Ore Permeability and Blending Evaluation to Optimize Leach Performance

Jason Keller, GeoSystems Analysis, Inc., USA
Tzung-mow Yao, GeoSystems Analysis, Inc., USA
Michael Milczarek, GeoSystems Analysis, Inc., USA
Vince Lofftus, Round Mountain Gold Corporation, USA
Stuart Myrhow, Round Mountain Gold Corporation, USA

Abstract

Efficient metal recovery from heap leaching requires good ore permeability. Depending on the ore type, consolidation under increasing heap heights may significantly decrease ore permeability, thereby causing increased leach times, incomplete recovery, and reduction of the economic value of the process. Physical, chemical, and hydraulic property laboratory screening tests were conducted on potassic and hydrothermally altered (argillic) ore samples from Round Mountain Gold Corporation's Gold Hill deposit in order to determine the solution permeability of the ore samples under increasing ore consolidation and controlling factors (e.g., particle size distribution and clay types).

Results were applied to evaluate the suitability of each ore type for standard heap leach operations and, for low permeability ores, identify appropriate ore blend ratios to maintain sufficient permeability. Correlation analyses indicated that "PSD Indicator" values may be used to predict permeability and blending requirements. Leach pad performance indicates that the test program properly defined blending ratios and successfully mitigated poor permeability ores.

Introduction

The Round Mountain Gold Corporation's (RMGC) Round Mountain mine is located in south-central Nevada approximately 55 miles north of Tonopah (Figure 1). In 2011 RMGC expanded the operation with the addition of a satellite deposit about two miles to the north, known as Gold Hill. The Gold Hill resource is a quartz-adularia low-sulfidation hydrothermal deposit hosted in volcanic ash-fall tuffs. Mineralization is fine grain (<50 microns) with electrum, silver sulfides, and sulfosalts in veins and veinlets. Whereas the unoxidized portions of the deposit have low precious metal recovery, the upper portions of the deposit have been oxidized, rendering the ores in these areas amenable to conventional cyanide heap leach methods.

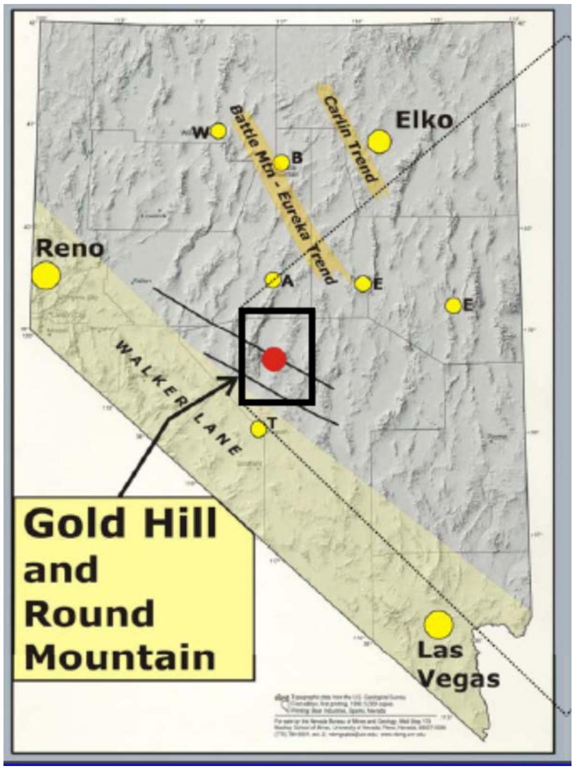

Figure 1: Location of Round Mountain Gold Corporation in Nevada

Gold Hill leach pad loading began in August of 2012 and conventional run-of-mine (ROM) heap leach cyanidation is used to process the ore. Almost immediately, percolation problems were encountered on the leach pad at the design irrigation rate of 0.003 gpm/ft^2. To prevent ponding, the application rate had to be reduced by half, which slowed the recovery rates and resulted in production not meeting budget.

In addition, the lift height was reduced from 50 ft to 25 ft to increase the gold production rate as much as possible. The reduction in irrigation rates and lift heights caused the mining rate to be cut in half, essentially doubling the mine life. Several studies were initiated to characterize the permeability problem and find solutions, including the completion of physical, chemical, and hydraulic property laboratory tests on the ROM ore to determine the solution permeability of the ore samples and blended ore samples to evaluate their suitability for standard heap leach operations.

Methods

Laboratory tests

ROM samples were selected by the owner and shipped to a third-party testing laboratory located in Tucson, Arizona, for testing. The ore samples originated from a single lithologic unit; however, they were categorized under three alteration ore types: argillic (A), advanced argillic (AA), and siliceous potassic (SP). Three non-leached ROM samples from each alteration ore type were tested to capture the expected variability within the ore types, in addition to three ore blends to evaluate blending strategies for low permeability ores. Table 1 lists the tests and standard methods that were conducted on the ROM ore samples. The A and AA samples were also blended at different ratios to determine whether hydraulic properties could be improved via blending; blend samples underwent hydraulic testing only.

Physical property screening tests included:

- Particle size distribution (PSD) of ore samples to determine the material size fractions.
- Particle density to determine the mineral density distribution.
- Atterberg limits to estimate soil plasticity.

Chemical property screening tests included:

- XRD analysis to determine the clay mineral composition of the ore samples.
- XRF analysis to determine the relative contents of major elements in the ore samples.

Hydraulic property screening tests were comprised of saturated hydraulic conductivity (K_{sat}) testing in 12-inch diameter by 12-inch-high dual-wall permeameters (Figure 2) over a range of bulk densities representative of various heap heights from the top of the heap to approximately 80 ft below the heap surface to estimate changes in K_{sat} under varying levels of overburden pressure (i.e., heap heights). The dual wall permeameter provides a more even distribution of pressure to the ore compared to the vertical pressures applied in a rigid wall (uniaxial) consolidation permeability test. The permeameters were packed with samples with a maximum particle size of 2.0 inches (51 mm).

Table 1: Laboratory tests and test methods

Test Type	Test method	Standard
Physical	Particle size distribution	ASTM D422–63, C136-03
	Particle density	ASTM D854-02
	Atterberg limits	ASTM D4318
Chemical	X-ray diffraction	MOSA Part 5, Chapter 4
	X-ray fluorescence	MOSA Part 5, Chapter 14
Hydraulic	Consolidation permeability (K_{sat})	ASTM D5084-03

(Sources: ASTM, 2009; MOSA, 2008)

Criteria for desirable ore permeability characteristics were established to include:

- A measured K_{sat} greater than 100 times the owners; forecast irrigation rate of 0.003 gpm/ft^2 (2.0×10^{-4} cm/s) for estimated heap heights up to approximately 80 feet. A safety factor of 100 is applied to account for variations in ore, irrigation rate and frequency, precipitation, and topographical variation in the heap.

- Absence of significant amounts of swelling (i.e., montmorillonite, smectite) type clays.
- Lack of significant ore consolidation under pressures mimicking increasing heap heights.

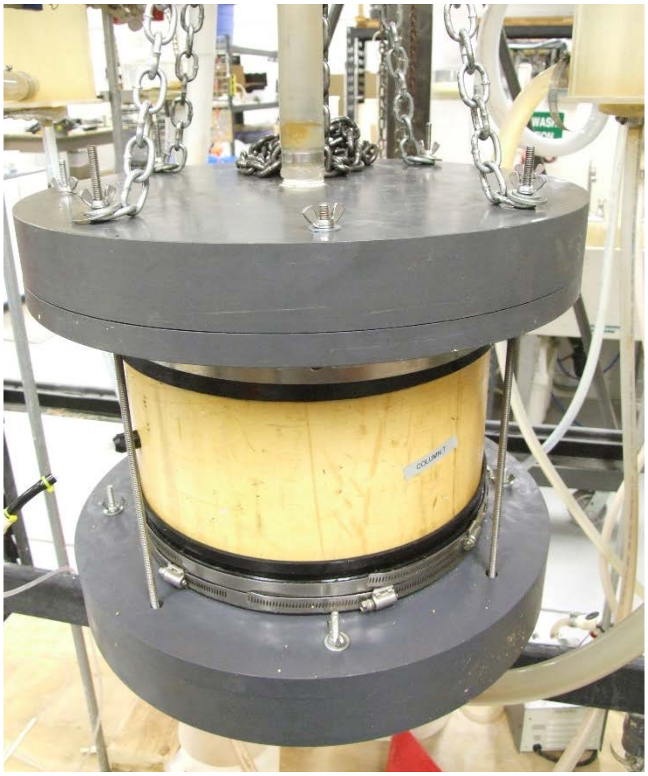

Figure 2: Dual-wall permeameter

Correlation analysis

Consolidation permeability testing of ROM ore material provides the best means of characterizing sample solution K_{sat}, but these tests require specialized equipment and highly trained staff, and therefore are expensive and time consuming. To determine whether lower cost physical property tests could be used to estimate K_{sat}, correlation analyses were conducted between the hydraulic property and physical and chemical property test results to determine parameters that may be used to help characterize permeability.

Correlation analyses were conducted by using the best fit functions (power or exponential) to the relationships between K_{sat} values at estimated heap heights of 20 ft (near the bottom of a first lift) and the following sample parameters:

- percent clay
- percent passing the #100 mesh
- PSD indicator
- clay activity from Atterberg limits testing
- total sample percent smectite from the XRD results.

Results

Laboratory tests

Particle size distribution

Table 2 provides the percent: gravel (larger than the #4 mesh [4.75 mm]); passing #100 mesh (0.15 mm); silt and clay (passing the #200 mesh [0.075 mm]), and clay (<0.002 mm) for the nine ore samples. Table 2 also provides the estimated PSD for the blended samples calculated from the weighted average PSD of the ore material comprising the blend samples. AA ore material was the finest grained sample with 14.7 to 28.4 percent of material classified as silt or finer and only 6.0 to 38.0 percent of the material classified as gravel. SP ore material was the coarsest ore sample, with 7.9 to 8.4 percent of the material classified as silt or finer and 71.0 to 78.0 percent of the material classified as gravel. In terms of both gravel and silt and clay content ranges, the A ore material was in between the AA and SP samples.

Table 2: Percent gravel, passing #100 mesh, silt and clay, and clay and PSD indicator

Sample	Gravel (>4.75 mm, %)	Passing #100 Mesh (0.15 mm, %)	Silt and clay (<0.075 mm, %)	Clay (<0.002 mm, %)	PSD indicator (% Gravel / % Passing #100 mesh)
SP-1	71	9.1	8.3	4.1	7.8
SP-2	78	9.1	8.4	3.8	8.6
SP-3	72	8.8	7.9	2.5	8.1
SP average	**73.7**	**9**	**8.2**	**3.5**	**8.2**
A-1	43	9	8	3.2	4.8
A-2	52	12.5	11.3	5.1	4.2
A-3	58	10.9	9.9	4.4	5.3
A average	**51**	**10.8**	**9.8**	**4.2**	**4.7**
AA-1	38	16	14.7	7.2	2.4
AA-2	6	32.8	28.4	12.1	0.2
AA-3	17	22.6	20	6.8	0.8
AA average	**20.3**	**23.8**	**21.1**	**8.7**	**0.9**
75% A-1/25% AA-2	33.8	14.9	13.1	5.4	2.3
75% A-1/25% AA-1	41.8	10.7	9.7	4.2	3.9
75% A-2+A-3/25% AA-3	45.5	14.4	13.0	5.3	3.2

Of the blend samples, sample 75% A-1/25% AA-1 had the least amount of material classified as silt or finer (9.7%), while samples 75% A-2+A-3/25% AA-3 and 75% A-1/25% AA-2 had nearly the same amount of silt and clay material (approximately 13%).

The calculated PSD indicator values are presented in Table 2. The PSD indicator is the ratio of the percentage of gravel (>4.75 mm) to material passing the #100 mesh (0.15 mm), and can be used as a potential index of ore permeability with the logic that gravel-sized particles influence macropore solution flow and finer-sized particles influence material consolidation and matrix pore solution flow. The PSD Indicator ranged from 0.2 to 2.4 for the AA ore samples, to 7.8 to 8.6 for the SP ore samples, with intermediate values of 4.2 to 5.3 for the A samples. Blend sample PSD indicator values ranged from 2.3 to 3.9.

Particle density and Atterberg limits

Particle density and Atterberg limit results for the ten ore samples are presented in Table 3. Particle density values ranged from 2.66 g/cm^3 for the A-3 sample to 2.80 g/cm^3 for the SP-2 sample. The SP ore samples had the highest particle densities, whereas the A and AA samples were similar.

The clay activity is calculated as the plasticity index divided by the percent clay in the Atterberg limits test sample. It provides an indication of the tendency of the ore to shrink and swell with changes in water content. Clay activity greater than 1.25 indicates soils with high shrink and swell tendencies (i.e., smectite type clay). Based on Atterberg test results, all samples had low shrink and swell tendencies.

Table 3: Particle density and Atterberg limits test results

Sample ID	Particle density (g/cm^3)	Liquid limit (LL)	Plastic limit (PL)	Plasticity index (PI)	Clay activity	Clay type
SP-1	2.72	44	21	23	0.65	Inactive
SP-2	2.8	37	22	15	0.43	Inactive
SP-3	2.73	27	23	4	0.19	Inactive
A-1	2.68	39	24	15	0.57	Inactive
A-2	2.68	41	22	19	0.59	Inactive
A-3	2.66	44	23	21	0.67	Inactive
AA-1	2.67	45	25	20	0.55	Inactive
AA-2	2.69	50	30	20	0.73	Inactive
AA-3	2.67	44	29	15	0.67	Inactive

XRD clay speciation

XRD analysis results (Table 4) indicate that swelling type smectite clays, which can greatly reduce hydraulic conductivity in small amounts, were present in largest quantities in samples AA-1 (4%) and AA-2 (8%). All other samples had 2% or less smectite clays. The low shrink-swell potential of samples AA-1 and AA-2 (Table 3) may be due to the large gravel fraction present in the ore material. In general, Atterberg limits calculated clay activity increased with percent smectite type clays present in the ore material.

Table 4: Clay fraction X-ray diffraction results

Sample ID	Clay (<0.002 mm)	Illite	Kaolinite	Smectite	Palygorskite
		Percent of total sample			
SP-1	4.1	1	1	2	ND
SP-2	3.8	2	2	<1	ND
SP-3	2.5	1	1	<1	ND
A-1	3.2	<1	<1	2	ND
A-2	5.1	2	2	1	ND
A-3	4.4	1	1	2	ND
AA-1	7.2	1	2	4	ND
AA-2	12.1	2	2	8	ND
AA-3	6.8	3	2	2	1

Consolidation permeability

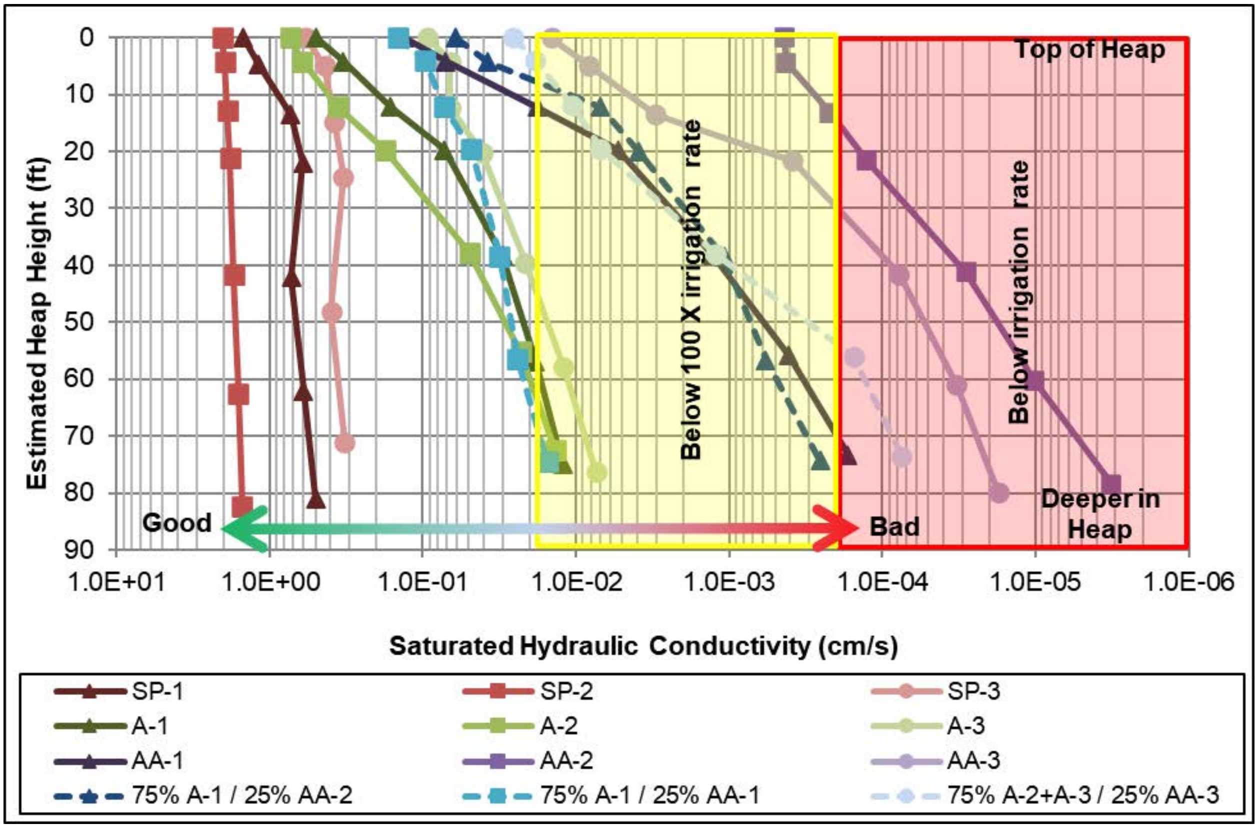

Figure 3: Consolidation permeameter measured K_{sat}

Consolidation permeameter measured K_{sat} values, reported as a function of calculated heap height, are presented in Figure 3. Measured K_{sat} values for the A ore samples decreased by approximately one to 1.5 orders of magnitude as simulated heap heights increased from zero to approximately 75 feet. AA ore measured K_{sat} decreased two to three orders of magnitude as the simulated heap height increased from zero to approximately 80 feet. In contrast, measured K_{sat} for the SP material decreased only slightly as heap height increased, reflecting the coarseness of these samples and relatively small amount of fines fraction. K_{sat} trends for blend samples 75% A-1/25% AA-2 and 75% A-2+A-3/25% AA-3 decreased by approximately 2 orders of magnitude from zero to 75 feet while blend sample 75% A-1/25% AA-1 decreased by only one order of magnitude from zero to 75 feet.

The red box in Figure 3 indicates K_{sat} values lower than the forecast irrigation rate of 0.003 gpm/ft^2 (2.0×10^{-4} cm/s); the yellow box indicates K_{sat} values lower than the 100X safety factor (0.3 gpm/ft^2, 2.0×10^{-2} cm/s), but greater than the forecast irrigation rate. The consolidation permeability results can be summarized as follows:

- All of the SP samples had greater K_{sat} values than 100× the forecast irrigation rate for all heap heights evaluated. These data indicate the SP material is sufficiently permeable under all anticipated heap conditions.
- The A samples A-1 and A-2 had K_{sat} values above the 100× safety factor at simulated heap heights less than 60 feet; sample A-3 K_{sat} was above the 100× safety factor at heap heights less than 40 feet. These data indicate the A material is sufficiently permeable under conditions of two to three 25-foot lifts.
- The AA samples AA-2 and AA-3 had K_{sat} values below the 100× safety factor for all heap heights tested and below the forecast irrigation rate at heap heights greater than 13 and 30 feet, respectively. Sample AA-1 K_{sat} was below the 100× safety factor at simulated heap heights above 12 feet, and below the forecast irrigation rate at 70 feet of estimated heap height. These results indicate that all AA materials are likely to experience problems with permeability at the forecast irrigation rate under first lift conditions and that solution percolation and irrigation rates should be carefully monitored for the AA ore materials.
- The 75% A-1/25% AA-2 blend sample had K_{sat} values above the 100× safety factor at simulated heap heights less than 60 feet and K_{sat} values above the forecast irrigation rate at all heap heights up to 75 feet. Blend samples 75% A-1/25% AA-1 and 75% A-2+A-3/25% AA-3 had K_{sat} values below the 100× safety factor at simulated heap heights exceeding approximately 5 feet. These results indicate that blending at a proportion of 75% A material and 25% AA-1 material results in ore that is sufficiently permeable under conditions of two lifts. Blending at a proportion of 75% A material and 25% AA-2 or AA-3 material results in an ore that is likely to experience permeability problems at the forecast irrigation rate under first lift conditions.

Correlation analysis

The parameter with the highest correlation to K_{sat} results was the PSD Indicator ($R^2 = 0.83$) (Figure 4). A strong correlation between K_{sat} and percent passing the #100 mesh, percent clay, percent smectite, and clay activity was not observed, producing R^2 values of 0.57 or less. The correlation analyses indicate that the PSD indicator may be used as an indicator of sample permeability. For example, from these relationships a ROM ore with a PSD indicator less than 4 may experience permeability problems under first lift conditions.

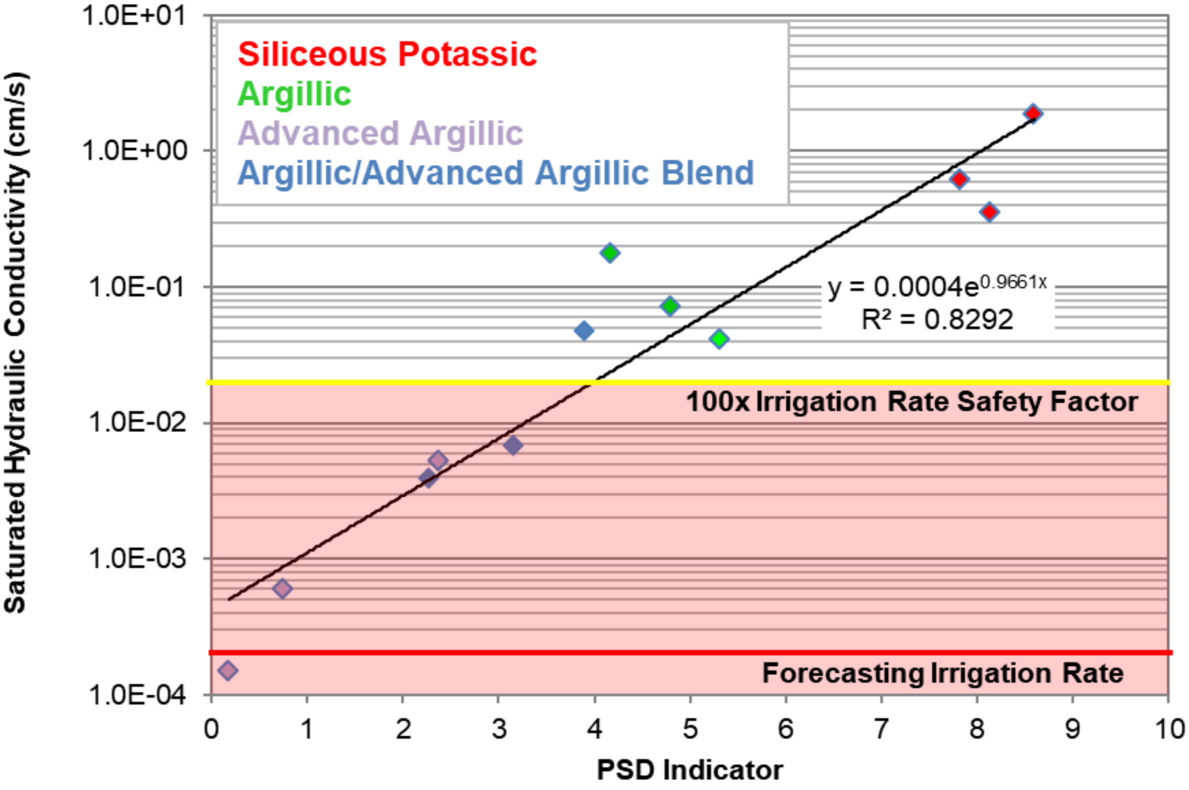

Figure 4: Correlation between PSD indicator and K_{sat} at an estimated heap height of 20 feet

Operational implementation

The leach pad recovery model was adjusted based on operating and permeability test results. Figure 5 shows the budgeted and actual monthly gold ounces produced from the leach pad from October 2012 through June 2022. Actual gold production was consistently less than the budgeted gold production through 2014. Integration of the test work and recalibration of the recovery model in 2015 resulted in the forecast model being able to better forecast gold production, in addition to allowing for identification of problem ore types and to optimize ore blends.

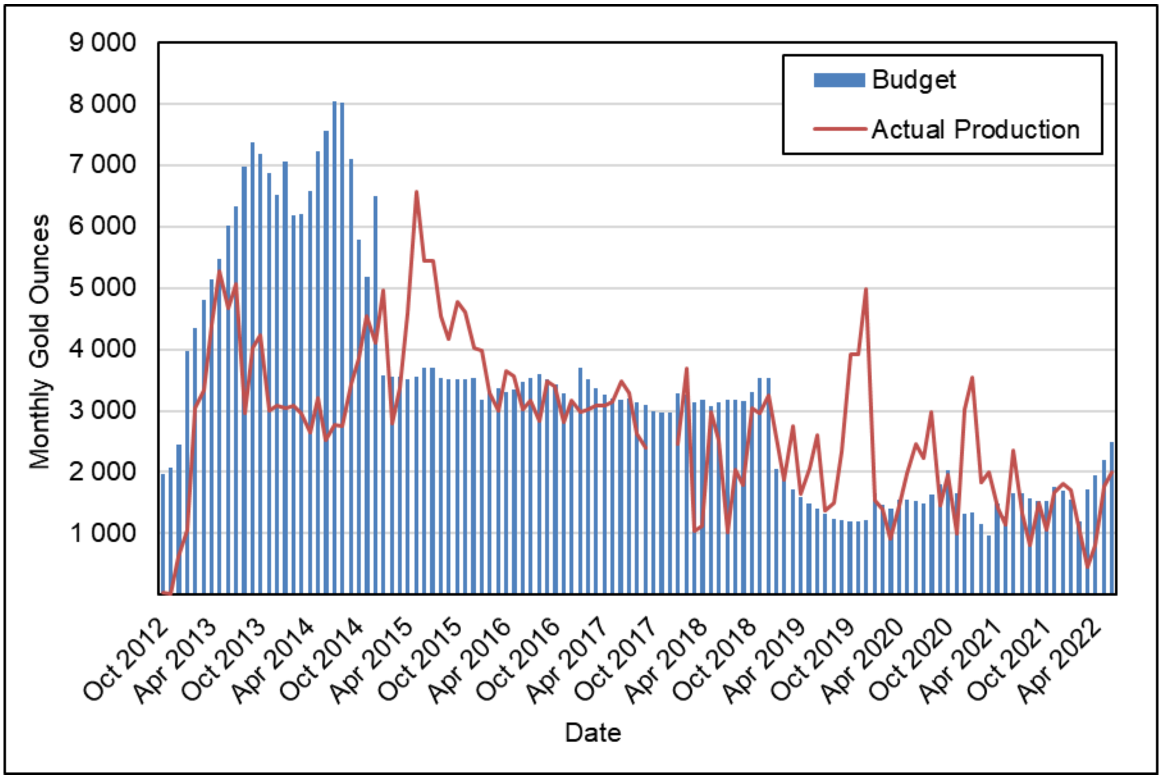

Figure 5: Budgeted and actual gold produced

Conclusion

SP ROM samples had the best permeability, showed minor consolidation under increasing pressure, and exceeded the 100× K_{sat} value safety factor up to simulated 70- to 80-foot heap heights. The A ROM samples and blend sample 75% A-1/25% AA-1 had intermediate permeability performance, exceeding 100× safety factor up to a minimum of 20 feet of estimated heap height and exceeding the forecast irrigation rate for all heap heights tested. AA ROM samples and blend samples 75% A-1/25% AA-2 and 75% A-2+A-3/25% AA-3 were below the 100× safety factor under first lift conditions (less than 20 feet).

Correlation analyses performed to assess relationships between measured K_{sat} and various physical parameters indicated that the PSD indicator values showed the strongest correlations to the measured K_{sat} values and may be used as an indicator of sample permeability. Using the K_{sat} versus PSD indicator relationship, ore blend compositions with a PSD indicator value greater than 4 should be targeted for the blend to be sufficiently permeable under one lift conditions.

Results from this study indicate that well designed hydraulic property testing can simulate operational conditions. The laboratory test data can be used to evaluate the effect of different ores on heap permeability, optimum heap height and irrigation rate to minimize effect of consolidation, and appropriate ore blend ratios. Furthermore, the use of physical property data correlated to permeability results can allow for mapping of ore body permeability.

References

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