TECHNICAL REPORT

A Sustainability Analysis for the M1 Air Stripper and Pumps of the M Area Groundwater Remediation System at the Savannah River Site

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Executive Summary

The design and rationale for the A/M Area groundwater remediation system at Savannah River Site are presented. System analysis and modifications are suggested by Florida International University (FIU) that would offer the potential for less electrical power consumption and lower groundwater pumping rates. Specifically, this report recommends:

1. A solar photovoltaic system for powering the A/M Area groundwater remediation system;
2. The determination and use of an optimal speed for the blower motor that is sufficient to run the countercurrent stripper and remove the volatile organic contaminants to below the 1 ppb required;
3. A groundwater modeling analysis be completed to optimize the pumping rate for each recovery well and for the entire system that provides hydrologic containment and maximizes the concentration of contaminants pumped to the stripper with possible lower total groundwater and air flow rates in the stripper; and
4. Replacement of groundwater pumps when they fail with new efficient pumps with power that matches the required pump rate of the recovery well (e.g., possibly more lower powered 1-5 hp pumps).

A key purpose of the groundwater remediation system is to contain the plume of trichloroethene (TCE) and tetrachloroethene (PCE) to the A/M Area by pumping recovery wells: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 17B and 17D. From a Green and Sustainable Remediation viewpoint, the current high electrical power consumption and large volume of water pumped daily might not be justified from an environmental protection rationale. With a coupled modeling of the groundwater and the pumping rates for all recovery wells, the system can be optimized, resulting in a lower overall volume of water pumped and higher concentrations of contaminants being received by the stripper. This would allow individual recovery wells to be matched with the best horsepower pump and even to run intermittently using less electrical power, pumping less water while still providing containment of the contaminant plumes. Optimized operation of each recovery well might allow some wells to be closed; others to be pumped at lower rates with lower horsepower pumps; and others to be pumped at higher rates with higher horsepower pumps. This analysis would permit real-time optimization of the blower fan speed to meet requirements and to consume less electrical energy.

The full-scale M1 air stripper was designed, built, installed and began operation in the 1980s when the TCE and PCE concentrations from all wells combined was an order of magnitude higher than it is today. The M1 air stripper was designed with a variable speed drive. FIU is unaware if there has been an optimization analysis performed which might allow the blower to run at much lower speeds or if the blower is being run at a lower motor speed. The full-scale M1 air stripper ran at 2000 cubic feet per minute for normal operations when it was started in 1985. Since the power consumed is proportional to the cube of the motor speed, a 50% decrease in speed yields an eight-fold (or 87.5%) reduction in electricity for the 15 horsepower motor.

Should a solar voltaic system be installed, the blower could be powered by direct current, allowing for a continuous range of motor speeds which could be optimized to run at the speed and electrical power required to strip TCE and PCE from the groundwater pumped from the recovery wells. Finally, a review of the variable frequency drive installed on the stripper is recommended for modern energy efficient electronics that have improved performance and decreased the size and cost of these variable frequency drives.

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Introduction

The Savannah River Site (SRS), located in Aiken, Allendale, and Barnwell Counties in South Carolina, is a nuclear production facility operated for the U.S. Department of Energy (DOE). SRS contains 36,000 acres of wetlands and an additional 5,000 acres of bottomland soils subject to flooding. By the 1950s, the SRS facility was focused on nuclear weapons production and power production. These operations led to the release to the environment of major quantities of contaminants. Like many defense operations sites in the 1970s and 1980s, trichloroethylene (TCE) and tetrachloroethylene (PCE) were main solvents used in degreasing and other industrial operations.[1] The M (or manufacturing) Area is located in the northwest quadrant of SRS and manufactured fuel and target assemblies for the site's reactors. Chemical wastes generated in this fabrication process were discharged to a settling basin in 1958 through July 1985. During 1981 routine monitoring of wells near the M-Area settling basin, hazardous volatile organic chlorocarbons were discovered in the shallow groundwater. Specifically, trichloroethylene, tetrachloroethylene, and 1,1,1-trichloroethane were found in the groundwater.[1] These contaminants are categorized as dense non-aqueous phase liquids (DNAPLs), semi-volatile, and hazardous chemical compounds.

In 1981-1982, analyses led to the selection, design and production of a pilot-scale air stripper for the M Area groundwater remediation system (GRS). This 20 gpm unit was installed in February 1983 and treated influent chlorocarbons in the 20 – 160,000 ppb range from recovery well #1 with effluent below 1 ppb discharged by gravity to the nearby settling basin area. Operation of this unit ended in February 1985. There was good correlation between the performance data and the design calculations which enabled high confidence in the designs for the prototype and full-scale air strippers. Operational experience was also used to improve these designs. Construction on the prototype 50 gpm stripper began in 1984 and the system was installed and connected to recovery wells 2 and 3 and run for a month before ending operation in March 1985. The 50 gpm stripper removed 15,500 pounds of solvents in a month compared to 16,000 pounds from the 20 gpm pilot-scale unit over 24 months.

Construction of the full-scale stripper began in September 1984 and initial startup of the system occurred in April 1985. Two primary problems with this stripper arose during the summer of 1985, namely, failure of the variable frequency drive from a lightning strike and improper grounding of the controls for the automatic operation of the recovery well network.[1] From June through August 1985, this prototype stripper was manually operated, connected to one recovery well at a time. This first major environmental cleanup operation at SRS included 3 of the earliest air strippers in history, designed, built and installed to contain the chlorocarbons. TCE, PCE, and TCA are also known as volatile organic compounds (VOCs). The prototype and full-scale strippers treat the groundwater effluent to less than 1 ppb VOC concentration.

<u>Full-Scale Stripper Design</u>

Since April 1985, contaminated groundwater in the A/M Area on the northern part of SRS has been treated with the M-Area groundwater remediation system (GRS) which consists of: the custom full-scale air stripper, an air blower with variable speed drive, a tails pump, air system instruments, a control building with associated piping instrumentation and controls and submersible groundwater pumps for each recovery well in the network. The GRS is connected to groundwater recovery wells #1-11 (connected in 1985) and recovery wells 17 B and 17 D (added years later). The treated groundwater is discharged to a tributary of Tims Branch, a small stream ecosystem also in the northern portion of the SRS. The recovery wells #1-11 were located within the contaminant plume to create a cone of depression to minimize lateral movement. The wells are ~200 feet deep and cover the entire Tertiary aquifer with screened sections located in zones with more permeable sands. The groundwater pumps currently installed vary from 1.5 to 7.5 hp. The 7.5 hp pumps operate from 50-75 gpm.[2] Over 2 miles of thick walled polyethylene piping was installed to connect the recovery well network to the air stripper.

The stripper column is 54 inches in diameter and 70 feet in height and is designed to process 400 gpm of contaminated groundwater. Inside the column is a liquid distributor plate, a liquid redistributor plate, 600 cubic feet of packing material and an entrainment separator (demister). **Figure 1** shows a photograph of the M1 full-scale air stripper building and system. A schematic diagram for the countercurrent air stripper design is shown in **Figure 2**.

The packing material consists of 1-inch diameter polypropylene pall rings. The rotary lobe air blower is driven by a 60 hp electric motor and controlled by a variable frequency drive. The blower has a maximum capacity of 5000 cfm but operated at 2000 cfm normally during the initial years of operation. The current operational volume air flow is unknown. The column is instrumented with a variety of sensors such as pressure, pH, water level, temperature, flowrate, etc. The stripper also has a custom air control system that provides a maximum 10 cfm dry air at 100 psi to the pneumatic control valves.

The 15 hp tails pump is used to circulate water to wet the column prior to startup or restart of the stripper and is used to pump the remediated groundwater effluent to a NPDES permitted outfall for discharge. It can pump from 60 – 400 gpm with a total dynamic head of 71 feet.

A more recent addition to the stripper is a mercury treatment system located just upstream of the air stripper. The pumped groundwater is altered with tin (II) chloride ($SnCl_2$ or stannous chloride), which reacts with mercury in the water to reduce it to elemental mercury. The groundwater enters the M-1 air stripper and the elemental mercury, which is more volatile than dissolved mercury, is stripped from the water along with the chlorinated solvents. The mercury concentration in the untreated groundwater is initially approximately 250 ng/L (parts per trillion) and the treatment system reduces the concentration of mercury in the treated groundwater to approximately 10 ng/L.[3]

Figure 1. Photograph of the full-scale M1 air stripper at the M-Area, SRS.

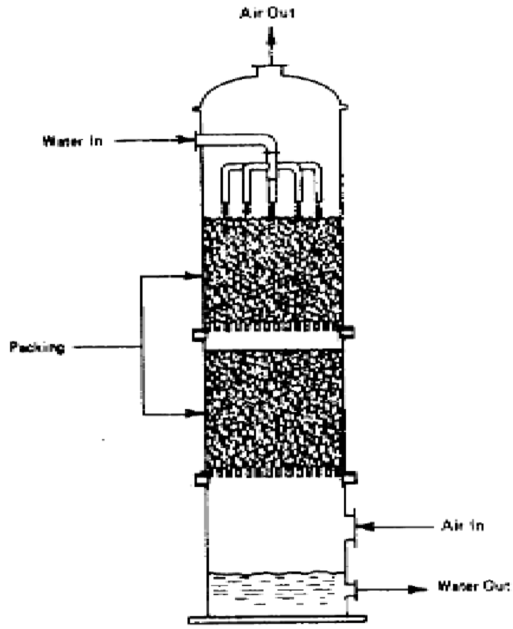

Figure 2. Schematic diagram of a countercurrent air stripper used in the M1 air stripper.

Figure 3 on the next page contains the spatial locations of the groundwater recover wells, soil vapor extraction units, and dynamic underground stripping wells. Recall that the M1 air stripper draws groundwater from recovery wells RWM-1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 17B and 17D. The injection of steam for 4 years as part of a "dynamic underground stripping" remediation process was very successful in removing and destroying much of the TCE and PCE in the nearby M Area settling basin area. The increased ground temperature has mobilized DNAPL and resulted in increased recovery from some wells. 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.[4]

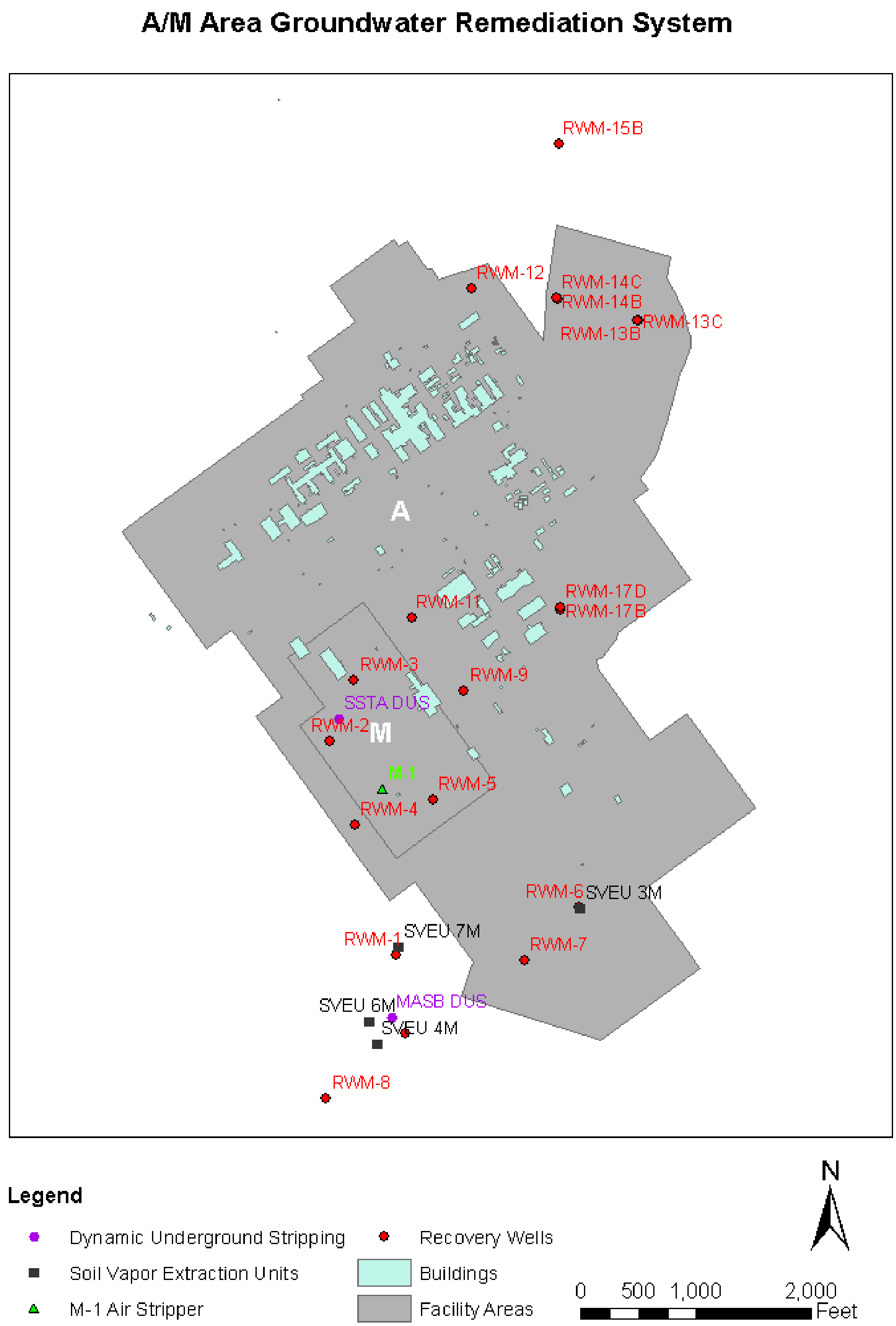

Figure 3. Spatial location of buildings, groundwater wells, soil vapor extraction units, and dynamic underground stripping wells for steam injection in A and M areas.

Air Stripping Theory for Volatile Contaminants

The air stripping process is a mass transfer operation that provides contact between air and water, encouraging the VOCs to move from the water to the air. There are different types of air strippers each more effective under certain site conditions. The most common one is the packed column air stripper which consists of a counter-current flow of water and air through a packing material in a big tower. The packing material is usually plastic, ceramic, or steel with different shapes and sizes that allow a higher surface-to-volume ratio and provide the necessary transfer surface to permit volatile components to move from the liquid stream to the air stream. In the packed column stripper, the contaminated water comes from an aeration nozzle at the top of the tower, and the air is blown from the bottom (**Figure 2**).[5]

Since the air stripping process involves association between air and water, it is important to know the solubility of the gas in the liquid to determine under what conditions the stripper will work adequately, and how easy it will be to strip the contaminant. This ratio of the contaminant at equilibrium in the liquid phase to the contaminant in the gaseous phase is a relationship called Henry's Law whereby, at equilibrium, as air molecules pass into the water, an equivalent number of molecules of the solvents in the liquid leave the water phase and become part of the vapor.

Under equilibrium conditions, the partial pressure of a gas above a liquid is proportional to the concentration of the chemical in the liquid:

$P_g = H\ C_L$

Where: P_g is the partial pressure of the gas,

H is Henry's constant, and

C_L is the concentration of the chemical in the liquid.

The design of an air stripper involves many parameters. The total desired groundwater flow rate will determine the diameter of the stripping column. The type of packing material, its size and shape are crucial in the process because this will have an impact on the mass transfer rate. The packing material provides the air-to-water interfacial area which will determine the efficiency of the stripping process. The air-to-water flow ratio will control the removal rate of the contaminant. If this ratio increases, usually it results in a greater removal rate. Although, if the entrance of the liquid goes through the air flow, the result is a spike increase in the air pressure drop, causing what is called flooding. The usual pressure drop in the tower should be in between 200 - 400 N/m^2.[6]

A key aspect in the proper operation of every machine is its maintenance. In the case of packed column air strippers, the fouling of the packing material requires diligent maintenance. The size of the towers on column air strippers makes it difficult to clean the packing material, and if not frequently maintained, mineral deposits such as calcium will concentrate on the packing, which reduces the surface area, therefore lowering the mass transfer process and preventing efficient stripping. In addition, routine blower and pump maintenance is required for optimum performance of the stripper.

Optimization of Air Strippers

In order to provide a proper analysis and optimization for the M1 air stripper design and operation, one needs to focus on the goals for the stripper, e.g., the actual treatment goal (which is never 100% efficiency in removal of all contaminants). Design and operational parameters such as: the air to water ratio (which is defined by Henry's constant); the water temperature; the inlet concentration and desired outlet concentration of the contaminants; the diameter of the tower; the flow rate, the current packing material; the blower speed; the discharge pump power; head pressure; the height of the tower, and the use of other ancillary equipment, all affect the effectiveness of the stripping process. A very important factor in tower air stripping is the packing material. One of the benefits of tower air strippers is the low energy usage due to the low overall pressure drop, but a huge disadvantage is the fouling of the packing material. The air flow rate is the most important factor in minimizing operating costs of the stripping, and is mainly affected by blower power consumption.

The removal efficiency of contaminants by packed towers involves many parameters. Economic considerations determine a desired balance between the volume of the tower and the air-to-water ratio as a function of pressure drop and the packing. Because the tower volume affects costs of the process, minimizing the volume of tower at a pressure drop that reduces energy consumption is one way to optimize the process in the design of the stripper. In any given application, the most favorable liquid rate packing height and air-to-water ratio will depend on specific characteristics of the site's water quality, the required and ideal efficiency, and economic considerations. Depending on which parameters the site decides to increase or decrease on removal efficiency and operational cost, and design of the tower, other parameters will change. In **Table 1**, different parameters are modified and the effects on the operations and cost are shown (assuming no changes in the tower design), as well as the effects on the tower design (assuming no change in removal efficiency). For example, for a given tower design (keeping the packing, diameter, and height fixed), increasing the water pumping rate to meet water demands will cause liquid loading to increase. This causes a decrease in the air-to-water ratio, resulting in a decrease in removal efficiency and an increase in operating costs due to the greater volume of air required to meet the target removal efficiency.[7-13]

Table 1. Parameters Important to Packed Tower Design

Parameter	Effect of Increasing (↑) Parameter on Operations and Cost, Assuming no Change in Tower Design	Effect of Increasing (↑) Parameter on Tower Design, Assuming Removal Efficiency is Maintained
Liquid Loading Rate	↓ Removal Efficiency ↑ Cost	↑ Tower Height (HTU)
Air/Water Ratio (AWR)	↑ Removal Efficiency ↑ Cost	↓ Packing Volume
Water Temperature	↑ Removal Efficiency ↑ Heating Cost ↑ Henry's Constant	↓ Packing Volume
Henry's Constant	↑ Removal Efficiency	↓ Packing Volume ↓ AWR
Packing Type and Size	↑ the Size ↓ Removal Efficiency	↑ the Size ↑ Packing Volume ↓ Pressure Drop
Pressure Drop / Depth	↑ Removal Efficiency ↑ Pump/Blower Cost	↑ AWR

Sustainability Analysis for the A/M Area Groundwater Remediation System

Analysis of Historic Contaminant Recovery

Since the DOE SRS A/M Area groundwater remediation system is expected to operate continuously for the foreseeable future, any improvements in system performance, increased contaminant recovery, decreased energy consumption, or lower greenhouse gas emissions will have positive enduring benefits due to the long time frame over which the benefits will accrue. 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.

The operation of the full scale M1 air stripper and well network at SRS began in 1985. The system has operated continuously for 30 years at an average electrical load of 150 kW and flow rate of 420 gpm.[14] This results in 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 26th 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 26th 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 1970s 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 13 recovery wells. Reducing the environmental costs of the M-Area 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. In some cases, the constant speed pumps may be producing an excess flow rate that is not required and, as a result, continuously consume energy that is not necessary for operation. Analysis of the piping diagram and operating pressure throughout the system might enable identification of wells which could be operated using a smaller pump while still maintaining the required 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 by an order of magnitude during the first 30 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 of the 60 hp blower motor would significantly reduce the electrical energy consumption.

Table 2 below shows the comparison of TCE and PCE removal between January 1987 and December 2012 for the M1 air stripper.[15]

Table 2. 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_2O Intensity, kg/Mgal	Dec. '12 H_2O Intensity, kg/Mgal	Jan. '87 removal (kg/mo.)	Dec. '12 removal (kg/mo.)	Jan. '87 H_2O 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	0.571	0.278

Solar Power Option for Powering the A/M Groundwater Remediation System

The remediation system is intended to operate in the foreseeable future to be able to continue with the hydraulic containment of contaminants. To be more resilient with the environment and to reduce the costs of operations of the system, an alternative of converting the power generation to solar power could be beneficial.

Photovoltaics

Photovoltaics (PV), which in its literal translation combines "light" with "voltage", is a way of converting solar energy into direct current (DC) by using semiconducting materials. A PV system utilizes solar panels or cells to supply the energy to a usable form of power. This power generation is a clean and sustainable way to provide electricity since its supplier is the most plentiful and widest distributor of renewable energy in nature, which is the sun.

Technology advancements and improvements in the manufacturing process have resulted in a steady decline in the cost of PVs over the years. Some argue that due to this trend, now might not be the best moment to invest in solar, while others claim that the cost of electricity is rising, so it balances out.

Photovoltaic (PV) systems are becoming more cost-effective and the total electrical power generation capacity has greatly increased in the past decade. The efficiency of the PV systems on energy generation depends on the location where it is deployed as it relies on the amount of sunlight the system receives and the position in which it is placed. Therefore, an important factor that determines efficiency is the solar irradiance and whether the solar panels are fixed or track the sunlight according to the season and hour of the day.

An analysis made by the Southern Atlantic Solar company[16], shown in **Figure 4**, depicts that the annual energy value at a municipal rate of $0.09 kWh is $131,400 per year (simplified for a ten year projection with no rate increases) in the city of Augusta, Georgia, which the closest location to the remediation system. The utility company in charge of powering the air stripper system is the South Carolina Electric and Gas (SGC&E). The current solar incentive value the utility company provides is $0.22/kWh. If a solar alternative were introduced to the project, the amount credited in one year would be $289,080, giving an annual cash surplus of $157,680.

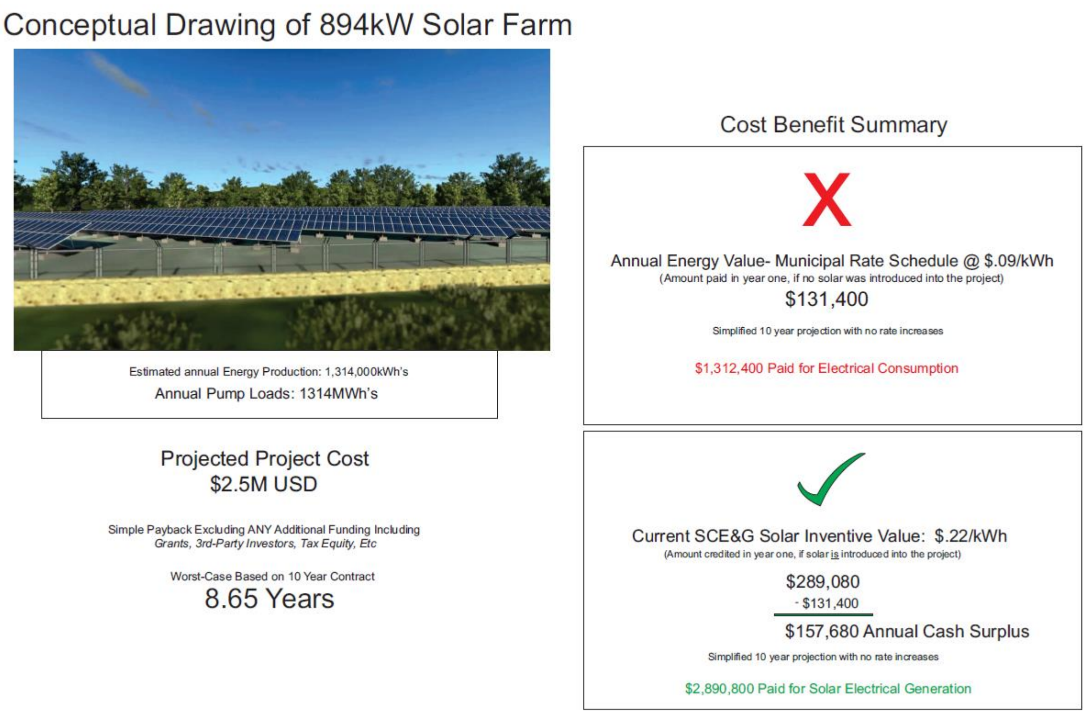

Figure 4. Solar photovoltaic system quote from the Southern Atlantic Solar Company.

Review of the monthly summary of SCE&G utility bills for the air stripper would enable an analysis to determine the price of electricity. There are months with excess energy generation;

however, the utility company may not buy the excess energy generated those months because of low demand for energy from the utility company.

There are 5 hours of sunlight per day averaged over the year and factoring in cloud coverage for the SRNL longitude and latitude (data from personal communications with 2 solar PV system installers). There is actual irradiance (watts/cm^2) data available for the SRNL area for every day of the past several years, allowing for a detailed analysis.

If DOE is tax exempt, then there is a new special federal program that provides $0.22/kW.

Packing Material Design and Optimization of Operation

The packing material is one of the most important elements of an air stripper for treating contaminated groundwater. The packing material consists of small objects usually made of plastic, ceramic, or steel with different shapes and sizes that allow for a high surface-to-volume ratio between the air and the water.

Because the objective of the remediation system is to contain the plume and treat the contaminated groundwater effluent to below regulatory requirements (1 ppb chlorocarbons for this GRS), the air-to-water ratio and the packing material are crucial factors for system effectiveness. To provide the most efficient use of the packing material, the material is placed in a specific orientation or randomly to enhance the interior and exterior surface area to obtain a greater air-water flow.

Installing the packing material randomly instead of stacking it was selected and deployed in the full scale air stripper because it offered a better liquid-gas crossing point because of the frequent change in fluid velocity and direction. The packing material currently being used is the Cascade Mini Rings. This packing material brings substantial improvements in the overall performance of the system through its:

1. Lower pressure drop: Because the largest opening of the ring is in the direction of the vapor flow, the vapor passes easily through the column, resulting in a lower pressure drop.
2. Better fouling resistance: Any solids entering the packed tower are more easily rinsed through the packing medium by the liquid.

Figure 5. Cascade Mini-Rings® random packing.

The fouling of the packing material is one of the major operational problems in packed tower aeration systems affecting the performance of the entire process. Buildup of fouling agents due to precipitation of calcium and magnesium salts, oxidation and precipitation of iron salts, or due to microbial growth and slime formation on the media, results in a pressure drop in the tower, bringing a loss in efficiency. A cleaning solution periodically circulated over the packing material helps to prevent this problem. Generally, a dilute hydrochloric acid is used to remove scale build up, and a dilute sodium hypochlorite is used to prevent fouling of the column due to biological growth.[11-13]

Pump Replacement Upon Failure Strategy

The groundwater pumps used in the M-Area GRS are submersible, centrifugal axial pumps that use mechanical forces to move a liquid below the ground to a desired destination though a hydraulic passage, which is the trajectory followed by the fluid inside the pump.

These submersible pumps (SPs) are manufactured by Grundfos and vary in horsepower to provide the pumping needed for each recovery well. The SPs are made of 100% high grade stainless steel that guarantees a more cost-efficient product against corrosiveness, making them long-lifetime products even in the most demanding environments.

Figure 6. Photograph of a Grundfos submersible pump.

The efficiency of a pump is defined as the ratio of energy delivered to the fluid divided by the energy supplied to the pump. Several design and operational parameters affect the overall efficiency of a centrifugal pump, but the hydraulic, mechanical, and volumetric losses in the pump are critical.

The volumetric loss is due to any leakage of fluid through the components of the pump. Mechanical losses include losses in mechanical components such as the bearing frame and the mechanical seals, that reduces the power transferred from the motor to the pumps. Hydraulic losses are caused by the frictional forces between the fluid and the walls of the hydraulic passage, acceleration, and interference in the fluid. The smoother the surface walls of the pump, the less flow fluctuations and thus less energy required to operate the pump. Hydraulic losses represent the largest losses in these pumps.

Over the past 20 years, there have been significant improvements made to groundwater pumps that have improved their lifetime and their efficiency. Bigger pumps are able to achieve greater head, larger flow rates and are more resilient to degradation from entrained solids and abrasives. It is recommended that the pumps that fail be replaced with efficient new groundwater pumps that are sized appropriately for the optimal pump rate of the recovery wells. This would include smaller horsepower pumps for wells that require a lower pumping rate.

The greater the overall efficiency of the pumping plant, the lower the overall pumping costs will be. One example is the use of coatings with a combination of properties such as hydrophobic and hydraulic smoothness to apply to the hydraulic passage.

Table 3 contains the different model numbers and horse power ratings for the 13 groundwater pump motors connected to the 13 recovery wells in the GRS. The discharge pump motor and the blower motor are also included.[2]

Table 3. Power and Voltage for Motors in the M-Area GRS.

Component	Model No.	Description	MCC Tap	Power	Historical Hp	Current Hp
MO-200-4-60		Discharge Pump Motor	2K	480/3-Phase	15	No Change
MOTOR-200-2-60		Blower Motor	2E	480/3-Phase	60	No Change
MO-100-1-60	16S20-18	Well 1 Motor	3G	480/3-Phase	5	2
MO-100-2-60		Well 2 Motor	3J	480/3-Phase	5	No Change
MO-100-3-60		Well 3 Motor	3L	480/3-Phase	7.5	No Change
MO-100-4-60		Well 4 Motor	4G	480/3-Phase	5	No Change
MO-100-5-60		Well 5 Motor	4J	480/3-Phase	5	No Change
MO-100-6-60	25S30-15	Well 6 Motor	4L	480/3-Phase	3	No Change
MO-100-7-60		Well 7 Motor	5G	480/3-Phase	5	No Change
MO-100-8-60		Well 8 Motor	5J	480/3-Phase	5	No Change
MO-100-9-60		Well 9 Motor	5L	480/3-Phase	5	No Change
MO-100-10-60	25S20-11	Well 10 Motor	6G	480/3-Phase	2	5
MO-100-11-60		Well 11 Motor	6J	480/3-Phase	7.5	No Change
N/A	40S50-15	Well 17B Motor	N/A	208/3-Phase	5	No Change
N/A	10S15-21	Well 17D Motor	N/A	208/3-Phase	1.5	No Change

Use of Variable Frequency (or Speed) Drives

The current blower 60 HP, 480V, 3-phase AC motor has a variable speed drive. It is unknown whether the M1 air stripper blower motor speed has changed since it began operation, with normal operation originally cited at 2000 cfm. One of the recommendations of this report is for an analysis of an optimal motor speed for the stripper sufficient to treat the contaminants to the desired 1 ppb release level. This has the potential to save a significant amount of electrical energy. A disadvantage of using AC power is that there are major electrical losses not suffered by DC motors.

Globally, there are over 230 million general-purpose, medium-size motors (0.75-375 kW) accounting for 68%[17] of the electricity consumed by motors. In the USA, ~65% of electrical energy is used to power motors. The motor load torque varies with the square of the speed and the power with the cube of the speed. Hence, at 63% speed, the motor consumes 75% less power than at full speed. It is estimated that 18% of electrical energy[18] used in motors in the USA could be saved by implementing energy efficient variable frequency drives.

Variable-frequency drives (VFDs) (also labeled as *adjustable-frequency drives or variable-speed drives)* is one type of adjustable-speed drive used in electro-mechanical systems to control motor speed and torque by varying the motor input voltage and frequency.[19]

VFDs are used in applications ranging from small appliances to the largest of mine mill drives and compressors. However, around 25% of the world's electrical energy is consumed by electric motors in industrial applications, which are especially conducive for energy savings using VFDs in centrifugal load service,[19] and VFDs' global market penetration for all applications is still relatively small. That lack of penetration highlights significant energy efficiency improvement opportunities for retrofitted and new VFD installations.

Over the last forty years, power electronics technology has reduced VFD cost and size and has improved performance through advances in semiconductor switching devices, drive topologies, simulation and control techniques, and control hardware and software.

Optimization of Pumping Rate and Schedule for each Recovery Well

During the execution of this sustainability task, FIU was given excellent access to scientists at the Savannah River National Laboratory but only had one short meeting with the remediation contractor involved with the day to day operations and review of the performance of the A/M Area Groundwater Remediation System (GRS). Publications[20-23] from SRS from 1976-1986 describe a detailed groundwater model for SRS that was developed in the 1980s in preparation for the installation of the pilot-scale, prototype, and full-scale air strippers. Due to problems that arose with the production-scale stripper, the system was run manually for nine months, connected to various different recovery wells, one at a time. Pumping rate and cone of depression data provide information on the hydrogeological characteristics of the site as well as the characteristics of the recovery wells 1-11 that were initially connected to the GRS. Recovery wells 17B and 17D were added many years later.

FIU performed detailed analyses of the TCE and PCE monthly recovery rates, as well as pumping flow rates for each recovery well for 1987-2012 from SRS sources.[15] The data tables originally supplied to FIU by SRNL 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.[24-32]

The monthly removal rate and the cumulative mass removed for TCE and PCE in the 13 recovery wells (RWM-1-11, 17B and 17D) were analyzed and presented at Waste Management 2015 Symposia.[15] The plots for the historical recovery of TCE and PCE from RWM-7 and RWM-9 are shown on the following page. Recovery well RWM-7 has the largest current recovery rate of TCE and PCE and recovery well RWM-9 has among the lowest monthly recovery rates. It is possible that increased pumping on RWM-7 with a larger horsepower pump and less pumping on RWM-9 with a smaller horsepower pump might improve contaminant recovery. That said, it was noted that there already has been shifting of different power pumps to match with improved recovery.

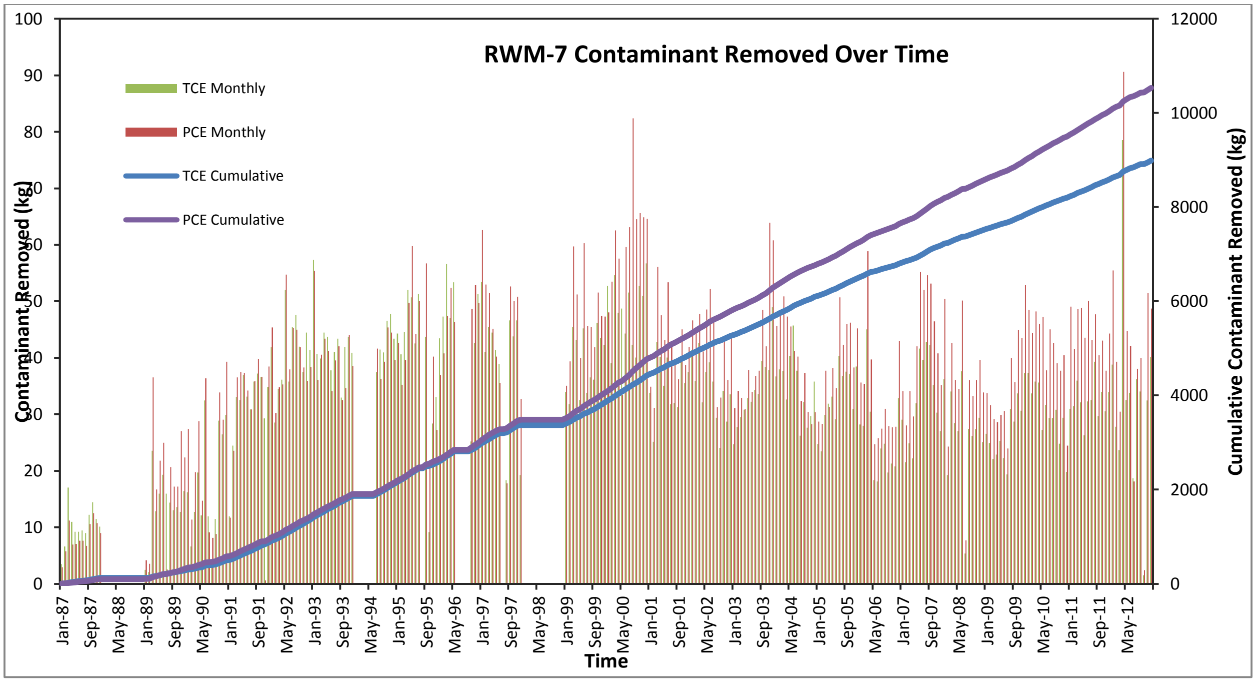

Figure 7. TCE and PCE removed per month and cumulative from 1987-2012 for RWM-7.

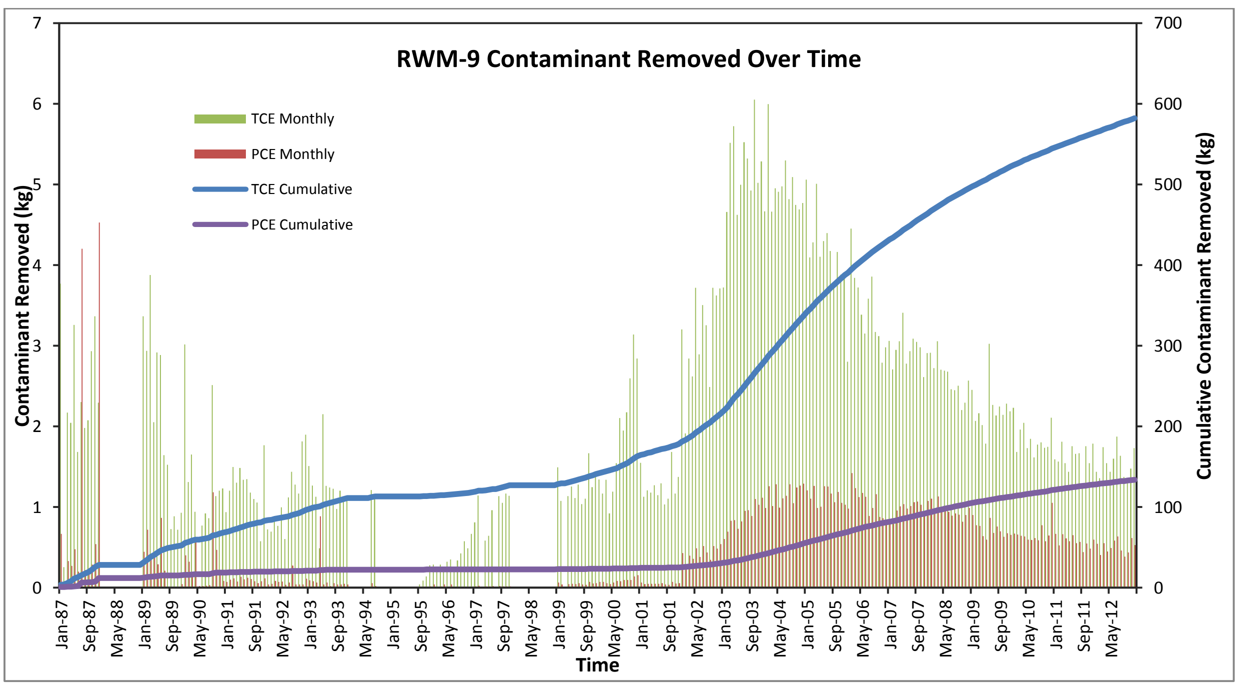

Figure 8. TCE and PCE removed per month and cumulative from 1987-2012 for RWM-9.

Conclusions

Analyses and modifications are suggested for the A/M-Area groundwater remediation system that would offer the potential for less electrical power consumption and lower total groundwater pumping rates. Specifically, this report recommends:

1. A solar photovoltaic system for powering the A/M Area groundwater remediation system;
2. The determination and use of an optimal speed for the blower motor that is sufficient to run the countercurrent stripper and removes the volatile organic contaminants to below the 1 ppb required;
3. A groundwater modeling analysis be completed to optimize the pumping rate for each recovery well and for the entire system that provides hydrologic containment and maximizes the concentration of contaminants pumped to the stripper with possible lower total groundwater and air flow rates in the stripper; and
4. Replacement of groundwater pumps when they fail with new efficient pumps with power that matches the required pump rate of the recovery well (e.g., possibly more lower powered 1-5 hp pumps).

The cost for solar photovoltaic systems has dropped by over an order of magnitude in the past decade or so. This is a result of improved materials, improved reliability, lower installation complexity and cost, and more competition. There are several federal and private company programs that provide incentives for solar power systems such as paying for the upfront installation cost in return for continued payment of the same monthly electrical bill prior to solar installation. The cost of battery systems has dropped more than an order of magnitude, allowing for more systems to be disconnected from the electrical grid for power. Some electrical utilities are required to connect customer only at one location to the grid which is not helpful for large area customers with large electrical needs such as SRS. In addition, the price that the electrical utility pays for solar system electricity is much less than what they charge the customer, encouraging more to look at battery systems. The quote from Southern Atlantic Solar Company for $2.3M is estimated to pay itself back in 8.65 years under the worst case scenario that none of the available solar incentive programs would be available. It is an actual quote that is meant to provide an estimate for a future solar voltaic system at SRS. There are additional consumers of electrical energy near the air stripper which might be included into the design of a larger, more cost-effective solar system.

The groundwater remediation system is designed to contain the 31 million gallons of trichloroethene (TCE), tetrachloroethene (PCE) and 1, 1, 1, trichloroethane (TCA) originally discharged to the settling basin in the M Area from 1958 to 1985. The analysis[1,20] completed by those that designed, constructed and optimized the original pilot-scale, prototype-scale and full-scale air strippers for the M-Area at SRS provides detailed groundwater modeling as well as an analysis of the hydraulic permeability and the cones of depressions for each of the recovery wells. The blower motor was designed with a variable speed drive. Different optimal recovery well pump rates were matched with appropriate horsepower groundwater pumps. Most impressive, the original calculations for the design of the stripper correlated well with the actual performance data. Over the 30 years of operation, there has been a major reduction in TCE and PCE source term contamination from dynamic underground stripping (DUS), soil vapor extraction, and through this pump and treat system. The contamination levels are still well above allowable MCLs. FIU was not able to secure information on the current analyses performed by the remediation contractor to improve or optimize the system. It is assumed that these analyses continue each year by the current remediation contractor. There is indirect evidence of continuous system improvements from the changing of groundwater pumps and the purchase of lower power pumps among other indications.

The air stripper system was designed to run at 400 gpm and to remove chlorocarbons from concentrations as high as 200,000 ppb in the influent and treat to less than 1 ppb in the effluent.[1,20] Much of the source term has been removed and the concentration entering the stripper is an order of magnitude lower today than at startup. There have been modifications to the subsurface since the system was designed such as the installation of a subsurface barrier and the heating of the soil temperature from DUS. A groundwater model analysis would allow for the determination of the minimum pumping rates of the recovery wells that would still effectively contain the contaminant plume. It would also allow for an optimization of the pumping rate from each recovery well and even indicate if some wells should be closed. Optimized pumping would result in less overall water pumped and increased monthly capture of contaminants.

The optimal pumping of individual wells would need to consider the performance of the air stripper with significantly lower air flow and with modest reductions in the total flow rate to the air stripper (e.g., 350-400 gpm). From simple stripper design analysis, a drop in influent chlorocarbon concentrations by an order of magnitude should allow for significantly less air flow to continue to remove all contaminants to less than 1 ppb. The full-scale M1 air stripper ran at 2000 cubic feet per minute for normal operations when it was started in 1985. Again, since the electric power consumed by the large 60 hp blower motor is proportional to the cube of its speed, there is a large potential cost savings, energy savings and greenhouse gas emissions savings possible with a modest reduction in motor speed. For example, a 50% decrease in speed yields an eight-fold (or 87.5%) reduction in electricity for the 15 horsepower motor.

An analysis of the stripper performance would permit optimization of the blower fan speed to meet requirements and use less electrical energy consumption. In addition, over time as the contaminant concentrations continue to drop, one could continue to lower the blower speed until it reaches the minimum air flow required for effective operation of the air stripper.

Should a solar voltaic system be installed, the blower could be powered by direct current, allowing for a continuous range of motor speeds which could be optimized to run at the speed and electrical power required to strip TCE and PCE from the groundwater pumped from the recovery wells. Finally, a review of the variable frequency drive installed on the stripper is recommended for modern energy efficient electronics that have improved performance and decreased the size and cost of these variable frequency drives.

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