Post-Closure Groundwater Remediation and Monitoring at The Sanitary Landfill, Savannah River Site – Transitioning to Monitored Natural Attenuation

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ABSTRACT

Resource Conservation and Recovery Act (RCRA) requirements for hazardous waste facilities include 30 years of post-closure monitoring. At Savannah River Site (SRS), implementation of an objective-based monitoring strategy has significantly reduced the amount of groundwater monitoring required as groundwater remediation transitions from an active biosparging system to monitored natural attenuation.

The lifecycle of groundwater activities at the SRS Sanitary Landfill (SLF) has progressed from detection monitoring and plume characterization, to active groundwater remediation, and now to monitored natural attenuation and post-closure 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. The present 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. As estimated, the proposed reduction will save nearly $2.5M over the course of the remaining 25 years of post-closure monitoring.

INTRODUCTION

Sanitary Landfill History

The 55-acre Sanitary Landfill Facility (SLF) received wastes from 1974 until 1994 and was closed with a Resource Conservation and Recovery Act (RCRA)-style geosynthetic cap in 1997. Detection monitoring began in 1975. By 1996, a monitoring well network of 89 wells had been established. Sampling results 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 (cVOCs). Groundwater modeling demonstrated that concentration reductions due to the cover and natural physical attenuation processes would result in cVOC concentrations below maximum contamination levels (MCLs) prior to discharge to downgradient surface water. Thus, an alternate concentration limit (ACL)/Mixing Zone was approved by the South Carolina Department of Health and Environmental Control (SCDHEC) in 2003. After vinyl chloride concentrations dropped below the ACL value, the biosparging system was suspended in 2005.

The Savannah River Site (SRS) is a 310 square-mile facility owned by the U.S. Department of Energy (USDOE) 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 the SLF within SRS.

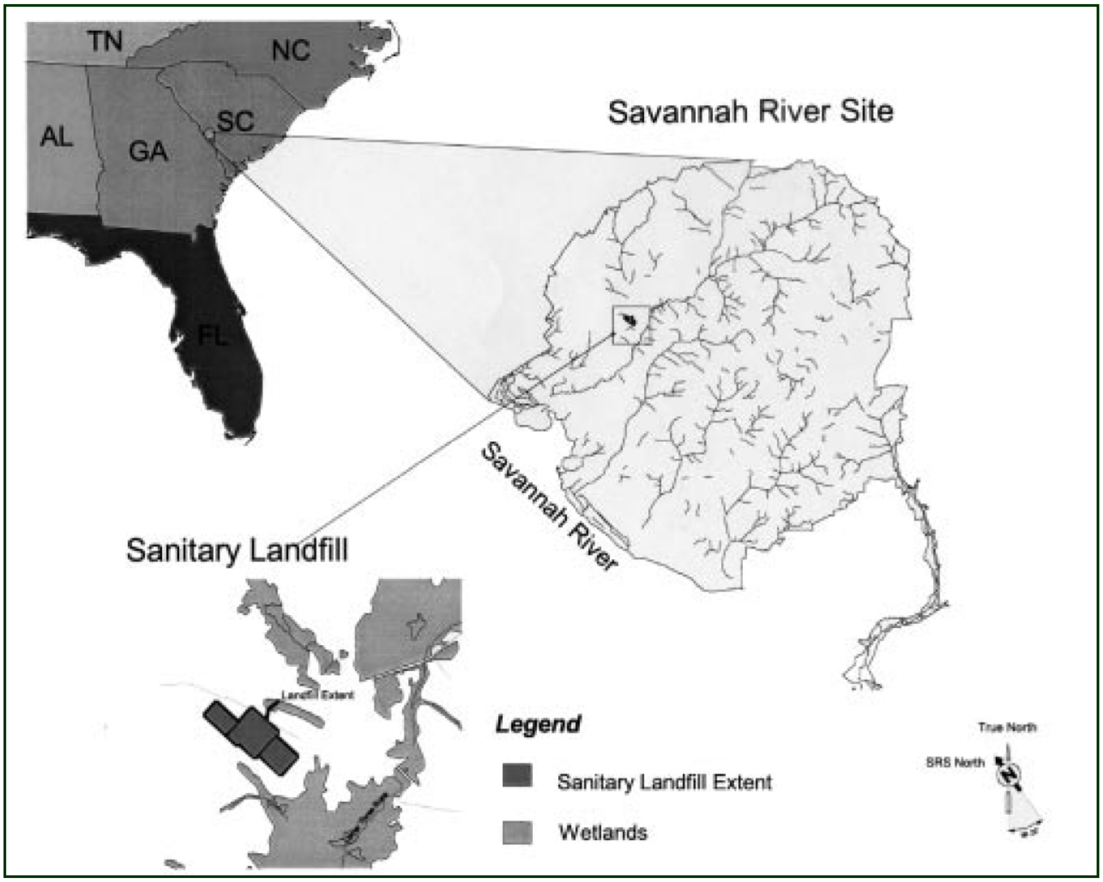

Figure 1. Location of the Sanitary Landfill at the Savannah River Site

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. In 1993, SCDHEC required submittal of a Closure Plan and a RCRA Postclosure Part B Permit Application based on the identification of solvent rags and wipes in the waste stream. In 1997, a RCRA-style geosynthetic cap was installed over the landfill. The landfill cap both minimizes infiltration and enhances the reductive dechlorination of contaminants in groundwater beneath the landfill. 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, which are located about 1,000 feet downgradient.

Biosparging was chosen as the RCRA corrective action, and operation of the biosparging system began in August 1999. The locations of the POC wells, treatment wells, and wetlands and creek downgradient are shown in Figure 2.

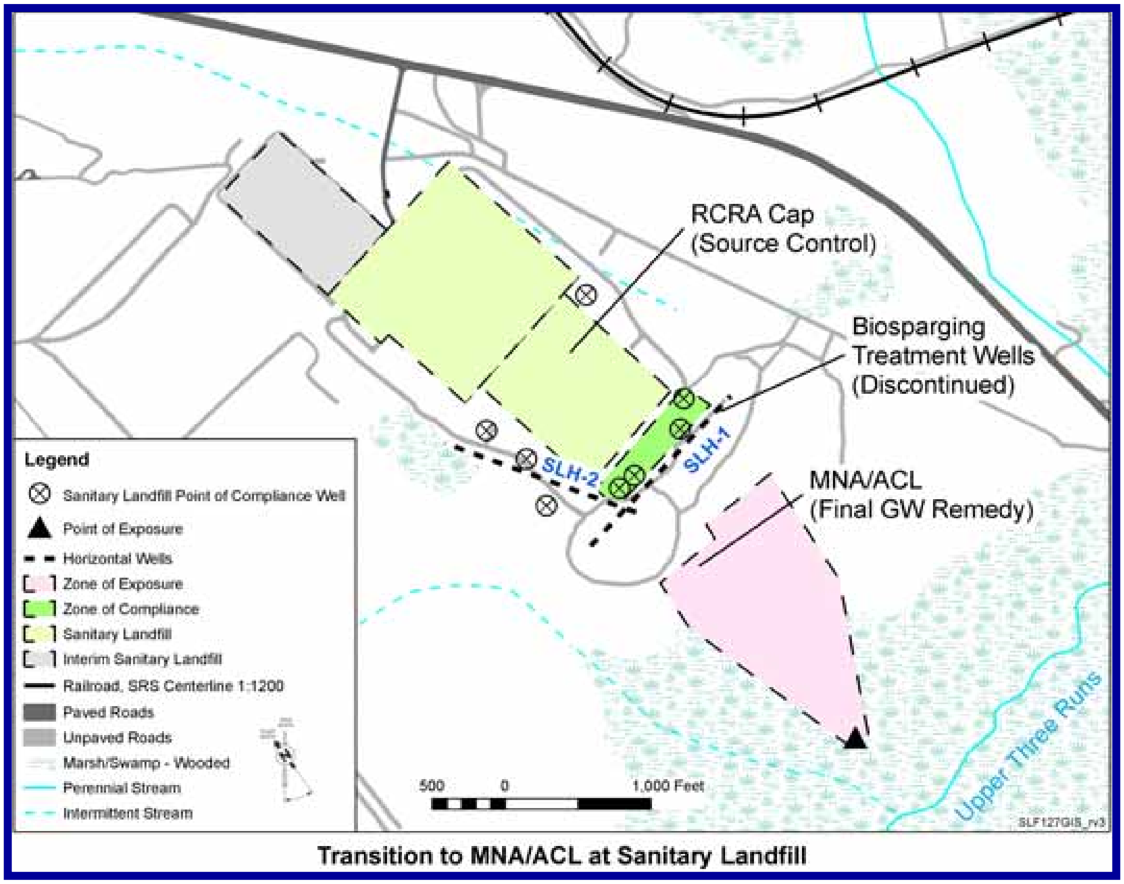

Figure 2. Sanitary Landfill remediation technologies

The 2000 RCRA Part B Permit Renewal Application for the SLF Postclosure, Vol. XXIII, Rev. 0, included an alternate concentration limit (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 ACLs for tetrachloroethene, TCE, cis-1,2-DCE, vinyl chloride, benzene, and dichloromethane. A revised RCRA Part B Permit Application (Revision 3) that focused on interpretation of radium-226, radium-228, gross alpha and 1,4-dioxane data was submitted to SCDHEC on August 16, 2004. SCDHEC provided comments on the submittal on March 22, 2005. SRS responses culminated in 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. (This revision is currently under review by SCDHEC.)

Objective-based Monitoring

In order to collect the appropriate quantity and type of data, groundwater monitoring should be based on a set of clearly defined 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.

As a permitted hazardous waste disposal facility, the SLF 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. Monitoring objectives will vary over time and will depend on the phase or life-cycle of the project or facility being monitored. For example, the objectives of detection monitoring are different than monitoring to evaluate the effectiveness of a remediation system. Figure 3, identifies four main distinct phases of monitoring, which have been specifically tailored to evaluate and implement monitored natural attenuation [6].

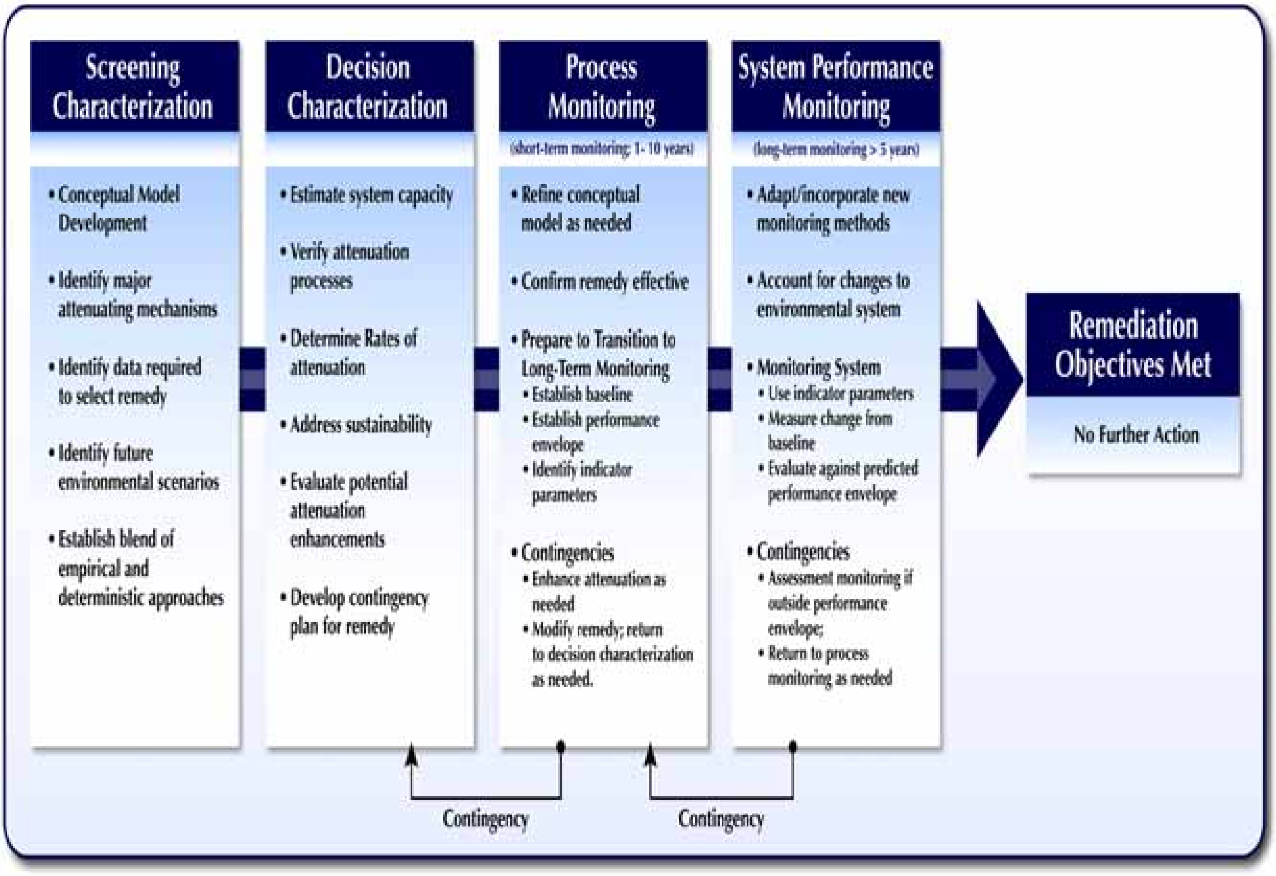

Figure 3. A four-phased approach to monitoring

The screening characterization phase focuses on defining a problem and developing a conceptual site model. Analysis performed during this phase should provide enough information on groundwater characteristics to allow screening of remedial or corrective action alternatives. The decision characterization phase provides additional detailed data to support the selection of the remedy or corrective action and helps guide the design of the remedial system. Process monitoring provides data specific to evaluation of the effectiveness of the treatment process implemented (e.g., if biodegrading TCE, are the expected breakdown products and microorganisms present?). The final phase, system performance monitoring, provides the data necessary to compare the remedial system to remedial goals.

DISCUSSION

The following sections discuss how the objective-based monitoring approach has been applied to collect data appropriate to the specific lifecycle of the SLF as it has evolved through various phases over time.

Compliance Monitoring

Beginning in 1975, a POC groundwater monitoring well network was installed in the water table aquifer (Steed Pond aquifer unit [SPAU]) around the SLF 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 to evaluate the plume movement and the remediation of the constituents of concern. The current groundwater sampling network includes 4 background wells, 13 POC wells, and 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. These constituents include dioxin/furans and polychlorinated biphenyls (PCB)s. Table I 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.

Corrective Actions

Based on the compliance monitoring program, twelve corrective action constituents have been 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 stimulates the degradation of contaminants by providing air, nutrients, and energy sources to indigenous microbes. From 1997 to 1998, a biosparging system was constructed to address volatile organic compound (VOC) contamination in groundwater, specifically targeting elevated levels of TCE and vinyl chloride in the upper 30 feet of the aquifer. To intercept these groundwater contaminants, 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.

Table I. Groundwater Monitoring Schedule at the Sanitary Landfill

	Sampling Frequency by Well Type			
Analyte Group	**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	N/A	N/A
Appendix IX Constituents	Annually	Annually	N/A	N/A
Field Parameters (pH, turbidity, specific conductivity, alkalinity, temperature)	Semi-Annually	Semi-Annually	N/A	Annually
Synchronous Water Elevations	Semi-Annually	Semi-Annually	N/A	Semi-Annually

N/A – Not Applicable

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

The system began operation in August of 1999, and operated on two-week injection cycles. In SLH-1 (see Figure 2) 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 1999 through 2003. 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, ethene (a vinyl chloride breakdown product), methane, and chlorinated solvents were also measured. Overall, these 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. Using both groundwater modeling and empirical data, it was demonstrated that natural attenuation by physical mechanisms alone could reduce concentrations of these contaminants below MCLs at the POE in the wetland downgradient of the LFW (see Figure 2). The ACL/mixing zone was approved by SCDHEC in the permit renewal for six of the VOCs. Because the other constituents were usually below MCLs, it was determined an ACL was not needed for those constituents. Upon regulatory approval of the ACLs, which were 4 to 6 times higher than the MCLs for the six VOCs, the need to continue operation of the biosparging system could be evaluated against this new set of ACLs. The biosparging system was subsequently placed in a stand-by mode in March 2005 since 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 seepline and Upper Three Runs Creek. These data 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). Data from these wells was compared to historical data collected in the early 1990s and results 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 evaluation revealed 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 mean sea level (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. This correlation was made based on the aerial overflight gamma radiation data and field identification of the sediment layer. [9]

RESULTS

Based on the data collected as described earlier, and understanding that the SLF is now in the post-closure monitoring phase, the objective-based monitoring approach can be applied to further refine the monitoring plan for the SLF.

Monitoring data collected since 1987 has included over 3,000 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. Both previous and subsequent results were non-detect, and the detection was at a background well. Further, there is no record of PCB disposal or 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 cap 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 list of analytes. It is expected that the analyte list will be further reduced in the future in the post-closure monitoring phase as trend data indicate 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 (screened below 80 feet msl) at the base of the SPAU. Analysis of the long-term trend data indicates that no significant 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 are no longer 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 biosparging system is not operating, data to monitor the effectiveness of that system is not needed. Data from two POC wells and two plume assessment wells, shown in Table II below, demonstrate how TCE and vinyl chloride concentrations have decreased over time. For TCE, the ACL is 21 µg/L. The last exceedance of this value in POC well LFW59D was in 2002. TCE concentrations have been below the MCL (5 µg/L) in downgradient well LFW65D since 2001. For vinyl chloride, the ACL is 12.1 µg/L. The last exceedance of this value in POC well LFW36R was in 2003. In downgradient well LFW58D, VC concentrations dropped quickly to non-detect levels in response to the biosparging that began in late 1999. Recent low level detections below the ACL are not unexpected given the cessation of biosparging in 2005. Finally, 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, including LFW 10A, -18, -21, -6R, and -45D, will be retained for sampling to provide data on constituents of concern relative to future expected concentrations at POC wells and on constituents potentially related to the Interim SLF, a solid waste landfill adjacent to the SLF.

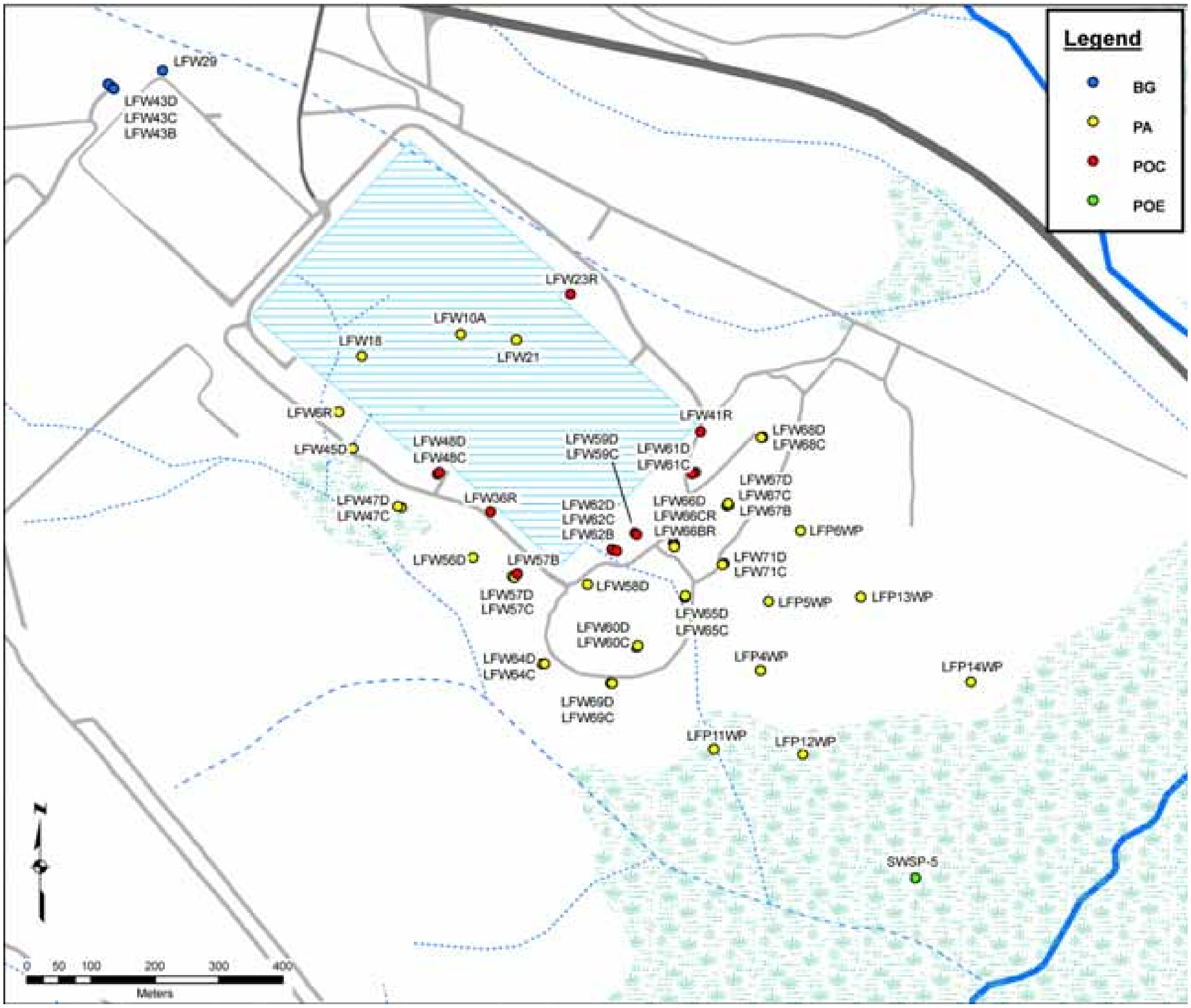

Figure 4. Monitoring Well Network at the SLF

Table II. Groundwater Monitoring Data for Selected Wells at the Sanitary Landfill

Date	TCE (μg/L) in LFW59D	TCE (μg/L) in LFW65D	VC (μg/L) in LFW36R	VC (μg/L) in LFW58D
13-Sep-1999	31	4.9	11	12
15-Dec-1999	12	7.1	37	10
7-Mar-2000	5.3	5.7	18	2.7
12-Jun-2000	4.5	7.2	27	ND
22-Sep-2000	7.5	5.7	19	ND
6-Nov-2000	5.5	5.6	14	ND
15-Jan-2001	15	6.2	12	ND
17-Apr-2001	ND	3.88	13	ND
31-Jul-2001	0.693	4.26	14.5	ND
11-Oct-2001	8.15	2.55	12.3	ND
23-Jan-2002	14.4	3.41	12.8	ND
22-Apr-2002	22.3	3.44	18.3	ND
19-Jul-2002	17.4	2.95	16.6	ND
4-Nov-2002	14.5	1.83	8.89	ND
11-Mar-2003	0.992	2.44	11.1	ND
1-May-2003	ND	2.74	13.6	ND
21-Jul-2003	ND	2.62	13	ND
27-Oct-2003	2.08	2.43	9.96	ND
29-Mar-2004	3.11	1.76	10.8	ND
17-Aug-2004	15.5	NS	ND	NS
21-Mar-2005	0.44	NS	8.9	NS
26-Jul-2005	0.5	1.3	8.8	0.59
18-Jan-2006	2.6	NS	8.2	NS
24-Jul-2006	3.09	1.26	4.07	2.12

ND - Not Detected

NS – Not Sampled

VC – Vinyl Chloride

In addition to the reduction in monitoring of both wells and analytes, the SRS is currently required to provide SCDHEC with semi-annual reports during corrective action activities in accordance with 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 acceptable based on the RCRA burden-reduction initiative.

CONCLUSIONS

The lifecycle of groundwater activities at the SLF has progressed from detection monitoring and plume characterization, to active groundwater remediation, and now to monitored natural attenuation and post-closure 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 a comprehensive sampling network up- and down-gradient of the horizontal wells to verify the system’s effectiveness. Currently, the scope of monitoring and reporting can be significantly reduced as the objective is to demonstrate that ACLs are being met at the POC wells and the MCL is being met at the surface water POE. 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 post-closure monitoring, as trend data indicates that many of the compliance monitoring constituents are no longer detected.

As monitored natural attenuation becomes accepted as the final remedy or corrective action for contaminated groundwater, the use of an objective-based approach should help to define long-term monitoring programs and focus on detecting significant differences in the observed contaminant plume over time as compared to predicted conditions.

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