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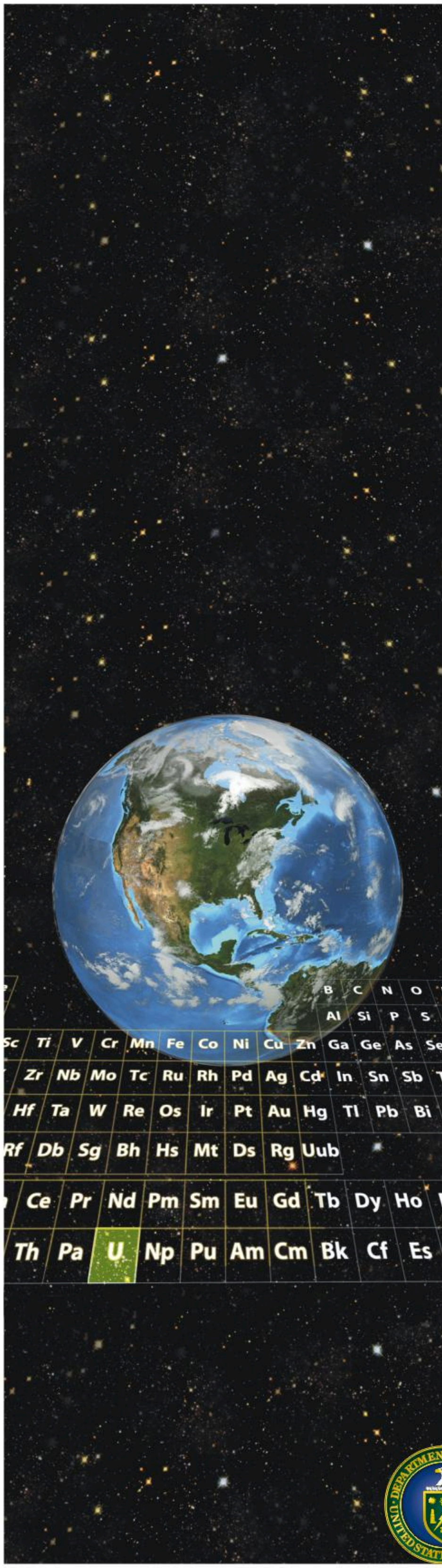

Long-Term Surveillance Operations and Maintenance Fiscal Year 2013 Year-End Summary Report

September 2013

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Contents

Tables

Abbreviations

As	arsenic
DEI	Diné Environmental Institute
DOE	U.S. Department of Energy
ECAP	Enhanced Cover Assessment Project
EMS	Environmental Management System
EPA	U.S. Environmental Protection Agency
ESL	Environmental Sciences Laboratory
ET	evapotranspiration
FY	fiscal year
ICP-OES	inductively coupled plasma optical emission spectrometry
LM	Office of Legacy Management
LMS	Legacy Management Support
LTS&M	long-term surveillance and maintenance
LTS–O&M	Long-Term Surveillance Operations and Maintenance
LTSP	Long-Term Surveillance Plan
m	meter
mm	millimeter
mm/yr	millimeters per year
Mo	molybdenum
NRC	U.S. Nuclear Regulatory Commission
Pb	lead
Se	selenium
SOARS	System Operation and Analysis at Remote Sites
SWCC	soil water characteristic curve
TDSP	Technology Deployment Strategic Planning
Th	thorium
TTP	Technical Task Plan
U	uranium
UMTRCA	Uranium Mill Tailings Radiation Control Act of 1978

1.0 Introduction

The Long-Term Surveillance Operations and Maintenance (LTS–O&M) subtask 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 and tools to ensure that implementation of LTS&M will be informed, efficient, and cost-effective. This effort includes moving long-term stewardship strategies and methods into the "state of the practice" at LM sites. Site leads also need better information and resources to work more effectively with regulators and stakeholders to ensure that improved approaches meet compliance 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.

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2.0 Objectives

The LTS–O&M subtask, which is part of Task Order 501, is at the core of LM efforts to fulfill a 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 site operation and maintenance to improve the sustainability of remedies.
- Provide LM with information 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 LTS–O&M project results in peer-reviewed journals to provide a measure of credibility in defending LM decisions, to bring visibility to LM initiatives, and to enable others to utilize the results.
- Use LTS–O&M projects to create and promote opportunities, discourse, and achievements in environmental education.

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3.0 Subsurface Projects

Groundwater contaminant plumes still remain at many LM sites, including many sites associated with former uranium-processing facilities. Groundwater models constructed over the past 25 years generally predicted that the contaminant concentrations in the plumes would decrease to acceptable values much faster than has been observed. Many hydrologic, geochemical, and biochemical processes are interacting in the subsurface environment, any of which could be responsible for this recalcitrant behavior. Compliance strategies are often based on the time frame of groundwater cleanup; thus, making accurate predictions of cleanup rates is important to the LM program. A major focus of the LTS–O&M Subsurface Projects is to identify and evaluate the dominant subsurface processes acting to decrease the rate of groundwater remediation.

Physical, chemical, and biochemical processes in the subsurface are highly variable, a condition referred to as heterogeneity. Conditions can change radically over millimeter- to kilometer-length scales. It is typically unreasonable to collect and analyze sufficient numbers of samples to accurately account for the high levels of variability in the subsurface, so interpretations must be made from a limited data set. To help establish reliable interpretations of incomplete data sets, a focus of the LTS–O&M Subsurface Projects is to determine the variability in subsurface data.

Another factor that sometimes complicates groundwater data evaluation is the presence of natural contamination. At some sites, such as former uranium-ore processing facilities, the suite of contaminants derived from natural sources is similar to that derived from the uranium-ore processing. To help evaluate these background sources of contamination, LTS–O&M Subsurface Project personnel are strategically collecting samples to establish key chemical and isotopic signatures representative of the different sources.

Other activities conducted under the LTS–O&M subtask order include operation of a geochemical/ecology laboratory and operation of a nationwide telemetry system called System Operation and Analysis at Remote Sites (SOARS). Following is more detailed discussion of the LTS–O&M Subsurface Projects activities.

3.1 Origins of Contamination in Many Devils Wash—Shiprock Site

Overview. Many Devils Wash is located about 0.5 mile east of the disposal cell at the Shiprock, New Mexico, Disposal Site. High concentrations of contaminants are present in pools and seeps along the wash. Because the suite of groundwater contaminants (nitrate, sulfate, selenium, and uranium) at the disposal cell is the same as that at Many Devils Wash, DOE accepted responsibility for remediation of the wash despite several indications that the contamination at Many Devils Wash could have been derived from natural sources.

Remediation efforts by DOE in 2003 included the installation of an interceptor drain under the channel of Many Devils Wash. The drain is about 450 feet 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. Over time, low-permeability sediment prevented contaminated surface water in the stream channel from infiltrating 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 collection sump increased from about

0.4 to 0.8 gallon per minute 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.

Fiscal Year (FY) 2013 Activities. Three Environmental Sciences Laboratory (ESL) reports were prepared from this study: (1) *Multivariate Statistical Analysis of Water Chemistry in Evaluating the Origin of Contamination in Many Devils Wash, Shiprock, New Mexico*; (2) *Characterization and Isolation of Constituent Causing Red Coloration in Desert Arroyo Seepage Water*; and (3) *Application of Environmental Isotopes to the Evaluation of the Origin of Contamination in a Desert Arroyo: Many Devils Wash, Shiprock, New Mexico*. A manuscript titled "Use of Chemical and Isotopic Signatures to Distinguish Between Uranium Mill-Related and Naturally Occurring Groundwater Constituents" was submitted to the journal *Groundwater Monitoring & Remediation*. Revisions were made in response to reviewers' comments and the manuscript was resubmitted.

Chemical and isotopic signatures were used to demonstrate that contaminated groundwater issuing from seeps in Many Devils Wash is likely derived from the Mancos Shale bedrock, rather than from the uranium mill tailings disposal cell. Several sites that are located far away from the disposal site and that do not have a hydraulic connection to it were sampled. These "analog sites" have seepage with a suite of contaminants similar to that in Many Devils Wash, providing strong evidence that contamination in Many Devils Wash is from natural processes.

3.2 Plume Persistence Project

Overview. Contaminant-residence and release-rate studies to help understand processes related to groundwater plume persistence were recommended in the *Five-Year Plan for Applied Science and Technology*. The overall goal of these investigations is to provide a scientific foundation for the observation that contaminant plumes at many LM sites persist for time frames that are much longer than predicted by traditional groundwater modeling. LTS–O&M projects include the physical and chemical interactions between the aqueous and solid phases in aquifers that have been contaminated from uranium-ore processing. The rationale is that existing models fail to accurately incorporate the dominant chemical and physical processes responsible for contaminant interactions. In FY 2012, the Grand Junction, Colorado, Site was selected for a preliminary investigation of plume persistence.

FY 2013 Activities. A task plan for this project was prepared and approved by LM. Geoprobe coring was conducted at 22 locations at the Grand Junction site. The area under investigation has slightly elevated concentrations of uranium that makes it suitable for this study. Core samples were collected every foot for a total of about 360 samples. The samples were air dried and sieved. A SOARS station, with water-level and specific-conductivity sensors, was established at a key well in the cored area.

Batch tests were conducted to determine the mass of uranium removed by four different extracting media in order of increasing potential to remove solid-phase uranium: (1) bicarbonate/carbonate solution (labile fraction), (2) 5 percent nitric acid, (3) concentrated nitric acid (microwave digestion), and (4) lithium metaborate fusion (total digestion). In addition, selected samples were subjected to an ammonium oxalate solution designed to remove poorly crystalline iron oxides. The results of these extractions are being used in conjunction with data from petrography and column testing to evaluate the mineralogic residences of the uranium. The results provide information to help determine how tightly the uranium is bound to the aquifer solids.

Polished thin sections were prepared for a subset of the samples. Fission-track maps of the polished thin sections were prepared on mica or lexan detector plates affixed to the thin sections. The mica–thin-section packages were subjected to a prescribed flux of slow neutrons to fission the uranium, which produced tracks in the detector plates. The detectors were then etched for microscopic analysis. To analyze the fission-track maps, significant improvements were made to the petrography laboratory. Two existing petrographic microscopes were outfitted with digital cameras. Software was purchased that allows images of the polished, thin section and the fission-track map to be projected side by side so that fission tracks can be accurately mapped to the mineral and textural feature in the thin section. These techniques provide a unique means to identify the mineralogic associations of uranium. The same suite of samples used for fission tracking were subjected to preliminary column tests. The column had periods of intentional interruption to evaluate the effects of rate-limited uranium desorption.

This project is still largely in the data collection stage. Results indicate that uranium is bound to the sediments in variable ways, as evidenced by the different removal efficiencies using various extraction media. Fission-track analyses indicate that some uranium resides in mineral coatings (probably iron oxide) on grain surfaces. Fission tracks are also concentrated in the fine-grained (perhaps iron-oxide rich) matrix of composite sedimentary grains. Column test results indicate that some of the uranium is bound in a way that causes variable desorption rates.

In FY 2014 and 2015, contaminant residence studies will continue, including more selective extractions and fission-track mapping. Additional column tests will be conducted to further investigate rate-limited processes. The small columns used in the tests to date are limited in that the effluent volume is insufficient for analysis of constituents other than uranium. Larger columns will be used in the future so that other constituents, including major ions, can be analyzed. Data evaluation, including 3-dimensional visualizations, will be conducted late in FY 2014 and continue into FY 2015. Models of flow and transport, including algorithms to simulate the rate-limited processes, will be conducted largely in FY 2015. A manuscript for submittal to a peer-reviewed journal will likely be written.

3.3 Variation Project

Overview. This project includes the study of variations in concentrations of dissolved constituents in groundwater. Contour maps of contaminant plumes are often the principal tool in evaluating the extent of contamination in an aquifer and the rate of groundwater cleanup. Implicitly, this approach assumes that the concentrations measured at a point in time can be used to represent the average flux through the aquifer at that time. However, concentrations in wells seldom display smooth monotonic trends over time, as would be expected with ideal plume migration. Several factors may affect concentrations that could impact interpretations of groundwater transport. For example, a well on the Shiprock floodplain was observed to have significantly different uranium concentrations at a single point in time if sampled in different ways. This artifact could be due to stratification in the aquifer, dead zones in the well containing old groundwater, or some other as-yet unidentified process. This project is aimed at identifying mechanisms responsible for major chemical variations that could impact traditional plume migration rate estimations.

FY 2013 Activities. A task plan for this project was prepared and approved by LM. Specific conductivity and temperature profiles were measured by slowly lowering a sonde into wells and recording data at 0.5-foot intervals. Profiles were conducted at a number of wells at several LM sites. The profiles indicate that conductivity in the water column in some wells has little variation, whereas conductivity in other wells varies by more than a factor of 2, and in some extreme cases, by an order of magnitude. In some wells, samples were collected from the same 0.5-foot intervals as the profiling and confirmed the strongly stratified nature of the groundwater chemistry. Radon-222 concentrations were measured in samples from selected wells. The radon-222 dissolved in stagnant water decays and can be used to indicate the length of time that the water was stagnant in the well. One of the highly stratified wells was instrumented with conductivity sensors placed at regular intervals throughout the saturated zone. Data from these instruments are being monitored through the SOARS system to establish long-term trends. A small pump that is used to homogenize the water in the well bore by circulation was placed in this same well. Monitoring data collected during rebound following homogenization are being used to delineate high-flux zones in the well. These data will also be used to help predict the causes of the stratification and relate well-bore stratification to chemical conditions in the aquifer.

4.0 Surface Projects

A substantial portion of LM funds is directed at LTS&M of disposal cells at Uranium Mill Tailings Radiation Control Act (UMTRCA) and other sites. Two key LM goals are to reduce LTS&M costs and to sustain the protectiveness of remedies (DOE 2011). Ecological succession, soil-forming processes, and climate may be changing surface remedies, including the as-built engineering properties of disposal cell covers, in ways that could increase costs and alter long-term protectiveness. The information needed to help LM improve LTS&M of surface remedies is acquired through existing and new Surface Projects including investigations of effects of ecological and soil-forming processes on the protectiveness of disposal cell covers with respect to rainwater percolation, radon attenuation, erosion, and contaminant bioaccumulation. Other projects are linking climate change studies, natural analog studies, and modeling to better understand the sustainability of covers. And still other projects are underway to allow staff to investigate ways to enhance the sustainability of conventional covers, monitor the performance of alternative cover designs, develop new monitoring tools, and investigate enhanced natural attenuation. The projects are applicable for designs, performance evaluations, and long-term stewardship plans for surface remedies at other sites both within DOE and elsewhere.

4.1 Enhanced Cover Assessment Project (ECAP)

Overview. The purpose of ECAP is to evaluate methods for enhancing the long-term performance of disposal cell covers for LM sites regulated under UMTRCA. This effort supports three LM strategic objectives: (1) increase confidence in the protectiveness of disposal cell covers, (2) enhance the sustainability of covers, and (3) reduce LTS&M costs (DOE 2011). The primary goal is to improve the hydraulic performance and sustainability of UMTRCA covers that have low-permeability radon barriers. A secondary goal is to reduce the LTS&M cost of controlling plant encroachment on covers as is currently required by many Long-Term Surveillance Plans (LTSPs).

The designers of UMTRCA disposal cell covers did not anticipate plant encroachment or the natural soil-forming processes that have altered the engineering properties of low-permeability radon barriers. Cover enhancement is based on the counterintuitive premise that these unanticipated natural processes may actually improve, rather than degrade, covers. The concept is to either allow these processes to progress unimpeded, or enhance them; to enhance vegetation establishment, evapotranspiration (ET), and water-storage capacity, effectively transforming low-permeability covers into water balance covers (Albright et al. 2010). Water balance covers rely on soil to behave like a sponge that stores water, and on plants to transpire (pump) water back into the atmosphere. Water balance covers are also designed to accommodate inevitable natural changes in vegetation and in the morphology and hydrology of cover soil layers and are thus likely more sustainable than low-permeability covers.

Several knowledge gaps need to be addressed to advance cover enhancement from concept to practice, including effects of natural processes and enhancements on (1) hydraulic performance, (2) radon attenuation, (3) cover surface erodibility, (4) biouptake and bioaccumulation of tailings contaminants, and (5) cover sustainability, including adaptation to climate change.

LM initiated ECAP to address the first knowledge gap: effects of natural processes and enhancement methods on the hydraulic performance of covers. Other interrelated knowledge gaps are being addressed through other Surface Projects.

LM constructed two ECAP test facilities at the Grand Junction, Colorado, Disposal Site to evaluate cover enhancement. One facility consists of two large-drainage lysimeters; the other is a large test pad.

Cover enhancement is also intended to mimic sustainable natural slopes that limit deep percolation of rainwater. Geomorphological and ecological evidence from natural analog sites near the Grand Junction disposal site supports the concept of loosening, blending, and planting the compacted soil and rock layers of the existing cover as a way to enhance or accelerate transformation to a water balance cover. In general, natural analog studies can provide clues from present and past environments as to possible long-term changes in engineered soil covers. At the Grand Junction analog sites, rock varnish, lichenometry, soil morphology, and plant community characteristics provide evidence of the long-term stability of the surface, long-term water movement patterns in the soil profile, and trajectories of plant succession.

FY 2013 Activities: In FY 2013, a technical task plan (TTP) was drafted for the project, soil water balance monitoring continued in the two lysimeter test sections, the revegetation study was refined, and reports and manuscripts were drafted detailing the as-built design of the lysimeter test sections, the methods and results of the test pad study, and the field hydraulic performance of the cover.

The TTP provides LM with a thorough rationale and scope for ECAP. (All subcontract work and field activities were discontinued during preparation of the TTP.) It includes sections on (1) the design and function of engineered earthen covers, (2) naturally occurring changes in the ecology and soil engineering properties of covers, (3) the objectives and scope of ECAP, and (4) the status of activities that are underway to achieve the objectives. The TTP defines four objectives for ECAP:

1. *Directly monitor the water balance and hydraulic performance of an UMTRCA cover.* Monitoring the soil water balance will provide (1) a direct measure of field percolation and hydraulic performance and (2) baseline data to evaluate enhancement methods. Rainwater percolation through UMTRCA covers has been estimated but never measured directly.
2. *Evaluate natural changes in the soil engineering properties of an UMTRCA cover.* ECAP activities will include measuring natural pedogenic changes in as-built soil engineering properties of the test section covers, properties that govern the hydraulic performance of a low-permeability radon barrier.

3. *Evaluate natural and enhanced ecological succession on an UMTRCA cover*. Assuming that the natural transformation to water balance covers can be beneficial, ECAP results will be used to evaluate revegetation methods for accelerating plant establishment and creating conditions on rock covers that are more favorable to plant growth, thereby increasing ET rates.
4. *Demonstrate, monitor, and model hydraulic performance enhancement methods.* Large test facilities will be used to evaluate effects of enhancement methods on revegetation success and cover hydraulic performance. Because the establishment of desert vegetation can take many years, long-term monitoring will be necessary to acquire meaningful results. Lysimeter monitoring data will also be used to validate cover performance models—to test models by comparing predictions to field lysimeter data.

4.1.1 Lysimeter Test Sections

LTS–O&M staff modeled the lysimeter test sections after designs used in the U.S. Environmental Protection Agency's (EPA's) Alternative Cover Assessment Program. The drainage lysimeters are like large, plastic swimming pools filled with soil, rock, and instrumentation. Placement of soil and rock layers in the lysimeters matched the engineering design, materials, and construction of the existing Grand Junction disposal cell cover. The instrumentation monitors the water balance of the simulated covers—how much water falls on the soil surface as precipitation, sheds as runoff, becomes stored in the soil sponge layer, evaporates and transpires out of the soil sponge by plants (ET), and, most important, how much percolates through the cover. Soil and rock layers in one test section will be ripped or furrowed on the contour and planted; the other test section is a control section and will be maintained similarly to the existing Grand Junction disposal cell cover.

As-Built Report: LTS–O&M staff wrote this report to thoroughly document the rationale, construction, material properties, instrumentation, and initial conditions for the unique large lysimeter test facility at the Grand Junction disposal site. The report describes testing conducted to characterize the as-built engineering properties of the test sections, the calibration of instruments installed in the lysimeter facility, and how the facility is used to monitor hydrologic conditions within the cover profile, including water content and matric potential, and boundary fluxes, including runoff, ET, and percolation.

Cover Performance Monitoring: LTS–O&M staff monitored the lysimeter test sections, checked calibration of instrumentation, and drafted a manuscript on the hydraulic performance of the UMTRCA cover. The lysimeter data show that percolation is relatively small (less than 3 percent of precipitation), there has been only trace runoff (less than 0.1 millimeter) in each lysimeter since construction, and ET is the dominant water balance flux. However, the site received less than 100 millimeters (mm) (4 inches) of precipitation between July 2012 and June 2013, continuing an extended drought. Nonetheless, percolation flux followed an intermittent or stair-step pattern, which is commonly associated with the formation of preferential flow paths. Each quarter a quality assurance (QA) evaluation is conducted, and lysimeter data (16 different parameters) are reduced and plotted. The QA evaluation indicated that the calibration of water content reflectometers in both lysimeters should be checked. Bulk samples of radon barrier soil from a stockpile were shipped to a geotechnical laboratory for this purpose.

4.1.2 Test Pad

LTS–O&M staff constructed a test pad at the Grand Junction disposal site in 2010 to evaluate cover enhancement methods, including options for soil manipulation and revegetation. The 25 meter (m) by 50 m test pad was constructed on a stockpile of the fine-textured soil used for the protective layer in the disposal cell cover. The desired effect was to vertically mix the layers, loosen the compacted low-conductivity protective layer, and provide improved habitat for plants. Soil manipulation treatments were imposed in 2011 and then described, sampled, and analyzed for changes in geotechnical properties in 2012 and 2013. A report explaining soil manipulation tests was drafted in 2013. A revegetation study is ongoing.

Test Pad Study Report: The purpose of the test pad study was to evaluate effects of different soil manipulation methods, including soil ripping and furrowing effects on (1) the extent of cover layer mixing, and (2) hydraulic properties, percolation flux, and water storage. The report begins with background information about resistive and water balance cover designs, natural processes that are changing cover engineering properties, and the cover enhancement concept. The body of the report details the soil manipulation strategies, test pad design and construction, experimental design, and evaluation methods and results. The concluding section of the draft report will provide a summary of the soil manipulation tests and recommendations for a cover enhancement treatment for the lysimeter test sections.

Revegetation Study: LM staff designed a revegetation study to evaluate methods for increasing ET on covers by accelerating vegetation establishment. The study is comparing the revegetation success of combinations of four species mixtures, two planting methods, irrigation, and effects of mychorrizae inoculum, all superimposed on seven soil manipulation tests (see Table 1). Installation of treatments will be complete in spring 2014.

Table 1. Seven Soil Manipulation Tests

Treatment	Level
Soil Furrowing and Ripping[a]	1. CS, 3 ft depth, 1 pass 2. WTS, 2 ft depth, 2 passes 3. WTS, 3 ft depth, 2 passes 4. POS, 4 ft depth, 2 passes 5. POS, 3 ft depth, 2 passes 6. POS, 3 ft depth, 1 pass 7. POS, 2 ft depth, 1 pass
Species Mixture [b]	1. Low-growing alkali shrub 2. Tall alkali shrub 3. Non-Atriplex shrub 4. Desert grassland
Planting Method	1. Broadcast seeding 2. Transplant dominant species [c]
Irrigation	1. Deficit irrigation [d] 2. No irrigation

[a] CS—conventional shank, WTS—wing-tipped shank, POS—parabolic oscillating shank

[b] Tables of species, varieties, and broadcast seeding rates for each species mixture are attached. Species mixtures 1 and 4 will be divided (1a, 1b, 4a, 4b) and seeded in alternating strips to lessen seedbed competition.

[c] The dominant species for the four species mixtures are 1(a&b). *Atriplex corrugata*, 2. *Atriplex canescens*, 3. *Ericameria nauseosa*, 4(a&b). *Elymus elymoides* and *Pleuraphis jamesii*.

[d] Irrigating significantly less than the potential evapotranspiration to prevent recharge.

Geotechnical Publication: Subcontractors from University of Wisconsin developed and published results of an evaluation of methods to estimate the soil water characteristic curve (SWCC) for soils samples from the test pad with graded fines and coarse rock. The publication was funded by others. The citation and a summary follow:

> The Bouwer-Rice correction method to account for large particles excluded during laboratory testing to measure SWCC was evaluated on samples of broadly graded alluvium. The analyses show that SWCCs measured on the fraction of alluvium finer than the No. 4 US sieve (4.8 mm) can be corrected reliably to represent the SWCC of bulk soil or fractions of bulk soil corresponding to different large-particle thresholds. The method can also be used reliably to correct SWCCs measured on soils prepared with different large-particle thresholds (e.g., finer than 25 mm, 12.5 mm, or 4.8 mm). A simplified version of the Bouwer-Rice method was also proposed and evaluated. Analyses show that this modified Bouwer-Rice method is simpler and results in an accurate representation of the SWCC of soil containing large particles (Bareither, C.A., and C.H. Benson, 2013, "Evaluation of Bouwer-Rice Large-Particle Correction Procedure for Soil Water Characteristic Curves," *Geotechnical Testing Journal 36*, [published online July 18, 2013].)

4.2 Plant Uptake on Disposal Cells

Overview: The uptake and bioaccumulation of tailings constituents by plants rooted in disposal cells is a potential ecological exposure pathway that has previously received only limited consideration at LM sites. Other aspects of plant growth have been investigated. LTS–O&M staff have investigated root intrusion effects on soil morphology and percolation and have also investigated methods to enhance plant growth and ET as a way to limit percolation (Section 4.1). LTS–O&M staff are also investigating effects of plant growth and transpiration on radon attenuation (Section 4.6.1).

LTSPs currently require vegetation removal on many disposal cell covers, while on other covers, LTSPs allow plant growth. LM needs a consistent policy that can be used to develop site-specific vegetation management plans for disposal cells. Developing a consistent policy will require an understanding of the balance of potential benefits and detriments of plant growth on disposal cells. The goal of this project is to acquire field data that can be used to evaluate risks of contaminant uptake by plants rooted in disposal cell covers. If risks are negligible, and if other projects show that the potential benefits of plants growing on disposal cell covers outweigh potential detriments, then LM may choose to discontinue vegetation control on selected disposal cell covers as a way to reduce LTS&M costs.

The objectives of this ongoing plant uptake study are to (1) compare levels of tailings constituents in plants currently rooted in covers with plants growing in reference areas (undisturbed areas with soil and vegetation similar to those on the disposal cell cover), (2) evaluate bioaccumulation of tailings contaminants in leaf litter and surface soil, and (3) if warranted, assess risks to human health and the environment. Because levels of these constituents in tailings, cover soils, and plants may be highly variable, the risk assessment may be contingent on a greenhouse study to establish plant/soil concentration ratios for current and likely future plant species growing on LM covers.

FY 2013 Activities: The field comparison of tailings constituents in plants rooted in disposal cell covers with plants growing in reference areas began in FY 2011. Carrie Joseph, a University of Arizona master of science student, participated in the study. In FY 2012, the student (a former LM summer intern) began the laboratory analyses of plant tissues. Table 2 lists the plant species sampled and analytes for each disposal site in the study.

Table 2. Plant Species Sampled and Analytes Listed

LM Site	Plant Species	Analytes
Tuba City, Arizona, Disposal Site	Fourwing saltbush, kochia	U, Th, As, Se, Mo, Pb
Bluewater, New Mexico, Disposal Site	Fourwing saltbush, Siberian elm	U, Th, Mo, Se
L-Bar, New Mexico, Disposal Site	Fourwing saltbush, rabbitbrush	U, Th, As, Se, Mo, Pb
Lowman, Idaho, Disposal Site	Ponderosa pine, mock orange	U, Th
Lakeview, Oregon, Disposal/Processing Site	Sagebrush, bitterbrush	U, Th
Sherwood, Washington, Disposal Site	Bitterbrush, ponderosa pine	U, Th, As,
Split Rock, Wyoming, Disposal Site	Rabbitbrush	U, Mn, Mo

Abbreviations:
U = uranium
Th = thorium
As = arsenic
Se = selenium
Mn = manganese
Mo = molybdenum
Pb = lead

In FY 2013, Carrie Joseph completed her master of science thesis, which focused on two sites, Bluewater and L-Bar. Plant tissue analyses for the remaining five sites was funded by LTS−O&M at the University of Arizona's Arizona Laboratory for Emerging Contaminants; and Legacy Management Support (LMS) and University of Arizona scientists are drafting a letter report of the results for all seven sites.

University of Arizona Thesis: Carrie Joseph completed her master of science thesis for the Department of Soil, Water, and Environmental Science. An LMS scientist directed the research and served on Ms. Joseph's graduate committee. The thesis compared concentrations of tailings constituents in stem and leaf tissue of deep-rooted shrubs and trees rooted in the covers of disposal cells at the Bluewater and L-Bar disposal sites with the same species growing in nearby reference areas. The Bluewater and L-Bar sites were selected for study in part because of their proximity to Pueblo villages. Soils at reference areas were similar to cover soils. The plant species sampled at these sites were fourwing saltbush (*Atriplex canescens*), rubber rabbitbrush (*Ericameria nauseosa*), and Siberian elm (*Ulmus pumila*).

The results of the thesis indicate significant statistical differences between contaminant concentrations in plants on the disposal cells compared to plants in reference areas. For saltbush, selenium, uranium, and molybdenum concentrations were significantly higher on the disposal cells than in reference areas. However, at the L-Bar site, where soils are derived from Mancos shale, selenium concentration in saltbush was significantly higher in the reference area. Rabbitbrush had significantly higher levels of selenium and molybdenum, and Siberian elm had significantly higher levels of molybdenum in the reference area than on the disposal cell. These results provide clues for improving long-term stewardship of disposal cell covers. Risks of plant uptake to human health and the environment will be evaluated in 2014.

4.3 Water Balance Cover Monitoring and Modeling

Overview: LM is investigating alternatives to conventional cover designs for cells containing uranium mill tailings. The Monticello, Utah, Disposal Site 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 (63-inch) layer of sandy clay loam soil overlying a 40-centimeter (16-inch) sand capillary barrier for water storage, and a planting of native sagebrush steppe vegetation to seasonally release soil water through ET.

The Monticello site is a good location for a long-term test of ET covers in general because of the relatively short growing season and semiarid to subhumid climate there—it is at the cool-wet climatic fringe for locations where ET covers might work. EPA and DOE installed a large pan lysimeter in 2000 during construction of the disposal cell cover at the Monticello site. EPA, DOE, and several states are using the unique data from the large in-service lysimeter at the Monticello site to help guide decisions on the use of ET-type covers at other sites.

FY 2013 Activities: Lysimeter monitoring continued for a 14th year in collaboration with University of Wisconsin, and the project continued to be valued for educational outreach and by other agencies involved in the design and monitoring of disposal cells.

Water balance monitoring within a 3-hectare drainage lysimeter provides convincing evidence that the cover has performed well, limiting percolation over a 14-year period (2000–2013). Precipitation, water storage, percolation, and ET are monitored in real time in the embedded lysimeter.

Lysimeter water balance data collected using SOARS were reduced and plotted quarterly. As of July 2013, the large embedded lysimeter had recorded zero percolation in 2013, for a percolation rate of about 0.5 mm per year (mm/yr) during 12.5 years of monitoring, or about 0.14 percent of annual precipitation. In contrast, average percolation in conventional covers and in similar environments, as measured in EPA's Alternative Cover Assessment Program using large lysimeters, was about 35.0 mm/yr, or 9.1 percent of precipitation.

In FY 2013, LM approved the following ongoing and additional tasks for this project:

1. Continue low-cost water balance monitoring, data reduction, and data QA.
2. Publish a monograph on water balance cover research at the Monticello site (monolith lysimeters, caisson lysimeters, embedded lysimeter, changes in engineering properties, natural analogs).
3. Use unique, large-scale, long-term water balance cover monitoring data to evaluate numerical models used for cover designs, sensitivity analyses, and long-term performance predictions.

4.4 Applications of LTS–O&M Surface Projects

Overview: A goal of LTS–O&M Surface Projects is to generate knowledge and tools to improve LTS&M of disposal cells and other surface remedies. This section describes activities of FY 2013 aimed at improving LTS&M of LM sites that began as Surface Projects.

4.4.1 Natural and Enhanced Attenuation Pilot Studies

LM, Navajo Nation, University of Arizona, and Diné College are jointly exploring alternative remedies for groundwater contamination at the Monument Valley, Arizona, Processing Site and the Shiprock site. The alternatives involve natural and enhanced attenuation processes—primarily phytoremediation—and microbial denitrification. Three applications of phytoremediation have been explored: phytoextraction, hydraulic control, and land farming. Ongoing pilot studies at the Monument Valley and Shiprock sites, now funded primarily under site budgets, were initiated as feasibility studies under a predecessor of LTS–O&M. LTS–O&M continues to support publications and educational outreach activities that are connected to these projects.

Monument Valley Pilot Study: Highlights in FY 2013 include a publication on remote sensing of transpiration at the site, a draft paper for publication on land-farm phytoremediation, and completion of the pilot study final report.

"Effects of Grazing on Leaf Area Index, Fractional Cover and Evapotranspiration by a Desert Phreatophyte Community at a Former Uranium Mill Site on the Colorado Plateau" was published in the *Journal of Environmental Management*. The study used livestock exclosures and revegetation plots to determine the effects of grazing, then projected the findings over the whole site using multiplatform remote sensing methods. Results show that ET is approximately equal to annual precipitation in grazed areas, but when desert phreatophytes are protected from grazing, they can develop high fractional cover and leaf area index values, and ET can exceed annual precipitation, with the excess coming from groundwater discharge. Therefore, control of grazing may be an effective method to slow migration of contaminants at this and similar LM sites.

LTS–O&M staff drafted "Land-Farm Phytoremediation of Groundwater Nitrate at a Former Uranium Mill Site near Monument Valley, Arizona" to be submitted to *International Journal of Phytoremediation*. Land farming was evaluated as an alternative remedy for contamination in a shallow alluvial aquifer at the Monument Valley site. Different varieties of native shrub transplants were irrigated with nitrate-contaminated water pumped from the aquifer. Fourwing saltbush thrived when irrigated with contaminant-plume water. Plant uptake and soil denitrification likely kept nitrate levels from building up in the land-farm soil; plant growth and transpiration limited recharge and leaching of nitrate and ammonia back into the aquifer; sulfate pumped from the plume remained in the soil profile, perhaps sequestered as calcium sulfate; and the land farm produced a native seed crop that could be used by the Navajo Nation for rangeland revegetation or mine land reclamation.

The *Monitored Natural and Enhanced Attenuation of the Alluvial Aquifer and Subpile Soils at the Monument Valley, Arizona, Processing Site: Final Pilot Study Report* was completed and approved by LM for distribution to the Navajo Nation. The pilot studies and report were completed with site funding and were written for policymakers. Book chapters and journal and proceedings publications funded through LTS–O&M were included to provide peer-reviewed technical backing for pilot study conclusions.

Shiprock Pilot Study: Educational outreach activities associated with the Shiprock phytoremediation pilot study and funded by LTS–O&M continued at Diné College in FY 2013. LTS–O&M staff presented seminars and organized field and laboratory activities for students enrolled in the Diné Environmental Institute (DEI).

4.4.2 Bluewater Disposal Cell White Paper

The Bluewater disposal cell white paper was written in part as an application of the results of LTS–O&M projects that are addressing the performance and sustainability of disposal cell covers. As directed by LM, the white paper set the stage for LM to investigate the performance of the main tailings disposal cell cover at the Bluewater site. The paper (1) reviewed precedent for LM action; (2) examined the design and as-built conditions from site records; (3) drew inferences about current conditions from inspections, observations, and key technical literature; (4) recommended methods for quantifying the current performance of the cover; (5) advanced a concept for enhancing cover performance, as an option; and (6) outlined a framework for projecting the long-term performance, or sustainability, of the cover.

The draft white paper assessed the current condition of the cover through the lenses of observation and inference. For example, plants rooted in the cover and inevitable natural soil-forming processes likely created fissures in the radon barrier, potentially increasing permeability and radon flux. The white paper identified information gaps and recommended activities to better characterize the current condition and performance of the cover—whether the cover is functioning as designed. Recommendations included (1) using LiDAR to determine if settlement in depressions is ongoing, (2) characterizing soil morphology and root density in the radon barrier, (3) testing radon barrier permeability and hydraulic properties, (4) evaluating radon attenuation by repeating U.S. Nuclear Regulatory Commission (NRC)–accepted radon flux calculations using existing moisture content and porosity, (5) evaluating effects of soil-forming processes and root intrusion on radon flux, (6) evaluating uptake of tailings constituents by plants and animals, and (7) characterizing analog of the dynamics and trajectory of pedogenesis and ecological succession. Finally, the white paper explored options for enhancing the performance of the cover or, in reality, accelerating the natural transformation of the Bluewater site cell cover into a water balance cover.

4.5 New and Renewed Surface Projects

In FY 2013, LM requested concept proposals for new Surface Projects. This section provides summaries of new projects and of renewed projects conceived by LTS–O&M scientists several years ago under the DOE Office of Environmental Management.

4.5.1 Effects of Pedogenesis on Radon Flux

Plants can potentially increase radon flux by drying the radon barrier, contributing to the formation of macroporosity in the radon barrier, and transporting radon in transpiration water. Soil-forming processes can potentially increase radon flux, even in the absence of vegetation, by creating fissures in radon barriers, reducing bulk density (compaction), and increasing soil porosity.

This study will evaluate effects of plant encroachment and soil development on radon flux at the surface of radon barriers both with and without vegetation. To be representative of a likely long-term scenario, the study will include existing UMTRCA covers that have (1) a low-permeability radon barrier with well-developed soil structure, (2) woody plants rooted through the radon barrier, (3) a well-developed (not sparse) plant community that has seasonally dried the radon barrier, and (4) ideally undergone an exceptionally dry year. An expanded version of the study would measure radon flux for ranges of these conditions. The study will also examine natural analogs of covers for clues about long-term effects of plant succession and pedogenesis on radon flux.

4.5.2 Depth of Pedogenesis in Covers

Although recent research and field tests have shown that soil development and associated changes in soil engineering properties that influence water percolation and radon flux should be expected in thinner covers (about 1.0 m thick), less is known about how soil development affects engineering properties of compacted soil layers that are overlain with protective layers of soil, or that are in the lower portions of exceptionally thick low-permeability radon barriers. This study will evaluate the depths at which natural soil development could alter the compaction, porosity, saturated hydraulic conductivity, and water retention characteristics of low-permeability radon barriers in UMTRCA covers. Tasks will include (1) reviewing the literature for evidence of the depths of changes in soil engineering properties in existing covers; (2) selecting test covers that represent ranges of cover thicknesses, soil types, plant communities, and climates; (3) identifying ecological and pedogenic processes that could alter engineering properties for selected test covers; (4) determining depths of pedogenesis and associated soil engineering properties; and (5) characterizing soil morphology and pertinent soil engineering properties for natural analog of covers.

4.5.3 Cover Performance Adaptation to Climate Change

For disposal cell covers to be sustainable—to continue to satisfy UMTRCA radon flux and groundwater protection requirements for 200 to 1,000 years—covers must accommodate (adapt to) inevitable long-term changes in the climate, soils, and ecology of the site. Previously, LM scientists and collaborators conceived a framework for projecting long-term cover performance that links (1) probabilistic, numerical, ecohydrology models; (2) monitoring of existing covers to calibrate and validate models; (3) climate change models; and (4) characterization of natural analogs. This study will refine the evaluation framework, use more current climate models that include climate variability and extreme events, and refine methods for selecting and characterizing analog sites that are intended to represent future environmental scenarios for a site.

4.5.4 Coupled Ecology and Soil Hydrology Models

The purpose of this project is to develop a numerical model, or couple existing models, to simulate both the soil hydrology and vegetation dynamics of disposal cell covers with sufficient realism and accuracy. Models are needed to (1) evaluate sensitivity of UMTRCA covers to design and performance variables, (2) compare conventional and water balance covers, (3) predict the effects of cover enhancements on hydraulic performance, and (4) project the long-term performance of covers in response to changes in climate, soil morphology, and ecology. Existing soil hydrology models are excellent tools for simulating water storage and percolation but do a poor job of simulating the effects of vegetation dynamics, plant succession, and other long-term ecological processes that will change the behavior and performance of UMTRCA covers. Existing ecology models focus on vegetation dynamics and ecological succession but do a poor job of simulating soil's physical properties, mainly because they do not solve Richard's Equation.

4.5.5 Erosion and Ecology of Rock-Soil Mixtures

Soil can become mixed with the rock armor on UMTRCA disposal cell covers, either deliberately as part of methods to enhance the hydraulic performance of covers (see Section 4.1), or naturally due to windblown and organic deposition. Of importance are the effects of deliberate or natural mixing of soil in rock layers on soil erosion, slope stability, and plant succession. Rock armor designs for UMTRCA covers are based on explicit NRC guidance regarding rock size, durability, and layer thickness to control worst-case water and wind erosion events. Deliberate mixing or natural deposition of soil may alter the rock armor designs.

A recent draft NRC NUREG reported on simulations of fluvial erosion and soil hydrology for several scenarios—combinations of climate, surface layer, topography, and vegetation—using coupled landform evolution and soil hydrology models. The topography of the Grand Junction disposal site was used as a realistic starting point. The simulations included rock and soil mixtures in arid, semiarid, and humid climates, both with and without vegetation, and with different slope angles and lengths. The current study will include a review of the NUREG modeling study, an evaluation of mineral and organic soil deposition and plant habitat in rock armor on in-service covers, and characterization of natural analogs for clues as to the long-term stability, ecology, and hydraulic performance of slopes armored with rock and soil mixtures. The research was funded by NRC via an Interagency Agreement with the U.S. Geological Survey and DOE Consortium for Risk Evaluation with Stakeholder Participation.

4.5.6 Remote Sensing Monitoring and Inspections

This purpose of this project will be to investigate remote sensing tools to both improve disposal cell cover inspections and reduce LTS&M costs. The goal is to assess the feasibility of remote sensing methods for (1) landscape-scale, low-cost monitoring of cover performance surrogates; (2) detection of site features not visible on the ground; and (3) less frequent, but more effective, onsite inspections.

Previously, LM investigated improvements in multispectral and hyperspectral remote sensing methods to detect changes in landscape features and patterns in vegetation, soils, and other surface anomalies. LM developed a protocol for landscape-scale monitoring of plant transpiration from measurements on individual plant canopies, and also used hyperspectral remote sensing to detect spatial and temporal patterns in species distribution. This project will include investigation of remote phytomonitoring methods that could be used to determine spatial and temporal patterns in vegetation that are indicative of, or can be surrogates for, direct measures of cover performance, including soil physical and hydraulic properties that control radon and percolation flux.

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5.0 LM Program Updates

Overview. In an effort to better communicate to nontechnical audiences the value of LTS–O&M projects in helping LM realize long-term strategic objectives, in FY 2013, LTS–O&M staff continued to contribute articles for publication in LM's *Program Update*, a quarterly newsletter prepared by LM and made available on the LM public website.

FY 2013 Activities. Three articles were submitted for publication, satisfying LM rating plan milestones.

"Weaving Community and Science: Former Summer Intern Is Investigating Plant Uptake of Contaminants on Disposal Cell Covers." The article included in the July–September 2013 *Program Update* featured the work of Carrie Nuva Joseph, a University of Arizona graduate student, former LM summer intern, and Native American community stakeholder. Ms. Joseph's research is helping LM understand the role of plants growing on engineered disposal cell covers, both beneficial and potentially detrimental (see Section 4.2).

Ms. Joseph views the sustainability of LM remedies through the lenses of science, community, and Hopi tradition. Her village of Moenkopi was founded in the late 1800s by residents of nearby Old Oraibi as a summer farming community irrigated from local springs. Old Oraibi dates back almost 1,000 years—possibly the oldest continuously inhabited community in the United States. In her words, "understanding the remediation efforts is increasingly important because our community is permanently fixed within a reservation boundary. Furthermore, as Native Americans, we have the stewardship responsibility to ensure our lifestyle continues for generations." Ms. Joseph hopes to contribute to this effort by combining her "educational background and traditional upbringing" and "modern science and traditional ecological knowledge to define effective and sustainable management practices for the future." Ms. Joseph views scientific knowledge and traditional knowledge as "equally important" as we evaluate the sustainability of LM remedies.

"Why Won't My Groundwater Plume Come Clean?" The October–December 2012 *Program Update* article discussed the difficulty in remediating groundwater plumes. Many LM sites still have strong groundwater plumes despite several decades of time passing since completion of surface cleanup. Groundwater flow-and-transport models completed in the early 1990s often predicted much faster cleanup than what has been observed. The article shows results of a "stop flow" column test that indicated the presence of rate-limited desorption of uranium, a process that was not considered in the early models. Most models lump all geochemical processes into a single factor (the distribution coefficient, or K_d) that is used to distribute contaminants between the aqueous and solid aquifer mineral phases. This simplification is also likely a factor in the limited, long-term success of the models.

"Have You Digested That?" The January–March 2013 *Program Update* article focused on the methods used to digest and analyze solid sediment samples. There can be a tendency to submit solid samples to a laboratory without regard for the sample digestion methods. The analytical result for a constituent can vary depending on the methods. In fact, the concentrations determined by using a variety of digestion methods can offer important information about the minerals the constituent is associated with. Data from core samples collected at the LTS–O&M test area at the Grand Junction site were used to demonstrate.

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6.0 Strategic Planning

LTS–O&M supported two strategic planning initiatives in FY 2013: Technology Deployment and Land Stewardship.

6.1 Technology Deployment

Overview. The LTS–O&M subtask supports the Technology Deployment Strategic Planning (TDSP) initiative. The scope of the TDSP initiative is to facilitate the investigation, evaluation, and deployment of promising environmental technologies for LM, focusing 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 TDSP page on the LM Intranet. The site contains a *Handbook of Technology Deployment for DOE Legacy Management Program* that is accessible to LM personnel at https://lmportal.lm.doe.gov/Contractor/Departments/Technology_Deployment.aspx.

The Handbook of Technology Deployment 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 in the Handbook. The TDSP Intranet site also contains a link to electronic copies of published papers that have been used in the LTS–O&M studies. EndNote, a widely used bibliographic software program, is used to organize and search the database of in-house holdings.

FY 2013 Activities. The TDSP Intranet site was continually updated and revised, and the Handbook of Technology Deployment was edited and extensively revised. The EndNote database now contains 3,251 citations, most of which provide direct access to PDF files of the published papers.

A draft cost-savings report on LTS–O&M projects was submitted to LM.

6.2 Land Stewardship

Overview. Land stewardship 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 goal of this initiative is to develop 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 also includes an evaluation of the ecology and sustainability of disposal cell covers. LTSPs often require suppression of vegetation on covers because plant roots can increase permeability of compacted soil layers and may take up and disperse contaminants. Alternatively, through ET, plants can be used to control the hydrology of disposal sites and improve the sustainability of remedies.

FY 2013 Activities. Accomplishments in FY 2013 are outlined below:

- The Environmental Management System (EMS) Land Stewardship (LS) team met monthly to address strategic planning and EMS LS group issues. Team members are ecologists and site managers from the Grand Junction office; Rocky Flats, Colorado, Site; Fernald, Ohio, Site; and Weldon Spring, Missouri, Site.
- An LTS–O&M scientist served as co-lead for the EMS LS team, participated in EMS core and technical meetings and provided input for EMS quarterly and annual reports. The EMS LS team will have new leadership in FY 2014.
- EMS LS team members continued to record efforts to improve ecosystem management at LM sites using the EMS Ecosystem Improvement Tracking Log (\\CROW\Projects\Ecosystem Improvements\Ecosystem Improvement Tracking Log). The format of the log was revised to include metrics for tracking successes and failures of ecosystem improvement activities.
- The EMS LS team revised a proposal to manage grazing as a means for improving vegetation condition and transpiration rates on the Monticello disposal cell. LM plans to forward the revised proposal to EPA Region 8 for consideration.
- The EMS LS team drafted an annotated outline for an Ecosystem Management Programmatic Plan.

7.0 Educational Outreach and Technology Transfer

Overview. This section describes FY 2013 activities related to three LTS–O&M 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 LTS–O&M projects to create and promote opportunities, discourse, and achievements in environmental education.

7.1 Educational Outreach

LTS–O&M staff performed the following educational outreach activities:

- Continued as adjunct faculty on the graduate committee for Carrie Joseph, a master of science candidate in environmental science at the University of Arizona. Ms. Joseph's research, jointly funded by LM, the Alfred P. Sloan Foundation, the Hopi Tribe Grants and Scholarships Office, and the Hopi Education Endowment Fund, is evaluating the uptake of tailings contaminants by plants rooted in disposal cell covers.
- Conferred with Ms. Joseph's University of Arizona PhD advisor, Dr. Karletta Chief, regarding the adaptability of disposal cells covers in the southwestern United States to climate change.
- Continued the following educational outreach activities with Diné College:
  - Directed DEI student field sampling for plant growth, plant uptake of groundwater contaminants, and plant water isotope analysis in the Shiprock pilot study plots (October 2012 and July 2013).
  - Gave an invited presentation at the DEI Science Speaker Seminar Series: "Environmental Science and Uranium Mill Tailings: Sustainable Disposal Cell Covers" (April 2013, Tsaile, Arizona).
  - Taught "Environmental Sampling and Statistical Analysis: Shiprock Pilot Study" for the DEI Summer Intern Program (July 2013).
  - Taught "Shiprock Phytoremediation: Objectives, Hypotheses, Experimental Design, Sampling Methods, and Data Analysis" for an environmental science class laboratory (September 2013).
  - Advised New Mexico State University student, Lindsey Deswood, on phytoremediation topics for her undergraduate research project. Lindsey is a graduate of Diné College.
- Accepted an invitation to speak at the Colorado Mesa University (in Grand Junction, Colorado) seminar series, "Natural Resources of the West," on October 21, 2013.

7.2 Miscellaneous Technology Transfer and Consultation

LTS–O&M staff carried out the following professional development, technology transfer, and consultation activities:

- Reviewed several geochemically oriented manuscripts submitted to scientific journals at editors' requests.
- Proposed an approach for revegetation of eroded areas at the Tuba City site that incorporates 1990s research results and includes partnering with Diné College to grow transplants in the Tuba City greenhouse.
- Drafted input on educational outreach and reviewed the climate change adaptation submission for the Site Sustainability Plan.
- Gave a presentation and led a discussion of vegetation management on disposal cells for the Task Order 501 staff meeting.
- Wrote a brief history of the Ecosystem Management Team and EMS LS groups for LM.
- Provided LM with options for evaluating the performance of the Bluewater site disposal cell cover, including using the disposal cell as an LTS–O&M test site for ecological and pedogenic effects on radon attenuation, cover permeability, and cover enhancement.
- Participated in an S.M. Stoller Corporation management assessment, "Coordination and Review of Public Presentations and Public Outreach Activities."
- Contributed to discussions and recommendations for vegetation management on the Durango, Colorado, Disposal/Processing Sites and Uravan, Colorado, disposal cells.
- Attended selected sessions of the UMTRA Regulations and Implementation Workshop.
- Attained recertification as certified senior ecologist through the Board of Professional Certification of the Ecological Society of America.
- Prepared a summary table of ongoing and proposed LTS–O&M Surface Projects for LM.
- Received LM approval to provide the designers of a White Mesa Mill disposal cell with information on Monticello site cover revegetation acceptance criteria and monitoring.
- Assembled photographs with captions of ecological field activities for a presentation to LM business employees.
- Received an invitation to participate in a panel discussion on Uranium Recovery and Reclamation at the 2013 American Nuclear Society Winter Meeting, November 10–14, in Washington, DC.
- Prepared slides on the status of existing and new LTS–O&M projects to be presented to LM management.

8.0 System Operation and Analysis at Remote Sites

Overview. The SOARS system was established in 2006 with LTS–O&M 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 postprocessing site for real-time use by project personnel. It has saved money by reducing the number of 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 employees. 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 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, water infiltration rate, and energy use. Electrical relays are used for remote control of 23 well pumps. A comprehensive operation and maintenance manual titled *Operation and Maintenance of the System Operation and Analysis at Remote Sites (SOARS) Network* is available as a Level 3 controlled document on the LM Intranet.

FY 2013 Activities. Numerous improvements were made to the SOARS system during FY 2013. The Vista Data Vision software that operates the SOARS website and serves as the database was updated to the current version (VDV2013). This upgrade allowed for additional graphing capabilities, an easier-to-use data alarm system, and a more user-friendly webpage layout. Two external hard drives were procured and are used for scheduled backups. The drives are housed in two different buildings for added security. Potential security issues with SOARS are being addressed through an ongoing collaborative effort with Cyber Security.

In support of the Variation Project, a variety of conductivity sensors were tested for use with SOARS. Sensor accuracy was evaluated in the calibration laboratory using 5-gallon buckets of conductivity standards. SOARS personnel continued monitoring sites as part of an EMS project to monitor power consumption at LM sites. Power consumption data are now available through SOARS for the Tuba City, Weldon Spring, and Fernald sites.

The SOARS inventory and calibration database was expanded and improved during FY 2013. This database is continually being updated with new instrument calibrations. A Google Earth file of SOARS stations was updated. The SOARS field systems are powered by 88 solar panels. Data are downloaded daily through 17 Internet protocol (IP) cell modems, 6 land-line IP connections, 1 satellite link, and 6 land lines. Onsite communication with the modems is accomplished using 105 radios. Approximately 300,000 data points are transmitted and graphed daily. Table 3 shows the changes in SOARS inventory through time.

Table 3. Comparison of SOARS Inventory Through Time

Fiscal Year	Number of States	Number of LM Sites	Number of Instruments	Number of Data Stations
2007	7	14	335	66
2008	9	16	435	86
2009	9	16	496	100
2010	8	15	540	100
2011	8	15	551	107
2012	8	20	584	116
2013	8	20	578	112

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 postprocessor graphs and data storage and retrieval programs. New graphs were added to better accommodate project reporting or analysis needs. Alarm settings that provided notifications of site-related issues (such as pump failure) or problems with the instrumentation were regularly updated.

Although the project sites are directly responsible for routine operation, maintenance, and calibration of the field instruments, LTS–O&M personnel support these efforts. Calibration checks were conducted on field instruments at many sites. Most of the instruments maintained calibration and functioned successfully. Instruments were regularly lab-tested and calibrated prior to installation at field sites. Outdated equipment was replaced during maintenance trips. Project documentation was maintained, including SOARS notes, Job Safety Analyses, Plan of the Day meetings, procurement logs, instrument inventories, metrics, and calibration logs.

9.0 Environmental Sciences Laboratory

Overview. Funding from the LTS–O&M 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 projects. Funding requirements include:

- Maintaining service contracts for equipment.
- Maintaining and repairing equipment.
- Developing new laboratory procedures.
- Procuring new equipment and consumable items.
- Updating laboratory manuals, including the *Environmental Sciences Laboratory Procedures Manual* and the *Environmental Sciences Laboratory 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.
- Inspecting and testing of emergency showers, eyewash stations, the automated external defibrillator, and first aid kits on a regular basis.
- 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 LM program. Due to the large emphasis on groundwater projects 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 2013 Activities. All laboratory maintenance and calibration tasks were completed, and the laboratory operated trouble-free. Samples were submitted to the ESL from the Old Rifle, Colorado, Processing Site; and Shiprock, Rocky Flats, and Tuba City sites for analysis on a regular basis. The laboratory procedures manual was updated. A laboratory security plan was established to improve building security.

Improvements to the laboratory include (1) hydride-generation capability for the inductively coupled plasma optical emission spectrometry (ICP-OES), enabling analysis of arsenic and selenium; (2) an automatic sample changer for the ICP-OES; (3) syringe pumps for better control on column tests; and (4) a new procedure for tritium analysis by liquid scintillation counting.

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10.0 Publications

Overview. LTS–O&M staff often publish project results. Through publication, others can utilize the findings, and LM 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 2013 Activities. A list of FY 2013 publications and presentations follows.

10.1 Published, Accepted, and Draft Journal Articles and Proceedings Papers

Bresloff, C.J., U. Nguyen, E.P. Glenn, W.J. Waugh, and P.L. Nagler, 2013. "Effects of grazing on leaf area index, fractional cover and evapotranspiration by a desert phreatophyte community at a former uranium mill site on the Colorado Plateau," *Journal of Environmental Management*, 114:92–104.

Bareither, C.A., and C.H. Benson, 2013. "Evaluation of Bouwer-Rice Large-Particle Correction Procedure for Soil Water Characteristic Curves," *Geotechnical Testing Journal 36*, published online July 18, 2013. This publication was an outcome of analytical methods developed for ECAP (see Section 4.1).

Kamp, S.D., and S.J. Morrison (accepted pending revision). "Use of Chemical and Isotopic Signatures to Distinguish Between Uranium Mill-Related and Naturally Occurring Groundwater Constituents," *Groundwater Monitoring and Remediation*.

Waugh, W.J., and E.P. Glenn (draft). "Land-Farm Phytoremediation of Groundwater Nitrate at a Former Uranium Mill Site Near Monument Valley, Arizona," to be submitted to *International Journal of Phytoremediation.*

Waugh, W.J., A.V. Gil, R.P. Bush (accepted but not presented). "Strategies for Improving Long-Term Surveillance and Maintenance of Disposal Cell Covers," *Proceedings of Waste Management 2013 Symposium*, Phoenix, Arizona.

10.2 Published and Draft DOE Reports

DOE (U.S. Department of Energy), 2012. *Applied Science and Technology Task Order Fiscal Year 2012 Year-End Summary Report*, LMS/ESL/S09384, ESL-RPT-2012-04, prepared by S.M. Stoller Corporation for the Office of Legacy Management, Grand Junction, Colorado.

DOE (U.S. Department of Energy), 2012. *Multivariate Statistical Analysis of Water Chemistry in Evaluating the Origin of Contamination in Many Devils Wash, Shiprock, New Mexico*, LMS/SHP/S09257, ESL-RPT-2012-03, prepared by S.M. Stoller Corporation for the Office of Legacy Management, Grand Junction, Colorado.

DOE (U.S. Department of Energy), 2012. *Characterization and Isolation of Constituents in Desert Arroyo Seepage Water*, LMS/S09339, ESL-RPT-2012-02, prepared by S.M. Stoller Corporation for the Office of Legacy Management, Grand Junction, Colorado.

DOE (U.S. Department of Energy), 2012. *Application of Environmental Isotopes to the Evaluation of the Origin of Contamination in a Desert Arroyo: Many Devils Wash, Shiprock, New Mexico*, LMS/SHP/S09197, ESL-RPT-2012-01, prepared by S.M. Stoller Corporation for the Office of Legacy Management, Grand Junction, Colorado.

DOE (U.S. Department of Energy), 2013. *Cover Performance Enhancement Tests at the Grand Junction, Colorado, Disposal Site: Construction Documentation, Material Testing, and Instrument Calibration*, LMS/GRJ/S07112, prepared by S.M. Stoller Corporation for the Office of Legacy Management, Grand Junction, Colorado.

DOE (U.S. Department of Energy), n.d. (draft). *Monitored Natural and Enhanced Attenuation of the Alluvial Aquifer and Subpile Soils at the Monument Valley, Arizona, Processing Site: Final Pilot Study Report*, LMS/MON/S07670. prepared by S.M. Stoller Corporation for the Office of Legacy Management, Grand Junction, Colorado.

DOE (U.S. Department of Energy), n.d. (draft). *Enhanced Cover Assessment Project: Soil Manipulation and Revegetation Tests*, prepared by S.M. Stoller Corporation for the Office of Legacy Management, Grand Junction, Colorado.

DOE (U.S. Department of Energy), n.d. (draft white paper). *Bluewater, New Mexico, Disposal Cell Cover: Design, Observations, and Performance Evaluation Options*, prepared by S.M. Stoller Corporation for the Office of Legacy Management, Grand Junction, Colorado.

DOE (U.S. Department of Energy), n.d. (draft). *Sorption of chromium, molybdenum, uranium and vanadium during the aging of amorphous ferric oxyhydroxide*, prepared by S.M. Stoller Corporation for the Office of Legacy Management, Grand Junction, Colorado.

DOE (U.S. Department of Energy), n.d. (draft). *Long-Term Surveillance and Maintenance, Operations and Maintenance Subtask: Cost Savings Estimates*, prepared by S.M. Stoller Corporation for the Office of Legacy Management, Grand Junction, Colorado.

10.3 Seminars

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10.4 Newsletter Articles

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