LMS/ESL/S07047
ESL-RPT-2010-03

Environmental Sciences Laboratory

Applied Science and Technology Task Order Fiscal Year 2010 Year-End Summary Report

September 2010

Prepared for

U.S. DEPARTMENT OF ENERGY | Legacy Management

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Abbreviations

ACAP	Alternative Covers Assessment Program
AS&T	Applied Science and Technology
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cm	centimeter
CRESP	Consortium for Risk Evaluation with Stakeholder Participation
CSL	compacted soil layer
DEI	Diné Environmental Institute
DOE	U.S. Department of Energy
EMS	Environmental Management System
EMT	Ecosystem Management Team
EPA	U.S. Environmental Protection Agency
ESL	Environmental Sciences Laboratory
ET	evapotranspiration
ft	feet
FY	fiscal year
GIS	geographic information system
gpm	gallons per minute
ha	hectare
IP	internet-protocol
LAI	leaf area index
LM	DOE Office of Legacy Management
LTSM	long-term surveillance and maintenance
m	meter
mm	millimeter
NASA	National Aeronautics and Space Administration
NRC	U.S. Nuclear Regulatory Commission
PRB	permeable reactive barrier
RECAP	Renovated Evapotranspiration Cover Assessment Project
SOARS	System Operation and Analysis at Remote Sites
SRNL	Savannah River National Laboratory
UMREG	Uranium Mining Remediation Exchange Group
UMTRCA	Uranium Mill Tailings Radiation Control Act
USC	University of South Carolina
USCS	Unified Soil Classification System

VDV	Vista Data Vision
WCR	water content reflectometer
WFM	water flux meter
yr	year

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 2009 through September 2010 are summarized below. DOE approved fiscal year (FY) 2010 projects in the fall of 2009 as developed from the original task order language. Some tasks were added to the scope with direction or approval from LM as discussed in quarterly program review meetings. Brief overviews of project objectives and scope are followed by summaries of activities and accomplishments for FY 2010.

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 demonstrated the feasibility of collecting data remotely in real time and transmitting the data to LM computer 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 data in real time. 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 2010 Activities: The SOARS system expanded during FY 2010 with the addition of 44 field instruments (Table 1). The SOARS stations at the Salmon Site, Mississippi, were discontinued because the site is being transferred to the State and the equipment would be in jeopardy of vandalism and theft. A satellite router was established at the Central Nevada Test Area.[1] The satellite link has proven to be highly reliable, opening the door for SOARS stations at any remote location, including those without cell phone coverage. The SOARS field systems are powered from 80 solar panels and 26 connections to line power. Data are downloaded daily through 14 cell modems, 1 satellite link, and 6 land lines. On-site communication with the modems is accomplished using 95 radios.

Table 1. Comparison of SOARS Inventory Through Time

	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
FY 2010	8	15	540	100

Testing of a SOARS station that collects meteorological data at the Grand Junction site using a modem connection that accesses an internet-protocol (IP) address was completed this fiscal year. These modems provide much faster data transfer and have now been shown to function well over time at several field sites. The replacement of obsolete cell modems with IP modems will continue on a priority basis until all modems are replaced.

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 297,742 data values are transmitted daily and stored on a secure LM server.

The VDV software is being used to automatically plot data and make calculations. This fiscal year, an upgrade to VDV was installed and debugged. An important feature of the new VDV version is the ability to track system changes using "Notes" pages that replace the formerly used "Activity Logs." Notes are a great improvement because they are accessible to all SOARS users, whereas Activity Logs were accessible only to LM users with specific system access rights.

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

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. New graphs were added to better accommodate project reporting or analysis needs. Alarm settings were regularly updated. These alarms provide immediate notifications of problems involving instrumentation or site-related issues (such as pump failure).

A rhodamine dye sensor was tested in LM's Environmental Sciences Laboratory (ESL) for use at the Mound, Ohio, Site. A datalogger program was written for the rhodamine sensor and sent to the site remotely without the need for travel to the site. Site personnel used the sensor to remotely (through SOARS) monitor a groundwater tracer test. The sensor responded well and could detect very low concentrations of rhodamine. The use of a downhole sonde that measures a tracer is a considerable improvement over other tracer methods we've used and will be considered at other LM sites.

Although the sites are responsible for operation, maintenance, and calibration of the field instruments, AS&T personnel support these efforts. 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, New Mexico, Disposal Site, were adjusted regularly through SOARS to optimize groundwater extraction systems.

One employee resigned this year and the hiring process was initiated for a replacement to service the SOARS system. Project documentation was maintained, including activity logs, Job Safety Analyses, Plan of the Day meetings, procurement logs, instrument inventories, metrics, and calibration logs. DOE will be accepting an award for the SOARS system at the upcoming "Department of Energy Management Awards Ceremony" on October 6, 2010, in Washington DC.

3.2 Monticello Treatment System

Overview: A permeable reactive barrier (PRB) was constructed at LM's Monticello, Utah, site in 1999 as part of a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) 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). The reactive media requires regular (approximately every 18 months) change out.

FY 2010 Activities: FY 2010 saw the successful completion of this AS&T project and responsibility for continued operation and maintenance of the treatment cells was transferred to Monticello site operations. The Monticello project is using the treatment cells to treat

contaminated groundwater. One aspect of the total system performance metrics is the ability to obtain an accurate measurement of the outflow of treated water. Efforts to implement a suitable outflow meter were conducted by AS&T in FY 2010.

The treated water contains a high concentration of dissolved iron (not a contaminant) that precipitates as iron oxide in the outflow stream. The iron oxide causes problems with flow metering. Another issue is that the hydraulic head driving the flow through a measuring device is rather small (about 4 feet [ft]). The pressure drop across many flow meters exceeds this value and will not function properly at the required flow rates. Attempts to measure the outflow included a variety of flow meters including: Great Plains Instruments (Model S10N) turbine meter, Smart Meter (Model SE700) with no moving parts, Signet (Model 2551) mag meter, and a Tracom Inc. (#12415) weir meter. The turbine and Smart meters had excessive pressure drop. To overcome this, dual meters were placed in a manifold configuration, but after relatively short time periods (weeks) they decreased in accuracy due to build up of iron oxide. The weir system required very accurate measurement (to tenths of inches) of water depth, and after time (and iron oxide build up) it lost accuracy as well.

In FY 2010, to overcome these problems, AS&T funded design of a large "tipping bucket" flow meter. Although these are commercially available, to match the flow rate and conditions at Monticello and in anticipation of needing operating adjustments, we designed one and are having it built locally. The cost of design-build is less than the cost of commercially available units. We anticipate that, because of the simplicity of this metering device, it will succeed where other meters have failed. There is no issue with hydraulic head, because there is no pressure drop with this design. Iron oxide may accumulate in the bucket but will likely be flushed at each tip and can be easily serviced by simply washing it out, if needed. We expect to have the meter laboratory tested and installed in fall of 2010.

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 2010 Activities: Two additional column tests were conducted using a laboratory-based water composition to simulate Monticello groundwater. One column contained citrate and the other did not. The effluent uranium concentrations were higher in the column with citrate than in the column without, suggesting that uranium was being chelated by citrate. These results contrast with earlier results from the Rocky Flats column tests. Interpretation of these results is continuing and an ESL report will be generated in FY 2011.

3.4 Evaluation of Floodplain Remediation—Shiprock, New Mexico

Overview: At LM's Shiprock, New Mexico, Disposal Site, two groundwater collection drains were installed in February 2005. Each drain is 200 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 2010 Activities: In FY 2010, pumping of Trench 2 was discontinued for much of the summer to limit the amount of water flowing to the evaporation pond and to observe contaminant rebound under non-pumped conditions. Pumping was resumed September 1, 2010, and continues to pump at about 15 gpm. Pumping cycles were controlled remotely through SOARS. During the shutdown period, specific conductance (an estimate of dissolved solid concentration that can be made continuously) showed little change, with perhaps a slight increase in the pumping well.

Because of the successful implementation at Trench 2, construction of a SOARS monitoring network at the other floodplain collection drain (Trench 1) and an area nearer the San Juan River (area 1089) were initiated in FY 2009. The SOARS system at these areas was completed early in FY 2010 and included construction of three new Geoprobe wells (well drilling was funded using site funds), addition of new datalogging stations, wiring of water level and specific conductance instruments in sixteen wells, and connection to SOARS.

The purpose of the SOARS monitoring system is to help evaluate effects of the pumping system on groundwater cleanup rates. Data from the combined systems (Trench 1 and area 1089) will be used to evaluate contaminant transport and cleanup rates for the central portion of the floodplain, an area containing the bulk of the contamination. A report describing the monitoring results from the Trench 1 and well 1089 areas will be prepared in FY 2010. Combined with the data from Trench 2, these data will provide a comprehensive understanding of groundwater flow and contaminant removal on the entire floodplain. The combined data will also be used to guide future remediation efforts.

3.5 Natural Contamination Study

Overview: This project was initiated in September 2010. The Mancos Shale has long been considered to be a suitable geologic substrate for disposal cells. Reasons often cited for its suitability include its low value of vertical hydraulic conductivity that limits surface water

infiltration, its limited use as a groundwater aquifer (virtually non-producing), and its content of high background concentrations of soluble salts and natural contaminants (such as selenium), which render the groundwater unsuitable for most uses. The Grand Junction, Colorado, Disposal Site, Grand Junction, Colorado and Shiprock, New Mexico, uranium mill tailings disposal sites were constructed on Mancos Shale. The Moab tailings are being moved to a disposal cell at Crescent Junction, Utah, which is also underlain by Mancos Shale. The Rocky Flats Site is on the Pierre Shale, a geologic formation equivalent to the Mancos Shale. Several compliance documents state that the Mancos Shale contributes selenium and other contaminants to groundwater and that in some areas near the DOE disposal cells, the selenium (and possibly uranium and other contaminants) are contributed not from the disposal site, but naturally from the Mancos Shale. The goal of this project is to evaluate the Mancos Shale as a natural contributor of these contaminants to groundwater systems. The project includes literature reviews, field reconnaissance, and groundwater sampling.

FY 2010 Activities: A proposal for this work was prepared and approved by DOE. Literature searches were conducted and are continuing on a wide range of applicable subjects including: (1) presence of seeps, wells, and other accessible occurrences of groundwater in the Mancos Shale; (2) occurrences of elevated concentrations of salts, selenium, uranium and other contaminants in the Mancos Shale groundwater; (3) use of uranium isotopic ratios to characterize source and reaction history of uranium in groundwater; and (4) use of boron concentrations to define groundwater origins in marine black shale such as the Mancos. Several field trips were made to areas in Colorado, Utah, and New Mexico to assess potential sampling sites for Mancos groundwater. Some key locations were targeted and developed into sampling points. Data were organized into a Google Earth kml file. A map of the Mancos depositional basin is in preparation.

Following the reconnaissance work, samples will be collected and analyzed for a target set of analytes including (but not limited to): uranium, uranium-234, uranium-238, boron, selenium, arsenic, major ions and field parameters. A report is due to DOE at the end of March 2011.

3.6 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, Disposal 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; however, the concentrations are different (for example, lower in uranium and higher in selenium). Paradoxically, contaminated seeps occur on the east wall of the incised valley but not on the western side. The western side 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 production diminished over time, 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 gpm to 0.8 gpm as a result of the additional water from the diversion structure.

FY 2010 Activities: The AS&T task order continues to monitor a SOARS station that was established at well 1049, located about 100 ft south of a series of seeps (the knickpoint seeps), for data that will help determine the seasonal flows to the seeps.

A new project was undertaken in FY 2010 aimed at determining the southern extent of the groundwater saturation in a tributary to East Fork of Many Devils Wash. Field data suggest that most or all of the contaminated water in Many Devils Wash originates in this area. The goals of the project are to help determine the source of the contaminated groundwater (mill related or natural) and to provide detailed data to improve the remediation system, possibly including a pumping location in the tributary. Twenty-five sampling points were installed, sampled, and analyzed. Elevation data on geologic contacts were collected to map channeling on top of the Mancos Shale that might control groundwater flow. Samples of loess were collected and analyzed to determine the concentrations of contaminants. Geographic information system (GIS) maps were made of the project site and data were entered into Google Earth to aid interpretation through visual displays. A draft report was prepared.

A project was proposed to address the source of contaminated groundwater in Many Devils Wash. There are currently two hypotheses: (1) contamination from the DOE uranium mill tailing disposal site and (2) natural contamination resulting from groundwater interaction with Mancos Shale or sediments derived from Mancos Shale. The proposed work includes Geoprobe drilling, searches of historical records, and field analysis of possible analog sites. A draft budget change proposal was prepared.

3.7 New Rifle Vanadium Investigation

Overview: Vanadium is dissolved in groundwater at the New Rifle Site near Rifle, Colorado, 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 Site 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 was 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.

FY 2010 Activities: Operation of a SOARS network, including transducers and conductivity sensors, continued in FY 2010. The oxidation-reduction sondes were removed because the calibration data indicated that the long-term readings were unreliable. Sampling from an auto-sampler continued partway into FY 2010 but has since been discontinued. Results of the static geochemical model developed in FY 2009 were used to construct a 1-D transport model to simulate the occurrences of high vanadium concentrations in the groundwater. Results of the sampling, analysis, and modeling were evaluated and a report was prepared in FY 2010.

3.8 Disposal Cell Cover Performance

Overview: LM is responsible for LTSM of disposal cells constructed to contain tailings and other residual milling materials as mandated primarily through the Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA). The key feature of UMTRCA disposal cells is an engineered cover designed to limit release of radon into the atmosphere and, at some sites, to limit percolation of rainwater and leaching of contaminants into groundwater—and to continue to do so in perpetuity. DOE routinely conducts visual inspections of the disposal cells as part of LTSM and intermittently conducts follow-up investigations of cover degradation processes and performance as a best management practice.

Cover design concepts, construction practices, and performance evaluations have undergone significant changes since passage of UMTRCA. Design improvements primarily reflected (1) efforts to satisfy U.S. Environmental Protection Agency (EPA) standards for groundwater quality, (2) a better understanding of degradation processes, and (3) overall advances in the state of the science. Before EPA mandated groundwater quality standards, the cover design process focused on radon attenuation and longevity. Early designs consisted basically of three layers: (1) a compacted soil layer (CSL) or radon barrier overlying the tailings, (2) a rock riprap layer at the surface to control erosion, and (3) a bedding layer of coarse sand or small gravel sandwiched between the CSL and riprap. Disposal cell covers at Burrell, Pennsylvania; Lakeview, Oregon; Shiprock, New Mexico; and Tuba City, Arizona, are examples of the early designs.

In anticipation of EPA groundwater quality standards, DOE estimated, retrospectively, that CSLs in the early covers (1) had a saturated hydraulic conductivity of approximately 10^{-7} centimeter (cm) s^{-1}, (2) would operate at an unsaturated hydraulic conductivity of 10^{-9} cm s^{-1}, and (3) that "any moisture that penetrated the upper portion of the radon barrier is held there until it is evaporated"; thus, "this design prevents the radon barrier from becoming saturated." DOE also developed a new design framework that placed greater emphasis on limiting percolation flux in the CSL. The framework recommended a conservative percolation flux for CSLs that is equivalent to a saturated hydraulic conductivity of between 10^{-7} and 10^{-8} cm s^{-1}. The framework included an option for placing a soil layer above the CSL to protect it from degradation processes that could increase the saturated hydraulic conductivity such as freeze/thaw cracking and biointrusion. Colorado examples of this improved, low-permeability design are the Durango, Gunnison, Grand Junction, and Rifle covers (http://www.lm.doe.gov).

Advances in the science of cover designs and lessons learned from observing and evaluating degradation processes in both the early covers and the later, low-permeability covers contributed to DOE's development of alternative designs. In many arid and semiarid ecosystems, relatively low precipitation, high potential evapotranspiration (ET), and thick unsaturated soils limit deep percolation. DOE and others developed covers that mimic this natural water conservation, sometimes called ET covers, in an attempt to provide more sustainable tailings isolation and groundwater protection. The disposal cell at Monticello, Utah (http://www.lm.doe.gov), a uranium mill tailings site regulated under Resource Conservation and Recovery Act/CERCLA, is an example of this alternative design. To limit percolation, the Monticello cover relies on a 160-cm layer of sandy clay loam soil overlying a 40-cm sand capillary barrier as a water storage layer, and a planting of native sagebrush steppe vegetation to seasonally remove soil water and limit percolation.

Since 2000, the focus of cover performance monitoring has been a large embedded lysimeter in the Monticello cover. 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 embedded in the Monticello disposal cell cover. Over the years, the facility has been used to evaluate various ET cover designs for DOE and 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.

FY 2010 Activities: Activities in FY 2010 included (1) workshops on cover performance, (2) monitoring soil water balance parameters in the 3-ha embedded lysimeter at Monticello, and (3) publication of a book on water balance covers.

3.8.1 LM/NRC Working Group Meeting on UMTRCA Covers

The AS&T Surface Program sponsored a workshop on the "Design, Performance, Renovation, and Sustainability of Engineered Covers for Uranium Mill Tailings Disposal Cells." The workshop was held at the LM office in Grand Junction on February 2–3, 2010. Attendees included professional staff from LM and the U.S. Nuclear Regulatory Commission (NRC). A summary of workshop topics, objectives, products, expected outcomes, and presentation titles follow:

1. Background Information

   Objective: Review regulatory history, different design requirements, design evolution, and LTSM requirements for UMTRCA) covers.

   Expected Outcome: Attendees will have a common understanding of critical background information leading up to current cover renovation and long-term performance evaluations.

2. Ongoing UMTRCA Cover Studies

   Objective: Present current LM and NRC studies on the performance of conventional and alternative covers, cover renovation, and long-term performance evaluations.

   Expected Outcome: Attendees will understand the purposes, objectives, and current results of ongoing LM and NRC cover performance studies.

3. Independent Cover Performance Studies

   Objective: Present the objectives, methods, and results of the EPA's Alternative Covers Assessment Program (ACAP) comparing conventional and alternative cover designs.

   Expected Outcome: Attendees will be aware of non-DOE research on cover performance and its relevance to UMTRCA cover monitoring and current LM and NRC studies.

4. Product: Areas of Common Understanding

   Objective: Outline and discuss UMTRCA cover monitoring and performance issues stemming from topical presentations and group discussions.

   Expected Outcome: Lists of areas of common understanding among LM and NRC attendees, and also unresolved issues.

5. Product: Summary of Technical Issues

   Objective: Identify and discuss technical issues.

   Expected Outcome: Summary statements of technical issues.

Presentations:

Design, Performance, Renovation, and Sustainability of Engineered Covers for Uranium Mill Tailings Disposal Cells – W. Waugh, S.M. Stoller Corporation.

UMTRCA Regulatory Requirements and Cover Designs for Uranium Mill Tailings Cells – D. Gillen, U.S. Nuclear Regulatory Commission (consultant).

Current LTSM Cover and Groundwater Monitoring Practices – C. Jacobson, S.M. Stoller Corporation.

Rock Sizing and Rock Durability – T. Johnson, U.S. Nuclear Regulatory Commission (consultant).

Performance of UMTRCA Covers: Radon Monitoring – C. Gauthier, S.M. Stoller Corporation.

Performance of UMTRCA Covers: Ecology and Soil Hydrology – J. Waugh, S.M. Stoller Corporation.

Monticello Water Balance Cover Design and Monitoring – J. Waugh, S.M. Stoller Corporation.

Alternative Cover Assessment Program: Water Balance Studies – B. Albright, Desert Research Institute.

Laboratory Studies of Clay Layers – J. Phillips, U.S. Nuclear Regulatory Commission.

Soil Development and Changes in Engineering Properties – C. Benson, University of Wisconsin.

Cover Renovation Study (RECAP): Purpose, Design, and Monitoring – J. Waugh (S.M. Stoller Corporation), B. Albright (Desert Research Institute), C. Benson (University of Wisconsin).

Monitoring, Modeling, Analogs, and Long-Term Performance Evaluation – J. Waugh (S.M. Stoller Corporation), B. Albright (Desert Research Institute), C. Benson (University of Wisconsin).

3.8.2 NRC Workshop on Engineered Barrier Performance

An S.M. Stoller Corporation (Stoller) scientist served on the organizing committee, gave presentations, and served on expert panels for NRC's "Workshop on Engineered Barrier Performance Related to Low-Level Radioactive Waste, Decommissioning, and Uranium Mill Tailings Facilities." The workshop took place August 3–5, 2010, at NRC Headquarters in Rockville, Maryland.

The objectives of the workshop were to "facilitate communication among Federal and State staff and contractors, and selected experts, on current engineered barrier issues and technical and regulatory experiences; discuss lessons learned and new approaches for monitoring and modeling; prepare recommendations to address maintenance of engineered barrier performance over time; identify topics for future research and the potential need to update technical guidance."

The AS&T Surface Program contributed the following presentations:

DOE Experience with Cover Degradation Processes, Design Improvements, and Cover Renovation for Uranium Mill Tailings Disposal Cells – J. Waugh.

A Role for Natural Analogs in the Design and Long-Term Performance Evaluation of Earthen Covers for Uranium Mill Tailings – J. Waugh.

An AS&T Surface Program scientist served on the following expert panels at the workshop:

Degradation Processes and Performance Evolution of Engineered Barriers.

Experience with Model Support and Multiple Lines of Evidence to Gain Confidence in Long-Term Performance.

3.8.3 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 6.0 millimeters (mm) over the 10-year (yr) monitoring period from August 2000 through July 2010 for approximately 0.6 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.

3.8.4 ET Cover Book

AS&T personnel contributed to publication of the following book:

Albright, W.H., C.H. Benson, and W.J. Waugh, 2010. *Water Balance Covers for Waste Containment: Principles and Practices,* American Society of Civil Engineers, Reston, VA.

As described on the back cover, “this book presents, for the first time in one place, results of the latest research regarding water balance covers for solid waste sites, along with case studies drawn from current field testing. It introduces water balance covers and compares them with conventional approaches to waste containment. The authors give detailed analysis of soil physics and design issues, introduce applicable ecological concepts and revegetation practices, and then move on to construction, modeling and maintenance. A viable alternative to conventional landfill cover systems, water balance covers (also known as store-and-release and evapotranspiration covers) cycle water from the soil to the atmosphere during the growing season, minimizing percolation of rainwater through the soil, and thus the production of lewachate from landfill contents. This book will valuable to practicing engineers, as well as regulatory analysts.”

3.9 Remote Sensing Studies

Overview: AS&T personnel are 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 2010 Activities: In FY 2010, a status report was prepared and submitted to LM. The report, "Remote Sensing Analysis of LM Closure Sites Monticello, UT and Monument Valley, AZ," was authored by Savannah River National Laboratory and the University of South Carolina. The report discusses progress in analyzing remote sensing and ground level data obtained at the Monticello, Utah, Disposal Site and the Monument Valley, Arizona, Processing Site, phytoremediation sites operated by LM. Ground level data were collected as a coordinated effort by the ESL, Savannah River National Laboratory (SRNL) and University of South Carolina (USC) in early June 2008. Aerial hyperspectral data was collected by HyVista Corporation concurrent with ground level collections at the two sites. Funding for data collection was provided by LM and the National Aeronautics and Space Administration (NASA). Data from the 2008 collections were archived and all but the digital imagery were distributed to the participating organizations. In May 2009, a proposal was prepared for LM to fund completion of the analysis, and funding was authorized at the Savannah River Site in September.

An initial description of the completion project and summary of ground level data collections was contained in the May 2009 proposal to LM. That proposal contained results for LAI, plant community composition, and porometer (transpiration) measurements collected at each of the sampling locations and additional data collected at the Monticello Mill Site. A description of the approach to be taken for the analysis of hyperspectral data was also presented.

The Monticello Disposal Cell was constructed as a component of the Monticello Remedial Action Project to accept contaminated materials produced as a part of the overall cleanup action and provide for safe, long-term isolation of those materials. The closure of the 90-acre disposal cell began in 1999 and was completed in 2000 with the exception of establishment of the vegetative cover, which was completed in 2001. The installation represents an advanced soil-vegetation cover design adapted to the climatological conditions of the region, whereby a carefully designed and constructed soil layer acts as a "sponge" during precipitation periods and the native vegetation layer acts as a "pump" during the growing season, resulting in minimal net runoff from the cell. Success of this system is dependent on correct functioning of both the soil and vegetative components of the cover system. The objective of the current project is to complete analyses of remote sensing data to (1) provide a comprehensive assessment of the composition and condition of the vegetative layer and (2) demonstrate the feasibility and utility of the remote sensing technology as a central element of the long-term monitoring strategy for closure-cap systems.

The Monument Valley, Arizona, Processing Site was used for initial milling of uranium ore. Surface remediation of the site was conducted from 1992 through 1994. Further investigation of the site revealed high concentrations of nitrate, ammonium, and sulfate in the alluvial aquifer. A phytoremediation feasibility study was initiated in 1998 to examine the ability of bioremediation/natural attenuation strategies for remediating the nitrogen compounds in the alluvial plume. Those studies will provide information needed to develop recommendations for the long-term remedial strategy for the site. The success of this phytoremediation strategy is clearly dependent on the proper functioning of the vegetation in providing some measure of hydrological control and in supporting metabolic processing of the nitrate and ammonium compounds. In this case, remote sensing analyses will be focused on using the technology to provide estimates of water processing in the vegetation and overall condition of the plant community.

The status report provides results from preliminary analyses of remote sensing data from the Monticello and Monument sites and a proposed outline for the final project report. Analyses presented are preliminary pending further rectification of the ground and image data. Nevertheless, significant consolidation and analysis of the data has occurred and preliminary results are encouraging.

3.10 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 2010 Activities: Activities in FY 2010 included the following: (1) monitoring percolation in the cover at the Lakeview, Oregon, Disposal Site, (2) monitoring soil water content in tailings in the Lakeview disposal cell, and (3) monitoring percolation at the Monument Valley site.

3.10.1 Percolation Monitoring at Lakeview

DOE constructed the Lakeview disposal cell in 1989 under UMTRCA 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.

In 2005, LM began a pilot study at the Lakeview disposal cell to test a new type of passive-wicking lysimeter. It involves a soil WFM that can be used to directly monitor percolation flux through disposal cell covers.

A letter report originally written in 2009 was revised in March 2010.

Three WFMs were installed in the top slope of the Lakeview disposal cell during the fall of 2005. WFMs were placed in holes augered into the upper tailings material just below the radon barrier. WFMs could not be installed in the side slope of the cover because the tailings were saturated and the installation holes rapidly filled with water; however, WCRs were installed in the side slope to monitor moisture content.

The results of the pilot study show that WFMs can be installed in existing disposal cell covers to directly monitor percolation flux. WFMs have lower levels of uncertainty than do more-conventional methods for estimating percolation. However, WFMs may have a relatively short operating life. One of the three WFMs employed in the test failed within 2 years of its installation.

The cumulative percolation has remained exceptionally high during the 4-year monitoring period—greater than total precipitation for the period. However, in 2009, total percolation was 50 percent of precipitation, possibly attributable to changes in precipitation patterns, changes in soil permeability, and/or increases in plant abundance on the cover. Percolation rates were probably high because the WFMs were strategically placed in downgradient locations where there may be a water-harvesting effect. The bedding layer is likely shedding some water, which accumulates downgradient, causing the drainage layers and CSL to remain saturated for an extended period at WFM locations.

3.10.2 Water Content in the Tailings at Lakeview

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. A manufacturer's calibration is supplied with the sensor; however, calibrations were checked against specific site soil conditions since salinity and other soil properties, such as mineralogy and specific gravity, can influence the calibration. WCR calibrations, developed for both the CSL and tailings materials in the Lakeview disposal cell, were reported previously.

The 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 that the moisture content of the CSL and the near-surface layer of the tailings fluctuate seasonally as well as in response to precipitation. However, at a depth of about 2 meters (m) (6 to 7 ft), the tailings remained saturated for the entire monitoring period from November 2005 through September 2010.

3.10.3 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 data showing that all were functioning correctly and capable of recording percolation events should they occur. However, when water was injected in WFMs in June 2010, only two of the four were still operating.

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.

3.11 Renovated Evapotranspiration Cover Assessment Project (RECAP)

Overview: LM initiated the RECAP in September 2007 to evaluate an inexpensive approach to improve long-term surveillance and maintenance of final covers for disposal cells. The objective is to accelerate and enhance natural processes that are transforming existing conventional covers (that rely on earthen hydraulic barriers) into water balance covers (that store water in soil and release it through soil evaporation and plant transpiration).

Covers employing the store-and-release principle have been shown to function well in semiarid to arid regions, whereas covers with conventional earthen barrier layers have performed unsatisfactorily. Conventional covers will be renovated by deliberately blending the upper layers of the cover profile and planting native shrubs. A test facility was constructed at the Grand Junction, Colorado, Disposal Site to evaluate the proposed methodology. The facility includes two test sections, one of which will be renovated using the proposed method. The other test section is a control. Effectiveness of the renovation treatment is being evaluated by monitoring hydrologic conditions within the cover profile (water content, matric potential) as well as boundary fluxes (runoff, evapotranspiration, and percolation).

FY 2010 Activities: In FY 2010 a test pad was installed to test ripping and revegetation practices and a lysimeter design and construction report was finalized

3.11.1 Test Pad Construction

A test pad was constructed at the Grand Junction Disposal Site to replicate the upper three layers of the disposal cell cover and the lysimeter test facility constructed in the autumn of 2007. Initial lysimeter construction was undertaken to evaluate a method to renovate conventional covers with soil barriers in a manner that deliberately accelerates their transformation to water balance covers. The objective is to accelerate and enhance the natural processes occurring in the field, where the riprap is slowly being filled with fine-textured soil. This will be accomplished by deliberately blending the riprap and underlying fine-textured soil by ripping and mixing the rock, drainage, and frost protection layers and planting native shrubs in the rip rows.

The test pad was constructed to evaluate various ripping and revegetation operations and to select the best method to renovate the cover prior to ripping operations on the lysimeter test facility. Ripping will extend through the rock cover, bedding layer, and a majority of the protective layer. A test pad report, including all phases of construction with photographs and initial soil physical properties, was drafted in September 2010.

3.11.2 Lysimeter Construction Report and Monitoring

The report, "The RECAP Test Sections at the Grand Junction Disposal Site: Construction Documentation and Instrument Calibration," describes the historical experience of final covers employing soil barrier layers at sites managed by DOE and others. It also describes the RECAP test facility, the testing conducted to characterize the as-built engineering properties of the RECAP test sections, the calibration of instruments installed at the RECAP test facility, and the monitoring data collected since the test sections were constructed.

Testing the renovation procedure on the existing cap was not practical. Thus, two identical large-scale test sections simulating the cover were constructed adjacent to the Grand Junction Disposal Site. One of these test sections will be renovated, whereas the other will be monitored as a control that simulates the existing cover. Both test sections were constructed in late summer and fall 2007, and currently are acclimating to ambient environmental conditions. The renovation treatment will be applied to one test section after surface conditions indicate deposition in the riprap is occurring and the monitoring data indicate that the radon barrier has become more permeable.

The RECAP test sections are modeled after the test sections used in the EPA's ACAP. Each test section contains a pan lysimeter (10 m × 20 m) that is used for monitoring percolation from the base of the cover, a runoff collection system, a collection of instruments used to monitor state variables within the cover profile, and a weather station to monitor meteorological conditions. This system permits quantification of all components of the water balance, namely precipitation, runoff, soil water storage, percolation, and evapotranspiration. The latter is obtained by closure of the water balance. Each test section includes a 10-m-wide buffer zone around the lysimeter.

The test sections were constructed using the same earthen materials employed for the full-scale cover, which had been previously stockpiled in 1992 for future closure activities. Therefore, all cover materials used in construction of the RECAP test facility are identical to those in the cover over the disposal cell. The radon barrier and the frost protection layer were constructed with moderately plastic clay having a Unified Soil Classification System (USCS) designation of CL. The radon barrier was underlain with a 460-mm-thick layer of road base gravel (broadly graded alluvium with a USCS classification of SW) that was stockpiled on site when the full-scale cover was constructed. This lower layer of road base gravel simulates the transition layer in the disposal cell. The bedding layer beneath the riprap was also constructed with road base gravel. Riprap for the surface was obtained from a stockpile on site left over from construction of the full-scale cell. Heavy equipment similar to that used for the full-scale cover was employed for construction.

3.12 Monument Valley and Shiprock Enhanced Attenuation

Overview: LM, the Navajo Uranium Mill Tailings Remedial Action Department, the University of Arizona, and Diné College are jointly exploring alternative remedies for groundwater contamination at the Monument Valley Processing Site that include natural and enhanced attenuation 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 2010 Activities: The Monument Valley and Shiprock enhanced attenuation pilot studies are now funded entirely through the site budgets. However, in FY 2010, AS&T received permission from LM to contribute a chapter to a book, *Science and Stakeholders: Solutions to Energy and Environment Issues*, to be published by Springer in 2011.

The book describes and examines the interactions and integration of science and stakeholders to find solutions to controversial energy-related issues. The book uses case studies to explore (1) methods of integration and collaboration among diverse communities and (2) ways to develop a synthesis of true stakeholder involvement in energy-related issues that results in acceptable solutions that protect both human and ecological health.

A Stoller scientist contributed the chapter titled “Helping Mother Earth Heal: Diné College and Enhanced Natural Attenuation Research at U. S. Department of Energy Uranium Processing Sites on Navajo Land.” A summary of the chapter follows:

Diné Environmental Institute (DEI) has become a key stakeholder and partner with DOE in efforts to develop and implement sustainable and culturally acceptable remedies for soil and groundwater contamination at uranium mill tailings processing and disposal sites on Navajo Nation land. DEI is a center for environmental education, research, and community outreach located on the Shiprock, New Mexico, campus of Diné College, the Navajo Nation institution of higher education. As a stakeholder, DEI plays a key role in shaping the philosophy of remedial actions, advancing the science of sustainable remedies, bridging communication and interaction among other stakeholders, listening to and responding to the concerns of the Navajo people, and training a new generation of scientists to address the uranium mining legacy and other environmental and energy issues on the Navajo homeland.

Through an educational philosophy grounded in the Navajo traditional living system called Sá'ah Naagháí Bik'eh Hózhóón, which places human life in harmony with the natural world, DEI has helped guide researchers to look beyond traditional engineering approaches and seek more sustainable remedies for soil and groundwater contamination at former uranium mill sites near Monument Valley, Arizona, and Shiprock, New Mexico. Following this philosophy, researchers are asking first, what is Mother Earth already doing to heal a land injured by uranium mill tailings, and second, what can we do to help her? This has led researchers to investigate applications of first, natural, and then, enhanced attenuation remedies involving native plants—phytoremediation, and indigenous microorganisms—bioremediation. Although such applications

are fairly common in wetland and humid environments, enhanced attenuation in the desert is new and innovative.

DEI faculty and students are working side by side with university and DOE scientists on pilot studies aimed at developing sustainable remedies for contaminated soil and groundwater at Monument Valley and Shiprock. Diné College faculty, student interns, and local residents have contributed to several aspects of the pilot studies including site characterization, sampling designs, installation and maintenance of plantings and irrigation systems, monitoring, and data interpretation. Research results look promising.

At Monument Valley, DOE removed radioactive tailings from the site in 1994. Nitrate and ammonium, waste products of the milling process, remain in an alluvial groundwater plume spreading from the soil source where tailings were removed. Planting and irrigating two native phreatophytic shrubs, fourwing saltbush and black greasewood, has markedly reduced both nitrate and ammonium in the source area over an 8-year period. Most of the reduction is attributable to irrigation-enhanced microbial denitrification rather than plant uptake. However, soil moisture and percolation flux monitoring show that the plantings control the soil water balance in the source area, preventing additional leaching of nitrogen compounds. Enhanced denitrification and phytoremediation also look promising for plume remediation. Microcosm experiments, nitrogen isotopic fractionation analysis, and solute transport modeling results suggest that most of the plume nitrate has been lost through natural denitrification since the mill was closed in 1968. Injection of ethanol may accelerate microbial denitrification in plume hot spots. Finally, landscape-scale remote sensing methods developed for the project suggest that transpiration from restored native phreatophyte populations rooted in the aquifer could limit further expansion of the plume.

At Shiprock, DOE contained mill tailings in an engineered disposal cell in 1986. Groundwater is contaminated by uranium, nitrate, and other constituents as a result of milling operations. Passive phytoremediation and hydraulic control are ongoing at Shiprock. Native phreatophytes are extracting water and possibly other groundwater constituents. Phytoremediation test plots were set up in 2006 with assistance from DEI student and faculty to evaluate the feasibility of enhancing hydraulic control. Researchers are evaluating several factors that will influence the success of enhanced phytoremediation, including site preparation methods, establishment and growth of different plant species, root access of plume groundwater, and uptake and toxicity of groundwater constituents.

DEI's insight and experience implementing an educational policy that fosters diversity of thought, the joining of tradition and science, and the importance of community, has been instrumental in building stakeholder relations. With firsthand knowledge of human health and environmental issues associated with the Navajo uranium legacy, lifelong practice of Navajo Way of Life, and experience directing community outreach programs, DEI faculty have been influential in helping mediate communication and interaction among stakeholders including federal regulators and administrators, research scientists, Navajo Nation agencies, and the Navajo people.

Finally, DEI and Diné College are training a new generation of scientists and community leaders who will write the next chapter in the Navajo story about uranium mining, milling, and environmental stewardship. They will know the history, they will continue the traditions, they

will advance the science, they will facilitate the needed partnerships, they will inform the people, they will protect human health, and they will fulfill their duty as caretakers of Mother Earth, helping her restore and sustain the health of the land.

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 2010 Activities: Accomplishments in 2010 are outlined below:

- Environmental Management System (EMS) Land Stewardship merged with the Ecosystem Management Team (EMT); an EMT member became the EMS liaison with responsibility for Land Stewardship goals, meetings, and deliverables.
- The EMT met on a monthly basis to address Strategic Planning and EMS Land Stewardship issues. Team members are ecologists and site managers from the Grand Junction, Rocky Flats, Fernald, and Weldon Spring sites.
- 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.
- EMT created and completed a survey for 501 site leads to identify new opportunities for ecosystem improvements. A screening form with a simple yes/no format was provided to the site leads for their responses. The results of the screening indicated that most site leads were not in touch with information that is not directly related to the required LTSM inspections. The focus of the inspections is to meet NRC inspection criteria. Baseline information is needed on other site aspects to enable selection of a site for improvement.

However, several opportunities for small-scale improvements were identified, including installation of "fence flags" on the Lakeview, Oregon, Processing Site fence as a way to reduce deer entanglements and mortality.

- LM approved the following EMT actions for FY 2011:

  1. Provide DOE with a concise year-end summary of ecosystem improvements including remedy improvements, land management improvements, and habitat improvements. The EMS Land Stewardship Team records improvements in an existing tracking log. DOE should get credit for ongoing improvements. Creation of the tracking log was an earlier EMS goal.
  2. Present DOE with a proposal to begin acquiring baseline characterization data on LM sites (range condition, revegetation condition, weed populations, habitat value, habitat condition of adjacent land, adjacent land owner willingness to continue improvements, and so on). Baseline data are needed as a basis for measuring ecosystem improvements. Baseline data are also needed to assist in identifying sites.

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 2010 Activities: A significant accomplishment in FY 2010 was establishment of the "Technology Deployment" strategic planning intranet site. The site is accessible to all LM personnel at:

\\Condor\LM_Public\Contractor\Departments\Environmental Sciences Laboratory\Technology Deployment Strategic Initiative\Handbook for Technology Deployment - DOE Legacy Management.doc

The site is divided into four main sections dealing with (1) Technologies Currently Deployed at LM Sites, (2) LM Future Needs, (3) Proven and Developing Technologies, and (4) Direction for Technology Deployment for LM. Each section is further subdivided and numerous links are available to internal documents and web sites. The site is continually updated as new information becomes available.

An ESL scientist was a member of an Expert Review panel that met at the Hanford Site to evaluate their investigation of gas injection to stabilize uranium in the subsurface. A facilitated session on AS&T for LM was organized for the LTSM conference to be held in November 2010. Quarterly status meetings for the AS&T subtask order were held.

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.

3.14.1 Diné College Educational Outreach

The AS&T Program sponsored the following educational outreach activities for Diné College DEI students in FY 2010:

- Two seminars: One on Monument Valley and Shiprock enhanced attenuation pilot studies, and a second on disposal cell cover performance and renovation (June 2010).
- Field sampling for plant uptake and tissue analysis in the Diné College orchard. Students sample buds, stems, leaves, and fruit for analyses of nitrate, sulfate, and metals (including uranium) known to be elevated in groundwater at other locations near the Shiprock uranium tailings disposal site. Students assisted Stoller in developing an experimental design and sampling the orchard trees (October 2009).
- Field sampling in the phytoremediation pilot study plots at Shiprock to determine if volunteer phreatophytic shrubs are taking up uranium and other metals at levels high enough to be harmful (October 2009).
- Students assisted in monitoring shrub growth in the source area, plume, and land-farm plots at Monument Valley and in the borrow pit and terrace plots at Shiprock. Survival, canopy volume, canopy cover, leaf area index, and dry-weight biomass of *A. canescens* and *S. vermiculatus* shrubs were measured (October 2009).
- Students assisted Stoller in sampling soils in the Land-Farm pilot study plots at Monument Valley to determine levels of nitrate and sulfate accumulation (November 2009).
- Students assisted Stoller in determining the water storage capacity of the Monument Valley fine sand using existing water flux meters and water content reflectometers (June 2010).

3.14.2 Vanderbilt University Adjunct Faculty

A Stoller scientist retained an adjunct faculty appointment with Vanderbilt University and served on the graduate committees of a PhD candidate in the Civil and Environmental Engineering Department. The PhD candidate successfully defended her dissertation, “Monitoring the Long-Term Performance of Engineered Containment Systems: The Role of Ecological Processes.”

3.14.3 University of Arizona Adjunct Faculty

A Stoller scientist’s adjunct faculty appointment with the University of Arizona was renewed for 2010. The scientist served on two graduate committees. An MS student successfully defended his thesis, “Pilot Test of Enhanced Nitrate Attenuation at the Uranium Mill Tailing Site in Monument Valley, Arizona.” A second MS student, who resides in Moenkopi, Arizona, is planning a thesis project related to the long-term performance of the Tuba City disposal cell.

3.14.4 U.S. Nuclear Regulatory Commission

A Stoller scientist helped plan and participated in two workshops involving the NRC and DOE:

- DOE/LM – NRC Workshop on Design, Performance, Renovation, and Sustainability of Engineered Covers for Uranium Mill Tailings Disposal Cells, February 2–3, 2010, Grand Junction, Colorado.
- NRC Workshop on Engineered Barrier Performance Related to Low-Level Radioactive Waste, Decommissioning, and Uranium Mill Tailings Facilities, August 3–5, 2010, Rockville, Maryland.
- Session organizer and participant in the EM-22 Long-Term Monitoring Technical Forum, February 11–12, 2009, in Atlanta, Georgia.

3.14.5 Consortium for Risk Evaluation with Stakeholder Participation (CRESP)

A Stoller scientist serves as an invited member of the CRESP DOE Landfill Partnership. The Partnership was initiated in FY 2010 as a vehicle to address stakeholder acceptance and lack of confidence in containment systems, performance assessments, and monitoring systems. The Partnership will conduct applied research and facilitate technical dialogue needed to build confidence in technologies used for on-site disposal facilities, the methodology used to design and assess these facilities, and the systems used for monitoring long-term performance. The Partnership consists of members of CRESP and regulatory stakeholders from EPA, NRC, DOE, and state agencies. These partners will be asked to identify applied research activities necessary to resolve technical issues and develop or recommend technical approaches to remedy technical inconsistencies in existing regulations. Several applied research themes requiring technological development were identified through a series of independent technical reviews conducted in FY 2007 and FY 2008 and a DOE landfill workshop held in FY 2009. Topics considered for the inaugural applied research agenda include radionuclide transport in barrier systems, innovative methods for waste characterization and forecasting, and evolutionary final cover designs.

3.14.6 Savannah River National Laboratory and University of South Carolina

A Stoller scientist continued collaboration with SRNL and USC on remote sensing research at Monticello, Utah, and Monument Valley, Arizona. The project is jointly funded by LM and NASA.

3.14.7 Uranium Mining Remediation Exchange Group (UMREG)

A Stoller scientist was invited to participate in an UMREG panel on international legacy waste issues at the 12th International Conference on Environmental Remediation and Radioactive Waste Management, October 11–15, 2009, in Liverpool, England. UMREG was set up originally as a forum for discussion between the professional staff of the Uranium Mill Tailings Remediation Project and their counterparts in the Wismut GmbH in Germany who were remediating the former East German uranium mining and milling legacy sites. Over the years the group expanded as professionals working on similar problems in Australia, Canada, France, Africa, Russia and Central Asia became involved.

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 2010 Activities. A new employee was hired and trained in all laboratory procedures. All laboratory maintenance and calibration tasks were completed, and the laboratory operated trouble free. All laboratory procedures were reviewed, reformatted, and reissued. A procedure for analyzing citrate by ion chromatography was developed and tested. Several new procedures were drafted. Samples were submitted to the laboratory from Rocky Flats, Old Rifle, and Tuba City for analysis on a regular basis.

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 2010 Activities: A list of FY 2010 publications and presentations follows.

3.16.1 Published, Accepted, and Submitted Books, Journal Articles, and Proceedings Papers

Books

Albright, W.H., C.H. Benson, and W.J. Waugh, 2010. *Water Balance Covers for Waste Containment: Principles and Practices*. American Society of Civil Engineers, Reston, VA.

Waugh, W.J., E.P. Glenn, P.H. Charley, M.K. Carroll, B. Maxwell, and M.K. O'Neill. (submitted). *Helping Mother Earth Heal: Diné College and Enhanced Natural Attenuation Research at U.S. Department of Energy Uranium Processing Sites on Navajo Land*. In: J. Burger (ed.), Science and Stakeholders: Solutions to Energy and Environment Issues, Springer.

Journal Articles

Carroll, K.C., F.L. Jordan, E.P. Glenn, W.J. Waugh, and M.L. Brusseau, 2009. Comparison of nitrate attenuation characterization methods at the uranium mill tailing site in Monument Valley, Arizona, *J. Hydrology*, 378(1-2):72-81.

Traynham, B., J. Clarke, J. Burger, and J. Waugh (submitted). "Identification of dominant ecological processes for long-term performance evaluations of landfill covers," *J. of Risk Analysis.*

Proceedings Papers

Waugh, W.J., C.J. Benson, and W.H. Albright, 2009. "Sustainable Covers for Uranium Mill Tailings, USA: Alternative Design, Performance, and Renovation," *Proceedings of 12th International Conference on Environmental Remediation and Radioactive Waste Management*, October 11–15, 2009, Liverpool, England.

Waugh, W.J., D.E. Miller, E.P. Glenn, D. Moore, K.C. Carroll, and R.P. Bush, 2010. "Natural and Enhanced Attenuation of Soil and Groundwater at the Monument Valley, Arizona, DOE Legacy Waste Site," *Proceedings of Waste Management 2010 Symposium*, Phoenix, AZ.

Traynham, B., J. Clarke, J. Burger, and J. Waugh, 2010. "An application of event tree analysis to ecological systems: Understanding the long term performance of engineered covers," *Proceedings of Waste Management 2010 Symposium*, Phoenix, AZ.

3.16.2 Abstracts, Presentations, Seminars, Workshops

Borden, A.K., J. Berkompas, Z. Miao, K.C. Carroll, W.J. Waugh, E.P. Glenn, and M.L. Brusseau, 2009. Pilot Tests of Enhanced Denitrification Using Ethanol. *Geological Society of America Annual Meeting*, October 21, 2009, Portland, OR.

Waugh, W.J., C.H. Benson, W.H. Albright, G.M. Smith, and R.P. Bush, 2009. Renovation of Landfill Covers for Uranium Mill Tailings, *Annual Meeting of the Society for Risk Analysis*, December 6−9, 2009, Baltimore, MD (invited speaker).

Pilz, E., J. Troyer, R. Bush, 2010. "Interactive Mapping and Remote Data Collection for U.S. Department of Energy Legacy Sites," *Waste Management 2010*, Phoenix, AZ.

Waugh, W.J., 2010. "DOE Experience with Cover Degradation Processes, Design Improvements, and Cover Renovation for Uranium Mill Tailings Disposal Cells," *Workshop on Engineered Barrier Performance Related to Low-Level Radioactive Waste, Decommissioning, and Uranium Mill Tailings Facilities,* U.S. Nuclear Regulatory Commission, August 3–5, 2010, Rockville, MD.

Waugh, W.J., 2010. "A Role for Natural Analogs in the Design and Long-Term Performance Evaluation of Earthen Covers for Uranium Mill Tailings," *Workshop on Engineered Barrier Performance Related to Low-Level Radioactive Waste, Decommissioning, and Uranium Mill Tailings Facilities,* U.S. Nuclear Regulatory Commission, August 3–5, 2010, Rockville, MD.

Gladden, J.B., 2010. "Aerial Remote Sensing as a Component of Closure Cap Monitoring," *Workshop on Engineered Barrier Performance Related to Low-Level Radioactive Waste, Decommissioning, and Uranium Mill Tailings Facilities,* U.S. Nuclear Regulatory Commission, August 3–5, 2010, Rockville, MD.

Waugh, W.J., 2010. "Performance of UMTRCA Covers: Ecology and Soil Hydrology," *DOE/LM – NRC Workshop on Design, Performance, Renovation, and Sustainability of Engineered Covers for Uranium Mill Tailings Disposal Cells*, February 2–3, 2010, Grand Junction, CO.

Waugh, W.J., 2010. "Monticello Water Balance Cover Design and Monitoring," *DOE/LM−NRC Workshop on Design, Performance, Renovation, and Sustainability of Engineered Covers for Uranium Mill Tailings Disposal Cells*, February 2–3, 2010, Grand Junction, CO.

Gauthier, C., W.J. Waugh, and P. Wetherstein, 2010. "Performance of UMTRCA Covers: Radon Monitoring," *DOE/LM – NRC Workshop on Design, Performance, Renovation, and Sustainability of Engineered Covers for Uranium Mill Tailings Disposal Cells*, February 2–3, 2010, Grand Junction, CO.

Waugh, W.J., W.H. Albright, and C.H. Benson, 2010. "Cover Renovation Study: RECAP," *DOE/LM – NRC Workshop on Design, Performance, Renovation, and Sustainability of Engineered Covers for Uranium Mill Tailings Disposal Cells*, February 2–3, 2010, Grand Junction, CO.

Waugh, W.J., W.H. Albright, and C.H. Benson, 2010. "Monitoring, Modeling, Analogs, and Long-term Performance Evaluation," *DOE/LM – NRC Workshop on Design, Performance, Renovation, and Sustainability of Engineered Covers for Uranium Mill Tailings Disposal Cells*, February 2–3, 2010, Grand Junction, CO.

Dayvault, J., (submitted). "Overview of U.S. Department of Energy Office of Legacy Management Applied Science and Technology Program," *Proceedings of Waste Management 2011 Symposium*, Phoenix, AZ.

Waugh, W.J., C.H. Benson, W.H. Albright, and R. Bush, (submitted). "Design and Installation of a Disposal Cell Cover Renovation Field Experiment, *Proceedings of Waste Management 2011 Symposium*, Phoenix, AZ.

Waugh, W.J., 2010. *Natural and Enhanced Attenuation of Soil and Groundwater at the Monument Valley, Arizona, DOE Legacy Waste Site*. Quarterly DOE / Navajo Meeting, April 2009, Monument Valley, AZ

3.16.3 Published and Draft DOE Reports

U.S. Department of Energy, 2010. *Applied Science and Technology Task Order Fiscal Year 2009 Year-End Summary Report*, LMS/ESL/S05802 (ESL-RPT-2009-02), Office of Legacy Management, Grand Junction, CO.

U.S. Department of Energy, 2010. *Analysis and Geochemical Modeling of Vanadium Contamination in Groundwater, New Rifle Processing Site, Colorado*, LMS/RFN/S06654 (ESL-RPT-2010-01), Office of Legacy Management, Grand Junction, CO.

U.S. Department of Energy, 2010. *Geology and Groundwater Investigation Many Devils Wash, Shiprock Site, New Mexico*, LMS/SHP/S06662 (ESL-RPT-2010-02), Office of Legacy Management, Grand Junction, CO (draft).

U.S. Department of Energy, (draft). *The RECAP Test Sections at the Grand Junction Disposal Site: Construction Documentation and Instrument Calibration*, Office of Legacy Management, Grand Junction, CO.

SRNL (Savannah River National Laboratory), 2009. *Status Report: Remote Sensing Analysis of LM Closure Sites Monticello, UT and Monument Valley, AZ*, Submitted to U.S. Department of Energy Office of Legacy Management, November 24, 2009.