CONSTRUCTION AND PRELIMINARY EVALUATION OF COPPER TAILINGS RECLAMATION TEST PLOTS AT CYPRUS MIAMI MINING CORPORATION[1]

by

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Abstract. Twenty pilot-scale test plots were constructed in mid-1998 at the Cyprus Miami mine to investigate the feasibility and cost-effectiveness of various reclamation strategies for establishment of self-sustaining native vegetation on acidic copper tailings. Four reclamation strategies are being tested: (1) directly covering acidic tailings with varying thicknesses of cover soil, (2) removing and/or neutralizing particularly acidic surficial tailings before soil cover placement, (3) chemically and/or physically inhibiting upward water and solute movement using neutralizing and neutral capillary barriers, and (4) constructing a subgrade of neutral tailings beneath cover soil. Preliminary results suggest that thicker soil covers and capillary barrier test plots initially support vegetation to a greater extent than other test plots, probably because of their increased moisture storage capacity. Results also suggest that salts are beginning to migrate upward from underlying tailings into cover soil. Data collected from ongoing vegetation surveys and soil testing will be used to evaluate the effect of various reclamation strategies on vegetation establishment and the potential impact of upward salt migration.

Additional Key Words: revegetation, phytotoxicity, salt migration, capillary barrier, soil cover.

Introduction

In 1989, the Cyprus Miami Mining Corporation (CMMC) initiated a tailings reclamation project on inactive impoundments at its copper mine located near Claypool, Arizona (Jones 1991). Several hundred acres of circumneutral pH (neutral) mill tailings have been successfully vegetated using a combination of traditional techniques such as soil cover placement, fertilization, and seeding, and innovative holistic resource management techniques such as controlled animal impact. While reclamation of neutral mill tailings has been fairly straightforward, reclamation of acidic mill and vat-leach tailings will be limited by their phytotoxic nature.

The pilot-scale vegetation test-plot project discussed in this paper was developed by CMMC and Hydro Geo Chem, Inc. to investigate the technical feasibility and cost-effectiveness of establishing self-sustaining native vegetation on soil covers over acidic mill and vat-leach tailings. Table 1 summarizes the rationale of test-plot design.

Mine tailings reclamation options are highly site specific and depend on factors such as climate, chemical and physical properties of the tailings, availability of cover soil, and primary reclamation objectives (e.g., minimize water or oxygen penetration, minimize erosion, or reclaim for specific land uses). At CMMC, the combination of a semi-arid climate and the phytotoxic nature of tailings presents the primary obstacle to reclamation because of the potential for upward migration of salts into the soil cover as a result of evapotranspiration and diffusion (Barth 1986). The local availability of Gila Conglomerate cover soil shown to be an effective growth medium (Jones 1991), and the large area (up to ~1,000 acres) to be potentially reclaimed, excludes the use of biosolids or other treatments designed to increase the suitability of the tailings materials themselves as a growth medium. Because the movement of moisture under unsaturated conditions is well understood and was not an important objective in this project, construction of lysimeters to monitor the water balance and extensive soil physical testing is not being conducted. Rather, we are focusing on soil chemical analyses and vegetation survey data to assess the ability of 20 reclamation configurations to minimize upward salt migration and support vegetation. Although treatments were not randomized or replicated, we expect to collect data which will assist CMMC in making final reclamation decisions.

Test Plot Configuration and Construction

Test plots were constructed in mid-1998 and completed to within a 1-inch thickness of design specifi-

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cations using a combination of manual labor and earthmoving equipment including a Komatsu D-37E bulldozer, a 3-cubic yard capacity Komatsu front-end loader, several 10-cubic yard capacity, ten-wheel haul trucks, and a Caterpillar motor grader. Four main types were constructed (Figures 1 and 2):

1. direct coverage (Plots G-J, S, and T),
2. capillary barrier (Plots A-D),
3. surface alteration (Plots K-R), and
4. subgrade addition (Plots E and F).

Plots A through R (Figure 1) are approximately 5,000 square feet each while Plots S and T (Figure 2) are 10,000 square feet each. The test plots were sized to minimize potential edge effects. Gila Conglomerate with a gravelly sand texture obtained from borrows on CMMC property was used as cover soil in all test plots.

Table 1
Test Plot Design Rationale

PLOT	DESIGN	BASIC QUESTIONS
CAPILLARY BARRIERS		
A	12" GC Cover over 6" Neutralizing Capillary Barrier	Are physical and chemical mitigation measures needed to protect vegetation from upward phytotoxic constituent migration? Does a geofabric support liner enhance the performance of a neutralizing capillary barrier by preventing fine-grained acidic tailings from entering and partially filling the pores of the capillary barrier?
B	12" GC Cover over 6" Neutralizing Capillary Barrier with Geofabric Support Liner	
C	6" GC Cover over 6" Neutral Capillary Barrier	Can physical mitigation measures protect vegetation from upward phytotoxic constituent migration? If so, what thickness of topsoil is required to effectively maintain vegetation?
D	18" GC Cover over 6" Neutral Capillary Barrier	
SUBGRADE ADDITION		
E	6" GC Cover over 6" Neutral Mill Tailings Subgrade	Will covering acidic mill tailings with neutral mill tailings from adjacent tailings dams help sustain vegetation in an overlying GC cover? If so, what minimum neutral mill tailings thickness is required?
F	6" GC Cover over 12" Neutral Mill Tailings Subgrade	
DIRECT COVERAGE		
G	18" GC Cover	Is it possible to directly cover acidic mill and vat-leach tailings with GC and sustain vegetation? If so, what minimum thickness of GC is required? What is the relationship between a cover's thickness and its ability to support vegetation and minimize upward migration of phytotoxic constituents from underlying acidic tailings?
H, S	12" GC Cover	
I	24" GC Cover	
J, T	6" GC Cover	
SURFACE ALTERATION		
K	18" GC Cover over Lime-Amended Acidic Mill Tailings	Is liming acidic mill tailings necessary for establishment of a vegetated GC cover? If so, what GC cover thickness is required?
L	6" GC Cover over Lime-Amended Acidic Mill Tailings	
M	18" GC Cover over 6" Scraped Surface	Does removal of particularly acidic surficial mill tailings before GC soil cover placement inhibit upward phytotoxic constituent migration? If so, what GC cover thickness is required to sustain vegetation?
N	6" GC Cover over 6" Scraped Surface	
O	18" GC Cover over Lime-Amended 6" Scraped Surface	Is removal of particularly acidic surficial mill tailings and liming the resulting surface necessary for establishment of a vegetated GC cover? If so, what GC cover thickness is required to sustain vegetation?
P	6" GC Cover over Lime-Amended 6" Scraped Surface	
Q	6" GC Cover over 6" Neutral Mill Tailings Subgrade over 6" Scraped Surface	Does removing the upper 6 inches of particularly acidic surficial mill tailings improve the performance of the neutral mill tailings subgrade test plots (E and F)?
R	6" GC Cover over 12" Neutral Mill Tailings Subgrade over 6" Scraped Surface	

GC = Gila Conglomerate

Direct Coverage Plots

Gila Conglomerate was directly applied onto the surfaces of acidic mill tailings (Plots G-J) and acidic vat-leach tailings (Plots S and T). The mill tailings are characteristically fine sands while the vat-leach tailings are gravelly silty sands. The soil was spread in thickness ranging from 6 to 24 inches to evaluate the effects of cover thickness on vegetation quality and upward salt migration.

Capillary Barrier Plots

Acidic vat-leach tailings obtained from a borrow located near Plots S and T were mechanically screened to isolate the 3/16-inch plus fraction, and used with ¾-inch minus limestone gravel obtained from a quarry located about 5 miles from the site, to create neutral capillary barriers in Plots C and D. The same limestone gravel was used to create neutralizing capillary barriers in Plots A and B following installation of a geofabric support liner in Plot B. The liner is being used to assess the added benefit of minimizing fine-grained, acidic mill tailings intrusion into the pores of the capillary barrier. Gila Conglomerate was spread on top of the capillary barriers in thickness ranging from 6 to 18 inches. While capillary barriers are likely to be cost-prohibitive on a large scale, they were included in the study to allow an evaluation of their effectiveness if they need to be used in highly acidic areas where other cover types might fail.

Surface Alteration Plots

Particularly acidic surficial mill tailings were removed from the area currently occupied by Plots M through R by scraping the surface to a depth of 6 inches. The total acidity in the top 6 inches of the resulting surface beneath Plots Q and R was neutralized by evenly applying, cross-ripping, and hydrating ⅛-inch-minus quicklime. The amount of lime added was based on the results of lime requirement and acid-base accounting tests. The total acidity of top 6 inches of the intact acidic mill tailings surface beneath Plots K and L was neutralized in the same manner. Gila Conglomerate cover soil was applied in thickness ranging from 6 to 18 inches following surface alteration. Surficial tailings were removed and/or neutralized with lime in these test plots to assess the additional benefit that these techniques would provide in minimizing upward salt migration and supporting vegetation.

Figure 1
Configuration of Test Plots Over Acidic Mill Tailings

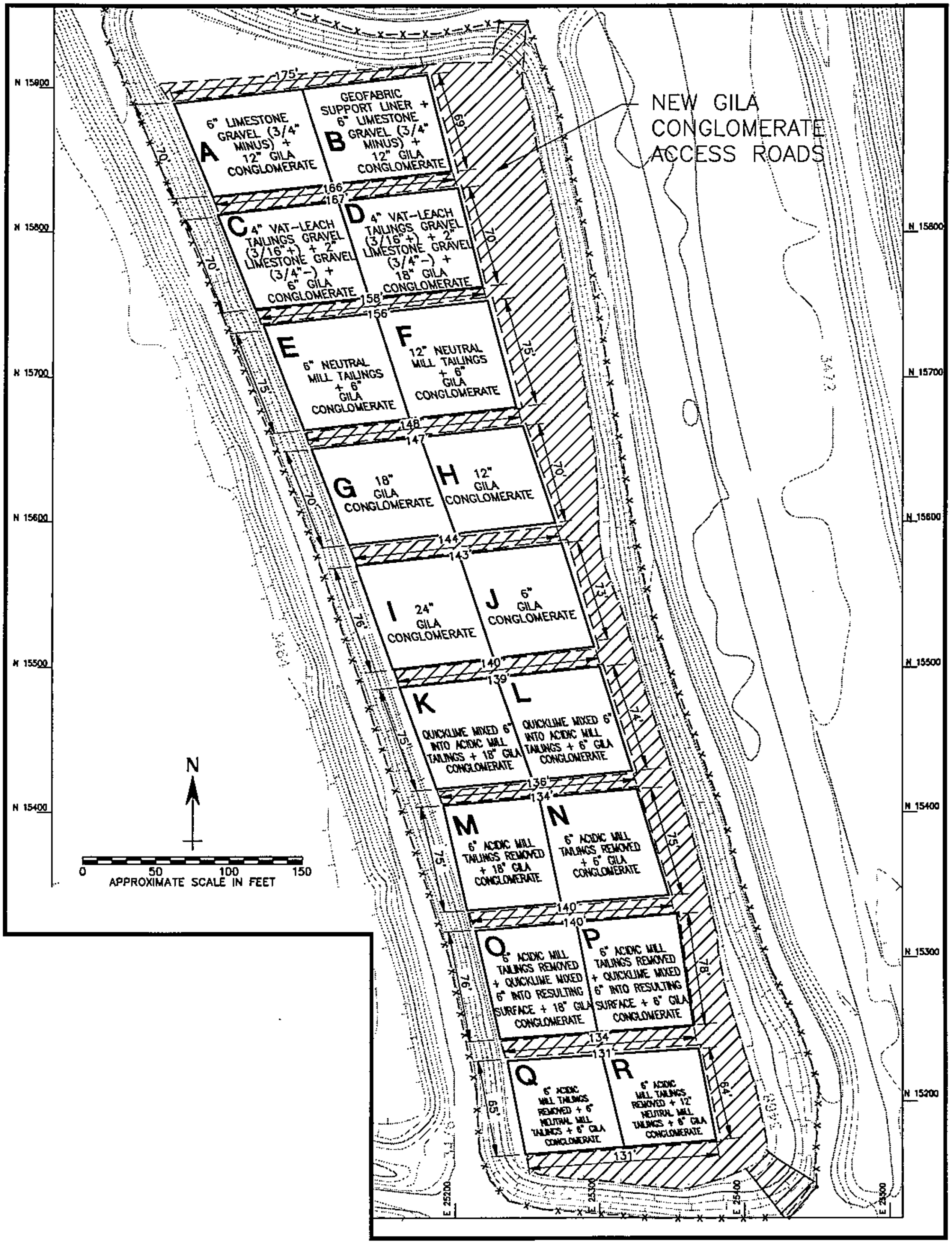
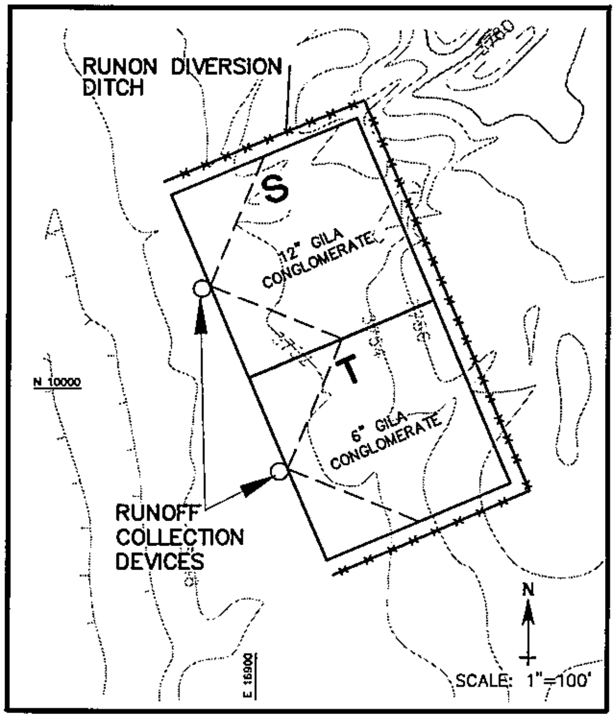


Figure 2
Configuration of Test-Plots Over Acidic Vat-Leach Tailings



Subgrade Addition Plots

Potential future regrading options for tailings impoundments which would place neutral tailings above acidic tailings are being evaluated in subgrade addition test plots. Sandy neutral mill tailings used in Plots E and F (and surface alteration Plots Q and R) were obtained from a nearby inactive CMMC tailings impoundment. The neutral mill tailings were dumped and spread in either 6- or 12-inch thicknesses on the intact acidic mill tailings surface before 6-inch Gila Conglomerate cover placement.

Hydroseeding

Following construction, all test plots were hydroseeded using an aqueous slurry composed of the following materials:

- seed mix as described in Table 2,
- a net 23% nitrogen, 13% phosphoric acid, 0% potassium (23-13-0) fertilizer composed of 2 parts ammonium phosphate (16-20-0) and 1 part slow-release methylene urea (38-0-0) at 287 lbs/acre,
- cellulose fiber mulch at 230 lbs/acre,
- humic acid soil conditioner at 17 gallons/acre,

Table 2
Hydroseed Species Mix

Common Name	Scientific Name	Pure Live Seeding Rate *pounds per acre*	Main Growing Season[b]
Grasses			
Sand Dropseed	*Sporobolus cryptandrus*	0.3	W
Green sprangle-top	*Leptochloa dubia*	0.5	W
Blue grama	*Bouteloua gracilis*	1.0	W
Side-oats grama	*Bouteloua curtipendula*	2.0	W
Purple three-awn	*Aristida purpurea*	1.0	Wc
Cane beardgrass	*Bothriochloa barbinodis*	1.0	W
Bottlebush squirreltail	*Sitanion hystrix*	2.0	C
Plains lovegrass	*Eragrostis intermedia*	0.5	W
Curly mesquite	*Hilaria belangeri*	1.0	W
Plains bristle grass	*Setaria macrostachya*	2.0	W
Alkali sacaton[a]	*Sporobolus airoides*	1.0	W
Forbs			
Globemallow	*Sphaeralcea ambigua*	0.5	WC
Desert marigold	*Baileya multiradiata*	0.5	WC
Indian wheat	*Plantago insularis*	5.0	C
Parry penstemon	*Penstemon parryi*	0.5	C
Mexican gold poppy	*Escholtzia mexicana*	2.0	C
Arroyo lupine	*Lupinus succulentus*	1.5	C
Desert lupine	*Lupinus sparsiflorus*	1.5	C
Woodies			
False mesquite	*Calliandra eriophylla*	2.0	W
Four-wing saltbush	*Atriplex canescens*	1.0	C
White thorn acacia	*Acacia constricta*	1.0	W
Catclaw acacia	*Acacia greggii*	2.0	W
Wait-a-minute bush	*Mimosa biuncifera*	0.5	W
Velvet mesquite	*Prosopis velutina*	1.0	W
Jojoba	*Simmondsia chinensis*	3.0	WC
Creosote bush	*Larrea tridentata*	3.0	W
Three leaf sumac	*Rhus trilobata*	2.0	WC

[a] Seeded in mid-September 1998 with irrigation water

[b] W = warm; Wc = mainly warm, occasionally cool; WC = warm and cool; C = cool

- pure mucilage tackifier at 62 lbs/acre, and
- natural organic compost at 5.2 yd^3/acre.

After hydroseeding, test plots were covered with straw mulch at a rate of 2.2 tons/acre and fixed by crimping and tacking using pure mucilage tackifier and cellulose fiber at rates of approximately 200 and 700 lbs/acre, respectively.

Costs

The capital cost for each of the test plots is listed in Table 3. Costs include materials and delivery, construction labor and supervision, tacking,

Table 3
Test Plot Construction Costs

Plot	Total Cost	Cost per Acre
A	$4,752	$34,935
B	$6,360	$46,757
C	$9,123	$69,845
D	$9,946	$76,141
E	$1,207	$9,225
F	$1,686	$12,884
G	$1,389	$11,877
H	$1,020	$8,722
I	$1,818	$15,015
J	$674	$5,562
K	$2,747	$23,369
L	$2,006	$17,063
M	$2,152	$18,237
N	$1,408	$11,929
O	$3,251	$26,849
P	$2,488	$20,547
Q	$1,529	$15,635
R	$1,884	$19,269
S	$3,196	$13,920
T	$1,872	$8,153

seeding, and amendment application. Engineering design and oversight, soil sampling and testing, and field surveys are not included. Unit construction costs are expected to be significantly lower for those techniques chosen for use on a larger scale.

Precipitation and Irrigation

Figure 3 illustrates precipitation measured in rain gauges near the test plots between July 8, 1998 and March 16, 1999. About 70% of the 6.6 inches of total precipitation over this 8-month period resulted from brief and intense summer thunderstorms. Although seedlings were growing on all test plots by mid-September 1998, uneven rainfall caused them to be inconsistently distributed. To compensate for the variable rainfall, about 1.5 inches of water was applied on Plots A through R over a four-day period using a temporary five-line, center-pivot sprinkler system along with hydroseeder truck applications in late September 1998. About the same amount of water was applied on Plots S and T over the same four days. No additional irrigation has been applied.

Preliminary Results and Discussion

Vegetation Surveys

Four surveys are planned over two years to document the density, diversity, and health of plants on each test plot. Surveys are scheduled for fall and spring in order to record the activity of both warm- and cool-season vegetation. Table 4 summarizes the data being gathered on all test plots including indices which measure plant response over time. Results from the first survey (October 1998) are summarized in Table 5 and discussed below. Results from all four surveys will be used to evaluate the effectiveness of plot configurations in sustaining plant communities.

Figure 3
Precipitation at the Test Plots

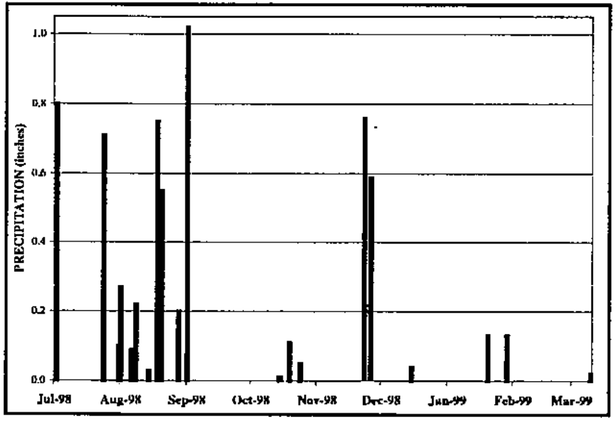


Table 4
Vegetation Survey Data

Whole Plot Plant Abundance
Relative number of plants of each species on entire plot:
0 = none
1 = rare (1-10)
2 = occasional (10-100)
3 = common (100-1000)
4 = abundant (1000+)

Plants in Quadrat
Total number of plants of each species in each of four 10-ft^2 quadrats per plot.

Average Size
Average height and width of each species in whole plot:
1 = <1 inch
2 = 1 to 5 inches
3 = 5 to 20 inches
4 = 20 to 40 inches
5 = >40 inches

Numbers are also given to indicate the relative number of leaves for grasses and stems for forbs and woody species:
1 = few
2 = many

Overall Vigor
Overall vigor of each species in whole plot:
0 = dead
1 = poor
2 = fair
3 = good
D = dormant

Phenology Range
Measure of the periodic change of plant maturity:
0 = Dead
1 = Seedling (cotyledons and few true leaves)
2 = Significant number of true leaves yet immature
3 = Bud stage, forming pre-flowering boots or buds
4 = Flowering
5 = Fruit or seed set
6 = Fruit or seed drop
7 = Post fruiting or seed drop
8 = Dormant

Diversity Index
Total number of seeded species observed on entire plot divided by total number of species seeded (27).

Quadrat Density
Total number of seeded plants in all four quadrats divided by the total area of the quadrats (40 ft^2).

Biomass Index
(Average seeded plant height) *x* (Average seeded plant width) *x* (Average seeded plant number of leaves or stems) *x* (Quadrat Density)

Vigor Index
Average vigor of seeded plants on plot. (Dormant plants not included.)

Health Index
(Vigor index) *x* (Quadrat Density)

The diversity index measures the proportion of seeded species observed to be growing on each test plot (Table 4). Given that 7 of the 27 seeded species are exclusively cold-season plants (Table 2), the maximum diversity index at this time should be 0.74. Values for this index in October 1998 ranged from 0.59 to 0.78, indicating that most species had germinated. However, the density of plants varied considerably (0.7 to 5.9 plants per square foot), as did the health of plants as measured by the health and vigor indices (Tables 4 and 5).

Variation in vegetation quality and quantity during the initial stages of this project is probably more due to differences in soil cover thickness and subgrade type than chemical effects such as upward salt migration from underlying acidic tailings. For example, the capillary barrier test plots (A through D; Figure 1) established denser stands of healthy vegetation as compared to the other test plots (Table 5), probably because capillary forces led to the preferential retention of moisture in the finer-grained cover soil above gravel. Moreover, it appears that the thinner the cover over the capillary barrier, the healthier and denser plants became (compare indices for Plots A through D, Table 5). Although this seems counterintuitive, it makes sense physically because the cover soil above the capillary barrier acts like a sponge due to its finer texture. If the same amount of water is applied to the thinner cover (smaller sponge) as the thicker cover (bigger sponge), the thinner cover will become more saturated than the thicker cover because of its smaller volume. Thus, cover soil in Plot C could provide more available moisture to seedlings with shallow root systems and consequently supported the densest and healthiest plant populations (Table 5).

Despite these preliminary observations, we expect that thicker covers over capillary barriers will eventually support vegetation to a greater extent because they have the potential to hold more moisture and provide a greater rooting volume to plants. This same premise holds true for those configurations without a capillary barrier because there is no subgrade to prevent water from moving deeper in the profile. For example, 12-inch direct coverage Plot S had considerably greater biomass and health indices than 6-inch direct coverage Plot T (Table 5). Nevertheless, the fact that we do not see a similar effect in the other four direct coverage test plots (G through J) indicates that other variables are likely influencing the initial vegetation growth on the test plots.

Table 5
Summary of Fall 1998 Vegetation Survey Results

PLOT	DIVERSITY INDEX	QUADRAT DENSITY	BIOMASS INDEX	VIGOR INDEX	HEALTH INDEX
A	0.74	4.4	24.8	2.80	12.25
B	0.78	3.5	22.6	2.79	9.75
C	0.70	5.9	27.2	2.11	12.42
D	0.78	2.6	15.4	2.81	7.23
E	0.74	2.7	15.6	2.55	6.89
F	0.59	1.4	7.2	2.63	3.61
G	0.70	1.8	9.9	2.71	4.88
H	0.63	1.4	9.5	2.76	3.87
I	0.78	1.9	10.5	2.64	4.96
J	0.70	2.1	11.9	2.66	5.52
K	0.78	2.5	15.4	2.74	6.71
L	0.74	1.8	9.8	2.60	4.62
M	0.70	2.1	11.5	2.58	5.29
N	0.78	4.5	24.4	2.17	9.80
O	0.74	3.5	18.9	2.75	9.49
P	0.67	2.9	17.8	2.61	7.51
Q	0.74	3.0	16.6	2.60	7.67
R	0.74	2.6	14.3	2.55	6.50
S	0.63	1.9	12.2	2.76	5.11
T	0.67	0.7	4.4	2.72	1.91
MAXIMUM	0.78	5.9	27.2	2.81	12.42
AVERAGE	0.72	2.7	15.0	2.63	6.80
MINIMUM	0.59	0.7	4.4	2.11	1.91

Salt Migration Study

Baseline Conditions. Baseline soil chemical conditions were evaluated using the following analyses: 1) ammonium acetate-extractable calcium, magnesium, sodium, and potassium; 2) bromide, chloride, molybdenum, nitrate, and electrical conductivity in a 1:1 weight/weight soil:deionized water extraction; 3) sodium bicarbonate-extractable phosphorus; 4) diethylenetriaminepentaacetic acid-extractable zinc, iron, manganese, copper, and lead; 5) hot-water extractable boron; 6) potassium chloride-extractable aluminum and ammonium; and 7) paste pH in a 1:1 weight/weight soil:deionized water slurry. Methods used for these analyses are described in Sparks et al. (1996).

Baseline results are compared to values that may be detrimental to plants (Table 6). All tested materials lack between 3 and 7 of the following plant macro- or micronutrients: nitrogen, boron, calcium, iron, magnesium, manganese, phosphorus, potassium, and zinc. Acidic mill and vat-leach tailings have potentially phytotoxic concentrations of aluminum and copper in addition to detrimental pH values. Neutral mill tailings used as a subgrade in Plots E, F, Q, and R contain high concentrations of copper and molybdenum.

Baseline results were used to select indicator constituents for salt migration monitoring over time. Aluminum, iron, manganese, molybdenum, calcium, copper, boron, paste pH, and electrical conductivity were identified as key constituents because they differ greatly between Gila Conglomerate cover soil and various subgrades.

Winter 1999 Results. Soil samples were collected at the base of the Gila Conglomerate covers near the center of the test plots in February 1999. Results were compared to baseline results using two-sample t-tests (Table 7). Iron concentrations in all sampled test plots were significantly greater than baseline iron values, suggesting upward mi-

Table 6
Baseline Soil Chemistry Results

Analyte	Unit	Phytotoxic Level	Gila Conglomerate[c]		Surficial Acidic Mill Tailings[d]	Buried Acidic Mill Tailings[d]	Neutral Mill Tailings[e]	Acidic Vat-Leach Tailings[f]
			Sample Size	Mean ± 95% Confidence Interval				
Aluminum	mg/kg	>2[a]	14	3.30 ± 2.29	310	62.7	1.81	244
Ammonium	mg/kg N	<10 or >130[a]	4	1.4 ± 1.8	12.2	0.7	1.7	<0.1
Boron	mg/kg	<0.2 or >5[a]	6	0.081 ± 0.061	1.19	0.177	0.017	0.078
Bromide	mg/kg	-	4	0.4 ± 0.32	<1.0	<1.0	0.5	<1.0
Calcium	mg/kg	<400-1000[g]	7	1483 ± 477	14,500	268	882	1,220
Chloride	mg/kg	-	4	23.8 ± 45.5	60.1	2.1	115	29.6
Copper	mg/kg	<0.2[a,h] or >30[a]	5	7.0 ± 17.5	73.0	32.4	95	1,260
Electrical Conductivity	mmhos/cm	>4[i]-8[a,h]	15	0.27 ± 0.06	5.46	2.13	1.57	5.04
Iron	mg/kg	<2.4-4.5[h,j] or >1000[l]	15	2.8 ± 0.4	157	88.8	12.2	2.45
Lead	mg/kg	>10-20[b]	4	0.25 ± 0.25	<0.08	<0.08	0.2	<0.8
Magnesium	mg/kg	<100-150[g]	4	316 ± 255	367	63.1	51.6	351
Manganese	mg/kg	<2[h] or >60[h]	6	1.87 ± 1.13	27.6	8.40	0.372	26.7
Molybdenum	mg/kg	>0.3[b]	9	0.015 ± 0.009	<0.009	<0.009	3.82	<0.09
Nitrate	mg/kg N	<10 or >130[a]	4	4.02 ± 6.48	1.72	0.43	3.73	0.45
pH	standard units	<5[a] or >8.4[b]	15	8.20 ± 0.35	2.81	2.78	7.98	3.88
Phosphorus	mg/kg	<30[g]	4	3.9 ± 5.6	<0.1	5.0	0.28	1.7
Potassium	mg/kg	<100[g]	4	151 ± 113	15.0	13.0	21	<57
Sodium	mg/kg	-	5	149 ± 103	108	6.60	111	32.7
SAR[k]	none	>12[a]	4	0.31 ± 0.16	0.08	0.03	0.34	0.07
Zinc	mg/kg	<0.5-1[h] or >40[h]	4	0.428 ± 0.436	3.95	2.73	1.02	3.43

[a] Barth, 1986 (see references section).

[b] Schafer, 1979 (see references section).

[c] Gila Conglomerate samples were taken from borrow pits before test plot construction (4/98) and from test plots shortly after construction (8/98).

[d] Composite sample taken at three locations across TP 5-4 before plot construction; surficial samples collected at the surface; buried samples collected at about 8 inches in depth.

[e] Average results of two 8"-deep samples, one each from Plots E and R (collected on August 18, 1998).

[f] Composite sample of vat-leach tailings taken on LP Discard before test plot construction.

[g] Consolidated Fertilizers Ltd. (Brisbane, Australia) Soil Test Manual. See Bell and Meecham (1978) in references section.

[h] Cox and Kamprath, 1972 (see references section).

[i] Richards, 1954 (see references section).

[j] Iron is analyzed because of antagonism with other nutrients. High Fe may mitigate high levels of other metals. Iron deficiency could also occur.

[k] Sodium adsorption ratio = Sodium concentration/[(Calcium + Magnesium concentration)/2]$^{1/2}$ where concentrations are expressed in meq/L. Values given are worst-case scenarios since ammonium acetate is a more powerful extractant than typically-used water.

[l] Approximate value from Brady and Weil, 1996 (see references section).

▨ = potentially phytotoxic level based on the mean result

Table 7
Selected Winter 1999 Salt Migration Results

Plot/Depth	Iron	Manganese	Molybdenum	EC	pH
	mg/kg			mS/cm	standard units
A/8"	6.35	-	-	0.33	8.29
B/8"	8.08	-	-	0.30	8.27
D/15"	7.08	-	-	0.33	8.17
E/4"	8.83	-	0.029	0.27	8.02
F/4"	8.69	-	0.034	0.27	8.15
G/16"	8.45	-	-	0.23	8.14
H/10"	7.90	-	-	0.21	8.43
I/20"	7.39	-	-	0.29	8.30
J/4"	7.34	-	-	0.23	8.38
K/16"	9.58	-	-	0.35	8.06
M/16"	6.24	-	-	0.27	8.40
O/16"	8.23	-	0.018	0.28	8.49
Q/4"	8.60	8.12	0.057	0.30	7.93
R/4"	6.71	3.96	0.069	0.28	8.45
S/10"	-	-	-	0.38	7.29

- = not analyzed

EC = Electrical Conductivity

Shaded values are not from the population having the same mean as the baseline results (Table 6), as based on 95% confidence t-testing.

gration of iron salts or weathering of disturbed iron minerals in the excavated Gila Conglomerate. Manganese concentrations at the base of the cover in Plots Q and R have increased over baseline values (Tables 6 and 7). Judging from baseline results (Table 6), the manganese source may be the acidic mill tailings beneath the Gila Conglomerate cover and neutral mill tailings subgrade. Increases in molybdenum concentrations have also occurred at the base of the Gila Conglomerate covers overlying the neutral mill tailings subgrade in Plots E, F, Q, and R. Because the neutral mill tailings were the only material having appreciable baseline concentrations of molybdenum (Table 6), concentration increases in the covers are probably due to upward salt migration from this subgrade.

Summary and Conclusions

The pilot-scale vegetation test plots were designed and constructed at CMMC to evaluate the technical feasibility and cost-effectiveness of establishing and sustaining native vegetation on acidic tailings. Preliminary results suggest that thicker direct coverage and capillary barrier test plots are initially supporting vegetation to a greater extent than other test plots, perhaps because of their enhanced ability to store moisture. Preliminary soil testing results suggest that salts may be beginning to migrate upward from underlying subgrades into the Gila Conglomerate covers. Future soil sampling and analysis at various depths within selected test plots will be used to monitor the advancement of underlying salts into the vegetated covers.

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