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**POSTCLOSURE GROUNDWATER REMEDIATION AND MONITORING AT THE
SANITARY LANDFILL, SAVANNAH RIVER SITE – TRANSITIONING TO
MONITORED NATURAL ATTENUATION**

Jeffrey A. Ross, Thomas F. Kmetz
Bechtel Savannah River Inc., Soil and Groundwater Closure Project
Aiken, SC 29808

David C. Noffsinger, Walter P. Kubilius
Washington Savannah River Company, Soil and Groundwater Closure Project
Aiken, SC 29808

Karen M. Adams
Department of Energy - Savannah River, Soil and Groundwater Project
Aiken, SC 29808

ABSTRACT

Resource Conservation and Recovery Act (RCRA) requirements for hazardous waste facilities include 30 years of post-closure monitoring. The use of an objective-based monitoring strategy allows for a significant reduction in the amount of groundwater monitoring required, as the groundwater remediation transitions from an active biosparging system to monitored natural attenuation.

The lifecycle of groundwater activities at the landfill has progressed from detection monitoring and plume characterization, to active groundwater remediation, and now to monitored natural attenuation and postclosure monitoring. Thus, the objectives of the groundwater monitoring have changed accordingly. Characterization monitoring evaluated what biogeochemical natural attenuation processes were occurring and determined that elevated levels of radium were naturally occurring. Process monitoring of the biosparging system required comprehensive sampling network up- and down-gradient of the horizontal wells to verify its effectiveness. Currently, the scope of monitoring and reporting can be significantly reduced as the objective is to demonstrate that the alternate concentration limits (ACL) are being met at the point of compliance wells and the maximum contaminant level (MCL) is being met at the surface water point of exposure. The proposed reduction is estimated to save about \$2M over the course of the remaining 25 years of postclosure monitoring.

INTRODUCTION

Sanitary Landfill History

The 55-acre Sanitary Landfill Facility (SLF) received wastes from 1974 until 1994 and was closed with a geosynthetic cap in 1997. Detection monitoring began in 1975 and a monitoring well network consisting of 89 wells by 1996 indicated the presence of organic contamination.

Groundwater remediation began in 1999 with the operation of a biosparging system, which included the injection of air and nutrients to promote aerobic cometabolic destruction of chlorinated volatile organic contaminants (cVOC). Groundwater modeling demonstrated that decreasing concentrations due to the cover and natural physical attenuation processes would reduce cVOC concentrations to below MCLs prior to discharge to downgradient surface water. Thus, an ACL/Mixing Zone was approved by the state for six cVOCs in 2003. Subsequently, the biosparging system was suspended in 2005 as vinyl chloride concentrations dropped below the ACL value.

The Savannah River Site (SRS) is a 310 square-mile facility owned by the U.S. Department of Energy (DOE) near Aiken, South Carolina. The SLF is an unlined landfill situated in the northwest quadrant of SRS and covers 55 acres. Figure 1 shows the location of SRS and SLF.

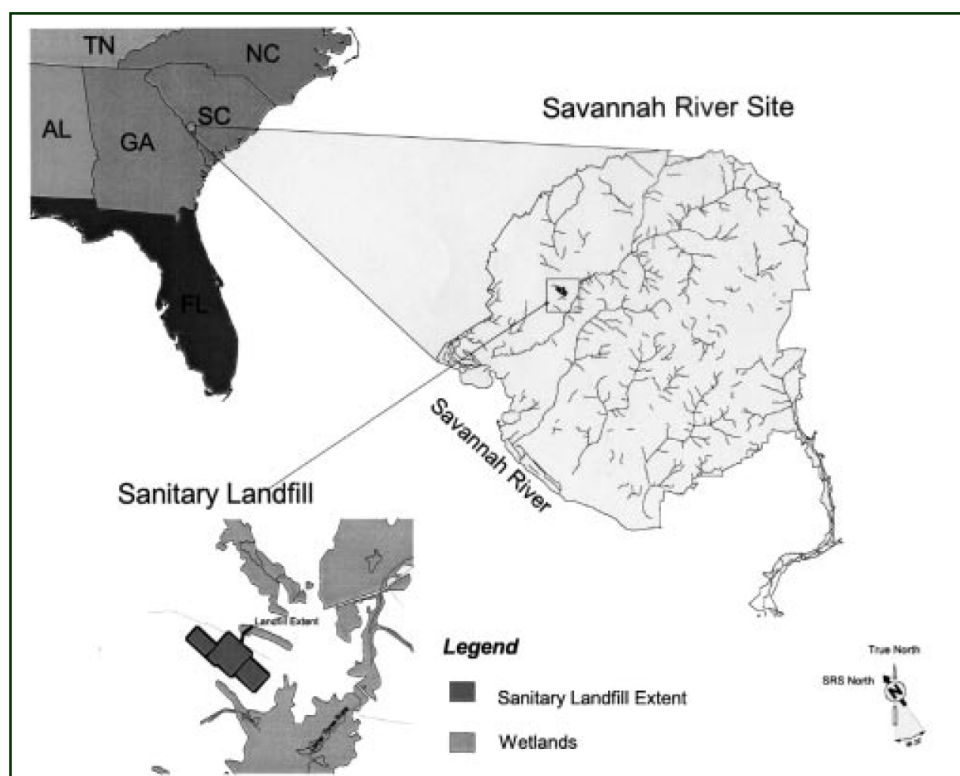


Figure 1. Location of the Sanitary Landfill at the Savannah River Site

From the early 1970s until the mid-1990s, SLF accepted sanitary wastes at SRS, including materials such as office wastes, cafeteria wastes, construction debris, and wastewater treatment sludge. In the late 1980s, elevated levels of hazardous compounds were detected in the groundwater. Based on the identification of solvent rags and wipes as part of the waste stream, the South Carolina Department of Health the Environmental Control (SCDHEC) required submittal of a Closure Plan and a RCRA Postclosure Part B Permit Application in 1993. Closure of the landfill was completed through installation of a RCRA-style geosynthetic cap in 1997. The landfill cap minimizes infiltration and enhances the reductive dechlorination of

contaminants in groundwater beneath the landfill. The key contaminants found in the groundwater were chlorinated solvents, including trichloroethene (TCE), cis-1,2-dichloroethene (DCE), and vinyl chloride, at concentrations above the MCL in point-of-compliance (POC) wells adjacent to the landfill. The water table is about 20 feet below the ground surface at the landfill, and discharges to a wetland and Upper Three Runs Creek located about 1000 feet downgradient. Biosparging was chosen as the RCRA corrective action, which Biosparging activities began in August 1999. The location of the point-of-compliance wells, treatment wells, and wetlands and creek downgradient are shown in Figure 2.

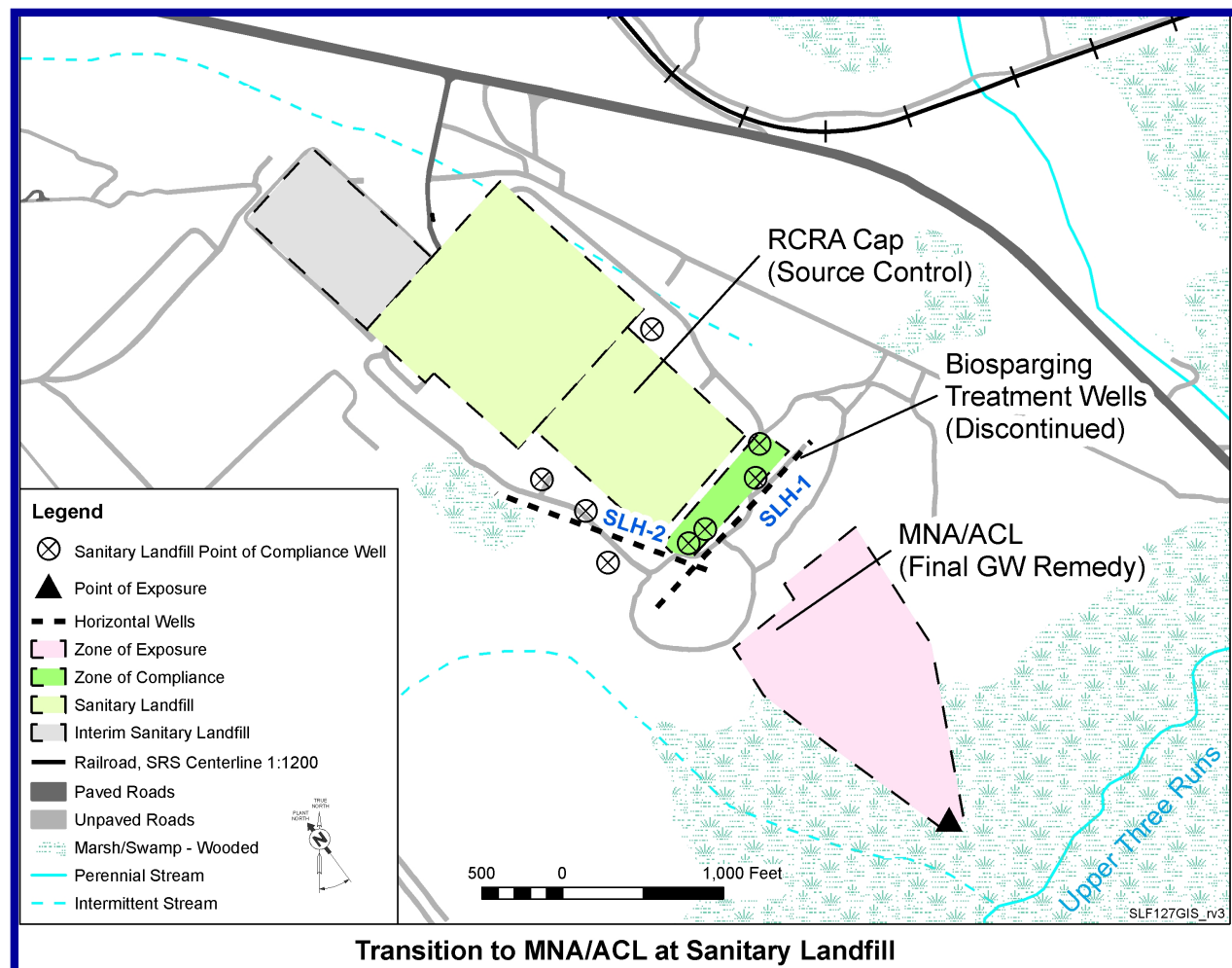


Figure 2. Sanitary Landfill remediation technologies

The 2000 RCRA Part B Permit Renewal Application for the SLF Postclosure, Vol. XXIII, Rev. 0, included an ACL / Mixing Zone Request. The final SRS hazardous waste permit that included the requirements for the SLF became effective on October 30, 2003. As part of the permit SCDHEC approved the ACL for six organic constituents. A RCRA Part B Permit Application Revision 3 that focuses on the interpretation of the radium-226, radium-228, gross alpha and 1,4-dioxane data was submitted to SCDHEC on August 16, 2004. The SCDHEC provided comments on the submittal on March 22, 2005. The SRS provided responses and Revision 4 of

the 2000 RCRA Part B Permit Renewal Application for SLF Postclosure in December 2005. This latest revision contains the significant changes to the groundwater monitoring and reporting that are the subject of this paper. Revision 4 is currently under review by SCDHEC.

Objective-based Monitoring

Groundwater monitoring should be based on a set of clearly defined objectives from which monitoring data is collected to specifically fulfill those objectives. Typically these objectives directly support project decision making. The justification for the monitoring plan (e.g the number of wells, frequency of sampling, laboratory analysis, reporting frequency) should be tied to the data quality objectives and uncertainties that require data in order to make project decisions. The decisions and thus the objectives to be met may vary depending on the type or stage of the project. The SLF, as a permitted hazardous waste disposal facility, is required to follow 40 Code of Federal Regulations Part 264 groundwater monitoring requirements. For Comprehensive Environmental Response, Compensation and Liability Act sites, requirements are often based on guidance [1, 2, 3, 4, 5] and negotiation with the regulators. The monitoring stages of the project can range from detection monitoring or initial characterization to post-closure monitoring. These monitoring stages or phases are summarized in Figure 3 below, which identifies four main distinct phases of monitoring specifically tailored to evaluating and implementing monitored natural attenuation [6].

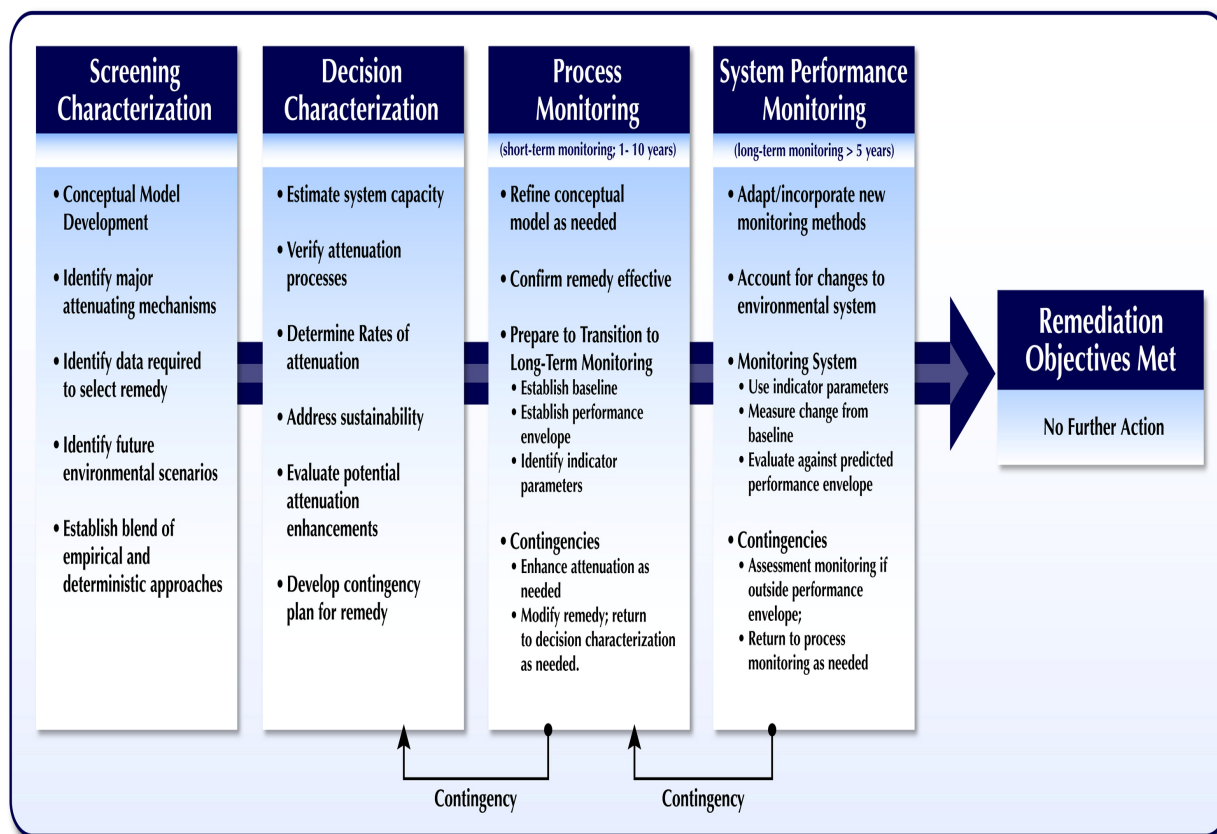


Figure 3. A Four-Phased Approach to Characterization and Monitoring

The screening characterization phase focuses on defining the problem, developing a conceptual site model and should provide enough information on the groundwater characteristics that remedial or corrective action alternatives be screened. The decision characterization phase often provides additional detailed data that supports the selection of the remedy or corrective action and helps guide the design of the remedial system. Process monitoring provides data specific to the evaluation of the effectiveness of the treatment process implemented (e.g. if biodegrading TCE, are the expected breakdown products and microorganisms present). Finally, system performance monitoring provides the data necessary to evaluate the remedial system as compared to remedial goals.

DISCUSSION

The following sections discuss how the objective-based monitoring approach has been applied to the SLF as the lifecycle of the landfill has evolved.

Compliance Monitoring

A point-of-compliance groundwater monitoring well network was installed in the water table aquifer (Steed Pond Aquifer Unit, SPAU) around the SLF beginning in 1975 to detect releases. Upon detection of hazardous constituents the well network was expanded to include plume assessment wells and piezometers downgradient of the contamination. Wells were installed in up to three clusters (different depths) based on an 80-foot thick aquifer. About 90 wells associated with the SLF currently exist. The monitoring well network was optimized to target the wells in the contaminant migration flow paths, while not diminishing the data needed for evaluating the plume movement and the remediation of the COCs. Current groundwater sampling network includes 4 background wells, 13 POC wells, 36 plume assessment wells, 8 of which also serve as corrective action effectiveness monitoring wells.

The groundwater assessment monitoring plan has three main categories of analytes: 1) corrective-action constituents, which are contaminants that exceed groundwater protection standards (GWPS) (typically MCLs), 2) compliance monitoring constituents, which are present in groundwater but do not exceed GWPS values, and 3) Appendix IX groundwater monitoring list constituents, which include over 200 constituents as specified under 40 CFR 264.99, sampled annually from POC wells. Table 1 provides a sampling schedule for the various analyte types against the type of monitoring point. This groundwater monitoring schedule is based on the 2003 RCRA Permit Renewal for the SRS.

Table I. Groundwater Monitoring Schedule at the Sanitary Landfill

Analyte Group	Sampling Frequency by Well Type			
	Background	Point-of-Compliance	Point-of-Exposure ¹	Plume Assessment
Groundwater Protection Standard List: Corrective Action/ACL/MZ Constituents	Semi-Annually	Semi-Annually	Annually	Annually
Groundwater Protection Standard List: Compliance Monitoring Constituents	Semi-Annually	Semi-Annually	NA	NA
Appendix IX Constituents	Annually	Annually	NA	NA
Field Parameters (pH, turbidity, specific conductivity, alkalinity, temperature)	Semi-Annually	Semi-Annually	NA	Annually
Synchronous Water Elevations	Semi-Annually	Semi-Annually	NA	Semi-Annually

NA – Not Applicable

¹The location of the POE was selected as the first measurable point where surface water can be consistently sampled in the wetland downgradient from the SLF (SWSP-5).

Corrective Actions

Based on the compliance monitoring program, twelve corrective action constituents are identified at the SLF. These consist of seven volatile organics, including PCE, TCE, cis-1,2,-DCE, vinyl chloride, 1,1-DCE, dichloromethane, and benzene. 1,4-dioxane was recently identified. Mercury is the only metal, and radium-226, radium-228, gross alpha, and tritium were also present above MCLs.

Biosparging system

A biosparging system was constructed in 1997 to 1998 to address VOC contamination in groundwater, specifically targeting elevated levels of TCE and VC contamination in the upper 30 feet of the aquifer. The biosparging system stimulates the degradation of contaminants by providing air, nutrients and energy sources to indigenous microbes. To intercept contaminants in groundwater, two horizontal wells were installed in the saturated zone directly south and southeast of the SLF. The horizontal well screens are 800 ft and 900 ft long, and at that time were the longest horizontal remediation wells operating in the United States. The average depth of the wells is 60 feet below ground surface. with the use of two horizontal injection wells. The system began operation in August of 1999, and operated on two-week injection cycles. In SLH-1 (see figure 3) methane, air, and nutrients (nitrous oxide and triethyl phosphate) were injected into the aquifer zone to stimulate the growth of methanotropic (methane oxidizing) organisms for

the complete mineralization of TCE. In SLH-2, air and nutrients were injected for the aerobic degradation and volatilization of vinyl chloride.

Process monitoring data was collected to evaluate the effectiveness of the biosparging system during (FY99-03). This objective was achieved in part by monitoring groundwater from background, upgradient, and downgradient (effectiveness monitoring) wells for key biological and geochemical parameters. Microbial techniques were used to assess structural and functional differences including bacterial densities and methanotrophic populations in SLF groundwater. Geochemical parameters including dissolved oxygen (DO), redox potential, pH, and key ions (nitrate, chloride, phosphate, and potassium). In addition, ethane (a vinyl chloride breakdown product), methane, and chlorinated solvents were also measured. Overall, this data showed that *in situ* microbial populations were favorably altered resulting in increased indigenous biodegradation of chlorinated solvents [7]. Based on this data, methane injection in SLH-1 was discontinued in January 2001.

ACL/Mixing Zone Demonstration

Concurrently with operation of the biosparging system, an ACL/mixing zone demonstration [8] was developed to establish ACL values for the corrective action constituents at the POC. It was demonstrated through both groundwater modeling and empirical data that through monitored natural attenuation, concentrations of these contaminants were below MCLs at the point-of-exposure (POE) in the wetland downgradient of the LFW (see figure 3). The ACL/mixing zone was approved by SCDHEC in the permit renewal for six of the VOCs. Based on the infrequent occurrence of the other constituents above MCLs, it was determined an ACL was not needed for those constituents. As a result, the biosparge system was placed in a stand-by mode in March 2005, as concentration levels of all corrective action constituents continued to remain below their respective ACLs at the POC for three consecutive sampling events in 2004.

Remedy characterization data that was key to supporting the ACL/mixing zone demonstration included contaminant data from the seep line and Upper Three Runs Creek that showed that the groundwater plume was not discharging above MCLs to surface water.

Naturally occurring constituents

In 2002, gross alpha as well as radium-226 and radium-228 detections were observed in several SLF groundwater monitoring wells above the GWPS (15 pCi/L for gross alpha and 5 pCi/L for combined radium). Comparison to historical data collected in the early 1990's indicated similar levels, and a spatial distribution inconsistent with the organic contaminant plume. Additional characterization monitoring of groundwater was conducted, including analysis for the naturally occurring radionuclide parents uranium-238 and thorium-232 and the daughter products expected to be in secular equilibrium.

A wide variety of evidence from both SRS and off-site locations was used to evaluate the occurrence of these radionuclides in SLF groundwater. Information included 3-D spatial analysis, consideration of groundwater flow paths using known contaminants as tracers, comparison of groundwater with possible leachate compositions, time trending of landfill

contaminants, pH calculations, gamma ray core logs and airborne gamma survey data, and core sediment examination. The conclusion was reached that gross alpha and radium-226 are entering deep groundwater at the base of the SPAU through acidification by natural oxidation of pyrite in clays within the confining unit beneath the aquifer. Radium-228 is naturally elevated in wells screened above 150 msl due to the presence of a stratigraphic sediment layer, identifiable regionally at a similar structural elevation, which is naturally rich in thorium-bearing minerals based on the aerial overflight data and field identification. [9]

RESULTS

Monitoring data collected since 1987 has included over 3000 individual polychlorinated biphenyl (PCB) and dioxin/furan records. These constituents have been required as part of the Appendix IX analysis. Only a single unqualified detection of any of these constituents has ever occurred, at a background well where both previous and subsequent results were non-detect. Further, there is no record of PCB disposal, nor burning of wastes at SLF that could produce Dioxins/Furans, and PCBs and Dioxins/Furans are generally insoluble, thus not expected in groundwater. Additionally, closure of SLF with a geosynthetic cover significantly reduces likelihood that any new constituents will migrate to groundwater; no new compliance monitoring constituents have been identified since 2001. Based on these lines of evidence, and the recent promulgation of the RCRA burden reduction initiative that allows for a reduction in the Appendix IX analysis [10], SRS has requested that these constituents be removed from the analysis list. It is expected that the analyte list will be further reduced in the future in the postclosure monitoring phase as trend data indicates that many of the compliance monitoring constituents are no longer detected.

As part of the monitoring network, SRS has been monitoring deep “B”-series wells at the base on the SPAU. Analysis of the long-term trend data indicate that no significant detections of corrective action or compliance monitoring constituents have been detected at these wells and that flow modeling indicates these “B” wells are significantly deeper than flow paths from the SLF. Thus, SRS has requested that these wells be removed from the list of wells to be monitored.

The most significant monitoring change that was requested is based on the shift from operating the biosparging wells to an ACL/mixing zone as the current corrective action. Data from downgradient plume assessment well locations no longer are useful in making project decisions, therefore sampling from most of these wells can be suspended. Figure 4 shows the current spatial distribution of the various wells types at the SLF. Since the corrective action constituents have an approved ACL/mixing zone value at the POC and POE sampling locations, decisions are not based on plume assessment well data (shown in yellow in Figure 4). Since the biosparge system is not operating, data to monitor the effectiveness of that system is not needed. All constituents with the exception of 1,4-dioxane are only infrequently detected in the plume assessment wells, the no discernable plumes exist to monitor. Gross alpha, radium-226, and radium-228, considered naturally occurring, no longer require monitoring in plume assessment wells. However, some of the upgradient plume assessment wells LFW 10A, -18, -21, -6R, and -45D, will be retained for sampling to provide data on COCs relative to future expected concentrations at POC wells and on COCs potentially related to the Interim SLF, a solid waste

landfill adjacent to the SLF. The plume assessment wells with suspended sampling will not be proposed for abandonment until time of abandonment of biosparge system.

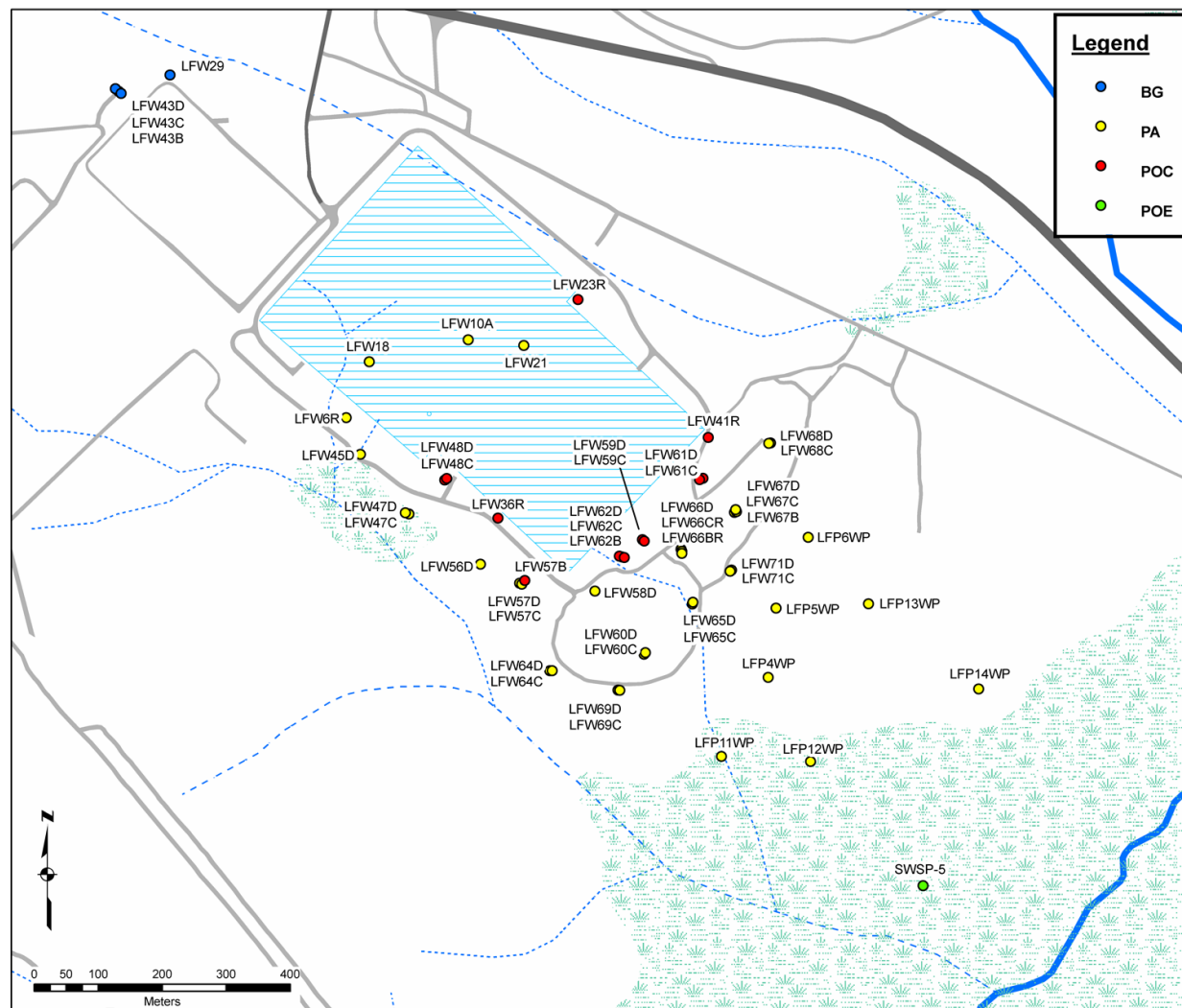


Figure 4. Monitoring well network at the SLF.

In addition to the reduction in monitoring of both wells and analytes, the SRS is currently required to provide SCDHEC with semi-annual reports required during corrective action activities per the South Carolina Hazardous Waste Management Regulation (SCHWMR) 264.100(g). With the cessation of active biosparging and reduced sampling frequency, the value of providing a semi-annual report is limited. No operational data is collected, and semi-annual data is only collected at POC wells, therefore limited spatial data is available to present and interpret. SRS has recommended that an annual report is adequate, with notification to the state should any results exceed ACLs at the POC. This should be allowable based on the RCRA burden reduction initiative.

CONCLUSIONS

The lifecycle of groundwater activities at the landfill has progressed from detection monitoring and plume characterization, to active groundwater remediation, and now to monitored natural attenuation and postclosure monitoring. Thus, the objectives of the groundwater monitoring have changed accordingly. Characterization monitoring evaluated what biogeochemical natural attenuation processes were occurring and determined that elevated levels of radium were naturally occurring. Process monitoring of the biosparging system required comprehensive sampling network up- and down-gradient of the horizontal wells to verify its effectiveness. Currently, the scope of monitoring and reporting can be significantly reduced as the objective is to demonstrate that the alternate concentration limits (ACL) are being met at the point of compliance wells and the maximum contaminant level (MCL) is being met at the surface water point of exposure. The proposed reduction is estimated to save about nearly \$100K per year, or about \$2M over the course of the remaining 25 years of postclosure monitoring. It is expected that the analyte list will be further reduced in the future as part of postclosure monitoring, as trend data indicates that many of the compliance monitoring constituents are no longer detected.

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