Overview of Science and Technology Improvements at Office of Legacy Management Sites

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ABSTRACT

The U.S. Department of Energy Office of Legacy Management (LM) supports science and technology (S&T) initiatives to more effectively manage LM sites, help protect human health and the environment, and reduce long-term costs of site maintenance and remediation by ensuring that sound engineering and scientific principles are used. Through the use of telemetry, LM's SOARS (System Operation and Analysis of Remote Sites) project provides project scientists and engineers with timely information needed to evaluate, maintain, and optimize remediation systems, while limiting the amount of required travel. This paper presents three recent S&T activities focused on enhancing remediation of ground water at LM sites.

INTRODUCTION

Three ground-water remediation projects present some applications of science and technology (S&T) relevant to the operation and maintenance of Office of Legacy Management (LM) sites. The U.S. Department of Energy (DOE) is committed to the use of S&T, where applicable, to clean up its legacy weapons and testing sites as stated in DOE's Strategic Theme 4: Environmental Responsibility: "Leverage science and technology to directly address the specific, applied needs for cleanup and closure" [1]. The three examples are (1) a permeable reactive barrier (PRB) and supplemental treatment system at Monticello, Utah; (2) passive treatment systems at Rocky Flats, Colorado; and (3) installation and monitoring of two collection drains to supplement a ground-water pump-and-treat system at Shiprock, New Mexico. Contaminated ground water is being removed from the subsurface at these sites to help reduce the time required for the aquifers to be cleaned by natural attenuation. The contaminated water is being chemically treated or evaporated. The improvements developed for these three projects help illustrate the application of S&T resources to save time, reduce costs, and improve the efficiency of LM ground-water projects.

SYSTEM OPERATION AND ANALYSIS AT REMOTE SITES (SOARS)

LM scientists use data to evaluate the progress of ground-water remediation at distant sites. At many sites, data are collected and processed by LM's SOARS system. This system involves automated data collection and storage equipment at a site that is regularly (usually daily) transmitted to data servers at Grand Junction, Colorado, where data are automatically processed into user-friendly graphs. Project personnel across the LM network access the SOARS system to view site data in near real-time on their desktop computers. Because of the long distances to many of the LM sites, the SOARS system saves time and money to track progress of remediation efforts and to make timely adjustments. Another advantage of SOARS is that multiple project personnel residing at different project sites have access to real-time data, increasing the effectiveness of interdisciplinary project teams. Because the system is easy to access, personnel use it regularly; thus, data anomalies are noted early and problems can be addressed expeditiously. Pumping regimes and other operational facets of the remediation projects can be modified remotely through the SOARS system.

The SOARS system currently includes 41 data logging stations supporting 234 instruments at 7 project sites in 5 states (Figure 1). Data are collected from flow meters, water-level meters, pressure sensors, unsaturated-zone water-flux meters, moisture sensors, and other instruments. Meteorological data (wind speed, wind direction, rainfall, and relative humidity) are also collected at five project sites in four states.

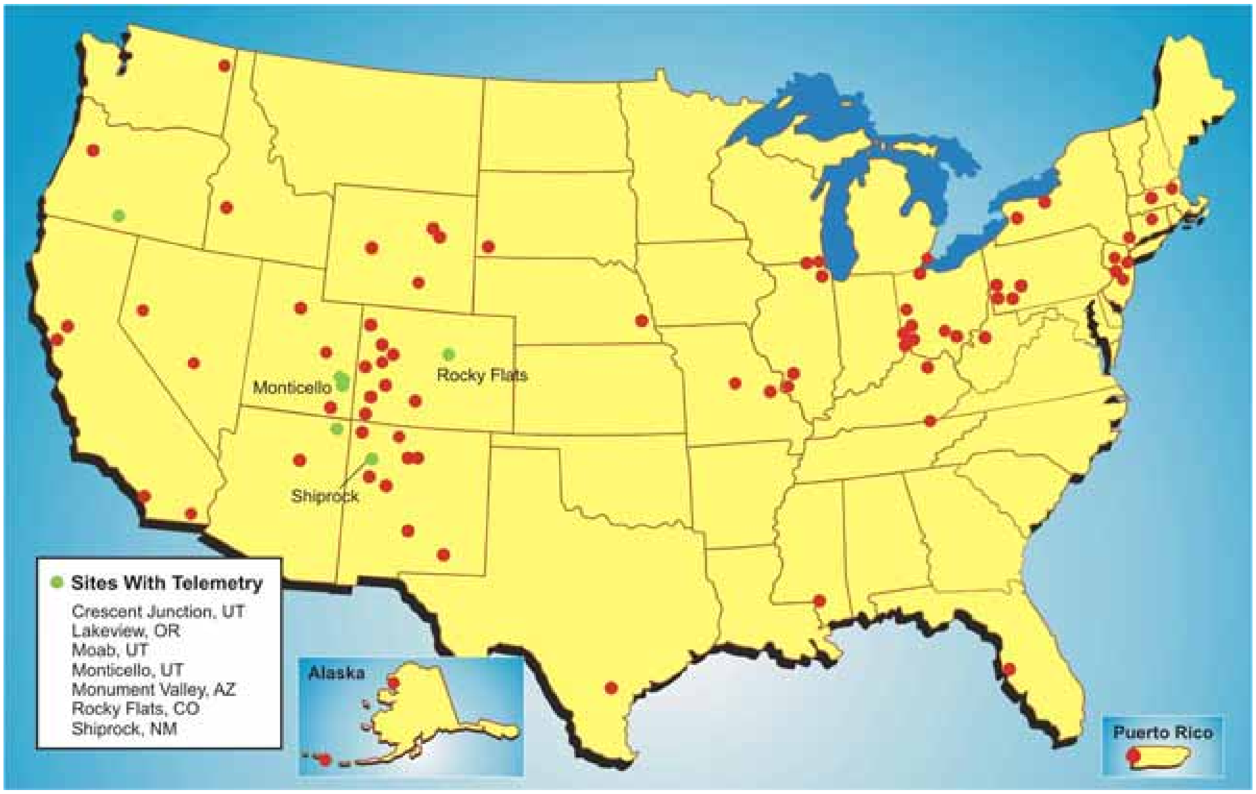

Fig. 1. LM sites (all dots) using LM's SOARS system (green dots).

IMPROVEMENTS TO GROUND WATER REMEDIATION SYSTEMS AT LM'S MONTICELLO, UTAH, SITE

Permeable Reactive Barrier

A permeable reactive barrier (PRB) was constructed at the LM Monticello, Utah, Site in 1999 as part of a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Interim Action. The Monticello Site was formerly a uranium- and vanadium-ore milling facility. Mill tailings were removed from the site, but contamination remains in the ground water. The zero-valent iron (ZVI) component of the PRB was intended to remove uranium from ground water and to enhance the natural flushing of the downgradient alluvial aquifer. The PRB has a 2-foot-wide (in direction of ground water flow) upgradient zone containing a mixture of pea gravel and ZVI (13 volume percent ZVI) and a 4-foot-wide zone of 100 percent ZVI [2]. Shortly after its installation, ground-water samples collected downgradient of the PRB had significantly lower uranium concentrations than those collected upgradient, indicating that the PRB was positively effecting ground water remediation.

Results of detailed monitoring of the PRB indicate that the permeability of the PRB is decreasing. The corrosion of ZVI led to precipitation of calcium carbonate, iron oxide, and other minerals that occluded pore space and restricted flow through the PRB. Hydraulic conductivity of the PRB was calculated from pneumatic slug test data collected from about 40 ground-water wells four times during its operation: June 2000, August 2003, November 2004, and November 2005. As shown in Table I, the mean values of hydraulic conductivity in the ZVI zone decreased from 1.99×10^{-2} to 4.59×10^{-5} centimeters per second (cm/s) during this period [3]. This significant decrease in hydraulic conductivity in the ZVI zone caused ground water to mound upgradient of the PRB and some ground water to flow around the ends without treatment.

Table I. Summary of the Hydraulic Conductivity Over Time in the Upgradient Alluvium and Reactive Zones of the Monticello PRB (cm/s); Each Value Represents the Mean of About 10 Measurements in Wells Throughout the Zones

Media	June 2000	August 2003	November 2004	November 2005
Alluvium	5.57×10^{-3}	3.78×10^{-3}	5.28×10^{-3}	6.39×10^{-3}
Gravel/ZVI	na	3.90×10^{-3}	1.90×10^{-3}	2.10×10^{-3}
ZVI	1.99×10^{-2}	3.38×10^{-3}	4.15×10^{-4}	4.59×10^{-5}

na = not analyzed.

To further evaluate the performance of the PRB, cores were collected three times during its operation: February 2002, August 2003, and March 2006. Mean values of solid-phase concentrations of uranium and calcium are shown in Table II. The initial concentrations (concentrations in the material before it was placed in the PRB) of uranium and calcium in the gravel/ZVI are about 0.5 and 1,000 milligrams per kilogram (mg/kg), respectively, whereas initial concentrations of these elements in the ZVI zone are negligible. Analytical results of samples collected from the gravel/ZVI zone suggest that a significant mass of uranium was removed from ground water by 2002; the precipitated mass about doubled by 2003. However, little additional uranium was removed between 2003 and 2006. Uranium concentrations in the ZVI zone were negligible compared to the gravel/ZVI zone. The small amounts in August 2003 (2.16 mg/kg) and March 2006 (1.47 mg/kg) are biased by high values in a few samples collected within one or two inches of the upgradient front of the ZVI zone. Because uranium concentrations in ground water exiting the PRB remained low, the solid-phase concentration results suggest that ground water was no longer flowing through the PRB at a significant rate after 2003, which is consistent with the decreasing hydraulic conductivity measurements and an increase in ground-water mounding upgradient of the PRB. On the basis of the February 2002 data, about 24 kg of uranium-bearing minerals had been deposited in the PRB [4]; this mass approximately doubled by August 2003.

Table II. Summary of Core Analyses of Monticello PRB Samples; Each Mean Value Represents Analyses of About 50 Samples From 10 Core Locations

Mean Concentrations (mg/kg)				
	Calcium	Calcium	Uranium	Uranium
	G/ZVI	ZVI	G/ZVI	ZVI
Initial	1000	~0	0.5	~0
February 2002	28083	12356	266.9	0.44
August 2003	31564	25500	546.1	2.16
March 2006	40208	26219	524.4	1.47

G/ZVI = samples from the gravel/ZVI zone,
ZVI = samples from the ZVI zone.

Results of the calcium analyses indicated that about 9 tonnes of calcium carbonate minerals had precipitated in the ZVI zone by February 2002 [4]. This mass approximately doubled by August 2003, but did not increase significantly between August 2003 and March 2006. This result supports the conclusion that ground-water flow through the PRB diminished substantially after 2003. Calcium concentrations in the gravel/ZVI zone also indicate precipitation of calcium carbonate minerals. Mineralization of the PRB caused ground water elevations to increase upgradient of the PRB and nearly reach ground surface by May 2005. Electron microprobe analyses of ZVI samples confirmed that calcium carbonate-, uranium-, and iron oxide- minerals coated ZVI grains and partially filled pore throats.

Ground Water Treatment System

Because of decreasing effectiveness of the PRB, a supplemental ex-situ treatment system was constructed in June 2005. The treatment system consists of a mixture of gravel and granular ZVI contained in a concrete culvert [5]. Contaminated ground water is conveyed to the treatment system from an extraction well located in the ground-water mound about 30 feet upgradient of the PRB. The water enters the treatment system at the bottom and flows upward; the treated water is discharged to a distribution gallery downgradient of the PRB. As of January 2007, the system had treated 3 million gallons of contaminated ground water at a typical rate of 5 gallons per minute (gpm). Uranium concentrations in monthly influent and effluent samples indicate that the system continues to meet project treatment goals (Table III). However, the effluent uranium concentrations are increasing. In the October 30, 2006 sampling, the concentration was 58 micrograms per liter (µg/L), which exceeds the ground water standard of 44 µg/L.

Table III. Monticello Treatment System Influent and Effluent Uranium Concentrations (μg/L).

Treated Volume (million gallons)	0.5	1.0	1.5	2.0	2.5
Influent Uranium	236	320	320	340	330
Effluent Uranium	4	15	25	25	35

Possible reasons for the gradual increase in effluent uranium concentrations include decreasing effectiveness of the ZVI (for example, passivation of reactive surfaces by mineral precipitation or depletion of the ZVI by dissolution) and increasing dispersion of the reactive media. Increased dispersion leads to shortened residence time and less effective treatment. To help evaluate the effects of dispersion, the hydraulics of the treatment system are continuously monitored by the SOARS system. Hydraulic conductivity of the treatment media, calculated from continuous measurements of inlet pressure and flow rates, has decreased slightly but steadily during the last 5 months from $10^{-2.3}$ to $10^{-2.6}$ cm/s. On the basis of tracer test results, dispersivity of the media increased from about 0.35 to 0.6 meters during the same time period (Fig. 2). The system is being closely monitored to determine what effects the decreasing hydraulic conductivity and increasing dispersivity values have on the effluent uranium concentrations. These data will be used to help optimize the composition of the treatment media and provide an early indication of treatment media degradation.

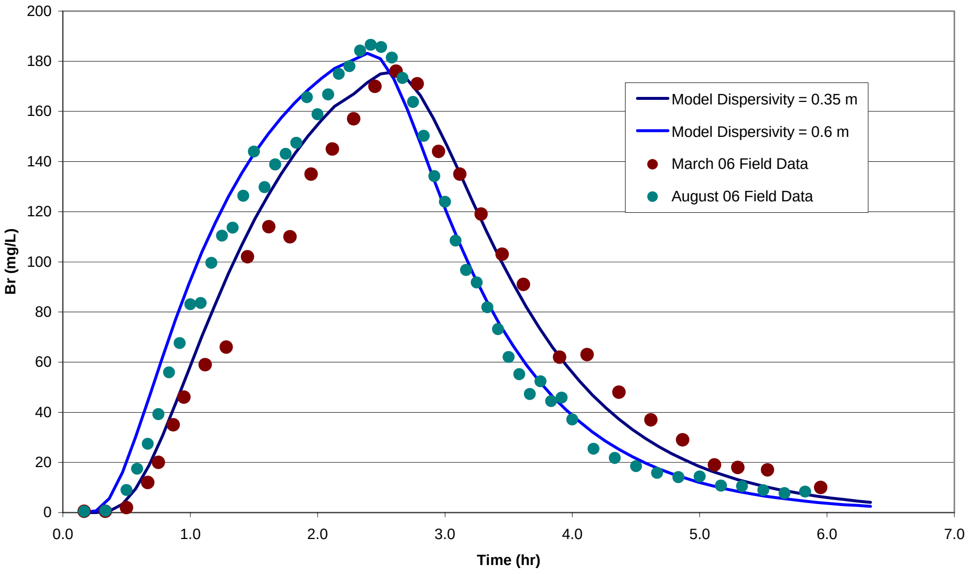

Fig. 2. Monticello treatment system bromide tracer test results

The costs of installation and operation of the treatment system are significantly less than those for the PRB for a comparable treatment rate. The ability to monitor major parameters of the operation of the treatment system remotely using the SOARS system helps lower costs and ensures that the system continuously meets ground-water remediation goals.

IMPROVEMENTS TO PASSIVE GROUND WATER TREATMENT SYSTEMS, ROCKY FLATS, COLORADO

Three passive treatment systems operating at the LM Rocky Flats, Colorado, Site are discussed. The Mound system, installed in 1998, consists of two circular 7,000-gallon high-density polyethylene (HDPE) tanks about two-thirds full of ZVI. The East Trenches system, installed in 1999, is similar in construction and design to the Mound system. The Solar Ponds system, installed in 1999, is a rectangular 150,000-gallon concrete vault divided into two treatment cells by a concrete partition. The first (upgradient) cell constitutes about three-fourths of the total volume of the vault and is filled about half way with a mixture of sawdust and ZVI. The second cell is filled about half way with a mixture of gravel and ZVI. After placing the reactive media, the vault was backfilled with wood chips and native soil. At each of these three systems, engineered drains collect contaminated ground water that is then conveyed to the respective treatment system, where it passes via series configuration, from top to bottom through each cell in the system. The Mound and East Trenches treatment systems remove volatile organic compounds (mostly trichloroethylene, dichloroethylene, perchloroethylene, and carbon tetrachloride) whereas the Solar Ponds system removes nitrate and uranium. The systems have been monitored for 6 to 7 years and have generally met treatment concentration goals. In the last quarter of 2006, the Mound, East Trenches, and Solar Pond systems were flowing about 0.7, 1.1, and 0.8 gallons per minute, respectively.

As an example of the treatment effectiveness, influent concentrations of TCE have been about 3,000 µg/L for the last 6 years in the East Trenches treatment system, but concentrations following treatment have been generally between 1 and 10 µg/L (Fig. 3). The ZVI media was changed twice when concentrations exceeded about 50 µg/L. Replacement of the media restored the treatment capacity (Fig. 3).

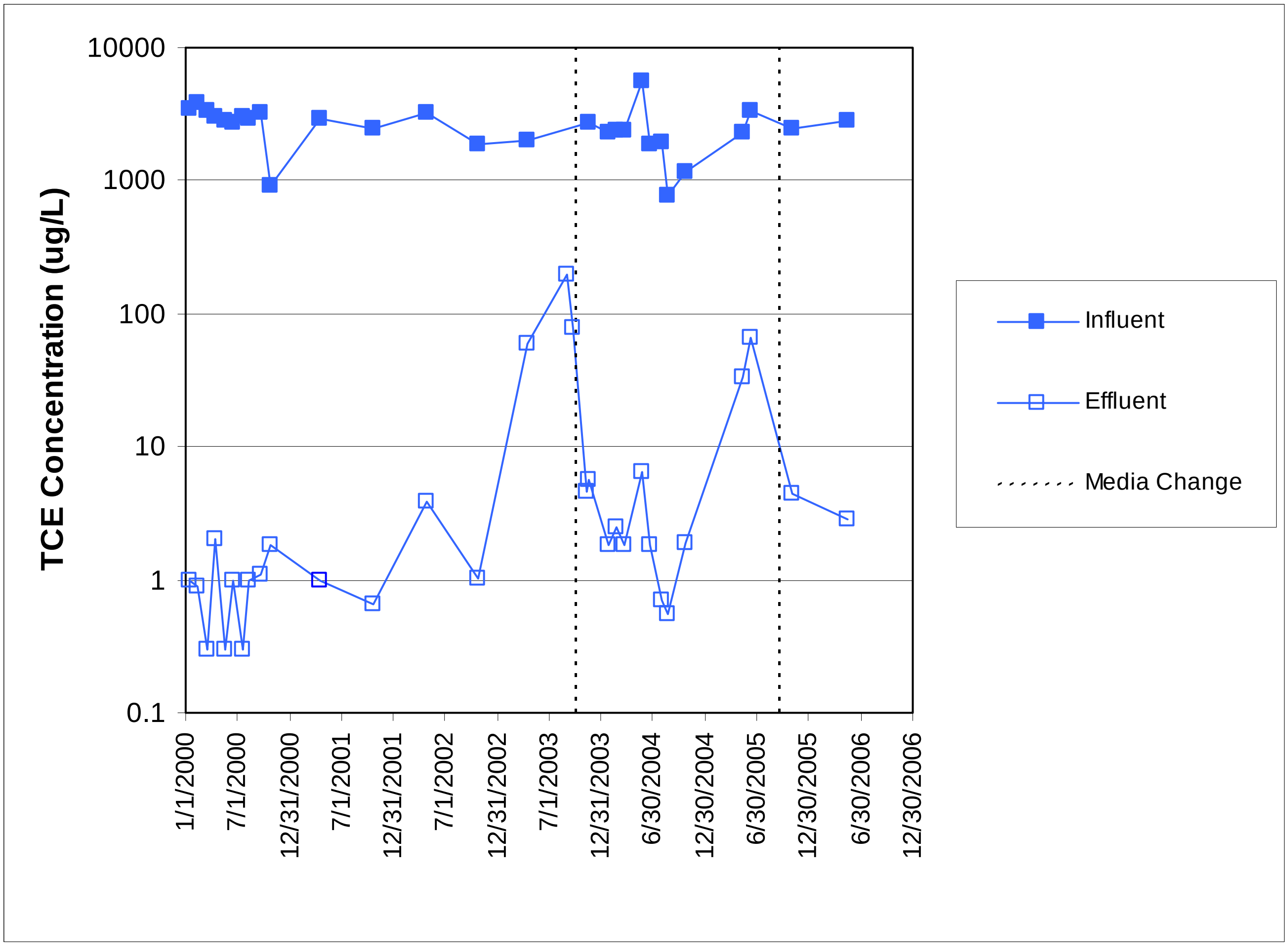

Fig. 3. TCE concentrations in East Trenches Treatment System, Rocky Flats, Colorado.

Reactive media in the Mound and East Trenches treatment systems were recently replaced because of decreasing hydraulic conductivity and increasing concentrations of contaminants in the effluent. The ZVI had hardened in the HDPE tanks, and removal was an arduous process requiring hydraulic hammering and hand excavation in the tanks for several weeks. Because of the high cost of changing the media, new instrumentation was installed to monitor flow rates, water depths, and line pressures and to provide data through the SOARS system for better evaluation of the hydraulics of the treatment process that could help optimize future performance of the treatment systems. Hydraulic conductivity values calculated from the SOARS data in these two systems have not changed since replacement of the media.

The Solar Ponds treatment system was designed to biodegrade nitrate using an organic media composed of sawdust as a substrate for nitrate-reducing bacteria. A small amount of ZVI was added to the sawdust because a treatability study indicated that the biodegradation process was enhanced in the presence of ZVI. Following treatment, the ground water flows through a second reactor containing ZVI and gravel to remove residual uranium.

From 2000 through 2006, influent concentrations of nitrate ranged from about 150 to 250 mg/L (as N). Effluent nitrate concentrations through mid-2005 were typically less than 0.5 mg/L (as N). During this same period of time (2000 through June 2005), influent uranium concentrations averaged about 21 µg/L, and effluent values were generally less than 0.2 µg/L. In June 2005, permeability had decreased in the ZVI cell, and water was backing up in the system. To alleviate this condition, valve settings were changed to force the water to bypass the ZVI cell. Shortly after this change, effluent concentrations of nitrate and uranium increased to nearly the influent levels. Although the ZVI media in the downgradient cell was replaced with fresh ZVI and the valves were changed to allow water to move through that cell, the high effluent concentrations of nitrate continued.

An initial concern was that the nitrate-reducing capacity of the sawdust media had declined. An investigation was conducted that included excavation to inspect the top of the reactive media. The inspection revealed that the cause of the reduced effectiveness was due at least in part to several failed valves and broken pipes. Samples of the sawdust media were collected, and bench tests were conducted. Results of this investigation showed that the sawdust media was still capable of nitrate reduction. After repairing the plumbing, the backfill was replaced, and the system continues to operate. Nitrate and uranium concentrations in effluent samples since the repairs have been consistent with earlier values (nitrate generally less than 0.1 mg/L as N, and uranium less than 1 µg/L), indicating that the repairs were effective.

IMPROVEMENTS TO A PUMP-AND-EVAPORATE GROUND-WATER TREATMENT SYSTEM AT SHIPROCK, NEW MEXICO

At the LM site in Shiprock, New Mexico, ground water is contaminated by ammonium, nitrate, sulfate, and uranium from a former uranium-ore processing plant. Ground water containing the highest concentrations of contamination is being extracted and evaporated in an 11-acre pond to decrease the time needed for natural flushing to remediate the aquifer. In April 2006, the ground-water extraction system included 11 pumping wells and 2 collection drains with a total production of about 18 gpm. The extraction rate, especially from wells, is limited by the channel-and-fill heterogeneity of the alluvial aquifer.

Improvements to this system consisted of the design, installation, and monitoring of two additional ground-water collection drains to increase the extraction rate of contaminated ground water. Each drain is 200 feet long, 15 feet deep, and 2 feet wide and is designed to intercept contaminated ground water before it reaches the San Juan River. The larger intake area within the trenches was planned to have a greater opportunity to intercept the discontinuous, highly conductive ground-water flow paths in the alluvial aquifer.

Drain installation was complicated because of the shallow ground-water table. Traditional construction methods of trenching and shoring would have been difficult because of sloughing of the trench walls. Instead, the trenches were installed using vegetable-based guar gum to hold the trenches open during excavation (Fig. 4). Following installation of the drains, an enzyme was used to break the guar gum into short-chained carbon molecules that dissolved in the ground water and left the trenches permeable. A time period of several weeks was required to sufficiently reduce the viscosity of the guar gum and allow ground water to flush it from the trench.

Fig. 4. Guar-gum-based construction of collection drain.

A 4-inch-diameter perforated HDPE pipe runs the length of each drain about 15 feet below ground surface. Pea gravel (0.5 inch) surrounds the drain pipe and affords a conduit for ground water. The pipe conveys the ground water to a vertical sump at one end of each drain. A submersible pump extracts the water and conveys it about 0.5 mile to the evaporation pond. A concrete vault at each drain site houses instruments used to measure water levels in the extraction sump and the in-line flow rate and pressure. The SOARS system logs and transmits data to LM personnel and is used to remotely control extraction pumps.

Effects of the drains on the aquifer are now being evaluated by monitoring the hydraulic characteristics using data from the SOARS system and analytical results of regular sampling. Since installation of the drains, extraction of contaminated ground water from the entire Shiprock extraction system has nearly doubled. One of the drains is producing an average of about 15 gpm and the other about 6 gpm; this will likely increase after a large diameter pipe to the evaporation pond is installed in 2007. Contaminant concentrations in water extracted from the drains has varied somewhat but has not changed significantly since drain installation.

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