The AA leach pad cover design – a successful reclamation project at a Nevada gold mine

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Abstract The AA Leach Pad at Barrick Goldstrike Mine was reclaimed using an evapotranspiration (ET) cover designed to limit meteorological infiltration. Monitoring of the sensors installed in the facility continued for eleven years. Data indicates that the cover is limiting net percolation to less than 1 % of precipitation. AA Leach Pad is the first large-scale closed mine waste facility which has been robustly monitored for a long time in Nevada. Results from the study provide an understanding of ET cover system performance for closure of other mine waste facilities, and offer guidance for ET cover system requirements in other arid regions.

Keywords Evapotranspiration (ET) cover, cover performance, leach pad, mine closure

Introduction

The Barrick Goldstrike Mines Inc. (BGMI), located 60 km northwest of Elko in north-central Nevada, is a large open pit and underground gold mining operation. The AA Leach Pad (AA Pad) at BGMI operated from 1987 through 1999 and at the end of operation consisted of 55 Mt of run-of-mine leached ore. The facility covers approximately 100 ha.

The climate at the site is semi-arid with hot summers and cold winters. Average annual daily temperature is about 9 °C. The majority of precipitation falls between December and May as snow. Annual precipitation is about 300 mm. Average annual pan evaporation is about 1500 mm.

The AA Pad was reclaimed in 2000/2001 using an evapotranspiration (ET) cover. ET extracts water from the cover layer predominantly during warmer periods (summer and fall), leaving a moisture-depleted plant root zone by fall, which then stores water in winter and spring.

Cover Design

Hydrological Design and Test

1. Laboratory Tests: Hydrologic property tests, including, saturated hydraulic conductivity (K_{sat}) and soil water characteristic curves (SWCC) were originally conducted on leach ore material and potential cover materials (Tertiary Carlin Formation Siltsone (TCS) and topsoil) at Daniel B. Stephens & Associates, Inc. (DBS) in Albuquerque, New Mexico. In the laboratory tests, the gravel portion was first removed from the samples and the test results were then adjusted with a published gravel-correction method. To avoid the potential errors induced by gravel-correction, leach pad ores and potential cover materials were retested with the gravel portion included using large diameter columns (150 × 300 mm) at GeoSystems Analysis, Inc. in Tucson, Arizona.

2. One-dimensional Simulation: Several unsaturated numerical codes were evaluated for the cover design and SoilCover (Geo-Analysis 1997) was chosen for the simulations. SoilCover is a one-dimensional (1D), finite element package that models transient conditions. The model is based on Darcy's and Fick's Laws, which describe the flow of liquid water and water vapor, and Fourier's law to describe conductive heat flow in the soil profile and soil/at-

mosphere boundary. The numerical analyses demonstrated that topsoil and TCS, have sufficient water holding capacity to be used for an ET cover. Additionally, the leach pad material was shown to be suitable as a capillary barrier layer when overlain by TCS/topsoil materials. The numerical analyses concluded that 90 cm of TCS/topsoil cover placed over the leach pad material would effectively minimize meteoric water percolating through the reclaimed leach pad (Zhan *et al.* 2000).

3. Two-dimensional Simulation: Since the AA Pad has long slopes, the real behavior of a cover system can be different than the idealized 1D model. A particular concern was moisture that builds up above the cover-leach ore interface could flow along the slope, and at a certain point the cover material could become wet enough to allow infiltration into the coarser leach ore. This point is called the Down Dip Limit (DDL) point. In order to examine whether or not the DDL would be reached, a two-dimensional (2D) simulation was conducted using the software HYDRUS2D (Simunek *et al.* 1999). The 2D simulated results demonstrated that in a normal precipitation year net percolation (infiltration minus ET) into the cover was close to zero and suction heads at the cover-leach ore interface were higher than the water entry value of spent ore material. Therefore, it was concluded the DDL will not occur along the slope under these conditions. In order to evaluate ET cover behavior during extreme precipitation events a separate risk assessment simulation was performed in which 10 days with no evapotranspiration was assumed and three 100-year return frequency storm events occurred Day 1, 2 and 3 respectively. The risk assessment simulation predicted that at all locations along the slope, the water content and pressure profiles at the bottom of the cover did not increase significantly to exceed the water pressure entry value of the leach ore. In other words, the capillary barrier would not be broken and water would not seep into the leach ore under these extreme precipitation conditions (Zhan *et al.* 2001a).

4. Pilot Field Test: Prior to full-scale cover installation a pilot study was conducted on a small-scale test cover plot placed on the AA Pad to examine the cover performance simulated rainfall conditions. For this test, a 7 × 7.5 m cover test plot with a thickness of 60 cm of TCS was constructed on the 3(H):1(V) east-facing slope of the AA Pad (Fig. 1). After the cover was put in place, drip irrigation tubes were installed on the surface of the cover. Water content sensors (time-domain reflectometry, TDR) and matric potential sensors (heat dissipation sensors, HDS) were installed on the lower part of the test slope since surface water run on makes these areas more susceptible to net percolation. Performance testing simulated intermittent irrigation of Approximately 227 cm of water (equal to about 7.6 years of precipitation) during the period of July to September 2000. The 1D numerical model was then calibrated to the observed data (Zhan *et al.* 2001b).

The volumetric water content of the cover reached as high as 0.30, during irrigation periods. Simulated volumetric water content corresponding to wilting point of 4 MPa, which is representative of desert plant communities in the Great Basin (Zhan *et al.* 2006), was 0.17, in-

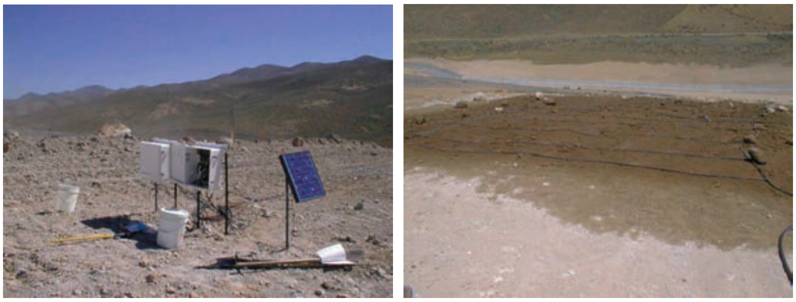

Fig. 1 *AA Leach Pad 2000 pilot field test: irrigated area (left) and data acquisition system (right).*

dicating a storage capacity of the cover equal to 0.13 cm^3/cm^3 (0.30 – 0.17). Consequently, a TCS cover thickness of 90 – 120 cm was predicted to be able to store 12 – 16 cm of water, independent of evaporation and lateral drainage. Based upon this analysis, the holding capacity of the cover would have sufficient volume to retain 3 continuous one-hundred year storm events (approximately 24 cm of water), assuming half the precipitation runs off the cover. Therefore, the cover would operate as designed even under extreme precipitation conditions.

Engineering Design

The engineering aspects associated with the closure of the AA Pad facility consisted of the following:

- Design of a permanent toe drain facility that would collect and isolate any water flux from the reclaimed heap leach pad over time.
- Preparation of a grading plan that would provide for adequate support and function of the soil cover, optimize revegetation and reclamation potential, minimize erosion risk and sediment yield, and provide a landform compatible with the natural landforms.
- Design of a drainage network on the cover surface which would safely and efficiently collect and remove surface runoff from the new landform, incorporating a natural looking configuration of drainages for the control of erosion and sediment yield (Fig. 2).
- Balancing earthwork quantities and construction pathways to minimize construction costs and provide adequate space for the ET cover layer construction.
- Design of a perimeter storm drainage network capable of safely collecting and removing storm water runoff from the recontoured heap surface.

Details about engineering design can be found from Myer *et al.* (2001). The geotechnical integrity of the cover system remains unchanged after having been in place for more than 10 years and experiencing numerous storms of varying intensity levels.

Fig. 2 *Freshly reclaimed AA Leach Pad showing drainage network on the cover surface (looking northwest).*

Vegetation Design

Planted vegetation at AA Pad included grass, forbs and shrubs. The seed mix was based on 5 years of site specific research of vegetation data. In March of 2001, the seedbed was prepared and then broadcast seeded 18 kg/ha of the selected seed Mix and then harrowed a second time to lightly cover seed. An organic mulch and tackifier were hydraulically applied over the entire unit at a rate of 9 t/ha and 168 kg/ha, respectively (Fig. 3).

Cover Monitoring Instrumentation

In different areas on the facility, the cover is composed of different materials of different thicknesses, with variable slope positions, solar aspects, and proximity to drainage channels. Cover system performance monitoring systems were installed between 2001 and 2005 on the AA Pad. Fourteen monitoring stations were located along three transects (East, West, and South, Fig. 2), with six, five, and three stations, respectively. At each transect, sensor stations were located near the crest, mid-slope, and foot-slope of the AA Pad, and in addition, adjacent to stormwater runoff channels at the East transect. Instruments include HDS to measure matric potential and temperature,

Fig. 3 *AA Leach Pad plant seeding (left) and organic mulch application (right).*

TDR or capacitance (ECH_2O) sensors to measure water content. Schematic diagrams showing sensor installation are shown in Fig. 4. Because both water content and matric potential sensors were installed as pairs at same depths, *in situ* SWCC could also be obtained.

Monitoring Data

Precipitation

Precipitation totals over the monitoring period from water year (WY, Oct 1 through September 30) 2002 to WY 2012 ranged from 201 to 493 mm, averaging 332 mm, 16 mm higher than the 316 mm long-term average. WYs were classified into average, wet, or dry years by defining a wet year as one with a WY precipitation total greater than one standard deviation above the long-term average, and a dry year as one with a total less than one standard deviation below the average. WYs 2005, 2006 and 2011 were wet years; 2008 was a dry year; and all other WYs were average years.

Vegetation

More than 10 years of AA Pad vegetation data indicates that plant succession is progressing in a positive direction, and the AA Pad vegetation appears to be stable and self-sustaining, as well as resistant to erosion. Total plant cover in 2011 was 52.1 % with 44.4 % being derived from perennial species (Fig. 5). By comparison the reference area only displayed 19.1 % perennial cover out of 58.4 % total plant cover. An example of the exemplary status of this reclamation effort is the 5.6 % composition contributed by bitterbrush (Purshia tridentata), an extremely important, but difficult to establish component of the northern Nevada rangeland.

Drain-down data

AA Pad is a synthetically lined facility and its drain-down data have been collected on a regularly basis: bimonthly or monthly through 2009 and quarterly since January 2010. Drain-down data are missing from January through November 2006. Data generally indicate seasonal increases in drainage rates in response to spring snowmelt (March-May) followed by declining rates over the summer and fall months.

Assuming that the October drain-down rates approximate residual drainage from the leach heap (baseflow) drain-down rates exceeding baseflow should then approximate the area-averaged net percolation rate through the AA Pad cover system into the underlying leach ore. Fig. 6 shows the average difference between the baseflow rate and the increased drainage rates in response to spring melt was 3.2 mm/a (0.94 % of precipitation) from October 2002 to October 2012.

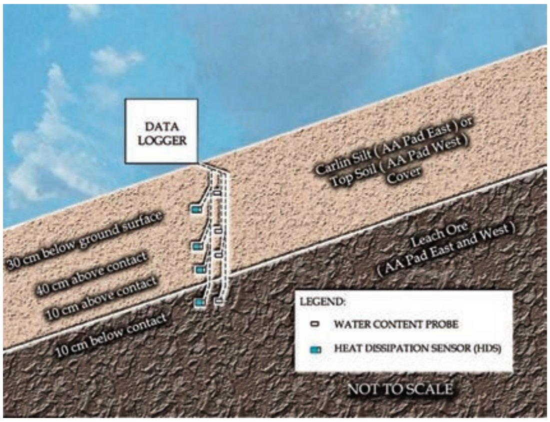

Fig. 4 *Installation schematic for cover performance monitoring stations.*

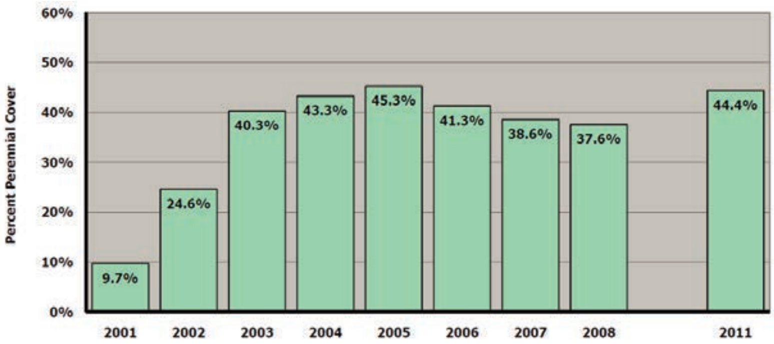

Fig. 5 *AA Leach Pad Perennial Plant Cover (2001–2011).*

High flow rates measured in December 2006 in response to the very wet precipitation year, indicate that significant net percolation may also have occurred in response to the above-average precipitation in WY 2006.

Estimates of Net Flux

After 11 years of monitoring, the cover performance is well understood. Consequentially, all stations were decommissioned in October 2012. Net percolation flux is defined as meteoric water that infiltrates into the cover and is not removed by ET. Net percolation flux will eventually exit the base of the AA Pad as drain-down.

Net percolation flux of meteoric water near the cover-leach ore contact was estimated at each monitoring station by calculating the 1D vertical flux. Flux rates were calculated from matric potential data measured from the two deepest HDS located at each station, together with matric potential versus water content relations (SWWC) and saturated and unsaturated hydraulic conductivity values measured in the laboratory. Flux rates calculated in this manner are referred to as matric-potential-based (MPB)-calculated flux.

The MPB-calculated flux data indicate that most flux occurred in wet WYs 2005, 2006, and 2011; whereas during average WYs, near-zero MPB flux values were calculated at most stations; stations near stormwater runoff channels recorded the highest MPB-calculated flux values of all the AA Pad stations. Weighting the MPB-calculated flux for the entire AA Pad with respect to the amount of surface area occupied by each monitoring station slope position (crest, mid-slope, foot-slope, and channels) is approximately 2.2 mm/a (0.63 % of precipitation). This value is very similar to the esti-

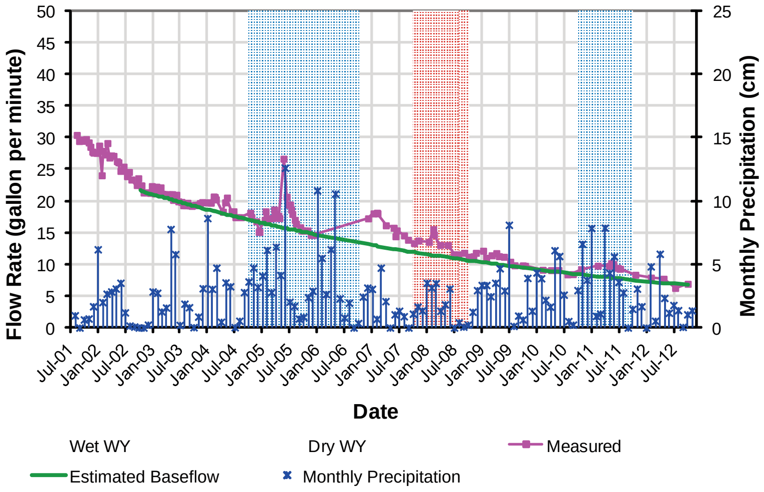

Fig. 6 *Predicted and measured drain-down from AA Leach Pad.*

mated net percolation flux calculated from the draindown data.

Conclusions

Eleven years of cover monitoring data at AA Pad indicate that the cover is limiting average annual net percolation flux through the cover to 2.2 mm/a (0.63 % of precipitation), based on the area weighted average MPB-calculated flux. Estimated average annual flux from seasonal increases in AA Pad drain-down rates in response to spring melt are slightly higher than the MPB-calculated flux, being 3.2 mm/a (0.94 % of precipitation). Considering the small difference, it is reasonable to conclude that net peculation through the cover is less than 1 % of the precipitation.

Eleven years of vegetation surveys indicate that plant succession is progressing in a positive direction and plants within these areas are self-sustaining and reclaimed sites appear at least as stable and resistant to erosion as nearby, undisturbed areas.

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