Many large plumes consist of several zones that are most efficiently addressed with separate complementary corrective actions/remedial technologies. The highest concentrations of contaminants are found in the source zone. The most robust, high mass removal technologies are best suited for remediation of the source zone. In the primary plume zone, active remedies, such as pump-and-treat, may be necessary to remove contaminants and exert hydraulic control of the plume. Alternatively, enhanced natural attenuation may be sufficient to meet remedial goals. In the dilute fringe zone, contaminants are generally in low concentrations and can often be treated with passive technologies such as monitored natural attenuation. Figure 3 includes the remediation systems both past and present at SRS.

4.2.1 Active Remediation Systems

A range of active remediation systems have been used at SRS. Pump and treat systems are used to exert hydraulic control over plumes. These can be paired with air strippers that remove the contaminants (VOCs). Thermal technologies have been employed in several areas to mobilize and remove dense non-aqueous phase liquid (DNAPL) VOCs in the vadose zone and groundwater. Dynamic Underground Stripping (DUS) utilized steam injection to enhance removal from large DNAPL source zones. Electrical Resistance Heating has been used in smaller DNAPL source zones. Active recirculation well systems remove VOC contamination from primary VOC plume areas. Soil vapor extraction (SVE) units remove VOCs from vadose zone source areas.

4.2.2 *Low Energy Systems*

Low energy remedial systems are used extensively at SRS. These are low-energy-consumption, low-carbon-emission systems that are not completely passive. These “green” technologies leverage natural systems and forces to protect, manage, and remediate groundwater.

Many existing SVE systems have been converted from active vacuum extraction powered by fossil fuels to low energy systems powered by natural non-fossil-fuel energy sources. MicroBlower™ systems are SVE wells with small vacuum pumps designed to be powered by solar power either directly or through a battery which exhaust VOC vapors from individual wells. These are zero-carbon-emission devices that remove moderate levels of VOC contaminants from the subsurface.

Barrier or treatment walls are used to provide a passive measure of hydraulic control and/or treatment of plumes without pumping. For example, at F-Area Seepage Basins, groundwater barrier walls channel groundwater flow toward base injection zones in a funnel-and-gate configuration to support *in situ* remediation. The base injection system is used to treat low-pH groundwater contaminated with metals.

Phytoremediation is in use as a low energy system. Tritium-contaminated groundwater is collected and controlled as it discharges to a dam/pond system. Water from the pond is used to irrigate a pine forest. The trees take up the tritium-contaminated water through their roots and release very low concentrations of tritium vapor into the atmosphere, where it is safely diluted. This semi-passive system makes use of natural processes of hydrology and evapotranspiration to reduce the volume of tritium-contaminated water entering site streams and ultimately the Savannah River. This project won the DOE sustainability award in 2022.

Subsurface injection systems are considered low energy systems when single or infrequent episodes of injection are planned to modify geochemical conditions and enhance natural processes that result in remediation. Edible oil has been injected into the subsurface to encourage microbiological activity that consumes or co-metabolizes VOCs. Silver chloride has been being injected in F Area to stimulate geochemical reactions that will bind and immobilize iodine-129. Zero-Valent Iron was injected into an aquifer zone to create a permeable reactive barrier that degrades VOCs to harmless byproducts (chloride) in groundwater through reductive dechlorination.

4.2.3 Passive Systems

Many existing SVE systems have been converted from active vacuum extraction powered by fossil fuels or low energy systems (MicroBlower™ systems) to BaroBall™ systems. BaroBalls™ rely on natural changes in barometric pressure to pump VOCs from the subsurface at individual SVE wells. They are equipped with a check valve that prevents inflow under high atmospheric pressure events. These are zero-energy-consumption, zero-carbon-emission devices that remove low levels of VOC contaminants from the subsurface.

MNA is a passive groundwater remedial action where the fringe and dilute areas of a plume degrade by natural biogeochemical or physical processes such as biodegradation, radioactive decay, and simple dispersion/diffusion. MNA remedies must be accompanied by source controls and a technical justification that conditions are favorable for natural attenuation. Generally, the groundwater plume should not be expanding significantly, and regulatory standards cannot be exceeded at the groundwater discharge point. MNA remedy justifications are supported by groundwater modeling and a commitment to continued monitoring and reporting until remedial goals within the plume are achieved. When only the uppermost aquifer is impacted, SCDHEC may issue a Mixing Zone (MZ) permit that is essentially a permit for an MNA remedy. SRS has a mixture of RODs that required MNA as the final action for groundwater under CERCLA, and RODs that require SCDHEC MZ permits to implement the MNA remedy. Under the RCRA Permit, an alternate concentration limit can be developed at point-of-compliance wells as part of the MNA remedy.

4.2.4 Transition and Shutdown Criteria

In determining whether remediation is complete, shutdown criteria are used, which are typically established in regulatory documents. For groundwater, maximum contaminant levels (MCLs) are the regulatory standards most often used. For vadose zone soils, soil remedial goals (RGs) are typically established based on protection of groundwater. Once a demonstration has been made to the regulators that these criteria have been achieved, the remediation is considered complete.

Experience has shown that soil RGs are often difficult to achieve. The RGs are typically back-calculated using simple fate and transport models and conservative input assumptions. The physical processes responsible for VOC-retention in fine-grained soils are often not considered. The following alternative closure criteria, which are not all-inclusive, should be considered to support a remedial strategy for closure that is not based strictly on a soil RG.

- Site characterization data,
- Remedial system design,
- Performance monitoring results, and
- Mass flux to and from groundwater and evaluation of rate-limited vapor transport.

Defining the transition points for conversion from active remediation systems to low energy or entirely passive remediation systems can be achieved by using lines of evidence described above. For groundwater systems, if LUCs are effective and surface water is not impacted, the transition point can be identified in a cost/benefit analysis. The active and passive remediation systems can be compared by considering the following:

- Cost,
- Contaminant concentration and removal rates,
- Time to reach MCLs and/or RGs,
- Carbon emission,
- Waste generation, and
- Natural resource protection.

For vadose zone remediation, controlling the flux to groundwater so that groundwater standards or risk-based concentrations are not contravened is the key criterion to consider from a protectiveness standpoint. Any combination of these parameters can be used for justification of a proposal to transition a project from an active to a passive remedy.

4.2.5 Modeling in Support of Groundwater Remediation

Groundwater modeling is used to support groundwater corrective action/remediation selection. Groundwater flow and transport modeling is used to predict how groundwater contamination will change with time. Future contaminant concentrations in groundwater and at stream discharge locations can be predicted. This is helpful in determining whether MNA is an appropriate alternative for a plume or whether more active technologies are needed. When active groundwater corrective action/remediation is called for, the effectiveness of various remedial groundwater strategies can be compared using predictive models. The mass of contaminants removed, future contaminant concentrations in groundwater, and the time to reach RGs can be predicted for remedial alternatives. This information provides a technical basis for the selection of the optimal corrective action/remedial selection for each groundwater plume that is acceptable to the regulators.

SRS uses a suite of groundwater modeling codes that are peer reviewed, widely used in the environmental professional community, utilized by other USDOE sites, and accepted by both USEPA and SCDHEC. Major groundwater modeling efforts have focused on A/M Area, F Area, H Area, Burial Ground Complex, and several of the reactor areas where the most extensive subsurface contamination is known to exist.

4.3 Groundwater Monitoring

4.3.1 Introduction

Extensive groundwater monitoring is conducted at SRS OUs and operating facilities. Wells are monitored regularly to meet sampling requirements in FFA-related approved monitoring plans and the SRS RCRA Permit. SRS personnel plan and mobilize sampling events, collect and ship the samples, and provide data management. SCDHEC-certified off-site commercial laboratories and on-site laboratories perform the sample analyses. The most common contaminants at SRS include chlorinated solvents such as tetrachloroethylene (PCE) and trichloroethylene (TCE), and tritium. However, based on the waste unit’s history and disposal practices other contaminants including metals, radionuclides, nitrates, other organic compounds such as 1,4-dioxane and per- and polyfluoroalkyl substances (PFAS), are also present.

Groundwater monitoring plans are typically developed to satisfy a specific regulatory requirement or to address technical data needs at a specific time in the regulatory process. Often the focus of these plans is collecting the data needed to answer specific questions (e.g., is the groundwater contaminated?). Monitoring plans also evaluate and address future questions (e.g., are microbes present to facilitate remediation?). Changes in the groundwater conceptual site model or monitoring objectives (e.g., characterization versus corrective action/remedial performance monitoring) may require changes to the plan. This objective-based monitoring is discussed in greater detail below.

4.3.2 Objective-based Groundwater Monitoring

Surface water and groundwater monitoring are based on a set of clearly defined objectives from which monitoring data are collected to specifically fulfill those objectives. Typically, these objectives directly support project decision making. The design of the monitoring plan (e.g., the number of wells, frequency of sampling, laboratory analyses, reporting frequency) is tied to the data quality objectives and uncertainties in order to make project decisions. The decisions and the objectives to be met may vary depending on the type or stage of the project. The typical OU project comprising a source of contamination and associated groundwater contamination usually consists of the following stages:

- Pre-characterization problem identification,
- Characterization problem identification,
- Remedy selection support,
- Pre-design refinement,
- Short-term remedy evaluation,
- Long-term remedy evaluation, and
- Post-closure long-term monitoring.

For each of these stages, the type, amount, and frequency of data will vary depending on the nature and scale of the problem being monitored and the specific decisions that need to be made. Thus, the monitoring conducted is tailored to the objectives to be met at each stage.

The seven stages identified above can be divided into two main phases: pre-remedy characterization and post-remedy monitoring. In general, the objectives of these phases are fundamentally very different: identifying the nature and scope of the problem and selecting an appropriate remedy and determining the effectiveness of that remedy. While pre-remedy characterization focuses on identifying the nature and scope of the problem and selecting an appropriate remedy, post-remedy monitoring involves determining the effectiveness of that remedy. Pre-remedy characterization usually consists of a few samples from a large number of wells, over a large area, for a broad spectrum of potential contaminants. Post-remedy monitoring includes long-term monitoring of conditions, typically from a focused area, often with a key objective to demonstrate whether the groundwater conditions are deviating from what is expected when the remedy is working as predicted. It is also important to recognize that the monitoring can change significantly as the remedy matures or changes. For example, if an active bioremediation system can be shut down and MNA is acceptable, the process monitoring or degree of remedial effectiveness measured by various biogeochemical parameters may no longer be needed.

In optimizing groundwater monitoring to meet the identified objectives, focus areas will include reporting (content and frequency), possible reduction in analyte analyses, and well network optimization (number of wells and frequency of sampling). Reporting content should be limited to value-added information, focusing on the key constituents with respect to RGs. Using the example cited above, continued reporting of methane concentrations, which provides nutrient information related to the effectiveness of a bioremediation process, would not add value if that remedial system was discontinued. Furthermore, if this process information was reported semiannually, it may now be appropriate to reduce reporting frequency to annually or biennially. Sampling analyses should focus on contaminants that are risk drivers. In addition, changes to RCRA monitoring requirements have been made. Under South Carolina Hazardous Waste Management Regulations

R.264.98, targeted Appendix IX analysis at point-of-compliance wells can now be conducted, and constituents inconsistent with the facility conceptual site model and long-term monitoring history can be dropped from the list (e.g., dioxins/furans) with regulatory approval. This objective-based approach should also be used to refine sampling well networks and the frequency of sampling. Large plumes in aquifers with relatively slow groundwater velocities require a lower density of wells and less frequent sampling. Tables 1 and 2 provide typical decision logic for retaining, adding or removing a well and changes in sampling frequency.

Although numerous statistical approaches exist to optimize monitoring networks, the specific conceptual site model and associated heterogeneities that exist when developing a monitoring plan must be considered. In addition, input from the Core Team (i.e., USDOE, USEPA, and SCDHEC) and their technical support should always be considered from an FFA perspective. SCDHEC input should always be considered from an SRS RCRA Permit perspective. Monitoring plans should be reevaluated upon each change in stage for a project lifecycle when a change in remedial systems is affected and at least every five years for long-term monitoring systems.

4.3.3 Reducing Long-Term Costs

An important objective of the groundwater management strategy is reducing long-term costs of groundwater corrective action/remediation and monitoring. Remediation alternatives are using a comparative analysis in a regulatory document such as a feasibility study, corrective measures study, or engineering evaluation/cost analysis. A cost benefit analysis of the various alternatives is typically conducted considering a metric such as reduction in time to reach remedial goals, where more robust alternatives would be compared to a base case MNA alternative.

For monitoring systems, the ground water optimization initiative described in Section 4.3.2 and begun in 2012 has saved nearly $400K per year at four RCRA-permitted facilities and seven FFA groundwater units. Another means of reducing monitoring costs is to eliminate unnecessary wells to reduce long-term maintenance. Figure 4 depicts the number of monitoring wells sampled at SRS as well as the number of wells installed and abandoned during the years 2000 through 2022. A monitoring program goal is not to increase the overall number of wells, if appropriate, which is accomplished by an ongoing assessment of OU monitoring well networks. Sampling at wells that do not provide data that support decision making is discontinued, and monitoring wells will be abandoned if they no longer provide data of value in the future. However, additional wells may be installed as necessary to track plume expansion, provide necessary data for planned remediation, or provide data for corrective action/remedial system assessment.

5.0 SCHEDULE

SRS developed the current schedule (Figure 5) for groundwater remediation consistent with the approved FFA Appendix E: Fiscal Year 2025 Long-Term Projections and the SRS RCRA Permit. Based on groundwater models or best professional judgment, it will take decades before RGs are reached for many of the projects.

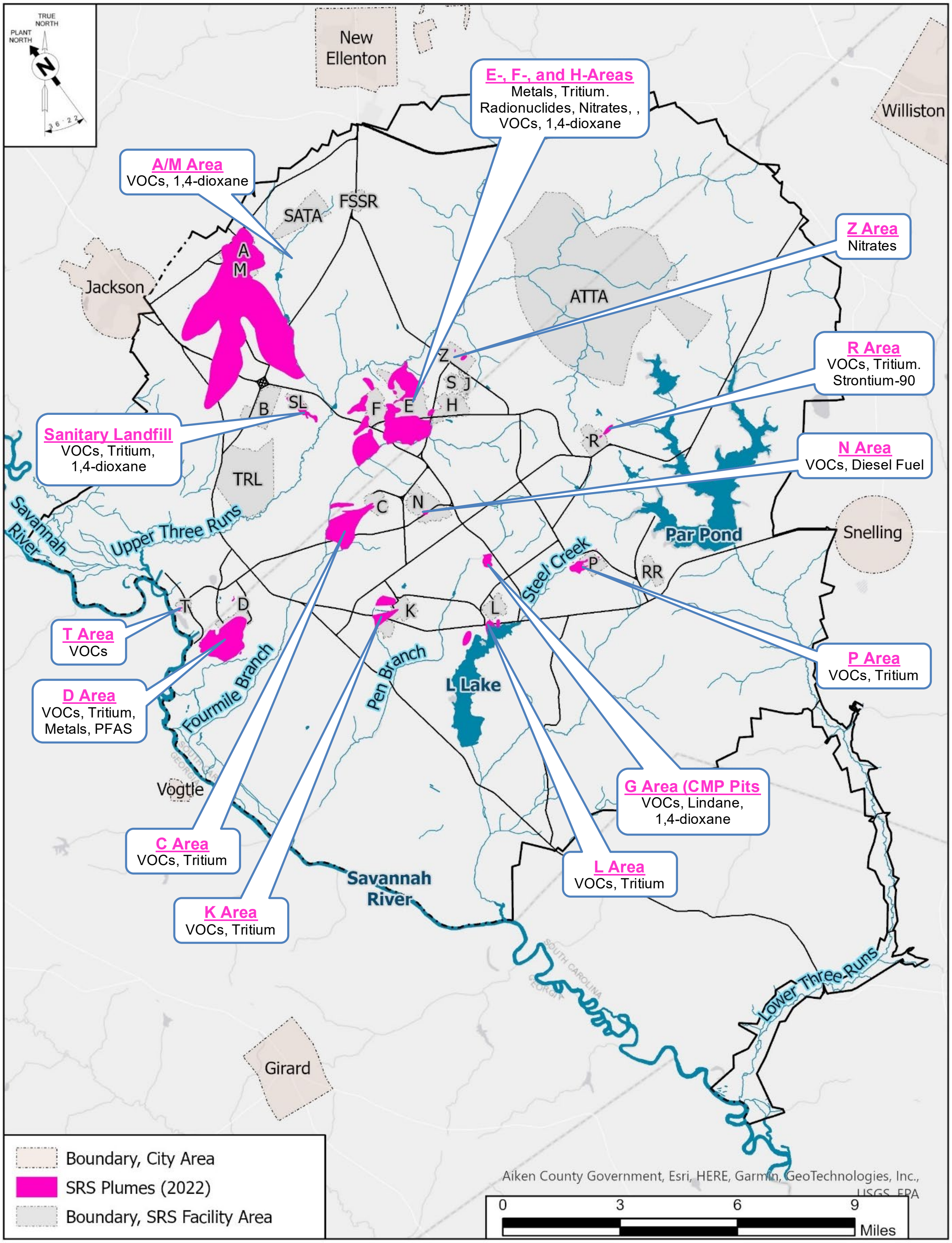

Figure 1. Groundwater Contamination Areas

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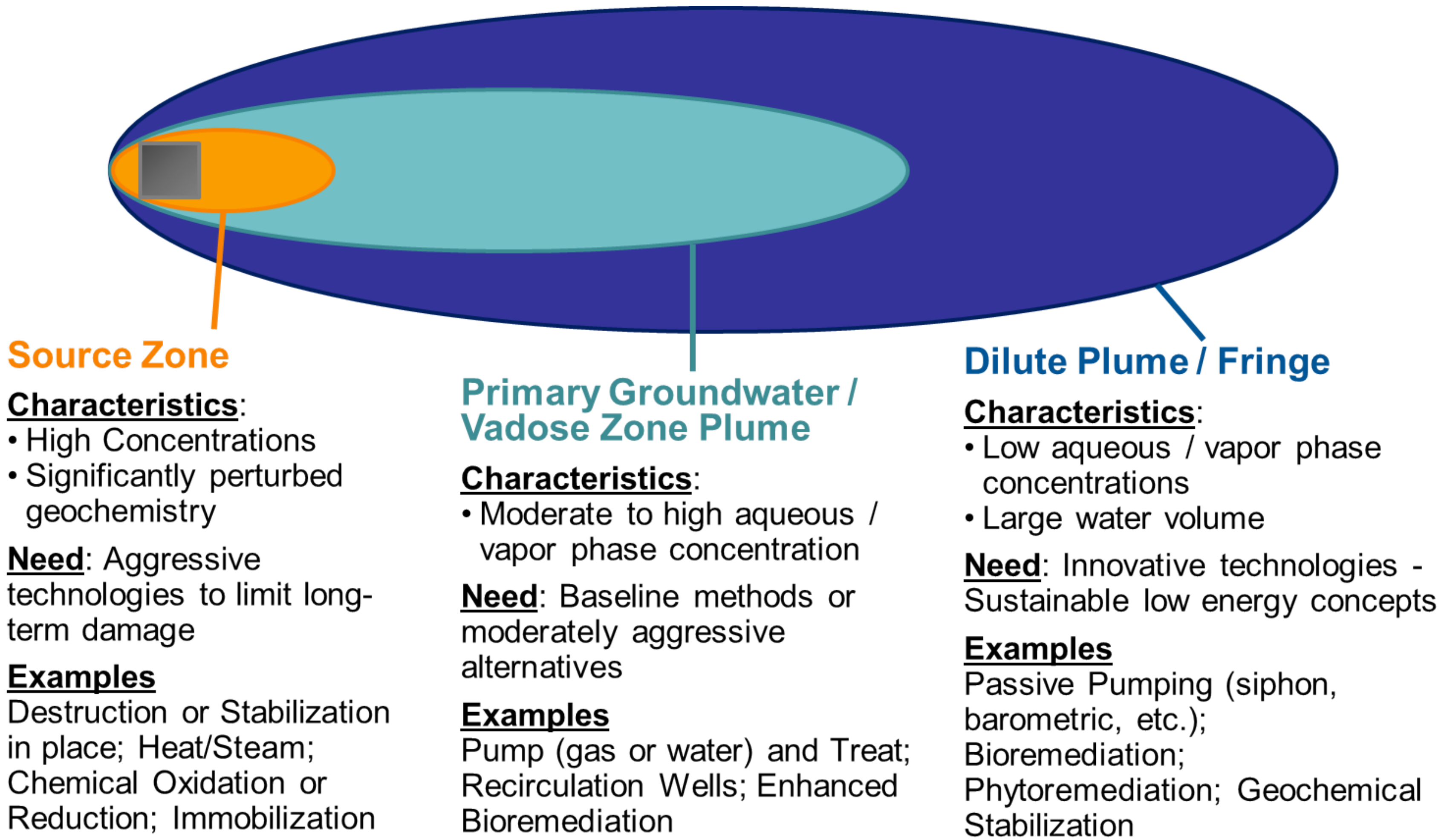

Figure 2. SRS Graded Approach to Groundwater Remediation

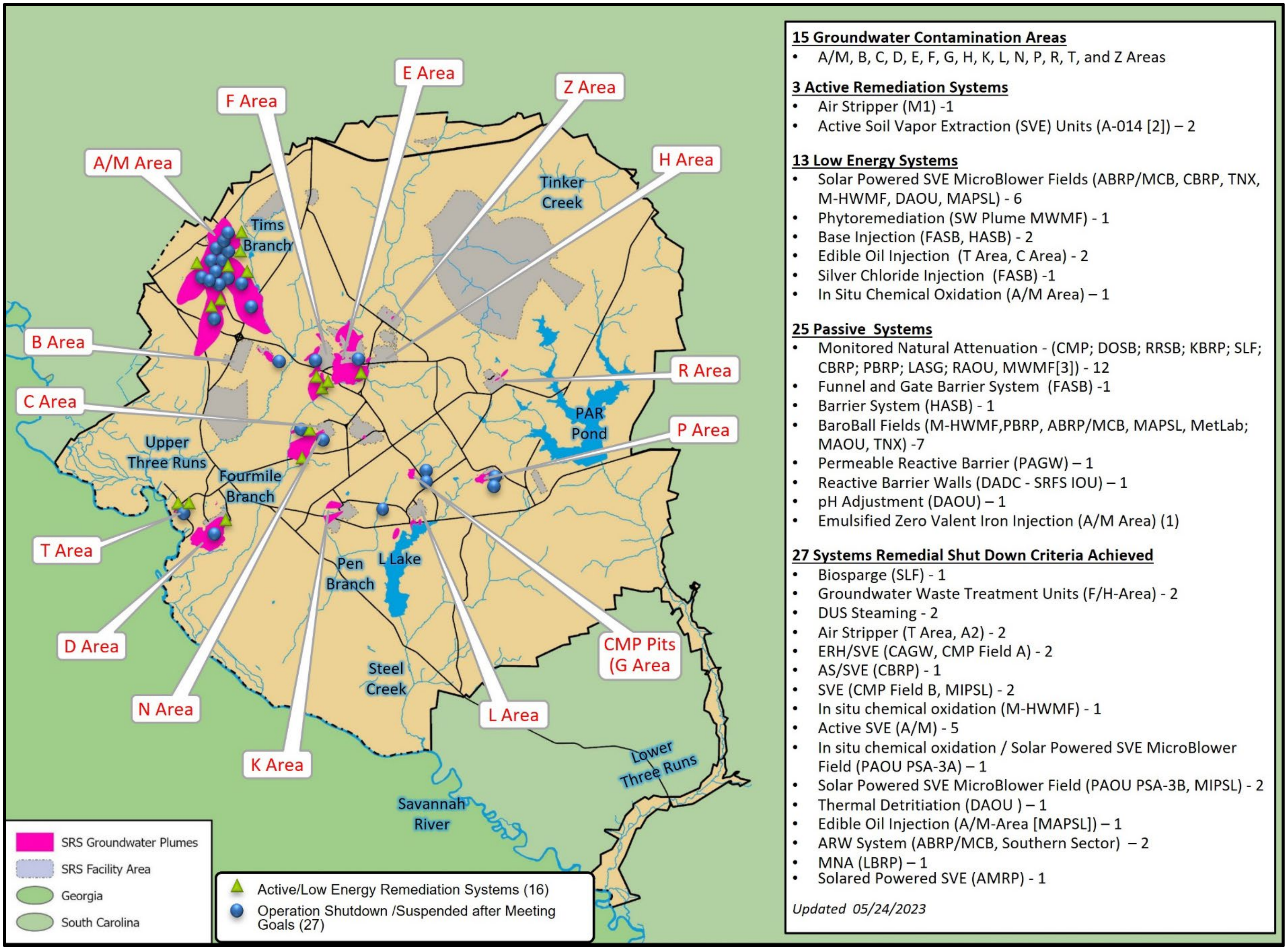

Figure 3. **SRS Groundwater Remediation Systems**

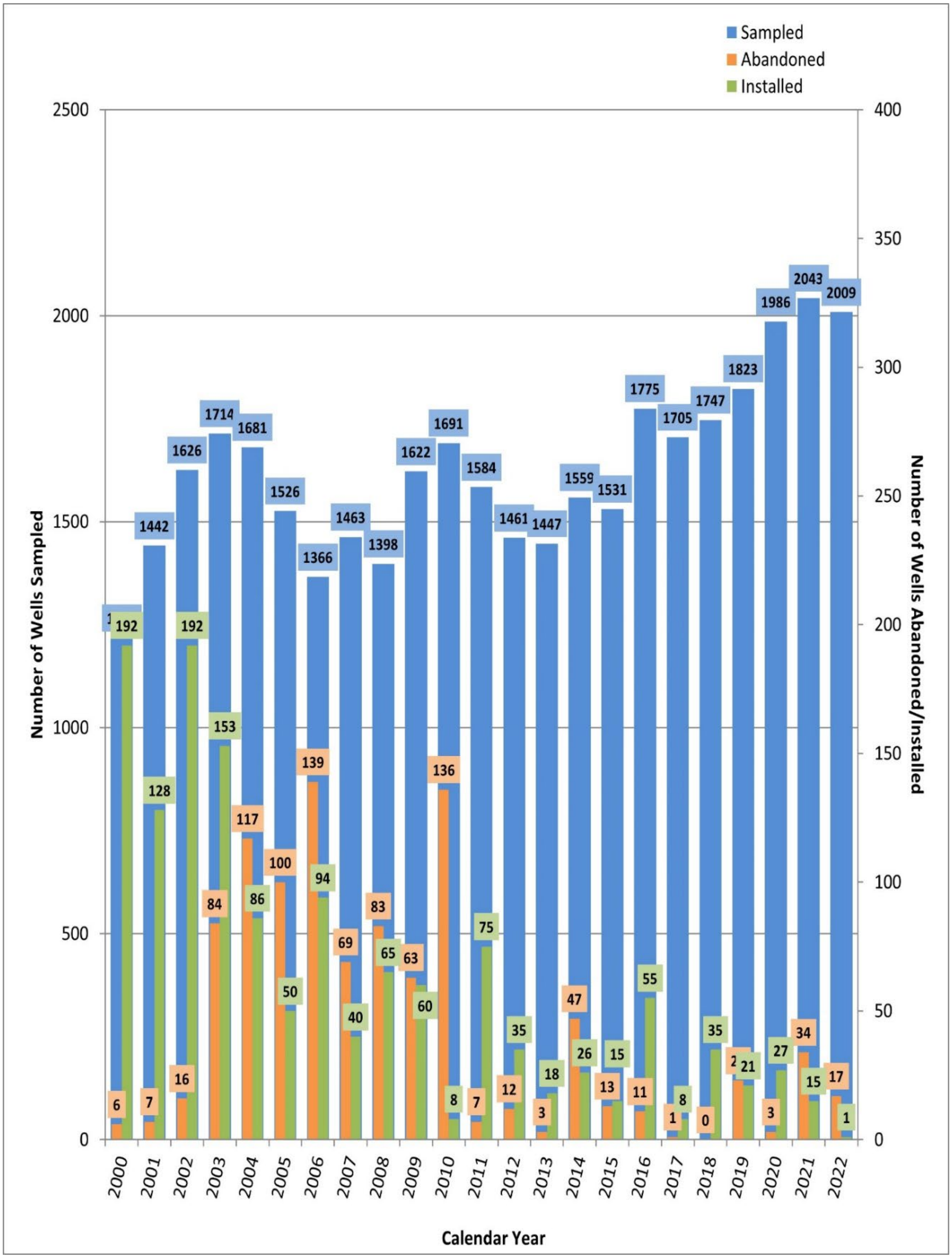

Figure 4. Number of Monitoring Wells Sampled, Installed, or Abandoned Annually at SRS (2000-2022)

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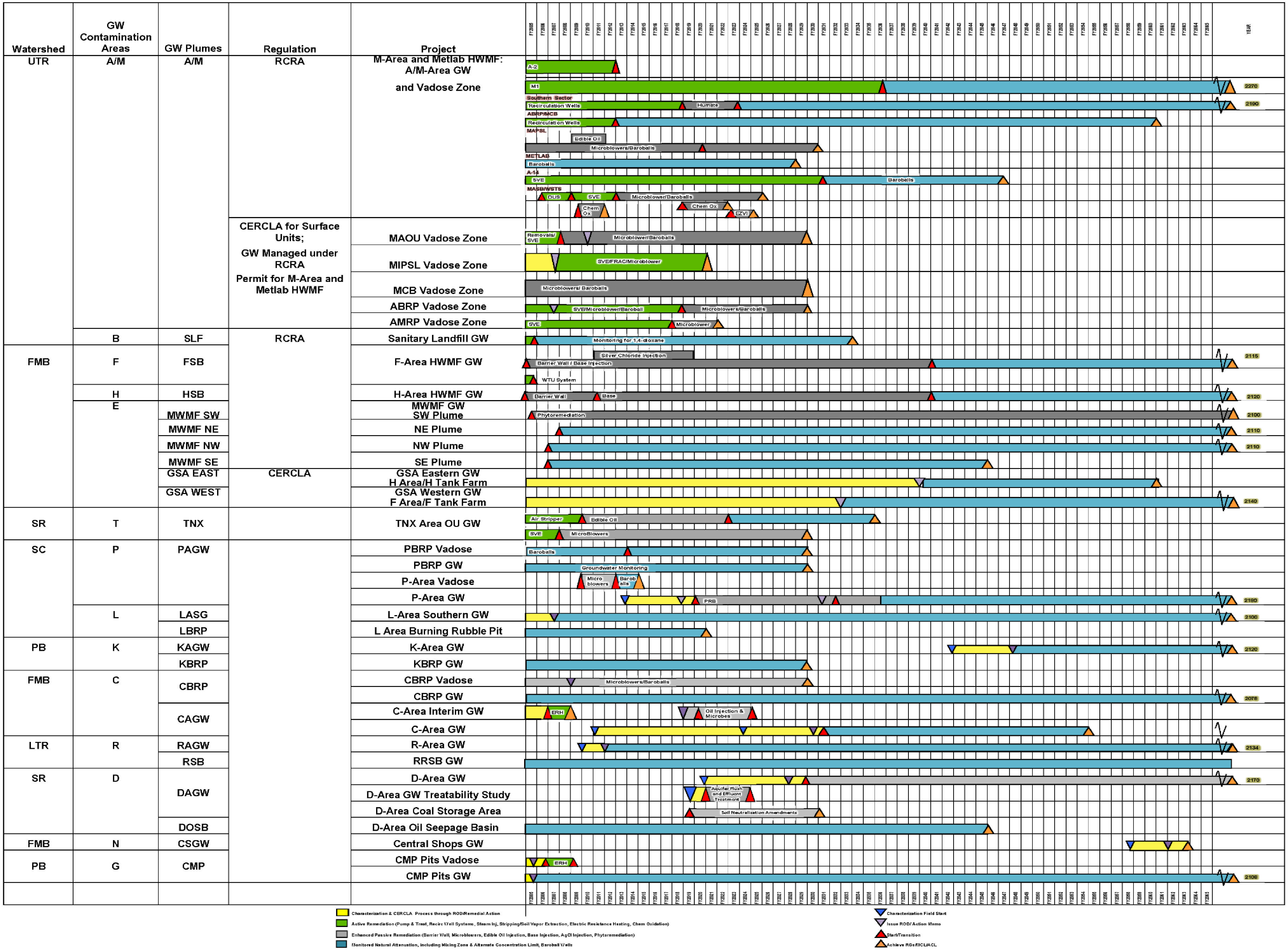

Figure 5. SRS Groundwater and Associated Source Strategy Schedule

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Table 1. Qualitative Monitoring Network Optimization Decision Logic

Reasons for Retaining or Adding a Well in a Monitoring Network	*Reasons for Removing a Well from a Monitoring Network*
Well is needed to further characterize the site or to monitor changes in contaminant concentrations through time.	Well provides spatially redundant information with a neighboring well (e.g., same constituents, and/or short distance between wells).
Well is important for defining the lateral or vertical extent of contaminants.	Well has been dry for more than two years and there is no expectation that the water levels will recover in the foreseeable future.
Well is needed to monitor water quality at a compliance point or receptor exposure point (e.g., sentinel well for municipal wells).	Contaminant concentrations are consistently below laboratory detection limits or cleanup goals.
Well is important for defining background water quality.	Well is not functioning properly (e.g., cannot be effectively redeveloped, screen improperly placed).

Table 2. Qualitative Monitoring Frequency Decision Logic

Reasons for Increasing Sampling Frequency	*Reasons for Decreasing Sampling Frequency*
Groundwater velocity is high.	Groundwater velocity is low.
Change in concentration would significantly alter a decision or course of action.	Change in concentration would not significantly alter a decision or course of action.
Well is close to source area or operating remedy.	Well is far from source area or operating remedy.
Whether concentrations will change significantly over time cannot be predicted or there is no ready explanation for recent irregular or contradictory data.	Concentrations are not expected to change significantly over time or contaminant levels have been below cleanup objectives for some period of time.

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Appendix A

IMPLEMENTATION PLAN

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A.0 INTRODUCTION

The Savannah River Site (SRS) approach to groundwater corrective action/remediation and monitoring is discussed in this implementation plan. The overall approach includes the following activities:

- Select the appropriate technologies;
- Apply those technologies efficiently;
- Transition from active to passive remedies, when appropriate; and
- Optimize monitoring.

A.1 Groundwater Remediation Implementation

The SRS groundwater management strategy is to mitigate the source of contamination in the environment to significantly reduce contamination transport through soil and groundwater. Treatment or containment of the source contamination is key to preventing further groundwater impact and a necessary criterion for monitored natural attenuation to be viable as a groundwater remedy. Contamination that is present in groundwater above regulatory limits is characterized to determine the most appropriate alternative to meet cleanup objectives. A wide range of corrective action/remedial activities has been implemented at SRS operable units (OUs), which are summarized in Figure 3 and Table A-1.

Successful implementation of the groundwater management strategy will move the program from active remedies to low energy and passive technologies over time. Through FY2023, 27 remediation systems achieved shutdown criteria, 25 systems are passive, thirteen systems are low energy, and only three active systems remain operating (Figure 3). As the program matures and the bulk of the contaminant mass is successfully removed from the source areas and primary plumes, the number of passive and low energy remedies is expected to continue to increase.

SRS has 15 distinct areas of groundwater contamination. Groundwater in the contamination areas typically migrates both downward and laterally, with eventual discharge into one of the five on-site streams or the Savannah River. These six receiving waterbodies encompassing the watersheds, integrate potential contaminants into the surface water bodies, stream systems, and associated wetlands and define the integrator operable units (IOUs) at SRS. The IOUs are listed below:

- Upper Three Runs (UTR),
- Fourmile Branch (FMB),
- Pen Branch,
- Steel Creek,
- Lower Three Runs (LTR), and
- Savannah River and Floodplain Swamp (SRFS).

The following sections of this document identify the progress toward implementing the Groundwater Management Strategy and achieving the goals of the project in each watershed. A description of each watershed, the associated groundwater plumes, groundwater contamination areas, remediation approaches, and significant accomplishments are provided for each.

A.1.1 *Upper Three Runs IOU*

A.1.1.1 Watershed Description

Upper Three Runs (UTR) originates northeast of the SRS boundary and follows a southwesterly direction for approximately 30.6 kilometers (km) (19 miles [mi]) within the SRS boundary. It discharges directly into the Savannah River approximately 1.45 km (0.9 mi) upstream of T Area. Within the SRS boundary, the UTR watershed drains approximately 251 km^2 (97 mi^2). The northern portion of the UTR watershed within the site boundary includes portions of A Area, M Area, and Savannah River National Laboratory (SRNL). The southern portion of the UTR watershed includes the majority of the B Area (Administrative Facilities), S Area (Vitrification Facility), and Z Area (Saltstone Facility), as well as portions of E Area (Waste Management Complex), F and H Areas (Separation Facilities), and R Area. The main tributaries within the SRS portion of the UTR watershed include Tinker Creek and Tims Branch. Smaller tributaries include Crouch Branch, McQueen Branch, and Mill Creek.

A.1.1.2 Groundwater Contamination Areas

Projects occurring within the UTR IOU are discussed below and listed in Table A-1.

A and M (A/M) Areas – A/M Areas contained the main SRS administrative functions and manufacturing areas. These areas are addressed together because of their proximity and commingled contaminants. When combined, the A/M Areas constitute one of the largest groundwater contamination areas in the country. The M-Area HWMF consists of the M-Area Settling Basin (MASB) (a seepage area, overflow ditch, and inlet process sewer line), Lost Lake (a shallow upland depression [Carolina Bay]), the Solvent Storage Tank Area (SSTA), the M-Area Abandoned Process Sewer Line (MAPSL) that connected the M-Area facilities with the MASB, the SRNL and associated process sewer lines, the A-014 Outfall and discharge tributary, and the A-Area Burning/Rubble Pits and Rubble Pit/Miscellaneous Chemical Basin/Metals Burning Pit (ABRP/MCB/MBP) OU. The Met Lab HWMF consists of the Met Lab Basin (a seepage area, overflow ditch, and inlet process sewer line) and a Carolina bay (shallow isolated wetland depression).

The A-014 Outfall and unnamed tributary of Tims Branch creek received wastewater that contained volatile organic compounds (VOCs) from the M-Area facilities from 1952 to 1979. Similarly, the unlined MASB operated from 1958 until 1985, receiving wastewater that contained VOCs, solvents used for metal degreasing, other chemical constituents, and depleted uranium from the M-Area fuel fabrication processes. The MASB was closed with a Resource Conservation and Recovery Act (RCRA) cap in 1992. The MAPSL transported M-Area process wastewater to the basin. The principal contaminants in the areas are VOCs (primarily tetrachloroethylene [PCE] and trichloroethylene [TCE]) in the groundwater and the vadose zone.

The ABRP/MCB/MBP OU were a series of trenches, pits, and basins that received waste from the early 1950's to the early 1980's. Originally, ABRP and MCB/MBP were separate OUs under the FFA. These units were later combined in the FFA as the ABRP/MCB/MBP OU. The soil and vadose zone contamination are addressed by remedial activities for the

ABRP/MCB/MBP OU under CERCLA. In 2006, groundwater contamination associated with the ABRP and the MCB/MBP subunits would be transferred to the RCRA program.

The Met Lab Basin received wastewater that contained VOCs and metals from the Met Lab Facilities from 1956 to 1983. The Met Lab Basin was closed with a RCRA cap in 1992. The principal contaminants in the areas are VOCs (primarily PCE and TCE) in the groundwater.

B Area – B Area contains an administrative office complex. Additionally, the Sanitary Landfill (SLF), which received solid waste containing RCRA-contaminated solvent rags and wipes, is located in B Area. The SLF was closed with a geosynthetic cap in 1997. The principal contaminants at the SLF are VOCs (primarily TCE, chloroethene [vinyl chloride], and 1,4-dioxane).

A.1.1.3 Remediation

The M-Area and Met Lab (MAML) HWMFs are managed under a RCRA permit and have vadose zone and groundwater corrective actions. The MAML HWMFs have been divided into five sectors to help manage corrective actions: Central, Northern, Southern, and Western Sectors and ABRP/MCB/MBP OU. Other units within the UTR watershed include the M-Area Operable Unit (MAOU), M-Area Inactive Process Sewer Line (MIPSL), A-Area Miscellaneous Rubble Pile (AMRP), and ABRP/MCB/MBP OU have vadose zone remedies managed under Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Records of Decision (RODs).

A/M Vadose Zone – Dense non-aqueous phase liquid (DNAPL) in silts and clays provides a long-term source of groundwater contamination that is difficult to remediate. Dynamic Underground Stripping (DUS) uses steam heating to volatilize VOCs that are then captured with vapor extraction wells. DUS was used at the SSTA and MASB. Two soil vapor extraction units (SVEUs) (i.e., 782-3M and A-014 Mobile #3) remain active as of 2023 to remove VOCs from the vadose zone. Hydraulic fracturing was utilized to open up the "tight" soils to allow remediation. This technique was applied in conjunction with a high-vacuum SVEU, A-014 Mobile #3. MicroBlowers™ and/or BaroBalls™ are removing contaminant mass from the vadose at SVE wells near the MAPSL, SSTA, Met Lab (Building 717-A), the SRNL, and the Western Sector Treatment System.

MicroBlowers™ and/or BaroBalls™ are also removing contaminant mass from the vadose at SVE wells within the MAOU, MIPSL, AMRP, and ABRP/MCB/MBP OU.

A/M Groundwater – The initial remediation strategy has been to hydraulically contain the high concentration portion of the plume in the Lost Lake Aquifer, while removing contaminant mass using recovery wells and air strippers. The M-1 Air Stripper has been fed by up to 15 recovery wells (i.e., RWM 1 through RWM 11, RWM 17B, RWM 17D, RWM018, and RWM019) in the Central Sector and has operated since 1985. The A-2 Air Stripper was fed by six recovery wells (i.e., RWM 12, RWM 13B, RWM 13C, RWM 14B, RWM 14C, and RWM 15B) in the Northern Sector and operated from 1996 through 2012, when it was placed in standby with the South Carolina Department of Health and Environmental Control's (SCDHEC) approval. The A-2 Air Stripper was permanently shut down in 2021. In the Southern Sector and the ABRP/MCB/MBP OU plume areas, recirculation well technology has been used to *in situ* air strip the VOCs. Twelve wells (i.e., SSR 1 through SSR 12) operated in Southern Sector from 1996 to 2011 and eleven wells (i.e., MIS 1 through MIS 11) in ABRP/MCB/MBP OU from 2002 to 2011. As of 2020 both these systems have been approved by SCDHEC for shutdown.

Field-scale demonstrations of innovative technologies have long been a part of the overall strategy for the A/M plume given its size and complexity. *In situ* chemical oxidation and emulsified zero-valent iron (EZVI) in Western Sector and humate amendments to enhance aerobic biodegradation in Southern Sector. In Western Sector in 2018, chemical oxidants (i.e., potassium permanganate and sodium persulfate) were successfully injected into eight injection wells. In 2020, a second round of oxidant injections occurred at the same project area in Western Sector at four new injection wells. In 2022, EZVI was injected into six injection points via hydraulic fracturing to target a potential DNAPL migration pathway northwest of the MASB. In Southern Sector, the humate project started in 2015, but was not able to successfully inject humate into the Lost Lake Aquifer so it was suspended in 2020. The future viability of the humate project is currently being evaluated.

SLF Groundwater – A groundwater remediation system consisting of bioremediation through nutrient injection operated from 1999 to 2005. The biosparging system focused on the cleanup of TCE and chloroethene (vinyl chloride). Concentrations of contaminants in the groundwater were reduced to levels that met the approval of an Alternate Concentration Limit (ACL)/Mixing Zone Concentration Limit (MZCL) application for several constituents in 2009. Monitoring continues under the ACL/MZCL remedy to ensure no additional active cleanup is required.

A.1.1.4 Accomplishments

Vadose Zone – Operation of active SVEUs have removed about 500,000 pounds of VOCs from the vadose zone to date. There are only two active SVEUs still operating. All other SVEUs have been fully transitioned to a combination of MicroBlowers™ and BaroBalls™. As concentrations continue to decline at the active SVEUs, evaluations of the systems are being conducted to determine how the system can be optimized. For example, 782-3M SVEU, which operates at the A-014 Outfall, has 3 of the original 13 vapor extraction wells in service. Nine wells were abandoned due to very low to no contaminant levels, and one was converted to photovoltaic-powered MicroBlowers™. The 782-6M SVEU was successfully shut down with SCDHEC approval in 2019. The SVE well network connected to the 782-6M SVEU was partially transitioned to photovoltaic-powered MicroBlowers™ in 2013. After shutdown in 2019, 16 wells are connected to MicroBlowers™ while the remaining wells have been abandoned. The United States Environmental Protection Agency (USEPA) and SCDHEC in 2020 approved the completion of the SVE effort at MIPSL, allowing dismantlement and abandonment of those SVE wells. USEPA and SCDHEC approved the completion of SVE at the AMRP in 2021 allowing dismantlement and abandonment of those SVE wells.

The two Western Sector DUS projects at SSTA and MASB also removed over 500,000 pounds of VOCs from the vadose zone and groundwater.

Groundwater – Operation of the two pump and treat systems and the recirculation wells have removed over 600,000 pounds of VOCs from the groundwater. As of 2023, the M-1 recovery well network has been optimized to remove four wells (i.e., RWM 9, RWM 11, RWM 17B, and RWM 17D) from operation due to low VOC concentrations, and add two wells (i.e., RWM018 and RWM019) to capture high concentration portions of the groundwater plume. In 2020, the A-2 Air Stripper was permanently shut down with SCDHEC approval. In 2018, SCDHEC approved the dismantle and removal of all equipment requiring maintenance at the Southern Sector and ABRP/MCB/MBP OU recirculation wells. SCDHEC also approved the abandonment of all eleven recirculation wells at ABRP/MCB/MBP OU, which was completed in 2019.

Operation of the biosparging system at the SLF from 1999 to 2005 reduced concentrations of the identified contaminants (vinyl chloride and TCE) to their respective cleanup goals.

Characterization activities continue in the various sectors of the MAML HWMFs to aid in developing corrective actions as noted in the corrective action plan schedules contained in the RCRA Permit.

A.1.2 *Fourmile Branch IOU*

A.1.2.1 Watershed Description

The FMB IOU, which is located entirely within the SRS boundary, originates near the center of SRS and follows a southwesterly direction for approximately 24 km (15 mi). In the lower reaches, FMB broadens and flows through portion of the Savannah River swamp and along a natural levee that defines the boundary of the swamp, prior to entering the Savannah River. The watershed drains about 57 km^2 (22 mi^2) and includes several SRS facilities: C Area (C-Reactor Complex), N Area (Central Shops), F, H, and E Areas (General Separations Areas [GSAs]), and the Solid Waste Disposal Facility. Castor Creek is the principal tributary of FMB.

The FMB headwaters include a small blackwater stream that has been relatively unimpacted by SRS operations. FMB receives effluents from F, H, and C Areas and contaminated groundwater discharges that have migrated from SRS facilities and OUs into the stream and its tributaries.

A.1.2.2 Groundwater Contamination Areas

Projects occurring within the FMB watershed are discussed below and listed in Table A-1.

E Area – E Area consists of several adjacent facilities that are current or former waste disposal facilities, primarily for hazardous and radioactive wastes and spent solvents generated from chemical and manufacturing processes. One facility, the Burial Ground Complex (BGC), occupies approximately 79 hectares (ha) (195 acres [ac]) and is composed of several contiguous facilities that served as disposal locations for radioactive and hazardous waste (e.g., RCRA-regulated metals, VOCs, tritium, and other radionuclides). The BGC is comprised of three primary units: Old Radioactive Waste Burial Ground (ORWBG), Low-Level Radioactive Waste Disposal Facility (LLRWDF), and MWMF, which has underlying contaminated groundwater. RCRA closure systems have been installed at both LLRWDF and MWMF. Effective corrective actions have been employed for the groundwater areas and are being managed under the RCRA Permit. ORWBG, the highest risk remaining surface unit, has been consolidated with four nearby OUs to form the General Separations Area Consolidation Unit (GSACU). Final remedial action at the GSACU, which includes installation of an engineered low permeability cap over the ORWBG, began in 2003 and was completed in 2008.

F Area – F Area is part of the general separations operations where plutonium was separated from irradiated assemblies for refinement into metal buttons. The principal contaminants are tritium within the groundwater, and strontium, uranium, iodine-129, heavy metals, and solvents both dissolved and in soils and sediments. The primary remedial goal is to achieve source and plume control to reduce the release of contaminants to FMB and UTR. Besides soil stabilization and low permeability capping, other remedies deployed to treat contaminants in F Area include an underground barrier wall system using Base Injection with a Funnel and Gate Barrier System, and injection of a silver chloride amendment to immobilize iodine-129.

H Area – H Area is part of the general separations operations where uranium was separated from spent fuel assemblies for recovery. H Area was also used to process tritium and uranium and to produce plutonium-238. The principal constituents of concern are tritium, strontium, and mercury. The primary remedial goal is to achieve source and plume control reducing the release of contaminants to FMB. Besides soil stabilization and low permeability capping, other remedies deployed to treat contaminants in H Area include an underground barrier containment system and a base injection system. Many of the H Area high-risk units have been completed or are in remediation including Warner's Pond, HP-52 (basin), and H-Area Retention Basin.

C-Area – All SRS reactor areas were constructed with similar facilities, and similar processes were used during their operations. The areas where the reactors are located also contain former disposal sites for hazardous substances such as burning/rubble pits and basins. Principal contaminants at the C Area are cesium-137, tritium, and spent organic chemicals. Monitoring wells indicate the presence of tritium and VOCs. A VOC groundwater plume extends from the CBRP to FMB. A VOC and tritium plume emanating from the C-Area Reactor Building Complex and Seepage Basins extend to Castor Creek to the south and FMB to the west.

N Area – N Area contains burning/rubble pits, equipment maintenance areas, and chemical and runoff basins that were used between 1951 and 1973 to dispose of various waste materials, including hazardous substances such as organic and inorganic chemicals and radioactively contaminated materials. In the Central Shops portion of N Area, groundwater was contaminated with hydrocarbons from leaking underground storage tanks.

A.1.2.3 Remediation Projects

MWMF Groundwater Southwest Plume – At the MWMF, phytoremediation is utilized by capturing tritium-contaminated water in a 10.2M liters (L) (2.7M gal) pond and irrigating the water on 24.7 ha (61 ac) of pine trees for transpiration, which has resulted in a 70% annual tritium reduction (from 1,500 to 2,000 curies to 450 curies) to FMB. The original 8.9 ha (22-ac) system was expanded and upgraded by adding an additional 15.8 ha (39 ac) of pine trees and doubling the capacity of the irrigation supply and distribution system.

F- and H-Area HWMFs Groundwater – A pump-and-treat system was operated at F- and H-Area HWMFs for several years; the system was replaced with a more passive funnel-and-gate treatment system at F Area and a barrier system at H Area. The barrier systems at F- and H-Area HWMFs have been very effective in managing tritium and metal flux to FMB. SRS has achieved several RCRA corrective action goals and is actively working to achieve the Phase 2b RCRA corrective action goals for the FMB wetlands.

The base injection system at F Area utilizes base to neutralize acid, which reduces the metal concentration in the groundwater. The system has been augmented with 24 additional wells between the barrier system and FMB to further reduce contaminant flux. A base injection system was constructed for the wetland area below the barrier at H Area; the system consists of 30 base delivery wells and a pumping and mixing system. SRS has developed an injectable capture media (silver chloride) to immobilize *in situ* iodine-129 in groundwater and has created a reactive treatment zone within one of the F Area gates.

C-Area Groundwater – The U.S. Department of Energy (USDOE), USEPA, and SCDHEC agreed in December 2016 to address a portion of the VOC plume that is discharging to surface water near Castor Creek using a non-time critical removal action administrative approach. A one-time injection of emulsified oil into the highest concentration portion of the VOC plume was completed in August 2019. Monitoring which began in December 2019 is assessing the performance of the removal action.

For the CBRP OU, MicroBlowers™ are used to remove VOCs from the vadose zone and monitored natural attenuation (MNA) is the selected remedy for groundwater. Both physical and anaerobic biological processes are attenuating VOCs in the plume.

A.1.2.4 Accomplishments

The base injection system at F Area was started in 2005 and the H Area system was started in 2010. The systems in both areas are operated as needed to adjust pH levels. Since operations began, F Area has injected approximately 174M gal and H Area injected approximately 60M gal of base solution. The base injection systems will likely require periodic operation until the groundwater pH returns to natural levels.

Deactivation of the F- and H-Area groundwater treatment units are completed.

A subsurface reactive treatment zone using an injectable silver chloride amendment has been constructed as a means of controlling iodine-129. Bench-scale testing and a pilot injection test indicated that the silver will be effective in managing the contaminant. Ultrafine ground solid silver chloride was injected in 2011, 2015, and 2019 at F Area. Reductions in the concentration of iodine-129 have been observed. SRS is continuing to monitor the effects of injection.

The MWMF phytoremediation system has operated since 2000. Evapotranspiration has been determined to be 80-90% effective, with tritium concentrations in FMB being reduced by 70%.

Electrical Resistance Heating (ERH) with SVE was used to address elevated levels of TCE in the vadose zone near the C-Reactor Building (105-C) Complex. This interim remedy was completed in September 2006. Subsequent soil sampling indicated that over 99% of the source contamination was removed. The residual TCE concentrations are being addressed through an emulsified oil treatment barrier prior to discharge to Castor Creek.

A.1.3 *Pen Branch IOU*

A.1.3.1 Watershed Description

The Pen Branch IOU originates near the center of SRS and flows in a southwesterly direction for approximately 17.6 km (11 mi), and then discharges into the Savannah River Swamp rather than flowing directly into the Savannah River. The Pen Branch IOU is located entirely on SRS property. Pen Branch flows southwesterly from its headwaters, about 3.2 km (2 mi) east of K Area, to the Savannah River Swamp. After entering the swamp, Pen Branch flows parallel to the levee for about 8.0 km (5 mi) before it enters and mixes with the water from Steel Creek, about 0.32 km (0.2 mi) from the mouth of Steel Creek at the Savannah River. The Pen Branch watershed drains about 54.4 km^2 (21 mi^2) and includes K Area (K-Reactor Complex), portions of N Area (Central Shops), the CMP Pits OU (located in G Area) and the L-Area Northern Groundwater (LANG) OU. Indian Grave Branch is the principal tributary of Pen Branch.

A.1.3.2 Groundwater Contamination Areas

Projects occurring within the Pen Branch watershed are discussed below and listed in Table A-1.

G Area – The CMP Pits are located about 1.6 km (1 mi) north of L-Reactor Complex. These pits were used to dispose of chemicals, metals, and pesticides. As a result of past disposal practices, surface soil, subsurface soil, and groundwater have been contaminated. Primary contaminants are VOCs and pesticides. In 1984, the pits were excavated, and highly contaminated soil was removed.

K Area – All SRS reactor areas were constructed with similar facilities, and similar processes were used during their operations. The areas where the reactors are located also contain former disposal sites for hazardous substances, such as burning/rubble pits and basins.

Principal contaminants in the reactor areas are cesium-137, strontium-90, tritium, and VOCs. Monitoring wells indicate the presence of tritium and VOCs in groundwater. Tritium is also present in Indian Grave Branch. USDOE, USEPA, and SCDHEC reached agreement to conduct annual monitoring and five-year reporting.

A.1.3.3 Remediation

CMP Pits – The ERH system was a soil treatment technology used to remediate localized solvent contamination in non-porous subsurface soils where electrodes are inserted into the subsurface to heat the soil to transform liquid solvents into the vapor phase. The contaminants were subsequently removed using SVE. Full-scale ERH operations began at the CMP Pits in March 2008. Confirmation sampling was conducted from 2009 to 2010 and indicated that RGs in the vadose zone were achieved. The final action for the groundwater is MNA.

KBRP OU– MNA with a groundwater mixing zone was implemented as the chosen remedy at the KBRP OU to monitor for VOCs in the groundwater associated with the unit.

A.1.3.4 Accomplishments

As stated in the Effectiveness Monitoring Report for the CMP Pits OU (SRNS-RP-2010-00896, Revision 0, June 2010), the SVE unit in combination with the ERH system removed approximately 2,300 pounds of VOCs (primarily PCE) from March 2008 through March 2009. After the ERH was completed, the SVE system reached the point of diminishing returns, and therefore, the system was shut down on April 23, 2009, and decommissioned. The SVE unit removed over 3,600 pounds of contaminants during its entire operation. MNA monitoring continues for VOCs and lindane in groundwater.

Annual groundwater reporting and the Sixth Five-Year Remedy Review Report for SRS OUs with Engineered Cover Systems (SRNS-RP-2020-00420, Revision 1, June 2021) for KBRP OU concludes that the mixing zone remedy combined with MNA is effective, and the PCE and TCE concentrations have remained below MCLs since 2019.

The USDOE, USEPA, and SCDHEC issued a No Action ROD for LANG in 2011.

A.1.4 *Steel Creek IOU*

A.1.4.1 Watershed Description

The headwaters of Steel Creek originate near P-Reactor, southwest of PAR Pond. Steel Creek flows southwesterly about 3.2 km (2 mi) before it enters L Lake. L Lake is a dammed lake/reservoir that is 6.4 km (4 mi) long with an area of about 418 ha (1,034 ac). Flow from the outfall of L Lake dam travels about 4.8 km (3 mi) before entering the Savannah River Swamp and another 3.2 km (2 mi) before entering the Savannah River. Steel Creek has received thermal discharges and increased flow from reactor operations that produced an extensive delta where Steel Creek enters the Savannah River Swamp. Meyers Branch, the main tributary of Steel Creek, flows approximately 9.6 km (6 mi) before entering Steel Creek. Meyers Branch has been and remains relatively undisturbed by SRS operations. The total area drained by the Steel Creek watershed is about 90.6 km^2 (35 mi^2) and includes portions of P and L Areas.

A.1.4.2 Groundwater Contamination Areas

Projects occurring within the Steel Creek watershed are discussed below and listed in Table A-1.

P and L Areas – All SRS reactor areas were constructed with similar facilities and similar processes were used during their operations. The areas where the reactors are located also contain former disposal sites for hazardous substances, such as burning/rubble pits and basins.

Principal contaminants in the reactor areas are cesium-137, strontium-90, tritium, spent organic chemicals, and low-level radioactive debris. L Area has ongoing missions, whereas P Area has been closed. The P-Area Reactor Building (105-P) Complex was remediated through *in situ* decommissioning, which was completed in 2011. Monitoring wells indicate the presence of tritium and VOCs in the groundwater.

A.1.4.3 Remediation

PAOU – The PAOU Early Action ROD included remediation of two vadose zone areas impacted with solvents. Remediation included hydraulic fracturing with chemical oxidation and SVE to treat these sources to the P-Area Groundwater (PAGW) OU

PAGW OU – A treatability study evaluating enhanced bioremediation was completed in the PAGW OU, which had limited impacts in the area tested. USDOE, USEPA, and SCDHEC agreed in May 2017 to address a portion of the VOC plume that is discharging to upper Steel Creek using a non-time critical removal action, which consisted of injecting zero-valent iron to create a permeable reactive barrier intersecting the VOC plume. The removal action targets TCE in the upper aquifer zone of the UTR Aquifer and was completed in December 2019. The removal action effectiveness will be monitored for five years and reported annually, from 2020 to 2024.

In addition to the non-time critical removal action, in the May 2017 meeting, the USDOE, USEPA, and SCDHEC agreed to additional investigation of the PAGW OU through soil sampling followed by long-term monitoring. Investigative soil sampling was completed in 2018 and results were presented to USDOE, USEPA, and SCHEC in a scoping meeting, where all parties agreed characterization efforts were complete in defining the nature of contamination in the PAGW OU and long-term monitoring would continue until a final action was defined in the ROD for the PAGW OU, currently scheduled for a May 2031 issuance in the FFA.

PBRP OU – To address the source of VOCs within the vadose zone at the PBRP OU an engineered cover system with BaroBalls™ was implemented as part of the chosen remedy. Land Use Controls with monitoring was selected as the chosen remedy for the groundwater beneath the unit to determine if a discernable plume above MCLs develops.

LASG OU – At LASG the surface units responsible for groundwater contamination have been remediated. Subsequently, a MNA remedy has been approved for groundwater.

LBRP OU – MNA with a groundwater mixing zone was implemented as the chosen remedy at the LBRP to monitor for VOCs in the groundwater associated with the unit.

A.1.4.4 Accomplishments

The MNA remedy for the LASG OU continues to be effective as documented in monitoring reports and the Sixth Five-Year Remedy Review Report for SRS OUs with Groundwater Remedies (SRNS-RP-2019-00511, Revision 1, July 2020) conducted from 2019 to 2020. Sampling and reporting optimization have been implemented for LASG.

The MNA remedy at the LBRP OU met remedial goals and was determined to be complete in 2017.

The vadose zone actions at PAOU were completed in 2012 with the achievement of remedial goals for TCE and PCE. This action has resulted in lower groundwater concentrations as the vadose zone source was destroyed. Monitoring results associated with the zero-valent iron permeable reactive barrier indicate significantly reduced VOC concentrations in the immediate vicinity of the barrier.

The selected remedy in at the PBRP OU continues to be effective as documented in monitoring reports and the Sixth Five-Year Remedy Review Report for SRS OUs with Operating Equipment (SRNS-RP-2022-00468, Revision 1, June 2023). Sampling and reporting optimization have been implemented for PBRP OU.

A.1.5 *Lower Three Runs IOU*

A.1.5.1 Watershed Description

The LTR watershed is located on the southeastern portion of SRS and lies partially within the SRS boundary. The LTR stream is the principal surface water body within the LTR watershed and is located entirely on SRS property that includes the narrow corridor that extends from Patterson Mill to the confluence with the Savannah River. The watershed, which drains about 461 km^2 (178 mi^2), includes R Area, a portion of P Area, ecological laboratories and various EC&ACP OUs. Industrial facilities located outside the eastern SRS boundary are also located within the LTR watershed. A mainstream impoundment, PAR Pond, was constructed along with several cooling water ponds on the headwaters of LTR streams to receive reactor cooling water discharges.

A.1.5.2 Groundwater Contamination Areas

Projects occurring within the LTR watershed are discussed below and listed in Table A-1.

R-Area – All SRS reactor areas were constructed with similar facilities, and similar processes were used during their operations. The areas where the reactors are located also contain former disposal sites for hazardous substances, such as burning/rubble pits and basins.

Principal contaminants in the reactor areas are cesium-137, strontium-90, tritium, spent organic chemicals, and low-level radioactive debris. In R Area, monitoring wells indicate the presence of strontium-90, tritium, and VOCs in the groundwater. R Area has been closed, and the R-Area Reactor Building (105-R) Complex was remediated through *in situ* decommissioning, which was completed in 2011.

A.1.5.3 Remediations

RRSB OU – At the RRSB OU the basins that are responsible for groundwater contamination have been remediated with the placement of an asphalt and concrete cover system. A groundwater mixing zone was chosen as the final remedy for the groundwater portion of the RRSB OU.

RAGW OU – MNA was selected as the final remedy for the R-Area Groundwater OU.

A.1.5.4 Accomplishments

The remedies in R Area continue to be effective as documented in monitoring reports and the Sixth Five-Year Remedy Review Report for SRS OUs with Groundwater Remedies (SRNS-RP-2019-00511, Revision 1, July 2020).

A.1.6 *Savannah River and Floodplain Swamp IOU*

A.1.6.1 Watershed Descriptions

The Savannah River watershed drains about 27,387 km^2 (10,574 mi^2), including western South Carolina, eastern Georgia, and a small portion of southwestern North Carolina. Approximately 31% of the watershed area, is situated in the central Savannah River area, is located in the Coastal Plain and includes SRS. The watershed includes Augusta, GA, SRS, and Savannah, GA and continues to the Atlantic Ocean. The SRFS IOU includes the 100-year floodplain (including the Savannah River Swamp) and any continuous wetlands, including the Savannah River adjacent and downgradient of SRS. This area encompasses approximately 72 km (45 mi) from the northern boundary of SRS above UTR southward to the U.S. Highway 301 Bridge. The five major SRS streams systems feed into the SRFS (UTR, FMB, Pen Branch, Steel Creek, and LTR). SRFS IOU includes portions of A/M Areas, D Area, and TNX Area.

A.1.6.2 Groundwater Contamination Area

Projects occurring within the SRFS IOU are discussed below and listed in Table A-1.

D Area – D Area was used beginning in the mid-1950s, the primary missions to produce heavy water and power for the site. Materials disposed of included coal ash, oil, chemicals, and construction debris. The coal burning power plant was operated in D Area, until shut down in 2012. Sampling results indicate that soil and groundwater in the area are contaminated by metals, tritium, and VOCs. Aqueous Film Forming Foam containing the emerging contaminants per- and polyfluoroalkyl substances (PFAS), which were used in firefighting and fire training, have the potential to contaminate groundwater. Results indicate that these contaminants are present in D-Area groundwater.

T Area – T Area was operated from the mid-1950s through the mid-1980s to conduct pilot tests to support SRS operations. The principal contaminants are mercury, thorium, uranium, radium, and chlorinated solvents. Because of its location near the Savannah River, the T Area was the first EC&ACP Completion in 2006.

A.1.6.3 Remediation

T Area – T Area (TNX) has a small persistent TCE/PCE plume that was remediated using pump & treat (T-1 Air Stripper) from 1996 to 2007 and, eventually reached a point of diminishing effectiveness. A new remediation strategy, which uses Edible Oil to sequester and biologically destroy the VOCs, was subsequently implemented. Neat Edible Oil was injected to sequester the VOCs (vadose zone source), and Edible Oil emulsion (food source) was injected into the aquifer to promote microbial activity and reducing conditions in groundwater (reductive dichlorination of PCE and TCE). A field scale treatability study allowed the edible oil to be deployed from 2008 through 2013 and provided the proof of concept to make EO the selected remedy the TNX OU, eliminating the use of the air stripper.

D Area – For D-Area Groundwater, historical field scale treatability studies included phytoremediation of VOCs using a drip irrigation delivery system, and sulfate-reducing biotreatment of the low pH metals plume. An ongoing treatability study was begun in 2020 to evaluate the efficiency of natural flushing of the aquifer with higher pH water from a deeper aquifer in D Area. A removal action was also completed in 2020 to address the low pH shallow soils through the addition and mixing of limestone amendment. For the DAOU, MicroBlowers™ are used to remove VOCs from the vadose zone.

For the DOSB, removal of debris and deep basin soils was conducted to remove the source of contamination. The selected remedy for the groundwater at the DOSB is MNA/ groundwater mixing zone with institutional controls. Naturally-occurring mechanisms will continue to reduce remaining contaminant concentrations over time.

A.1.6.4 Accomplishments

The edible oil treatability study demonstrated the ability to decrease the contaminant mass and areal extent of the TCE plume in less time and at lower cost than the remedy selected in the TNX Area OU ROD and still be protective of the groundwater. Therefore, an Explanation of Significant Difference was issued in 2013, with the following modifications to the remedy selected in the ROD for the TNX Area OU groundwater component:

- Injection of additional edible oil treatment as needed using the existing well network if a sustained rebound lasting over one (1) year in excess of 75 µg/L of TCE, PCE, or carbon tetrachloride occurs in any well. If the rebound occurs, then additional edible oil will be determined appropriate by the USDOE, SCDHEC, and the USEPA.

- Permanent removal of the T-1 Air Stripper from service. The T-1 Air Stripper was closed in accordance with a state approved closure plan.

In 2015, additional edible oil was injected in ten wells although the rebound conditions to trigger additional oil injections had not been exceeded. Both Emulsified Oil Substrate® and neat oil were injected. Monitoring results collected since the 2015 indicate that TCE concentrations are less than the MCL in most wells in the treatment area, and reductive conditions are present in the treatment area.

The DAOU SVE MicroBlowers™ results indicate that the VOCs in the vadose zone may be remediated as concentrations have greatly decreased and are almost non-existent. The MicroBlowers™ will be converted to passive BaroBalls™ until soil sampling can be conducted to confirm if the vadose zone soil concentrations are below RGs.

Preliminary results from the recent actions to address the low pH driven metal contamination indicate both the vadose zone and groundwater actions have been successful in raising the pH.

A.2 Groundwater Monitoring Implementation

Groundwater monitoring is required by RCRA post-closure care permit conditions at the following facilities:

- F-Area Hazardous Waste Management Facility (HWMF),
- H-Area HWMF,
- M-Area HWMF,
- Metallurgical Laboratory (Met Lab) HWMF,
- Mixed Waste Management Facility (MWMF), and

- SLF.

Groundwater monitoring is required as part of a remedy under a CERCLA ROD for the following OUs:

- C-Area Burning/Rubble Pit (CBRP),
- C-Area Groundwater (CAGW),
- Chemicals, Metals, and Pesticides (CMP) Pits,
- D-Area Oil Seepage Basin (DOSB),
- K-Area Burning/Rubble Pit (KBRP),
- L-Area Southern Groundwater (LASG),
- P-Area Burning/Rubble Pit (PBRP),
- P-Area Operable Unit (PAOU),
- R-Area Operable Unit (RAOU),
- R-Area Reactor Seepage Basin (RRSB), and
- TNX Operable Unit (T Area).

Groundwater monitoring is implemented at each OU and RCRA facility in accordance with the appropriate site-specific monitoring plan. Monitoring requirements (e.g., wells and surface water stations to be sampled, frequency of sampling, constituents to be analyzed, and the reporting frequency) are explicitly identified in the appropriate regulatory document. The monitoring requirements are optimized to meet specific data needs and objectives for each specific unit, as previously discussed in Section 4.3.2.

Table A-1. SRS Groundwater and Vadose Zone Corrective Action/Remediation Projects

Area	IOU	Plume	Project	Remedial Activities
A/M	Upper Three Runs	A/M	• A/M Groundwater and Vadose Zone; • M-Area HWMF, Met Lab HWMF, and ABRP/MCB/MBP OU	• *DUS (Completed)* • SVEUs • Pump & Treat (Air Stripper) • *Recirculation Wells (Completed)* • Fracture Enhanced SVEU • *Vadose Zone Oil Treatment (Completed)* • Chemical Oxidation • EZVI • Bioremediation (Humate) • MicroBlowers™ • BaroBalls™
		MAOU	• M-Area Operable Unit	• BaroBalls™
		MIPSL	• M-Area Inactive Process Sewer Line	• SVE (Completed)
		AMRP	• A-Area Miscellaneous Rubble Pile	• SVE (Completed)
		ABRP/MCB/ MBP OU	• A-Area Burning/Rubble Pits and Rubble Pit (ABRP)	• MicroBlowers™ • BaroBalls™
B	Upper Three Runs	SLF	• Sanitary Landfill Groundwater	• *Biosparging (Completed)* • Alternate Concentration Limit (ACL) / Mixing Zone Concentration Limit (MZCL)
C	Fourmile Branch	CAGW	• C-Area Groundwater – Interim • CAGW Removal Action	• *Electrical Resistance Heating (ERH) with SVE (Completed)* • *Emulsified Oil with Microbial BioBarrier*
		CBRP	• C-Area Burning/Rubble Pit	• MicroBlowers™ • MNA
D	Savannah River and Floodplain Swamp	DAGW	• D-Area Groundwater	• Characterization started in FY2020
		DOSB	• D-Area Oil Seepage Basin	• MNA/Mixing Zone (MZ)
E	Fourmile Branch	MWMF	• MWMF Groundwater Northeast	• MNA
			• MWMF Groundwater Southeast	• MNA
			• MWMF Groundwater Northwest	• MNA
			• MWMF Groundwater Southwest	• Phytoremediation
		GSA Eastern	• GSA Eastern Groundwater / H-Area Tank Farm	• Characterization in progress
		GSA Western	• GSA Western Groundwater / F-Area Tank Farm	• Characterization in progress

Table A-1. SRS Groundwater and Vadose Zone Corrective Action/Remediation Projects *(Continued/End)*

Area	IOU	Plume	Project	Remedial Activities
F	Fourmile Branch	F-Area Seepage Basin	• F-Area HWMF Groundwater	• Water Treatment Unit (Dry layup since March 2005) • Barrier Wall with Base Injection • Silver Chloride Injection
G	Pen Branch	CMP Pits	• CMP Pits Groundwater	• MNA
			• CMP Pits Vadose Zone	• *SVE, ERH with SVE (Completed)*
H	Fourmile Branch	H-Area Seepage Basin	• H-Area HWMF Groundwater	• Water Treatment Unit (Dry layup since March 2005) • Barrier Wall with Base Injection
K	Pen Branch	KBRP	• K-Area Burning/Rubble Pit	• MNA/MZ
		KAGW	• K-Area Groundwater	• Characterization planned to start in FY2042
L	Pen Branch	LANG	• L-Area Northern Groundwater	• No Action
		LASG	• L-Area Southern Groundwater	• MNA
		LBRP	• L-Area Burning Rubble Pit	• MNA (*Complete*)
		CSGW	• Central Shops Groundwater	• Characterization planned to start FY2059
P	Steel Creek	PBRP	• P-Area Burning/Rubble Pit	• Land Use Controls with Monitoring
		Potential Source Areas 3A/3B	• P-Area Operable Unit	• In-situ decommissioning • Hydraulic fracturing with chemical oxidation • SVE
		PAGW	• P-Area Groundwater	• Long-term monitoring on-going • In-situ bioremediation
			• P-Area Groundwater – Removal Action	• Zero-valent iron permeable barrier wall
R	Lower Three Runs		• RAOU	• R-Area Operable Unit
		RRSB	• R-Reactor Seepage Basin	• MNA/MZ
		RAOU-RAGW	• R-Area Groundwater	• MNA
T	Savannah River and Floodplain Swamp	TNX	• TNX Groundwater	• *SVE* - MicroBlowers™ and BaroBalls™ • *Pump & Treat (Air Stripper) (Completed)* • Bioremediation using Edible Oil
Z	Upper Three Runs	Z Area	• Saltstone	• Characterization in progress