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TECHNICAL ARTICLE

11 Years of Evapotranspiration Cover Performance at the AA Leach Pad at Barrick Goldstrike Mines

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Abstract The AA Leach Pad at Barrick Goldstrike Mine was reclaimed using an evapotranspiration (ET) cover designed to limit the infiltration of precipitation into the facility. Water content and matric potential sensor stations were installed in the cover and underlying leach material after cover system placement. Monitoring of the sensor nests continued for 11 years. Data indicates that the cover is performing well, limiting net percolation to less than 1 % of annual precipitation. The AA Leach Pad is the first large-scale closed mine waste facility that has been robustly monitored for a relatively long time in Nevada, USA. The results provide an understanding of ET cover system performance for closure of mine waste facilities and offer guidance for ET cover system requirements in other arid regions.

Keywords Store-and-release cover · 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, at which time it comprised 55 million metric tons (t) of run-of-mine leached ore. The facility covers approximately 100 ha and has a maximum height of approximately 90 m.

The AA Pad was reclaimed in 2000/2001 using a monolayer evapotranspiration (ET) cover to reduce net percolation, limit erosion, and support a robust plant community. The AA Pad ET cover design relies on a 1.2 m thick fine-textured cover material layer overlying coarse leached ore material. The cover layer stores water during the wetter winter and spring months until the plant growing period (summer and fall), depletes the soil moisture via ET by the following fall.

Cover systems evolve over time as the cover material develops in response to processes such as freeze/thaw cycles and plant root propagation and decay, which result in a decrease in soil bulk density and possibly the development of soil macro-pores (Benson et al. 2011). Additionally, the plant community changes over time (species succession), and transpiration increases as the plant community becomes better developed and root depth and density increases. BGMI monitored water balance and vegetation performance from the AA Pad cover system for 11 years. This paper presents long-term cover system performance data from the AA Pad including results from water balance instrument monitoring, rooting surveys, and in-situ hydraulic testing.

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Materials and Methods

Site Characteristics

The climate at the site is semi-arid with hot summers and cold winters. Weather data has been collected since 1990 at

Table 1 Average North Block weather station data, 1990–2012

Months	Precipitation (mm)	Temperature (°C)	Potential evapotranspiration (mm)
January	32.0	0.8	51
February	22.4	2.7	56
March	30.0	3.2	72
April	38.3	9.9	103
May	44.5	12.8	127
June	22.4	19.1	157
July	8.9	22.8	173
August	5.4	23.1	164
September	13.1	16.3	118
October	19.7	9.0	85
November	24.5	−0.3	47
December	37.1	0.1	47
Total or average	298.2	9.9	1,199

the North Block weather station located approximately 5 km northwest of the AA Pad. Average annual daily temperature is 9.9 °C. Average annual precipitation and potential evaporation (PE) are 298 and 1,200 mm, respectively (Table 1). During the period of 1990 through 2012, annual precipitation ranged between 179 and 493 mm. Most precipitation occurs between December and May as snow.

Vegetation in areas surrounding BGMI is primarily sagebrush and grass. Wyoming big sagebrush is the dominant woody sagebrush plant; cool-season perennial grasses are the dominant herbaceous plants.

Cover System Hydrological Design

Potential borrow materials for the AA Pad cover system consisted of salvaged topsoil from the construction of the AA Pad and also salvaged topsoil materials or Tertiary-aged valley fill deposits (Tertiary Carlin Silt, TCS) that were removed as overburden from the mine pit. Placing a fine-grained material layer (TCS or topsoil) above a coarse-grained material (leached ore) can induce a capillary barrier effect. Under unsaturated conditions, the hydraulic conductivity of a coarse-grained material can be much lower than the hydraulic conductivity of a fine-grained material because of its reduced capability to retain water by capillary forces. Provided sufficient contrasts exist between the unsaturated hydraulic conductivities and soil water characteristic curve (SWCC) of the coarse- and fine-grained materials, flow through a cover with capillary barrier effects (CCBE) is minimized until the upper fine-grained material becomes nearly saturated. In a CCBE configuration, the coarse material layer serves as a hydraulic barrier, while the fine material serves as a storage layer.

The cover design was conceived and tested through the following process:

1. Laboratory Tests: Hydrologic and hydro-geotechnical property tests include dry bulk density, specific gravity, particle-size-distribution (PSD), saturated hydraulic conductivity (K_{sat}), and SWCC. To avoid potential errors introduced by gravel-correction, leach pad ores and potential cover materials were tested with the gravel portion included using large diameter columns (150 mm × 300 mm) at GeoSystems Analysis, Inc. in Tucson, Arizona. To more completely describe the relationship between soil water content, hydraulic conductivity, and matric potential, the SWCC measurements were used with the RETC code (van Genuchten et al. 1991) to fit van Genuchten (1980) parameters to the measured data. Fitted van Genuchten parameters are shown in Table 2.
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/atmosphere boundary (Wilson 1990). The numerical analyses demonstrated that both topsoil and TCS materials had 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 that moisture that builds up above the cover-leached ore interface could flow along the slope, potentially causing the cover material to become wet enough at a down-gradient point to allow infiltration into the coarser leached ore. This point is called the down dip limit (DDL) point (Ross 1990). 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

Table 2 van Genuchten (1980) parameters for cover and leached ore material

Material	K_{sat} (cm/s)	Residual water content (cm^3/cm^3)	Saturated water content (cm^3/cm^3)	Alpha (cm^{-1})	n (–)	m (–)	l (–)
Tertiary Carlin Silt	1.30×10^{-4}	0.09	0.27	0.02	1.35	0.26	0.5
Topsoil	1.52×10^{-4}	0.04	0.38	0.04	1.25	0.20	0.5
Leached ore	4.00×10^{-2}	0.091	0.23	0.162	1.88	0.47	0.5

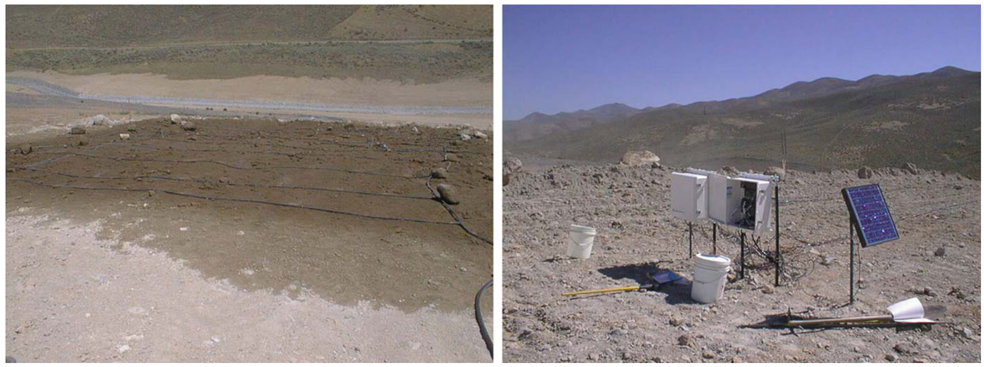

Fig. 1 AA Leach Pad 2000 pilot field test: irrigated area (*left*) and data acquisition system (*right*)

precipitation year, net percolation (infiltration minus ET) into the cover was close to zero and suctions at the cover-leached ore interface were higher than the water entry value of the spent ore material. Therefore, it was concluded that the DDL will not occur along the slope under these conditions. To evaluate ET cover behavior during extreme precipitation events, a separate risk assessment simulation was performed in which 10 days with no ET was assumed, and three 24-h, 100-year return frequency storm events (7.84 cm/day) 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 would not increase sufficiently to exceed the water pressure entry value of the leached ore. In other words, the capillary barrier would not be broken and water would not seep into the leached ore under extreme precipitation conditions (Zhan et al. 2001a).

4. Pilot Field Test: Prior to full-scale cover installation, a pilot-scale study was conducted on a small test cover plot placed on the AA Pad to examine the cover performance under simulated rainfall conditions. For this test, a 7 m × 7.5 m cover test plot with a thickness of 60 cm of TCS was constructed on the 3:1 (horizontal:vertical) 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 7.5 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 water content of the cover reached as high as 0.30 cm^3/cm^3 during irrigation periods. Simulated volumetric water content corresponding to a wilting point of 4,000 kPa, which is representative of desert plant communities in the Great Basin (Zhan et al. 2006), was 0.17 cm^3/cm^3 and indicated a storage capacity of the cover equal to 0.13 cm^3/cm^3 (0.30–0.17 cm^3/cm^3). 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 on this analysis, the holding capacity of the cover would be sufficient to retain three continuous one-hundred year storm events (≈24 cm of water), assuming half the precipitation runs off the cover. Therefore, the cover would operate as designed, even under extreme precipitation conditions.

Cover 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.

- 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 topography compatible with natural landforms.
- Design of a drainage network on the cover surface that 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.
- 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 re-contoured heap surface.

Details about the engineering design can be found in Myers 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. The largest storm event occurred June 1, 2002 and dumped more than 40 mm of water on the AA Pad within 20 min. This storm intensity far exceeded the predicted 500 year return period event.

Vegetation Design

The AA Pad was seeded with a mix of grasses, forbs, and shrubs (Table 3). 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 at 18 kg/ha of the selected seed mix, and then harrowed a second time to lightly cover the 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. Vegetation surveys to assess the resultant plant cover and species distribution on the AA Pad were performed annually from 2001 to 2011.

Cover Monitoring Instrumentation

The cover is composed of different materials of different thicknesses, with variable slope positions, solar aspects, and proximity to drainage channels. Cover system monitoring stations were installed between 2001 and 2005 on the AA Pad. Fourteen monitoring stations were located along east-, west-, and south-facing transects (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.

Table 3 Species in the seed mix

Great Basin wildrye	Bluebunch wheatgrass	Crested wheatgrass
Thickspike wheatgrass	Lewis flax	Indian ricegrass
Palmer Penstemon	Fourwing saltbrush	Big bluegrass
Sandberg bluegrass	Small Burnet	Forage Kochia
Winterfat	Wyoming big sagebrush	Regreen

Fig. 2 AA Leach Pad monitoring site and test trench locations

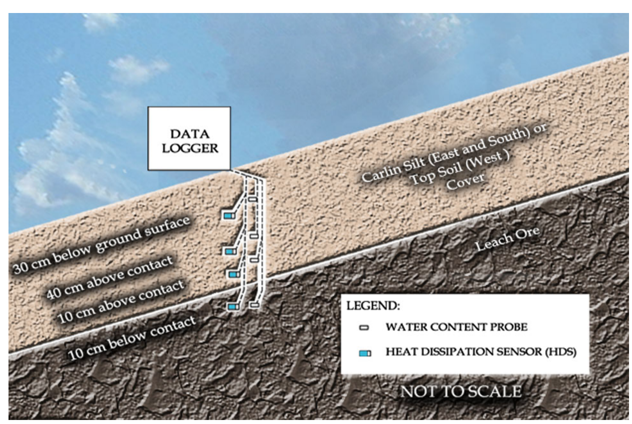

Fig. 3 Installation schematic for cover performance monitoring stations

Instruments included heat dissipation sensors (HDS, Campbell Scientific Inc., Logan, UT) to measure matric potential and temperature, time domain reflectometry (TDR, Campbell Scientific Inc., Logan, UT), and capacitance (ECH_2O, Decagon Inc., Pullman, WA) sensors to measure water content. Schematic diagrams showing generic sensor installation are shown on Fig. 3.

Rooting Survey and In-Situ Hydraulic Characterization

The cover system performance monitoring stations were decommissioned in mid-October 2012. In conjunction with the decommissioning of the cover monitoring stations, in-situ testing of cover material K_{sat} and plant rooting surveys in the cover and leached ore materials were completed near the three monitoring transects. Two trenches, one upslope (A) and one downslope (B), were excavated at each of the three transects, and two additional trenches were excavated adjacent to the East transect stormwater runoff channel sensor locations (D-A and D-B) as shown on Fig. 2. At each trench, K_{sat} tests were conducted at two depths using a Woodings infiltrometer (Soil Measurement Systems, Tucson, AZ) and soil K_{sat} calculated using the methods described in Wooding (1968).

Root surveys were completed in triplicate at each of the eight trenches. Root size and density were determined according to Schoeneberger et al. (2002), with density and size rankings modified slightly to account for the arid terrain and sparse vegetation. Across the wall of each trench, 10 cm by 10 cm areas were examined at six depths, three in cover and three in the leached ore to the maximum trench depth, in triplicate, for a total of 18 measurements per trench. Rankings assigned for root density and root size are provided in Table 4.

Table 4 Root density and root size rankings

Root density		Root size	
Ranking	Descriptor	Ranking	Descriptor
0	None (0 roots)	Very fine (vf)	less than 1 mm diameter
1	Very few (1–3 roots)	Fine (f)	1–2 mm diameter
2	Few (4–6 roots)	Medium (m)	2–5 mm diameter
3	Few/common (7–9 roots)	Coarse (c)	5–10 mm diameter
4	Common (10–12 roots)	Very coarse (vc)	Greater than 10 mm diameter
5	Common/many (13–18 roots)		
6	Many (more than 18 roots)		

Calculation of Net Percolation Flux

Net percolation flux of meteoric water near the cover-leached ore contact was estimated at each monitoring station by calculating the 1D vertical flux from Darcy's Law for steady-state equilibrium as modified by Buckingham (1907) for unsaturated flow and van Genuchten's (1980) analytical solution to Mualem's (1976) theoretical model of the relationship between unsaturated hydraulic conductivity and matric potential. Flux rates were calculated from matric potential data and the measured hydraulic gradient between the two deepest HDS located at each station, together with van Genuchten parameters determined from SWWC and K_{sat} values measured in the laboratory (Table 2). Net percolation flux rates calculated in this manner are referred to as matric-potential-based (MPB)-calculated flux.

Net percolation flux rates were also estimated from AA Pad draindown flow data. Since closure, the AA Pad has been draining the residual solution remaining from the heap leach operations. Draindown flow rate data have been collected on a bimonthly or monthly basis from 2002 through 2009 and approximately quarterly since January 2010. Draindown is characterized by slowly decreasing flow rates with annual spikes in the flow rate resulting from net percolation into the AA Pad during spring melt. Assuming that the draindown flow rates observed in (the driest month of) October approximate drainage rates solely from the residual heap leach solution (baseflow), draindown flow rates that exceed baseflow should approximate the area-averaged net percolation rate through the AA Pad cover system.

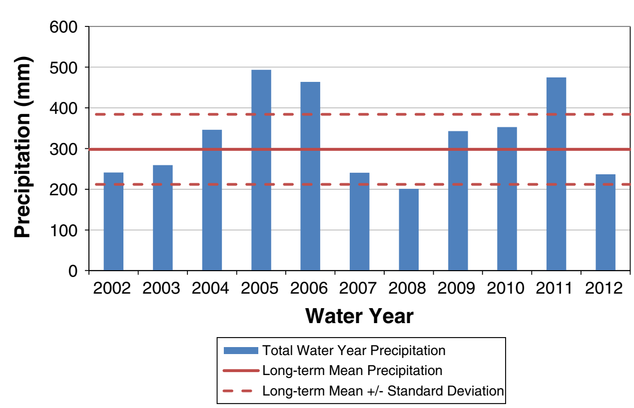

Fig. 4 Water year, long-term mean, and long-term mean ±1 SD precipitation

Results

Precipitation

Precipitation totals over the monitoring period from water year (WY, October 1 through September 30) 2002 to WY 2012 ranged from 201 to 493 mm, averaging 332, 34 mm higher than the 298 mm long-term average (Fig. 4). WYs were classified into average, wet, or dry years by defining a wet year as one with a WY precipitation total >1 SD (86 mm) above the long-term average, and a dry year as one with a total <1 SD below the average. WYs 2005, 2006, and 2011 were wet years, WY 2008 was a dry year, and all other WYs were average years.

Vegetation

AA Pad vegetation survey data indicates that 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. There were 22 plant species observed on the AA Pad with 16 being perennial species, compared to 33 total species on the reference area with 19 perennial species. Overall, the AA Pad perennial forbs contributed 16.8 %, perennial grasses 15.3 %, and shrubs 12.3 % plant cover which demonstrates good diversity and balance within the established plant community. An example of the exemplary status of this reclamation effort is the 5.6 % composition contributed by bitterbrush (*Purshia tridentata*), an extremely important plant for desert wildlife, but one that is difficult to establish in the northern Nevada rangeland.

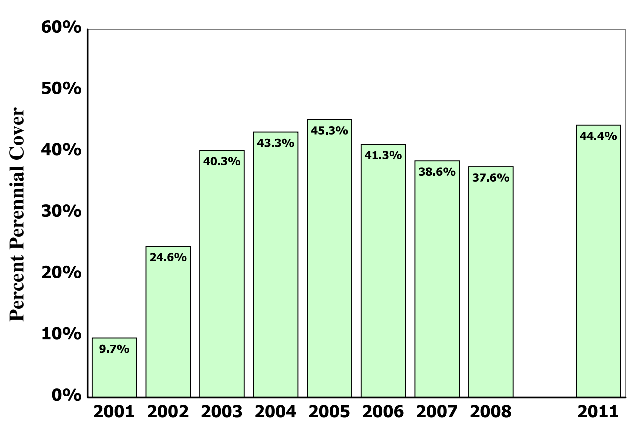

Fig. 5 AA Leach Pad perennial plant cover (2001–2011, no survey in 2009 and 2010)

Water Content and Matric Potential Data

An example of typical water content sensor response at the West and South transect stations, and the East transect stations are presented on Figs. 6 and 7, respectively. Typical matric potential sensor response at the West and South transect stations, and the East transect stations are presented on Figs. 8 and 9, respectively. Matric potentials are expected to increase (become less negative, indicating wetting) in response to precipitation in fall and early winter and to snowmelt in late winter or spring; and then to decrease (become more negative, indicating drying) as the summer-growing season progresses. The 107 cm matric potential sensor at the east transect station stopped functioning after July, 2006. Wetter conditions were observed at most monitoring stations during and following significant rainfall and snowmelt events in late fall, winter, and early spring; drier conditions were observed during periods of decreased precipitation and high ET demand in late spring, summer, and early fall. The West and South transect stations showed relatively dry conditions throughout average precipitation WYs 2003, 2007 through 2010, and 2012, indicating that the cover material in these areas is able to store and release most, if not all, infiltrating precipitation during WYs with average precipitation. During wet WYs (e.g. 2005, 2006, and 2011) the measured water content and matric potential in the underlying leached ore showed relatively wet conditions, indicating that the storage capacity of the cover material had been exceeded and water percolated into the leached ore. The East transect stations generally showed increased water content at all depths each year between late February and early April, indicating that water is percolating to the depth of the leached ore sensor during all WYs. Nonetheless, the leached ore water content and matric potentials in the East transect stations also dried out more during the late summer and fall dry season indicating the ET depth was deep in the East transect area. These data support a conceptual model wherein, during WYs with average precipitation, the cover material stores and releases most if not all of the infiltrating water back into the atmosphere via ET, while during wet WYs water years, some water percolates into the leached ore material. In general, the maximum observed water content decreased over time at all transect stations, which indicates greater cover system efficacy, most likely in response to vegetation establishment.

Draindown Data

AA Pad draindown data generally showed seasonal increases in drainage rates in response to spring snowmelt (March–May) followed by declining rates over the summer and fall months. Baseflow interpolated from the October

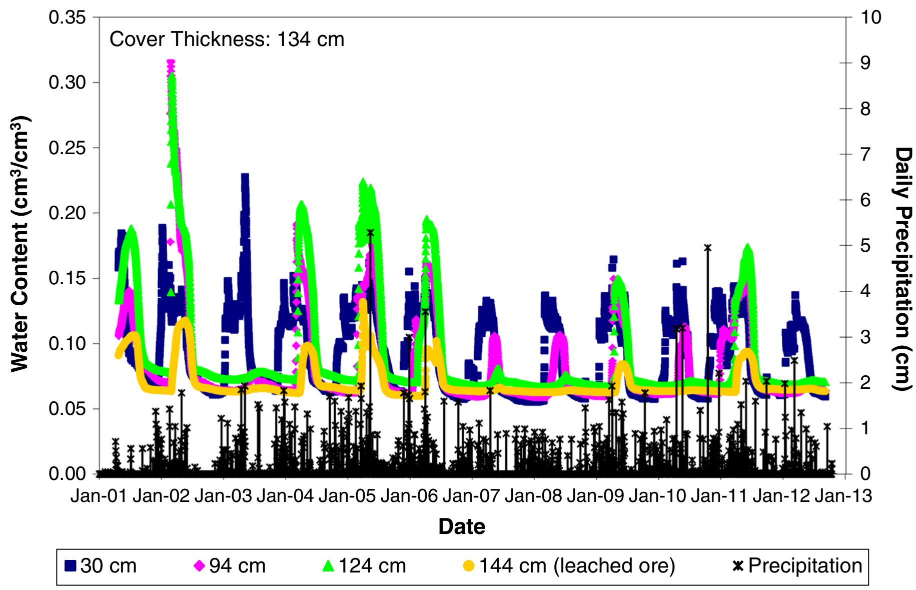

Fig. 6 Volumetric water content: West 2 (topsoil cover, mid-slope)

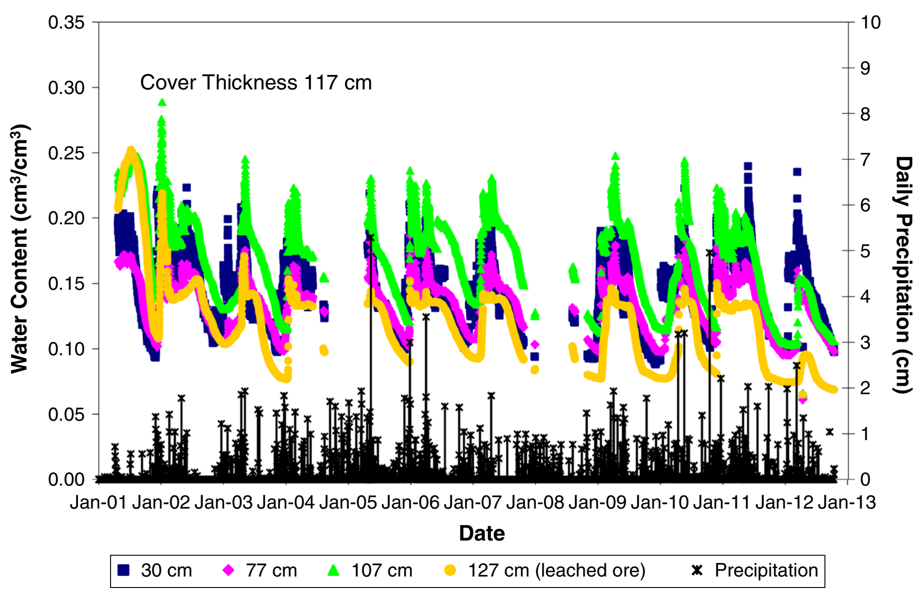

Fig. 7 Volumetric water content: East 3 (Carlin cover, mid-slope)

draindown measurements is shown on Fig. 10. The average difference between the interpolated baseflow rate and the measured increased drainage rates in response to spring melt (i.e. net percolation flux) was 3.2 mm/year (0.94 % of precipitation) from October 2002 to October 2012.

Draindown rates above estimated base-flow rates were most significant during wet WYs 2005 and 2006; elevated rates persisted through WY 2007 before returning to estimated base-flow rates midway through dry WY 2008. By comparison, increased draindown rates during wet WY 2011 were not as elevated as WY 2005 or 2006 flow rates, and flow rates returned to estimated base-flow conditions during WY 2012. The reduced draindown response to wet WY 2011 relative to wet WYs 2005 and 2006 indicates that two successive wet WYs magnified the net infiltration passing through the cover system, or that the cover system performance improved over time, which could have occurred due to maturation of the vegetation on the cover material or changes in hydraulic properties.

Decommissioning Rooting Survey

For all trenches, root density generally decreased with depth, though a trend of increasing root density with depth was observed in the leached ore at the East transect trenches and may be a result of wetter conditions within the leached ore at the East transect (Fig. 11). Roots were typically seen at the maximum depth in each trench, indicating that at AA Pad water within the top meter or more of

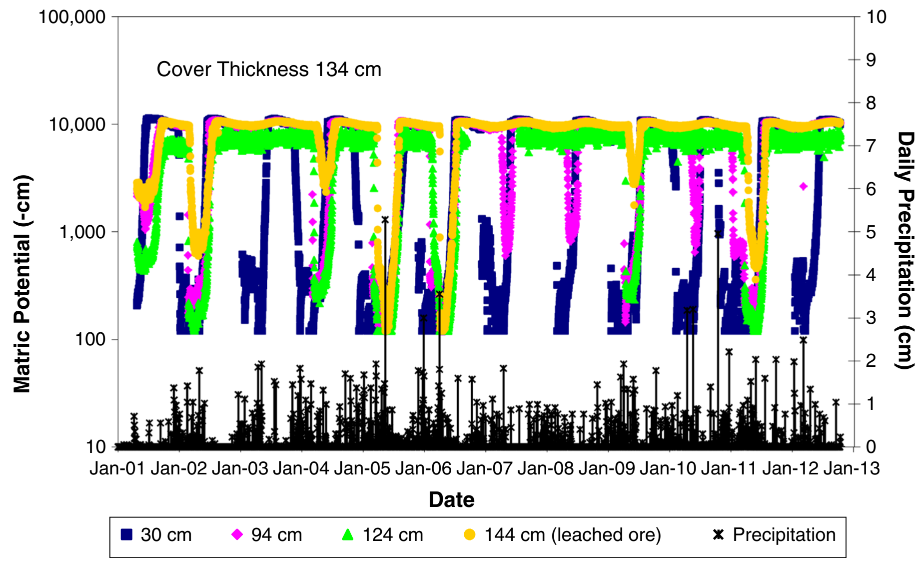

Fig. 8 Matric potential: West 2 (topsoil cover, mid-slope)

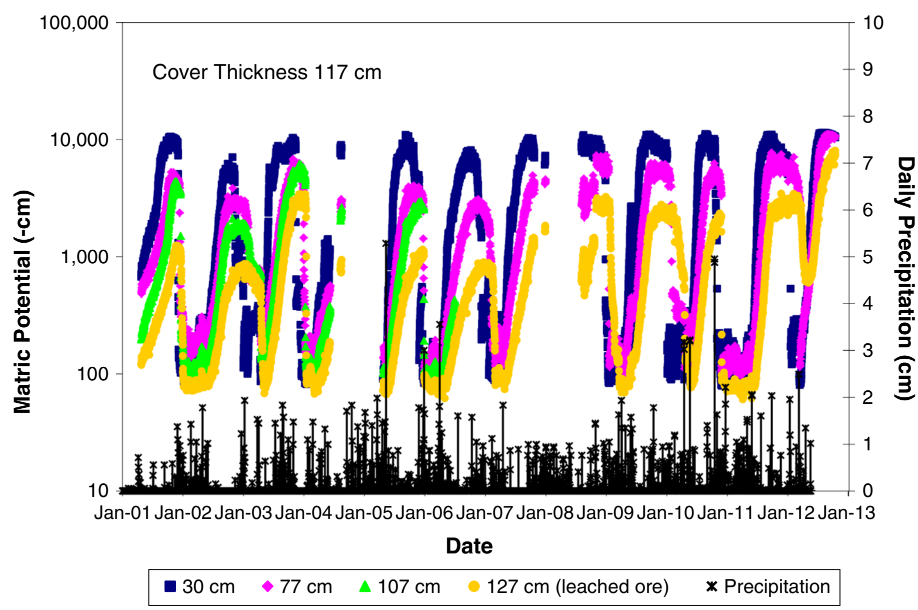

Fig. 9 Matric potential: East 3 (Carlin cover, mid-slope)

the leached ore is accessible by vegetation, as supported by leached ore drying in the summer.

The greatest leached ore root density was observed in the East transect trenches, which also agrees with the observed higher density of deeper rooting shrubs at the East transect compared to other transects (Fig. 11). The thicker cover material but shallower root density at the West transect trenches also agrees with the observed greater vegetation ground cover of predominately forbs and grasses at the West Transect.

In Situ Hydraulic Characterization

Mean surface K_{sat} was similar across transects, while at the 90 cm depth, the mean K_{sat} values ranged over an order of magnitude (Table 5). Mean K_{sat} values at the West and East transects were approximately 5 times greater than the previous laboratory-measured K_{sat} values in Table 2 assigned for estimates of net flux (as described in the next section); K_{sat} values for the South transect were 10 times greater. The larger in-situ measured K_{sat} values is most likely from soil development processes, such as freeze/thaw cycles and root propagation and decay that result in a decrease in soil bulk density in addition to the possible development of soil macro-pores (Benson et al. 2011).

Estimates of Net Flux

The MPB-calculated net percolation flux estimates indicate that the majority of net percolation occurred in wet WYs

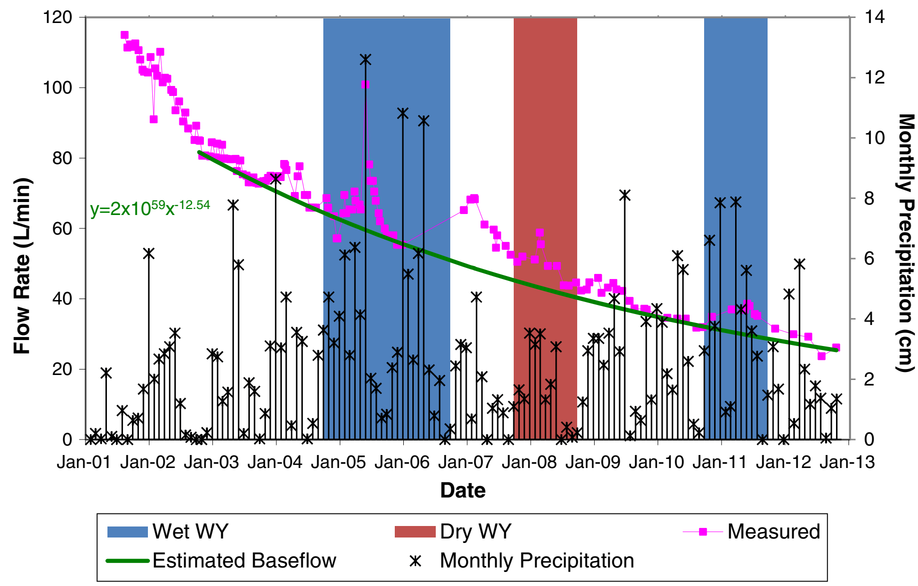

Fig. 10 Predicted and measured draindown from AA Leach Pad (x is days since January 1, 1900)

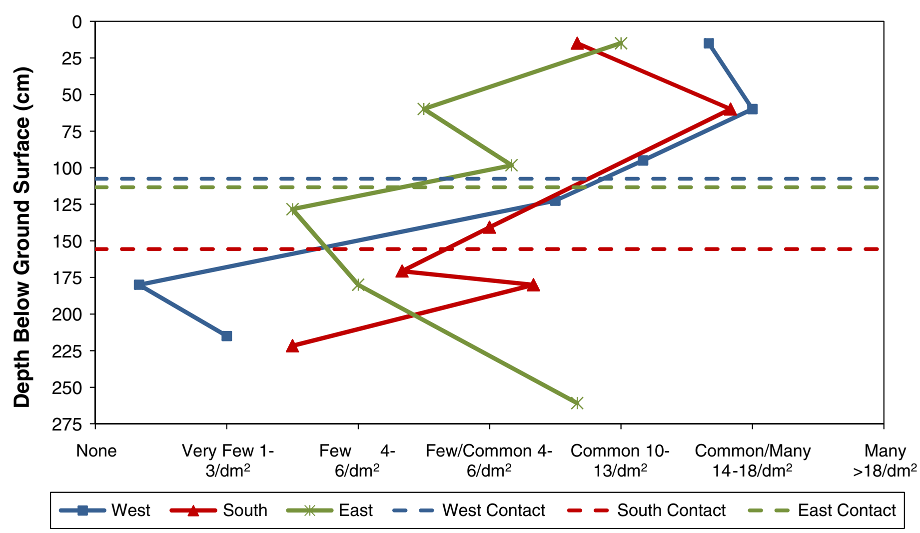

Fig. 11 Root density survey results

2005, 2006, and 2011, whereas during average WYs, near-zero MPB-calculated net percolation values were calculated at most stations. Stations near stormwater runoff channels recorded the highest MPB-calculated flux rates. Weighting the MPB-calculated net percolation flux with respect to the amount of surface area on the AA Pad occupied by each monitoring station slope position (crest, mid-slope, foot-slope, and channels) results in an annual net percolation estimate of approximately 2.2 mm/year (0.63 % of precipitation) (Table 6).

The weighted average MPB-calculated net percolation flux is less than the net percolation estimated from the draindown data. Two possible reasons for this difference may be that actual net flux beneath the channels is higher than calculated since the monitoring sensors were not directly located below the drainage channel(s) or because the sensor upper measurement (wet-end) limit was exceeded during winter/spring precipitation and snowmelt conditions. Channel conditions may, in fact, be wetter than measured and greater rates of net percolation may occur. Additional reasons for the difference between MPB-calculated net flux and draindown data estimated net percolation may be: the occurrence of macro-pore flow during large wetting events (e.g. snowmelt, high intensity precipitation) that is not detected with point measurements made by the matric potential sensors; errors associated with the MPB flux model assumption of uniform flow, and; the precision of the matric potential sensors. Nonetheless, the average channel station MPB-calculated flux was 5.5 times the average MPB-calculated flux for the crest, mid-slope and foot-slope stations, well within the range of drainage flux to inter-drainage flux values that others have reported (Flint and Flint 2007; Scanlon et al. 1999).

Table 5 In-situ measured cover material saturated hydraulic conductivity

Sampling location	Saturated hydraulic conductivity (cm/s)		
	Surface	90 cm depth	Mean
West-A	3.6E−03	1.4E−04	7.1E−04
West-B	1.5E−04	2.7E−03	6.4E−04
West mean	7.4E−04	6.2E−04	6.8E−04
South-A	7.7E−04	1.0E−02	2.8E−03
South-B	1.4E−04	1.1E−03	4.0E−04
South mean	3.3E−04	3.4E−03	1.1E−03
East-A	1.3E−03	6.5E−04	9.1E−04
East-B	2.5E−04	1.9E−04	2.2E−04
East mean	5.6E−04	3.5E−04	4.4E−04
East-D-A	4.7E−05	6.6E−04	1.8E−04
East-D-B	1.5E−03	1.0E−03	1.2E−03
East-D mean	2.6E−04	8.2E−04	4.6E−04

Table 6 Area-weighted MPB-calculated flush using laboratory and in-situ measured cover material K_{sat}

Slope position	Area (ha)	Laboratory K_{sat} Area-weighted average flux (mm/year)	In-situ K_{sat} Area-weighted average flux (mm/year)
Crest	16.4	0.5	0.4
Mid-slope	66.3	1.0	0.8
Foot-slope	8.1	0.2	−0.1
Channels	4.8	0.5	0.4
Total	95.6	2.2	1.5

MPB-calculated net flux at the East and West transects was also estimated using the mean in-situ measured cover material K_{sat} determined from the decommissioning study (Table 5). The mean in-situ K_{sat} value for the East transect was 3.5 times greater (4.6×10^{-4} cm/s) and for the West transect was 4.5 times greater (6.8×10^{-4} cm/s) than the original laboratory derived K_{sat} value used in the above net percolation calculations (Table 2). The South transect was excluded from this analysis because MPB-calculated net flux at the South transect only used sensors located in the leached ore material.

Increasing the cover material K_{sat} to the measured in-situ K_{sat} values reduced the average annual MPB-calculated net flux at the East transect from 5.6 to 3.0 mm (1.66–0.88 % of precipitation) and at the West transect from 2.1 to 1.8 mm (0.62–0.54 % of precipitation). Thus, increasing the cover material K_{sat} reduced the area-weighted average MPB-calculated net flux estimate to 1.5 mm/year (Table 6). At both transects, the decrease in MPB-calculated net flux is due to a predicted increase in upward flux during periods of cover material drying in late summer and fall. While an increased cover material K_{sat} would be expected to increase the rate of downward water movement within the cover during precipitation and snowmelt events, the increased downward flux in the cover is negated by less resistance to upward flux when hydraulic gradients are upward. Average annual estimated flux at the East transect is comparable to the West transect even though greater percolation into the leached ore is observed at the East transect during average water years (Figs. 6, 7, 8, 9). These values indicate that deep rooting vegetation (i.e. shrubs) remove water that has percolated beyond the cover system during the dry season.

Changes in cover material K_{sat} would occur gradually over time and not as a single point in time as applied here. As a result, the estimated decrease in MPB-calculated net flux with increased cover K_{sat} would likely be less. This is possibly corroborated by the decrease in draindown flow response to wet WY 2011 in comparison to wet WYs 2005 and 2006. It is worth noting that variability between in-situ K_{sat} measurements within transects was over an order of magnitude. Consequently, spatial variability in hydraulic properties between monitoring stations also likely affected matric potential sensor response and estimated net percolation flux estimates.

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/year (0.63 % of precipitation), based on the area-weighted average MPB-calculated flux. Estimated average annual flux from seasonal increases in AA Pad draindown rates in response to spring melt are slightly higher than the MPB-calculated flux, being 3.2 mm/year (0.94 % of precipitation). Considering the small difference, it is reasonable to conclude that net percolation through the cover is less than 1 % of the precipitation. Eleven years of vegetation surveys indicate that plants at AA Pad are self-sustaining and that the reclaimed site appears at least as stable and resistant to erosion as nearby, undisturbed areas.

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