Modeling and Quantitative Assessment of Green and Sustainable Remediation Options for the M1 Air Stripper System at DOE SRS – 15660

David Roelant *, Ralph Nichols **, and Natalia Duque *
* Applied Research Center - Florida International University
** Savannah River National Laboratory

ABSTRACT

The effectiveness of remediation systems needs to be reviewed periodically to assess their performance over the years relative to efficiency and effectiveness. New technologies and Best Management Practices have emerged that can improve existing remediation systems. From a Green and Sustainable Remediation analysis, the higher energy and/or water usage of older systems might not be justified from an environmental protection rationale. For example, remediation systems can run intermittently and with slower flow rates, use less power, and still provide the required level of environmental remediation and protection.

This research by the Applied Research Center at Florida International University (FIU) is the preliminary phase of a Green and Sustainable Remediation (GSR) analysis of the operations of the M1 air stripper and the A/M Area groundwater remediation system at the Savannah River Site (SRS). An initial baseline analysis has helped identify opportunities for implementing Green and Sustainable Remediation (GSR) practices while maintaining the hydraulic containment and effectiveness of the remediation system. This study included the collection of contaminant recovery data from SRS reports into a database of trichloroethene (TCE) and tetrachloroethene (PCE) removal from contaminant recovery wells RWM-1 through RWM-12. Presented below are data and preliminary findings from these recovery wells. Findings show that 7 of 12 recovery wells have transitioned to more PCE removal than TCE removal; the nearby steam injection remediation of "Dynamic Underground Stripping" mobilized DNAPL and resulted in increased recovery in nearby wells.

INTRODUCTION

Since the A/M Area groundwater remediation system is expected to operate continuously for the foreseeable future, any improvements in system performance, increased contaminant recovery or decreased energy consumption, will have positive enduring benefits due to the long time frame over which the benefits will accrue. Opportunities exist to increase the rate of contaminant recovery while maintaining hydraulic containment. Increased contaminant recovery will reduce the overall time necessary to meet regulatory requirements. Options for improved contaminant recovery include restoring well efficiency and redistributing pumping within the existing network. Information compiled in the baseline analysis will be used to identify opportunities to increase contaminant recovery using existing wells.

The operation of the M1 air stripper and well network at SRS began in 1985. The system has operated continuously for over 27 years at an average electrical load of 150kW and flow rate of 420 gpm. This represents an average of 1,247,000 kW-hr of electricity consumed per year and 209,714,000 gallons pumped per year. The influent TCE concentration to the air stripper has decreased exponentially from 25,200 ug/L in 1986 to 2,230 ug/L by the end of 2012. This concentration decrease is common for groundwater remediation systems that use groundwater pumping. The M1 air stripper at SRS removed 33,231 pounds of TCE during its first full year of operation and removed 2,092 pounds of TCE during its 26^{th} year of operation while consuming the same amount of electricity and removing the same amount of water in both years. The pumping and overall electrical energy efficiency (per 1 pound of TCE removed and destroyed) has decreased to 6% of the initial year of operation. That is, it now requires 15.9 times more energy and groundwater to remove 1 pound of TCE in the 26^{th} year of operation than it did in the first year of operation. PCE was used early at SRS and operations switched to TCE in the 1970's due to the perceived hazard of PCE. PCE is many times less soluble and less volatile than TCE. For these reasons, recovery for the first 25 years has been dominated by TCE recovery and will be dominated by PCE recovery for the next 25 years. Already, PCE recovery equals or exceeds TCE recovery in 7 of 12 recovery wells. Reducing the environmental costs of the A/M groundwater remediation system will reduce the overall cost to SRS to operate the system through improved mass recovery and reduced use of energy and other site resources.

Recovery wells in the A/M Area groundwater remediation system have been operated with constant speed pumps since the system began operation. The constant speed pumps produce line pressures that range from 35 – 95 psig. In some cases, the pumps may be producing excess pressure that is not required and as a result are continuously consuming energy that is not necessary for operation. The piping diagram and operating pressure throughout the system will be studied to identify wells which may be able to operate using a smaller pump while still maintaining the same flow rate.

The overall objective of the A/M Area groundwater remediation system is to provide hydraulic containment of the most contaminated portion of groundwater until regulatory requirements are met. The M1 air stripper has operated at a constant air/water ratio since it began operation. The air/water ratio was set to treat the prevailing influent contaminant concentrations existing at start-up. Contaminant concentrations have decreased an order of magnitude during the first 27 years of operation and as a result the air/water ratio can likely be decreased. The water flow rate is set by the hydraulic containment objective and is not considered to be an option for improvement. The air flow rate, however, is based on the influent contaminant concentration. It is believed that the air flow rate can be reduced and still meet the discharge limits at the outfall receiving effluent from the M1 air stripper. Reducing the air flow rate would significantly reduce the energy demand since the M1 air stripper operates constantly.

RESULTS

The monthly rainfall at SRS from 1987 through 2012 was collected from the USGS and is plotted below in Fig. 1. Data from wet and dry periods were compared to TCE and PCE monthly removal rates without any correlations obvious via simple inspection of the data.

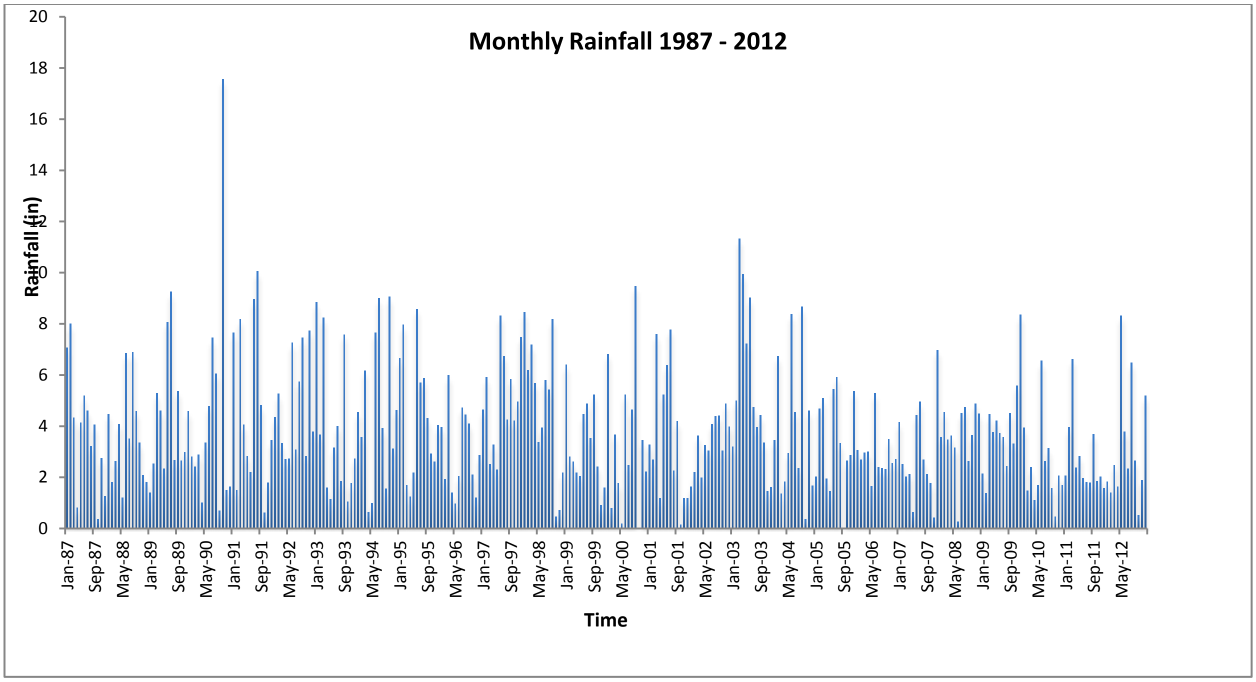

Fig. 1. Monthly Rainfall at SRS from 1987-2012

TCE and PCE monthly recovery rates, as well as pumping flow rates for this period from SRS sources had many months of missing data. SRS did have the total monthly removal rates of all wells combined for this period. FIU sifted through numerous historic site documents to identify missing data as well as specific months when specific wells were not operational. [1-9]

A significant amount of data was found in the following reports:

- 1990 M-Area Hazardous Waste Management Facility Post-Closure Care Permit Groundwater Monitoring and Corrective Action Program
- Fourth Quarter 1992 and 1992 Summary M-Area Hazardous Waste Management Facility Groundwater Monitoring Report, Volume I
- Fourth Quarter 1994 M-Area Hazardous Waste Management Facility Groundwater Monitoring and Corrective-Action Report
- Third and Fourth Quarters 1995 M-Area Hazardous Waste Management Facility Groundwater Monitoring and Corrective-Action Report
- Third and Fourth Quarters 1996 M-Area and Metallurgical Laboratory Hazardous Waste Management Facility Groundwater Monitoring and Corrective-Action Report, Volume I
- Third and Fourth Quarters 1997 M-Area and Metallurgical Laboratory Hazardous Waste Management Facility Groundwater Monitoring and Corrective-Action, Volume I
- Third and Fourth Quarters 1999 Annual M-Area and Metallurgical Laboratory Hazardous Waste Management Facility Groundwater Monitoring and Corrective-Action Report, Volume I and II

- Annual 2010 M-Area and Metallurgical Laboratory Hazardous Waste Management Facilities Groundwater Monitoring and Corrective Action Report, Volume I
- Annual 2011 M-Area and Metallurgical Laboratory Hazardous Waste Management Facilities Groundwater Monitoring and Corrective Action Report, Volume I

A baseline report projected for the end of February 2015 will contain all the information that was found.

The monthly removal rate and the cumulative mass removed for TCE and PCE in the 12 recovery wells (RWM-1 through RWM-12) are plotted on the next 6 pages. These plots use all monthly well data collected to date. For the several remaining months when wells were operating but for which there is still missing data, FIU will apportion the total recovery from 12 wells per month to each well according to its relative contribution to recovery rates prior to that month.

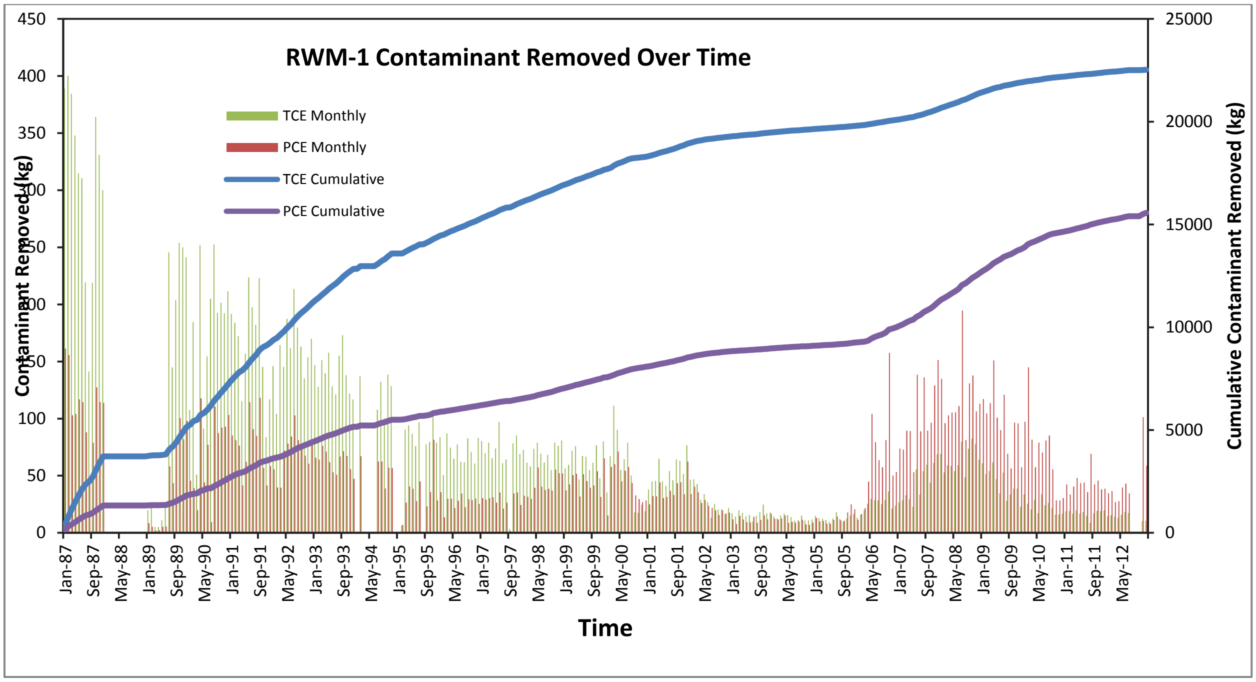

Fig. 2. TCE and PCE Removed per Month and Cumulative from 1987-2012 for RWM-1

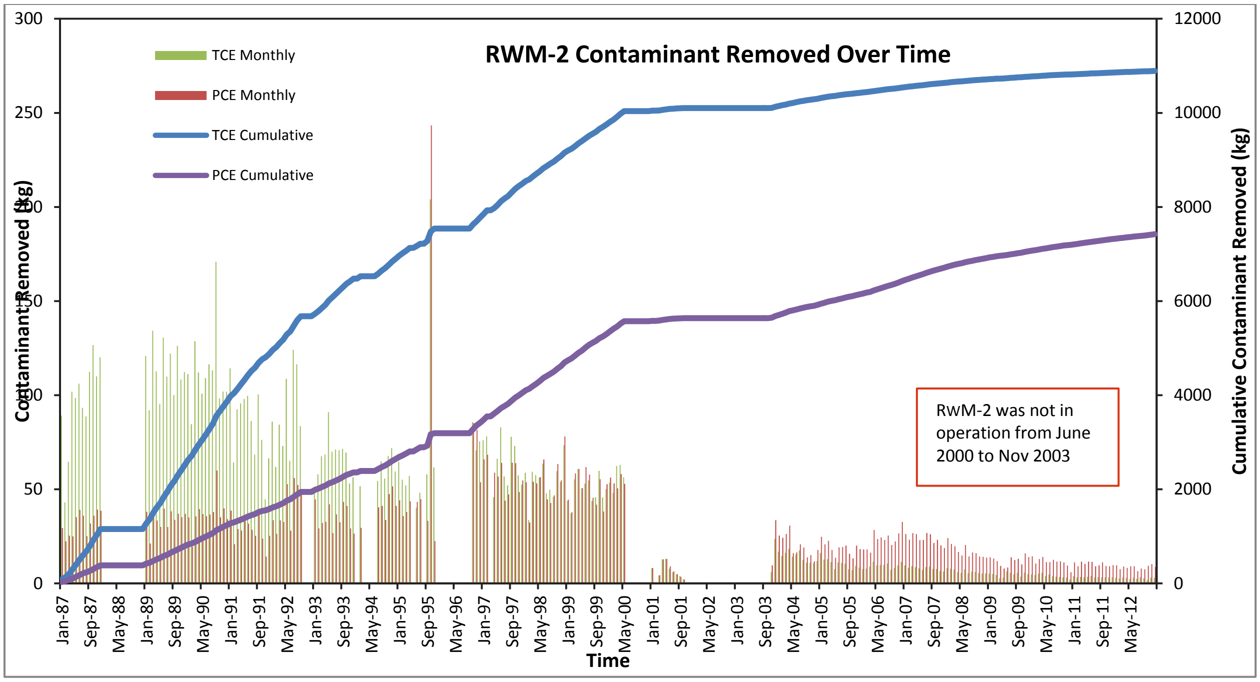

Fig. 3. TCE and PCE Removed per Month and Cumulative from 1987-2012 for RWM-2

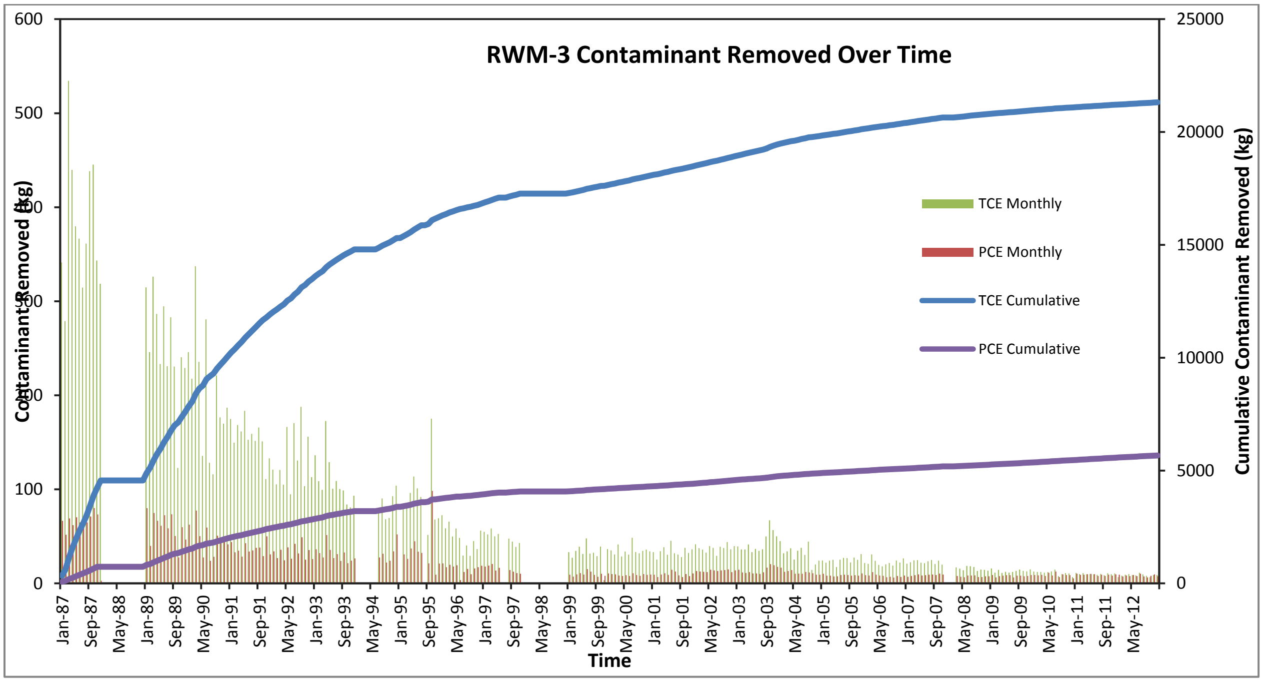

Fig. 4. TCE and PCE Removed per Month and Cumulative from 1987-2012 for RWM-3

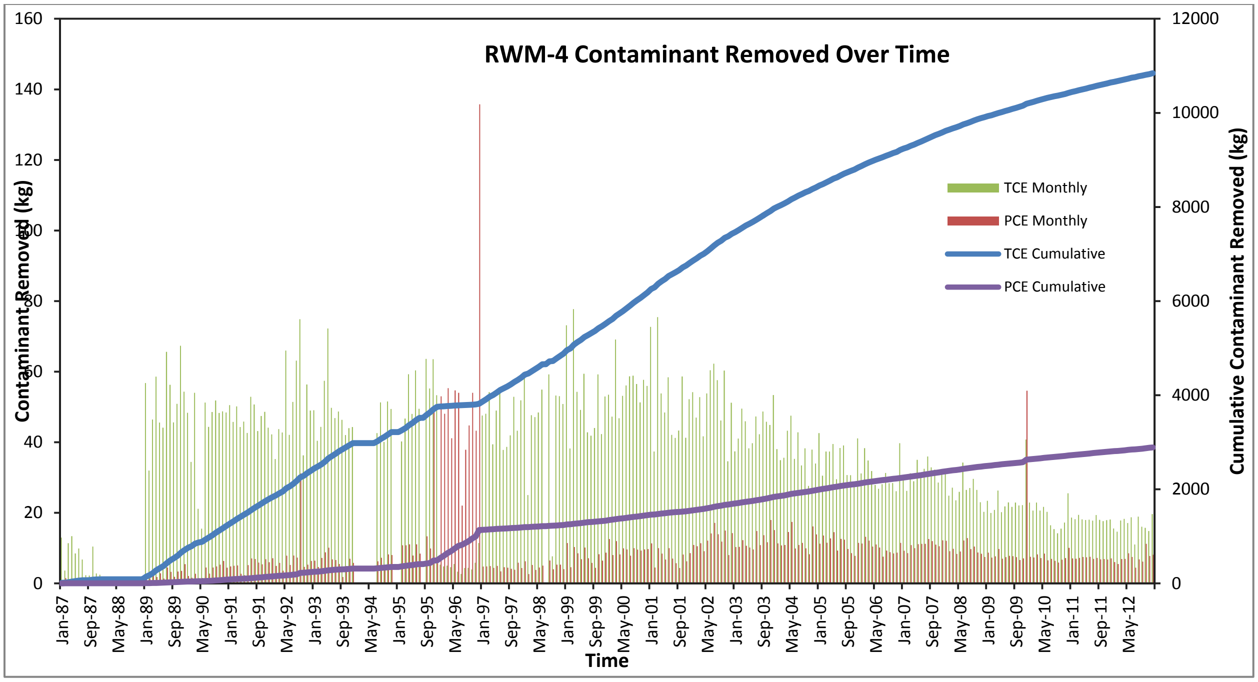

Fig. 5. TCE and PCE Removed per Month and Cumulative from 1987-2012 for RWM-4

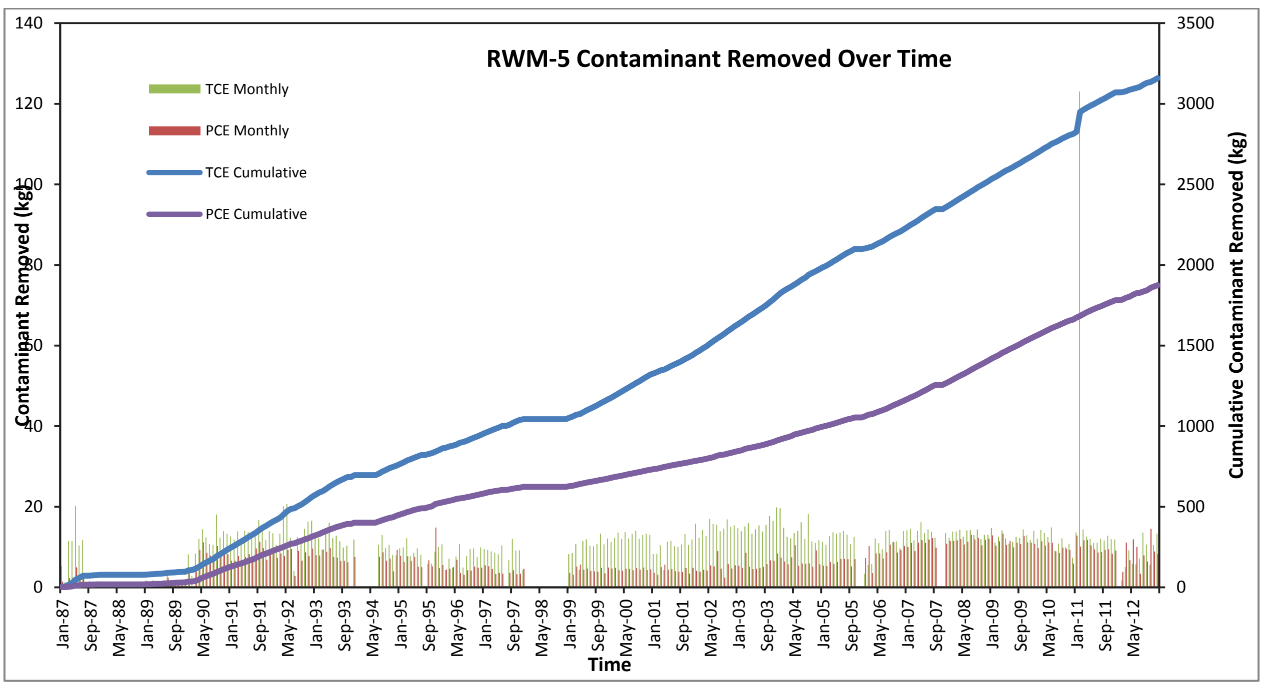

Fig. 6. TCE and PCE Removed per Month and Cumulative from 1987-2012 for RWM-5

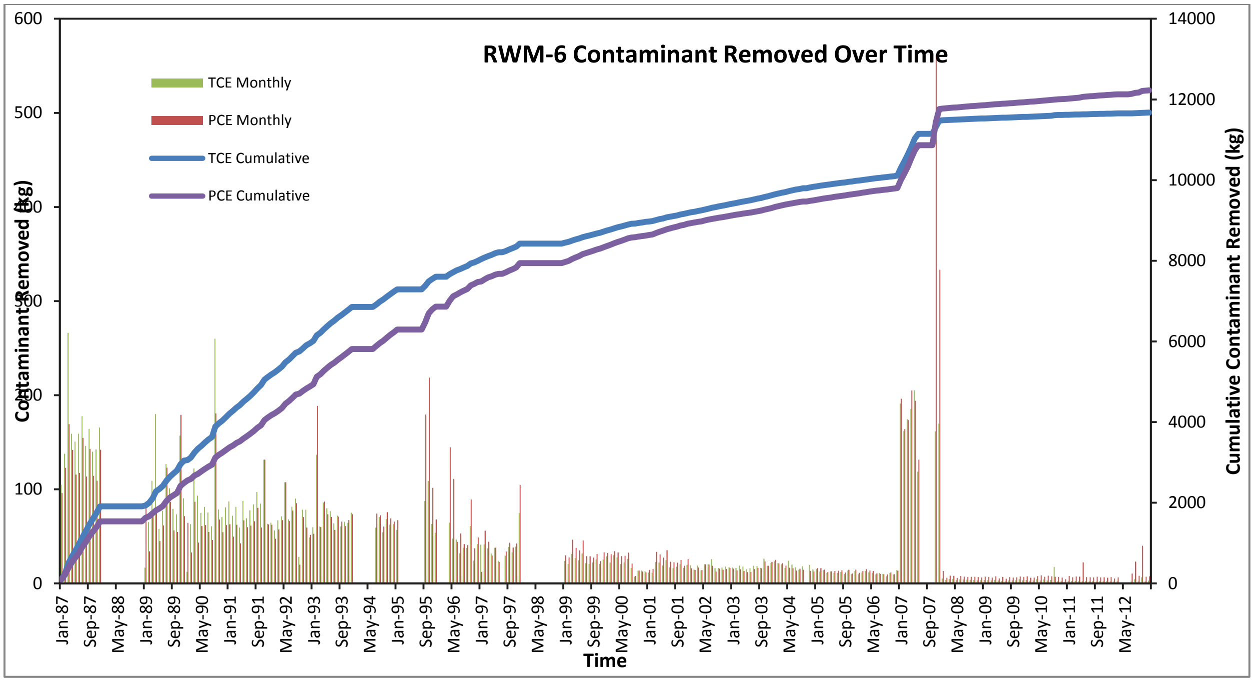

Fig. 7. TCE and PCE Removed per Month and Cumulative from 1987-2012 for RWM-6

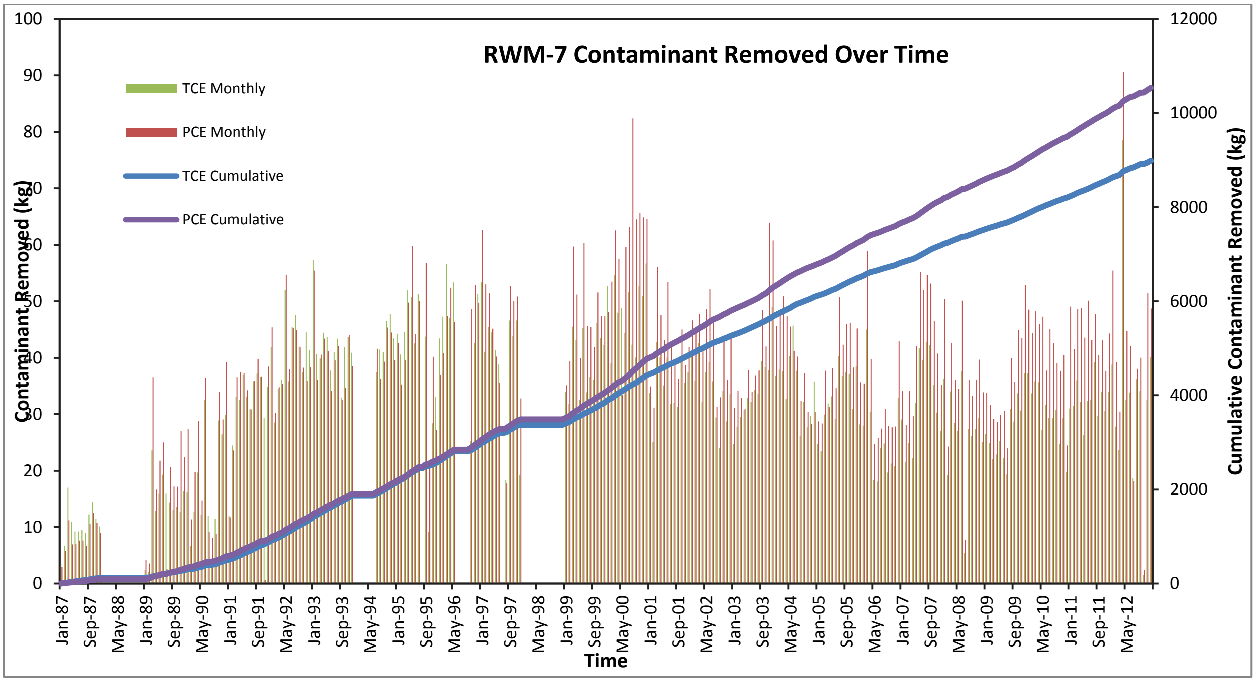

Fig. 8. TCE and PCE Removed per Month and Cumulative from 1987-2012 for RWM-7

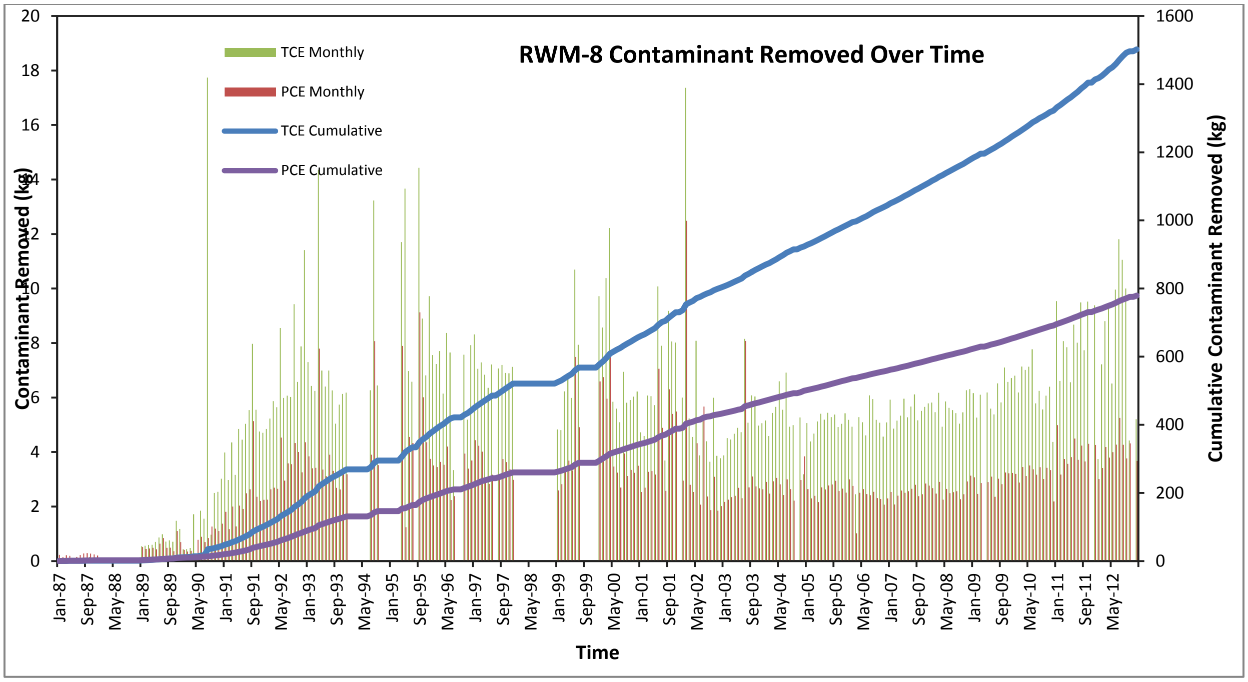

Fig. 9. TCE and PCE Removed per Month and Cumulative from 1987-2012 for RWM-8

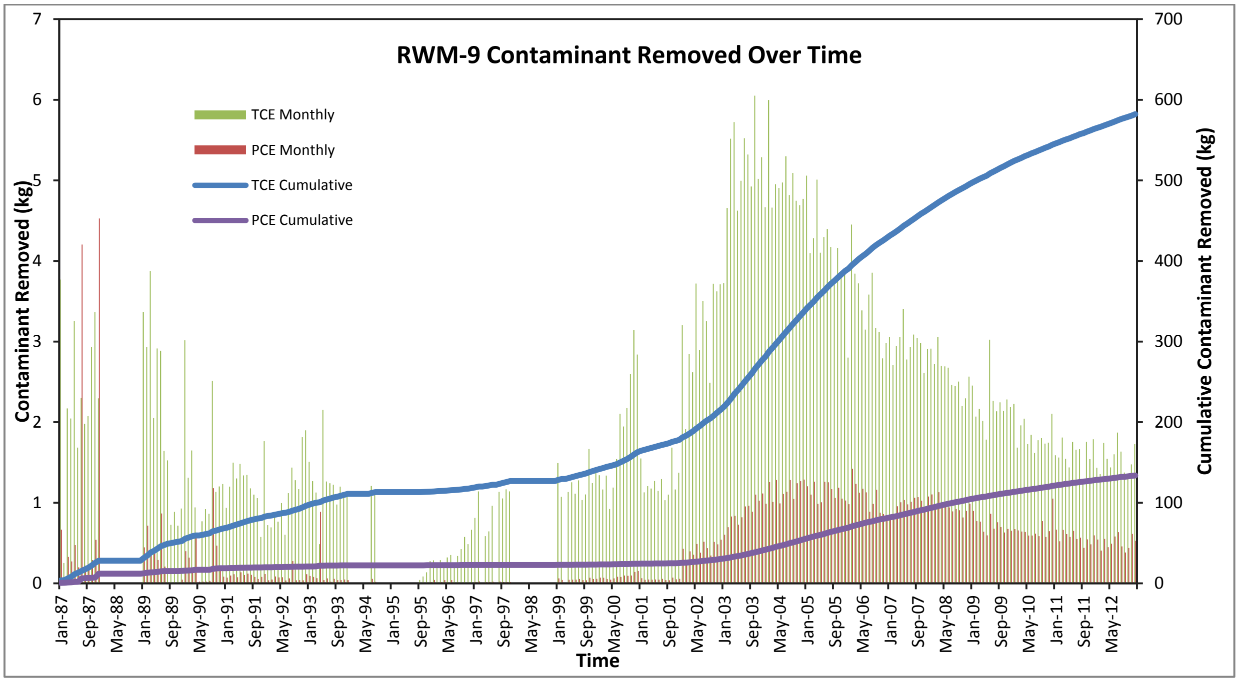

Fig. 10. TCE and PCE Removed per Month and Cumulative from 1987-2012 for RWM-9

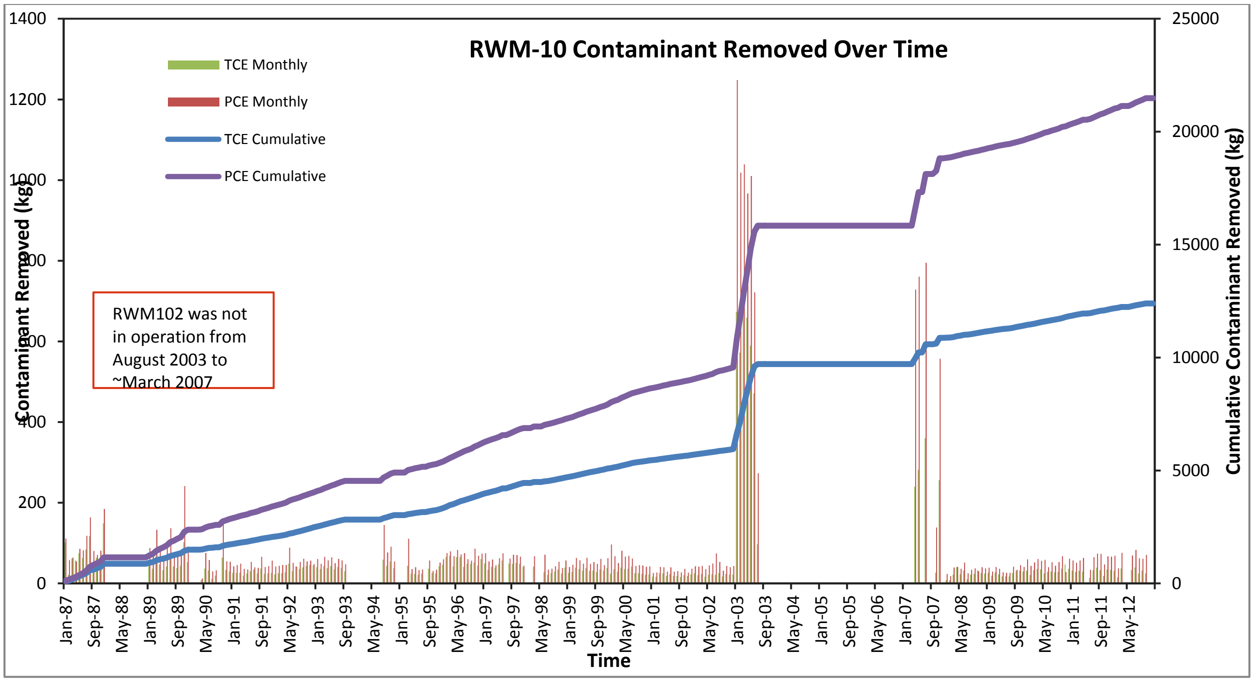

Fig. 11. TCE and PCE Removed per Month and Cumulative from 1987-2012 for RWM-10

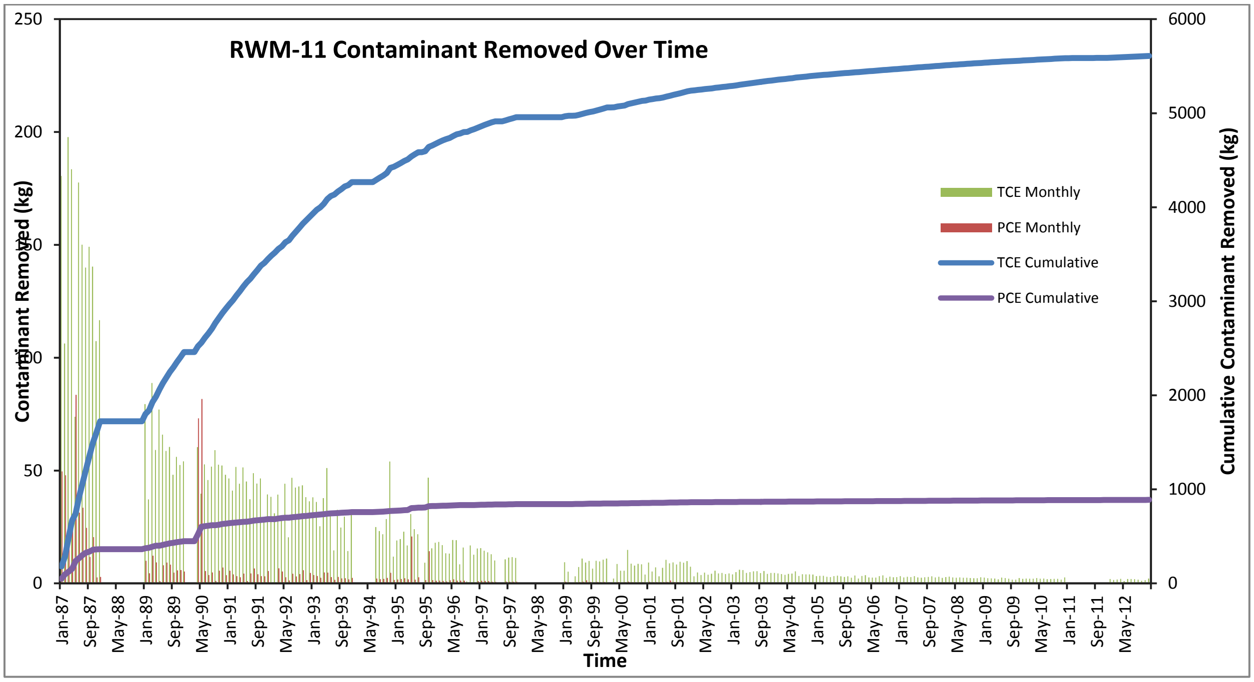

Fig. 12. TCE and PCE Removed per Month and Cumulative from 1987-2012 for RWM-11

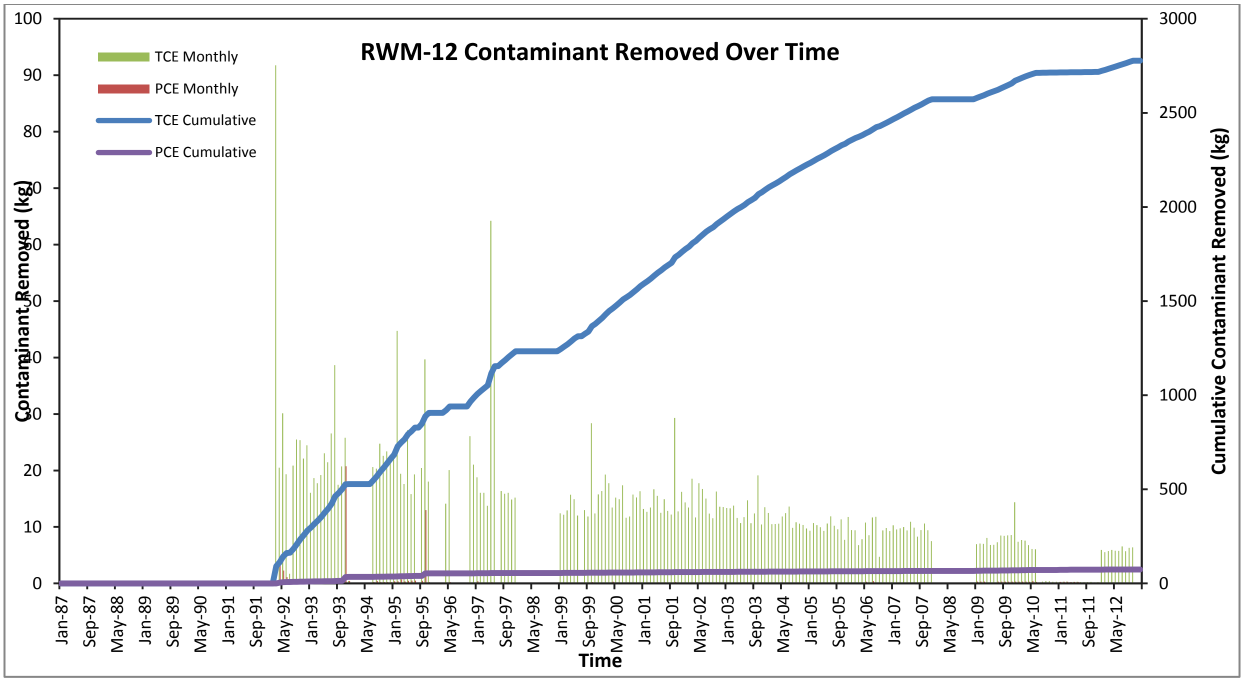

Fig. 13. TCE and PCE Removed per Month and Cumulative from 1987-2012 for RWM-12

Table I. Comparison of Contaminant Removal 1987 to 2012.

Well ID RWC-	TCE				PCE			
	Jan. '87 removal (kg/mo.)	Dec. '12 removal (kg/mo.)	Jan. '87 H_20 Intensity, kg/Mgal	Dec. '12 H_2O Intensity kg/Mgal	Jan. '87 removal (kg/mo.)	Dec. '12 removal (kg/mo.)	Jan. '87 H_20 Intensity, kg/Mgal	Dec. '12 H_2O Intensity kg/Mgal
1	389.00	10.57	243	26.9	161.35	58.76	101	149
2	89.09	3.00	98.2	3.24	29.43	8.68	32.4	9.39
3	341.37	8.94	116	3.89	66.55	7.53	22.7	3.27
11	180.52	2.18	69.6	.931	49.59	0.16	19.1	0.0665
4	12.96	19.64	23.1	10.0	0.00	8.13	0.00783	4.15
5	5.29	13.35	5.32	6.57	1.43	8.26	1.44	4.07
7	3.48	40.15	7.32	23.8	2.90	48.72	6.10	28.9
8	0.09	5.20	0.129	2.66	0.22	3.67	0.305	1.88
10	101.16	24.89	52.0	18.5	111.05	70.67	57.1	52.4
6	105.00	2.90	73.7	2.70	95.94	7.58	67.3	7.04
12	91.76	6.39	39.3	3.11	0.05	0.06	0.0196	0.03.13
9	3.77	1.73	3.23	9.08E-07	0.67	0.53	.571	.278

DISCUSSION

The interesting features of TCE and PCE recovery for each well are discussed below as well as the trends, connections to remediation operations and contaminant mobility considerations.

For the RWM-1 recovery well (see Fig. 2), PCE recovery significantly surpasses TCE recovery from early 2006 until Dec. 2012. This trend of more PCE than TCE recovery is seen in 7 of the 12 wells and will be the case in all wells by 2024 or soon thereafter. This is an expected phenomenon. TCE was used initially at SRS and replaced by PCE in the 1970's. TCE is more than 4 times as soluble in groundwater compared to PCE and it is also more volatile. For these reasons, TCE recovery dominates that of PCE for years before PCE recovery ultimately surpasses TCE. Data of monthly removal from each well is missing for 1988. The total removal of TCE and PCE from all wells combined is documented. FIU will apportion the amount removed in 1988 to these 12 wells based upon the removal rate immediately prior to the missing year.

The rate of recovery in this well and other wells were affected by steam injection remediation operations at SRS to remove source term and mobilize contaminants for removal. There were 2 remediation programs targeted to the M-Area Settling Basin area dense nonaqueous phase liquid (DNAPL) source which is not too distant from the area being treated by the M1 stripper and RWM-1 through RWM-12. The steam injection was part of a treatment process known as "Dynamic Underground Stripping." The pilot-scale remediation removed 32 tons of DNAPL contamination during its year of operation ending in September 2001. The major steam injection remediation campaign began in August 2005 and ended September 2009. There are clear increases in TCE and PCE removal in this well during the months of steam injection. The heating of the ground to over 100°C by August 2009 has been cooling slowly since and will remain higher than background soil temperature for several more years. The TCE removal rate has dropped in RWM-1 to near its level in 2005 prior to the steam injection since much of the contaminant has been removed. The PCE removal rate is still well above its rate in 2005 prior to the steam injection.

In RWM-2 (see Fig. 3), the pump was not operated from June 2000 through November 2003. The steam injection campaign from 2005-2009 did not enhance the mostly depleted TCE but did significantly enhance the PCE removal. The spike in TCE and PCE removal in many of the wells during October 2005 is not understood. It is speculated that it might be a calibration error from the lab analyses.

The TCE and PCE removal rates in well RWM-3 (see Fig. 4) appear small in the graph above but its relative size is not small compared to other wells. It appears small due to the large scale for the Y-axis. Note that all graphs are scaled to display the highest monthly recovery rate as near full scale on the Y-axis.

The removal rate data for TCE and PCE in well RWM-4 (see Fig. 5) for the year 1996 seems to have been switched. The TCE removal rate dropped by about a factor of 7, matching the PCE removal data in 1995 and 1997. Similarly, the PCE removal rate increased by a factor of 7 to match the TCE data in 1995 and 1997.

There is a major increase in TCE and PCE removal in well RWM-6 (see Fig. 7) for the year 2007 and a huge drop in recovery from 2008 to the present.

The recovery of TCE and PCE in well RWM-9 (Fig. 10) shows a major increase beginning in 2002 and continuing to the present.

Recovery in RWM-10 (see Fig. 11) had an enormous increase for both TCE and PCE in 2003 about 1 year after the pilot-scale remediation program ended. Since the recovery rates were so large (over 1000 kg per month) in 2003, the well was not operational from mid-2003 to mid-2007.

Recovery of TCE and PCE is very low since 2002 in well RWM-11 (see Fig. 12).

The removal of TCE and PCE after 26 years is presented in Table I. Mass of contaminant removed per month in January 1987 is compared to that for December 2012. In addition, the mass of contaminant removed per 1000 gallons of water pumped are compared. Certain wells exhibited similar trends over the past 26 years, for example, wells 1, 2, 3, and 11 exhibit exponential decay in contaminant removal. Wells 4, 5, 7, 8, 10, and 13 exhibit "steady" concentration. Wells 6, and 12 exhibit "linear" decreases and well 9 has a unique, anomalous trend. The Green and Sustainable Remediation analyses underway seem very relevant given the trends and inefficiencies in the current remediation system.

Overall, the process of data analysis and validation was as expected. Increased monthly recovery rates related to heating of the subsurface was expected as was the transition from more TCE recovered during the first 20 years to more PCE recovered than TCE after many years of pump and treat and source term reduction.

PATH FORWARD

The efficiencies and electrical power used for each pump and the M1 stripper from 1987 until present day was analyzed and is being incorporated into the Baseline Analysis Report for SRS's M1 Stripper and Groundwater Remediation System that is scheduled for completion in February 2015.

Current influent concentrations will be used with published design guidelines for air strippers to determine the minimum air flow rate that would meet treatment specifications. A new blower will be recommended based on the outcome of the air stripper analysis. In particular, it allows for correlations between hydraulic flow rates and contaminant mass flow rates, and between airflow rates and contaminant removal rates. This effort will use a combination of tools, including Excel, OCTAVE, R, and analytical and numerical tools for well drawdown calculations and system optimization.

Detailed baseline mass flow charts for each well, loading rates, removal efficiencies, energy expenditures and additional parameters as a function of time and operation scenarios are all part of the baseline analysis for the current system. Statistical analysis of the baseline data allows for the development of correlations between system performance and operating parameters.

Understanding these correlations, energy efficiencies and remediation system efficiency, and working with key SRS stakeholders, will allow FIU and SRNL to propose performance metrics for the operation of each well and for the entire system and propose performance targets. These metrics will permit analyses to evaluate potential areas of improvement based on the proposed performance targets and based on the statistical correlations.

The next steps include: (1) investigation of operations strategies to increase system performance by optimizing the hydraulic loads, pumping rates, contaminant mass flow rates and well drawdown levels; (2) determination of a set of metrics which will correlate the pumping rates, the cone of depression, and the interaction between the wells with the contaminant mass flow rates; and (3) determination of the best set of operating parameters that will ensure overall steady increase of performance between the optimal well pumping rates and greatest mass flow rates of contaminants.

CONCLUSIONS

FIU has located missing data for many monthly recovery rates of TCE and PCE for recovery wells RWM-1 through RWM-12 and input the data into a more complete database. FIU searched through volumes of SRS documents to locate the data. The more complete monthly data for all wells allows for several types of analyses. The spatial and temporal removal rates can be correlated to spatial and temporal data of contaminant disposal (source locations) and remediation operations. Graphs for the monthly recovery of TCE and PCE are analyzed showing the effects of remediation on removal rates. In Table 1 there is a comparison of the remediation progress over 26 years. More importantly, there are groups of wells that have contaminant removal that are decreasing exponentially and others are decreasing linearly and still others are somewhat constant. Finally, there is 1 well with anomalous results.

The pumping and overall electrical energy efficiency (per 1 pound of TCE removed and destroyed) has decreased to 6% of what it was during the initial year of operation. That is, it now requires 15.9 times more energy and groundwater to remove 1 pound of TCE in the 26th year of operation than it did in the first year of operation. The next phase of this project will identify options that will offer significant opportunities for improved efficiencies related to electrical energy, water usage, human labor, and the use of other resources.

Findings show that 7 of 12 recovery wells have transitioned to more PCE removal than TCE removal. This was an expected result. This is important to our GSR analyses and future remediation options since PCE is much more difficult to mobilize and remove due to its much lower solubility in water than TCE.

The injection of steam for 4 years as part of “Dynamic Underground Stripping” remediation process was very successful in removing and destroying TCE and PCE in the nearby M Area settling basin area. The increased ground temperature has mobilized DNAPL and resulted in increased recovery in several of the RWM 1-12 wells at this nearby but separate DNAPL location. Soil temperatures have been cooling since steam injection ended in 2009 but the elevated temperatures will continue for another decade and continue to enhance removal of TCE and PCE.

FIU is developing a set of proposed actions for the existing infrastructure of the groundwater remediation system that will reduce the environmental burden of the A/M Area groundwater remediation system. A schedule of reduced hours of operation for the treatment system and specific component replacements for old, inefficient components are recommendations under analysis. The A/M Area groundwater remediation system has operated continuously for 27 years and is expected to operate continuously for the foreseeable future. Improvements in system performance, increased contaminant recovery, or decreased energy consumption, will have positive enduring benefits due to the long time frame over which the benefits will accrue. This work will directly support the Dept. of Energy EM-12/EM-13 Sustainable Remediation (SR) program and will be executed in coordination with the SR program lead. The effort is also referred to as "Green and Sustainable Remediation (GSR)" or "Green Remediation" in the literature and in various implemented programs.[10]

REFERENCES

1. Westinghouse Savannah River Company. (1998). *3Q/4Q99 Annual M-Area and Metallurgical Laboratory Hazardous Waste Management Facility Groundwater Monitoring and Corrective-Action Report, Third and Fourth Quarters 1999, Volume I and II.* Aiken, SC.

2. Savannah River Nuclear Solutions, LLC. (2012). *Annual 2011 M-Area and Metallurgical Laboratory Hazardous Waste Management Facilities Groundwater Monitoring and Corrective Action Report, Volume I.* Aiken, SC.

3. Westinghouse Savannah River Company. (1993). *Fourth Quarter 1992 and 1992 Summary M-Area Hazardous Waste Management Facility Groundwater Monitoring Report, Volume I.* Aiken, SC.

4. Westinghouse Savannah River Company. (1997). *M-Area and Metallurgical Laboratory Hazardous Waste Management Facility Groundwater Monitoring and Corrective-Action, Third and Fourth Quarters 1996, Volume I.* Aiken, SC.

5. Westinghouse Savannah River Company. (1998). *M-Area and Metallurgical Laboratory Hazardous Waste Management Facility Groundwater Monitoring and Corrective-Action, Third and Fourth Quarters 1997, Volume I.* Aiken, SC.

6. Westinghouse Savannah River Company. (1995). *M-Area Hazardous Waste Management Facility Groundwater Monitoring and Corrective-Action Report, Fourth Quarter 1994.* Aiken, SC.

7. Westinghouse Savannah River Company. (1996). *M-Area Hazardous Waste Management Facility Groundwater Monitoring and Corrective-Action Report, Third and Fourth Quarters 1995.* Aiken, SC.

8. Westinghouse Savannah River Company. (1990). *M-Area Hazardous Waste Management Facility Post-Closure Care Permit Groundwater Monitoring and Corrective Action Program.* Aiken, SC.

9. Savannah River Nuclear Solutions, LLC. (2011). *Annual 2010 M-Area and Metallurgical Laboratory Hazardous Waste Management Facilities Groundwater Monitoring and Corrective Action Report, Volume I.* Aiken, SC.

10. Interstate Technology & Regulatory Council. (2011). *Green and Sustainable Remediation: State of the Science and Practice.* Washington, DC.