OPTIONS TO REVEGETATE NEUTRALIZED HEAP LEACH MATERIAL[1]

by

R.R. Cellan[2], L.M. Burnside[3] and G.E. McClelland[4]

Abstract. Revegetation of neutralized heap leach material in the and environment of the Great Basin represents a challenge of available technology. The chemical and physical environment of spent and neutralized ore is inhospitable for germination and establishment of desirable long term vegetation. Common soil amendments were tested to determine if the heap material could be made more conducive to plant growth. Decommissioned heap material profile samples were collected and reconstructed in columns at bench scale. The column profiles were amended and subjected to three leaching regimes, and representative meteoric conditions. The soil amendments provided positive results for ameliorating the heap material limitations and providing a medium conducive to plant growth. The bench scale study also provided insight for the future of heap leach planning and design with successful reclamation in mind at the forefront.

Introduction

The Santa Fe/Calvada Mine, owned and operated by Homestake Mining Co., is located 25 miles east of Hawthorne, Nevada, in the Gabbs Valley Range at an elevation of 6,400 feet. Average annual precipitation is 5 inches (12.7 cm), with average maximum and minimum temperatures of 70 and 53 degrees Fahrenheit. Effective precipitation generally falls during the spring and winter. Summer convection stonns are common, however, during periods of high daily temperatures, high evapo-transpiration results.

Mining and gold production on the Santa Fe deposit commenced in 1988 and the Calvada expansion was completed in 1992. The project is a conventional open pit leach pad gold operation consisting of four main open pits and four leach pads. Precious metals were recovered from pregnant solutions using a conventional carbon adsorption process plant. Ore was generally crushed to nominal 3/4 inch and most was agglomerated before being placed on the leach pads. Cyanide leaching was terminated in 1994. 17.6 million tons of ore were mined and leached over the life of the project.

From 1989 through 1994 the mine waste rock dumps and haul roads were reclaimed. Closure and reclamation objectives for the Santa Fe project were designed to restore the site to pre-operation land use. Objectives were to reestablish vegetation and wildlife/grazing habitat, and ensure protection of surface and groundwater resources. The Bureau of Land Management (BLM) and Nevada Division of Environmental Protection (NDEP) have further ensured post mining land uses with the development of Nevada Reclamation Standards. Standards require that reclaimed areas achieve as close to 100 percent of the perennial plant cover of representative undisturbed vegetation communities. Homestake prides itself on active pursuance of successful concurrent reclamation. To date 572 of the 797 acres disturbed have been revegetated, and are involved in a monitoring program. The remaining 225 acres to be reclaimed and revegetated include facility sites, access roads and four heap leach pads.

In 1996, a heap leach pad test plot program was implemented to evaluate revegetation techniques and plant species adapted to site specific conditions. Techniques emphasized heap material amendment to develop a suitable growth medium, and a seed mix was designed based on the characteristics of the native plant communities, climatic conditions, and heap material characteristics. Limitations of the heap material and low precipitation resulted in minimal response in the test plots. Most severe limitations were heap material color, gradation and chemical conditions resulting from the cyanide leach process. Amelioration of these conditions are time and cost sensitive. This paper discusses a laboratory testing protocol developed by Homestake, MLI and RCI to determine the success of two alternative methods for establishing desirable long term vegetation on neutralized heap material.

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[2]Roy R. Cellan, Corporate Manager - Reclamation, Homestake Mining Company, 650 California Street, San Francisco, CA 94108.

[3] Leslie M. Burnside, Sr. Resource Specialist, Resource Concepts, Inc. 340 N. Minnesota Street, Carson City, NV 89703.

[4]Gene E. McClelland, Metallurgist/President, McClelland Laboratories, Inc., 10 16 Greg Street, Sparks, NV 89431.

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Field Sampling and Analysis Parameters

Of the four project heaps (pads), Pad 1 South and Pad 4 were unique warranting separate sampling and testing with their respective surface salt layers. Pad 1 is crushed black material (gravel to cobble), Pad 4 is medium brown finely crushed (pebble to gravel). Pads 2, 3 and the north slope of Pad 1 were physically and chemically similar justifying composite samples. Overall, surface salt accumulation was most evident on Pad 1, with the south portion presenting the worst case situation, because it was the surface evaporative site for excess neutralized barren solution. Native growth medium used during testing was collected in a composite sample from three on-site native growth medium stockpiles. Sufficient on-site well water was collected and transported to the laboratory with heap and growth medium samples for the testing program.

Baseline solids analysis focused on constituents which limited the response of the 1996 revegetation test plots. Solids analysis included major and micro nutrients such as nitrogen, phosphorous, potassium, calcium, magnesium and sodium. Toxic element analysis included boron, chloride, sulfate and electrical conductivity. Sodium (Na) and electrical conductivity (EC) were the most limiting constituents for establishment of desirable vegetation on these heaps. High levels of nitrate (NO_3), a by-product of solution cyanide compound degradation were also observed in the heap material. All solids were analyzed by an agricultural laboratory using standard procedures.

Laboratory Testing and Sampling Protocol

Specialized testing protocols were used to achieve objectives based on the minimal response of the test plots. Objectives for the testing program were to determine if:

1. application of well water and gypsum to neutralized heap surfaces was effective in leaching salts to below the rooting zone, and thus support vegetation growth; and,

2. normal meteoric and climatic cycles would cause salts contained in the heap surface layer to capillate into surface applied native growth medium thus impeding vegetation growth, and what depth of growth medium is required to prevent salt capillation, such that vegetation growth is not impeded.

Seven column percolation salt load leaching tests were conducted on various neutralized heap material composites and surface salt layer samples from the site to accomplish objective 1. Four meteoric/climatic cycle simulation column tests were conducted on select neutralized heap material composites, surface salt layer samples, and varied depths of native growth medium to accomplish objective 2.

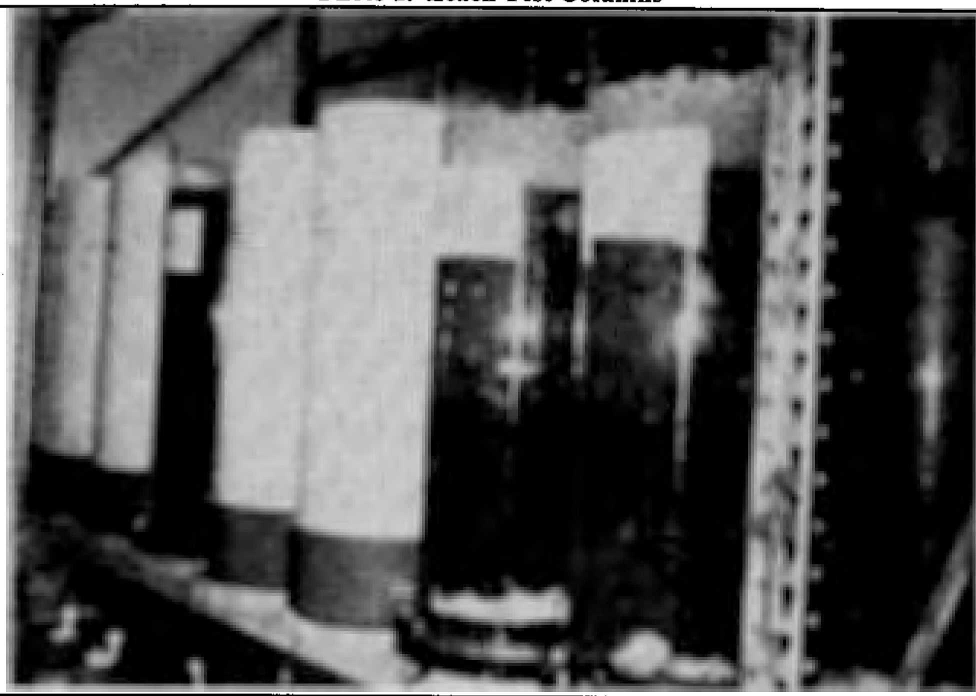
All tests were conducted in 12 inch diameter (30 cm) clear acrylic or PVC columns of varied height. Columns were loaded by placing heap material (26 or 30 inch beds) onto a perforated punch plate and compacting to an equivalent on-site bulk density (110 lb/ft^3). Surface salt layer samples and/or native growth medium was placed on top of the heap material and was similarly compacted to an equivalent on-site bulk density. A gypsum application equal to 4,000 lbs/acre, was applied to the surface of the salt load leach test column charges. A description of solid materials loaded into salt load leach test columns is provided in Table 1.

Table 1. Column Percolation Salt Load Leach Test Summary, 4,000 lbs Gypsum/Acre Applied to Surface of Each Column Charge

Heap Composite		Surface Salt		Well Water
Location	Depth	Location	Depth	Applied, inches
Pad 4	30"	N/A	N/A	5
Pad 4	30"	N/A	N/A	10
Pad 4	30"	N/A	N/A	15
Pad 1 N, Pad 2+3	26"	Pad 1 N	4"	5
Pad 1 N, Pad 2+3	26"	Pad 1 N	4"	10
Pad 1 N, Pad 2+3	26"	Pad 1 N	4"	15
Pad 1 S	26"	Pad 1 S	4"	5, 10, and 15

Column percolation salt load leach tests were conducted on Pad 4 (no surface salt layer), Pad 1 North, Pad 2, and Pad 3 (composite) and Pad 1 South heap material (with surface salt layer) to determine if contained salts could be leached to below the rooting zone. Leach test columns are shown in Photo 1.

Photo 1. Leach Test Columns



Three quantities of minesite well water (5, 10, and 15 inches or 12.7, 25.4, and 38.1 centimeters) were used in the leach tests. Well water used for the salt load leach tests was slightly alkaline at pH 7.24, and contained alkalinity (344 mg/l), Calcium (290 mg/l) and several other elevated constituents. However, general chemistry of the well water was acceptable for supporting vegetation establishment. General column leach procedures are summarized as follows:

1. Apply well water daily at a rate of 0.75 inches (1.9 cm) over 8 hours;
2. Suspend application for 16 hours;
3. Repeat items 1 and 2 above until the desired well water application was achieved;
4. Measure effluent volume after each desired well water application and analyze for Na, Ca, and Mg to evaluate salt leaching efficiency; and
5. Allow column solids to free drain and sample at varied bed depths for subsequent solids analyses.

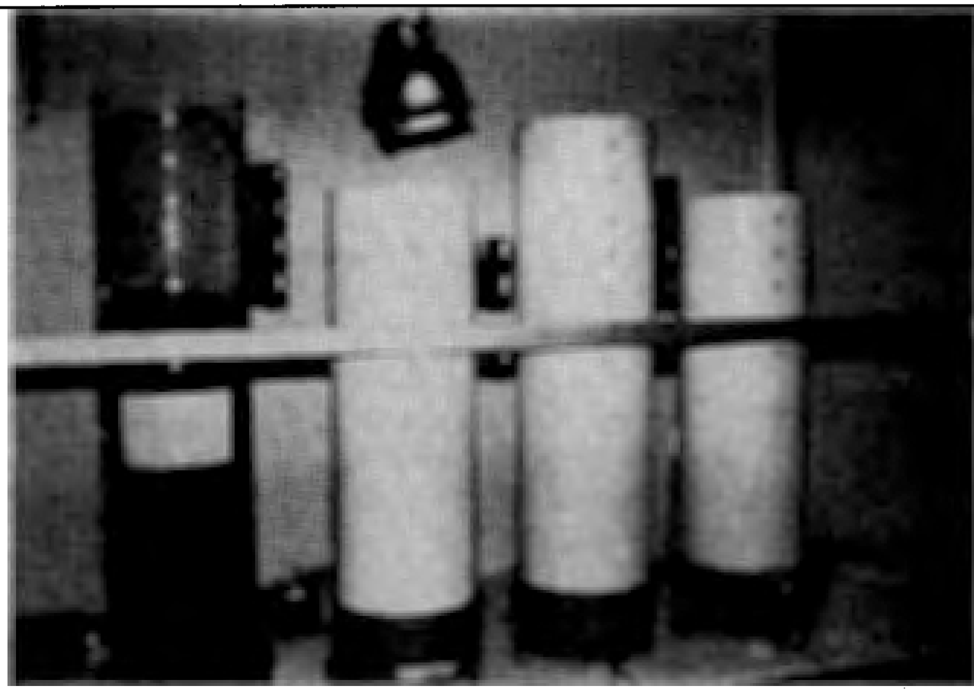
Meteoric/climatic cycle simulation column percolation tests were conducted on two samples, Pad 1 North, Pad 2 and 3 (composited) heap material, Pad 1 North surface salt, 6 inches (15.24 cm) and 12 inches (30.5 cm) of native growth medium. The second sample was Pad 1 South heap material, Pad 1 South surface salt, and 6 inches and 12 inches of native growth medium. Four total tests were conducted to determine if surface salts would migrate upward into the surface applied growth medium. A description of materials loaded into the meteoric test columns is provided in Table 2.

Table 2. Column Meteoric/Climatic Cycle Simulation Test Summary

Heap Composite		Surface Salt		Growth Medium Depth	Annual Climatic Cycles Simulated
Location	Depth	Location	Depth		
Pad 1 N, Pad 2+3	26"	Pad 1 N	4"	6"	2
Pad 1 N, Pad 2+3	26"	Pad 1 N	4"	12"	2
Pad 1 S	26"	Pad 1 S	4"	6"	2
Pad 1 S	26"	Pad 1 S	4"	12"	2

Column charges were loaded as described earlier, and bedded in increments during column loading procedures to allow temperature and moisture probes to be installed. Temperature probes were installed at surface and every 3 inches (7.6 cm) into the growth medium, and

Photo 2. Meteoric Test Columns



in the heap material 2 inches (5 cm) below the surface salt layer. Moisture probes were installed every 3 inches into the growth medium and into the heap material 2 inches below the surface salt layer. Meteoric test columns are shown in Photo 2.

Two annual climatic cycles were simulated, using deionized water, for each column test as summarized in Table 3.

Table 3. Climatic Cycle Simulation Summary

Season	Meteoric Event		Ambient Surface Temperature, °F	
	Rain Equiv. Inches	Volume Applied, Liters	Day	Night
Winter	2.57	4.373	60	60
Spring	1.11	1.885	84	60
Summer	0.76	1.291	111	60
Fall	1.56	2.649	84	60
Total/ Annual Cycle	**6.00**	**10.198**		

About 70 days was required to complete two simulated annual climatic cycles. Meteoric/climatic cycle simulation test procedures are summarized as follows:

1. Obtain volume of deionized water required to simulate each seasonal meteoric event.

2. Apply that volume of deionized water to column charges at constant rate over a 6 hour period.

3. Maintain room temperature at 60°F each night, and during the day for winter simulation cycles.

4. Adjust infrared lights to the appropriate height above the column charges to ensure desired day time surface temperatures for spring, summer, and fall seasons.

5. Allow a one day soak time for solution percolation into the solids after each meteoric event.

6. After soaking, measure temperature and moisture content for each depth at end of daily shift. Dry cycles were: Winter, spring, and fall - 7 days; spring - 4 days

7. Measure effluent volume and composite on a volume weighted basis and analyze for Na, Ca, and Mg.

8. Repeat procedure for the 2nd annual climatic cycle.

9. Allow column solids to free drain and sample at varied bed depths for specific solids analyses.

Solids sampling of the column charges for both the leach and meteoric tests required column sacrifice. Sampling increments were based on the layers of material as loaded in the column and the test objectives. To obtain undisturbed samples, columns were cut in half lengthwise. One half of the charge was sacrificed, while the undisturbed half was sampled at specified depths.

Solids for each leach column were sampled in the salt layer (0 to 4 inches), and in 5 inch increments through the heap material. Meteoric column sampling focused on the growth medium material to determine if salts migrated upward. Growth medium was sampled in 3 inch increments. The salt layer and heap material were sampled as separate composites to determine change in salt content.

Discussion of Results

Salt Load Column Leach Test

Current industry practice is to cover material inhospitable for vegetation establishment with a suitable growth medium. These test results offer some alternatives to that practice.

Overall effluent analysis results from the seven column percolation salt load tests indicate that at least 5 inches, but not more than 10 inches of well water must be applied to the various heaps to leach the salt load to an acceptable depth to support vegetation growth. This indication was confirmed from the solids analysis results.

Application of soil chemical and physical amendments in association with the practice of leaching with high quality water, is common in the agricultural industry. Heap material, however, is not at all similar to crop soils. Consequently, applicability of agricultural soil rehabilitation practices to heap material raised some practical questions. At Santa Fe/Calvada, the question was not would leaching move salts down below the rooting zone for plant establishment, but rather what quantity of low quality well water would be required to accomplish sufficient leaching? The closest Homestake well for the Santa Fe/Calvada project is 2.5 miles and approximately 200 feet below in elevation. In addition, the quality of the well water is less than that normally required for effective leaching as per typical agricultural practices. These conditions raised concerns for capability to leach salts with a minimum quantity of water considering the associated substantial pumping costs for a leaching program.

Laboratory results indicated that leaching was a viable alternative for this site if sufficient well water was available. The 5 inch application of well water provided a wetted front and initiated the leaching process. The 10 inch application accomplished adequate leaching within the rooting zone, and the 15 inch application moved the area of accumulation deeper in the heap material. Figure 1, illustrates the layers of sample materials as they were loaded in the columns for testing, baseline conditions and results of leaching for Pad 1 South materials.

Figure 1. Summary Results, Salt Load Column Leach Test, Pad 1 S Surface Salts, Pad 1 S Heap Material, 15" Well Water Applied

Solid	Depth,	Before Leach			After Leach		
Material	Inch	Na	NO_3	EC	Na	NO_3	EC
Surf. Salt	0-4	2760	240	62	313	6.1	2.9
Heap	0-5	1702	65	10	230	3.0	2.6
Heap	5-10	1702	65	10	248	2.3	2.7
Heap	10-15	1702	65	10	373	205	2.8
Heap	15-20	1702	65	10	506	307	3.0
Heap	20-Bot.	1702	65	10	506	209	3.1

Note: Na and NO_3 conc. in mg/kg, EC in mmhos/cm^2.

Pad 1 South heap material with in-situ surface salts were presumed to represent worst case conditions for salt load because it was used to evaporate excess barren solution. Baseline concentration of the surface salt layer was 2,760 mgNa/kg, 240 $mgNO_3$/kg, and an EC of 62 mmhos/cm^2. Baseline material concentrations were 1,702 mgNa/kg, 65 $mgNO_3$/kg, and 10 mmhos/cm^2 for EC.

Initial indications of worst case conditions justified leaching and solids analysis for the cumulative leaching of a total of 15 inches of well water. Concentrations of the three constituents in the surface salts decreased by 89 to 97 percent. Within the rooting zone (0 to 14 inches), sodium decreased an average of 87 percent. Nitrate and EC decreased an average of 96 and 81 percent, respectively. Below the rooting zone (14 to 26 inches) sodium decreased an average of 74 percent, NO_3 accumulated in this zone by an average of 269 percent, and EC decreased an average of 70 percent.

The Pad 1 North surface salts contained 3,312 mgNa/kg, 47 $mgNO_3$/kg, and EC was 22 mmhos/cm^2 (Figure 2). The heap material composite concentrations were 1,150 mgNa/kg, 47 $mgNO_3$/kg, and 22 mmhos/cm^2 EC. After the 5 inch application, concentrations of the three constituents in the surface salts decreased by 72 to 84 percent.

Within the rooting zone, Na decreased an average of 58 percent, NO_3 86 percent, and EC 73 percent. Below the rooting zone 5 inches of well water resulted in a slight accumulation of Na (18 percent), but NO_3 and EC continued to decrease by 41 and 57 percent, respectively.

After the 10 inch leach application for the surface salts, the three constituents decreased between 83 and 92 percent. Within the rooting zone, Na decreased an average of 57 percent, NO_3 93 percent, and EC 75 percent. Below the rooting zone, Na decreased overall, 37 percent. Nitrate removal averaged 89 percent and EC 67 percent.

The 15 inch application rate resulted in the three constituents decreasing between 85 and 88 percent. Within the rooting zone Na decreased 82 percent, NO_3 93 percent, and EC 80 percent. Below the rooting zone Na, NO_3, and EC continued leaching by an average of 64, 96, and 73 percent, respectively.

Figure 3 presents the baseline and test results for Pad 4 material. Prior to this testing program, Pad 4 material had been ripped mixing and surface salts into the heap material. These column charges are comprised of 30 inch composite heap material. Pad 4 contained the finest crushed heap material, and was expected to be more difficult to leach than the coarser heap materials. Baseline concentrations 2,208 mgNa/kg, 25 $mgNO_3$/kg, and an EC of 11 mmhos/cm^2.

Figure 2. Summary Results, Salt Load Column Leach Tests, Pad 1 N Surf. Salt, Pad 1 N, Pad 2, Pad 3 Heap Composite

Solid	Depth,	Before Leach			After Leach: Na Well Water			NO_3 Well Water			EC Well Water		
Material	Inch	Na	NO_3	EC	5"	10"	15"	5"	10"	15"	5"	10"	15"
Surf Salt	0-4	3312	47	22	920	552	400	7.5	3.8	6.2	4.2	3.4	3.2
Heap	0-5	1150	47	22	377	506	235	1.6	2.4	2.0	3.1	3.1	2.1
Heap	5-10	1150	47	22	736	782	267	8.7	2.6	1.7	3.7	3.5	2.8
Heap	10-15	1150	47	22	1196	446	294	26	2.7	1.5	4.5	3.6	2.8
Heap	15-20	1150	47	22	1518	1012	442	21	6.6	1.8	5.0	4.0	3.0
Heap	20-Bot.	1150	47	22	1518	1012	506	21	6.6	1.5	5.0	4.0	3.1

Note: Na and NO_3 conc. in mg/kg, EC in mmhos/cm^2.

Figure 3. Summary Results, Salt Load Column Leach Tests, No Surf. Salt, Pad 4 Heap Composite

Solid Material	Depth, Inch	Before Leach Na	Before Leach NO_3	Before Leach EC	After Leach Na Well Water 5"	10"	15"	After Leach NO_3 Well Water 5"	10"	15"	After Leach EC Well Water 5"	10"	15"
Surf Salt	0-4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Heap	0-5	2208	48	25	506	317	294	9.1	2.6	3.1	3.6	3.2	2.9
Heap	5-10	2208	48	25	736	304	225	2.8	1.7	2.5	3.7	3.0	2.7
Heap	10-15	2208	48	25	1288	552	253	5.5	2.3	2.9	4.6	3.4	2.9
Heap	15-20	2208	48	25	1748	920	386	14	3.5	2.6	5.6	4.1	3.0
Heap	20-Bot.	2208	48	25	2346	1380	690	33	3.9	2.7	6.7	4.6	3.5

Note: Na and NO_3 conc. in mg/kg, EC in mmhos/cm².

In the rooting zone, the average decrease of Na and EC increased with additional applications of well water and were 72, 86 and 88 percent, and 67, 72, and 75 percent, respectively. For NO_3, the average percent leaching was 77, 92, and 89 percent for the three well water applications. Average percent leaching increased, below the rooting zone, for Na (19, 59, 80 percent), NO_3 (30, 87, 89 percent) and EC (49, 63, 72 percent).

The 15 inch application to the surface heap material resulted in the three constituents decreasing between 85 and 88 percent. Within the rooting zone, Na decreased an average of 82 percent, NO_3 93 percent, and EC 80 percent. Below the rooting zone, Na leaching decreased with depth, but, again showed overall was 63 percent. Nitrate and EC leaching was consistent at 96 and 73 percent, respectively.

Salt load leach test results verify that inhospitable constituents can be effectively leached with varying applications of low quality well water.

In comparison to agricultural standards, final concentrations were still high for EC, yet in a manageable range for revegetation. For sodium, all quantities of well water applied brought the concentration in the heap material to equivalent or lower levels than that of the native growth medium. Resulting sodium and EC levels in the solids indicate that the 5 inch (12.7 cm) application initiated the leaching process, the 10 inch (25.4 cm) application decreased critical constituents to manageable levels, and the 15 inch (38.1 cm) application is optimal to ensure deep leaching if well water is readily available. The long term effectiveness of leaching extreme levels of inhospitable micro nutrients and salts below the rooting zone in coarse, organic matter free heap material has yet to be field tested. However, these results do provide one technique to progress toward creating a suitable growth medium from neutralized heap material. Additional amendments may be required.

Meteoric/Climatic Cycle Simulation Column Test

The task of moving earthen material is an expensive cost for even the smaller mining sites. Therefore, when heap material is not wholly conducive as suitable growth medium, and must be covered with suitable material, there must be reasonable assurance for revegetation success to justify the cost. Assurance should focus on protecting the surface applied growth medium from the plant growth inhibiting constituents of the heap material.

In the case of the Santa Fe/Calvada heap material, the concern was twofold; if growth medium was applied directly on top of the heap material, would the sodium and salts migrate up into the growth medium? and, if upward migration did occur, what depth of growth medium would be required to protect the rooting zone? Under meteoric conditions in low precipitation zones (4 to 6 inches or 10.2 to 15.2 cm), it was expected that a wetted front sufficient to induce capillary rise from the heap material would not form, and the growth medium would be protected.

Figures 4 through 7 illustrate layers of sample material loaded in the meteoric test columns, baseline conditions, and results after being subjected to two meteoric/climatic cycles. The same growth medium composite was applied to all the meteoric test column charges. Baseline concentrations in the growth medium were 460 mgNa/kg, 5.9 mgNO_3/kg, with an EC of 1.4 mmhos/cm^2.

For both the 6 and 12 inch application depths for growth medium on Pad 1 South with in-situ surface salts Na and EC did not increase or migrate up into the growth medium. To the contrary, overall Na, NO_3 and EC became vulnerable to the leaching process. With a 6 inch application of native growth medium (Figure 4), Na decreased an average of 57 percent, EC 50 percent, and NO_3 83 percent throughout the growth medium layer. In the surface salt layer the three constituents decreased between 92 and 99 percent. Leaching also occurred in the heap material, although to a lesser degree. The decrease in the three constituents varied from 14 to 62 percent.

With a 12 inch application of native growth medium (Figure 5), Na decreased an average of 61 percent, EC 57 percent, and NO_3 61 percent in the growth medium layer. The three constituents decreased between 91 and 99 percent in the surface salt layer. Leaching also occurred in the subsurface heap material and a 22 to 74 percent decrease in the three constituents was observed.

The Pad 1 North, Pad 2 and Pad 3 heap material composite with Pad 1 North surface salts for both the 6 and 12 inch depth applications of growth medium also demonstrated that Na and EC did not migrate up into the growth medium, but moved down in the solids beds as a results of the leaching process. Overall EC decreased throughout the column charge, yet Na and NO_3 accumulated in the heap material. With a 6 inch application of native growth medium (Figure 6), Na decreased an average of 65 percent, EC 67 percent, and NO_3 44 percent in the growth medium layer. In the surface salt layer, Na and EC decreased between 73 and 94 percent, respectively, but, NO_3 showed a 1.5 percent accumulation. In the heap material, EC decreased 70 percent, yet Na and NO_3 increased 12 and 169 percent, respectively. Relative to the Pad 1 South Na load, the Pad 1 North surface salts contained a higher baseline concentration for Na.

With the 12 inch surface application of native growth medium (Figure 7), Na and EC decreases were similar to the 6 inch test at 58 and 59 percent, respectively. The decrease in NO_3 concentration was much lower at 14 percent for the growth medium layer. In the surface salt layer, Na and EC decreased 75 to 90 percent, but, NO_3 increased 4 percent. EC was the only constituent that decreased in the subsurface heap material at 68 percent. Na and NO_3 accumulated in the subsurface heap material.

Although leaching was not the objective for meteoric testing it generally occurred throughout the rooting zone of the tested material. More importantly, meteoric tests verified that a wetting front sufficient to induce upward migration of Na and salts will not develop in the rooting zone under these particular meteoric conditions.

Figure 4. Summary Results, Meteoric/Climatic Cycle Simulation Column Test, 6" Native Growth Medium, Pad 1 S Surface Salt, Pad 1 S Heap Material

Solid	Depth,	Na, mg/kg		NO_3 mg/kg		EC mmhos/cm^2	
Material	Inch	Before	After	Before	After	Before	After
Growth Med.	0-3	460	202	5.9	7.7	1.4	0.7
Growth Med.	3-6	460	193	5.9	1.0	1.4	0.6
Surf. Salt	0-4	2,760	230	240	1.4	62	2.7
Heap	26	1,702	1,472	65	25	10	4.6

Figure 5. Summary Results, Meteoric/Climatic Cycle Simulation Column Test, 12" Native Growth Medium, Pad 1 S Surface Salt, Pad 1 S Heap Material

Solid Material	Depth, Inch	Na, mg/kg Before	Na, mg/kg After	NO_3 mg/kg Before	NO_3 mg/kg After	EC mmhos/cm² Before	EC mmhos/cm² After
Growth Med.	0-3	460	179	5.9	4.6	1.4	0.7
Growth Med.	3-6	460	152	5.9	1.6	1.4	0.4
Growth Med.	6-9	460	189	5.9	1.7	1.4	0.5
Growth Med.	9-12	460	225	5.9	2.2	1.4	0.6
Surf. Salt	0-4	2,760	248	240	2.2	62	2.7
Heap	26	1,702	1,334	65	17	10	4.4

Figure 6. Summary Results, Meteoric/Climatic Cycle Simulation Column Test, 6" Native Growth Medium, Pad 1 N Surface Salt, Pad 1 N, Pad 2, Pad 3 Heap Composite

Solid Material	Depth, Inch	Na, mg/kg Before	Na, mg/kg After	NO_3 mg/kg Before	NO_3 mg/kg After	EC mmhos/cm² Before	EC mmhos/cm² After
Growth Med.	0-3	460	161	5.9	3.5	1.4	0.5
Growth Med.	3-6	460	156	5.9	3.2	1.4	0.4
Surf. Salt	0-4	3,312	193	1.0	2.5	8.0	2.2
Heap	26	1,150	1,288	3.6	9.7	14.0	4.2

Figure 7. Summary Results, Meteoric/Climatic Cycle Simulation Column Test, 12" Native Growth Medium, Pad 1 N Surface Salt, Pad 1 N, Pad 2, Pad 3 Heap Composite

Solid Material	Depth, Inch	Na, mg/kg Before	Na, mg/kg After	NO_3 mg/kg Before	NO_3 mg/kg After	EC mmhos/cm² Before	EC mmhos/cm² After
Growth Med.	0-3	460	147	5.9	5.6	1.4	0.6
Growth Med.	3-6	460	179	5.9	4.6	1.4	0.5
Growth Med.	6-9	460	198	5.9	4.9	1.4	0.5
Growth Med.	9-12	460	244	5.9	5.2	1.4	0.7
Surf. Salt	0-4	3,312	354	1.0	4.6	8.0	2.0
Heap	26	1,150	1,426	3.6	23	14.0	4.5

Potential Benefit to the Mining Industry

The authors feel that this or a similar laboratory testing evaluation for establishing suitable revegetation conditions at a minesite during project development and/or production phases of a project would provide substantial benefits to the mining industry. Laboratory testing to determine required growth medium (processed material and native growth medium) amendments can be extended to include actual revegetation in the amended test samples to establish plant varieties which would thrive in the specific minesite environment. Some benefits that early laboratory testing could provide include:

1. Substantial decrease in mine closure time.
2. Decreased duration of disturbance at minesite.
3. Earlier completion of reclamation plans and decisions, thereby decreasing closure time and risk.
4. Lower closure and reclamation costs.

Conclusions and Future Applications

Existing revegetation technology does not directly address the unique limitations posed by neutralized heap materials. The chemical and physical conditions post neutralization render the material, in many cases, unfavorable to the establishment of desirable long term vegetation. A suitable growth medium must be present to accomplish successful revegetation. Neutralized heap material chemical conditions can be amended with gypsum and leached to decrease the plant growth inhibiting by-products of the cyanide leaching process (sodium and electrical conductivity/salts). Heap material does not contain the standard constituents of a growth medium. The plant establishment depth (0 to 36 inches) of heap material is void of organic matter, lacking in fine material, and therefore has minimal water holding capacity and microbial populations for root zone development. Amending the physical conditions of heap material to create a suitable growth medium is necessary in many cases and can be costly.

Results of the laboratory testing protocol conducted by Homestake Mining Company for the Santa Fe/Calvada Mine, provides assurances that leaching can be successfully accomplished on neutralized heap material if the operator wishes to engage in the cost of amending the heap material to create a suitable growth medium. In addition, the results also verified that if adequate growth medium is readily accessible, it can be applied to the surface of the heap material and be protected from upward migration of plant growth inhibiting constituents from the heap material.

These results have provided the required assurances for Homestake Mining Company to apply these principles in the field at the Santa Fe/Calvada Mine. This mine site is currently in the closure phase and therefore the emphasis is on short term action to ensure the establishment of successful revegetation on the heap material. For operations that are in the construction and production phases, either of these principles are potentially viable options for successful revegetation.