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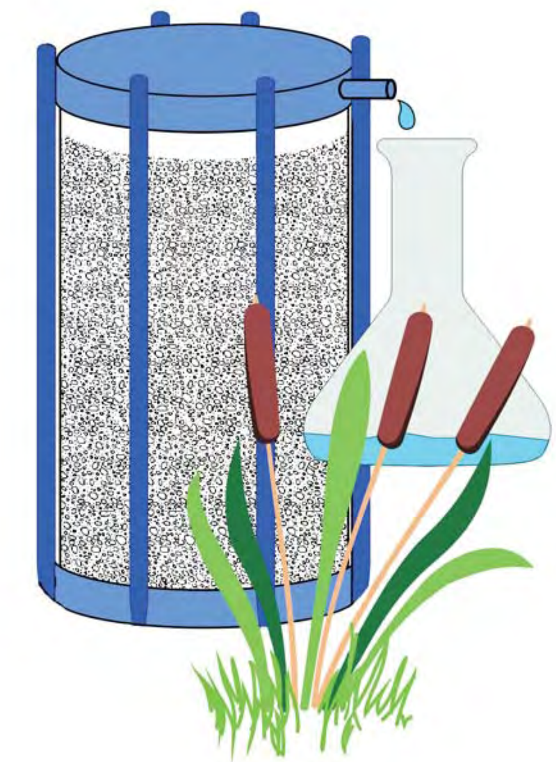
Applied Science and Technology Task Order Fiscal Year 2008 Year-End Summary Report

February 2009



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Abbreviations

ACAP	Alternative Cover Assessment Program
AEP	air-entry permeameter
AS&T	Applied Science and Technology
cm	centimeter
cm/s	centimeter per second
CSL	compacted soil layer
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
ET	evapotranspiration
ft	feet
FY	fiscal year
gpm	gallons per minute
ha	hectares
kg	kilograms
LDPE	low-density polyethylene
LM	Office of Legacy Management
LTSM	long-term surveillance and maintenance
LTSP	Long-Term Surveillance Plan
mg/L	milligrams per liter
mm	millimeters
NSF	National Science Foundation
ORP	oxidation-reduction potential
PRB	permeable reactive barrier
RECAP	Renovated ET Cover Assessment Project
SOARS	System Operation and Analysis at Remote Sites
SRNL	Savannah River National Laboratory
USC	University of South Carolina
VDV	Vista Data Vision
WCR	water content reflectometer
WFM	water flux meter

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1.0 Introduction

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

2.0 Objectives

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

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

3.0 Projects and Accomplishments

Projects and accomplishments of the AS&T task order for October 2007 through September 2008 are summarized below. DOE approved fiscal year (FY) 2008 projects in October 2007 as developed from the original task order language. Some tasks were added to the scope with direction or approval from LM. Brief overviews of project objectives and scope are followed by summaries of activities and accomplishments for FY 2008.

3.1 SOARS (System Operation and Analysis at Remote Sites)

<u>Overview</u>. This project established the feasibility of collecting data remotely and transmitting it to LM servers where it can be accessed by all LM personnel through a website. Many LM sites are in remote locations, and collecting data by regular field visits can be costly. Well pumps are being controlled remotely through the SOARS system to further lessen travel needs. Another advantage of SOARS is that data are available immediately, and corrective actions can be expedited. SOARS greatly improves our ability to diagnose problems and make timely repairs.

SOARS data are automatically processed using Vista Data Vision (VDV) software to produce real-time graphs available to all project scientists and managers across the LM network.

FY 2008 Activities. The SOARS system grew significantly during FY 2008 with the addition of 100 field instruments, 20 datalogger stations, and 2 new project sites at Mound and Salmon (see Table 1). New stations were installed at Central Nevada, Old Rifle, the Rifle disposal cell, and New Rifle.[1] The SOARS system is powered using 62 solar panels and 26 connections to line power. Data are downloaded daily through 12 cell modems, 6 landlines, and 1 satellite link. On-site communication with the modems is accomplished using 82 radios. Instruments include sensors for the following: flow rate, water level, in-line pressure, pH, oxidation-reduction potential (ORP), conductivity, unsaturated-zone moisture, wind speed and direction, relative humidity, solar radiation, rainfall, and water infiltration rate. SOARS also uses 23 electrical relays for remote operation of well pumps.

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

	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

A powerful post-processing program (VDV) is being used to automatically plot data and make calculations. A large effort was made this year to reconfigure the VDV software so that it resides on a secure server. The main benefit of the reconfiguration is to allow Stoller personnel better access to maintain the system. The reconfiguration involved a major effort to transfer files, reinstall software, reestablish alarms, reissue user passwords, and perform debugging operations. During the reconfiguration, an updated version of VDV was installed. The updated version provides added calculation and graphics capabilities. Web access to the SOARS system was functional in excess of 95 percent of the time during this fiscal year.

Only occasional minor maintenance issues were required to keep the SOARS system operational. Issues included cell modem malfunctions at Lakeview and Mound, rain gauge wire chewed by rodents at Monument Valley, incorrect flow meter cables installed at Mound, and flow meter malfunctions at Shiprock. Calibration checks were conducted on field instruments on an ad hoc basis. Most of the instruments maintained calibration and functioned successfully. Dataloggers and radio links functioned well. The communication systems using cell modems, landlines, and one satellite link operated successfully. The Mound system was down for several months due to a malfunctioning cell modem. It was brought back online with minimal loss of data. A subcontractor at the Mound site was trained to service the system to prevent future downtime.

Pumping cycles, particularly for the Shiprock site, were adjusted regularly through SOARS to optimize groundwater extraction systems. A training course on the SOARS system was presented. Many improvements were made to the looks of the website, particularly the implementation of numerous information pages containing instrument specifications, calculation methods, maps, and figures. New alarms were set to alert users to unusual or critical data events. Alarms are also broadcast if data from any site fail to be collected. A challenging task this year

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

was achieving cell communication with the Central Nevada site. This was accomplished by adding a cellular host modem to the network which was modulated properly to communicate with the slower analog modem at Central Nevada.

3.2 Monticello Treatment System

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

Activities. During FY 2008, the system treated about 2.5 million gallons at typical flow rates of 3 to 10 gpm. Influent and effluent samples were collected and analyzed approximately monthly. Measured uranium concentrations of these samples indicate that the system continues to meet project treatment goals. The hydraulics of the treatment system were continuously monitored by the SOARS system. Because the infiltration gallery was not capable of accepting all the treated water, discharge was diverted to Montezuma Creek on June 28, 2008. The discharge permit requires regular monitoring of pH and iron concentration. Sampling locations were established to meet this requirement, and the locations were sampled three times.

Maintenance for the treatment system is normally minimal; however, blockage of effluent pipes from the gradual buildup of iron oxide required attention this year. Maintenance included installation of vent pipes and surging of effluent lines to improve flow of treated water from the system. Visual inspection of the effluent piping indicated that accumulation of iron-oxide scale on the pipe walls substantially affected the flow. The decreased pipe diameter caused air blockage, and the pipes required routine "burping" to reestablish flow. This problem has a simple fix: the effluent piping needs to be replaced with larger-diameter pipes. Plans were made to replace the pipes early next fiscal year. Other minor maintenance included replacement of the pump control box. No other maintenance was required for the well pump, which operated continuously all year. No maintenance was required for the SOARS system components.

Because of the success of the Monticello treatment cells, Stoller personnel were subcontracted to oversee the design and construction of a nearly identical system installed at a private mine site in Idaho. Larger effluent piping was used for this system, and it has performed flawlessly since its installation in June 2008.

3.3 Guar-Constructed Collection Drains

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

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

Activities. In FY 2008, monitoring of Trench 2 continued, and pumping rates were about 15 to 20 gpm. A comprehensive report documenting the results of the Trench 2 study was prepared and is in the review cycle. The report includes a groundwater flow model that provides a reasonable simulation of the flow and chemical results.

A one-time sampling of all available wells on the floodplain was conducted to help plan the monitoring of Trench 1 and to identify strategic locations for additional drains. The sampling included 76 wells, providing a detailed assessment of the distribution of uranium, nitrate, sulfate, and other analytes. These data are being assessed, and a proposal for Trench 1 monitoring was prepared. Trench 1 is in an area that has higher levels of uranium contamination than Trench 2 and is farther from the San Juan River. Depending on monitoring results from the two drains, additional drains may be proposed to enhance cleanup of the floodplain aquifer.

3.4 New Rifle Vanadium Investigation

Overview. Vanadium is dissolved in groundwater at the New Rifle site in concentrations up to several tens of milligrams per liter. The areal distribution is spotty, with the highest contamination in areas of former tailings and evaporation ponds. The vertical distribution is also heterogeneous with some of the highest concentrations observed within 10 ft of the ground surface, but high concentrations were also found to depths exceeding 25 ft. An effort was made in 2001 to remove some of the vanadium from the subsurface by extracting the groundwater, treating it with zero-valent iron, and injecting the treated water back into the aquifer. About 3 million gallons of groundwater was removed and treated, but vanadium remains at about the same concentrations as were present prior to the pump-and-treat operation. The New Rifle property is now owned by the City of Rifle, and the City is constructing various facilities that require excavation into the subsurface groundwater system. This study is designed to better understand vanadium chemistry and to monitor the transport and fate of vanadium during subsurface disturbances.

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

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

Activities. A meeting was held on November 21, 2007, to decide on an approach to investigating the vanadium issue using AS&T funding. Four new Geoprobe wells (0683, 0684, 0687, and 0688) were completed in the East Area. A surveyor was contracted to delineate the locations and elevations of the new wells. A meteorological station (wind speed and direction, relative humidity, rainfall, solar radiation, and air temperature) was installed and connected to SOARS. Instrumentation to continuously monitor ORP, conductivity, water level, and temperature was installed at each of the four new wells and at wells 0215 and 0857 in the East Area. Well 0687 soon went dry, and the instruments were moved to well 0863. The same instrumentation was installed at three wells (0201, 0590, and 0680) in the West Area. Data from all instruments are recorded at 5-minute intervals and are available in SOARS. Three 3-point computations were entered into SOARS to track water-table orientations in real time.

A GPS unit was used to locate the 37 wells used by the City of Rifle to dewater the East Area during construction of a water treatment plant. The dewatering wells were operated nearly continuously (although not all wells were active at the same time) starting in February 2008. The GPS coordinates were entered into the LM GIS system, and maps were prepared.

Groundwater samples were collected in five events. Up to 30 wells were sampled for each event, including the instrumented wells, dewatering wells, and other strategic wells. An autosampler was installed at well 0857 (near the center of the vanadium plume) and programmed to collect samples at 4-day intervals. Discharge to the river from the dewatering operation was also sampled. The samples were analyzed for uranium and vanadium to better define changes in the plumes during dewatering by the City of Rifle.

3.5 Disposal Cell Cover Performance

Overview. At many LM sites, engineered disposal cells were constructed to contain subsurface contaminants for 100s of years. The AS&T Project combines three tools—monitoring, modeling, and natural analog studies—to evaluate both the near-term and long-term performance of disposal cells. Performance monitoring is usually conducted during follow-up investigations when LM site inspectors observe potentially detrimental conditions on covers, such as biointrusion or rock degradation. Performance modeling and natural analog studies are conducted to project performance of disposal cells for possible future environmental scenarios (e.g. climate change, ecological succession, soil formation). These activities often involve external collaboration and cost-sharing.

In 2008, cover performance evaluations focused on monitoring a large embedded lysimeter at the Monticello site. At semiarid sites such as Monticello, relatively low precipitation, high potential evapotranspiration (ET), and thick unsaturated soils favor long-term hydrologic isolation of buried waste. However, simple precipitation/potential ET relationships inadequately predict recharge in semiarid regions. Recharge can be minimized using covers designed with thick, fine-textured soil layers that store precipitation, and ET to seasonally remove water. Capillary barriers consisting of coarse-textured sand and gravel placed below this soil "sponge" can enhance water storage and limit unsaturated flow.

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

Lysimeters consist of instrumentation designed to monitor the water balance (precipitation, water storage, runoff, ET, and percolation) of natural and engineered soil profiles, including disposal cell covers. The Monticello facility has four types of lysimeters: small monolith lysimeters, a large array of small weighing lysimeters, large caisson drainage lysimeters, and a 7.5-acre drainage lysimeter imbedded in the Monticello disposal cell cover. Over the years, the facility has been used to evaluate various ET cover designs for DOE and the U.S. Environmental Protection Agency (EPA). Lysimeter studies of ET covers often require several years of monitoring to allow vegetation to mature and to encompass (or impose) a range of climatic and ecological conditions.

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

Activities. Activities in FY 2008 included (1) monitoring soil water balance parameters in the 7.5-acre embedded lysimeter at Monticello, (2) characterizing the ecology of test covers constructed in large lysimeters for the Alternative Cover Assessment Program (ACAP), and (3) teaching a short course on alternative covers.

3.5.1 Lysimeter Water Balance Monitoring

Precipitation, water storage, percolation, and ET are monitored in real time in the 7.5-acre embedded lysimeter. Since 2000, only approximately 4.8 millimeters (mm) of water have percolated from the capillary barrier in the cover. Percolation occurred primarily during the fall, winter, and spring of 2004 when ET was negligible and soil water storage exceeded 500 mm, more than twice the highest storage measured during the previous 5 years. During 2006, water storage dropped back to 2004 levels in response to high ET rates. Peak water storage in March 2006 was less than half of the storage capacity for the cover (~ 450 mm). Again in 2007, water storage remained considerably below the storage capacity, and zero percolation occurred. However, in spring 2008, water storage reached 325 mm, the second-highest value recorded. The

8-year average percolation flux is approximately 0.6 mm per year, 100 to 1,000 times less than has been monitored in the conventional cover at Lakeview, a site with similar soils, climate, and vegetation (see below). The EPA target threshold for the Monticello cover is less than 3.0 mm per year.

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

3.5.2 ACAP Ecology

In 1998, EPA recognized the scarcity of data on the hydrologic performance of final covers used for solid and hazardous waste landfills, and initiated the ACAP as a 5-year monitoring study to fill the information gap. The cornerstone of ACAP is a network of 28 test sections, or large lysimeters, simulating landfill final covers at 12 sites distributed throughout the United States. Each instrumented lysimeter monitored the water balance and meteorological conditions. Percolation data from the lysimeters show that some of the covers functioned as anticipated. However, others transmitted more percolation than expected after a few years of low percolation, probably as a consequence of preferential flow. Ancillary data suggest that changes in the cover materials (soils, geosynthetics), the vegetation, or both may be responsible for the unexpected behavior.

In 2008, Stoller teamed with Desert Research Institute and the University of Washington to develop more rigorous explanations for these observations including an understanding of how the cover materials and vegetation have changed. To this end, exhumations of the test lysimeters began at several sites. Soil structure, soil hydraulic properties, geosynthetic properties, and plant ecology were studied in detail and compared to the time of construction.

In July 2008, Stoller ecologists characterized the plant ecology on lysimeter test sections and in adjacent analog plant communities. The objectives of this field work follows:

- Evaluate revegetation success on the test lysimeters and compare them to existing plant communities with revegetation criteria.
- Compare vegetation on the different cover test sections, primarily conventional vs. alternative cover designs.
- Compare lysimeter vegetation with a reference or analog plant community—ideally, relatively undisturbed vegetation at the soil borrow site.
- Infer plant community responses to soil properties: physical properties (bulk density), hydraulic properties (K_{sat} and SWCC), soil morphology (primarily soil structure and horizonation), root depth and abundance, and edaphic properties (nutrients, organic matter, pH, etc.).

The results of this field ecology work will be included in a final report to the National Science Foundation (NSF). Stoller's involvement in this project is a spin off of similar work conducted by LM at the Monticello site. Funding for this project was provided through a grant from the NSF.

3.5.3 Alternative Cover Short Course

An LM scientist teamed with Desert Research Institute and the University of Washington to teach a 2½-day course, "Alternative Covers for Landfills, Waste Repositories, and Mine Wastes: Design, Modeling, Construction, and Monitoring," on April 15 and 16, 2008, in Portland. This short course was scheduled in association with the annual meetings of the Solid Waste Association of North America. Over 200 people from federal and state regulatory agencies as well as the private sector attended.

3.6 Soil Formation, Ecology, and the Hydrologic Performance of the Monticello Cover

Overview. The LM Monticello site is the only ACAP study site with a large lysimeter embedded in a final cover (see Section 3.5, "Disposal Cell Cover Performance"). Surface runoff and percolation are continuously monitored along with the distributions of soil temperature, water content, and matric suction. Ambient meteorological conditions are monitored with an on-site weather station, and an extensive sampling and testing program has been conducted to characterize the as-built properties of the cover soil. Some of the covers evaluated by ACAP functioned as anticipated—and in some cases much better than anticipated—transmitting zero percolation. In contrast, other covers functioned more poorly than anticipated. Those that functioned poorly included industry-standard or conventional covers with compacted soil layers as well as some of the ET covers. The Monticello ET cover, however, performed very well.

Understanding why some covers performed as anticipated, whereas others performed poorly, is critical to the future design of effective final covers. This study focused on collecting the information needed to develop this understanding by carefully evaluating the physical structure and hydraulic properties of the cover materials and the vegetation for comparison with conditions that were documented at the time of construction. Evaluations help identify key factors that control cover performance and will provide insight into how cover performance changes over time in response to environmental stresses (soil development; wet-dry, freeze-thaw, and thermal cycling; biological intrusion; and climate change). The lessons learned will be used for improved assessment of the long-term performance of the Monticello cover, and can be used to develop guidance for more-effective cover design and construction.

Activity. The final report for this study was published in April 2008. A summary follows.

Hydrological and geomorphological properties of the earthen component of the final cover at the Monticello uranium mill tailings disposal cell were examined in two areas (the East Area and the West Area) in July 2007. Soils in two caisson lysimeters (North and South Caissons) simulating the final cover were also evaluated. Field tests for saturated hydraulic conductivity were performed, large-scale undisturbed samples were collected and tested for hydraulic properties, and geomorphological and ecological surveys were conducted.

Significant soil structure exists in the final cover and the caisson lysimeters. Fractures are very prevalent at the surface, and the density decreases with depth. Structure has developed deeper in the West Area of the cover and the South Caisson. Roots were observed in the biota barrier layer in both test areas and both caissons, and below the biota barrier in all locations except one caisson. Shrubs are more abundant in the more structured soils in the western side of the cover. As soil structure in the eastern side develops deeper and more completely, a more favorable habitat for shrubs should also develop.

Field and laboratory testing showed that the hydraulic properties of the cover soils (saturated hydraulic conductivity, soil water characteristic curve) are relatively independent of depth and location, and exhibit characteristics consistent with the development of soil structure. The saturated hydraulic conductivity exhibits a modest amount of scale dependency due to the presence of structure, and very high saturated hydraulic conductivities (> 1 cm per second [cm/s]) occur periodically at the upper surface of the storage layer due to flow in fractures. The saturated volumetric water content of the soil has also increased, and the air entry suction has decreased.

The hydrologic properties present at Monticello are similar to those observed at other sites in ACAP where significant soil structure has developed. At these other sites, sampling and testing conducted over time has shown that most of the changes in hydraulic properties occur within a few years after construction. Thus, the hydraulic properties described in this report should represent longer-term characteristics of the final cover, unless other pedogenic processes that alter characteristics of the soil structure (e.g., infilling of cracks, precipitation of salts) occur.

Water balance data collected from the ACAP test section at the UMTR have shown that the cover has continued to perform as intended even under severe meteorological conditions. Thus, the changes in hydraulic properties that have occurred since construction have not affected the cover adversely. However, if other pedogenic processes that have a different effect on soil structure occur, performance of the cover may change. Consequently, long-term hydrologic monitoring of the cover is recommended.

Based on the testing that was conducted, saturated hydraulic conductivities ranging between 4×10^{-5} to 4×10^{-4} cm/s can be used to describe the final cover. Typical conditions can be represented using 1.5×10^{-4} cm/s as the saturated hydraulic conductivity.

3.7 Hyperspectral Remote Sensing Study

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

Several important cover performance parameters can be remotely monitored. Multispectral and hyperspectral sensors can be used to map spatial patterns and temporal changes in vegetation growing on and surrounding disposal cells. Changes in vegetation may alter the performance of covers in different ways. For conventional covers, Long-Term Surveillance Plans (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. Variations in water content is often manifested in vegetation biophysical parameters, such as leaf area index and biomass, and can be detected in optical spectral reflectance characteristics. Vegetation spectral responses have also been successfully used for the detection of contaminant leaks at Superfund sites and on landfills. Remote sensing can therefore be used to survey the spatial and temporal variation of vegetation as a surrogate measure of other changes taking place on covers.

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

Activity. In 2008, the AS&T Program teamed with scientists from Savannah River National Laboratory (SRNL) and the University of South Carolina (USC) and collected hyperspectral data and field reconnaissance data for remote sensing case studies at the Monticello disposal site and the Monument Valley mill site. These cases studies were funded jointly by LM and the National Aeronautics and Space Administration.

In June 2008, LM, SRNL, and USC collaborators acquired ground data at pre-marked sample points at the same time fixed-wing overflights were acquiring hyperspectral data. Ground and overflight sampling occurred at the Monument Valley phytoremediation pilot study plots on May 26, and at the Monticello disposal cell and Monticello mill site on May 27. HyVista Inc. was contracted to fly these sites and acquire hyperspectral data. Surface sampling involved acquiring data for the following parameters within several small plots selected to represent different vegetation types of other surface features at each site:

- Visual photograph of the marked plots.
- GPS coordinates.
- Plant species composition.
- Percent canopy cover by species.
- Leaf prorometer measurements of transpiration.
- Measurement of leaf area index at four cardinal directions using either a ceptometer of an LAI-2000 instrument.
- Spectroradiometer measurements (400–2,400 nm).

All ground and hyperspectral data have been compiled and reduced for analysis. A status report will be prepared and distributed by December 31, 2008.

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 is capable of measuring flux rates of 0.2 mm per year or less.

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

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

Activity. Activities in FY 2008 included the following: (1) monitoring percolation in the cover at the Lakeview disposal site, (2) monitoring soil water content in tailings at Lakeview, (3) monitoring percolation at the Monument Valley site, and (4) giving presentations at tribal meetings and publishing results in LM reports.

3.8.1 WFMs at Lakeview

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

In 1997 and 1998, air-entry permeameters (AEPs) were used to measure saturated hydraulic conductivity (K_{sat}) in the Lakeview CSL. The mean K_{sat} for 17 AEP tests was 3.0×10^{-5} cm/s, 300 times greater than the design target. The highest K_{sat} values were measured near the top of the CSL at locations both with and without roots; the lowest K_{sat} values were measured deeper in the CSL. These results are consistent with findings at other sites. Multiple lines of evidence show that many existing CSLs fall short of low-permeability targets, often soon after construction, and sometimes by several orders of magnitude.

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

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

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

The cumulative percolation was exceptionally high during the 3-year monitoring period—greater than total precipitation for the period. The high percolation rates likely occurred because the WFMs were strategically placed in downgradient locations where there may be a water-harvesting effect. The bedding layer is likely shedding some water, which accumulates downgradient, causing the drainage layers and CSL to remain saturated for an extended period at WFM locations.

3.8.2 Water Content in the Tailings at Lakeview

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

Test holes augered to a depth of 6 ft at two locations in the side slope rapidly filled with water. Because they cannot be submerged, WFMs were not installed in the side slope. Instead, at both side slope locations, WCRs were installed in the cover and tailings to monitor soil moisture and percent saturation. WCRs were placed in the bedding layer just above the CSL, at 1 to 2 ft in the CSL, and at 1 to 2 ft and at 6 to 7 ft in the upper part of the tailings. Results of soil moisture monitoring show that the volumetric water content of the gravel bedding layer remains low, as would be expected, but is responsive to precipitation events. The results also show seasonal fluctuation in moisture content of the compacted soil layer and the near-surface layer of the tailings, also in response to precipitation. However, at a depth of about 2 meters (6 to 7 ft), the tailings remained saturated for the entire monitoring period from November 2005 to August 2008.

3.8.2.1 Lakeview Recommendations

The combination of high percolation flux and saturated tailings raises concerns about leaching of contaminants and groundwater protection. An evaluation of the fate and transport of tailings constituents and associated human health and ecological risks is warranted.

The saturated tailings are also an indication of a phreatic surface at about 5.5 meters. A cursory evaluation suggested that seismic activity may render the disposal cell slope unstable and out of compliance. Further investigation of slope stability may be warranted. The extent and depth of the phreatic surface should be confirmed, perhaps using well-point piezometers along the slope crest. The liquefaction potential should be reevaluated after the location of the phreatic surface is known.

3.8.3 Percolation and Soil Moisture Monitoring at Monument Valley

Four WFMs were placed at depths of 10 to 12 ft in a phytoremediation plantings at Monument Valley (see Section 3.10, "Monument Valley Enhanced Attenuation"). Percolation monitoring is necessary to confirm that irrigation water is not moving below the root zone and potentially leaching contaminants. Instrument clusters were installed in the south-central area of the 1999 planting, and in the northeast, northwest, and southeast areas of the 2006 planting. Instrument clusters consisted of one WFM placed about 370 cm deep in the soil profile with four WCRs placed above the WFM at 30 to 60, 90 to 120, 180 to 210, and 270 to 300 cm depths.

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

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

Results from WCRs placed above WFMs show that soil water content (volumetric) is somewhat variable both spatially and temporally. The highest volumetric water content values (~ 16 percent) occurred at a 6-ft depth in a mature planting, while the lowest values (~ 2 percent) occurred a 10-ft depth in a recent planting, the opposite of what would be expected if irrigation rates were uniform across the plantings. However, the greatest seasonal change in water content did occur in the more mature planting, as would be expected. By summer 2008, water content at all depths at all four locations was decreasing, indicating that soil profiles were drying in response to ET. Irrigation rates were subsequently increased so as to enhance denitrification.

3.9 Renovated ET Cover Assessment Project (RECAP)

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

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

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

Activity. Two large (20 × 30 ft) lysimeters were constructed at the Grand Junction, Colorado disposal site in the fall of 2007 using a design developed for EPA's ACAP. The construction sequence follows:

- Removed vegetation and topsoil to the side of the test site, constructed a 3-ft-high foundation for the lysimeters, put low-density polyethylene (LDPE) liners, sumps, and pipes in place to collect water that percolates through the cover, and placed a geotextile composite above the LDPE liner to collect percolation water.
- Constructed the test covers (mimicking the as-built specifications of the Grand Junction disposal cell cover) from the bottom up: (1) an 18-inch cobble and gravel drainage layer with high permeability (not part of the original cover), (2) a 2-ft CSL or radon barrier using a clay stockpile processed from glacial debris soils, and (3) a 2-ft frost protection layer using sandy clay (also processed from glacial debris flows). A 6-inch bedding layer,

consisting of sandy gravel, and a 12-inch basalt riprap layer will be constructed in October 2007.

- Placed a biobarrier material (geofabric impregnated with the herbicide trifluralin which is a mitotic inhibitor—prevents root cell division without killing the plant) to keep roots out of the geotextile composite.
- As part of the monitoring program, calibrated WCRs and heat dissipation units to monitor soil moisture content and soil water matrix potential, respectively, and placed them in the drainage layer, the CSL, the frost protection layer, and the gravel bedding layer.
- Conducted laboratory analyses of salinity (EC), pH, and sodium absorption ratio for all stockpiles and for archived soil samples from the disposal cell cover.
- Extracted four large, intact block samples of the CSL for analyses of saturated hydraulic conductivity, water retention characteristics, and dry-weight bulk density.
- Installed LDPE liners, sumps, and pipes to collect lateral flow between the CSL and the frost protection layer.
- Placed the frost protection layer, the gravel bedding layer, and rock riprap layer.
- Seeded the disturbed area surrounding the test lysimeters in March 2008.

Lysimeter water balance parameters (precipitation, percolation, water storage, runoff) are monitoring using telemetry. Monitoring will continue for at least 1 year to establish baseline conditions before the renovation treatment is imposed on one of the lysimeters. Renovation will likely consist of ripping the cover to a depth of 4 ft and planting native shrubs in the rip rows. Ripping will be done in one of the lysimeters on the contour of the cover top slope. The preparation of a RECAP lysimeter installation report began in September 2008.

3.10 Monument Valley Enhanced Attenuation

Overview. 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 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? (2) Can we efficiently enhance natural attenuation if necessary? Below are highlights of pilot study results reported in 2008, which help answer these questions. The highlights are organized as four different phases of pilot studies: source containment and removal, groundwater phytoremediation, groundwater denitrification, and land farming.

3.10.1 Source Containment and Removal

One objective of planting phreatophytes in the source area is to control the soil–water balance and limit percolation and leaching of nitrate, much like an ET disposal cell cover. Plantings are purposefully under-irrigated to prevent recharge. However, in 2008, irrigation rates were increased to enhance denitrification. Soil moisture profiles are monitored with neutron hydroprobes and time-domain reflectometry; percolation flux is monitored with WFMs.

Although monitoring data show that percolation is not occurring, irrigation rates may decrease in the future because monitoring data show wetting trends at depth.

About 1.7 hectares (ha) of the source area was planted in 1999, and the remaining 1.6 ha was planted in 2006, primarily with the native desert shrub *Atriplex canescens* (four-wing saltbush). Canopy growth and nitrate concentrations in plant tissues are monitored annually to evaluate growth and nitrate extraction rates. Plant canopy volume and growth rates varied across the plantings, probably in response to the age of the planting, irrigation rates, and soil fertility. Total nitrogen uptake estimates were 204 kilograms (kg) in the 1999 planting (since 2000) and 42 kg in the 2006 planting.

An area of poor plant growth exists in the western third of the 1999 planting. Previous analysis suggested that the discolored soils in this area had both an excess and a deficiency of several ions. Follow-up investigations included (1) a greenhouse study, conducted by students at Diné College (Tsaile Campus), of the effects of high salt content on uptake of certain micronutrients, and (2) a laboratory analysis of the discolored soils in areas with stunted plant growth. Micronutrient amendments in the greenhouse study greatly improved both biomass production and survival of plants grown in discolored soil. Laboratory analyses suggested that nodules in the discolored soil likely formed from the co-precipitation of iron and manganese during the milling process. Changes in the redox state induced by irrigation water and increased soil biological activity may have caused colored bands observed near irrigation emitters. There is now a need to determine if excessive bioaccumulation of manganese is occurring in saltbush.

Planting and irrigating the source area has been exceptionally effective in removing nitrate from the soil by microbial denitrification, the conversion of nitrate to nitrogen gas. Denitrification rates rose when soils were wettest and dropped when plantings matured and dried the soil. Batch and column studies have shown that ethanol, a carbon source, can also greatly enhance denitrification. However, a 2007 field study that supplied ethanol though the irrigation system did not enhance denitrification rates. Denitrification rates are usually highest in wet, anaerobic soils. Average soil moisture content remained well below field capacity, suggesting that in the source area, soil moisture (not carbon) is the limiting factor for dentrification.

3.10.2 Groundwater Phytoremediation

The pilot studies are evaluating natural and enhanced attenuation remedies for groundwater contamination in the alluvial aquifer at Monument Valley with a focus on two attenuation processes: phytoremediation to remove nitrate and sulfate and to slow plume dispersion, and microbial denitrification.

Preliminary studies found that protecting existing native phreatophytic shrubs (*Atriplex canescens* and *Sarcobatus vermiculatus*) from grazing could double biomass production, transpiration rates (water extraction from the aquifer by plants), and nitrogen uptake rates. It was also demonstrated how, on a small scale, greenhouse-grown transplants of native shrubs could be established in denuded areas of the plume, and with managed irrigation, send roots 30 ft and deeper into the alluvial aquifer. In fall 2005, four large plots (grazing exclosure and revegetation plots) were fenced to see if the preliminary studies could be repeated on a large scale. After two growing seasons, canopy cover of phreatophytic shrubs was more than 2 times greater inside than outside the grazing exclosures. However, growth of shrub transplants remained low in the revegetation plots because of herbivory by small mammals.

Phreatophytic shrubs growing over the nitrate plume may extract enough water to slow the spread of the plume during the time it takes for denitrification to reduce nitrate to safe levels. In 2006 and 2007, transpiration rates of individual *A. canescens* and *S. vermiculatus* plants were measured both inside and outside the grazing exclosure plots using sap-flow instrumentation. These data were extrapolated to a landscape scale using Quickbird and MODIS satellite estimates of shrub cover. The results show that even under current conditions (heavy grazing), ET is already removing large quantities of water from the plume; ET rates are almost double precipitation. In contrast, annual ET rates were about 8 times greater for volunteer phreatophytes protected from grazing for several years inside the source area fence. Using a conservative estimate, managing (but not eliminating) grazing could more than double the amount of water extracted by phreatophytes growing over the plume.

3.10.3 Groundwater Denitrification: Monitoring and Modeling

The pilot studies have shown that natural attenuation is occurring in the plume. In 2007, the feasibility of relying on or enhancing natural attenuation processes as part of the final remedy was evaluated. LM scientists (1) characterized the occurrence and rates of natural attenuation processes (denitrification, sorption, and dispersion), (2) completed laboratory microcosm experiments for injecting carbon sources to enhance denitrification, (3) conducted a temporal and special analysis of plume well data, and (4) calibrated a nitrate transport model to predict and compare natural and enhanced attenuation scenarios.

Results of these studies confirm that the natural attenuation of nitrate is occurring at the site. Dispersion and sorption, estimated from the laboratory microcosm experiments, had minor effects on nitrate transport. Denitrification appears to be the dominant process as determined by microcosm decay and isotopic fractionation experiments, field-scale isotopic fractionation analyses, and numerical modeling. The modeling exercise suggested that although natural attenuation is occurring, it may take more than 150 years to achieve cleanup standards without enhancements. However, the modeling exercise also suggested that the injection of ethanol as a substrate for denitrification could substantially increase denitrification rates and shorten the cleanup time by more than 100 years.

3.10.4 Land Farming

Land farming is considered to be an active phytoremediation alternative that would be used only if more passive alternatives (natural and enhanced attenuation) were found to be inadequate. Land farming would involve pumping plume water from the aquifer to irrigate fields of native plants. This would remove nitrate and sulfate from the aquifer, convert nitrate into healthy plant tissue, and—mimicking natural gypsic soil horizons in the area—store sulfate as gypsum in the farm soil. Irrigation would be managed to prevent contaminants from leaching back into the aquifer. As with other phytoremediation alternatives, land farming would improve the rangeland ecological condition and could produce a crop, such as native plant seed, that could be marketed for mine-land reclamation for the Navajo Nation.

The land-farm pilot study was designed and constructed in 2005 to compare different crops and different nitrate concentrations in irrigation water. Although a drop in well-pumping rates caused non-uniform irrigation rates among treatments and required us to alter the original experimental design, results show that plants receiving the highest nitrate concentration—750 milligrams per liter (mg/L) of nitrate—grew the largest, and *A. cansecens* grew significantly larger than *S. vericulatus*. In 2009, LM plans to conduct a pump test on the plume extraction well and sample nitrate and sulfate accumulation in land-farm soils and plants.

3.11 Shiprock Phytoremediation

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

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

The groundwater nitrate plume spreads away from the site towards the San Juan River floodplain west of Shiprock. The plume originates in a bedrock swale just south of the disposal cell. Groundwater flows west and northwest of the swale in an ancestral river channel where the alluvial saturated thickness exceeds 4 ft. Nitrate concentrations decline moving from east to west but remain above the maximum concentration limit (the limit is 44 mg/L) where the plume passes northwest into the San Juan River floodplain. Diné College operates an experimental farm at the western edge of the nitrate plume. Within the farm, the plume follows a topographic gradient from upland soils and habitat to riparian habitat in the floodplain.

<u>Activities</u>. Several activities were conducted in FY 2008, with support from New Mexico State University, Diné College, and the University of Arizona, to evaluate the feasibility of using phytoremediation at Shiprock.

Diné College interns measured plant growth in the test plots in fall 2007. Overall, transplants had grown larger in the terrace plots than in the borrow pit plots and, as at Monument Valley, *A. cansecens* grew significantly larger than *S. vericulatus*.

Analysis of oxygen and deuterium isotope signatures for different water sources led to the following inferences:

- San Juan River water consists of a mixture of summer and winter precipitation, as would be expected as water is released from the Navajo Dam upstream.
- Water from tailings in the Shiprock disposal cell appears to be local summer and winter precipitation that has percolated through the disposal cell cover.

- Water from wells in the San Juan River floodplain are similar to river water, indicating that the wells intercept the floodplain aquifer. Water in the tissue of *Tamarix* plants growing adjacent to the floodplain wells are rooted into and extracting water from the aquifer.
- Mature *S. vermiculatus* plants growing on the terrace may be extracting water from the capillary fringe above the alluvial aquifer that passes between the disposal cell and the floodplain.
- Water from wells near the northeast end of the terrace had signatures that plotted close to water from tailings in the disposal cell, indicating possible movement of water from the disposal cell to the terrace at that location.
- Water in tissue of mature phreatophytic shrubs growing in the borrow pit appears to be primarily from the vadose zone water and possibly a mixture of vadose zone water and shallow groundwater.

3.12 Vegetation Management Working Group

Overview. The LM Vegetation Management Working Group was formed in 2006 to identify and implement smarter, more cost-effective, and more sustainable ways to manage vegetation at LM sites. The working group's goals included protecting groundwater resources, preventing noxious weed establishment, managing habitat (including the establishment of native plant communities) better, identifying long-term sustainable solutions that are cost-effective, and educating stakeholders. The working group is addressing the following existing problems:

- The construction of the disposal cells created habitat for noxious weeds, which have established instead of desirable vegetation.
- The ecological impacts of older disposal cell designs were generally not taken into consideration.
- Vegetation control recommendations in the LTSPs did not take into consideration ecological sustainability.
- Ecological changes in disposal cells and impacts on groundwater conditions are not well known.

Activities. Activities in 2008 included the creation of a webpage on the LM website, the application of the Vegetation Management Framework at the Burrell site as a test case, and the presentation of AS&T research on cover performance and sustainability to other team members.

3.13 Share Technologies with Stakeholders; Tribes; Federal, State, and Local Governments; Colleges, and Other Contractors

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

Activities.

Mesa State College Seminar Series

Each fall, Mesa State College in Grand Junction conducts a public seminar series on environmental science issues ("Natural Resources in the West. The theme for 2007 is Global Change: Impacts on Natural Resources"). An LM scientist gave a presentation ("Climate Change and the Long-Term Performance of Radioactive Waste Disposal Facilities") on November 26, 2007.

Diné College Field Class

An LM scientist gave a presentation on Monument Valley phytoremediation, led a tour of the site, and taught Diné College environmental science students in a field ecology class on May 2.

Vanderbilt University Seminar

An LM scientist presented, "Ecological remedies for U.S. Department of Energy Legacy Waste" to students and faculty at Vanderbilt University's Department of Civil and Environmental Engineering.

Two special projects were completed this fiscal year:

1. Mineral scale from an ion-exchange water treatment system at the Fernald site was potentially affecting the performance of the treatment process. AS&T provided funding to conduct analyses in the ESL to help determine the composition of the mineral scale. The composition of the samples was largely calcium carbonate with lesser iron and manganese oxides. A brief report of the findings and recommendations was provided to site personnel.
2. Uranium concentrations have been increasing in a well downgradient of the Durango Bodo Canyon disposal cell. AS&T provided funding to collect a sample and analyze for ^{222}Rn. The result was somewhat inconclusive but indicated that the groundwater in the well had not been in recent contact with tailings.

3.14 Lab Maintenance

Overview. Funding from the AS&T task order is used to maintain the ESL in Grand Junction. The ESL operates a fixed-based laboratory and a mobile laboratory with capabilities to conduct geochemical and ecological testing. Funding requirements include the following: (1) service contracts for equipment, (2) maintenance and repairs of equipment, (3) development of new laboratory procedures, (4) purchase of new equipment and consumable items, (5) the updating of laboratory manuals, including the *ESL Procedures Manual* and the *ESL Chemical Hygiene Plan*, (6) the management of waste disposal issues, (7) the management of facility issues, and (8) training. ESL continues to be an integral part of the Grand Junction site. 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.

Activities. This year, a new ion chromatograph was purchased to replace the outdated model, which is no longer being supported by the vendor. An ESL analyst is being trained in its use.

Calibration weights were checked for accuracy by a third party. Pipettes and many other laboratory instruments were checked for calibration. The ESL was inspected by DOE and received favorable comments. The flow-meter calibration laboratory was used to check the accuracy of numerous flow meters prior to field deployment. A management assessment and an inspection by the chemical hygiene officer were conducted.

3.15 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 DOE 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.

Activity. A list of FY 2008 publications and presentations follows.

3.15.1 Published Journal and Proceedings Papers

Jordan, F., W.J. Waugh, E.P. Glenn, L. Sam, T. Thompson, and T.L. Thompson, 2008. “Natural bioremediation of a nitrate-contaminated soil-and-aquifer system in a desert environment,” *Journal of Arid Environments* 72(5): 748–763.

Waugh, W.J., C.H. Benson, and W.H. Albright, 2008. “Monitoring the Performance of an Alternative Landfill Cover Using a Large Embedded Lysimeter,” *Proceedings of the Global Waste Management Symposium*, Penton Media, Orlando, Florida 1–10.

Waugh, W.J., M.K. Kastens, L.R.L. Sheader, C.H. Benson, W.H. Albright, and P.S. Mushovic, 2008. “Monitoring the Performance of an Alternative Landfill Cover at the Monticello, Utah, Uranium Mill Tailings Disposal Site,” *Proceedings of Waste Management 2008 Symposium*, Phoenix, Arizona.

3.15.2 Abstracts, Presentations, Seminars, and Short Courses

Waugh, W.J., 2007. “Design and Long-Term Performance of Radioactive Waste Disposal Facilities: Ecology, Soils, and Climate.” Presented at “Natural Resources of the West, Global Change: Impacts on Natural Resources,” Mesa State College, November 26, 2007, Grand Junction, Colorado (seminar).

Waugh, W.J., 2008. “Got it Covered? Design, Performance, Renovation, and Sustainability of Disposal Cell Covers at DOE Legacy Waste Sites,” February 27, 2008, U.S. Department of Energy, Albuquerque, New Mexico (seminar).

Waugh, W.J., 2008. “Enhanced Attenuation Pilot Studies: Growing Answers for Soil and Groundwater Contamination at Monument Valley, Arizona, and Shiprock, New Mexico,” April 22, 2008, Window Rock, Arizona.

Waugh, W.J., 2008. “Got it Covered? Design, Performance, and Renovation of Disposal Cell Covers at DOE Legacy Waste Sites,” Solid Waste Association of North America Conference, April 17–18, 2008, Portland, Oregon (invited paper).

Waugh, W.J., 2008. “Monitoring the Performance of an Alternative Landfill Cover at the Monticello, Utah, Superfund Site,” Association of State and Territorial Solid Waste Management Officials, July 29–31, 2008, Scottsdale, Arizona (invited paper).

3.15.3 Papers and Abstracts Accepted, Submitted, or In Review for Publication

Bartlett, T.R., and S.J. Morrison (in review). “Radon Tracer Method to Determine Ground Water Residence in Permeable Reactive Barriers,” submitted to *Ground Water*.

Gee, G.W., B.D. Newman, S.R. Green, H. Rupp, R. Meissner, Z.F. Zhang, J.M. Keller, W.J. Waugh, and J. Salazar (accepted). “Passive-wick water fluxmeters: Practical applications,” *Water Resources Research*.

Glenn, E., K. Morino, K. Didan, F. Jordan, K. Carrol, P. Nagler, K. Hultine, and J. Waugh, 2009 (accepted). “Scaling sap flux measurements of grazed and ungrazed shrub communities with fine and course-resolution remote sensing,” *Ecohydrology*.

Jordan, F., J. Waugh, E. Glenn, 2008 (accepted). “A Plant-Based Approach to Remediating a Nitrate-Contaminated Soil/aquifer System in a Desert Environment,” 2008 Joint Meeting of The Geological Society of America and Soil Science Society of America, October 5–9, 2008, Houston, Texas.

Maestas, J., R. Bush, T. Ribeiro, S. Surovchak, J. Powell, T. Bartlett, C. Carpenter, C. Jacobsen, D. Miller, S. Morrison, J. Boylan, K. Broberg, C. Glassmeyer, W. Hertle, 2009 (in review). “Remediation of Uranium at DOE’s Legacy Management Sites,” Waste Management 09 (conference), Phoenix, Arizona.

Waugh, W.J., 2008 (accepted). “Overview of Plant-Based Remedies at U.S. Department of Energy Legacy Waste Sites, ” 2008 Joint Meeting of the Geological Society of America and Soil Science Society of America, October 5–9, 2008, Houston, Texas (invited paper).

Carroll, K.C., F.L. Jordan, E.P. Glenn, W.J. Waugh, and M.L. Brusseau, 2008 (submitted). “Comparison of Nitrate Attenuation Characterization Methods for Groundwater Remediation,” American Geophysical Union, San Francisco, California.

3.15.4 Published and Draft DOE Reports

Benson, C.H., W.H. Albright, and W.J. Waugh, 2008. “Hydraulic Properties and Geomorphology of the Earthen Component of the Final Cover at the Monticello Uranium Mill Tailings Repository,” Geo Engineering Report No. 08-04, University of Wisconsin, Madison, Wisconsin.

U.S. Department of Energy, 2008. *Natural and Enhanced Attenuation of Soil and Ground Water at Monument Valley, Arizona, and Shiprock, New Mexico: 2007 Status Report*, LMS/MON/S04243, U.S. Department of Energy Office of Legacy Management, Grand Junction, Colorado.

U.S. Department of Energy, 2008. *Demonstration of Water Flux Meters at the Lakeview, Oregon, Disposal Cell: Fiscal Year 2008 Progress Report*. U.S. Department of Energy Office of Legacy Management, Grand Junction, Colorado

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