Governance and Management: Using KPIs and Early Indicator Dashboard to Manage and Communicate Heap Leach Pad Facility Performance

Patrick Nketia, Freeport-McMoRan Inc., Morenci Operations, USA
Omololu Ogunseye, Freeport-McMoRan Inc., Morenci Operations, USA

Abstract

Management of a Heap Leach Pad (HLP) facility involves the use of critical control measurements and Key Performance Indicators (KPIs) to detect, monitor, and mitigate significant safety and environmental risks to the performance of a HLP. Freeport-McMoRan Inc.'s operations with HLP use KPIs and an Early Indicator Dashboard to guide operational and technical teams in managing the day-to-day performance of a HLP and to drive clear communications and good practice actions. The KPIs form part of the operational, maintenance, and surveillance guidance in managing and monitoring the physical stability of the HLP. KPIs are used to show that day-to-day operational construction meets the Engineer of Record's (EOR) design criteria and good practices for HLP safety. Guidance for managing KPIs can be found in the *Operational, Maintenance and Surveillance Manual (OMS Manual)* together with Standard Operating Procedures (SOP) and Work Instructions (WI) to help to smoothly onboard newly hired geotechnical engineers. Each Early Indicator KPI has a Work Instruction developed to define the purpose of the Early Indicator KPI, how it is measured / calculated and describe how the scores are obtained.

The site geotechnical engineering group, in collaboration with Leaching Operations, Leaching Technical Service (LTS), Crush and Convey, and the EOR, will monitor, summarize, and interpret different sources of data. These data will generally consist of the following: Pore Pressure, Superficial and Deep Movements, Pond Management, Material Placement, Crushed Ore Material Quality, Solution Balance, and Visual Inspections. The Dashboard also includes progress on implementing recommended actions from EOR and third-party Crushed Leach Stewardship Team inspections.

The Early Indicator Dashboard provides site Senior Management teams with information to proactively drive performance and ensure objectives are consistently met effectively and efficiently. The Early Indicator Dashboard also keeps Corporate Senior Leadership and Technical Management apprised of day-to-day conditions and trends of the HLP.

Introduction

Heap leach pad facilities consist of ore from the pit that is crushed, agglomerated, and stacked on an engineered pad in designed lifts. A weak acid solution is then circulated through the heap and target metal is extracted in the form of a pregnant leach solution (PLS). Heap leaching is a fully coupled geotechnical-hydrometallurgical process (Wooten et al., 2015). It is critical that the geotechnical stability of the facility is managed closely while seeking optimal metal recoveries throughout the life cycle of the facility.

The current industry practice of HLP management involves developing an internal framework that guides risk management, often tailored to site-specific conditions. Examples of these management plans are well documented in the literature (Strata Gold Corporation, 2019; YukonZinc Corp, 2011). These management plans consist of measurable key performance indicators (KPIs) used to assure the daily operation of the HLP meets the design intention at a frequency approved by the Engineer of Record (EOR). KPI data provides operational and design performance information and consistently ensures objectives are met based on a scoring system that classifies data into alert levels. Internal stakeholders review, provide comments, and confirm the performance of the HLP on a monthly basis using recorded KPI data. The main benefit of this approach is that deviations from the intended design or performance are quickly identified, and corrective actions are then taken before challenges develop into issues of significant risk. Historical performance can also be tracked, and general trends identified, for further action and decision making. An informed knowledge of the HLP performance is crucial in maintaining a manageable risk profile.

Freeport-McMoRan has a strong safety culture for management of large HLP facilities. This paper describes an example of how this safety culture is embodied in day-to-day work. Freeport-McMoRan's HLP KPIs focus on geotechnical stability in the near term, as well as good practices for maintaining stability over the longer term. Freeport-McMoRan site geotechnical engineers measure KPI data and compare the results to EOR-defined alert levels, resulting in easy-to-access KPI scoring that is summarized in an early indicator dashboard for managing and communicating the operational performance of HLP across its portfolio. The report is provided monthly to site leaders and corporate technical reviewers; a summary is further provided to corporate senior leadership quarterly.

The following KPIs are used in managing the safe performance of the HLPs; however, selected KPIs will be described in this paper for brevity. These KPIs are grouped into seven main categories, and each category is further divided into sub-sections.

- Phreatic surface (piezometer water elevation, piezometer system operational availability, and piezometer system operational availability – single instrument).
- Crushed ore material quality (agglomeration, P80, fines content [–200 sieve], and total clay content).

- Movement rate (inclinometers and shape arrays, surface movement InSAR, and surface movement GPS units).
- Pond management.
- Material placement (surface preparation, updated stacking plan, and adherence to stacking plan).
- Raffinate and PLS flows (raffinate application rate, PLS flow decrease/increase and monthly solution balance).
- Monitoring and inspection (site engineer inspections, EOR inspections and action items status, crushed leach stewardship action items status, and number of new action items related to seep management).

KPI scores are denoted by description of conditions and indicate trigger levels as follows:

- Within Limits – operating conditions meet design intent and good practice. Continue current operating practices.
- Approach Limits – conditions during the reporting period approach limits of design intent or expectation of good practice. Increase level of attention required and/or action plan required to move towards being within limits of operating conditions.
- Exceeded Limits – does not meet design intent or expectations of good practice. Immediate development of an action plan needed to achieve being within limits of operating conditions.

Phreatic surface

Slope movement occurs when the driving force tending to cause slope movement exceeds the resisting shear strength of the soil. A common trigger for slope movement is the buildup of pore pressure in a slope. Pore pressures reduce the shear strength of the soil along a potential failure plane by reducing the effective normal stress. There is always some uncertainty associated with the potential pore pressure that may develop and its impact on the shear strength of the crushed ore. Considering the potential safety risks associated with slope failure, as well as environmental and economic risks, it is imperative to carry out routine pore pressure monitoring to identify conditions that could lead to slope failure and to determine if the design assumptions require modification. The potential variability of the pore pressures in the stockpile is one of the factors that could reduce slope stability during its operational lifetime.

The pore pressures may be influenced by:

- Operational abnormalities such as high application rates, failure of the solution collection system, or failure of the solution distribution system.
- High volume precipitation events.
- Changes in the hydraulic flow properties of the ore materials due to loading and ore decrepitation.

Freeport-McMoRan HLP uses vibrating wire piezometers to measure pore pressure conditions/ solution levels within the stockpile. These piezometers are installed in clusters to measure pore pressure at different depths. Also, regular CPT and drilling/testing campaigns are conducted to update the piezometer thresholds regularly to account for changes in the properties of the crushed ore over time. Piezometers are connected to an automatic data acquisition, transmission, and storage system (supplied by Canary).

The EOR for Freeport-McMoRan HLP uses a two-dimensional (2-D), limit-equilibrium stability, computer modelling program to conduct the slope stability analysis for each control section of the HLP. From stability analysis using material characterization based on multiple lines of evidence, the EOR assigns Alert Level elevations to each piezometer resulting from a range of factors of safety corresponding to that section. A summary table of alert level elevations assigned to each piezometer is provided to the site geotechnical engineer from the EOR after analyzing the stability of each control section of the pad, as shown in Table 1.

Table 1: Piezometers and their assigned alert level elevations and depth

Name	Cross section model	Set depth (m-bgs)	Set elevation(2) (m-msl)	Alert level 1			Alert level 2		
				Elevation (m-msl)	Depth (m-bgs)	Height above instrument (meter)	Elevation (m-msl)	Depth (m-bgs)	Height above instrument (meter)
PZ-3a_L3	1	19.8	1,419.1	1,420.3	18.6	1.2	1,424.3	14.6	5.2
PZ-16-L6a	1	31.1	1,422.7	1,423.9	29.9	1.2	1,430.1	23.8	7.4
PZ-16_L9a	1	57.3	1,421.5	1,423.9	56.1	1.2	1,438.6	40.1	17.1
PZ-16_L9b	1	45.7	1,433.2	1,434.4	44.5	1.2	1,438.6	40.2	5.4
PZ-21_L12	1	84.9	1,412.5	1,413.7	83.7	1.2	1,438.6	58.8	26.2
PZ-2a_L3	2	19.5	1,420.8	1,422.1	18.3	1.2	1,426.3	14.1	5.5

The site geotechnical engineer updates the piezometer tracker daily using the calculated distance to Alert Level 2; this identifies piezometers with solution level approaching Alert Level 2. A summary of piezometers with solution levels within 3 meters to Alert Level 2 and their respective KPIs are sent out to the Hydromet team daily for adjacent leaching sections to be turned off to control pore pressure in the area.

If the KPI is at 85% and increasing, the irrigation for corresponding section is recommended to be progressively turned off, as shown in Table 2.

Table 2: Summary of piezometers within 3 meters to Alert Level 2, their KPIs and respective turn off sections

Piezometer ID	Alert level 2 depth	Distance to AL2 (KPI)	Turn off sections (recommended)		
			1st	2nd	3rd
PZ-26-L12b	0.5	0.6 (0%)	South 31	South 32	–
PZ-118_L12c	1.61	1.2 (25%)	South 33	South 43	–
PZ-45_L12b	14.9	1.9 (88%)	South 26	South 27	–
PZ-110_L9a	3.4	1.8 (47%)	North 65	North 66	–
PZ-15_L6a	8.7	1.9 (78%)	South 038	South 039	–

The recorded piezometer data for the entire month enables the site geotechnical engineer to score piezometric elevation and availability based on the KPI criteria set shown in Table 3.

Table 3: Scoring criteria set for phreatic surface monitoring

No.	Parameter	This month's score	Scoring criteria		
			Within limits	Approach limits	Exceed limits
1.1.1	Piezometer water elevation	Within limits	Solution level is <85% of distance between action level 2 and piezometer set elevation or ≥85% and solution level is stable or decreasing.	Solution level is ≥85% of distance between Action Level 2 and Piezometer set elevation and increasing.	Solution level has reached or is above action level 2.
1.1.2	Piezometer system operational availability – system	Within limits	≥92% critical instrument availability	85% ≤ X <92% critical instrument availability	<85% critical instrument availability
1.1.3	Piezometer system operational availability – single instrument.	Within limits	Action plan developed and on schedule for all unavailable critical instruments or single critical instrument unavailable ≤4 weeks with no action plan.	Action plan is not developed to address connection with any single critical instrument down >4 weeks but ≤6 weeks. Any action plan is not anticipated to be complete per agreed schedule.	Action plan is not developed to address connection with any single instrument down >6 weeks or action plan is behind schedule to address connection with any critical instrument regardless of time down.

The scores and data are transmitted via internal digital workspace to the Crushed Leach EOR, the Leaching Manager and the Corporate HLP Point of Contact (POC) for reviews, comments, and acceptance for final distribution to management. A summary report using Power BI is generated and distributed to all relevant stakeholders. Figures 1 and 2 show the digital workspace and Power BI respectively used to communicate.

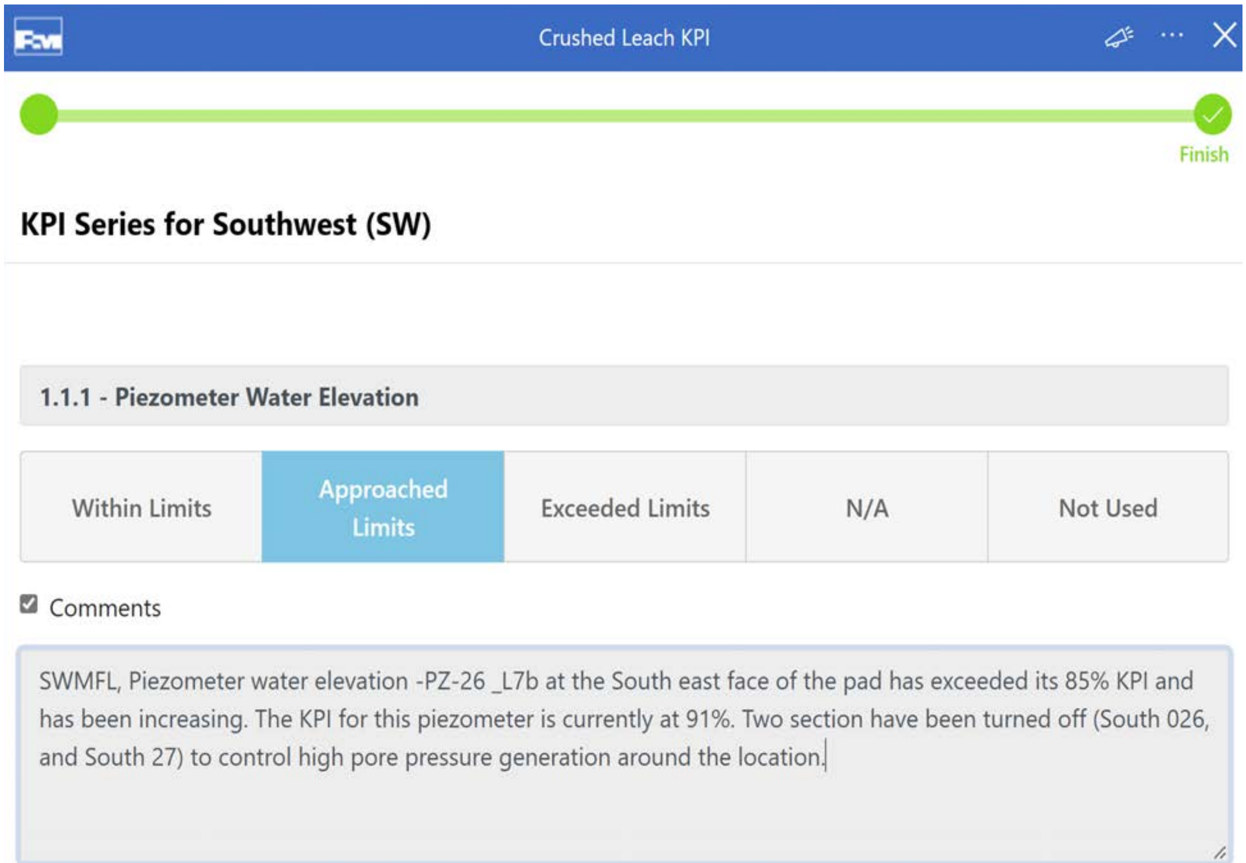

Figure 1: Digital workspace showing piezometer water elevation KPI score

Figure 2: Power BI showing a summary of phreatic surface KPI score for a particular month

Crushed ore material quality

From the hydrometallurgy point of view, smaller crushed size material will lead to larger overall particle surface areas susceptible to leaching. The bigger the surface area available for leaching, theoretically, the more metal can be recovered quickly. However, smaller particles may experience a more rapid timeline for decrepitation and strength change, which may have a negative impact on the stability of the pad. Also, a high variability of the P_{80} sizes can lead to the long-term variable permeability of the stockpile and possibly lead to a reduction in permeability due to increased fines migration. This has the tendency to create high pore water pressure within the pad, thereby reducing the shear strength of material in the pad.

The presence of a significant amount of fines content could reduce the overall voids of the crushed ore and produce a significant reduction in the drainage capacity of the HLP. In this case, the material would present a low hydraulic conductivity. Application of solution on low hydraulic conductivity material will develop ponding on the surface and potentially saturated areas with the generation of pore water pressures within the pad. The shear strength of crushed leach material in the pad is highly influenced by the amount of fine-grained material deposited as well as continuous leaching of the ore. Recovery of metal also tends to be low during the leaching process in areas of high fines content. In general terms, when the amount of fines is low and they are of low plasticity or non-plastic, the mechanical and hydraulic behaviour of the mineral is more like that of granular soils (gravels and sands); i.e.: drained behaviour when subjected to shear stresses, high effective friction angle, high stiffness, low compressibility, and high permeability. As the amount of fines increases and they are of high plasticity, the mechanical and hydraulic behaviour becomes more like that of cohesive soils (silts and clays); i.e.: undrained behaviour, low angle of effective friction, less stiffness, high compressibility, and low permeability when subjected to loading.

The presence of a significant amount of clay materials can be a source of problems in crushed leach operation. Generally, material with high clay content has low shear strength, high compressibility, a high level of volumetric change, and low hydraulic conductivity. Application of solution on low hydraulic conductivity material will develop ponding on the surface and potentially saturate areas with the generation of pore water pressures within the pad. The shear strength of crushed leach material is highly influenced by the amount of clay content in them. Recovery of metal also tends to be low during the leaching process in areas of high clay content or minerals.

The Freeport-McMoRan HLP site geotechnical engineer tracks all these parameters on a weekly basis to ensure laboratory test results do not violate the KPIs set for these parameters. If any of these test results do not meet the KPI target, actions are taken for a future slope monitoring program. Some of the actions taken include:

- The Crushed Leach Geotechnical Engineer investigates information from the crushed and convey team regarding the location (cell or section) that was stacked on the day(s) that the KPI was violated.
- The shape file of the location stacked is stored in the GIS database as reference for the routine geotechnical weekly inspection and monitoring program.
- The site geotechnical engineer will also notify the EOR and the corporate POC of the situation for future geotechnical drilling and sampling program, CPT testing, and piezometers installation. Operations also increase the density of wick drains during surface preparation for the next lift. Figure 3 depicts a shape file in ArcGIS on how surveyed location is kept for KPI violation.

In addition to these, routine drilling and sampling and CPT programs are conducted to update material geotechnical properties of previously placed lifts to account for the decrepitation process.

Figure 3: Shape (yellow), showing high clay content of material stacked on a particular day

The laboratory test results for P_{80}, total clay and fines content for the entire month enables the site geotechnical engineer to score each individual parameter based on the KPI criteria set shown in Table 4.

The scores and data are transmitted via internal Digital Workspace to the HLP EOR, the Leaching Manager and the corporate HLP POC for reviews, comments, and acceptance for final distribution to management. A summary report of Power BI is generated and distributed to all relevant stakeholders. Figures 4 and 5 show the digital workspace and Power BI used to communicate to stakeholders.

Table 4: Scoring criteria set for P_{80}, fines content and total clay content

No.	Parameter	This month's score	Scoring criteria		
			Within limits	Approach limits	Exceed limits
3.2.2	P_{80}	**Within limits**	>12.7 mm (daily)	One day exceedance of <12.7mm but >11.4mm	One day exceedance <11.4mm
3.2.3	Fines content (passing #200 sieve)	**Within limits**	<10% (daily)	One day exceedance of ≥10% but < 15%	One day exceedance of ≥15%
3.2.4	Total clay content	**Within limits**	<14% over 24k tons average and <16% over 8k ton average	More than 14% but less than 16% over 24k ton average or more than 16% but less than 18% over 8 k tons average	More than 16% over 24 k ton average or more than 18% over 8 k ton average

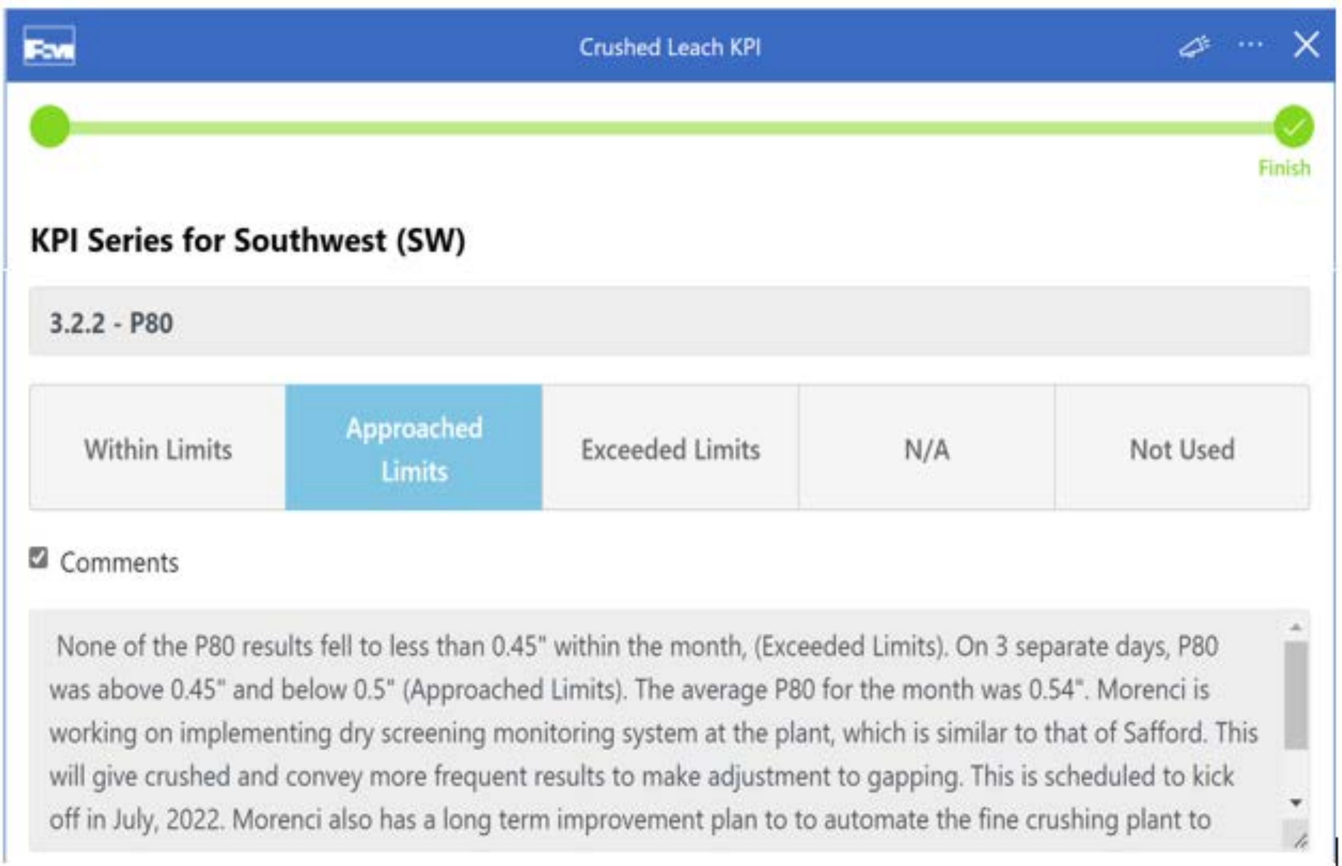

Figure 4: Digital workspace showing P_{80} and fines content KPI score

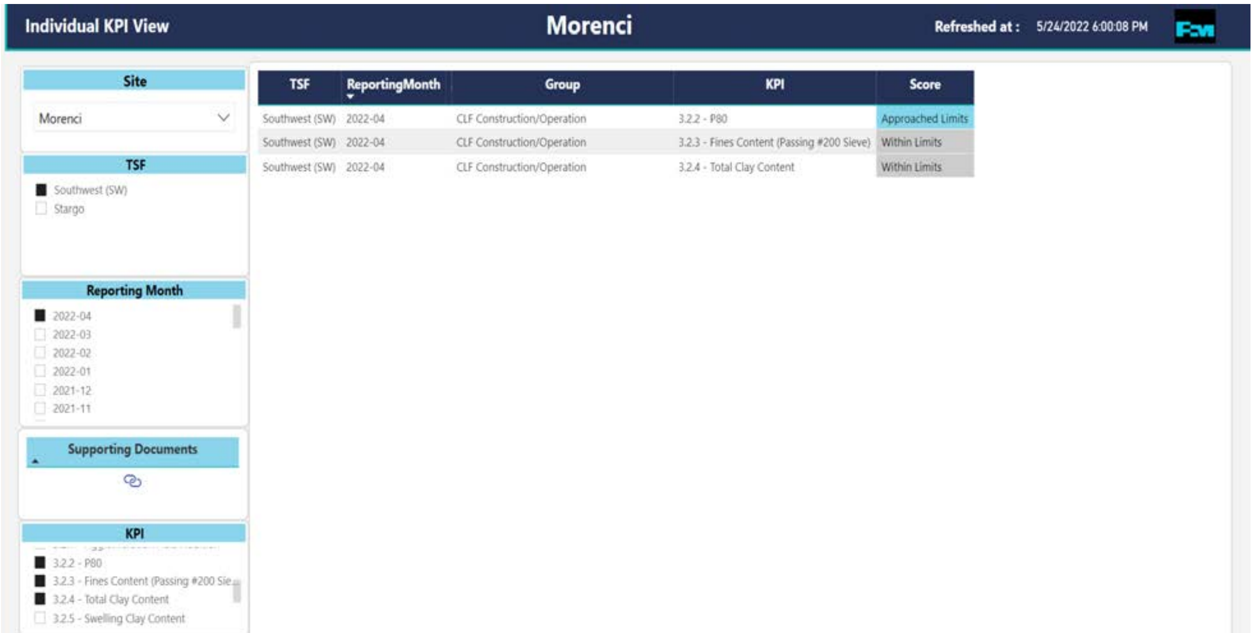

Figure 5: Power BI showing a summary of P_{80}, fines content and total clay content KPI score

Monitoring and inspection

The purpose of these KPIs is to visually assess the performance of the HLP for early detection of physical conditions that may indicate the potential for slope instability in the HLP. On-site personnel, along with consultants, perform the inspections to find early indicators of slope instability conditions or possible problems so that they can be corrected before they impact the safety and operations of the facilities. Inspections are conducted on a weekly, quarterly, and yearly basis. The site geotechnical engineers perform inspections on a weekly basis and send out weekly inspections' findings and their respective corrective actions to be taken. The EOR, corporate POC, and leaching operations, together with site engineers, conduct inspections quarterly for findings, their corrective actions, and timelines to complete these action items.

Annual inspections and technical reviews are also conducted by the Crushed Leach Stewardship Team (CLST), which is led by a third-party consultant along with corporate experts and site participants. The third-party consultant reviews all data associated with the HLP. These include piezometers' data, drilling, and sampling test results, EOR quarterly site visit reports and recommendations, CPTu tests' results, site crushed leach geotechnical weekly inspection reports, EOR quarterly instrumentation review reports, annual report, and all construction activities performed within the year, as well as future projects. The external consultant writes a report with findings and recommended actions, including a date by which Freeport-McMoRan should complete the recommendations.

Each Freeport-McMoRan HLP has individual KPIs set for all inspections and recommendations performed by all the teams mentioned above. Table 5 summarizes the KPIs set for all inspections and recommendations. The site geotechnical engineer manages all action items and recommendations and scores each KPI based on its status.

No.	Parameter	This month's score	Scoring criteria		
			Within limits	Approach limits	Exceed limits
3.4.1	Site (TCLW engineer or designee) inspection	Within limits	Inspection completed on schedule	Inspection not completed on schedule for the reporting period	Two or more scheduled inspections have been missed
3.4.2	EOR inspection	Within limits	Inspection completed on schedule	Inspection not completed on schedule for the reporting period	Two or more scheduled inspections have been missed
3.4.3	Site (TCLW engineer or designee) action item status	Within limits	All actions on schedule and/or complete	At least one action which is not anticipated to be complete per agreed schedule	At least one item past due on completion
3.4.4	EOR inspection action items status	Within limits	All actions on schedule and/or complete	At least one action which is not anticipated to be complete per agreed schedule	At least one item past due on completion
3.4.5	CLST action items status	Within Limits	All actions on schedule and/or complete	At least one action past its due date by one month or less	At least one item past its due date by greater than one month
3.4.6	Number of new action items related to seep management	Within Limits	≤15 findings[1]	>15 but ≤25 findings[1]	>25 findings[1]

Table 5: Scoring criteria set for monitoring and inspections

A summary report is sent out for approval, as discussed previously. A summary report (score, comments and actions taken, and supporting data) of all KPIs listed in the introduction is sent out each end of the month to the site processing manager, director of Tailings, Crushed Leach, and Water (TCLW) as well as all other stakeholders in a Power BI format. Figure 6 presents a summary of how the final report is distributed.

[1] These criteria also consider severity of the seepage (flow rate, turbidity, piping etc.)

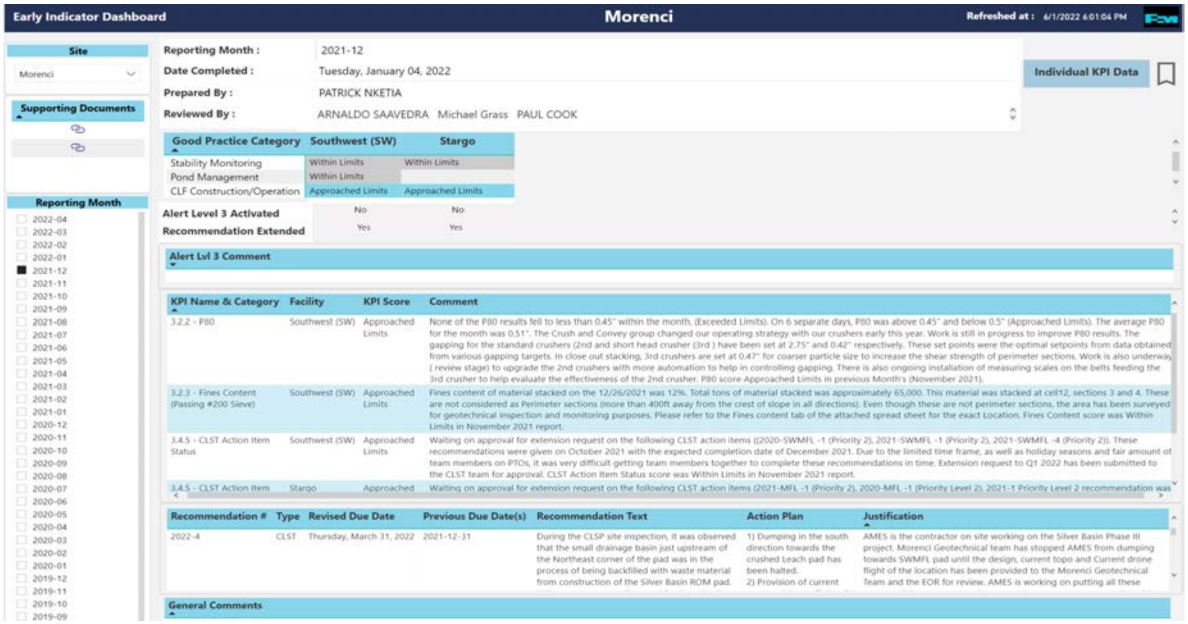

Figure 6: Power BI summary report of all KPI(s)

The criteria shown in this paper are for a snapshot in time. Criteria or Alert levels for each KPI vary during the life of the HLP based on many factors. To update the Alert Levels for a given KPI, the EOR makes a recommendation and provides justification for the change; site engineers submit the agreed recommended changes to the corporate PoC and TCLW Director for approval prior to updating alert levels.

Conclusion

Using the KPIs scores and reporting system at the HLP site allows site geotechnical engineers to analyze, review, and interpret data and take remediation actions quickly and effectively. It gives a clear and accurate picture of the performance of the HLPs. Through the KPIs scores and use of the early indicatory dashboard report, all internal stakeholders can understand the status and performance of the HLP. Data interpretation and visualization become simple for stakeholders who are not directly involved in the day-to-day management of the facilities. This also serve as a communication tool to advise on situations of concern and highlight areas requiring leadership support.

Acknowledgement

Our sincere appreciation goes to Tamara Johndrow, Arnaldo Saavedra, Michael Grass, Mike Waldron, Oscar Silva, Teresa Speigl, and Georgia Lysay for reviewing this paper.

References

StrataGold Corporation. 2019. *Eagle Gold Project Heap Leach Facility Operation, Maintenance and Surveillance Manual.* Available at: http://www.emr.gov.yk.ca/mining/pdf/mml-eg-heap-leach-facility-OMS_manual-version-2019-01.pdf

Wooten, Chris, Zenner Chase and Warren Dean. 2015. Leach pad monitoring and control through instrumentation. *Proceedings of Heap Leach Solutions Conference,* pp: 37–48. Reno, Nevada, USA. Published by InfoMine.

YukonZinc Corp. 2011. *Ground Control Management Plan.* Yukon, Canada. Available at: https://emrlibrary.gov.yk.ca/minerals/MajorMines/wolverine/ground_control_management_