See the Metal You Left Behind: In-Heap Sensors for Monitoring Fluid Flow

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Abstract

Through analysis of data collected from wireless sensors embedded inside a heap leach pile at an operating gold mine, we demonstrated there was 9.6% more recoverable gold available to be leached. Further, we identified an additional 0.7% recoverable gold on the edges of the leach pad. We estimate process operating cost savings of 13% can be realized by reduction of the reagents and energy used to leach metals.

The geotechnical stability of a heap dictates that the flow of solutions through it should occur under unsaturated conditions. The two key concerns are adequate flow and uniform flow through the heap. Adequate flow is necessary for the heap to be leached in an economic time, while a uniform flow is needed to allow all the ore to be thoroughly leached. If the solution does not flow evenly throughout the heap and instead flows preferentially through distinct paths, portions of the heap will not receive sufficient contact with the solution and will remain dormant.

Through the review of independent scientific literature and our own column testing, we have confirmed that moisture variation by 25% affects gold recovery by up to 69%. We also have observed that moisture within a heap is not uniform and varies by up to 50%.

Scanimetrics has developed a wireless hardware and data analysis software solution for assessing the leaching effectiveness of a heap leach operation and predicting yield. The system measures moisture and temperature of ore at the surface or inside a heap leach pile in real time using wireless sensors. The data is collected from the sensor network to a cloud server, analyzed and made available through a web application. The heap leach data are used to increase productivity, lower operating costs, improve worker safety, and lower the cost of regulatory compliance. In addition, operators can be notified electronically when critical heap leach parameters are outside their normal operating range.

Introduction

The goal of this work was to improve the leaching process and, in doing so, increase the yield of this process by producing more precious metals.

This was the first of several undertakings to evaluate leach processing to improve yield, through characterizing and modeling key heap dynamics. This work focused on conductivity, considered as one of the most important heap variables, and its impact on yield. The hypothesis is that, by characterizing moisture dynamics within the heap, we can correlate it to the irrigation process to achieve better moisture uniformity and yield.

The project shall explore the following heap dynamics:

- heap conductivity profile;
- heap conductivity curve;
- heap density profile.

The work characterized these heap moisture dynamics, in the context of the existing profiles for density and mining process. The premise is that better management of the irrigation system, through sprinkler head placement and flow rates, should result in higher yields of the leaching process. From this data we hope to model:

- heap irrigation effectiveness;
- heap geotechnical integrity;
- and their relationship to heap density profile.

This work does not intend to make recommendations regarding other mining process such as crushing and stacking; that may be the focus of future work. Nevertheless, we monitored the density since it may seriously affect heap conductivity.

The scope of work included installing sensing equipment and wireless data logging devices called "Motes" (see drawings and pictures in Appendix A for more details). Data from these sensors were collected and stored in the Motes and then transmitted via a wireless connection to an Internet Gateway. The Internet Gateway uploaded the data to the "Scanimetrics' Cloud," which reports to a web application. The Internet Gateway communicated to the Scanimetrics' Cloud via an Internet connection. A local Wi-Fi network facilitated communication from the Internet Gateway to an internet access point at the mine site.

The sensors and Motes were placed in an array of commercial grade urethane piping and covered as the heap was built. The array's design was to protect the moisture sensors from damage, either by the pressure of surrounding ore, or the movement of ore as the lift was built.

Each Mote can be programmed to an appropriate sample rate or for a specific time interval. The Motes were programmed to sample continuously once per minute for this application.

This work required router/repeater devices to improve communications between the Motes and the Gateway. The Motes generally need to be placed within 10 to 20 meters (m) of the Internet Gateway to communicate directly with it.

Methods

Column testing

Scanimetrics provided the necessary supplies for installing sensors into columns at the mine site laboratory to measure and evaluate the moisture vs. gold recovery of the columns at different moisture content profiles.

Two columns were used, 6 feet high by 6 inches in diameter, using an automatic drip system with variable drip rate of 4 to 16.1 L/hr/m^2. The leaching solution consisted of NaCN and was adjusted for pH to reduce the production of HCN. A solution collection tank was used for each column.

Ore was uniformly mixed, and large particles greater than 1 inch were removed. The weight of the ore was recorded before drying and then the ore samples were dried using a kiln at the mine laboratory. A gold assay was performed on a sample of the ore. The weight of the dry ore was recorded. The initial moisture level was recorded using a moisture sensor.

The ore was placed into each column, with a moisture sensor near the bottom and a second sensor near the surface. The depth of the sensors relative to the top of the ore was recorded. Drip rates were set by the mine laboratory for each column and dripping was initiated.

The laboratory maintained a daily record of the volume of solution collected from each column and collected a sample for gold assay.

At the end of the test period the column drips were stopped, the ore sample weight for each column was recorded, the ore was dried, and the dry ore weight was recorded.

In-situ heap testing

Scanimetrics provided the necessary supplies for the installation and did the system validation checks once the sensors were assembled and embedded into the heap. Scanimetrics assisted the mine operator in integrating the sensor array to connect to the mine Internet.

A web portal was provided to allow the processed data and reports from the Scanimetrics' Cloud to be accessed from any computer through a secure Internet login.

The sensor array was comprised of 15 moisture sensors, six Motes, three routers and one Gateway, with Wi-Fi interface to the mine Internet.

The mine collaborator indicated that cellular service is unreliable at the mine site; therefore, we deployed a Wi-Fi service in the Internet Gateway and link to the site-wide Wi-Fi network, extending it to the heap location using a point-to-point link. In addition, a site survey was performed to establish the optimum line of site placement of the Internet Gateway and routers.

The leach pad is approximately 5 m in height, and the bench slope face was estimated to be about 45 degrees at the sensor's vertical position. The top sensor (Sensor V1 in Figure 1) is approximately 2 – 3 m inside the perimeter of the leach pad.

Regarding the vertical column of sensors, the sensor located at position V1 is approximately 0.3 m below the pad's surface. The vertical distance between every two sensors in the vertical column is approximately 0.95 m (i.e., 1.35 × cos45) except between sensors 3 and 4, which is approximately 1.2 m. The compaction sensor is located 0.95 m below Sensor V3.

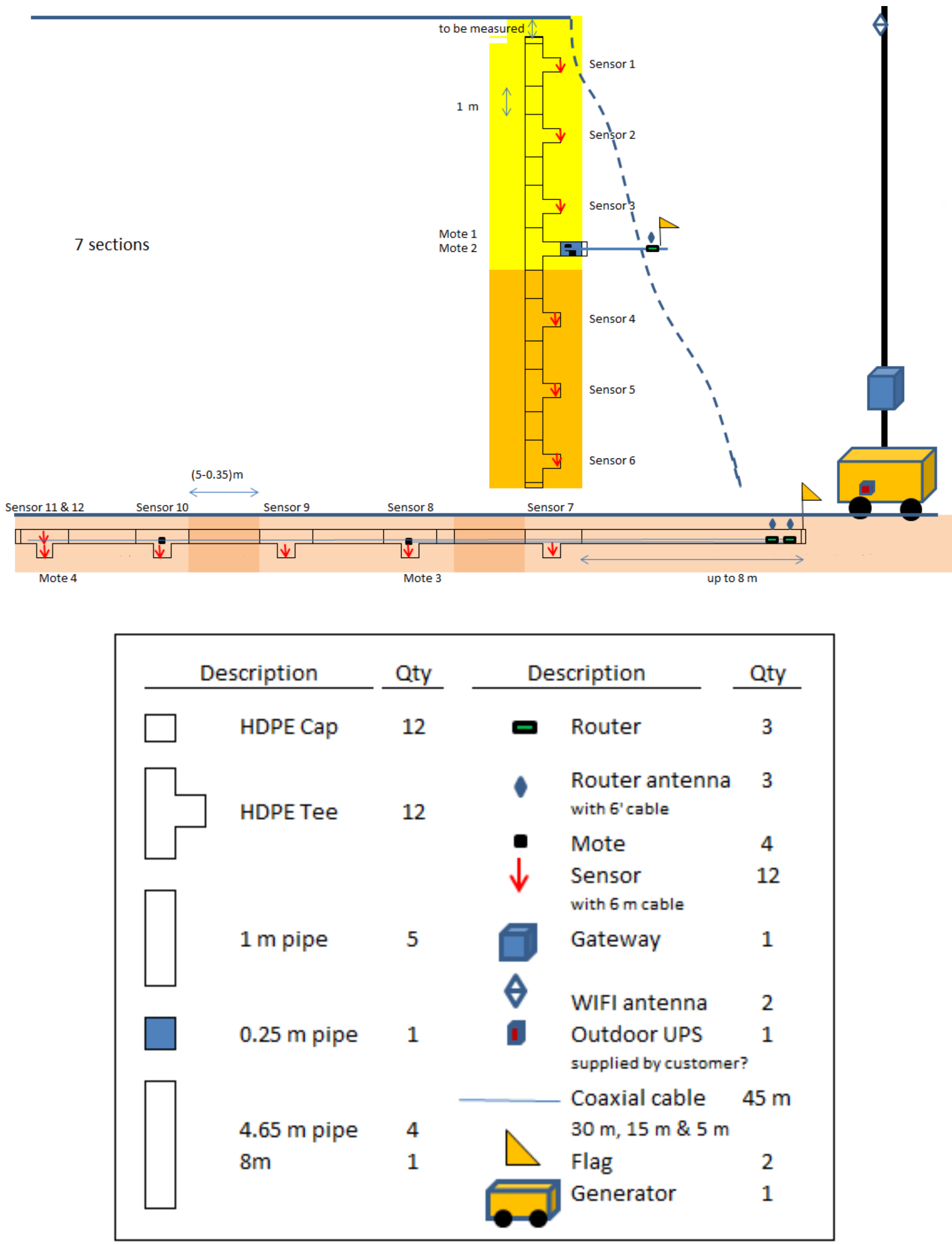

Figure 1: Leach pad sensor installation diagram

Regarding the horizontal row of sensors, the side denoted with a flag in Figure 1 is approximately 2 to 3 m outside the heap's perimeter , while the sensor at location H7 is approximately 7.5 m from that end. The horizontal distance between each two neighbouring horizontal sensors is 5 m.

The mote and moisture sensor were integrated into the sensor array at Scanimetrics' facility and were shipped to the mine site. Additional supplies were provided at the mine site, reducing the installation time required.

For this pilot test, urethane pipes were used solely as conduits for the motes, sensor cables, and coax cables. Four motes and the sensor cables were protected within the urethane pipes, except the sensor at location H12. Coax cables were used for coupling the wireless signals to the edge of the leach pad. Routers were placed at the end of these coax cables so the wireless signal could be re-transmitted to the Internet Gateway. In the future, we expect the motes and sensor cables will not require urethane pipes for protection. Thus, the wireless system installation could be significantly simplified.

As seen in Figure 1, the Internet Gateway is mounted on a light post with its Wi-Fi antenna communicating with an antenna located on a distant tower at the top of a hill. The Wi-Fi antenna is mounted on a lamp post fixed to a generator that provides elevation for the antenna to assure a clear line of sight and provides power to the Internet Gateway as well as the Wi-Fi antenna. In the future, the Internet Gateway can be provided with an optional solar-powered power supply to eliminate the need for a generator.

Following the installation of the sensor array and Internet Gateway, the sensor network was commissioned, and the Internet Gateway was configured to operate on the mine site Wi-Fi network.

After the systems were installed and commissioned, Scanimetrics initiated data aggregation on its cloud. The data was aggregated daily and was accessible to the mine collaborator through a secure web portal provided by Scanimetrics. Data aggregation was performed for an initial 13-week period from the installation date, followed by an additional 13-week period.

Upon network commissioning, Scanimetrics monitored the data received from the sensors. Scanimetrics generated weekly reports on equipment conditions and operational performance based on the data. The data and reports were delivered using the web portal.

To facilitate the objectives and reporting, our mine collaborator provided the following information to Scanimetrics:

- the build schedule for the current lift;
- operational hours for the lift build;
- shift data of the leaching process operators;
- the ore body composition and the density profile of the ore being used to build the current lift; and
- weather reports.

The data was accessible by the mine collaborator throughout the project through a secure web portal provided by Scanimetrics, and contained the following information:

- moisture data;
- moisture dynamics; and
- significant anomalies.

Results

Column test data

The test started on June 5th at two irrigation rates: normal (8 $L/hr/m^2$, inner column, C1) and fast (17.56 $L/hr/m^2$, outer column, C2). From the mine's standard water weight ratio measurement, the ore sample had an initial average water weight ratio of 2.54%.

Converting the water weight ratio to the Volumetric Water Content:

VWC or θ = Vw/VT = (mwet-mdry)/mwet x(dwet/dwater) = (PH-PS)/PH *(dwet/dwater).

For the water weight ratio 2.54%, the calculated VWC was approximately 4.22%. Here the specific gravity of the ore sample (dwet) was calculated from the weight ~57.5 kg, and the volume of the ore samples: 6-inch column at the height of ~ 190 cm and was approximately 1.66.

In each column, there were two moisture sensors. One sensor (#13 in C2 outer column and #15 in C1 inner column) was 15 cm below the top surface; the other sensor (#14 in C2 outer and #16 in C1 inner) was 115 cm below the top surface.

We observed a 3% difference in the baseline sensor moisture values (Figures 4 and 5) using uncalibrated sensors within the sensor's specification.

The column inspection was completed on July 9th. Ore samples were removed from the columns (Figure 2). Under visual inspection, the water content in the ore samples was relatively even, and no significant water pooling was observed. The mine's standard water weight ratio measurement (shown in Figure 3) was used to calculate the ore sample's final water weight ratio, 8.9248% for C1 and 8.9549% for C2. The final water weight ratio to the volumetric water content (VWC), was approximately 16.7% ± 0.1% for both columns. Note: the specific gravity of the wet ore in the column was increased to 1.87 due to the compaction.

From the moisture sensor data, the VWC for each sensor location is plotted below.

Figure 2: Ore sample at the end of the test

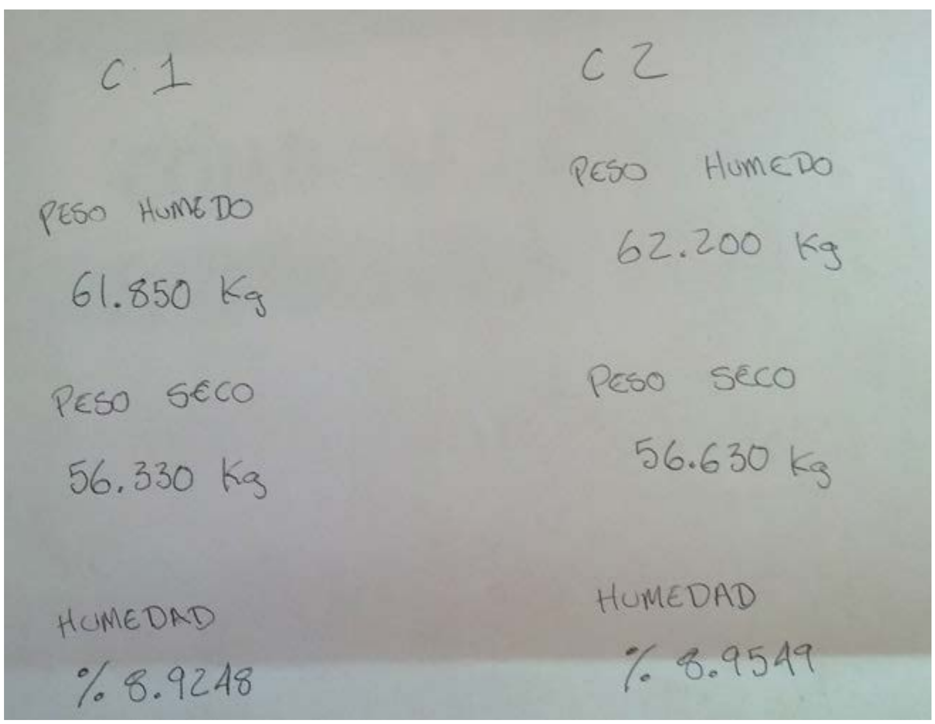

Figure 3: Ore final water weight ratio

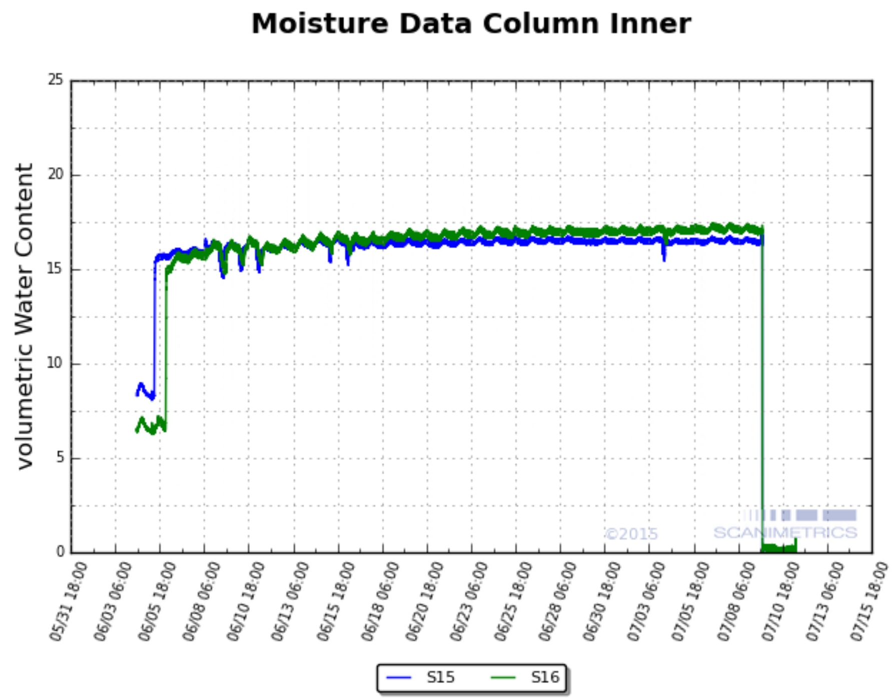

Figure 4: Moisture sensor data in the inner column C1 (8 L/hr/m²). S15 is 15 cm deep from the top, and S16 is 115 cm from the top

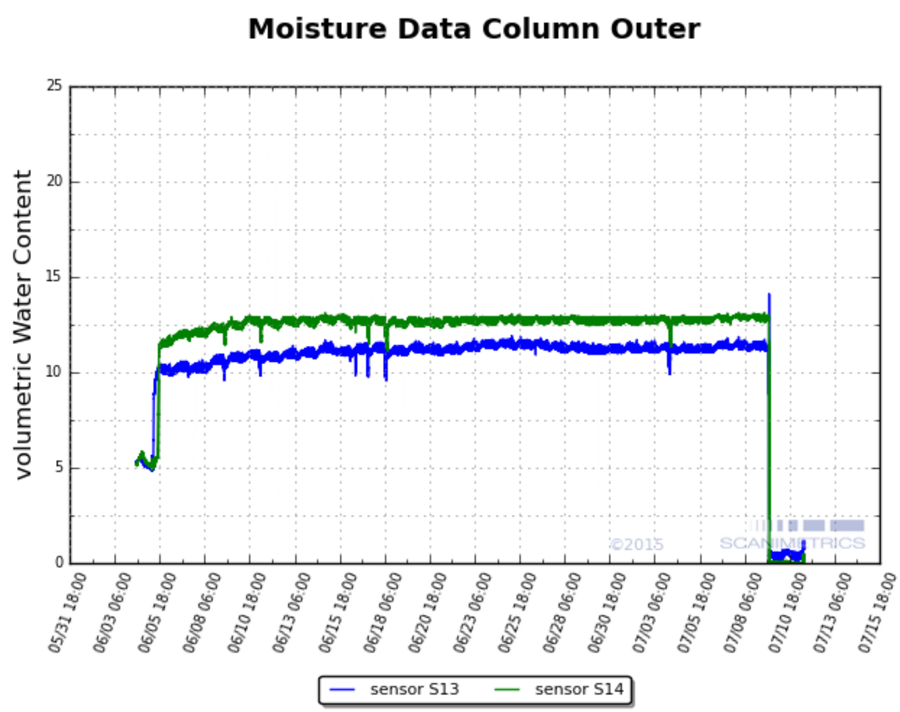

Figure 5: Moisture sensor data in the outer column C2 (17.56 L/hr/m²). S13 is 15 cm deep from the top, and S14 is 115 cm from the top

A subsequent column test was performed using flow rates of 8 L/hr/m^2 and 4 L/hr/m^2 to avoid formation of preferential fluid flow paths. The gold recovery at these applied flow rates is illustrated in Figure 6.

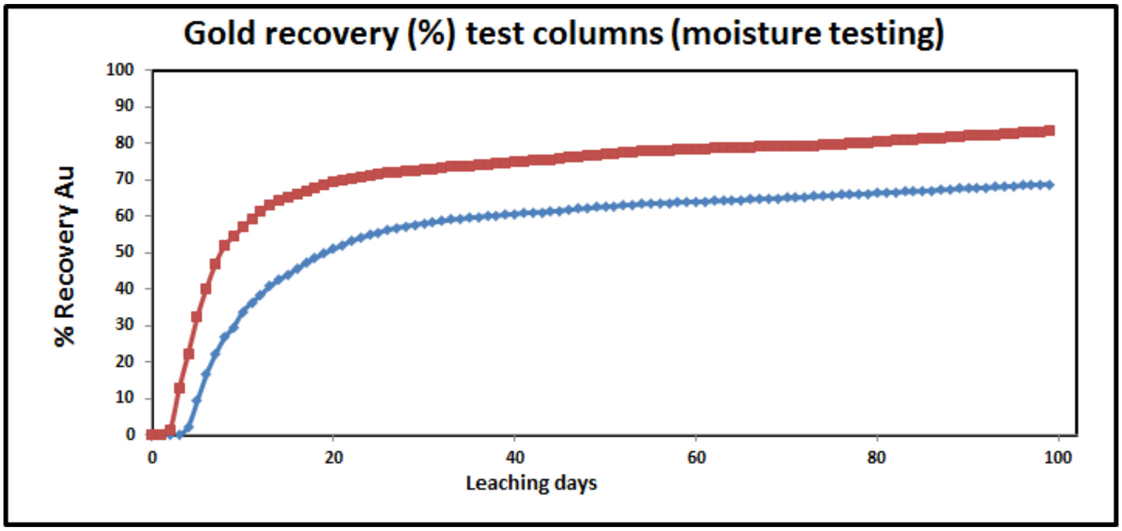

Figure 6: Gold recovery of the test columns (red 8 L/hr/m^2, blue 4 L/hr/m^2)

Another column test was performed using flow rates of 4 L/hr/m^2, 8 L/hr/m^2 and 16 L/hr/m^2 to evaluate elapsed time to gold recovery. These results are illustrated in Figure 7.

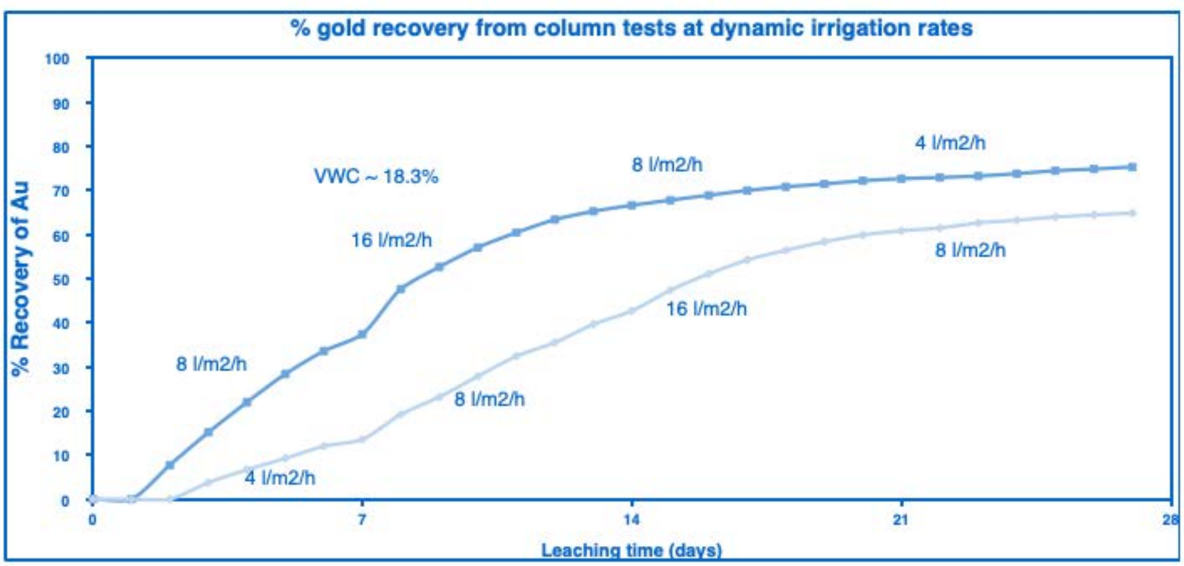

Figure 7: Gold recovery versus time of test columns at 4, 8, and 16 L/hr/m^2

Leach pad moisture sensor data

The baseline data from the sensors are illustrated in Figures 8 and 9. The highest VWC is at location H11,

~ 8.5%, which was visually observed during the installation. And the lowest VWC is at location H6 ~2.5%. The average VWC for all of them was approximately 6%. The variation in the observed sensor reading baselines is mainly due to the VWC difference in the ore sample used to backfill around each sensor during installation.

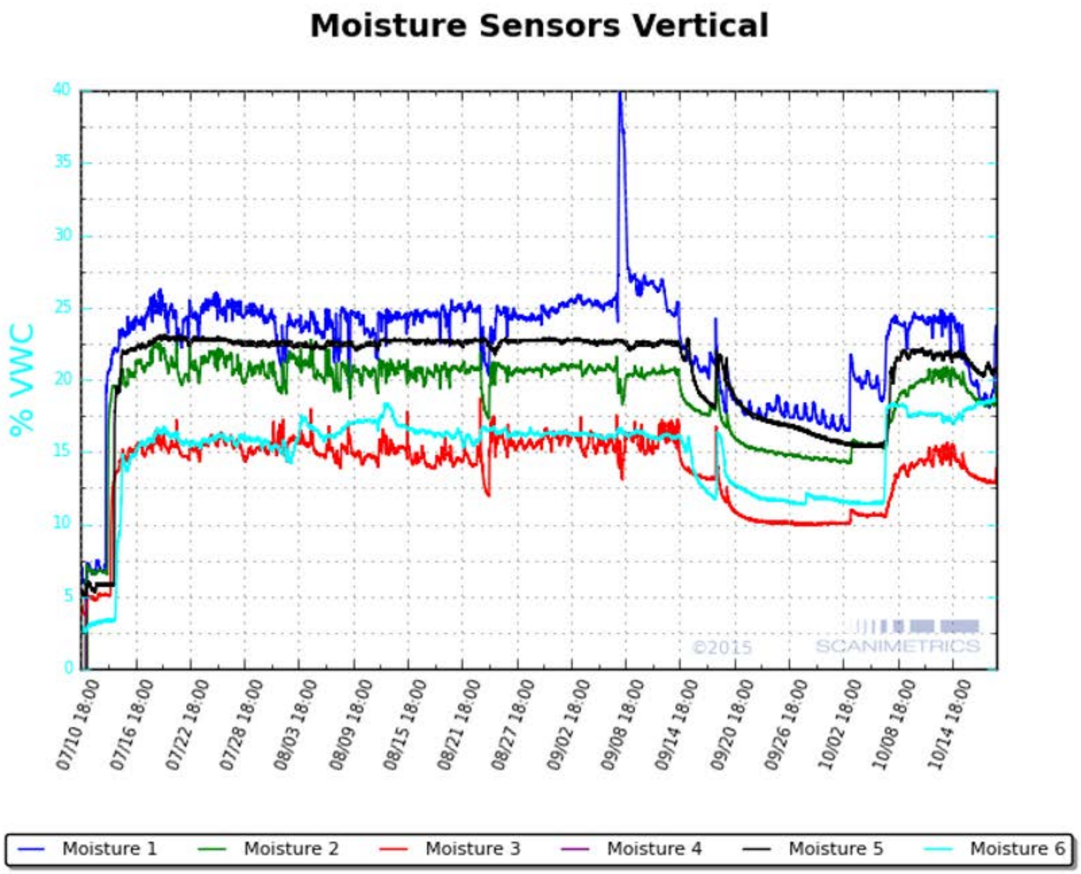

Figure 8: Moisture sensor data from vertical sensor locations

We confirmed with the mine operations that the irrigation drip started on July 13th. All the sensors (except #4) detected the water front within 2 days after July 13th in the order from V1, V2, and V6 to H7-12 (Figure 9).

Rainfall precipitation in millimeters was recorded at the leach pad by the mine operator, and the precipitation during the period of the trial is illustrated in Figure 10. Figure 11 illustrates the response of the compaction sensors during the trial period.

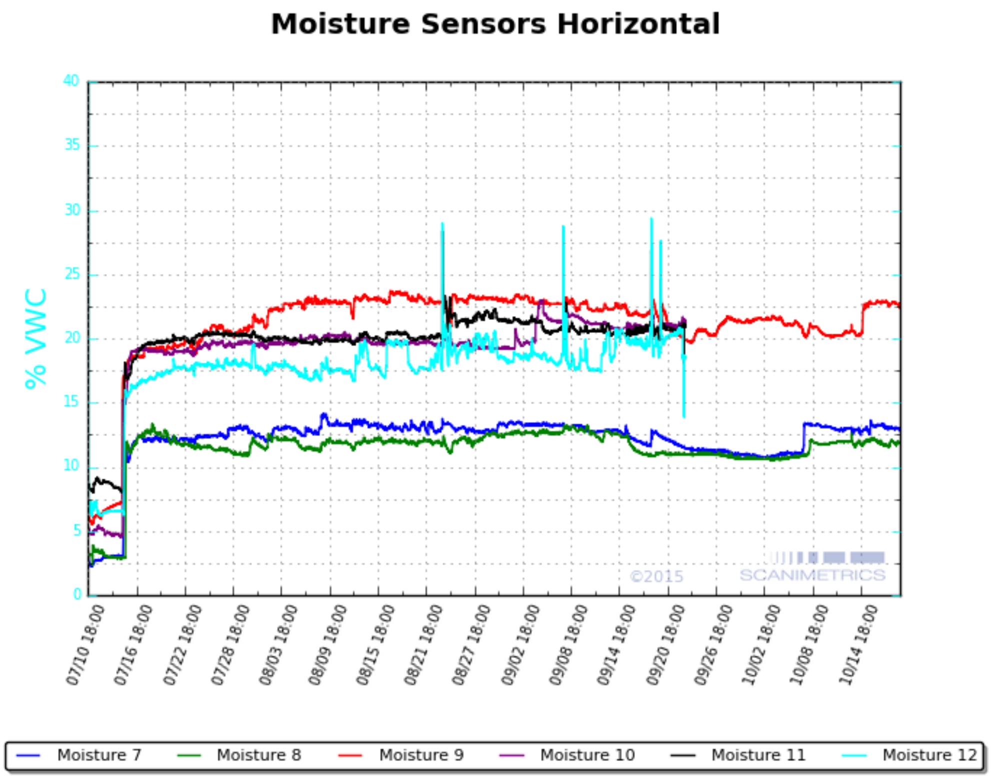

Figure 9: Moisture sensor data from horizontal sensor locations

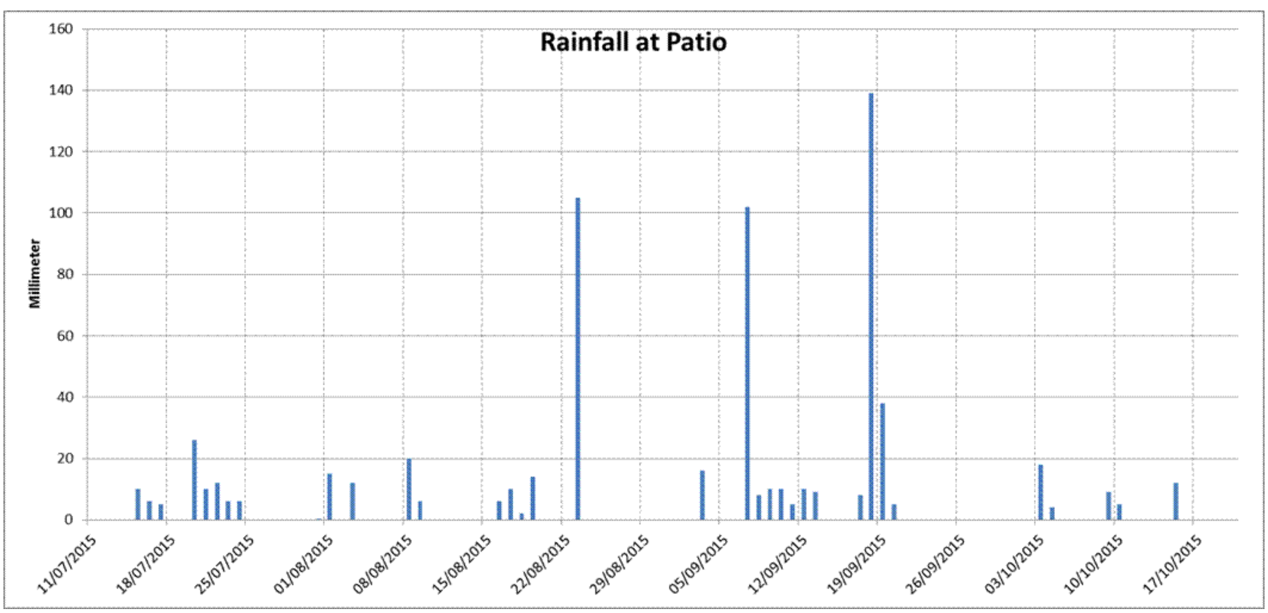

Figure 10: Rainfall at leach pad

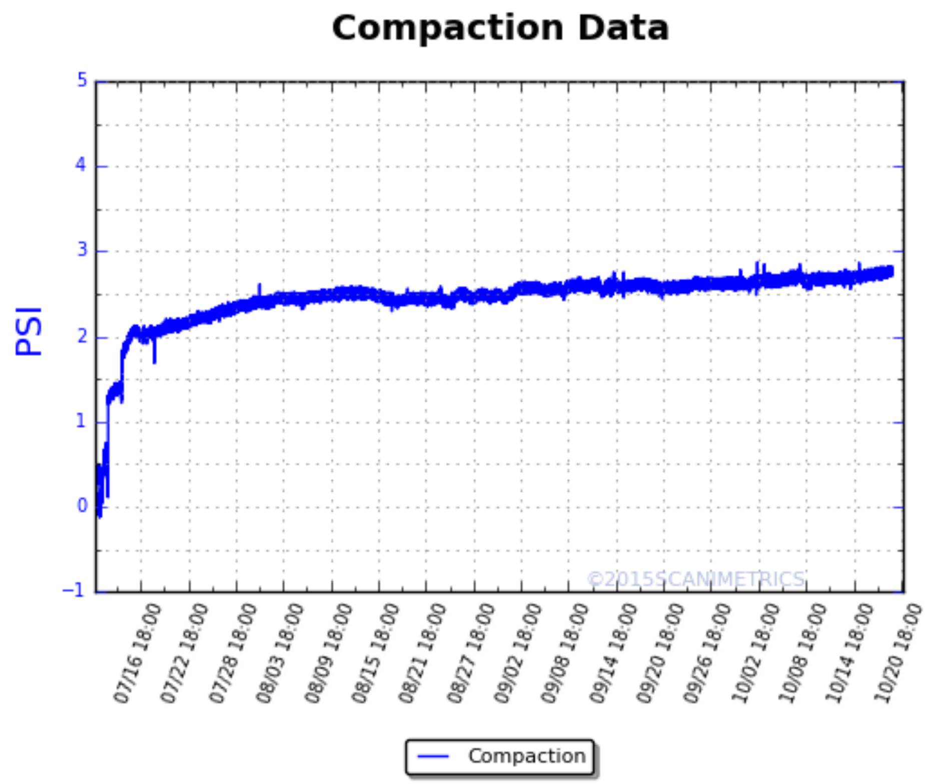

Figure 11: Compaction sensor data

Discussion

Column test data

The evaluation of gold recovery versus moisture content shows that a variation of moisture by 25% affects gold recovery by 69%. Dr. Delwyn G. Fredlund[1] concludes that 50% of saturation is the best moisture for leaching. Assuming that the porosity of the ore is approximately 36.5% at the leach pad, and using the following equation used in soil mechanics and petroleum engineering, θ (VWC) = Sw (water saturation) × φ (porosity). A 50% saturation of a 36.5% porosity ore, θ = 50% × 36.5% = 18.3%. Thus, the optimum VWC ~18.3%. According to this equation, it is obvious that as the ore compaction increases, the porosity φ will reduce, and the optimum moisture content for the leaching will decrease accordingly.

Leach pad data

We observed that the moisture content at the horizontal locations shown within the inner area of the leach

[1] Dr. Delwyn G. Fredlund was the Professor Emeritus of Civil Engineering (1968–2000) at the University of Saskatchewan. He has written hundreds of publications in the field of unsaturated soils mechanics.

pad achieved an optimum VWC range for most of the irrigation period. We also noted that the edge of the leach pad was under-irrigated. We recommended the adjustment of the sprinkler system to improve the irrigation coverage at the edge, which resulted in higher VWC within these areas. The additional gold available for recovery from these leach pad areas is 0.7%.

Large rainfall events occurred at the leach pad during August and September, and the impact of these events on VWC is evident in the data. Water saturation occurs especially at locations near the surface. The moisture content recovered as the water drained from the leach pad when the rain event subsided.

Irregular moisture observations suggested over- and under-irrigation at some locations. Over-irrigated observations indicate the existence of direct flow paths and insufficient oxygen for leaching, whereas under-irrigated areas require longer irrigation time. Lower moisture content at some locations suggests that the leaching process is less efficient. More energy must be expended to increase the leaching, or lower gold recoveries are achieved.

The leach pad's compaction (ore density) increased rapidly during ore placement, and as the leach solution penetrated the pad. However, the rate of the increase of compaction (slope of the compaction line) asymptotically approached a steady state of 0 after the first week. There were no observations that indicated a loss of stability of the heap or undesirable settlement events within the heap during the trial.

We also have observed that moisture within a heap is not uniform and varies by as much as 50%. Evaluation of this leach pad suggests that 9.6% more gold is available to be recovered from this leach pad by improving the uniformity during the application of the leach solution.

Conclusion

We have shown that moisture and particle compaction within a heap leach pad can be measured continuously in real-time at multiple locations. Column testing confirms the literature that VWC affects gold recovery. We observed sensors placed inside of the heap could identify excess water and chemical usage. We also observed that sensors along the edge could identify the gold that would otherwise be lost. The mine began irrigating the edges and repaired several problems with the irrigation system that affected the moisture at certain points within the heap. The moisture levels recovered and the column tests and literature described here provide evidence that the mine increased its gold recovery accordingly. Finally, this work suggests that if the leaching process gets off to a bad start, the mine operators can never recover all the gold they would otherwise have recovered if they had properly initiated the leaching process. The most important thing to achieve maximum gold recovery is to ensure the first week is done properly, which means getting the moisture levels to their ideal levels as quickly as possible.