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ESL-RPT-2009-02

Applied Science and Technology Task Order

Fiscal Year 2009 Year-End Summary Report

September 2009

U.S. DEPARTMENT OF ENERGY | Legacy Management

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Abbreviations

AS&T	Applied Science and Technology
cm	centimeter
CSL	compacted soil layer
DOE	U.S. Department of Energy
EA	enhanced attenuation
EM	DOE Office of Environmental Management
EMT	Ecosystem Management Team
EPA	U.S. Environmental Protection Agency
ESL	Environmental Sciences Laboratory
ET	evapotranspiration
ft	feet
FY	fiscal year
gpm	gallons per minute
ha	hectare
LAI	leaf area index
LM	DOE Office of Legacy Management
LTSM	long-term surveillance and maintenance
m	meter
mg/kg	milligrams per kilogram
mm	millimeter
MODIS	Moderate Resolution Imaging Spectrometer
NASA	National Aeronautics and Space Administration
NSF	National Science Foundation
PRB	permeable reactive barrier
RECAP	Renovated ET Cover Assessment Project
SOARS	System Operation and Analysis at Remote Sites
SRNL	Savannah River National Laboratory
USC	University of South Carolina
VDV	Vista Data Vision
WCR	water content reflectometer
WFM	water flux meter

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1.0 Introduction

Applied Science and Technology (AS&T) has a critical long-term surveillance and maintenance (LTSM) role in that the U.S. Department of Energy (DOE) needs knowledge (science) and tools (technology) to ensure that implementation of LTSM will be efficient and cost-effective. In general, this means moving the "state of the science" in long-term stewardship strategies and methods into the "state of the practice" at DOE Office of Legacy Management (LM) sites. Site stewards also need better information and resources to work more effectively with regulators and stakeholders in exploring whether new or improved approaches may work better than baseline technologies. The overriding goal is to explore and apply innovative ways to reduce LTSM costs and risks to human health and the environment.

2.0 Objectives

This task order is the basis of LM efforts to fulfill a science and technology strategy that includes the following objectives:

- Ensure that sound engineering and scientific principles are used to conduct LTSM.
- Evaluate and improve the effectiveness of LTSM practices.
- Track and apply advances in science and technology to improve sustainability of remedies.
- Share technologies and lessons learned with stakeholders, regulators, and state, tribal, and local governments.
- Publish AS&T project results to provide a measure of credibility in defending LM decisions, to bring visibility to LM science and technology initiatives, and to enable others to utilize the results.
- Collaborate and share project costs with other DOE offices, other agencies, academia, and industry.

3.0 Projects and Accomplishments

Projects and accomplishments of the AS&T task order for October 2008 through September 2009 are summarized below. DOE approved fiscal year (FY) 2009 projects in October 2008 as developed from the original task order language. Some tasks were added to the scope with direction or approval from LM. Brief overviews of project objectives and scope are followed by summaries of activities and accomplishments for FY 2009.

3.1 SOARS (System Operation and Analysis at Remote Sites)

Overview. SOARS was established in 2006 to improve data collection at LM sites. This project established the feasibility of collecting data remotely in real time and transmitting to LM servers. Many LM sites are in remote locations, and collecting data by regular field visits is costly. Remote data collection improves safety by limiting driving. Well pumps and water treatment systems are also controlled remotely through SOARS to further lessen the need for travel. SOARS data are available immediately, and corrective actions can be expedited. SOARS greatly improves the ability to diagnose problems and make timely repairs and adjustments. SOARS improves project teaming efforts because project personnel based at LM sites across the nation can access the same data. SOARS data are automatically processed using Vista Data Vision (VDV) software to produce real-time graphs available to any personnel connected to the Internet.

FY 2009 Activities. The SOARS system expanded during FY 2009 with the addition of 61 field instruments and 14 data logger stations (Table 1). New stations were installed at the Central Nevada Test Area and at the Shiprock, Rocky Flats, and Old Rifle sites[1]. The SOARS field systems are powered from 75 solar panels and 26 connections to line power. Data are downloaded daily through 14 cell modems and 6 land lines. On-site communication with the modems is accomplished using 95 radios.

Parameters measured by field sensors include flow rate, water level, in-line pressure, pH, oxidation-reduction potential, conductivity, unsaturated-zone moisture content, wind speed and direction, relative humidity, solar radiation, rainfall, and water infiltration rate. SOARS also operates 23 electrical relays for remote control of well pumps. About 270,000 data values are transmitted daily and stored on a secure LM server.

Table 1. Comparison of SOARS Inventory for FY 2007, FY 2008, and FY 2009

	Number of States	Number of LM Sites	Number of Instruments	Number of Data Stations
FY 2007	7	14	335	66
FY 2008	9	16	435	86
FY 2009	9	16	496	100

A powerful post-processing program (VDV) is being used to automatically plot data and make calculations. This fiscal year, additional RAM was added to the workstation hosting VDV, which improved Web-users' ability to download large data sets. Web access to the SOARS system was functional more than 95 percent of the time during this fiscal year. Only occasional minor maintenance issues were required to keep the SOARS system operational. Data loggers and radio links functioned well. Many improvements were made to post-processor graphs and data storage/retrieval programs. Historical data were added to some SOARS sites. New graphs were added to better accommodate project reporting or analysis needs. Alarm settings were regularly updated. These alarms provide immediate notifications of problems with the instrumentation or site-related issues (such as pump failure).

Calibration checks were conducted on field instruments at many sites. Most of the instruments maintained calibration and functioned successfully. Instruments were regularly lab tested and calibrated prior to installation at field sites. Outdated equipment was replaced during maintenance trips. Pumping cycles, particularly for the Shiprock site, were adjusted regularly through SOARS to optimize groundwater extraction systems. A SOARS test station that collects meteorological data was installed at the Grand Junction site. A modem connection that accesses an IP address was bench tested at the test station. The connection increased download speeds

[1] Funding responsibility is often shared between the sites and AS&T.

substantially and deploys a Web-based page-hosting capability. More thorough testing is in progress in hopes these can be used to gradually upgrade the modems currently used by SOARS.

Two new employees were hired to maintain and operate the SOARS system. All training requirements were completed, including calibration/maintenance trips to most of the project sites. Laptop computers with docking stations were procured for these employees. Project documentation was maintained, including activity logs, Job Safety Analyses, Plan of the Day meetings, procurement logs, instrument inventories, metrics, and calibration logs.

3.2 Monticello Treatment System

Overview. A permeable reactive barrier (PRB) was constructed at LM's Monticello, UT, site in 1999 as part of a Comprehensive Environmental Response, Compensation, and Liability Act Interim Action. Because of decreasing effectiveness of the PRB, DOE built an experimental ex situ treatment system in June 2005. The treatment system contains a mixture of gravel and granular cast iron designed to remove uranium and other contaminants from the groundwater. The cost to construct, operate, and monitor the treatment system is significantly less than for the PRB, and the ex situ system provides a comparable rate of groundwater treatment. Because of the success of the treatment system, a second treatment cell was added in April 2007 to double the capacity. The system is now capable of treating groundwater at a rate exceeding 14 gallons per minute (gpm). Site employees replaced the zero-valent iron media in both treatment cells on March 18, 2009.

FY 2009 Activities. During FY 2009, the system treated about 3.3 million gallons at typical flow rates of 5 to 10 gpm. Influent and effluent samples were collected and analyzed approximately monthly. Measured uranium concentrations of these samples indicate that the system continues to meet project treatment goals. The hydraulics of the treatment system were continuously monitored by the SOARS system. Iron precipitation in the effluent piping caused repeated clogging; this problem was solved by replacing the piping with larger (6-inch-diameter) piping.

A weir-type flow meter was added to measure discharge to Montezuma creek. This flow meter was less accurate than desired, and a flow-through meter with no moving parts (Smart Meter) was installed to replace it. No other maintenance was required for the system, including the SOARS system components.

FY 2009 saw the successful completion of this AS&T project. Responsibility for continued operation and maintenance of the treatment cells has been transferred to Monticello site operations. The Monticello project is using the treatment cells to help meet groundwater regulation requirements. The AS&T task order supports a bench-scale project to help extend the life of zero-valent iron treatment cells (see next section) that, if successful, may be recommended for cost improvement at Monticello.

3.3 Chelation Enhancement of Zero-Valent-Iron-Based Treatment Cells

Overview. Treatment cells at the Monticello site and elsewhere have been cost effective in removing contamination from groundwater using zero-valent iron. However, significant cost improvements may be possible if the longevity of the zero-valent iron can be extended. Tracer testing of the Monticello treatment cells in prior years indicated that preferential flow paths develop in the reactive media during operation, leading to decreased uranium uptake. The changes in the pore structure are caused by iron oxide and calcium carbonate mineral precipitation. This project is testing the use of citrate to chelate calcium and iron, thus preventing its precipitation in the media. Citrate is a biodegradable, food-grade, environmentally friendly additive. In a prior column test in support of the Rocky Flats Solar Pond Treatment System pilot test, the addition of citrate increased the longevity by about twofold.

FY 2009 Activities. An ion chromatograph was specially equipped to analyze for citrate. The analysis method was complicated by interferences. Bench testing indicated that the interferences were due to calcium and magnesium. An ion exchange method deploying sodium sulfonate was found to be effective in removing the interference and allowing an accurate citrate analysis. The citrate analysis method was thoroughly tested for accuracy and reproducibility prior to the first column tests.

Two column tests were conducted over a period of about 2 months. Results to date indicate that citrate is chelating calcium and iron as anticipated. Virtually no calcium carbonate or iron oxide accumulated while citrate was added. However, in contrast to the earlier columns that used Rocky Flats groundwater, uranium in the Monticello columns was not adequately treated, perhaps because the uranium ion was also chelated. Additional tests are being designed that will examine the use of lower citrate concentrations and the possibility of "occasional" media rejuvenation.

3.4 Evaluation of Floodplain Remediation—Shiprock, New Mexico

Overview. At LM's Shiprock, New Mexico, site, two groundwater collection drains were installed in February 2005. Each drain is 200 feet (ft) long and is intended to help protect the environment by intercepting contaminated groundwater flowing toward the San Juan River. Standard construction methods of digging and shoring were impractical because of the shallow groundwater table. The AS&T Program provided technical support to the construction effort by investigating alternative means of drain installation. The result was successful implementation of the drains using vegetable-based guar gum to support the open trenches during excavation. The guar gum was later treated with an enzyme designed to "break" the carbon molecular chains, so that the guar gum dissolves, leaving the collection drains permeable to groundwater flow.

In FY 2007 a network of wells was installed around one drain (Trench 2) to better evaluate effects of the drain on the groundwater system. Groundwater levels and electrical conductivity are monitored at 5-minute intervals, and these data are available in the SOARS system. Groundwater samples are collected regularly for chemical analysis. The drains are capturing a large volume of the contaminated groundwater, which is subsequently pumped to an evaporation pond.

FY 2009 Activities. A comprehensive report documenting the results of the Trench 2 study was issued. The report includes a groundwater flow model that provides a reasonable match to the flow and chemical results. In FY 2009, monitoring of Trench 2 continued, and pumping rates were about 15 to 20 gpm until May 15, 2009. On that date, the extraction pump was shut off to conserve space in the evaporation pond. Rebound of the aquifer during the shutdown of Trench 2 is currently being evaluated to help understand groundwater flow paths and sources of contamination to the floodplain.

Because of the successful implementation at Trench 2, a SOARS monitoring network was established at the other floodplain collection drain (Trench 1) during FY 2009. A SOARS system was also installed at a pumped area of highly contaminated groundwater on the floodplain (well 1089 area) near the San Juan River. The purpose of the SOARS monitoring system is to help evaluate effects of the pumping system on groundwater cleanup rates. The combined systems (Trench 1 and area 1089) include instrumentation to measure water levels and electrical conductivity (a measure of dissolved salt content) at 18 stations.

Calibrations were maintained on all SOARS instruments at the Trench 1 and Trench 2 project areas. Evaluation of the Trench 1, Trench 2, and 1089 areas using data collected by SOARS and groundwater sampling will continue in FY 2010.

3.5 Evaluation of Many Devils Wash—Shiprock, New Mexico

Overview. Many Devils Wash is located about 0.5 mile east of the disposal cell at LM’s Shiprock, New Mexico, site. High concentrations of contaminants are present in numerous pools and seeps along the wash. The contaminants (nitrate, sulfate, selenium, and uranium) are similar to those found in groundwater near the disposal cell. Paradoxically, contaminated seeps occur on the east wall of the incised valley but not on the western side, which is closer to the disposal cell and in a position hydrologically that is more likely to receive site groundwater.

In 2003, Shiprock site personnel installed an interceptor drain under the channel of Many Devils Wash. The drain is about 450 ft long and extends under a significant portion of the contaminated channel. The drain conveys contaminated groundwater to a collection sump where it is pumped to the evaporation pond. Initially, the drain produced up to 1.5 gpm, but recently production diminished, perhaps in response to silting of the geotextile fabric surrounding the drain.

Contaminated surface water flows in the stream channel and is unable to infiltrate low-permeability sediment to access the interceptor drain. To capture this contaminated surface water, site personnel installed a diversion structure in August 2009. The flow rate of water from the sump increased from about 0.4 to 0.8 gpm as a result of the additional water from the diversion structure.

FY 2009 Activities. The AS&T task order funded a new project in FY 2009 aimed at providing additional insights into the contamination at Many Devils Wash. A SOARS station was established at well 1049, and water levels are being monitored. This well is located about 100 ft south of a series of seeps (the knickpoint seeps) and should help determine the seasonal flows to the seeps. Fieldwork began in FY 2009 and included resampling of surface seeps and ponds, reconnaissance of the region, review of historical data, and mapping of key features.

Data from this field survey and key historical data were entered into a KML file for use with Google Earth. The visualizations displayed by Google Earth have proven useful in enhancing the evaluation process. Work for FY 2010 is in the planning stage.

3.6 New Rifle Vanadium Investigation

Overview. Vanadium is dissolved in groundwater at the New Rifle site in concentrations exceeding several tens of milligrams per liter. The areal distribution is spotty; the highest contamination is in areas of former tailings and evaporation ponds. The vertical distribution is also heterogeneous; some of the highest concentrations were observed within 10 ft of the ground surface, but high concentrations were also found to depths exceeding 25 ft. An effort was made in 2001 to remove some of the vanadium from the subsurface by extracting the groundwater, treating it with zero-valent iron, and injecting the treated water back into the aquifer. About 3 million gallons of groundwater was removed and treated, but vanadium remains at about the same concentrations as were present prior to the pump-and-treat operation.

The New Rifle property is now owned by the City of Rifle, and the City is constructing various facilities that require excavation into the subsurface groundwater system. The City of Rifle installed 37 large-diameter extraction wells to dewater an area just to the east of the former mill site for construction of a water treatment plant. The dewatering wells were operated nearly continuously (although not all wells were active at the same time) starting in February 2008. This study is designed to better understand vanadium chemistry in the groundwater and to monitor the transport and fate of vanadium during dewatering efforts and other projected subsurface disturbances.

It appeared that vanadium concentration increased in one or more wells during a period of surface reclamation, leading to the hypothesis that surface disturbances cause the release of vanadium from aquifer sediments. The postulated mechanism was that surface disturbance causes an influx of oxygen to the groundwater and mobilizes vanadium. While it is reasonable to hypothesize that surface reclamation affected the increase in groundwater vanadium, supporting data are limited, and interpretations of the chemical mechanism are speculative.

A meeting was held on November 21, 2007, to decide on an approach to investigating the vanadium issue using AS&T funding. During FY 2008, four new Geoprobe wells (0683, 0684, 0687, and 0688) were installed. Instrumentation to continuously monitor oxidation-reduction potential, conductivity, water level, and temperature was installed at each of the four new wells and at wells 0215 and 0857. Well 0687 soon went dry, and the instruments were moved to well 0863. A meteorological station was installed and connected to SOARS.

Another issue being addressed in this study is the transport of contamination downgradient of the former tailings piles. Groundwater from the site flows toward gravel pit lakes west of the site. The gravel pit lakes represent the first location at which the contaminated groundwater can reach the surface environment. Groundwater upgradient of the gravel pit lakes is being monitored through SOARS at three wells (0201, 0590, and 0680) as part of this investigation. This portion of the project is referred to as "West Area," whereas the portion dealing with City of Rifle construction is referred to as "East Area."

FY 2009 Activities. Transducers, conductivity sensors, and oxidation-reduction sensors were calibrated on several occasions to ensure accuracy of the SOARS data for this project. Groundwater sampling continued in FY 2009. Up to 30 wells were sampled for each event, including the instrumented wells, dewatering wells, and other strategic wells. An autosampler, installed at well 0857 (near the center of the vanadium plume) continued to collect samples on

4-day intervals. Samples were analyzed for uranium and vanadium to better define changes in the plumes during dewatering by the City of Rifle.

One well (0855) had unusually high vanadium concentration of up to 1,600 milligrams per liter. The chemistry of this well was used to help assess the mineralogical makeup of the aquifer using a static (no water flow) geochemical model. The model suggested that uranium and vanadium occur in discrete minerals (such as tyuyamunite) at or near chemical equilibrium. This result is consistent with the occurrence of green stains on surface soils in the City's well field. These green-tinted soils were analyzed and found to contain high concentrations of vanadium, suggesting the presence of vanadium and/or uranium/vanadium minerals. Results of the static geochemical model are being used to develop a 1-D transport model to simulate the occurrences of high vanadium concentrations in the groundwater. If successful, the model will be used to test the effects of a variety of subsurface disturbances on the vanadium plume.

3.7 Disposal Cell Cover Performance

Overview. At many LM sites, engineered disposal cells were constructed to contain subsurface contaminants for hundreds of years. The AS&T project combines three tools—monitoring, modeling, and natural analog studies—to evaluate both the near-term and long-term performance of disposal cells. Performance monitoring is usually conducted during follow-up investigations when LM site inspectors observe potentially detrimental conditions on cell covers, such as biointrusion or rock degradation. Performance modeling and natural analog studies are conducted to project performance of disposal cells for possible future environmental scenarios (e.g. climate change, ecological succession, soil formation). These activities often involve external collaboration and cost-sharing.

In 2009, cover performance evaluations focused on monitoring a large embedded lysimeter at the Monticello site. At semiarid sites such as Monticello, relatively low precipitation, high potential evapotranspiration (ET), and thick, unsaturated soils favor long-term hydrologic isolation of buried waste. However, simple precipitation/potential ET relationships inadequately predict recharge in semiarid regions. Recharge can be minimized using covers designed with thick, fine-textured soil layers that store precipitation, and ET to seasonally remove water. Capillary barriers consisting of coarse-textured sand and gravel placed below this soil “sponge” can enhance water storage and limit unsaturated flow.

The Monticello cover is fundamentally an ET cover with a capillary barrier. It consists of a 163-centimeter (cm) fine-textured soil sponge layer overlying a 38-cm sand layer. A gravel admixture controls erosion and, functioning as a mulch, enhances seedling emergence and plant growth. The soil depth is more than adequate to protect underlying Resource Conservation and Recovery Act components (compacted soil layer [CSL] and geomembrane) from frost damage. The soil sponge thickness is the primary biointrusion deterrent. Water retention in the soil sponge limits deep root penetration, and the layer exceeds the depth of most burrowing vertebrates in the area. A layer of cobble-sized rock 30.5 cm above the capillary barrier is an added deterrent should deeper burrowers, such as prairie dogs, move into the area in response to climate change. Fine-textured soil fills the interstices of the cobble layer. The topsoil layer has physical and hydraulic properties similar to those of the rest of the soil sponge but also contains available nutrients, propagules, and microorganisms needed to establish a sustainable plant community.

Lysimeters consist of instrumentation designed to monitor the water balance (precipitation, water storage, runoff, ET, and percolation) of natural and engineered soil profiles, including disposal cell covers. The Monticello facility has four types of lysimeters: small monolith lysimeters, a large array of small weighing lysimeters, large caisson drainage lysimeters, and a 3-hectare (ha) drainage lysimeter imbedded in the Monticello disposal cell cover. Over the years, the facility has been used to evaluate various ET cover designs for DOE and the U.S. Environmental Protection Agency (EPA). Lysimeter studies of ET covers often require several years of monitoring to allow vegetation to mature and to encompass (or impose) a range of climatic and ecological conditions.

All lysimeter and meteorological data for this study are collected and stored using the LM SOARS telemetry program (see above).

FY 2009 Activities. Activities in FY 2009 included (1) monitoring soil water balance parameters in the 3-ha embedded lysimeter at Monticello and (2) authoring a chapter for a book pertaining to ET covers.

3.7.1 Lysimeter Water Balance Monitoring at Monticello

Precipitation, water storage, percolation, and ET are monitored in real time in the 3-ha embedded lysimeter. Total percolation measured in the embedded lysimeter was 4.8 millimeters (mm) over the 9.5-year (yr) monitoring period (approximately 0.5 mm yr^{-1}), satisfying the goal of an annual average percolation of <3.0 mm yr^{-1}. Most of the total percolation measured in the embedded lysimeter (3.4 mm) occurred during the exceptionally wet winter and spring of 2004–2005; there was no percolation in the ET cover during the first 4 years of monitoring. Most of the surface runoff (35 of 56 mm) also occurred during 2004–2005. Total precipitation for the 6-month period, September 2004–February 2005 (531 mm), was greater than 250 percent of the long-term average (211 mm [1948–2007]). January 2005 precipitation (172 mm) was the highest January total and the second highest monthly total on record for the Monticello National Weather Service station.

A cyclical soil water storage time series measured in the lysimeters reflects the amount and seasonality of precipitation and ET. Seasonal high and low water storage occurred in mid to late spring and mid to late fall, respectively. An overall drying trend from 2000 through 2001 can be attributed to less than average precipitation in 2001 (228 mm; 59 percent of average) and greater water extraction as plants matured. Soil water storage remained low from 2002 to 2004, fluctuating between seasonal lows of around 125 mm and highs of around 225 mm.

Percolation occurred when water storage spiked at about 480 mm during the exceptionally wet winter and spring of 2004–2005. Water storage exceeded the upper storage limit of 440 mm and caused percolation. ET extracted soil water to a lower limit of about 150 mm following the 2005 spike, to 150 mm again in 2007, and to 142 mm in 2008. Higher soil water content measured near the bottom of the cover profile caused the elevated extraction limit after the spike. Water accumulation near the bottom of the profile may have been a consequence of poor shrub establishment and, hence, poor root water extraction deeper in the cover profile.

Monticello is a good test of ET covers, in general, because of the relatively short growing season and semiarid to subhumid climate. The long-term average annual precipitation is about 460 mm according to the National Oceanic and Atmospheric Administration. EPA and DOE are using the unique data from the embedded lysimeter at Monticello to help guide decisions on the use of ET-type covers at other sites.

3.7.2 ET Cover Book

LM approved funding for Stoller authorship of a book chapter, “Introduction to Ecology and Revegetation of Water Balance Covers.” The book, *Water Balance Covers for Waste Containment: Principles and Practices*, will be published in 2010 by the American Society of Civil Engineers. Co-authors are William Albright, Desert Research Institute, and Craig Benson, University of Wisconsin. The chapter is an introduction to basic concepts, principles, and practices pertaining to the ecology, revegetation, and sustainability of ET covers. The goal of the chapter is to convey to design engineers that a successful ET cover program requires a sound ecological foundation.

3.8 Remote Sensing Studies

Overview. The AS&T Program is investigating the efficacy of using remote sensing technologies to improve performance monitoring of disposal cells and eventually reduce the costs of LTSM at LM sites. Remote sensing can provide nondestructive and spatially comprehensive (entire surface area) reconnaissance of LM disposal sites. Remote sensing might also reduce the frequency and enhance the effectiveness of on-site inspections by LM personnel.

Several important cover performance parameters can be remotely monitored. Multispectral and hyperspectral sensors can be used to map spatial patterns and temporal changes in vegetation growing on and surrounding disposal cells. Changes in vegetation may alter the performance of covers in different ways. For conventional covers, Long-Term Surveillance Plans often require control of plant encroachment and root intrusion, especially infestations of noxious weeds. In contrast, alternative covers often rely on vegetation to extract soil water and limit deep percolation and contaminant leaching.

Vegetation on covers might be monitored as a surrogate for other performance parameters. Changes in vegetation patterns and health can occur in response to disturbances, such as erosion or animal burrowing. Changes in the growth and health of vegetation may also reflect changes in soil moisture patterns or the presence of heavy metals. Variation in water content is often manifested in vegetation biophysical parameters, such as leaf area index (LAI) and biomass, and can be detected in optical spectral reflectance characteristics. Vegetation spectral responses have also been successfully used for the detection of contaminant leaks at Superfund sites and on landfills. Remote sensing can therefore be used to survey the spatial and temporal variation of vegetation as a surrogate measure of other changes taking place on covers.

Remote sensing could be used to detect changes in other physical features that influence the performance of disposal cells. Bare-earth digital terrain models can be created using photogrammetric or lidargrammetric techniques. These models can identify, on the order of just a few centimeters, differential settlement of the cover, erosion, and other direct topographic expressions. Passive microwave detectors might be used to remotely measure spatial and temporal patterns in soil moisture, which is needed to monitor the hydrologic performance of covers.

FY 2009 Activities. In 2009, the AS&T Program worked on two remote sensing studies: (1) a hyperspectral study at Monticello and Monument Valley funded jointly by National Aeronautics and Space Administration (NASA)and LM, and (2) a landscape-scale evaluation of evapotranspiration at Monument Valley, funded jointly by LM and University of Arizona.

3.8.1 Hyperspectral Remote Sensing Study

In 2008, the AS&T Program teamed with scientists from Savannah River National Laboratory (SRNL) and the University of South Carolina (USC) and collected hyperspectral data and field reconnaissance data for remote sensing case studies at the Monticello disposal site and the Monument Valley mill site. These cases studies were funded jointly by LM and NASA. In June 2008, LM, SRNL, and USC collaborators acquired ground data at pre-marked sample points at the same time that fixed-wing overflights were acquiring hyperspectral data. Ground and overflight sampling occurred at the Monument Valley phytoremediation pilot study plots on May 26, and at the Monticello disposal cell and Monticello mill site on May 27. HyVista Inc. was contracted to fly these sites and acquire hyperspectral data. Surface sampling involved acquiring data for the following parameters within several small plots selected to represent different vegetation types of other surface features at each site: Visual photograph of the marked plots, GPS coordinates, plant species composition, percent canopy cover by species, leaf porometer measurements of transpiration, measurement of LAI at four cardinal directions using either a ceptometer or an LAI-2000 instrument, spectroradiometer measurements (400−2,400 nanometers).

In 2009, all ground and hyperspectral data were compiled and reduced for analysis. A status report was prepared and submitted to LM. The report, *Remote Sensing at DOE Legacy Management Sites: Monticello, UT, and Monument Valley, AZ,* was authored jointly by SRNL, the Environmental Sciences Laboratory (ESL), USC, and the State University of New York. The report presents preliminary analyses of remote sensing data from the Monticello disposal cell and a summary of the ground-level parameters that were measured at each location. Preliminary analysis of the hyperspectral data demonstrates the capability to detect vegetation species patterns with only primary analysis procedures with little integration of ground-level data. Ground-level data include vegetation composition and cover, LAIs, transpiration rates for selected species and locations, site meteorological data at the time of acquisition, and sample coordinates for all sampling points. The report also included a proposal outlining the data analysis strategy needed to complete the study.

3.8.2 Landscape-Scale Estimation of Evapotranspiration

A combination of field measurements and remote sensing was used to measure transpiration by native phreatophytes, black greasewood (*Sarcobatus vermiculatus*) and fourwing saltbush (*Atriplex canescens),* growing over the nitrate plume at Monument Valley. The AS&T Program is studying the use of black greasewood and fourwing saltbush to control hydraulic gradients and slow spread of the plume. Heat balance sap flow sensors were used to measure transpiration by the two phreatophytes, and results were scaled to larger landscape units and longer time scales using LAI, fractional vegetation cover, meteorological data, and the enhanced vegetation index from the Moderate Resolution Imaging Spectrometer (MODIS) sensors on the Terra satellite. Transpiration was high, depending on leaf area, and was controlled by vapor pressure deficit in the atmosphere. Black greasewood tended to have higher transpiration rates than fourwing saltbush and had a steeper response to vapor pressure deficit, but both exhibited midday depression of leaf conductance. Over most of the site, fractional vegetation cover and area-wide LAI were low due to heavy grazing by cattle and sheep. However, a portion of the plume that had been protected from grazing for 10 years had higher transpiration rates. Transpiration rates on a ground-area basis varied with LAI. Controlling grazing could, theoretically, slow or halt the movement of the contamination plume by allowing the shrub community to extract more water than is recharged in the aquifer.

This research was published in December 2008:

Glenn, E., K. Morino, K. Didan, F. Jordan, K. Carroll, P. Nagler, K. Hultine, L. Sheader, and J. Waugh, 2008. "Scaling Sap Flux Measurements of Grazed and Ungrazed Shrub Communities with Fine and Course-Resolution Remote Sensing," *Ecohydrology*, 1(4):316–329.

Also in FY 2009, a protocol was developed for monitoring Monument Valley. The protocol uses annual, high-resolution (0.5 meter [m]) Quickbird imagery (DigitalGlobe, Inc., Longmont, CO) and 16-day composite low-resolution imagery from the MODIS sensors on NASA's Terra satellite.

3.9 Soil Water Flux Meter Pilot Study

Overview. Monitoring the hydrologic performance of disposal cell covers has proven to be a challenge. Water content and water potential sensors are generally inadequate because they do not measure flux rates directly. Water-sensing data must be coupled with estimates of the soil's unsaturated hydraulic conductivity, giving rise to water flux estimates that are uncertain, often by more than an order of magnitude. Similarly large uncertainties exist with water balance models used to predict drainage, particularly at low flux rates. The only direct and proven way to verify flux rates is by lysimetry. Percolation flux might be measured directly within existing covers using a new device called a water flux meter (WFM)—a passive wicking lysimeter. This device is capable of measuring flux rates of 0.2 mm per year or less.

This project is investigating methods for installing and monitoring WFMs in disposal cell covers and at phytoremediation sites, and for evaluating the uncertainty and bias associated with the scale of measurements and with the disturbances caused by the installation. The WFMs, developed by Pacific Northwest National Laboratory, feature a funnel to direct water from the soil into a passive wick for moisture tension control, a miniature tipping bucket for real-time flux measurements that can be calibrated from the surface, and a pipe or chimney extending above the funnel to minimize divergent flow.

All WFM data, water content reflectometer (WCR) data, and meteorological data for this study are collected and stored using the LM SOARS telemetry program (see Section 3.1).

FY 2009 Activities. Activities in FY 2009 included the following: (1) monitoring percolation in the cover at the Lakeview Disposal Site, (2) monitoring soil water content in tailings in the Lakeview disposal cell, and (3) monitoring percolation at the Monument Valley site.

3.9.1 Percolation at Lakeview

DOE constructed the Lakeview disposal cell in 1989 under the Uranium Mill Tailings Radiation Control Act of 1978. The cover relies on a CSL to limit radon escape from and water percolation into underlying tailings. From bottom to top, the cover consists of a 45-cm-thick CSL, a 15-cm sand drainage layer, and a 30-cm rock and soil layer. Shortly after construction, inspectors observed recruitment of native shrubs on the cover from surrounding plant communities. Follow-up investigations determined that mature shrubs growing on the cover were rooted in the CSL, which was of concern because water extraction by roots can desiccate and crack CSLs even when overlying soils are wet.

Three WFMs were installed in holes augered through the top slope of the cover and into tailings in the fall of 2005. WFMs were placed into the upper contaminated materials layer just below the radon barrier to measure percolation through the cover. WFMs could not be installed in the side slope of the cover because the contaminated materials layer was saturated and rapidly filled the installation hole.

WFM data from Lakeview show significant percolation through the cover. The three WFMs installed below the top slope cover began recording percolation through the cover in mid-November 2005, 7 days after the start of a prolonged precipitation event. Percolation was continuous in all three WFMs until early June 2006 following a wetter-than-average winter and spring. Percolation occurred more sporadically between November 2006 and June 2007, a winter that was much drier than average, with less than a fifth of the cumulative percolation that occurred the previous winter. Cumulative percolation during the 2009 was about half of precipitation in the two operating WFMs (154 mm percolation, 314 mm precipitation).

Results of the pilot study support the concept that WFMs can be installed in existing disposal cell covers to provide direct monitoring of percolation flux. Alternative, more-conventional methods for estimating percolation carry high levels of uncertainty. However, these sensors may have a relatively short operating life. One of the three test WFMs failed within 2 years of installation.

3.9.2 Water Content in the Tailings at Lakeview

WCRs were installed in tailings below the side slope of the Lakeview cell cover to monitor moisture content and percent saturation. A WCR consists of two parallel rods attached to an electronic signal generator. A pulsed wavelength traveling down a waveguide is influenced by the type of material surrounding the conductors. If the dielectric constant of the material is high, the signal propagates more slowly. Because the dielectric constant of water is much higher than that of most other materials, a signal within a wet or moist medium propagates more slowly than in the same medium when dry. The WCR measures the effective dielectric as a pulse transit time, which in turn is calibrated against water content. Although a manufacture’s calibration is supplied with the WCRs, the AS&T project developed calibrations for Lakeview soils and tailings, since salinity and other soil properties, such as mineralogy and specific gravity, can influence the calibration.

Test holes augered to a depth of 6 ft at two locations in the side slope rapidly filled with water. Because they cannot be submerged, WFMs were not installed in the side slope. Instead, at both side slope locations, WCRs were installed in the cover and tailings to monitor soil moisture and percent saturation. WCRs were placed in the bedding layer just above the CSL, at 30 to 60 cm in the CSL, and at 30 to 60 cm and at 180 to 210 cm in the upper part of the tailings. Results of soil moisture monitoring show that the volumetric water content of the gravel bedding layer remains low, as would be expected, but is responsive to precipitation events. The results also show seasonal fluctuation in moisture content of the CSL and the near-surface layer of the tailings, also in response to precipitation. However, at a depth of about 2 m, the tailings have remained saturated for the entire monitoring period from November 2005 to September 2009.

3.9.3 Percolation and Soil Moisture Monitoring at Monument Valley

Four WFMs were placed at depths of 3.0−3.5 m in phytoremediation plantings at Monument Valley. Percolation monitoring is necessary to confirm that irrigation water is not moving below the root zone and potentially leaching contaminants. Instrument clusters were installed in the south-central area of the 1999 planting and in the northeast, northwest, and southeast areas of the 2006 planting. Instrument clusters consisted of one WFM placed about 370 cm deep in the soil profile with four WCRs placed above the WFM at 30 to 60, 90 to 120, 180 to 210, and 270 to 300 cm depths.

The WFMs are installed near the bottom of the root zone and are capable of directly monitoring saturated and unsaturated water fluxes ranging from 0.02 mm per year to more than 1,000 mm per year. WCRs were calibrated at the ESL. The procedure involves (1) compacting a soil to a specified dry bulk density for three different moisture contents ranging from wetter than air-dry moisture content to slightly above the optimum moisture content, as specified by the Standard Proctor Test, and (2) inserting a WCR into the soil to obtain a reading. The procedure was repeated three times. A linear calibration was used, so the products of the calibration were coefficients of a linear regression of the three sets of data.

The four WFMs have recorded zero percolation since they were installed in March and July 2006. These results support the conclusion that infiltration from the combination of ambient precipitation and irrigation has been stored in the fine-sand profile and is not percolating and leaching nitrate. In October 2008 and again in March 2009, water was injected in the WFM calibration tubes. All instruments recorded tips showing that all were functioning correctly and capable of recording percolation events should they occur.

Results from WCRs placed above WFMs show that soil volumetric water content is somewhat variable both spatially and temporally. Many of the observed patterns were expected. Seasonal fluctuations in water content are a response to meteorological conditions and the irrigation schedule. Seasonal fluctuations in water content deeper in the profiles lag fluctuations closer to the surface. Rapid wetting and drying is evident closer to the surface, whereas changes in water content are more gradual and produce smoother curves for WCRs located deeper in the profiles.

Water content was consistently higher at WFM1, a location with more mature plants in the 1999 planting. The deepest WCR at the WFM1 location has recorded yearly increases in water content since 2006, suggesting that deep percolation and leaching of nitrate is more likely there. WFM2 and WFM3, located in areas of the 2006 planting where shrubs have grown largest, have recorded yearly declines in water content at all depths, which is likely a response to increasing leaf area and ET. The lowest water content values occurred at the 270–300-cm depth where plants in the 2006 planting have grown largest.

3.10 Renovated ET Cover Assessment Project (RECAP)

Overview. The purpose of this study is to evaluate a renovated cover design at an LM disposal cell constructed with a low-permeability cover. Most disposal cell covers at LM sites rely on CSLs to limit water infiltration and percolation. Although design targets and performance standards for CSLs vary, a common goal of DOE design guidance is to achieve a saturated hydraulic conductivity (K_{sat}) of less than 1×10^{-7} cm/s. Multiple lines of evidence, including field studies sponsored by EPA and DOE, show that in many existing covers, CSLs fall short of the low-permeability targets, often at the time of or shortly after construction, sometimes by several orders of magnitude, and are causing higher-than-expected percolation. Several reasons are cited:

- Unanticipated ecological consequences of designs that encourage biointrusion.
- Compaction, either dry or wet of the optimum moisture content, during construction.
- Desiccation and freeze-thaw cracking.
- Differences between laboratory and field-determined hydraulic conductivities.
- Differential settlement.
- Retention of borrow soil structure (clods) during construction and pedogenesis (soil formation processes) after construction.

In contrast, in many arid and semiarid ecosystems, relatively low precipitation, high potential ET, and thick unsaturated soils naturally limit recharge. Alternative covers, called ET covers, that mimic this natural water conservation may provide long-term hydrologic isolation of subsurface contaminants. Without intervention, such as herbicide spraying, ecological succession and soil development processes will, over time, effectively transform existing low-permeability covers into ET-type covers. The goal of accelerating this transformation—or cover renovation—would be to accommodate inevitable ecological processes and, thereby, sustain a high level of performance, reduce long-term maintenance costs, and reduce long-term risks associated with deep percolation through underlying waste.

Two large (20 × 30 ft) lysimeters were constructed at the Grand Junction, CO, Disposal Site in the fall of 2007 using a design developed for EPA's Alternative Covers Assessment Program. Lysimeter water balance parameters (precipitation, percolation, water storage, runoff) are monitored using telemetry. Monitoring will continue for 2−3 years to establish baseline conditions before the renovation treatment is imposed on one of the lysimeters. Renovation will likely consist of ripping the cover to a depth of 4 ft and planting native shrubs in the rip rows. Ripping will be done in one of the lysimeters on the contour of the cover top slope.

FY 2009 Activities. In FY 2009 a report was drafted describing the historical experience of final covers employing soil barrier layers at sites managed by DOE and others, the RECAP test facility, testing conducted to characterize the as-built engineering properties of the RECAP test sections, calibration of instruments installed at the RECAP test facility, and monitoring data collected since the test sections were constructed. Monitoring data have been collected from the RECAP test sections since 15 November 2007.

Both test sections have behaved similarly since construction. Evapotranspiration has been the dominant flux from both test sections, percolation has been very small (<2 percent), and runoff has been nil. In 2008, the first complete year of monitoring, both test sections transmitted 1.1 mm of percolation, emitted 155 mm (C-control) or 158 mm (R-renovate) of surface evaporation, and had no runoff. Throughout the entire monitoring period, Test Section C has transmitted 1.8 mm of percolation, and Test Section R has transmitted 2.8 mm.

The difference in cumulative percolation between test sections is due almost exclusively to differences in the amount of construction water discharged as percolation during the first 3 months of monitoring (0.8 mm at C, 2.5 mm at R). Percolation during this period exhibits the classical half-order (square root of time) release curve associated with downward draining of pore water. This water collected in the transition layer during storms that occurred during construction.

Soil structure appears to be developing in Test Section C. The percolation record for this test section since March 2008 exhibits a more irregular stair-step pattern that is commonly associated with the formation of preferential flow paths. Thus, greater percolation rates from Test Section C may be realized in the future. Similar conditions have not yet been observed in Test Section R.

3.11 Monument Valley Enhanced Attenuation

Overview. LM, the Navajo Uranium Mill Tailings Remedial Action (UMTRA) Department, the University of Arizona, and Diné College are jointly exploring alternative remedies for groundwater contamination at Monument Valley, Arizona, that include natural and enhanced attenuation (EA) processes. DOE removed radioactive tailings from Monument Valley, a former uranium mill site, in 1994. Nitrate and ammonium, waste products of the milling process, remain in a shallow groundwater plume spreading from a mill site soil source. A conventional cleanup strategy might involve drilling wells and pumping groundwater to a treatment facility on the surface. Pilot studies jointly funded by LM and the University of Arizona are answering two questions: (1) what is the capacity of natural processes to remove nitrate and slow plume dispersion, and (2) can we efficiently enhance natural attenuation if necessary?

FY 2009Activities. Below are highlights of pilot study results that are helping to answer these questions. The highlights are organized as two different aspects of pilot studies: source containment and removal and groundwater attenuation.

3.11.1 Source Containment and Removal

Phreatophytes were planted in the nitrate plume source area (soils remaining after tailings were removed) to limit percolation and leaching of nitrate by controlling the soil water balance. About 1.7 ha of the source area was planted in 1999, and the remaining 1.6 ha was planted in 2006, primarily with the native desert shrub fourwing saltbush *(Atriplex canescens*).

Source Area Nitrogen and Sulfur

Soil cores were collected in the source area soil from the 1999 planting (original field) and the 2006 planting (extended fields) in March 2007 and May 2008 and analyzed for nitrate as N, ammonium as N, and sulfate as S. Both nitrate and ammonium concentrations have decreased significantly since 2000. The rate of decrease in nitrate may have slowed, as expected for a substrate-dependent, exponential decay process. On the other hand, ammonium levels are still decreasing. Nitrification (of ammonium) is a likely reason for the slow decrease in nitrate.

Enrichment of ^{15}N ($\delta^{15}N$) provides additional evidence that loss of nitrogen is due to denitrification in the case of nitrate, and of nitrification followed by denitrification in the case of ammonium. Denitrification favors ^{14}N over ^{15}N, so residual nitrate in the soil becomes enriched in ^{15}N as nitrate becomes depleted.

Overall, the results show that planting and irrigating of native shrubs has produced a marked reduction in both nitrate and ammonium in the source area over an 8-year period. Total nitrogen has been reduced from 350 milligrams per kilogram (mg/kg) in 2000 to less than 200 mg/kg in 2008. Microbial processes rather than plant uptake are responsible for most of the nitrogen reduction. However, the plants help control of the site water balance, preventing additional leaching of nitrogen compounds into the aquifer.

Manganese Chemistry

Source area soils have elevated levels of calcium (Ca) and iron (Fe) in places that display a discolored surface in aerial photographs. On the ground, several color phases including black, red, green, and pink have been observed. Some source area soils also have a shallow layer of dark brown mottled material, which has been associated with areas of stunted plant growth. Manganese (Mn) concretions (Fe and Mn precipitates) were identified in samples from the mottled soil areas. Oxides of Mn at different oxidation states, deposited in the soil during extraction of uranium, may be the source. These different oxidation states could be responsible for the "rainbow" colors around drip emitters in the stained areas, and especially in the former evaporation pond.

Uranium processing included the use of sulfuric acid solutions passed through leached bed to mobilize uranium ions. With the low-pH, reduced, and anaerobic soil, naturally occurring Mn was likely also leached and translocated within the vadose zone. The most likely forms of Mn at the site are sulfate-containing species. At this arid site, it is also likely that soluble (reduced) forms of Mn were formed during the period of operations. But after operation ceased, dry conditions set in, precluding the re-oxidation of Mn to much more stable and common forms of Mn such as pyrolusite. Now that the site is irrigated, oxidation (at least in the unsaturated zone) of Mn is likely occurring, leading to more stable forms over time. This process may be responsible for the formation of nucleation sites that form the dark brown concretions rich in Mn and the rainbow rings around drip nozzles that have been observed on irrigation soils at this site.

Because the levels of Mn are within values for normal soils and are well below any levels of concern for human health risks, further testing or remediation is not recommended. Current irrigation practices and natural attenuation processes will likely continue to convert the soluble forms of Mn into insoluble oxides normally present in soils.

3.11.2 Groundwater Attenuation

Interrelationships of Ammonium (NH_4), Nitrate (NO_3), Sulfate (SO_4), and Moisture Content

Contamination of the alluvial aquifer by nitrate, ammonium, and sulfate are the major concerns at the Monument Valley site. In 2008, transport and fate processes that influence ammonium, nitrate, and sulfate concentrations were evaluated, and a manuscript comparing nitrate attenuation characterization methods developed for Monument Valley was submitted to the *Journal of Hydrology*.

Results from the collection of spatial and temporal concentration data from a transect of monitoring wells located along the plume centerline indicate that nitrate, ammonium, and sulfate concentrations are decreasing by natural attenuation processes. Adsorption appears to partly control the transport and fate of ammonium in the plume. Sulfate concentrations are most likely controlled by equilibrium formation/dissolution of the solid mineral phase gypsum. Naturally formed gypsic lenses are already found in soils at the site. Calcium ions in the soil react with sulfate in the source area and contamination plume to produce gypsum deposits, which are relatively immobile.

Nitrification may be occurring in the upgradient part of the plume as well as in the source area (see above). Nitrate biotransformation occurs through reduction to atmospheric nitrogen gas (i.e., denitrification) in both the irrigated subpile soils and the downgradient region of the plume.

The occurrence and rate of denitrification was evaluated through microcosm experiments, nitrogen isotopic fractionation analysis, and solute transport modeling. First-order rate coefficients calculated with each method were comparable. The composite natural attenuation rate coefficient was slightly larger than, but similar to, the denitrification rate coefficient, which suggests that microbially induced decay primarily controls nitrate attenuation at the site. Sulfate reductive biotransformation was not evident from the available data.

An estimated 30–70 percent of nitrate in the plume has been lost through natural denitrification since the mill was closed in 1968. Estimates of sulfate losses through gypsum formation are not yet available. but eventually Equilibrium with gypsum is expected to limit sulfate concentrations in the hotspots of the plume, resulting in lower sulfate concentrations in the more distal portions of the plume.

Ethanol-Enhanced Denitrification of the Alluvial Aquifer

EA can be defined as initiating and/or augmenting natural and sustainable attenuation processes. The goal is to increase the magnitude of attenuation by natural processes beyond that which occurs without intervention. Enhancing in situ biological denitrification through injection of amendments has been deemed a promising method for remediation of nitrate-contaminated groundwater.

The Monument Valley site is considered to be an excellent candidate for in situ EA denitrification. The region of high nitrate contamination in the plume is in a relatively small volume of the aquifer. Treatment of this high-concentration portion of the plume could allow natural attenuation of the remainder of the plume. Questions that remain to be addressed are the degree of enhancement that can be achieved and the optimal means of implementation. These questions will be addressed with a pilot-scale demonstration in 2009 supplemented with mathematical modeling analyses. This report includes a detailed work plan for a field-scale injection of ethanol as a denitrification enhancement substrate.

Changes in Vegetation

Preliminary studies demonstrated that grazing protection overlying the plume may have positive effects on biomass productivity, ground cover, and rates of phreatophyte transpiration and nitrogen uptake. In 2005, two large plots were fenced to evaluate grazing protection on a landscape scale. Vegetation canopy cover and shrub density were sampled in 2007 and 2008 in the two grazing exclosure plots and compared with adjacent control plots not protected from grazing. Results suggest that to date, no clear trends in the response of vegetation cover and shrub density to reduced grazing are apparent. However, grazing exclosures do appear to have increased overall LAI and ET (see below).

3.12 Shiprock Phytoremediation

Overview. LM is conducting pilot studies of alternative remedies, including phytoremediation, for contaminated soil and groundwater at a former uranium-milling site near Shiprock, NM. Shiprock was the site of a uranium-vanadium mill that operated from 1954 to 1968. Mill tailings were contained in an engineered disposal cell in 1986. Groundwater in the mill site area was contaminated by uranium, nitrate, and sulfate as a result of milling operations. The groundwater system is divided hydrologically and physiographically into two regions, terrace and floodplain, that are separated by an escarpment. A groundwater nitrate plume spreads primarily to the south and then to the west of the disposal cell in old river terrace deposits. Uranium and sulfate plumes in groundwater spread primarily north and west of the disposal cell in floodplain sediments. Uranium- and sulfate-contaminated seeps occur at the base of the escarpment.

In March 2003, DOE began pump-and-treat remediation of groundwater in the terrace area south of the disposal cell. Water is pumped into an evaporation pond. Ten extraction wells and two interceptor drains were expected to produce about 20 gpm, but as of March 2004 they were producing only about half that amount. In 2004, DOE reevaluated the site conceptual model for Shiprock and provided recommendations for improving the groundwater treatment system. LM chose to accept a recommendation to evaluate the feasibility of phytoremediation at the site.

Test plots were set up in 2006 in the borrow pit area and on the terrace between the disposal cell and the escarpment above the San Juan River floodplain. At each location, two irrigated plots measuring 15 m by 15 m were created. Each plot has small planting basins for 42 plants, seven plants each in six rows on 7 ft spacing. Plants are irrigated from a large, elevated tank. A Navajo Nation employee regularly fills the tanks with San Juan River water. Students from Diné College in Shiprock maintained the plantings and the irrigation system. Saltbush and greasewood transplants were grown in the greenhouses at the University of Arizona from seed acquired on Navajo Nation land.

Activities. Diné College students measured plant canopy dimensions in all plots in October 2007 and again in October 2008. Overall, plants in the escarpment plots have grown more than borrow pit plants ($p < 0.05$) even though the escarpment plots were planted later. Prairie dogs chewing through irrigation lines and foraging on plants in the borrow pit plots has been a nuisance. At both locations, differences between plots were not significant. Values for the different growth parameters were more dispersed (greater variability) in 2008 than in 2007; many plants grew much larger between 2007 and 2009, while many grew very little. The inconsistent growth patterns may be attributable to insufficient irrigation in 2008. At this stage of the study, soil type and depth to groundwater do not appear to have influenced canopy size. In most plots, canopy cover and volume of *Atriplex* is significantly greater than that of *Sarcobatus*.

The study is also evaluating contaminant uptake in *Atriplex* and *Sarcobatus*, both volunteer and transplanted in test plots in the terrace between the disposal cell and the escarpment above the San Juan River floodplain. Tissue samples were obtained and analyzed for the suite of metals. Results will be reported in the Proceedings of the 2010 Waste Management Conference.

3.13 Strategic Planning Initiatives

3.13.1 Ecosystem Management Team

Overview. Ecosystem management is a significant and growing component of annual maintenance costs. Of particular concern are rising costs to control noxious weeds and unwanted vegetation on legacy land and disposal cells. This strategic initiative is developing a strategy to identify and implement more cost-effective and sustainable ways to manage vegetation, wildlife habitat, and ecosystem health at legacy sites. In addition, as the ecology of a site may be strongly influenced by surrounding lands, working with area landholders may lead to more effective regional approaches and cost sharing.

This initiative will also evaluate the ecology and sustainability of disposal cell covers. Long-Term Surveillance Plans often require suppression of vegetation on covers because plant roots can increase permeability of compacted soil layers and may take up and disperse contaminants. Alternatively, through evapotranspiration, plants can be used to control the hydrology of disposal sites and improve the sustainability of remedies.

FY 2009 Activities. Accomplishments in 2009 are outlined below:

- Formed an Ecosystem Management Team (EMT). Team members are ecologists and site managers from the Grand Junction, Rocky Flats, Fernald, and Weldon Spring sites.
- The EMT proposed 3 strategic initiatives and 10 operational initiatives to improve LM ecosystem management practices; team members volunteered as initiative “champions.”
- Champions wrote objective statements, scope, and schedules for initiatives.
- Environmental Management System (EMS) Land Stewardship merged with the EMT; an EMT member became the EMS liaison with responsibility for Land Stewardship goals, meetings, and deliverables.
- The EMT convened a 1-day workshop in May 2009:
  - — Changed name from Vegetation management to Ecosystem Management.
  - — Identified ecosystem improvements that should reduce LTSM costs.
  - — Began developing a systematic framework for screening and selecting LM disposal cell covers for possible renovation.
  - — Identified some near-term and long-term metrics.
- EMT members met with Task Order 501 site managers to brainstorm improvements at 501 sites.

- A Stoller intern from Vanderbilt University began developing a risk-based screening process to identify LM disposal cells that may be candidates for cover renovation—a sustainable remedy performance improvement. The intern may pursue this topic as a graduate thesis project.
- A share folder was created for EMT members to record and track LM ecosystem improvements and metrics. Categories of improvements include Land Management, Remedy Performance, and Ecosystem Health. The share folder serves three purposes:
  - — A log for EMT members to share information on successes and failures,
  - — One-stop shopping for managers and clients to review summaries of ecosystem improvements, and
  - — A tracking system for EMS Land Stewardship to document ecosystem health improvements.
- The AS&T Program funded a reconnaissance of the Tuba City disposal cell and provided recommendations regarding the efficacy of using desert phreatophytes to remove water via transpiration that is shedding off of the disposal cell and would otherwise recharge the contaminant plume.

3.13.2 Technology Deployment

Overview. Stoller and DOE implemented a strategic planning initiative process in FY 2009. The AS&T task order supports the "Technology Deployment" Strategic Planning Initiative. The scope of the Technology Deployment Initiative is to facilitate investigation, evaluation, and deployment of promising environmental technologies for LM. The focus is on technologies that improve groundwater remediation and characterization, disposal cell cover performance, and modeling.

FY 2009 Activities. Technologies investigated during FY 2009 include:

- Use of citrate to enhance capacity of uranium treatment cells,
- Use of geochemical modeling to project future impacts on a vanadium plume,
- Widespread implementation of the SOARS system,
- Use of large collection drains to remediate a contaminated floodplain,
- Establishment, ecology, and sustainability of water balance cover vegetation,
- Use of large-scale drainage lysimeters to compare the soil water balance of conventional and renovated disposal cell covers,
- Comparison of microcosm experiments, nitrogen isotopic fractionation analysis, and solute transport modeling methods for characterizing nitrate attenuation,
- Method for scaling sap flux measurements of phreatophyte transpiration with Quickbird and MODIS satellite imagery,
- Demonstration of hyperspectral remote sensing to provide a long-term monitoring capability for LM sites, and
- Methods for characterizing the influences of pedogenic processes on hydraulic properties of disposal cell cover soils.

As part of the Technology Deployment Initiative, an emphasis is placed on interactions with technology developers in other parts of DOE (e.g., Office of Environmental Management [EM] and Office of Science), other federal agencies (e.g., EPA, U.S. Department of Defense, Army Corps of Engineers), and other public and private sectors. AS&T helped fund (1) a meeting with DOE Office of Science staff to discuss collaboration on LM AS&T needs, (2) a presentation at an EM Landfill Workshop, and (3) a session organizer and participant at an EM Long-Term Monitoring Technical Forum. Plans for the next 6 months include compiling a list of LM needs and identifying technologies that could improve the LM mission.

3.14 Share Technologies with Stakeholders, Universities, and Other Agencies

Overview. One of the objectives of the AS&T task order is to share technologies with others. Also, the AS&T task order occasionally funds small "special projects" at the request of project managers and site leads. These projects are related to compliance or remediation issues at specific sites.

Activities.

3.14.1 Diné College Educational Outreach

The AS&T Program sponsored the following educational outreach activities for Diné College Environmental Science students in FY 2009:

- A presentation on cover designs and long-term performance, and a field trip to the Monticello Disposal Site (November 2008).
- Field sampling and data analysis classes for vegetation monitoring at the Monument Valley and Shiprock phytoremediation pilot study sites (October and December 2008).
- Field sampling class investigating uptake of uranium and other metals in orchard trees and native phreatophytes growing over groundwater plumes at Shiprock, New Mexico.
- Co-author of a USDA Tribal College Grant proposal with Diné College as the lead institution. The proposal, "Joint Project for Economical Removal of Uranium, Biological Contaminants, and Nitrate from Rural Water Sources," includes New Mexico State University and University of Nevada Reno as Cooperative Agreement partners. The project provided additional Diné College student support of LM phytoremediation projects at Shiprock and Monument Valley.
- A presentation on uranium mill tailings remediation for a Pathways science camp organized by Diné College and Northern Arizona University. The Pathways program encourages Navajo high school students to study science and math in college.
- A Stoller scientist was featured in a segment of a National Science Foundation film, **"**Weaving STEM Education and Culture: The Faces, Places, and Projects of the Tribal Colleges and Universities Program." STEM is an acronym for Science, Technology, Engineering, and Math.
- A Stoller scientist mentored a Diné College student with preparation of a poster on the Shiprock phytoremediation pilot study that the student presented at a National Science Foundation (NSF) conference in Washington DC. The annual conference is organized by

NSF's Division of Human Resource Development, which focuses on increasing participation by underrepresented groups and institutions in science education.

3.14.2 Vanderbilt University Adjunct Faculty

A Stoller scientist received an adjunct faculty appointment with Vanderbilt University and serves on the graduate committees of a PhD candidate and an MS candidate in the Civil and Environmental Engineering Department. The PhD candidate is developing a GoldSym model to evaluate ecological change and performance of disposal cell covers. The MS student is developing a screening process for identifying sites for cover renovation.

3.14.3 University of Arizona Adjunct Faculty

A Stoller scientist's adjunct faculty appointment with the University of Arizona was renewed for 2009. Graduate students in the Soil, Water, and Environmental Science department are supporting AS&T Program research on phytoremediation, bioremediation, and remote sensing of phreatophyte transpiration.

3.14.4 DOE Office of Engineering and Technology (EM-22)

A Stoller scientist participated in two EM-22 workshops in FY 2009:

- Presentation on the ecology and performance of disposal cell covers at the Landfill Workshop, October 7−8, 2008, in Chicago, Illinois.
- Session organizer and participant in the EM-22 Long-Term Monitoring Technical Forum, February 11−12, 2009, in Atlanta, Georgia.

3.14.5 Navajo Nation Department of Agriculture

The phytoremediation pilot studies at Monument Valley are improving land use and ecosystem health while cleaning up groundwater. Emergence of healthy saltbush and greasewood stands is restoring rangeland condition and ultimately will increase carrying capacity for livestock. These shrubs are fertilized with nitrate from the plume, and each fall they also become laden with seed worth 10 dollars a pound. The AS&T Program is working with the Navajo Nation Department of Agriculture exploring opportunities to create a local enterprise that could market seed for rangeland restoration and mine land reclamation near Kayenta, Arizona.

3.14.6 Savannah River National Laboratory and University of South Carolina

A Stoller scientist collaborated with SRNL and USC on a status report, "Remote Sensing at DOE Legacy Management Sites: Monticello, UT, and Monument Valley, AZ." The project is jointly funded by LM and NASA.

3.14.7 International Atomic Energy Agency

The AS&T Program supported compilation of SEEPro historical tailings pore fluid chemistry data for use by International Atomic Energy Agency researchers working on a uranium mill tailings transport model.

3.15 Lab Maintenance

Overview. Funding from the AS&T task order is used to maintain the ESL in Grand Junction. The ESL operates a fixed-base laboratory and a mobile laboratory with capabilities to conduct geochemical and ecological testing. Funding requirements include:

- Service contracts for equipment,
- Maintaining and repairing equipment,
- Developing new laboratory procedures,
- Procurement of new equipment and consumable items,
- Updating laboratory manuals, including the ESL Procedures Manual and the ESL Chemical Hygiene Plan,
- Managing waste disposal issues,
- Managing facility issues, housekeeping, and cleaning,
- Maintaining chemical inventory, including a separation and segregation system, Material Safety Data Sheets, and certificates of analysis,
- Regular inspection and testing of emergency showers, eyewash stations, automated external defibrillator and first aid kits,
- Maintaining backups of electronic instrument files,
- Conducting inspections and tours,
- Calibrating flow meters and other field equipment, and
- Training.

The ESL continues to be an integral part of the Grand Junction site and LM program. Due to the large emphasis on groundwater and containment technology inherent to the work conducted in LM, a laboratory is often needed by a wide range of technical staff.

FY 2009 Activities. The laboratory supervisor was trained on a new ion chromatograph. An intern was hired and trained in many laboratory procedures. Calibration weights were checked for accuracy by a third-party laboratory. All laboratory maintenance and calibration tasks were completed, and the laboratory operated trouble free.

3.16 Publications and Presentations

Overview. Scientists funded by the AS&T task order often publish project results. Through publication, others can utilize the findings, and the LM Grand Junction site gains visibility in the technical arena. Publication is also a measure of expertise, which can be of value in defending the credibility of project decisions.

FY 2009 Activities. A list of FY 2009 publications and presentations follows.

3.16.1 Published and Accepted Book Chapters, Journal Papers, and Proceedings Papers

Bartlett, T.R., and S.J. Morrison, 2009. "Tracer Method to Determine Ground Water Residence in a Permeable Reactive Barrier," *Ground Water*, v. 47, pp. 598–604.

Waugh, W.J., 2009. “Chapter 4: Introduction to Ecology and Revegetation of Water Balance Covers.” In: W.H. Albright, C.H. Benson, and W.J. Waugh, *Water Balance Covers for Waste Containment: Principles and Practices*, American Society of Civil Engineers, Reston, VA (in press).

Glenn, E., K. Morino, K. Didan, F. Jordan, K. Carroll, P. Nagler, K. Hultine, L. Sheader, and J. Waugh, 2008. “Scaling Sap Flux Measurements of Grazed and Ungrazed Shrub Communities with Fine and Course-Resolution Remote Sensing,” *Ecohydrology*, 1(4):316–329.

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