LMS/ESL/S08237
ESL-RPT-2011-04

Environmental Sciences Laboratory

Applied Science and Technology Task Order Fiscal Year 2011 Year-End Summary Report

September 2011

Prepared for

U.S. DEPARTMENT OF ENERGY | Legacy Management

This page intentionally left blank

LMS/ESL/S08237
ESL-RPT-2011-04

Applied Science and Technology Task Order

Fiscal Year 2011 Year-End Summary Report

September 2011

This page intentionally left blank

Contents

Table

Abbreviations

AS&T	Applied Science and Technology
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cm	centimeter
cm/s	centimeters per second
COPC	constituent of potential concern
CSL	compacted soil layer
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
EVI	Enhanced Vegetation Index
ft	foot
FY	fiscal year
GIS	Geographic Information System
gpm	gallons per minute
ha	hectare
IP	Internet protocol
LAI	leaf-area index
LM	Office of Legacy Management
LTS&M	long-term surveillance and maintenance
LTSP	Long-Term Surveillance Plan
m	meter
mm	millimeter
mm/yr	millimeter per year
MODIS	Moderate Resolution Imaging Spectrometer
MTMF	mixture tuned matched filtering
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
NRC	U.S. Nuclear Regulatory Commission
PRB	permeable reactive barrier

REP	red-edge positioning
SOARS	System Operation and Analysis at Remote Sites
UMTRA	Uranium Mill Tailings Remedial Action
UMTRCA	Uranium Mill Tailings Radiation Control Act of 1978
VDV	Vista Data Vision
WCR	water content reflectometer
WFM	water flux meter

1.0 Introduction

The Applied Science and Technology (AS&T) task order has a critical long-term surveillance and maintenance (LTS&M) role in that the U.S. Department of Energy (DOE) Office of Legacy Management (LM) needs knowledge (science) and tools (technology) to ensure that implementation of LTS&M will be informed, 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 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 LTS&M costs and risks to human health and the environment.

2.0 Objectives

The AS&T task order is at the core of LM efforts to fulfill a science and technology strategy that includes objectives published in the 2011–2020 Strategic Plan (DOE 2011):

- Ensure that sound engineering and scientific principles are used to conduct LTS&M.
- Evaluate and improve the effectiveness of routine LTS&M practices.
- Evaluate the long-term performance of disposal cells, groundwater treatment systems, and institutional controls.
- Track and apply advances in science and technology to improve the sustainability of these remedies.
- Provide LM with the science and technology needed to make informed decisions regarding potential future corrective actions and modifications of selected remedies.
- Share technologies and lessons learned with stakeholders; regulators; and state, tribal, and local governments.
- Collaborate and share project costs with other DOE offices, other agencies, universities, and industry, and offer "test beds" to other organizations that fund LTS&M research and development.
- 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.
- Use AS&T projects to create and promote opportunities, discourse, and achievements in environmental science education.

3.0 Projects and Accomplishments

Projects and accomplishments of the AS&T task order for October 2010 through September 2011 are summarized below. DOE approved fiscal year (FY) 2011 projects in the fall of 2010 as developed from the original task order language and from objectives in the 2011–2020 Strategic Plan (DOE 2011). 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 2011.

3.1 System Operation and Analysis at Remote Sites (SOARS)

Overview. The SOARS system was established in 2006 with AS&T funding to improve data collection at LM sites. The system fulfills a need to collect data from LM sites nationwide and transmit the data to a central post-processing site for real-time use by project personnel. It has saved money by reducing the number of necessary trips to sites and has improved site evaluations by affording immediate access to detailed data sets. The system has grown considerably since its initiation in 2006 and is now staffed by two full-time personnel. This project demonstrated the feasibility of collecting data remotely in real time and transmitting them to LM computer servers. Many LM sites are in remote locations, and collecting data by regular field visits is costly. Well pumps and water treatment systems are also controlled remotely through SOARS to further lessen the need for travel. SOARS data are available immediately, expediting corrective actions. 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 authorized personnel connected to the Internet.

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. Twenty-three electrical relays are used for remote control of well pumps.

FY 2011 Activities. The SOARS system expanded during FY 2011 with the addition of 11 field instruments and 7 data stations (Table 1). A satellite router, the first in the SOARS system, was installed at the Central Nevada Test Area in FY 2010.[1] The satellite link experienced some power management issues that were corrected during FY 2011. The SOARS field systems are powered from 81 solar panels. Data are downloaded daily through 14 cell modems, 1 satellite link, and 6 land lines. On-site communication with the modems is accomplished using 101 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
FY 2011	8	15	551	107

In FY 2011, upgrades using modem connections that access Internet-protocol (IP) addresses continued. These modems provide much faster data transfer and have been shown to function

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

well over time at several field sites. About 307,000 data values are transmitted daily and stored on a secure LM server.

A great improvement to the SOARS system in FY 2011 was the development of an Access database to track and inventory instruments, dataloggers, and communication devices used by SOARS. A data report that provides a calibration schedule for each instrument (about 600 of them) is forthcoming.

In FY 2011, SOARS personnel participated in an Environmental Management System (EMS) project to install and monitor power consumption at LM sites.[2] A test station was installed and optimized at Grand Junction, Colorado, and the first field installation was completed at Tuba City, Arizona. Power consumption data are now available on SOARS.

Web access to the SOARS system was functional more than 95 percent of the time during this fiscal year. 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 notifications of problems with the instrumentation or site-related issues (such as pump failure).

Although the project sites are directly responsible for routine operation, maintenance, and calibration of the field instruments, AS&T personnel support these efforts.[2] 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 is replaced during maintenance trips.

Project documentation was maintained, including SOARS Notes, Job Safety Analyses, Plan of the Day meetings, procurement logs, instrument inventories, metrics, and calibration logs. DOE accepted an award for the SOARS system at the DOE Management Awards ceremony, held on October 6, 2010, in Washington, DC.

3.2 Monticello, Utah, Treatment System

Overview. AS&T funded the development of two small treatment cells at the Monticello Processing Site, a uranium mill tailings site being closed under the Resource Conservation and Recovery Act/Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The treatment cells employ zero-valent iron to treat uranium-contaminated groundwater. They now operate with minimal maintenance costs, and the system has been transferred to Operations. The cells treat groundwater that was formerly being treated by a permeable reactive barrier (PRB). The PRB was constructed in 1999 as a demonstration of PRB technology, which was in the experimental stage of development. The PRB was later incorporated into a CERCLA Interim Action for the site. Because of the PRB's decreasing effectiveness, DOE built an experimental ex situ treatment cell in June 2005. The treatment cell contained 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 was significantly less than the PRB, and the ex situ system provides a comparable rate of

[2] Funding responsibility was shared between the sites and AS&T.

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 can now treat groundwater at a rate exceeding 14 gallons per minute (gpm). The reactive media requires regular (approximately every 18 months) change out. AS&T now provides consulting support to Operations as needed.

FY 2011 Activities. FY 2009 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 help meet groundwater regulation requirements. One aspect of the total system performance metrics is the ability to obtain an accurate measurement of the outflow of treated water. A "tipping bucket" flow meter was designed and installed by AS&T in FY 2010 to measure outflow to Montezuma Creek. This flow meter design was implemented after multiple attempts, using conventional flow meters, failed to effectively measure the outflow. The tipping bucket appears to be a viable solution to this problem, and AS&T continued to evaluate its performance in FY 2011.

Riser pipes installed by Operations to allow for faster dewatering of the treatment cells during media change out inadvertently caused flow bypass and early failure of the treatment media. AS&T personnel assisted Operations with evaluation, including tracer testing and consultation to correct this issue. It was determined that refilling the cells with new reactive media was needed to correct this issue, and this action is in progress.

3.3 Evaluation of Floodplain Remediation—Shiprock, New Mexico

Overview. Two groundwater collection drains were installed in February 2005 at LM's Shiprock Site. 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 design effort by investigating alternative means of drain installation. As a result, drains that use vegetable-based guar gum were successfully installed 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 the drain's effects on the groundwater system. In FY 2009, SOARS networks were installed at the "1089 Area," where two extraction wells are operating near the San Juan River and at the other collection drain (Trench 1). The collection drains and extraction wells are capturing a large volume of the contaminated groundwater, which is subsequently pumped to an evaporation pond. Groundwater levels and electrical conductivity data are available in the SOARS system, and groundwater samples are collected regularly for chemical analysis.

An evaluation report of the Trench 2 area, including a local hydrologic model, was completed in FY 2009. Because of the successful implementation at Trench 2, construction of a SOARS monitoring network at Trench 1 and the 1089 Area was implemented in FY 2010. This construction included the installation of three new Geoprobe wells,[3] the addition of new datalogging stations, the wiring of water level and specific conductance instruments in 16 wells,

[3] Funding responsibility was shared between the sites and AS&T.

and the establishment of a connection to SOARS. SOARS monitoring was used to help evaluate effects of the Trench 1 and 1089 Area pumping systems on groundwater cleanup rates. In FY 2011, the project was transferred to site personnel who are using results to evaluate contaminant transport and cleanup rates for the entire floodplain, using a holistic approach.

FY 2011 Activities. Detailed operational notes for Trench 1 and the 1089 Area were incorporated into the SOARS system. These notes were used to prepare a detailed analysis of data quality and performance of the extraction system. A comprehensive report describing the results from Trench 1 and the 1089 Area was completed.

3.4 Natural Contamination

Overview. This project was initiated in September 2010. The Mancos Shale has long been considered 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 Shiprock; Cheney, Colorado; and Grand Junction Disposal Sites were constructed on Mancos Shale. The Moab, Utah, tailings are being moved to a disposal cell at Crescent Junction, Utah, which is also underlain by Mancos Shale. The Rocky Flats, Colorado, 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) is 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.

In FY 2010, a proposal for this work was prepared and it was approved by DOE. Literature searches were conducted that cover a wide range of applicable subjects, including (1) the 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) the use of uranium isotopic ratios to characterize the source and reaction history of uranium in groundwater; and (4) the use of boron concentrations to define groundwater origins in marine black shale such as the Mancos.

FY 2011 Activities. More than 50 groundwater seeps were identified over the depositional basin of the Mancos Shale. These seeps were sampled and analyzed. Scientific literature was reviewed on such subjects such as (1) salt and selenium release from the Mancos Shale, (2) uranium isotopic systematics, (3) boron from marine shale and boron isotopic systematics, (4) organic and sulfide composition of black shales, (5) mass balance analyses to determine chemical losses and gains during weathering of black shale, and (6) uranium content and geochemistry in black shale.

Two areas were located that have well-defined hydrology and were excellent sites for using geochemical modeling to test ideas about chemical reactions that cause the release of salts and metals (including uranium). A reaction progress model was used to simulate geochemical reactions in the Mancos Shale that might have produced the naturally contaminated groundwater.

A prominent characteristic of these seeps is their red and yellow seepage water. The coloration was found to result from high organic carbon concentrations, although the situation may actually be more complex. Many of the seeps, including those in two arroyos within 6 miles of the Shiprock Site, were found to have high concentrations of uranium, nitrate, selenium, and sulfate in the seep water. Uranium isotopic ratios were found to be higher than the near-secular-equilibrium values characteristic of many uranium tailings.

A draft report titled *Natural Contamination from the Mancos Shale* was prepared and transmitted to DOE for review on March 16, 2011. The report has been issued and is available on the LM website. At DOE's request, a manuscript was prepared for submittal to the refereed journal, *Environmental Science & Technology*.

3.5 Origins of Contamination in Many Devils Wash—Shiprock

Overview. Many Devils Wash is located about 0.5 mile east of the disposal cell at the Shiprock 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 (e.g., 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. 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. The diversion structure is now largely clogged with sediment, and little water enters the collection system. AS&T personnel continue to monitor the flow from this collection system via SOARS. SOARS is also used to monitor 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 aimed at determining the southern extent of the groundwater saturation in a tributary to East Fork of Many Devils Wash was undertaken in 2010. Field data suggested that most or all of the contaminated water in Many Devils Wash originates in this area. The goals of the project were 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. More than 25 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.

FY 2011 Activities. In FY 2011, a project was proposed to more thoroughly evaluate the source of contaminated groundwater in upper Many Devils Wash. There are currently two hypotheses on its origin: (1) contaminated groundwater 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 included Geoprobe drilling, searches of historical records, and field analysis of possible analog sites.

This project was initiated in November 2010. Cores of tamarisks were collected, and their ages were determined. Internet searches were conducted for literature on Luna Leopold (a U.S. Geological Survey geomorphologist who was known to have conducted studies in Many Devils Wash in 1948). A visit was made to the Center of Southwest Studies at Ft. Lewis College (in Durango, Colorado) to examine historical topographic maps and other research materials that might be useful in determining the origin of seeps in Many Devils Wash. A Google Earth KML file that includes our data and other pertinent features (such as oil wells) was constructed.

Fieldwork and sampling were conducted in two analog arroyos located about 4 miles north of the Shiprock Site: Salt Creek Wash and Upper Eagles Nest Arroyo. The first round of sampling was conducted in April 2011. Chemical signatures were similar to those of samples from Many Devils Wash. A more comprehensive sampling was conducted in September 2011, and samples are now being analyzed for a wide range of constituents, including isotopes of hydrogen, nitrogen, oxygen, and sulfur. The goal of this work is to determine sources of the groundwater.

Geoprobe drilling was conducted in an area extending several miles south (upstream) of the seepage areas in Many Devils Wash to identify possible sources of groundwater in this area. Permitting was completed, and 13 borings were drilled. Only one contained water; however, several had moisture in the bottom sediments. Four were completed as monitoring wells. The project was temporarily suspended pending the outcome of an interruption due to issues with DOE's access authority. Drilling is expected to continue soon, and 30 borings will likely be drilled.

3.6 Disposal Cell Cover Performance

The projects discussed in this section were designed to address LM strategic objectives with respect to evaluations of the performance of disposal cells and advancements in the design and sustainability of disposal cell covers (DOE 2011).

LM is responsible for the LTS&M 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, to control erosion, 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 LTS&M 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 reflect (1) efforts to satisfy U.S. Environmental Protection Agency (EPA) standards for groundwater

quality, (2) a better understanding of cover degradation processes, and (3) overall advances in the state of the science. Before EPA mandated groundwater quality standards in 1995, 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; and Tuba City are examples of the early designs.

In anticipation of EPA groundwater quality standards, DOE estimated, retrospectively, (1) that CSLs in the early covers had a saturated hydraulic conductivity of approximately 10^{-7} centimeters per second (cm/s), and (2) that CSLs in the early covers would operate at an unsaturated hydraulic conductivity of 10^{-9} cm/s, and (3) that any moisture that penetrated the upper portion of the radon barrier is held there until it is evaporated, thus ensuring that the 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 between 10^{-7} and 10^{-8} cm/s. 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. Examples of this improved, low-permeability design in Colorado are the Durango, Gunnison, Grand Junction, and Rifle covers.

Advances in the science of cover designs and lessons learned from observing and evaluating degradation processes in both the early and 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 is an example of this alternative design.

FY 2011 Activities. Activities in FY 2011 included (1) support to publication of the proceedings of the U.S. Nuclear Regulatory Commission (NRC) workshop on cover performance; (2) design and field sampling for a study of the uptake of tailings constituents in deep-rooted plants growing on disposal cell covers; (3) monitoring soil water balance parameters in the 3-hectare (ha) embedded lysimeter at Monticello; and (4) preliminary recommendations for an evaluation of the Bluewater, New Mexico, disposal cell cover.

3.6.1 NRC Workshop on Engineered Barrier Performance

The NRC Workshop on Engineered Barrier Performance Related to Low-Level Radioactive Waste, Decommissioning, and Uranium Mill Tailings Facilities was held from August 3 through 5, 2010, at NRC Headquarters. The proceedings are posted on the NRC public website at http://www.nrc.gov/reading-rm/doc-collections/nuregs/conference/cp0195/.

The workshop was coordinated with the states, tribal nations, and federal agencies. The workshop focused on engineered surface covers and bottom liners designed to isolate waste by impeding surface water infiltration into the waste systems and mitigating the migration of contaminants from the waste disposal site.

Workshop topics included engineered barrier performance; modeling; monitoring; and regulatory experiences at low-level radioactive waste, decommissioning, and uranium mill tailings sites. The workshop objectives included (1) the facilitation of communication among federal and state staff and contractors and selected experts on current engineered barrier issues and technical and regulatory experiences; (2) a discussion of lessons learned and approaches for monitoring and modeling; (3) the preparation of recommendations to address maintenance of engineered barrier performance over time; and (4) the identification of topics for future research and the potential need to update technical guidance. Recommendations and insights given during session presentations, panel debates, and the discussions that followed were documented by the session reporters and are included in this report.

An AS&T scientist served on the organizing committee, served on expert panels, chaired a session, and presented two papers at the workshop. An AS&T scientist also contributed to writing and reviewing the workshop proceedings (NRC 2011), which will help guide future research and policy on the design and performance of disposal cell covers. The AS&T task order will use the proceedings to help guide future projects that address performance monitoring, projections of long-term performance, and future corrective actions for and modifications of disposal cell covers.

NRC plans to use the lessons learned on cover performance and approaches for monitoring and modeling to help guide future recommendations and the potential need to update technical guidance on long-term monitoring and maintenance of engineered covers.

Presentations given by an AS&T scientist at the workshop included “DOE Experience with Cover Degradation Processes, Design Improvements, and Cover Renovation for Uranium Mill Tailings Disposal Cells” and “A Role for Natural Analogs in the Design and Long-Term Performance Evaluation of Earthen Covers for Uranium Mill Tailings.”

Expert panels included “Degradation Processes and Performance Evolution of Engineered Barriers,” which an AS&T scientist co-chaired, and “Experience with Model Support and Multiple Lines of Evidence to Gain Confidence in Long-Term Performance.”

3.6.2 Uptake of Tailings Constituents of Potential Concern (COPCs) by Deep-Rooted Plants Growing On Disposal Cells

The uptake and bioaccumulation of tailings constituents by plants rooted in disposal cell covers—a process called “bio-uptake”—constitute an ecological exposure pathway that has received only limited consideration at LM sites. DOE and others have shown that trees and shrubs can root through UMTRCA covers and into tailings. Research has shown that plants can greatly increase the saturated hydraulic conductivity of covers, but as leaf-area index (LAI) increases, plant transpiration can also improve the soil water balance and control percolation.

Allowing vegetation to naturally establish on covers may also greatly reduce long-term maintenance costs. Currently, many Long-Term Surveillance Plans (LTSPs) require vegetation control, while on other covers, LM has instituted practices to enhance plant growth. LM has investigated root intrusion and burrowing effects on percolation as an exposure pathway but has not addressed the bio-uptake pathway. Any consideration of cover enhancement at a site (see

Section 3.9) would require an evaluation of bio-uptake. Also, eliminating bio-uptake as a potential pathway could lead to less vegetation management and a reduction in LTS&M cost.

The objective of the ongoing study is to compare levels of tailings COPCs in plants currently rooted on covers with plants growing in reference areas (undisturbed areas whose soil type and natural vegetation are similar to those of the disposal cell cover). These data may be needed for risk evaluations and changes in vegetation control practices. Because levels of COPCs in materials (soils and tailings) that plants are rooted in are highly variable, a follow-up greenhouse study is recommended to establish plant/soil concentration ratios for current and likely future plant species growing on LM covers.

During July and August 2011, stem and leaf tissues of deep-rooted plant species growing on disposal cell covers at the following LM sites, and in nearby reference areas, were clipped and dried for analysis: Tuba City, Arizona; L-Bar and Bluewater, New Mexico; Lowman, Idaho; Sherwood, Washington; Lakeview, Oregon; and Split Rock, Wyoming. Carrie, Joseph, a University of Arizona graduate student (and 2011 DOE summer intern) contributed to this project as part of her master's thesis in Environmental Science. The AS&T Surface Program plans to contract a University of Arizona laboratory for COPC analyses, enabling the student to participate.

3.6.3 Lysimeter Water Balance Monitoring at Monticello

LM is investigating alternatives to conventional cover designs for uranium mill tailings. The Monticello disposal cell, completed in 2000, has a conventional, low-conductivity composite cover overlain with an alternative ET cover designed to mimic the natural soil water balance as measured in nearby undisturbed native soils and vegetation. To limit percolation, the alternative cover design relies on a 160-centimeter (cm) layer of sandy clay loam soil overlying a 40 cm sand capillary barrier for water storage, and a planting of native sagebrush steppe vegetation to seasonally release soil water through ET. Water balance monitoring within a 3.0 ha drainage lysimeter, embedded in the cover during construction, provides convincing evidence that the cover has performed well over an 11-year period (2000–2011). Precipitation, water storage, percolation, and ET are monitored in real time in the 3 ha embedded lysimeter.

Lysimeter water balance data collected using SOARS are reduced and plotted quarterly. As of September 2011, the large embedded lysimeter had recorded 0.1 millimeter (mm) of percolation so far for 2011, for a percolation rate of about 0.6 millimeters per year (mm/yr) over 10½ years of monitoring, or about 0.15 percent of precipitation, satisfying the goal of an annual average percolation of <3.0 mm/yr. In contrast, average percolation in conventional covers and in similar environments, as measured using large lysimeters by the EPA's Alternative Cover Assessment Program, was about 35.0 mm/yr, or 9.10 percent of precipitation (Albright et al. 2004).

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 there. 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.

The Monticello lysimeter study is of interest internationally for ET covers because of its size, monitoring duration, and performance data—and, uniquely, because the lysimeter is monitoring the performance of an operational cover and not a test section.

3.6.4 Bluewater Cover Performance

The Bluewater Disposal Site has several large depressions on the north top slope of the disposal cell where runoff water pools after storm events. The Site Lead asked AS&T personnel to visit the site. The objectives of the site visit included (1) observing existing conditions on the disposal cell cover; (2) considering how existing conditions may influence the performance of the disposal cell now and in the long term; and (3) providing recommendations, if warranted, with respect to follow-up investigations of disposal cell performance.

An AS&T scientist walked the northern portion of the disposal cell cover on October 13, 2010, to observe and describe depressions in the cover, and subsequently walked a circuitous route across the top slope of the cover from north to south and back, taking notes and photographing features of interest, and then drafted a report of observations, interpretations with respect to cover performance, and recommendations.

The observations of water pooling in depressions on the nearly flat northern facet of the Bluewater cover has raised concerns that the disposal cell could be a continuing source for water moving through the cell. Evidence from the follow-up site visit, combined with cover design information, cover performance evaluation data from similar UMTRCA sites, and independent scientific literature, lends credibility to this concern. An interpretation of site observations based on lessons learned at other UMTRCA sites and on cover performance research by LM and others led to the conservative assumption that percolation of rainwater is significant through the entire cover and into tailings, not just in the depressions, unless shown to be otherwise.

The draft report proposes a four-phase follow-up investigation:

Phase 1—Records Review: Review cover design documents and completion reports to acquire information on cover design objectives, specifications, and as-built conditions.

Phase 2—Risk Evaluation: Conduct a screening-level risk assessment of the disposal cell, primarily as a continuing source for a groundwater contamination exposure pathway, and secondarily as a source for radon flux and bio-uptake exposure pathways.

Phase 3—Site Characterization and Analysis: If warranted by the screening-level risk assessment, characterize current soil hydrology, soil morphology, and plant ecology related to cover performance and potential exposure pathways.

Phase 4—Cover Renovation Evaluation: If risk assessments (Phase 2) and cover performance evaluations (Phase 3) indicate that the disposal cell is likely a continuing source for groundwater contamination and adverse risk, then corrective action may be warranted. The

corrective action may include methods to enhance cover performance. The goals of cover enhancement are sustainable reductions in risk and LTS&M costs. The concept is to accelerate and enhance natural processes that would effectively transform the cover from a low-permeability design into a water balance design. See Albright, Benson, and Waugh (2010) for guidance on the function and design of water balance covers.

All activities on the disposal cell would be coordinated with NRC.

3.7 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 LTS&M 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, LTSPs 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 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 CERCLA 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, information that is needed to monitor the hydrologic performance of covers.

FY 2011 Activities. Two remote sensing research projects continued in FY 2011: (1) the hyperspectral study conducted by the University of South Carolina and Savannah River National Laboratory at Monticello and Monument Valley and (2) a plant transpiration scaling study by the University of Arizona at Monument Valley as part of LM's enhanced natural attenuation research.

3.7.1 Hyperspectral Remote Sensing Study at Monticello and Monument Valley

The University of South Carolina and Savannah River National Laboratory drafted a manuscript for publication—"Vegetation Cover Analysis of Hazardous Waste Sites in Utah and Arizona Using Hyperspectral Remote Sensing" (Im et al. [drafted])—using field data collected by AS&T scientists. The research was funded by the National Aeronautics and Space Administration (NASA) and LM, among others. AS&T coordinated field activities at Monticello and Monument Valley. The draft abstract for the manuscript follows:

> Remote sensing technology can provide a cost-effective tool for monitoring hazardous waste sites. This study investigated the usability of HyMap hyperspectral remote sensing data (126 bands at 2.3 × 2.3 m resolution) to characterize the vegetation cover on two hazardous waste sites, including a) the U.S. Department of Energy, Monticello, UT, Disposal Cell; and b) the Monument Valley, AZ, Phytoremediation Site. Grass and shrub species were mixed in the Monticello site while shrub species were dominant in the Monument Valley site. The specific objectives of this study were to: 1) estimate leaf-area-index (LAI) of the vegetation using three different methods (i.e., vegetation indices, red-edge positioning (REP), and machine learning regression trees), and 2) map the vegetation cover using machine learning decision trees based on either the scaled reflectance data or mixture tuned matched filtering (MTMF)-derived metrics and vegetation indices. Regression trees resulted in the best calibration performance of LAI estimation ($R^2 > 0.80$). The use of REPs failed to accurately predict LAI ($R^2 < 0.2$). The use of the MTMF-derived metrics (matched filter scores and infeasibility) and a range of vegetation indices in decision trees improved the vegetation mapping when compared to the decision tree classification using just the scaled reflectance. Results suggest that hyperspectral imagery are useful for characterizing biophysical characteristics (LAI) and vegetation cover on capped hazardous waste sites. However, it is believed that the vegetation mapping would benefit from the use of higher spatial resolution hyperspectral data due to the small size of many of the vegetation patches (~ 1 m or less) found on the sites.

A review of the manuscript raised concerns about plant species distribution maps, and what may have led to the misinterpretations.

At the Monticello Site, although vegetation indices on the disposal cell cover appeared to be correct, indices for the side slopes indicate a very high percentage of rabbitbrush, which is incorrect. At Monument Valley, most of the area mapped as black greasewood is actually fourwing saltbush. The mapping units shown for saltbush and greasewood represent a difference between mature, woody, seed-producing saltbush, and immature, more herbaceous saltbush. Greasewood is a minor component over most of the area shown.

These are not subtle discrepancies between image interpretation and reality. The phytoremediation study at Monument Valley was designed, in part, to compare the two dominant native desert phreatophytes[4]: the obligate black greasewood and facultative four-wing saltbush. If the hyperspectral procedure cannot distinguish between the two, it will be of little value for long-term monitoring. At Monticello, rabbitbrush is an early successional shrub adapted to

[4] Phreatophytes are plants that extract water from shallow aquifers as well as from the vadose zone (unsaturated soil above groundwater).

disturbed, unstructured soils. Sagebrush is a later successional shrub that appears to be increasing in abundance as soil structure develops in the engineered soil cover, creating preferential flow pathways for water to move deeper in the profile and, hence, gradually creating a more favorable habitat for sagebrush. Again, if the hyperspectral procedure cannot depict the difference, it will be of little value for long-term monitoring. As case studies for possible future applications of the hyperspectral methodology for long-term monitoring of LM sites, differentiating rabbitbrush and sagebrush at Monticello, and greasewood and saltbush at Monument Valley are critical tests.

3.7.2 Remote Monitoring of Phreatophyte Transpiration

The purpose of this study was to develop a remote sensing protocol to monitor vegetation and ET over large parcels of land at the Monument Valley Site. AS&T scientists collaborated with the University of Arizona on the study. The Monument Valley Site covers about 230 ha, including the source area of an alluvial aquifer plume and the surface footprint over the plume. Satellite data for this project included annual Quickbird and Landsat images, and 16-day images from the Moderate Resolution Imaging Spectrometer (MODIS) sensors on the Terra satellite. The University of Arizona developed remote sensing protocols, calibrated with ground data collected by AS&T scientists, that can be used to quantify LAI, fractional vegetation cover, and plant water use (ET) over the site.

Research at Monument Valley and elsewhere has shown that vegetation, and particularly ET from desert phreatophytes, plays a key role in determining the soil water balance and recharge at desert sites. The two dominant shrubs at Monument Valley are black greasewood and fourwing saltbush, both of which are phreatophytes. When these shrubs are protected from grazing, they can develop dense ground cover with high ET rates. They can consume more water than arrives as precipitation, with the balance extracted from groundwater. This theoretically will slow or reverse the spread of contamination in the aquifer away from the source area. On the other hand, this site has a history of heavy grazing, which can greatly reduce shrub ground cover and LAI. Such a reduction in shrub ground cover and LAI can increase the spread of contaminants away from the source area due to expansion of the contamination plume via recharge from precipitation over the site and runoff from adjacent uplands into the aquifer.

Annual surveys of plant cover, LAI, and standing biomass were conducted in these areas from 2000 through 2010. In 2006 and 2007, transpiration of individual plants was measured using sap flux sensors. Time-series imagery from 2000 and 2010 was obtained from the MODIS sensors on the Terra satellite. This satellite has nearly daily coverage of the globe, and data are supplied as preprocessed vegetation indices or other products in 16-day composite increments. Enhanced Vegetation Index (EVI) products were used for analyses of ET. EVI data were combined with maximum daily temperature data to calculate ET using an algorithm calibrated with sap flux data collected on site. Visual changes in site vegetation were also analyzed using Landsat TM-5 images obtained in the summers of 2000, 2005, 2007, and 2009. Fine level estimates of percent cover and LAI were made on Quickbird satellite images of the Normalized Difference Vegetation Index (NDVI). Percent cover was estimated by converting pixels into two classes—one class represented bare soil; the other, vegetation. The accuracy of the classification system was tested by comparing these estimates of ground cover with estimates determined by visual inspection of images using a point intercept method. Areas representing a wide range of cover conditions were analyzed. LAI was calculated from NDVI in areas of interest using a regression of measured LAI values and leaf harvesting. LAI was measured on individual plants and was

extended to stands of plants by multiplying LAI by fractional ground cover as determined on a Quickbird image.

Results show that over the past 10 years, grazing pressure has been reduced over the site, and vegetation cover has increased. ET estimates show that the water balance of the plume area has converted from an area of recharge (less water used than arrives as precipitation) to one of discharge (transpiration exceeds precipitation), indicating that water from the aquifer is being removed. A healthy plant community can slow or stop the farther migration of contaminants in the plume. Increased vegetation density was due partly to revegetation projects conducted over the source area, as well as an observed decrease in grazing over the plume. Since vegetation dynamics and grazing pressure will continue to vary in the future, continued monitoring of the site using this remote sensing protocol is recommended.

3.8 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 can measure flux rates of 0.2 mm/yr 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 SOARS system.

FY 2011 Activities. Soil moisture and percolation monitoring continued at the Monument Valley Site during FY 2011.

WFMs were installed in phytoremediation plantings at Monument Valley in 2006 to monitor percolation flux. Percolation monitoring is necessary to confirm that irrigation water is not moving below the root zone and potentially leaching contaminants to the alluvial aquifer. Four instrument clusters were installed. Instrument clusters consisted of one WFM placed about 370 cm deep in the soil profile and four WCRs placed above the WFM at depths of 30 to 60, 90 to 120, 180 to 210, and 270 to 300 cm.

The WFMs are located near the bottom of the root zone and can directly monitor saturated and unsaturated water fluxes ranging from 0.02 mm/yr to more than 1,000 mm/yr. WCRs were

calibrated at the Environmental Sciences Laboratory (ESL). The procedure involved (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.

WCRs measure soil water content by electrical conductivity, and data are reported daily. WFMs directly measure the actual downward flux of water through the soil by collecting mobile water via a funnel and wick, then quantifying water flux with a tipping-bucket collection and weighing device.

The four WFMs have continued to record zero percolation since they were installed in 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.

Up to 2006, soil moisture levels tended to be stable and below field capacity throughout the phytoremediation plot. In 2006, irrigation rates were increased to stimulate additional plant growth, especially in the newly planted areas. Irrigation rates were increased from 165 mm yr^{-1} in 2006 to 496 mm yr^{-1} in 2007. This extra water led to an accumulation of moisture in the root zone of some of the plots, and in 2008, irrigation was reduced to 285 mm yr^{-1}, which has been maintained through 2011.

From 2006 through 2011, soil moisture measured with WCRs has had a clear seasonal trend at the soil depths of 20 to 60, 90 to 120, and 180 to 210 cm. Water content was highest in July and lowest in February; this trend is expected because irrigation water is applied April through September or October. Moisture content decreased with soil depth, and also by year for the first three soil depths. Spikes of high soil moisture were evident in the 30-to-60-cm depth, presumably due to summer monsoon rains. These spikes were dampened at greater depths. Soil moisture in the top part of the profile was highest in 2006 because the new plantings were being irrigated (moisture accumulated in the soil profile because transpiration rates of the young plants were very low). Soil moisture also was high in 2007 due to the more aggressive irrigation schedule but decreased to low levels as the new plants developed and irrigation volume was reduced. The soil moisture content at the 270-to-300-cm depth was relatively low but tended to increase in fall and winter, perhaps due to the infiltration of rainfall and excess irrigation water at that depth. However, because WFMs have shown no net flux of water at the 370-cm depth since they were installed, it can be assumed that recharge is not occurring.

Mean soil moisture levels in 2011 were below field capacity throughout the soil profile and did not increase with depth as would be expected if moisture was draining past the root zone. The strategy of revegetating the site and deficit-irrigating the plantings appears to have succeeded in controlling the site water balance to favor discharge, rather than recharge, over the source area. The source area probably now supports as much vegetation as is possible at current rates of precipitation and irrigation.

3.9 Enhanced Cover Assessment Project

Overview. LM is evaluating methods for enhancing the long-term performance of conventional, engineered soil covers for disposal cells. The long-term goals are (1) to reduce vegetation management costs and (2) to reduce long-term risk by improving the hydrological performance of covers. LM constructed two test facilities at the Grand Junction Disposal Site to evaluate cover enhancement methods. The proposed methods include ripping and planting the upper rock and soil layers of conventional covers in ways that mimic natural soil and ecological analogs. Cover enhancement is effectively an effort to accelerate the ongoing natural transformation of conventional covers into water balance covers.

Conventional disposal cell covers at LM sites include CSLs designed to limit radon escape into the atmosphere and to limit percolation of rainwater into underlying waste materials. Field investigations by LM and others have shown that the saturated conductivity can be much higher than expected. The higher-than-expected saturated conductivity generally can be attributed to (1) unanticipated ecological consequences of biointrusion, desiccation, and freeze-thaw cycling; (2) the retention of borrow soil structure (clods) during construction; and (3) natural soil-formation processes after construction. After several years with these natural processes acting upon the compacted soils, the percolation rate into underlying waste may also be much higher than anticipated.

In contrast, studies by DOE, EPA, and others have shown that water balance covers can be very effective at limiting percolation at arid and semiarid sites. Water balance covers consist of thick, fine-textured soil layers that store precipitation in the root zone, like a sponge, where it can be removed seasonally through soil evaporation and plant transpiration—ET. Water balance covers can be designed to accommodate changes in soil hydraulic properties caused by the environmental conditions that damage conventional covers.

LM scientists have learned that, without intervention, natural soil development and ecological succession processes are slowly transforming existing conventional covers into water balance covers. The premise of cover enhancement research is that deliberately loosening and blending the upper rock and soil layers of conventional covers will increase the soil water storage capacity, accelerate plant succession, and increase plant transpiration rates. Geomorphological and ecological evidence from natural analog sites suggest that a vegetated rock and soil cover would be adequate to control erosion and limit percolation for hundreds to thousands of years.

Due to regulatory requirements, LTS&M at many LM sites includes herbicide spraying to control plant establishment and root intrusion on disposal cell covers. Costs of herbicide spraying have increased and will likely continue to do so as ecological conditions become more favorable for plant growth. On many covers in arid and semiarid regions, soil from eolian deposition is filling voids in rock riprap layers, also contributing to a more suitable plant habitat. Given the inevitable increase in plant growth on most conventional covers, and the likely increase in long-term costs to control plant growth, LM is currently evaluating options to decide whether to continue spraying, to stop spraying and allow plant succession to progress naturally, or to accelerate and enhance this natural transformation to water balance covers.

FY 2011 Activities. In FY 2011, a test pad, installed in 2010, was ripped, a revegetation plan was drafted, baseline soil water balance monitoring continued in two large lysimeters, a paper

was published in the proceedings of the 2011 Waste Management Conference and a draft status report was prepared. The report covers the design, installation, initial engineering, and edaphic properties; early water balance monitoring for the lysimeters through 2011; and the construction and initial soil properties of the test pad. The report has been edited and should be ready for DOE review this fall.

LM constructed two test facilities at the Grand Junction Disposal Site to evaluate low-cost cover enhancement methods and to compare the hydrological performance of conventional and enhanced cover designs. One facility consists of two test sections, each including a large drainage lysimeter. The other is a large test pad constructed to compare and evaluate implements for ripping and blending rock and soil layers. The drainage lysimeters are analogous to plastic-lined swimming pools filled with engineered soil layers, and they are instrumented to monitor precipitation that falls on the soil surface, water running off of the soil, changes in the amount of water stored in the soil, and the rate water drains or percolates from the soil.

In the two test sections, test covers were constructed with the same design and the same materials as the existing Grand Junction disposal cell cover in order to allow for a direct comparison of hydrological performance. One test section will be ripped and planted; the other is a control and will be maintained similarly to the existing disposal cell cover. LM is using the lysimeters to evaluate the effectiveness of the renovation treatment by monitoring hydrologic conditions within the cover profile as well as all water entering and leaving the system. The test pad was also constructed using the same design and the same materials as the existing Grand Junction disposal cell cover, but with no lysimeter instrumentation.

3.9.1 Test Pad Ripping

Ripping treatments were implemented in August 2011. Three implements for ripping and blending rock and soil layers were tested: (1) a conventional straight shank; (2) a wing-tipped shank fabricated specifically for the study; and (3) an oscillating, wing-tipped, parabolic shank. The third implement is a patented device designed to prepare compacted earth for planting vineyards. In fall 2011, LM scientists and colleagues from the University of Wisconsin and Desert Research Institute plan to excavate trenches perpendicular to rip lines, measure the vertical and lateral extent of soil disturbance, and obtain large block samples of soil for an evaluation of ripping effects on soil physical and hydraulic properties. Other portions of the test pad will be used to evaluate revegetation practices—different combinations of plant species and planting methods.

3.9.2 Lysimeter Monitoring

The lysimeter test sections are modeled after designs used in EPA's Alternative Cover Assessment Program. Each test section contains a pan lysimeter (10 meters [m] by 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 ET. The last is obtained by closure of the water balance. Each test section includes a 10-m-wide buffer zone around the lysimeter.

As of July 2011, lysimeter data show that ET has been the dominant water balance flux from both lysimeters, percolation has been very small (less than 4 percent), and there has been only a trace of runoff (0.1 mm in 2011). Both lysimeters are beginning to change because the percolation records have followed a more intermittent or stair-step pattern at times, which is commonly associated with the formation of preferential flow paths. In 2010, the percolation rate increased appreciably but then dropped in both lysimeters in 2011 (2010 was the wettest year during the monitoring period).

Data for water contents and suctions for the soil layers in both lysimeters displayed relatively large swings in water content in response to infiltration during precipitation events and surface evaporation. In contrast, subtle variations in water content occurred within the radon barrier and the transition layer in both lysimeters. The riprap and the bedding layer appear to be functioning as an inverted capillary barrier that limits water removal from most of the radon barrier and the interim cover layer in both lysimeters. Modest oscillations in matric suction in the lower portion of the protection layer, the radon barrier, and the bedding layer also support the presence of an inverted capillary barrier at the surface of the lysimeter.

Comparisons of water contents in the upper and lower nests of WCR probes in each lysimeter indicate that conditions are reasonably uniform at a given depth. Moreover, the uniformity increases with depth: the water contents recorded by the deepest probes in the upper and lower nests of each lysimeter are nearly identical. Comparing the two lysimeters' respective water contents also indicates that both lysimeters are behaving essentially the same. The only significant difference was the higher peak water contents in Lysimeter C during the first winter and spring of the monitoring program.

3.10 Monument Valley and Shiprock 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. These 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 2011 Activities. The Monument Valley and Shiprock enhanced attenuation pilot studies are now funded entirely through the site budgets. However, in FY 2011, an AS&T scientist drafted and published a book chapter on LM's work with the Diné Environmental Institute at Diné College (Waugh, Glenn, Charley, Maxwell, and O'Neill 2011). The book examines the interactions and integration of science and stakeholders to find solutions to some of the nation's controversial energy-related issues. The chapter's abstract is as follows:

> Diné College is a key stakeholder and partner with the U.S. Department of Energy 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. Through an philosophy grounded in the Navajo traditional living system which places human life in harmony with the natural world, the College 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. Students and 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 guidance has led researchers to investigate applications of natural and enhanced attenuation remedies involving native plants – phytoremediation, and indigenous microorganisms – bioremediation. 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.

3.11 Retrospective Monitoring—Shiprock Dendrochemistry

Overview. This project is one of several tasks that are examining the source of groundwater supplying the seeps along the east margin of Many Devils Wash. Retrospective monitoring involves the use of natural evidence to reconstruct past trends or shifts in contamination levels for time periods that occurred before instrumental monitoring began. The premise for Many Devils Wash is that the chronology and chemistry of annual growth rings of tamarisk trees may provide evidence for changes in groundwater chemistry coincident with the beginning of milling operations. No change would support natural contamination. A step change might indicate an anthropogenic source.

The study was designed in two phases. The first phase is to determine if tamarisk and other phreatophytic trees growing in the Wash date back to pre-milling times. If so, contaminants such as uranium and selenium will be measured in annual growth rings produced both before and after milling began.

FY 2011 Activities. Cores of tamarisks, cottonwoods, and Russian olives growing in Many Devils Wash and in the San Juan River floodplain were obtained (with assistance from Diné College students), a lab protocol was developed, and ESL staff prepared and sanded cores for cross dating. A preliminary ring count on cores indicated that trees are younger than pre-milling times. However, many if not all cores probably missed the oldest rings because of the asymmetry of growth rings as observed on one tamarisk cross section. The one cross section may be evidence that at least some of the tamarisks sampled are older than the cores indicated.

This project was postponed in July 2011.

3.12 Strategic Planning Initiatives

3.12.1 Ecosystem Management Team (EMT)

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. LTSPs often require suppression of vegetation on covers because plant roots can increase permeability of CSLs and may take up and disperse contaminants. Alternatively, through ET, plants can be used to control the hydrology of disposal sites and improve the sustainability of remedies.

FY 2011 Activities. Accomplishments in 2011 are outlined below:

- The EMT met monthly to address strategic planning and EMS Land Stewardship group issues. Team members are ecologists and site managers from the Grand Junction; Rocky Flats; Fernald, Ohio; and Weldon Spring, Missouri, Sites.
- An AS&T scientist served as lead for the EMS Land Stewardship group, participated in EMS core and technical meetings, and provided input for EMS quarterly reports.
- Two sites—Monticello and Shiprock—were selected for potential improvements related to vegetation management and remedy improvements.
- The EMT met with LM and LMS land reuse personnel to brainstorm ecosystem improvements that would qualify for land reuse acreage.
- The EMT submitted a draft year-end summary of ecosystem improvements, including remedy improvements, land management improvements, and habitat improvements. The EMS Land Stewardship group records improvements in an existing tracking log. LM should get credit for ongoing improvements. The creation of the tracking log was an earlier EMS goal.
- The EMT brainstormed and listed parameters that could be included in a baseline ecological characterization of LM sites (e.g., range condition, revegetation condition, weed populations, habitat value, habitat condition of adjacent land, adjacent land owners' willingness to continue improvements). Baseline data are needed as a basis for measuring ecosystem improvements. Baseline data are also needed to assist in identifying sites for improvements.
- The EMT submitted and LM approved the following goals and initiatives for EMS Land Stewardship in 2012:

  Target Goal—Complete grazing management proposal for Monticello with emphasis on habitat improvement, cover enhancement, and land reuse acreage.

  Stretch Goal—Acquire regulatory approval and project funding to begin implementing the proposal.

  Initiatives:

  1. With DOE concurrence, develop a plan for the systematic acquisition of baseline ecological data for applicable LM sites, and initiate ecological monitoring at selected sites.
  2. Prepare a revegetation plan for the Shiprock terrace to control annual weeds and enhance ongoing phytoremediation research.

3.13 Technology Deployment

Overview. The AS&T task order supports the Technology Deployment strategic planning initiative. The scope of the Technology Deployment initiative is to facilitate the 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.

A significant accomplishment in FY 2010 and 2011 was the establishment of the Technology Deployment strategic planning site on the LM Intranet. The site is accessible to 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 sections: (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 to internal documents and websites are available.

FY 2011 Activities. The site has been continually updated and revised. A major addition was the inclusion of a folder containing electronic copies of applicable journal articles.

3.14 Share Technologies with Stakeholders, Universities, and Other Agencies

Overview. This section describes FY 2011 activities related to three AS&T objectives:

- Share technologies and lessons learned with stakeholders; regulators; and state, tribal, and local governments.
- Collaborate and share project costs with other DOE offices, other agencies, universities, and industry, and offer "test beds" to other organizations that fund LTS&M research and development.
- Use AS&T projects to create and promote opportunities, discourse, and achievements in environmental science education.

Activities.

3.14.1 LTS&M Workshop

AS&T scientists chaired sessions, gave presentations, and led a field tour for the 2010 LTS&M Conference held from November 15 through 18, 2010, in Grand Junction. Sessions at the conference included "Applied Science and Technology" and "Disposal Cell Covers," and presentations included "Overview of DOE-LM AS&T Activities" and "Cover Designs, Natural Succession, Performance, and Long-Term Surveillance and Maintenance" (Waugh 2010).

3.14.2 Educational Outreach—Graduate Committees

- An AS&T scientist is participating on a thesis committee for Paul Garvin, a master's degree candidate at the University of Nevada, Reno. Paul's research involves nitrogen isotopic signatures in groundwater at the Shiprock disposal cell.
- As an adjunct faculty member at the University of Arizona, an AS&T scientist is serving on the graduate committee for Carrie Joseph, a Master's of Science candidate in Environmental Science, and participated on the thesis committee for Andrew Borden, a 2011 Master's of Science graduate in Environmental Science. Carrie's thesis research, jointly funded by a University of Arizona grant and LM, is comparing the uptake of tailings constituents by deep-rooted plants growing on LM disposal cell covers with the same species growing in nearby reference areas. Andrew's thesis was a pilot test of enhanced groundwater nitrate attenuation at the LM Monument Valley Processing Site. Andrew's research was also published as a journal article (Borden et al. 2011).
- As an adjunct faculty member at Vanderbilt University, an AS&T scientist mentored Stacey Worman, a 2011 Master's of Science graduate who was employed as an LMS intern in 2010, and served on the graduate committee for Brooke Traynham, a 2010 doctoral graduate. Both were students in the Civil and Environmental Engineering Department at Vanderbilt. Stacey's thesis title is "A Simple Probabilistic, Biologically Informed Model of the Population Dynamics of Desert Shrubs." In 2011, Brooke submitted two journal manuscripts on her research: "Identification of Dominant Ecological Processes for Long-Term Performance Evaluations of Landfill Covers" (Traynham et al. [accepted)] and "An Application of Event Tree Analysis to Ecological Systems: Understanding the Long-Term Performance of Engineered Covers" (Traynham et al. [submitted]).

3.14.3 Education Outreach—Diné College Environmental Institute

An AS&T scientist supported Diné Environmental Institute students in FY 2011 in the following ways:

- Presented seminars to Diné Environmental Institute intern students:
  - "Phytoremediation and Bioremediation Research at Uranium Mill Tailings Sites on Navajo Nation Land" (October 2010).
  - "Application of Dendrochemistry for Retrospective Environmental Monitoring at the Shiprock Disposal Site" (February 2011).
- Taught a lab on data reduction and statistical analysis for a plant uptake study. Students had helped collect samples for the study in 2010. Students had sampled stems, leaves, and fruit for analyses of nitrate, sulfate, and metals (including uranium) in the Shiprock phytoremediation test plots and at the Diné College orchard in the fall of 2009 (November 2010).
- Supervised students collecting tree cores for an LM tree-ring chemistry study of contaminant dispersion in Many Devils Wash and on the San Juan River floodplain (February 2011).
- Co-authored "Using Native Phreatophytes to Decrease Movement of a Ground Water Uranium Plume at Shiprock, New Mexico, Navajo Nation" (White and Waugh 2011), presented by Rita White, a Diné College Environmental Institute student, at the 2011

Emerging Researchers National Conference in STEM, held from February 23 through 26, 2011, in Washington, DC.

- Helped organize a ceremony transferring the Tuba City greenhouse from DOE to Diné College, gave a presentation on the history and potential future use of the greenhouse, and wrote an article on the greenhouse transfer for the S.M. Stoller Corporation's *Synergy* newsletter.
- With LM's approval, forwarded a summary of uranium sampling results for fruit and leaf tissue from the Diné College experimental orchard to the Diné College Extension Service.
- Drafting a booklet for distribution to Diné College and the Navajo Nation, highlighting DOE's partnership with Diné College to research sustainable remedies.

3.14.4 U.S. Environmental Protection Agency

An AS&T scientist gave an invited presentation at the EPA Tribal Colleges and Universities Collaborative Workshop on June 28, 2011, in Albuquerque, New Mexico: "Helping Mother Earth Heal: Diné College and Enhanced Attenuation Research at U.S. Department of Energy Uranium Processing Sites on Navajo Land" (Waugh, Charley, Carroll, and Glenn 2011).

3.14.5 U.S. Nuclear Regulatory Commission

An AS&T scientist served on the organizing committee, served on expert panels, chaired a session, and presented two papers at an NRC workshop on engineered covers in August 2010, and in 2011, contributed to writing and reviewing the workshop proceedings (NRC 2011).

3.14.6 DOE 2011 Summer Internship Program

An AS&T scientist mentored two 2011 DOE summer intern students:

- Garry Jay from Diné College conducted a paper study of risk communication and risk perception with application to members of the Navajo Nation in Shiprock.

  Garry helped give the following presentation at the DOE–Navajo Nation public meeting at the Shiprock Chapter House, on August 17, 2011, titled "Diné College and Natural Remedies for U.S. Department of Energy Uranium Processing Site at Shiprock, New Mexico."
- Carrie Joseph from the University of Arizona began her Master of Science research on plant uptake of tailings constituents on LM disposal cells located near Native American communities. Carrie gave a presentation on her research proposal at a Native American science symposium in August 2011 in Flagstaff, Arizona.

An AS&T scientist gave two seminars to 2011 DOE summer intern students and LM staff:

- "Designs, Natural Succession, and LTSM of Disposal Cell Covers for Uranium Mill Tailings."
- "Helping Mother Earth Heal: Diné College and Enhanced Attenuation Research at U.S. Department of Energy Uranium Processing Sites on the Navajo Reservation" (Waugh et al. 2011).

3.14.7 Consortium for Risk Evaluation with Stakeholder Participation (CRESP)

In FY 2011, an AS&T scientist continued to serve 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.

3.14.8 Savannah River National Laboratory and the University of South Carolina

An AS&T scientist concluded collaboration with Savannah River National Laboratory and the University of South Carolina on remote sensing research at Monticello and Monument Valley. The project was jointly funded by LM and NASA, resulting in a journal article (Im et al. [drafted]).

3.14.9 Miscellaneous Outreach Activities and Consultation

AS&T scientists were involved in these additional miscellaneous internal and external outreach and consultation activities:

LM and LMS Consultation

- Toured the Rocky Flats Site and discussed ways to improve the performance and sustainability of remedies for the Original Landfill and Solar Ponds Plume.
- Visited the Bluewater, Ambrosia Lake, and L-Bar, New Mexico Sites at the request of LMS Site Leads, drafted a report on evidence of cover performance, and developed recommendations for follow-up investigations.
- Contributed to discussions with LMS Site Leads and provided recommendations for vegetation management on new Title II disposal cell covers.
- Provided LM with a brief write-up on the history of UMTRCA cover designs, whether covers are performing as designed, and a conceptual perspective on renovation.
- Gave a PowerPoint presentation to LM on evidence of current and possible long-term performance of the Bluewater disposal cell cover, and provided recommendations for follow-up investigations.
- Gave a PowerPoint presentation, “Land Farm Phytoremediation of Groundwater Nitrate Using Native Desert Shrubs: Monument Valley Field Experiment,” at the LMS Ecology/ Hydrology Group staff meeting on April 6, 2011.

- Met with LM and Colorado State University researchers to brainstorm a possible collaboration on a combined biofuel/phytoremediation study at the Rifle Site.
- Drafted an appendix for the Split Rock LTSP that explores the state of the science of conventional cover designs with respect to natural degradation processes, alternative designs, and opportunities to enhance long-term performance and reduce long-term maintenance costs.
- Reviewed a draft report prepared by a subcontractor, "Shiprock Disposal Cell Internal Water Balance and Cell Performance."
- Drafted an article on test pad ripping at the Grand Junction Disposal Site for the LM quarterly *Program Update* newsletter, "Ripping up a Cover Enhancement Research Project."

External Outreach and Consultation

- Received a request from a DOE Office of Environmental Management contractor for soil moisture and geotechnical data from the Grand Junction Disposal Site lysimeters to be used in radon flux calculations for the Crescent Junction disposal cell cover.
- Provided publications and references on the performance of conventional and alternative covers, as requested, to the Missouri Department of Natural Resources.
- Met with UMETCO staff to discuss plant root intrusion, biouptake, and vegetation management at the Uravan, Colorado, Title II Site.
- Responded to a request from the Laboratory for Energy-Related Health Research for information on modeling soil water balance, runoff erosion, and sediment yield for disposal cells.
- Contacted project managers for the Homestake and Ambrosia Lake West Title II sites near Grants, New Mexico, about opportunities for LM to cooperate with site owners on baseline cover performance research.
- Received an invitation from Pacific Northwest National Laboratory to serve as an LM representative on a DOE Office of Environmental Management working group assigned to put together a science and technology strategy document for monitoring the performance of remediated sites.
- Reviewed sections of a U.S. Geological Survey paper on uranium mill tailings remediation, to be submitted to the journal *Reviews in Economic Geology*.
- Led a field tour of enhanced attenuation research at Monument Valley for the Southwest Partnership, which consists of state and tribal abandoned mine land programs for Utah, Colorado, and New Mexico and the Hopi, Crow, and Navajo Nation tribes.
- Presented "Ecology of Long-Term Remedies for Uranium Mill Tailings" at an environmental science seminar series at Colorado Mesa University, on September 26, 2011, in Grand Junction.
- Received an invitation from EPA to help teach a short course on alternative covers at Salt Lake City, Utah, in FY 2012.
- Presented "Diné College and Natural Remedies for U.S. Department of Energy Uranium Processing Site at Shiprock, New Mexico" at Shiprock public meeting.

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.
- Procuring 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 a 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, the automated external defibrillator, and first aid kits.
- Maintaining backups of electronic instrument files.
- Conducting inspections and tours.
- Calibrating flow meters and other field equipment.
- 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. The laboratory is now staffed with two full-time personnel.

FY 2011 Activities. All laboratory maintenance and calibration tasks were completed, and the laboratory operated trouble free. Several new procedures were drafted. Samples were submitted to the ESL from Rocky Flats, Old Rifle, Shiprock, and Tuba City for analysis on a regular basis.

Laboratory capabilities were greatly enhanced in FY 2011 with the addition of new instrumentation. An inductively coupled plasma emission spectrometer was procured to replace and upgrade the capability of a flame atomic absorption spectrometer. This acquisition increases the number of elements that can be analyzed and improves the detection limits for many others. A new liquid scintillation counter was procured to replace the existing one. The old counter was acquired many years ago from EPA. It was no longer functional, and replacement parts were unavailable. Training was provided for laboratory personnel on both of the new instruments.

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 Book Chapters, Journal Articles, and Proceedings Papers

Books

Waugh, W.J., E.P. Glenn, P.H. Charley, B. Maxwell, and M.K. O'Neill, 2011. "Helping Mother Earth Heal: Diné College and Enhanced Natural Attenuation Research at U.S. Department of Energy Uranium Processing Sites on Navajo Land," in Burger, J. (ed.), *Stakeholders and Scientists: Achieving Implementable Solutions to Energy and Environmental Issues*, New York: Springer Science.

Journal Articles

Borden, A.K., M.L. Brusseau, K.C. Carroll, N. H. Akyol, A. McMillan, J. Berkompas, Z. Miao, F. Jordan, G. Tick, W.J. Waugh, and E.P. Glenn, 2011. "Ethanol Addition for Enhancing Denitrification at the Uranium Mill Tailings Site in Monument Valley, Arizona," *Water, Air, and Soil Pollution*, August 3.

Im, J., J.R. Jensen, R.R. Jensen, and J. Gladden (drafted). "Vegetation Cover Analysis of Hazardous Waste Sites in Utah and Arizona using Hyperspectral Remote Sensing."[5]

Morrison, S., C. Goodknight, A. Tigar, R. Bush, and A. Gil, 2011 (submitted). "Naturally Occurring Contamination in the Mancos Shale," submitted to *Environ. Sci. & Technol.* September 2011.

Traynham, B., J. Clarke, J. Burger, and J. Waugh (accepted). "Identification of Dominant Ecological Processes for Long-Term Performance Evaluations of Landfill Covers," *Journal of Risk Analysis*.

Traynham, B., J. Clarke, J. Burger, and W. Waugh (submitted). "An Application of Event Tree Analysis to Ecological Systems: Understanding the Long-Term Performance of Engineered Covers," *Environmental Monitoring and Assessment*.

Proceedings Papers

Benson, C.H., W.J. Waugh, W.H. Albright, and R.P. Bush, 2011. "Design and Installation of a Disposal Cell Cover Fie Attenuation (MNA) of Groundwater: Is Past Performance an Indication of Future Results?," *Proceedings of Waste Management 2011 Symposium*, Phoenix, Arizona.

[5] AS&T scientists collected field data for this remote sensing study at the Monticello and Monument Valley Sites.

Dayvault, J., S. Morrison, and J. Waugh, 2011. "Overview of U.S. Department of Energy Office of Legacy Management Applied Science and Technology Program," *Proceedings of Waste Management 2011 Symposium*, Phoenix, Arizona.

Morrison, S., and R. Bush, 2011 (in review). "Background Concentration of Uranium in Groundwater at Former Uranium Milling Sites," submitted to the Waste Management 2012 Symposium, Phoenix, Arizona.

NRC (U.S. Nuclear Regulatory Commission), 2011. *Proceedings of the Workshop on Engineered Barrier Performance Related to Low-Level Radioactive Waste, Decommissioning, and Uranium Mill Tailings Facilities*, NUREG/CP-0195, U.S. Nuclear Regulatory Commission, Rockville, Maryland.[6]

3.16.2 Abstracts, Presentations, Seminars, and Workshops

Morrison, S., and R. Bush, 2011. "Applied Science and Technology – Future Directions in Groundwater Science," presentation at facilitated breakout session, 2010 Long-Term Surveillance and Maintenance Conference, November 15–18, Grand Junction, Colorado.

Waugh, W.J., 2010. "Cover Designs, Natural Succession, Performance, and Long-Term Surveillance and Maintenance," 2010 Long-Term Surveillance and Maintenance Conference, November 15–18, 2010, Grand Junction, Colorado.

Waugh, W.J., C.H. Benson, and W.H. Albright (accepted). "Water Balance Cover and Conventional Cover Enhancements for Sustainable Hydraulic Isolation of Uranium Mill Tailings," Soil Science Society of American 2011 Annual Meeting, October 16–19, 2011, San Antonio, Texas.

Waugh, W.J., P.H. Charley, M.K. Carroll, and E.P. Glenn, 2011. "Helping Mother Earth Heal: Diné College and Enhanced Attenuation Research at U.S. Department of Energy Uranium Processing Sites on Navajo Land," EPA Tribal Colleges and Universities Collaborative Workshop, June 28–30, 2011, Albuquerque, New Mexico.

White, R., and J. Waugh, 2011. "Using Native Phreatophytes to Decrease Movement of a Ground Water Uranium Plume at Shiprock, New Mexico, Navajo Nation," 2011 Emerging Researchers National (ERN) Conference in STEM, February 23–26, 2011, Washington, DC.

3.16.3 Published and Draft DOE Reports

DOE (U.S. Department of Energy), 2010. *Applied Science and Technology Task Order Fiscal Year 2010 Year-End Summary Report*, LMS/ESL/S05802 (ESL-RPT-2010-03), prepared by S.M. Stoller Corporation for the U.S. Department of Energy Office of Legacy Management, Grand Junction, Colorado.

DOE (U.S. Department of Energy), 2011a. *Natural Contamination from the Mancos Shale*, LMS/S07480, ESL-RPT-2011-01, prepared by S.M. Stoller Corporation for the U.S. Department of Energy Office of Legacy Management, Grand Junction, Colorado.

[6] An AS&T scientist served on the organizing committee, chaired a session, and gave two presentations.

DOE (U.S. Department of Energy), 2011b. *Preliminary Evaluation of the Trench 1 Collection Drain Floodplain Area of the Shiprock, New Mexico Site, June 2011*, LMS/SHP/S07374, ESL-RPT-2011-03, prepared by S.M. Stoller Corporation for the U.S. Department of Energy Office of Legacy Management, Grand Junction, Colorado.

DOE (U.S. Department of Energy), 2011c. *Geology and Groundwater Investigation Many Devils Wash, Shiprock Site, New Mexico*, LMS/SHP/S06662, ESL-RPT-2011-02, prepared by S.M. Stoller Corporation for the U.S. Department of Energy Office of Legacy Management, Grand Junction, Colorado.

DOE (U.S. Department of Energy), n.d. (draft). *Cover Performance Enhancement Tests at the Grand Junction, Colorado, Disposal Site: Construction Documentation, Instrument Calibration, and Baseline Conditions*, prepared by S.M. Stoller Corporation for the U.S. Department of Energy Office of Legacy Management, Grand Junction, Colorado.

DOE (U.S. Department of Energy) n.d. (draft). *Natural and Enhanced Attenuation of Soil and Groundwater at the Monument Valley, Arizona, Processing Site: Final Pilot Study Report and Recommendations*, prepared by S.M. Stoller Corporation for the U.S. Department of Energy Office of Legacy Management, Grand Junction, Colorado.

4.0 References

Albright, W.H., C.H. Benson, G.W. Gee, A.C. Roesler, T. Abichou, P. Apiwantragoon, B.F. Lyles, and S.A. Rock, 2004. "Field water balance of landfill final covers," *J. Environ. Qual.* 33:2317-2332.

Borden, AK, M.L. Brusseau, K.C. Carroll, N. H. Akyol, A. McMillan, J. Berkompas, Z. Miao, F. Jordan, G. Tick, W.J. Waugh, and E.P. Glenn, 2011. "Ethanol addition for enhancing denitrification at the uranium mill tailings site in Monument Valley, Arizona," *Water, Air, and Soil Pollution*, August.

DOE (U.S. Department of Energy), 2011. "2011-2020 Strategic Plan, Managing Today's Change, Protecting Tomorrow's Future," DOE/LM-0512, U.S. Department of Energy Office of Legacy Management, Washington DC.

Im, J., J.R. Jensen, R.R. Jensen, and J. Gladden (drafted). "Vegetation Cover Analysis of Hazardous Waste Sites in Utah and Arizona using Hyperspectral Remote Sensing."

NRC (U.S. Nuclear Regulatory Commission), 2011. *Proceedings of the Workshop on Engineered Barrier Performance Related to Low-Level Radioactive Waste, Decommissioning, and Uranium Mill Tailings Facilities*, NUREG/CP-0195, U.S. Nuclear Regulatory Commission, Rockville, Maryland.

Traynham, B., J. Clarke, J. Burger, and J. Waugh (accepted). "Identification of Dominant Ecological Processes for Long-Term Performance Evaluations of Landfill Covers," *Journal of Risk Analysis*.

Traynham, B., J. Clarke, J. Burger, and W. Waugh, (submitted). "An Application of Event Tree Analysis to Ecological Systems: Understanding the Long-Term Performance of Engineered Covers," *Environmental Monitoring and Assessment*.

Waugh, W.J., 2010. "Cover Designs, Natural Succession, Performance, and Long-Term Surveillance and Maintenance," 2010 Long-Term Surveillance and Maintenance Conference, November 15–18, 2010, Grand Junction, Colorado.

Waugh, W.J., E.P. Glenn, P.H. Charley, B. Maxwell, and M.K. O'Neill, 2011. "Helping Mother Earth Heal: Diné College and Enhanced Natural Attenuation Research at U.S. Department of Energy Uranium Processing Sites on Navajo Land," in Burger, J. (ed.), *Stakeholders and Scientists: Achieving Implementable Solutions to Energy and Environmental Issues*, New York: Springer Science.

Waugh, W.J., P.H. Charley, M.K. Carroll, and E.P. Glenn, 2011. "Helping Mother Earth Heal: Diné College and Enhanced Attenuation Research at U.S. Department of Energy Uranium Processing Sites on Navajo Land," EPA Tribal Colleges and Universities Collaborative Workshop, June 28–30, 2011, Albuquerque, New Mexico.

White, R., and J. Waugh, 2011. "Using Native Phreatophytes to Decrease Movement of a Ground Water Uranium Plume at Shiprock, New Mexico, Navajo Nation," 2011 Emerging Researchers National (ERN) Conference in STEM, February 23–26, 2011, Washington, DC.

This page intentionally left blank