In-situ Monitoring of a Closed Waste Rock Facility[1]

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ABSTRACT

Subsurface air flow and infiltration processes were monitored within a closed rock disposal area (RDA) facility at a mine site in northern Nevada. The RDA contains a steep angle-of-repose slope face as well as an under-drain system to route up-gradient surface water under the RDA. The study was designed to evaluate whether infiltration of air and water through the steep, rock-covered angle-of-repose slope face is the primary source of sulfate in surface water exiting the RDA toe via the under-drain. Four monitor wells drilled to depths of 41 to 86 meters were instrumented at various depth intervals to allow collection of in-situ air and pore-water samples as well as automated measurements of temperature, oxygen content, and water content every six hours. Two of the monitor wells were also instrumented to collect water quality samples, and to record water level and electrical conductivity data in the under-drain system. Surface water flumes upstream and downstream of the RDA were installed to record under-drain flow rates, electrical conductivity, and temperature. Data indicate that the interior of the RDA, rather than the rock-covered angle-of-repose slope face, is the primary source of high-sulfate water exiting the RDA.

Additional Key Words: sulfate, EC, oxygen, temperature, water content, under-drain, pore water, angle of repose

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INTRODUCTION

The DASH Rock Disposal Area (RDA) was designed, constructed, and operated from the late 1980s to late 1990s. Significant components of the design included: an under-drain system to allow up-gradient surface water to flow under the DASH RDA, and a steep, rock-covered DASH angle-of-repose (DAR) slope face located at the toe of the DASH RDA. The remaining slopes and benches of the DASH RDA have been covered with soil and re-vegetated. A topographic map showing these RDA components as well as monitoring boreholes and flumes are presented in Figure 1.

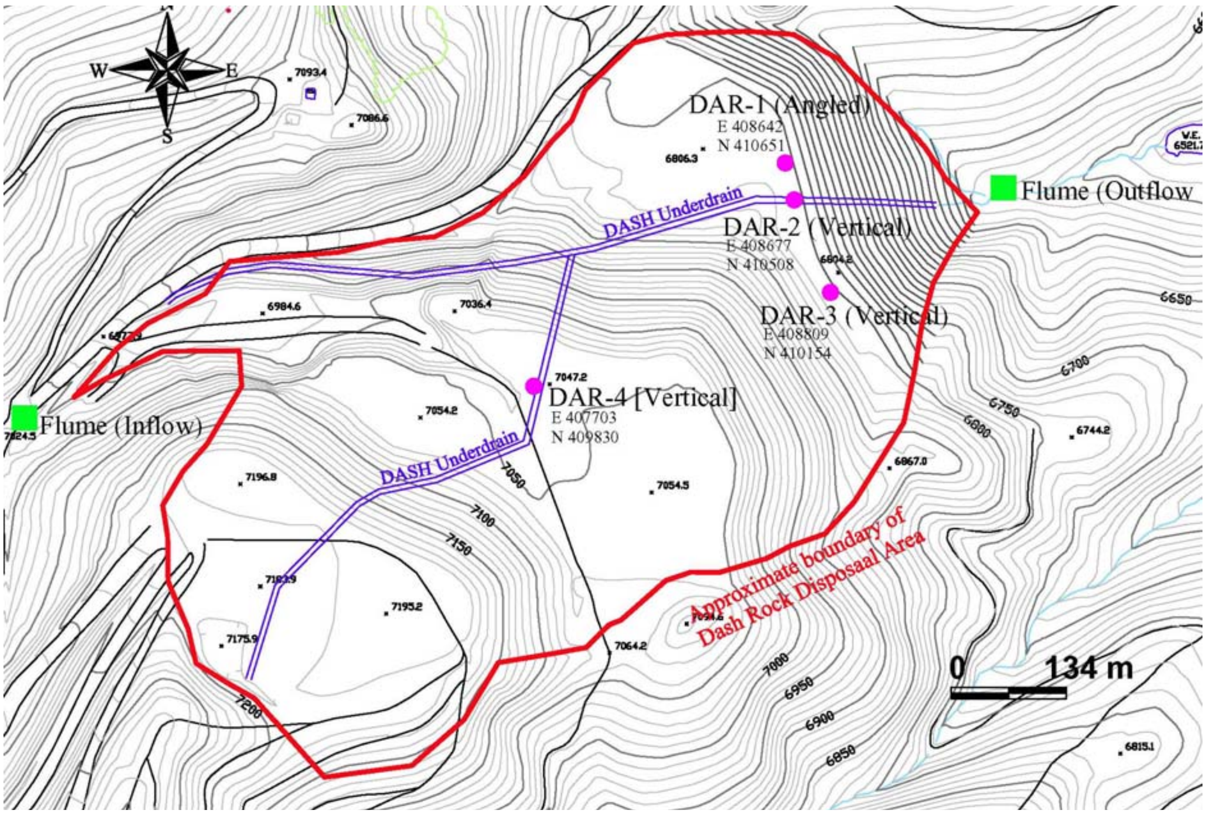

Figure 1. DASH Rock Disposal Area Borehole and Monitoring Locations

State of Nevada environmental regulators had expressed concern whether infiltration of precipitation and air flux through the steep rock-covered DAR slope face is generating and releasing high sulfate water; and had recommended that the DAR face be regraded to a 3(H):1(V) slope angle and reclaimed. In response, Queenstake Resources USA, Inc. (Queenstake) and GeoSystems Analysis, Inc. (GSA) proposed a study to monitor and compare conditions within the DAR face and the interior of the DASH RDA to determine the influence of the DAR slope face on high-sulfate water quality in the under-drain.

This paper describes vadose zone, groundwater, and surface water monitoring methods; results and analyses of temperature, oxygen, water content, and water quality monitoring data; and conclusions regarding the impact of the DAR on under-drain water quality as well as implications for the design, closure, and management of waste rock facilities

METHODS AND MATERIALS

Monitoring wells were installed in April and May of 2005. Details of this characterization and monitoring program are presented in GSA (2006):

- Drilling and sampling of four boreholes (DAR-1, -2, -3, and –4) for waste rock geochemical, physical, and hydraulic properties.
- Instrumention of boreholes to monitor temperature, gaseous oxygen, water content, and pore water and under-drain water quality within the DASH RDA.
- Monitoring of water levels and water quality in the under-drain system via two boreholes (DAR-2 and -4) that penetrate the under-drain.
- Installing flumes upstream and downstream of the under-drain system and monitoring air and water temperature, electrical conductivity (EC), and water level/flow in the flumes.

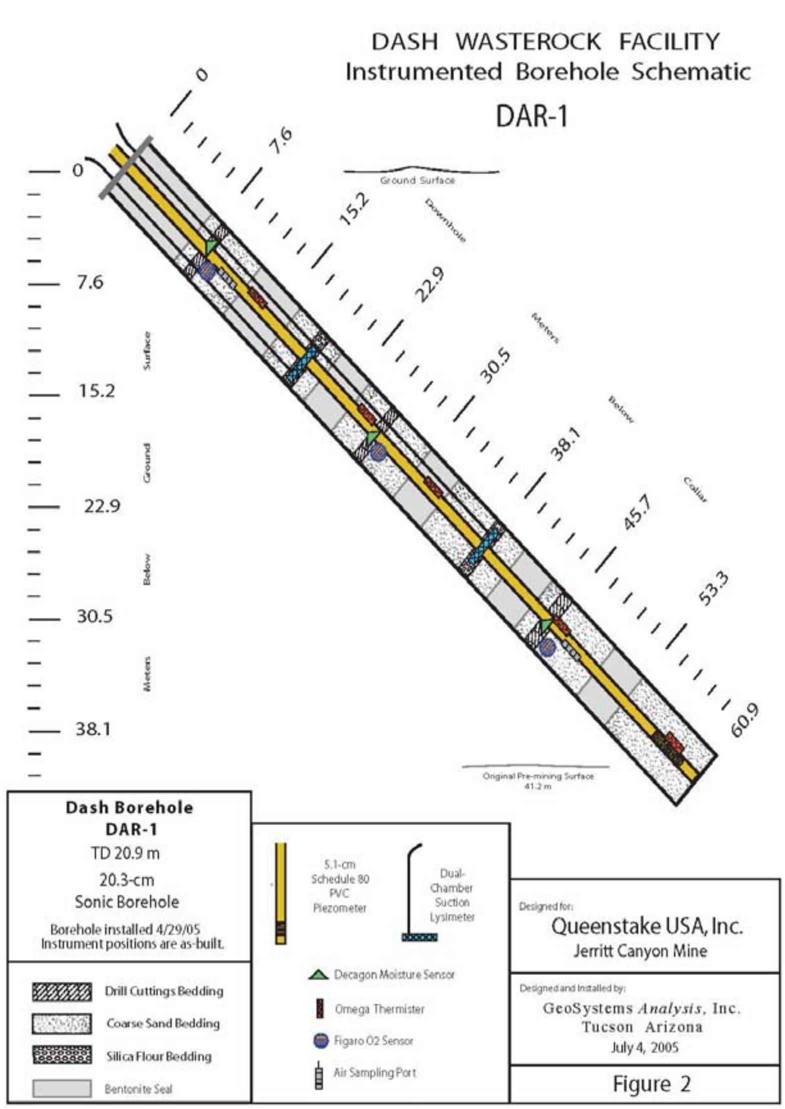

Figure 2. DAR-1 Instrumented Borehole Schematic

The four boreholes were located and constructed as follows:

DAR-1: drilled on the first bench above the DAR face at an angle approximately parallel to the DAR face: offset to the north of the under-drain.

DAR-2: drilled vertically on the same bench as DAR-1; intercepts the under-drain.

DAR-3: drilled vertically on the same bench as DAR-1 and –2; south of the under-drain.

DAR-4: drilled vertically on the second bench above the DAR face; intercepts the south branch of the under-drain channel approximately 450 m upstream from the DAR face.

Each of the four boreholes was completed with the monitor well instruments listed below.

- Two air piezometers for air sampling.
- Two suction lysimeters for unsaturated zone pore water sampling and chemical analysis.
- Three oxygen sensors for determining the percentage of oxygen in air.
- Two (DAR-3) or three (DAR-1, -2, and -4) water content sensors.
- Three (DAR-3), four (DAR-1 and DAR-2), or five (DAR-4) temperature sensors.

In addition, DAR-2 and DAR-4 were instrumented to collect water quality samples and to collect water level and EC data in the under-drain system. The instruments listed above were distributed throughout the depth of each vadose monitor well to facilitate measurement of existing gradients. For example, instrument depths within DAR-1 are shown in Figure 2. Vadose monitor well and flume data and water quality samples were collected periodically from the monitoring sites from May 5, 2005 to October 4, 2007.

RESULTS

Temperature Data

Temperatures at all instrumented depths from DAR-1, -2, and -3 either remained below, or decreased below approximately 27°C by the end of 2007. This temperature trend is illustrated in Figure 3 for DAR-1. These well temperatures were higher than the ambient air temperature, indicating that pyrite oxidation was occurring in the RDA material around these boreholes. However, the relatively moderate and decreasing temperatures over the entire monitoring period indicate that oxidation rates at these vadose monitor wells were relatively low. Conversely, observed temperatures in DAR-4 (Figure 4), located in the center of the DASH RDA, were much higher, indicating higher waste rock oxidation rates.

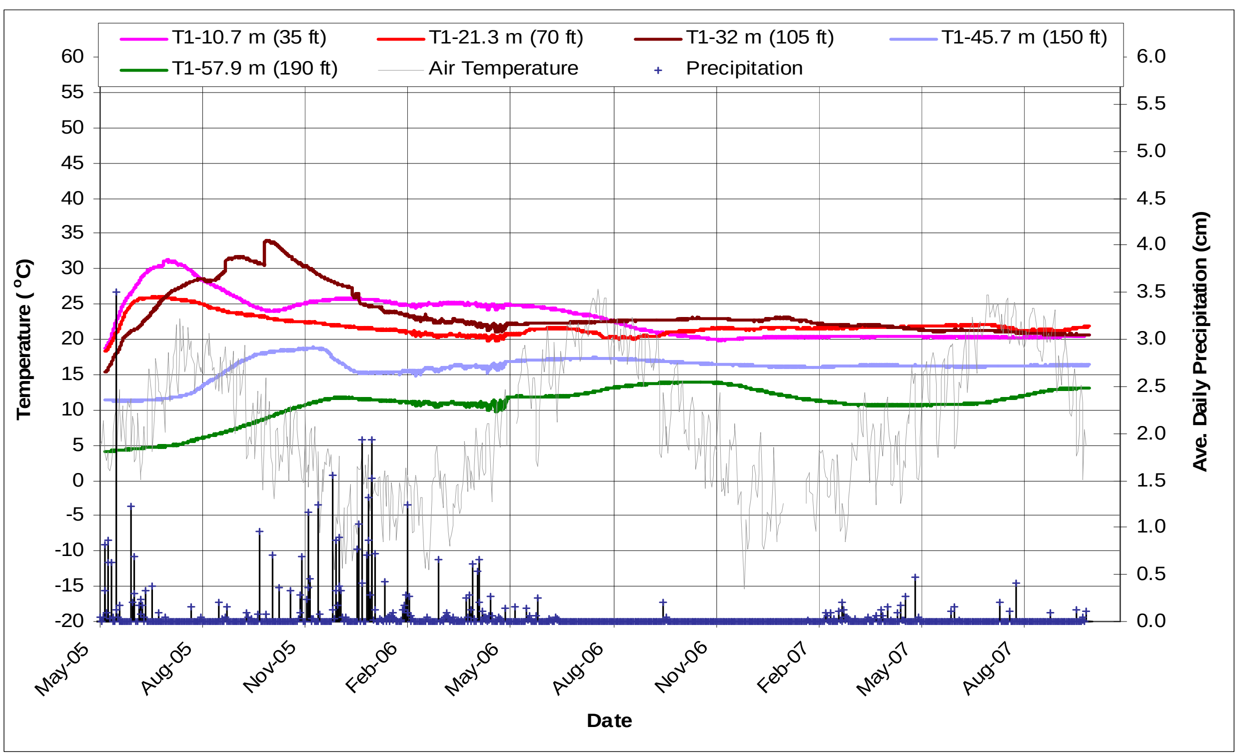

Figure 3. DAR-1: Temperature over time, by depth

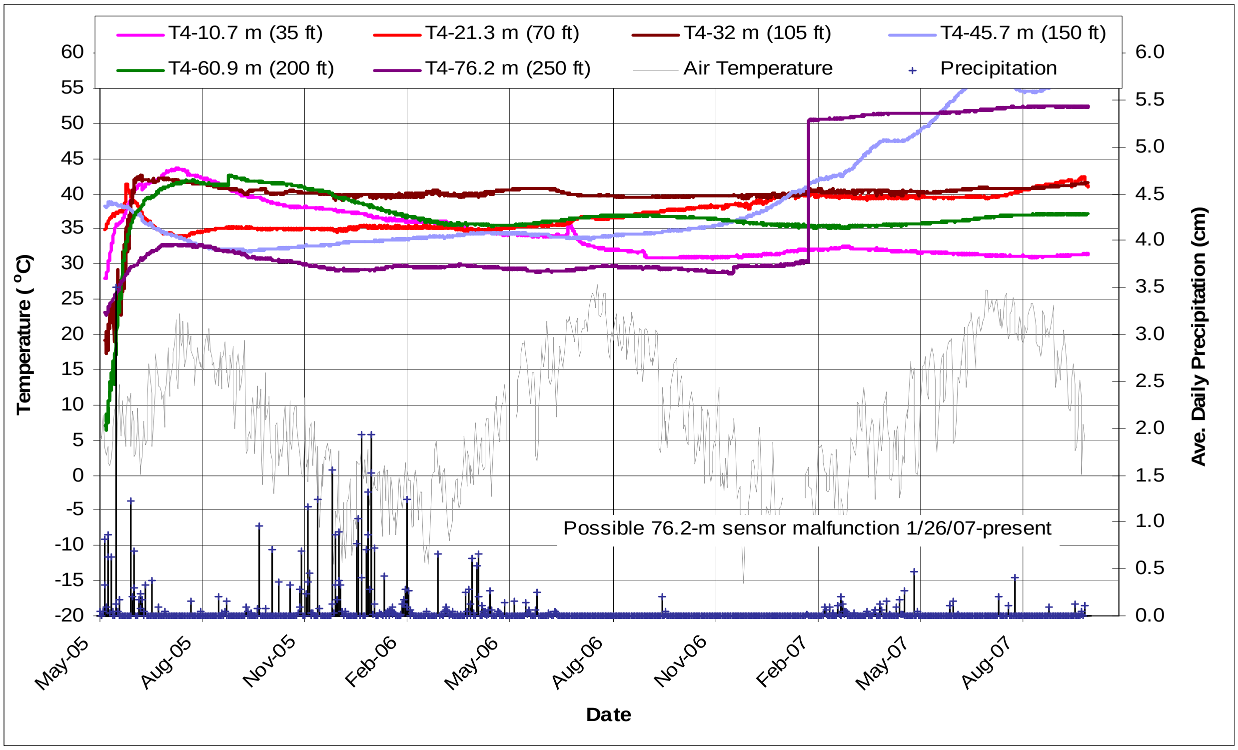

Figure 4. DAR-4: Temperature over time, by depth

DAR-1, the sloping well along the DAR face, exhibited the lowest temperatures at the deepest depths from the ground surface (Figure 3), indicating that cool air flows into the base of the DAR face and is warmed as is rises through the RDA material. Many of the DAR-1 and DAR-2 temperature sensors exhibited diurnal temperature changes during the February to May 2006 snow melt period (Figure 3), with the diurnal change most pronounced in the deepest DAR-2 temperature sensors (data not shown) in proximity to the under-drain system. These data indicate that cooling of the waste rock was occurring from evaporation of moist, cool air entering the waste rock from the exterior of the dump, and in particular, the under-drain system.

Oxygen Content Data

Oxygen levels at nearly all depths in all DAR monitor wells also show a seasonal response to ambient air temperatures, with higher oxygen percentages during the cooler fall and winter months and lower percentages when temperatures rise in the summer, as illustrated in DAR-2 and DAR-4 in Figures 5 and 6, respectively. Increased air (oxygen) movement into the DASH RDA during the winter is due to the large temperature differences (gradients) between the atmosphere and the warmer DASH RDA materials. The greatest air-flow (replenishment of oxygen) in DAR-2 is observed in the deepest sensors closest to the under-drain.

The DAR-4 sensors showed lower oxygen levels (Figure 6) and higher temperatures (Figure 4) indicating higher waste rock oxidation rates compared to the other vadose monitor wells. DAR-4 also exhibited higher reduced sulfur values in drill cuttings than DAR-1, -2, and –3.

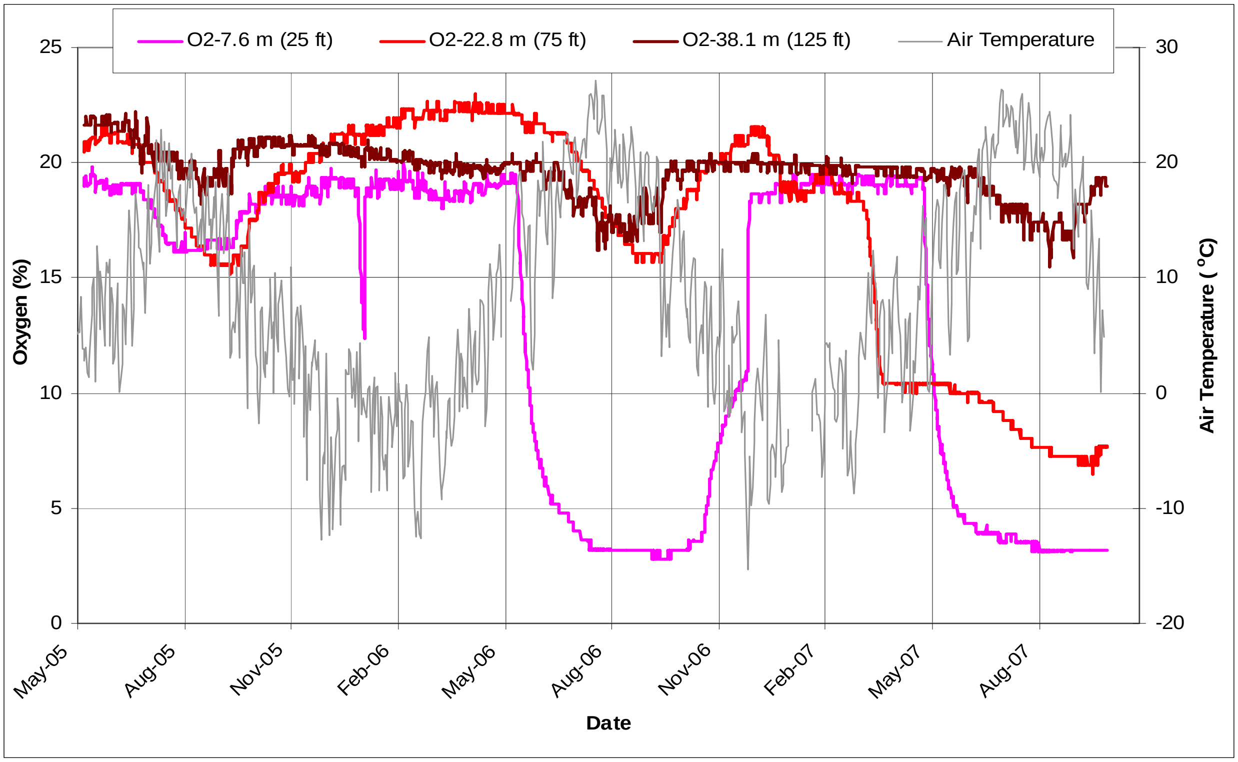

Figure 5. DAR-2: Oxygen percentage over time, by depth

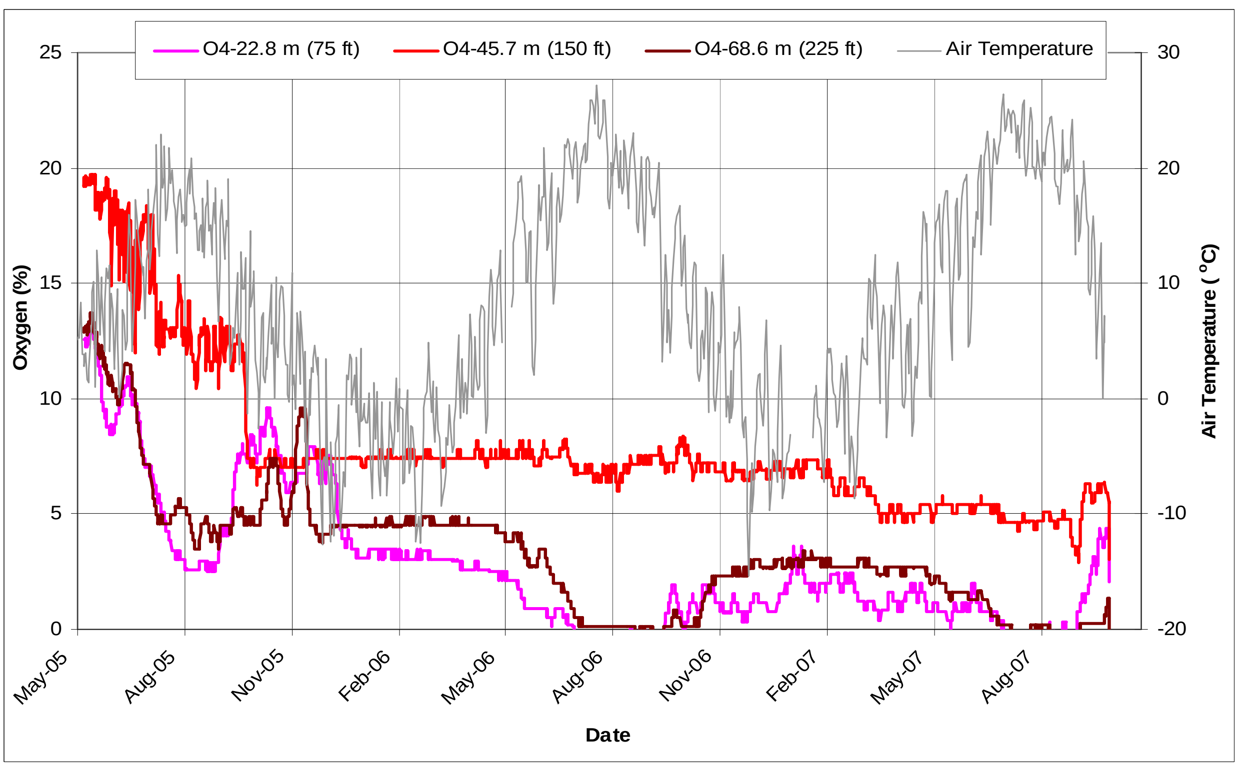

Figure 6. DAR-4: Oxygen percentage over time, by depth

Water Content Data

The DAR-1 (Figure 7) and DAR–2 water content sensors generally showed increasing water content at depth, whereas, DAR-3 and DAR-4 water contents were relatively stable. The decreasing temperature, higher oxygen content, and increasing water content trends in DAR-1 and DAR-2 support the hypothesis that moist air circulates from the base of the DAR into the DASH RDA at these locations. DAR-3 showed much weaker trends in water content, oxygen content, and temperature, indicating that air circulation is not as significant as in DAR-1, located near the DAR face, or DAR-2, located above the under-drain. DAR-4 showed variable trends at depth for water content, oxygen, and temperature. However, air circulation at DAR-4 must be significant to support measured temperatures and oxygen levels. This air circulation may be due to under-drain air circulation or to air flow from reclaimed side-slopes between the first and second benches.

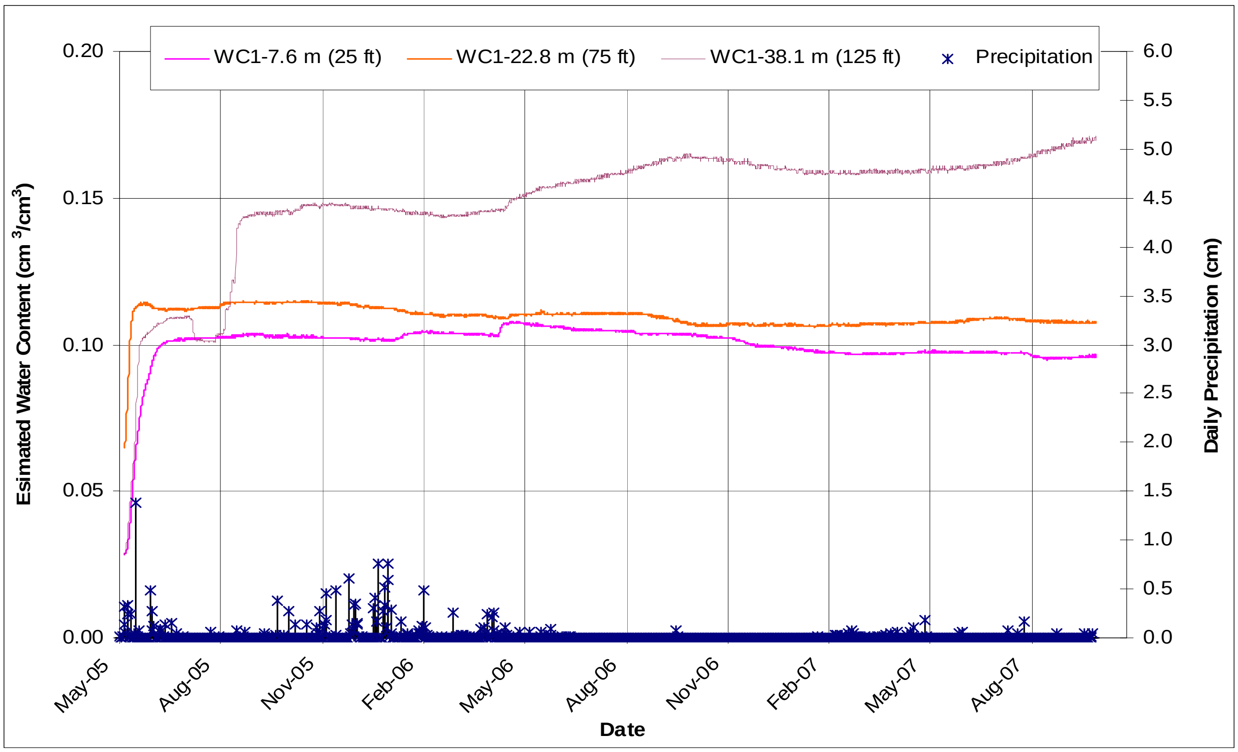

Figure 7. DAR-1: Estimated water content over time, by depth

Under-drain and Flume Temperature, Water Level, and EC

In the DAR-2 under-drain, water levels varied from approximately 0.4 m to 1.2 m above the native ground surface. Electrical conductivity fluctuated from 1,500 to 13,000 µS/cm, generally correlated to high and low water levels in response to snow melt and dry summer conditions, respectively. DAR-4 water and EC levels were not responsive to snow melt and dry conditions, indicating that the south branch of the under-drain experiences less flow than the main branch penetrated by DAR-2.

The lower flume showed a maximum flow rate of approximately 3,409 liters/minute and EC values ranging from 500 to nearly 12,500 µS/cm (Figure 8). During the early spring of 2006, the lower flume EC values decreased in response to high measured flows, whereas, in late spring 2006, after the upper flume had ceased flowing, lower flume EC values increased slightly after peak flows. These data indicate that high flows coming exclusively from the DASH RDA contribute high salinity water, which is diluted by flow from the upper flume. Very low flow periods from November 2006 to August 2007 resulted in EC values increasing to the highest levels monitored.

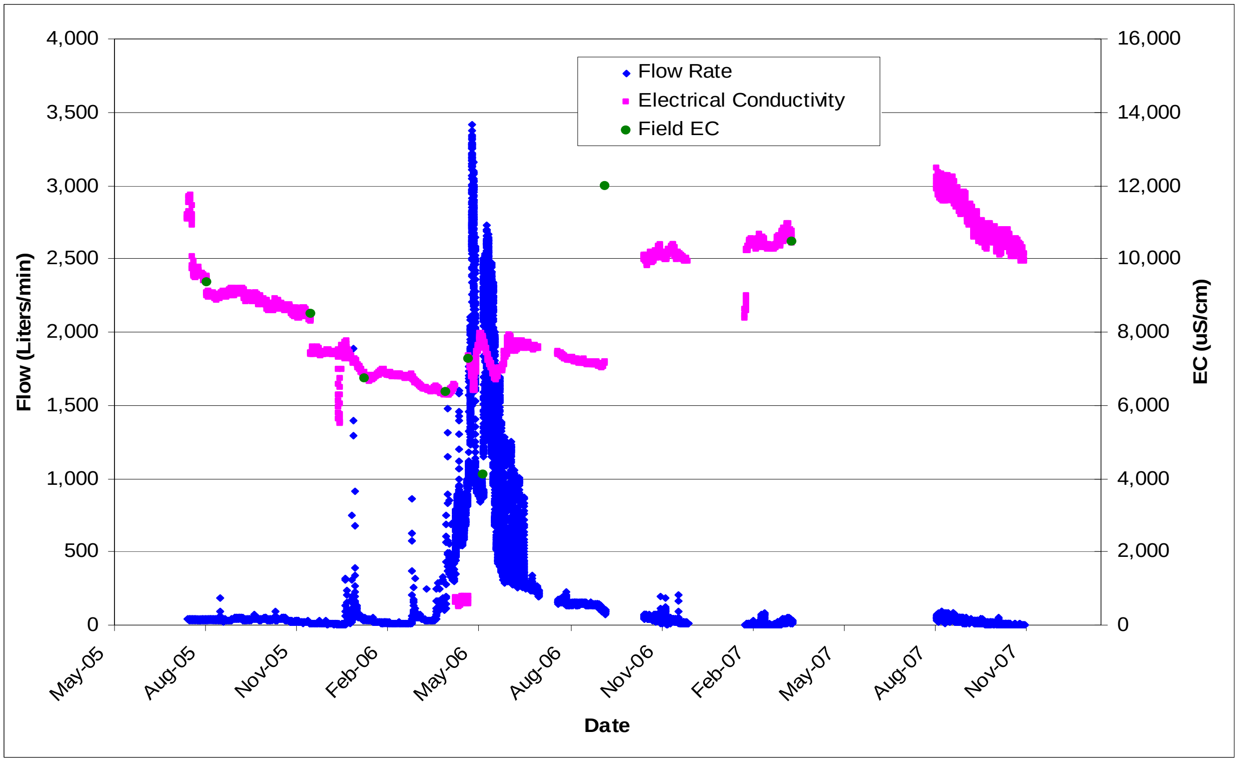

Figure 8. Lower flume: Flow rate and electrical conductivity over time

Lysimeter, Under-drain and Flume Water Quality Samples

The pH of samples collected from all points throughout the monitoring period remained above 7.4 with no discernable trends. Sulfate concentrations in all lysimeters in DAR monitor wells, in DAR-2 and DAR-4 under-drains, and in upper and lower flumes are summarized in Figure 9. Sulfate levels in the DAR-1, -2, and –3 lysimeters appeared relatively stable, ranged from 3,500 to 11,000 mg/l, and were within the range of sulfate values collected from the DAR-2 under-drain and the lower flume. Sulfate concentrations in both DAR-4 lysimeters approximately doubled from May 2006 to June 2007 and this well showed the highest sulfate levels from any location. There were also significant increases in other water quality parameters in DAR-4 lysimeter samples during this time period.

Water quality data showing that sulfate values at the DAR-1 and -2 lysimeters and at the lower flume are approximately 2,500 mg/l (or more) lower than sulfate values at the DAR-2 under-drain indicate that underdrain water quality improves between DAR-2 and the lower flume. In addition, samples from the under-drain at the base of DAR-2 showed higher sulfate values than DAR-2 lysimeter samples, suggesting greater sulfate contribution from upstream in the under-drain than from RDA material around DAR-2.

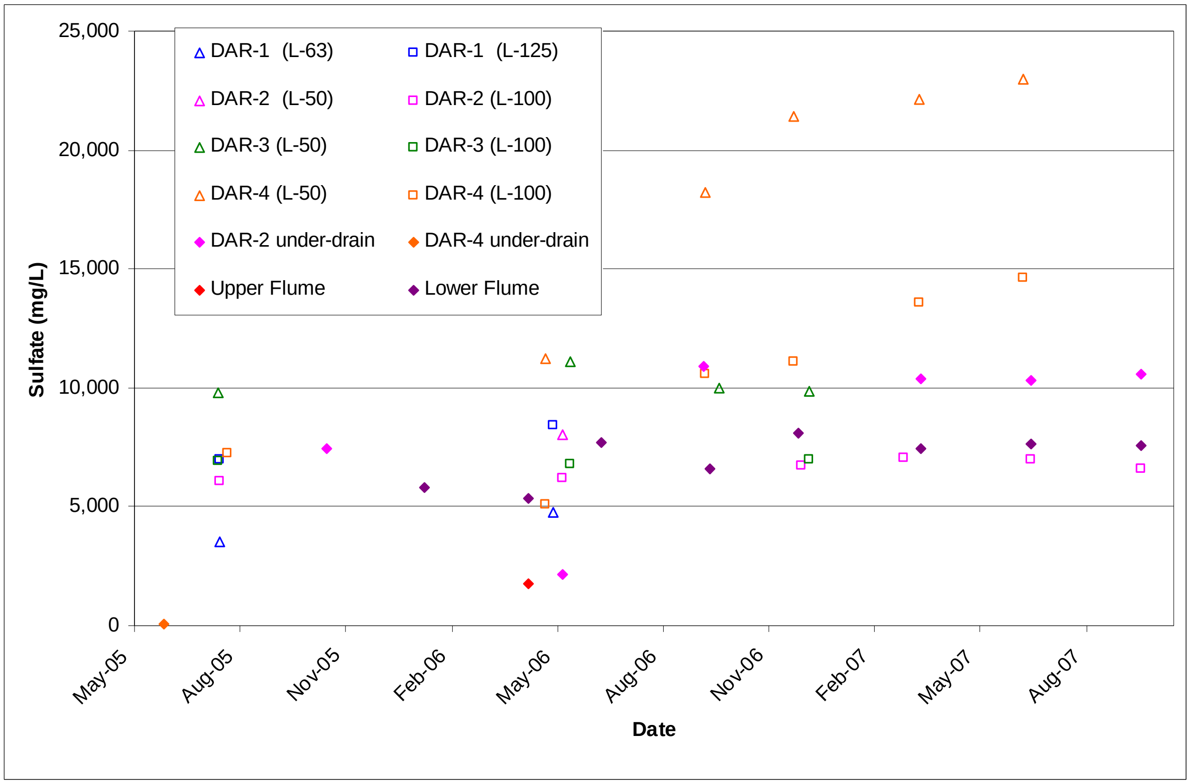

Figure 9. Sulfate levels in lysimeter and under-drain water samples over time

In general, the lower flume samples met the primary drinking water quality standards except for arsenic and occasionally nitrate, at the standards of 0.01 mg/l and 10 mg/l, respectively. High arsenic levels were measured in several samples at the DAR-1 38.1-m (125-ft) lysimeter and the single upper flume sample, however, generally low arsenic values at other sampling points indicate that arsenic could be primary the insoluble arsenic species, As_2O_3.

CONCLUSIONS

All vadose monitor wells show evidence of pyrite oxidation, sulfate generation, and moisture flux from the DASH RDA. However, infiltration of precipitation into the DAR slope face does not appear to be the primary contributor to high sulfate levels present in outflow from the facility. Air flow to the DAR-1, -2 and -3 vadose monitor wells appears to be primarily from the base of the DAR or from the under-drain, with air flow effects most significant in DAR-2, less significant in DAR-1, and least significant in DAR-3. In comparison, DAR-4, near the center of the DASH RDA, exhibits lower oxygen, higher temperatures and higher pore water sulfate concentrations, which are consistent with high sulfide oxidation rates. These data taken together suggest that the interior of the DASH RDA, up-gradient from DAR-2 (including the area around DAR-4), may be the primary source of sulfate exiting the DAR face at the toe of the DASH RDA. Moreover, the data also indicate that the DASH RDA under-drain system promotes air flow into the RDA, which may, in turn, increase oxidation rates within the RDA. Consequently, re-grading and reduction of the DAR slope may not be sufficient to reduce air flow into the facility. Additional evaluation of the reduction of air flow into the under-drain system is planned.

Water percolating through the DASH RDA also facilitates sulfur oxidation and the transport of sulfate to the accessible environment beyond the toe of the RDA. Future work will evaluate the effects of increasing the depth of the store-and-release soil cover and planting of additional vegetation on the DASH RDA.

REFERENCES

GeoSystems Analysis, Inc., 2006. Evaluation of potential sulfate generation in the DASH Angle-of-Repose slope face: Installation report and preliminary data presentation. Prepared for Queenstake Resources USA, Inc., December 13, 2007.