Final Results for the Morenci Tailings Experimental Reclamation Plots

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Abstract

Experimental monolayer evapotranspiration cover systems were installed in 1997-98 over mine tailings at the Morenci mine in the semi-arid southwestern United States. Test plots were constructed on the tailings dam side-slope to examine effects of cover treatments on vegetation and net infiltration flux into the tailings. Treatment variables were: cover thickness, three organic amendments applied at different rates, two mulch types, and seed mixes with native species only or native plus non-native species.

Vegetation monitoring results indicated minimal differences in ground or canopy cover or species frequencies between cover depths, but greater mean vegetation cover was seen in organically-amended compared to unamended plots, and in mulched compared to unmulched plots. No differences were identified between seed mix variables. Matric potential data showed that, under normal precipitation conditions, the 60-cm cover more effectively limited infiltration of precipitation into the tailings at 180 cm below ground surface than did the 30-cm cover, but storm sequences delivering precipitation of 2.5 cm or more resulted in wetting of sensors at this depth. Unsaturated flow models calibrated to in-situ matric potential data indicate long-term net percolation rates of less than 1 cm per year, with only nominal decreases in net percolation if the cover thickness is increased beyond 60 cm.

1 Introduction

In 1997-98, experimental monolayer evapotranspiration cover system test plots were constructed at the Morenci mine in the semi-arid south-western United States. Test plots were located at the base of a tailings dam to examine the effects of various cover treatments on vegetation and net infiltration flux. Variables included: cover thickness, three organic amendments applied at different rates, two mulch types, and seed mixes with native species only or native plus non-native species. Reference plots were constructed on a previously-reclaimed tailings dam and also on undisturbed natural slopes. The tailings selected for the test plots were acidic (pH < 3) and the cover material was a cobbly, gravelly sandy loam with moderate water holding capacity (< 0.10 cm/cm)

Vegetation monitoring was conducted over twelve years, with one above-ground vegetation biomass survey in 2007; soil matric potential was monitored over ten years to evaluate the net infiltration flux. Results of annual vegetation surveys indicate minimal differences in ground or canopy cover or species frequencies between cover depths. Compared to unamended plots, biosolids- and cattle-amended plots had greater mean vegetation ground and canopy cover at the end of the experiment. Mulch treatments also resulted in greater vegetation cover. Ground and canopy cover were greater on undisturbed slopes than unamended plots and similar or less than the biosolids-treated plots.

Matric potential data showed that, under normal precipitation conditions, the 60-cm cover limited infiltration of precipitation into the tailings more than the 30-cm cover, but precipitation sequences of 2.5 cm or more resulted in wetting of sensors to a depth of 180 cm. Unsaturated flow models calibrated to *in-situ* matric potential data indicate long-term net percolation rates of less than 1 cm per year, with only nominal decreases in net percolation if the cover thickness is increased beyond 60 cm.

2 Methodology

Sixty-six test experimental plots were constructed near the base of the tailings dam with an east-facing slope of approximately 4H:1V. Test plots were constructed using native Gila conglomerate material for the reclamation cover (Gila cover). Five experiments were designed to test the efficacy of evapotranspiration (ET) cover treatment variables on tailings side-slopes. These variables included cover depth, organic cover amendments, seed mix species composition, and mulching as follows:

- Experiment 1: 7.6 m by 15.2 m test plots: 12 treatments as a combination of three treatment variables, including cover thickness (30 or 60 cm), biosolids application rate (0, 47, or 141 dry tonnes/hectare), and seed mix (native species only or native plus non-native species).
- Experiment 2: Bare tailings monitoring for deep percolation flux.
- Experiment 3: A mixture of Gila cover with tailings to 46 cm, topped by Gila cover to a thickness of 15 cm, seeded with native plus non-native species and with variable biosolids application rates (0. 47, 141, dry tonnes/hectare).
- Experiment 4: 30.3 m by 30.3 m test plots: Three treatments, : no amendment, biosolids (94 dry tons/hectare), and cattle (2000 days/hectare), all on 30-cm cover depths. Seeded with native and endemic non-native species.
- Experiment 5: 7.6 m by 15.2 m test plots: Two reference areas: 1) undisturbed by mining and 2) a covered tailings site reclaimed in 1977 with an unknown species mix.
- Experiment 8: 15 m by 15 m test plots: Three treatments: no amendment, hay mulch (4.5 tons/hectare), and hay mulch with a commercial organic amendment, Biosol® (1.7 tons/hectare), all on 30 cm cover depth. Seeded with native and endemic non-native species.

Plots in Experiments 1 and 4 were initiated and seeded with a sterile cover crop of oats or barley in January 1998; they were then over-seeded with the experimental seed mix in June of 1998. Experiment 8 was initiated in the July of 1999 and directly seeded without a cover crop. Reference areas were selected which had a comparable soils, slope angles and solar aspect to the experimental plots. All treatments were triple-replicated.

2.1 Site Conditions

Morenci is located at the edge of the Madrean Archipelago, between the northwestern Chihuahuan desert and the northeastern Sonoran desert. The experimental test plots are located at approximately 1,200 m above mean sea level. Vegetation in the area is a mix of shrubs/forbs and grasses representing both Sonoran Desert scrub and Chihuahuan Desert species.

Temperature and precipitation data collected in the nearby town of Clifton from 1893 to 2009 indicate that the mean monthly temperature ranges from a maximum of 27.2°C to a minimum of 10.9°C; the mean annual temperature is 18.9°C. From June through September, the mean maximum air temperature exceeds 34°C. On average, the area is frost-free 235 days a year from early to mid-March through early to mid-November.

Average total annual precipitation at the Morenci weather station from 1998 through 2010 was 92 percent of the Clifton historical average (1893-2009) of 337 mm, with annual variation between 50 and 126 percent of average. Precipitation is bimodal, with approximately 55 percent occurring from short, intense thunderstorms from July through September, and the remainder occurring as low-intensity, extended precipitation events from January through March. Monthly reference evaporatranspiration (ETo) values from nearby Safford, Arizona range from 64 mm in December to 273 mm in June (annual mean 1,963 mm).

2.2 Tailings and Cover Material Properties

Physical and hydraulic properties of tailings and cover material have been previously described in Milczarek et al. (2003). Textural characteristics of the tailings layers range from clay loam to sandy loam, with the predominant tailings texture being sandy loam. Based on differences in particle size distribution, saturated hydraulic conductivity (Ksat) and moisture retention characteristics, the tailings at several infiltration-monitoring locations were classified into one of three generally-defined hydrologic units. The textural properties of the Gila conglomerate cover material used in these experiments can be classified as cobbly, gravelly sandy loam.

2.3 Vegetation Monitoring

Vegetation surveys were conducted annually in late summer (September) beginning in 1999 and included measurements of groundcover, canopy cover, and species frequency parameters (Interagency Technical Reference, 1996). A 0.5 m by 0.5 m survey frame was placed at approximately 1-m intervals along transects randomly run each year perpendicular to the slope in each plot. The number of frames necessary to acquire a valid sample size for each experiment was determined via collecting an excess number of transects during the first year of surveying in 1999.

Groundcover was measured at the four frame corners, with a groundcover determined for each corner from the following: soil (<2mm particle size), gravel (2 mm-8 cm), cobble (8-25 cm), rock (>25 cm), grass, forb or shrub (forb/shrub), or litter. The number of corners with each groundcover type was summed and a percentage calculated for each groundcover type within each treatment.

Canopy cover was quantified for each species present in a frame using modified Daubenmire (1959) cover classes: 0 to 5 percent, 5 to 15 percent, 15 to 50 percent, and 50 to 100 percent. To calculate canopy cover along each transect, the class midpoint value was assigned, i.e. 2.5 percent, 10 percent, 32.5 percent, and 75 percent. Canopy cover values were averaged for each species observed in each transect and a percentage calculated for each species within each treatment.

Species frequency, a presence or absence parameter, was calculated from canopy cover data, with mean percentages determined for each species within each treatment.

A survey of above-ground vegetation biomass was conducted in September 2007 in plots in four experiments. The frames used for the annual surveys were used to collect plant samples clipped at the base and sorted into paper bags by growth type, grasses, forbs, or shrubs. The grasses were further sorted into native or non-native species (all forb and shrub samples were native). Samples were dried and weighed and mean masses calculated for each treatment sampled.

2.4 Erosion Monitoring

Erosion monitoring was conducted in the Experiment 4 and 5 plots using a portable microtopographic profile gauge (Hudson, 1993), mounted for use on pairs of permanently-installed transect stakes. Baseline measurements collected the first year are compared with subsequent annual measurements to assess any gain or loss of soil from the surface along each transect over time. The linear mean annual soil gain or loss is calculated across the length of each transect by dividing the average change for that year by the number of years since the baseline measurements were made. This mean value is then converted to an estimated soil gain or loss (tons/hectare), assuming a mean cover bulk density of 1.65 g/cm3.

2.5 Soil Matric Potential Monitoring

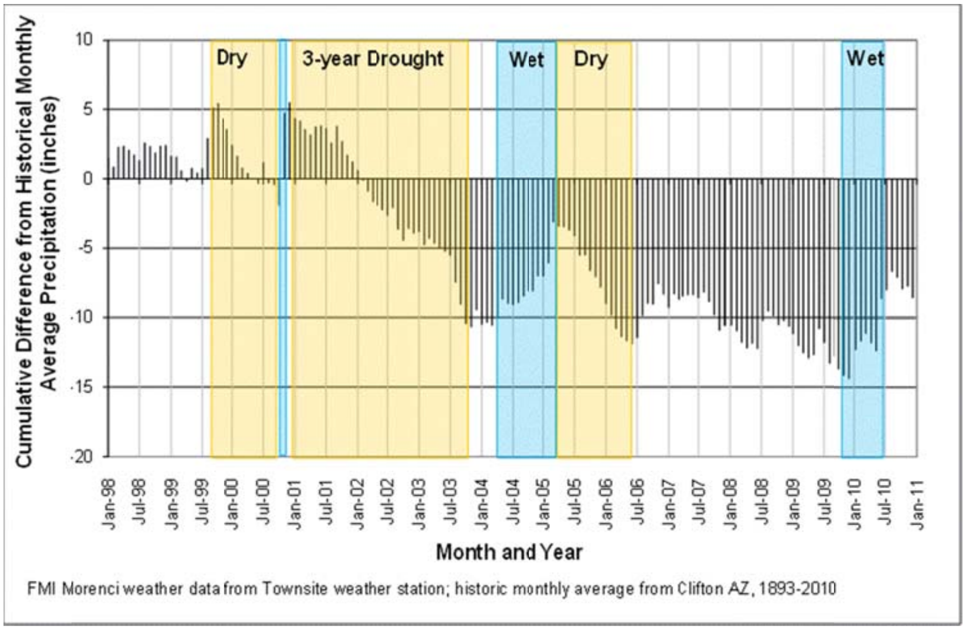
In August 2000, 48 heat dissipation sensors (HDS) were installed at depth intervals of 15, 45, 90 and 180 cm below ground surface (bgs) in selected plots with 30-cm and 60-cm cover depths and with sparse and dense vegetation. Installation details are provided in Milczarek et al. (2003). An additional 15 HDS were installed in uncovered tailings in June 2005. HDS data were recorded twice daily and indicate soil water pressure potential status at, and hydraulic gradients between, the sensor depths. Because pressure potential monitoring shows upward hydraulic gradients from the tailings into the cover system during dry periods, test-pitting and geochemical analyses of the tailings and cover system profiles were conducted in 2002 and 2008 to investigate the potential for salinization of the cover system. Finally, downward flux below the cover into tailings at each sensor nest location was estimated using the measured soil water pressure potential, the equivalent unsaturated conductivity for the tailings layers at each depth interval, and the total hydraulic gradient between sensors, as described in Milczarek et al. (2003).

2.6 Unsaturated Flow Modeling

Several unsaturated flow models using the numerical code UNSAT-H (Fayer, 2000) were developed to predict the effect of alternative configurations of cover thickness (45 to 90 cm) on net infiltration through the cover system. Forward modeling to estimate long-term cover system performance incorporated a 98-year synthetic climate record statistically representative of the Morenci area, as well as spatial variability in slope and hydraulic properties typical of tailings facilities and cover material. Prior to carrying out long-term simulations, hydraulic properties assigned to the model were calibrated to *in-situ* tailings conditions using the ten-year record of pressure potential data from the test plots.

3 Data and Results

The monitoring period was characterized by three dry periods, two wet periods and less than normal precipitation. Figure 1 shows the cumulative difference between monthly precipitation and the historic monthly mean. Precipitation in 1998 and 1999 was above normal. Severe drought then occurred from October 1999 through October 2003, interrupted only by several large storm events in October 2000. Precipitation from summer through winter 2004-2005 was above average, followed by a dry year in 2004 and subsequently average precipitation from 2005 to 2010.



FMI Morenci weather data from Townsite weather station; historic monthly average from Clifton AZ, 1893-2010

Figure 1. Cumulative difference from historic monthly mean

3.1 Vegetation Monitoring Results

Vegetation ground and canopy cover generally decreased in dry years and increased in wetter years. Also of note, the seeded non-native species Lehmann lovegrass (*Eragrostis lehmanniana*) and blue panicgrass (*Panicum antidotale*) invaded the plots seeded with the native-only mix**,** resulting in higher ground and canopy cover values than expected for native-only seeding plots.

3.1.1 Effect of Organic Amendments

Plots treated with biosolids in Experiment 1, have shown greater mean vegetation groundcover than unamended plots throughout the monitoring period, however, due to significant interactions between the cover depth and different seed mix variables, the differences are not considered significant (Figure 2). Similar trends were also observed separately for grass, and forb and shrub groundcover in addition to canopy cover. Biosolids-treated plots in Experiment 4 also showed greater vegetation groundcover than either the cattle treated or unamended plots (Figure 3). While the Biosol® and hay mulch plots typically showed greater vegetation groundcover over time, differences were not significant after 2001 (Figure 4). Finally, a 2007 rooting survey indicated that roots in the biosolid amended plots penetrated deeper into the cover and closer to the tailings (Milczarek et al., 2010)

The reference plots did not show as much inter-annual variation as the experimental test plots (Figure 5), possibly due to more mature plant communities. For example, canopy cover was consistently greater in the undisturbed reference plots than in all experiments. Typically, grass as a percentage of total vegetation in Experiments 1, 4 and 8 was greater than 85% compared to around 60% in the undisturbed reference plots. Experiment 1 biosolids-treated plots also showed significantly greater shrub and forb groundcover than the unamended plots, however, this was not observed in Experiment 4 most likely as a result of the shallow (30 cm) cover depth in these plots. Of note, Experiment 7 test plots treated with 22 dry tons/hectare biosolids showed similar trends as Experiment 4, prior to its damage in 2005.

2007 biomass measurements indicate that the greatest native and non-native grass biomass was produced on Experiment 1 plots with 47 tons/hectare biosolids (Table 1). Experiment 4 cattle treated plots showed over 90% non-native grass, while the unamended plots showed over 90% native grass but low groundcover, again most likely due to shallow cover depths. The addition of Biosol® or mulch showed no significant difference over unamended plots in Experiment 8.

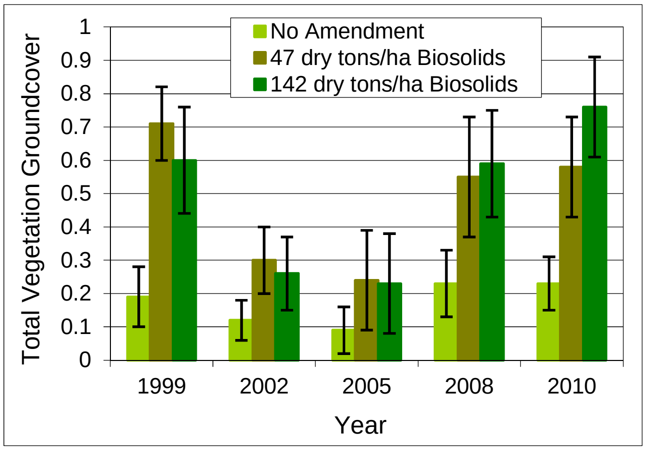
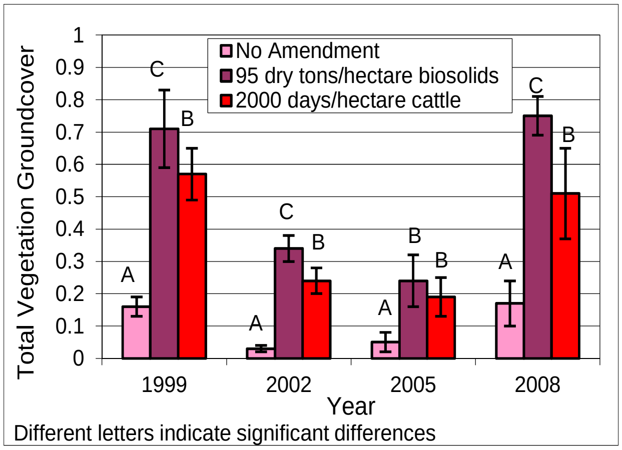
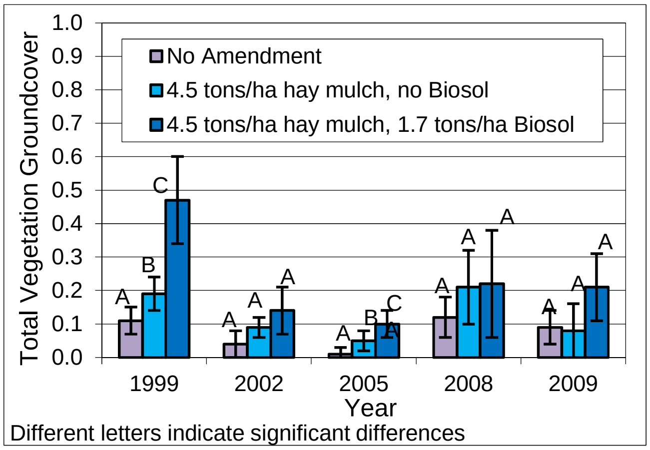


Figure 2. Mean Vegetation Groundcover by Biosolids Application Rate: Experiment 1



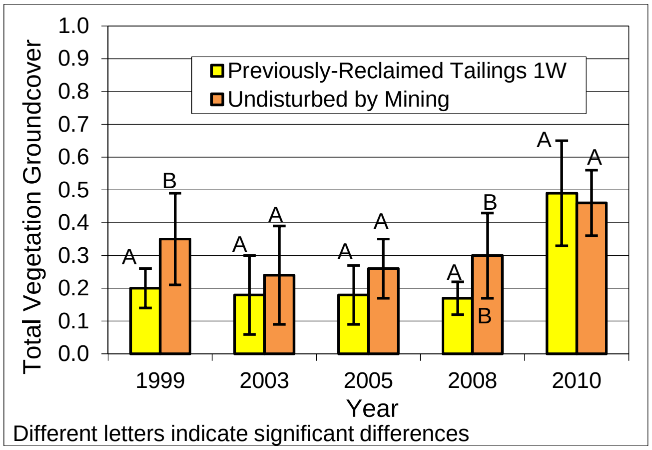
Different letters indicate significant differences

Figure 3. Mean Vegetation Groundcover by Organic Amendment: Experiment 4



Different letters indicate significant differences

Figure 4. Mean Vegetation Groundcover by Amendment: Experiment 8



Different letters indicate significant differences

Figure 5. Mean Vegetation Groundcover by Reference Area: Experiment 5

Table 1. Results summary of 2007 biomass survey

Treatment	Variable	Total Grass		Native Grass		Non-native Grass	
		Mean (kgs/ hectare)	ANOVA Results[1]	Mean (kgs/ hectare)	ANOVA Results[1]	Mean (kgs/ hectare)	ANOVA Results[1]
Experiment 1							
Cover Depth (cm)	30	647	A	194	B	453	A
	60	599	A	292	A	307	B
Biosolids (dry tons/hectare)	0	415	C	182	B	233	C
	47	849	A	280	A	569	A
	142	605	B	267	AB	338	B
Native only seed mix		640	A	310	A	330	B
Native + non-native seed		606	A	176	B	430	A
Experiment 4							
No amendment		109	B	103	A	6	B
2000 Cattle days/hectare		705	A	42	B	663	A
Experiment 5							
Undisturbed by Mining		420	A	387	A	32	B
Reclaimed Area (1977)		235	A	0	B	235	A
Experiment 8							
Hay Mulch (tons/hectare)	0	259	A	85	A	174	A
	5	362	A	102	A	259	A
Biosol® (tons/hectare)	0	313	A	99	A	214	A
	1.87	357	A	92	A	265	A

[1] Different letters indicate significant mean differences among treatments

3.1.2 Effect of Cover Depth

Differences in total vegetation, grass, and forb/shrub groundcover were not observed between the different cover depths. However, native species frequency and grass biomass were greater on the 60 cm covers whereas greater non-native species frequency and grass biomass were observed on the 30 cm covers (Table 1). The latter result may be explained by higher tolerance of Lehmann lovegrass to limiting conditions and may reflect low-level salinity/pH intrusion from the tailings material up to distances of 15 cm above the cover system contact (Milczarek et al., 2010). Lower native species success shown on the shallow 30-cm cover in Experiment 1 can also help explain the generally low native species success and lower vegetation ground cover in Experiments 4 and 8.

3.1.3 Native versus Non-native Seed Success

Greater native species frequency and grass biomass occurred on Experiment 1 plots seeded only with native species compared to the native plus non-native plots. However, invasion by non-native grasses accounted for about half the biomass (Table 1). Biosolids addition increased both vegetation cover and native and non-native grass biomass in Experiment 1; native vegetation increases were observed primarily in Plains bristlegrass (*Setaria vulpiseta*) and Four-wing saltbush (*Atriplex canescens*). Unamended plots generally showed additional native species (greater diversity) but lower overall frequency and biomass. Experiment 4 showed few non-native species in the unamended plots, whereas Experiment 8 showed similar native grass biomass between unamended and amended test plots (Table 1). Experiment 1 had almost double the native grass biomass across all treatments compared to biomass levels in Experiments 4 or 8.

3.1.4 Reference Plots versus Test Plots

Mean vegetation groundcover and canopy cover values were consistently greater, though not always significantly different, in the undisturbed reference area compared to the previously (1977)-reclaimed reference area (Figure 5). In addition, significantly greater native grass biomass was observed in the undisturbed area (Table 1). The 1977-reclaimed area is dominated by non-native grasses with some native shrub and forbs.

Statistical analyses cannot be performed across experiments. However, general observations are as follows. Over 12 years, mean vegetation groundcover in all Experiment 1 and 4 biosolids-amended plots and in Experiment 4 cattle plots exceeded the reference areas. However, Experiment 4 cattle plots are almost exclusively dominated by non-native species. Unamended test plots in all experiments, and the Experiment 8 test plots, did not achieve similar vegetation success as the undisturbed reference area. Groundcover values for Experiment 1 test plots were also consistently greater than similar treatments (i.e. unamended plots) in other experiments, indicating that initial environmental factors can significantly affect long-term revegetation success. Potential vegetation differences may also have been caused from cover material placement in Experiment 1 and Experiments 4 and 8. Experiment 1 cover material was generally rockier than cover in Experiments 4 and 8; Experiment 1 plots were hand-seeded whereas Experiment 4 was mechanically seeded; and Experiment 8 was seeded in a different precipitation year in addition to having slightly shallower cover depth (< 25 cm).

3.2 Erosion Monitoring Results

Erosion data indicate that soil loss varies strongly with position (upslope vs downslope) and year, which reflects dynamic degradation and aggradation processes along the slope. Soil loss was typically greatest from up-slope positions; several locations showed aggradation over the period of monitoring. Significant statistical differences in erosion between treatments were not observed due to high variability between treatment replicates. Average soil cover loss from the up-slope positions within specific treatments were typically less than 0.15 cm/year (-23 tons/hectare/year) and less than 0.07 cm/year (-14 tons/hectare/year) in the down-slope positions. In a number of locations aggradation had occurred (up to 0.2 cm/year) over the period of monitoring. Soil erosion across all treatments for down-slope positions averaged 0.05 cm/year aggradation (+10 tons/hectare/year) and 0.19 cm/year degradation (-38 tons/hectare/year) for upslope positions. In comparison, erosion from bare-tailings plots averaged 2.91 cm/year (480 tons/hectare per year).

3.3 Soil Water Pressure Potential Monitoring Results

Pressure potential data indicate that the cover systems are effectively storing and releasing precipitation, though episodic sequences of above-average precipitation can result in net infiltration past the cover system. Figures 6 and 7 compare the average pressure potential record at each of the monitoring locations for the 90-cm and 180-cm HDS depths, respectively and the relative difference from the historic precipitation record. To account for the relative time period for propagation of infiltration at depth, the average monthly precipitation and average 3-month precipitation are plotted for the 90 cm and 180 cm sensor depths respectively. Wetting and drying patterns shown at the 90-cm depth (Figure 6) show that, during periods of average precipitation, subsurface tailings are drier (more negative pressure potential) below the 60-cm cover than the 30-cm cover (i.e., Aug-06 to Jan-08). When above-average precipitation follows very dry periods, equivalent or greater wetting occurs at depth below the 60-cm cover than the 30-cm cover (i.e., Aug-02 and Jul-06, Figures 6 and 7). As previously discussed in Milczarek et al. (2003), 198 mm of precipitation in October 2000 resulted in significant wetting to depths of 180 cm in all locations. This pattern was repeated in February 2005, and to a lesser extent in July 2002 and February 2007, depending on the monitoring location (Figure 7). Of note, the 180-cm sensors for the 60-cm low vegetation cover in Figure 7 are believed to be anomalously dry.

These data indicate that, under normal precipitation conditions, the 60-cm cover is more effective at limiting net percolation than the 30-cm cover. However, after periods of drought, differences in evapotranspiration rates could be diminished, and the thicker profile of higher-conductivity cover material over low conductivity tailings may actually result in increased net infiltration due to more rapid downward percolation of precipitation through the upper 60 cm. Of note, the bare-tailings plots consistently showed drier conditions than did covered plots at the 90-cm and 180-cm depths (Figure 6 and 7). This result is not unexpected due to higher runoff rates from the bare tailings surface than from the cover material.

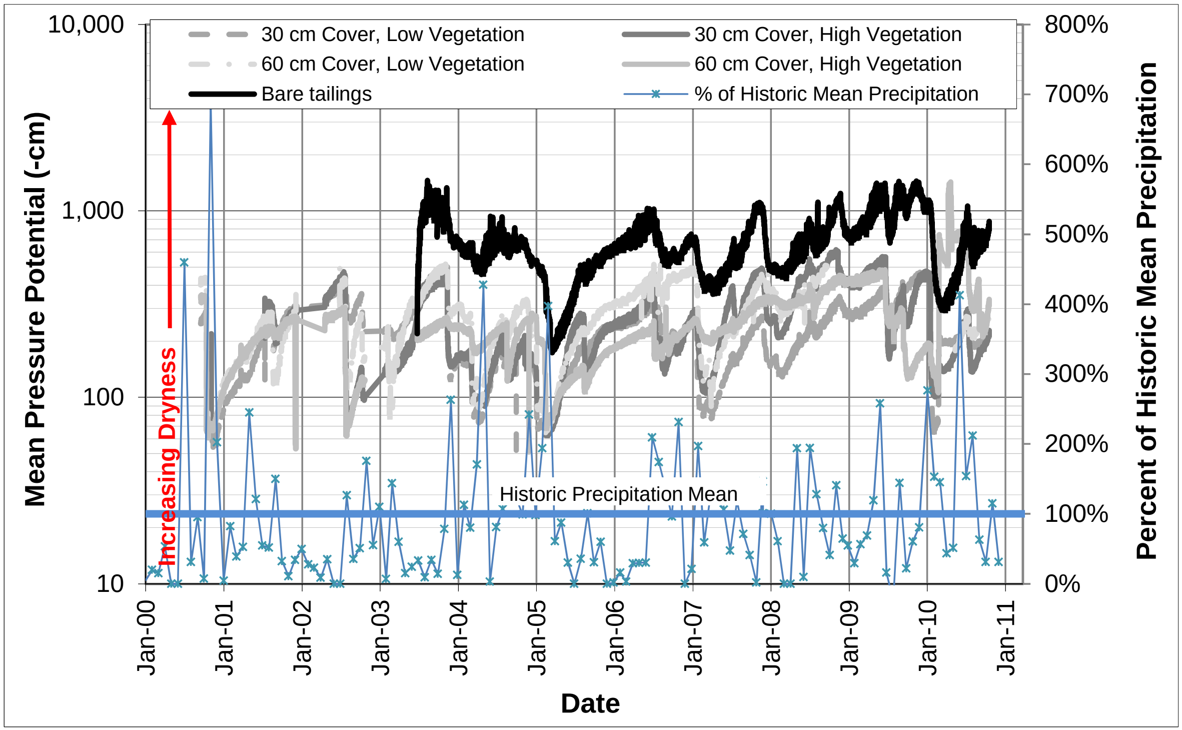


Figure 6. Comparison of Mean Pressure Potential across Treatments at 90 cm bgs

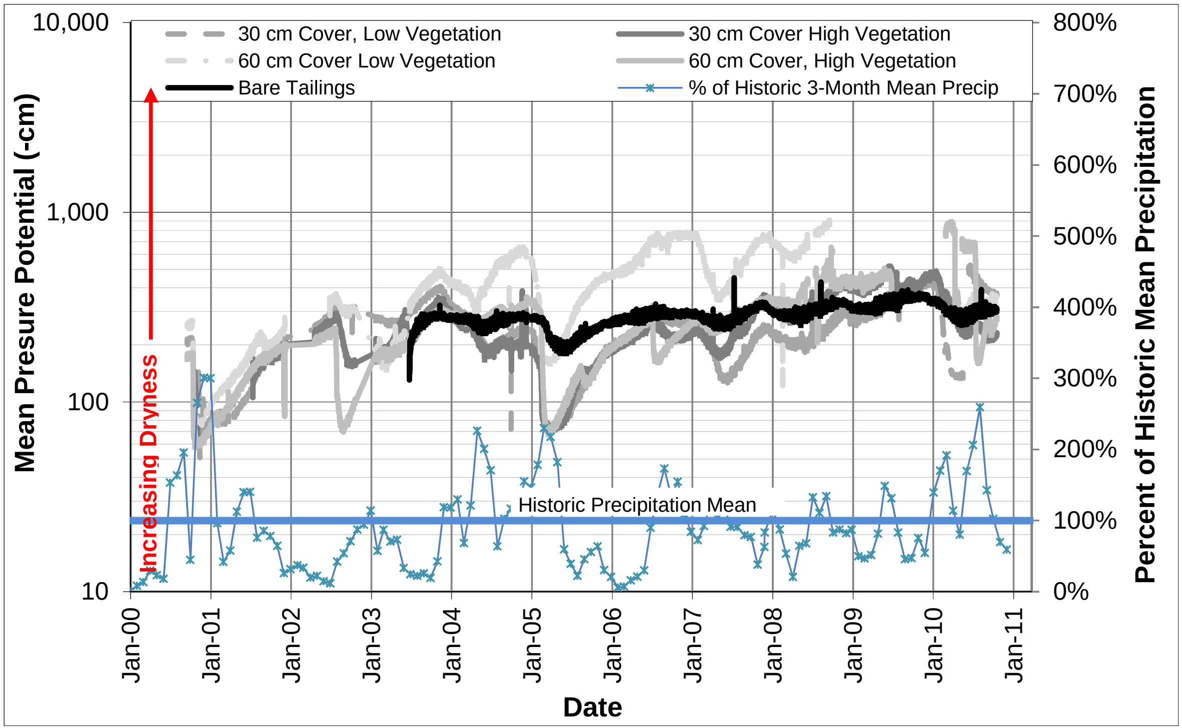


Figure 7. Comparison of Mean Pressure Potential across Treatments at 180 cm bgs

Table 2 presents the estimated total and average downward flux across each treatment via the simplified two-layer model described in Milczarek et al (2003). Predicted downward fluxes through the 60-cm cover systems were slightly greater or equivalent to the 30-cm cover systems depending on the vegetation density. The higher estimated flux rates through the deeper covers are due to observed lower-permeability tailings layers below the 30-cm cover plots than the 60-cm cover plots as shown by the slightly reduced observed wetting depth from the two large wetting events in October 2000 and February 2005 (Figures 6 and 7).

Table 2. Average estimated downward flux rates, 9/14/2000 - 10/25/2010

Sensor Nest/Plot Location	Total Downward Flux (cm)	Annual Flux (cm/year)	Annual Flux Rate (cm/s)	Estimated Flux as Percent of Precipitation
30 cm cover, low vegetation				
Average (3 to 2 nests)[1]	4.15	0.57	1.80E-08	1.29%
Standard Deviation	*1.62*	*0.33*	*1.04E-08*	*0.92%*
30 cm cover, high vegetation				
Average (3 to 2 nests)[1]	1.19	0.20	6.25E-09	0.26%
Standard Deviation	*4.17*	*0.08*	*2.45E-09*	*0.27%*
60 cm cover, low vegetation				
Average (3 to 1 nest)[1]	3.08	0.44	1.40E-08	0.79%
Standard Deviation	*1.24*	*0.27*	*8.65E-09*	*0.68%*
Average 60 cm cover, high vegetation				
Average (3 to 2 nests)[1]	1.76	0.21	6.51E-09	0.32%
Standard Deviation	*0.28*	*0.03*	*9.66E-10*	*0.09%*
Bare Tailings				
Average (3 nests)	0.59	0.08	2.57E-09	0.12%
Standard Deviation	*0.43*	*0.06*	*1.87E-09*	*0.20%*

[1] Various sensor failures from Dec-04 to Sept-08

Variability between sensor measurements within treatments was also high (Table 1). A number of sensors failed in the latter half of the experiment such that the quality of the data was lower during the final years of the experiment. Consequently, with the exception of the bare-tailings plot, the average estimated flux rates are not significantly different and indicate that downward flux rates averaged about 0.7% of total precipitation from 2000 through 2010. The predicted flux estimates are also conservative in that the flux estimation method does not account for potential upward flux via solution or vapor flow (Milczarek et al., 2003).

3.5 Unsaturated Flow Modeling

Unsaturated flow models calibrated to the pressure potential data presented above indicate that under a 98-year synthetic climate record typical of conditions at Morenci, the side-slope vegetated covers used for the test plot study could be expected to limit net infiltration to between approximately 4.5 to 7 mm per year, depending on cover thickness. Increasing the cover thickness from 45 cm to 90 cm was predicted to only nominally decrease the net infiltration by 2.5 mm per year. However, modifying the estimated hydraulic properties of the underlying tailings to approximate differences between the slimes and beach areas showed greater predicted reductions due to the reduced wetting front depths and subsequently higher available moisture for evapotranspiration (Figure 8).

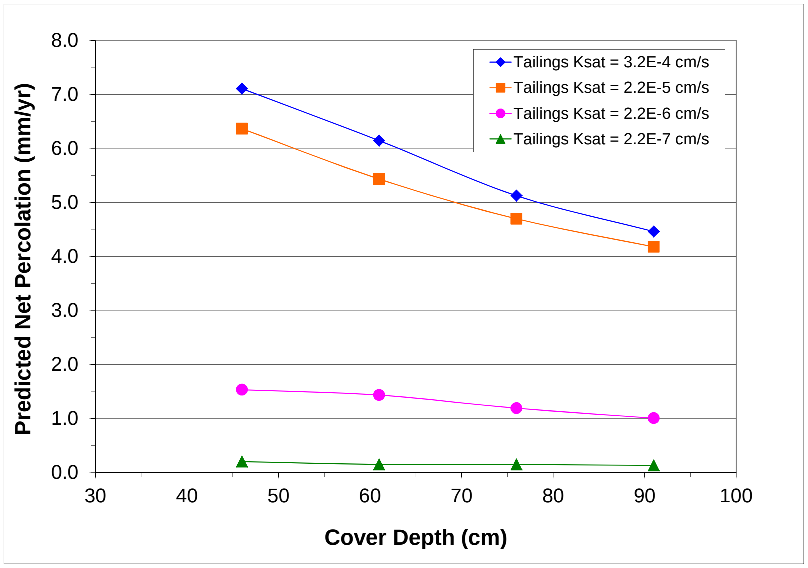


Figure 8. Predicted Net Percolation with Different Cover Material Depths and Tailings Saturated Hydraulic Conductivity (Ksat)

It should be noted that these simulations cannot estimate the long-term efficacy of vegetation on cover systems, and actual cover system performance will vary relative to variability in hydraulic properties of the underlying tailings and vegetative cover health.

3.6 Salinity Monitoring Results

Two salinity surveys were conducted in 2002 and in 2007 and are discussed in detail in Milczarek et al. (2010). Test pit surveys were conducted in 2002 with samples were collected at 5-cm depth intervals in the cover system profile at multiple test plot locations. Samples showed decreased pH and higher electrical conductivity (EC) values within 5 to 10 cm above the tailings/cover system contact. EC and pH values were at background levels in the cover system within 15 cm above the tailings contact. A second test pit survey was conducted in 2007, ten years after placement of the cover system. The 2007 survey showed that pH and EC values had not increased beyond the levels measured in 2002. These results indicate that long-term salinity migration in this semi-arid climate may be limited because: 1) unsaturated hydraulic conductivities and upward flux rates greatly diminish with distance above the contact, and: 2) high calcium carbonate contents in the cover material neutralize low-pH solution.

4 Conclusions

Experimental test plot data indicate that after 12 years, native plant species were successfully revegetated though at species frequency and vegetative cover rates less than undisturbed reference areas. The addition of non-native species endemic to the area increased vegetative cover above natives-only by 100 percent or more. The addition of organic amendments increased both native and non-native vegetation cover throughout the monitoring period. The 60-cm cover depth also showed increased native species success over 30-cm depth. Non-experimental variables such as the year the covers were built and seeded also appeared to have significantly affected long-term vegetation success.

Soil water pressure potential data indicate that cover system efficiency is affected by vegetative health. Under normal precipitation conditions, the 60-cm cover was more effective in preventing infiltration of precipitation into tailings than was the 30-cm cover. However, in response to above-average precipitation and after periods of drought, little difference in wetting front depth and pressure potentials were observed between different cover treatments. Bare-tailings plots consistently indicated drier conditions and less net infiltration than the cover system plots, most likely due to higher runoff rates from the bare tailings surface. The predicted net infiltration rates at each of the different instrument nests were highly variable and averaged around 0.6% of annual precipitation for the 60-cm cover depths and 0.8% for the 30-cm cover depths.

Observed upward hydraulic gradients at depth during dry periods indicated the possibility of upward migration of acid solution from tailings into the monolayer cover system. Salinity surveys conducted in 2002 and 2007 indicate that salinity migration into the cover systems is limited to 5 to 10 cm above the tailings/cover system contact and has not progressed over time.

Unsaturated flow models calibrated to the collected pressure potential data predict that increasing the cover depth from 45 cm to 90 cm in the side-slope test plot area only nominally decreases long-term net infiltration. The hydraulic properties of the underlying tailings are also predicted to significantly affect net infiltration rates such that net infiltration rates into low-permeability tailings are predicted to be insignificant.

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