Guidance for the Safe and Optimized Operation of Waste Rock Facilities

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Executive Summary

Failure of Waste Rock Facilities (WRF) can be a major concern because it can put human life and surrounding environment at extreme risk. As such, waste rock piles should be considered structures, and rigorous attention should be afforded in design and operation of WRF. Selecting an appropriate operational strategy can greatly lessen the risks involved. The important aspects in the operational phase of a WRF, which impact the stability, include the use of appropriate design criteria, waste material segregation, and rate of deposition, operational load, operational manual, deposition plan and instrumentation. This paper discusses, in detail, the importance of operational parameters and how these can be controlled to reduce the overall risk associated with such facilities. It further discusses the importance of integrating design into deposition plans, the use of operational manuals to document good operating practices and the supervision of ongoing operations.

- Note that this white paper was presented at the Tailings and Mine Waste'18 Conference in Colorado State University.

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Introduction

Waste rock storage facilities (WRSF) are large, massive structures constructed over the course of the life of a mining project. These structures are part of mining environments, landscaping, and layouts; instabilities in these structures can impact critical nearby mining infrastructure, equipment and personnel as well as the surrounding environments including lakes, streams and rivers.

Despite the significance of these structures it is common practise to treat them as dumps, with very little effort allocated to design, engineering, construction, supervision and monitoring, stockpiles deposition planning, site characterization or operations. Those typically charged with the operations of these facilities are also held accountable for the economical and profitable exploitation of the mining operation, thus these facilities risk being treated as cost generators with little focus on the long term liabilities that these WRSF can represent to the mining company.

The result of this type of approach and philosophy towards waste rock facilities has resulted in numerous failures. Between 1968 and 2005 in excess of 200 incidents of waste rock facility failures were recorded in BC (Canada) alone. The magnitude of these failures is variable from minor runouts and up to 30Mm3 of material (Cunning and Hawley, 2017). This data is based on a commissioned study in BC and represents a mere sampling of the number of failures that could be expected across Canada and the rest of the mining community.

Despites the compelling reported data, which has been know and documented as far back as the early nineties, not all operators acknowledge the need to treat these facilities as structures. Thankfully some jurisdictions have adopted design criteria which will compel operators to design and operate these facilities as structures.

If one considers, WRSF as structures, standardization of procedures will be required. This will include design, construction, operation and monitoring. This paper discusses some of the key elements which need to be incorporated in standardized procedures.

Standard procedures

Design criteria

WRSF that are considered and operated as simple dumps, do not required any form of design. In a best case scenario, a factor of safety of 1.0 will most certainly be achieved (on a competent foundation) with descending construction methods. Any variability in the material properties or an increase in water table elevation within the pile can give rise to instability. Operating in this manner can put WRSF at risk and outside of compliance.

Regulators have already recognized WRSF as structures and have applied the same level of regulation as those governing tailings management facilities, which include design criteria for bearing capacity, short and long term local stability, and short and long-term static and pseudostatic overall stability.

Factors of safety as defined by regulators accounts for risk and uncertainty, as such it is more stringent than just attempting to maintain equilibrium, relying solely on material properties to avoid instabilities. The design of stockpile needs to be based on long-term facility closure requirements rather than short term operational conditions.

Rate of advancement

In many operations the common practice is to operate WSRF based on cycle's times between waste stockpiles and pit operations. This practice continues until the mining operation moves to a new area of the pit or a failure occurs, and only then will the deposition proceed in a different sector.

This trial and error approach is not acceptable for ensuring short-term stability of structures. For example, the rate of rise when building a dam over soft clay is strictly controlled, to account for increases in pore water pressure; the same principles need to be applied when advancing a waste stockpile. The common practice described, for WRSF, is not consistent with the concept or philosophy that WRSF are considered structures by operators.

The rate of advance can affect stability both of the foundation and the pile itself. With respect to the foundation, the example given above with the rate of loading of a clay

layer during dam construction applies equally to the advance of a stockpile over the same stratigraphic unit. Advance too quickly and you risk failure in the foundation clay layer.

It is noted that granular materials also need time to settle when being deposited, if such settlement occurs too quickly failure and instability can ensue. Several cases of failures have reportedly occurred as result excess of rate of advance regardless of the foundation condition.

Incorporating rate of advance within the operation of a WRSF can be logistically challenging. Mine sites will often be operating more than one pit within the same site and multiple waste stockpiles simultaneously. Some waste stockpiles are dedicated to specific pits, while others are shared between pits, thus increasing the level of complexity, as illustrated in Figure 1. The complexity is further increased if a decision is made to segregate wastes (e.g. fine and coarse), creating additional waste streams.

The stability of a waste rock pile is influenced by several parameters such as the geometry of the pile, the quality of the materials, the climatic conditions and the materials comprising the foundations. However, several cases of historical failures show that they are closely related to the height and rate of advance of the pile. During deposition of waste rock, it is important to evenly distribute the materials on the crest, allowing materials (foundation and/or stockpile) to settle and consolidate naturally.

On sloping ground the rate of advance will change over time as the height of the pile increases. Proper intervals for reassessment of the rate of advance should be established for each pile. The length of the deposition front can be varied to compensate for a reduction on rate of advance should the volume to deposition remain constant. This is illustrated in Figure 2.

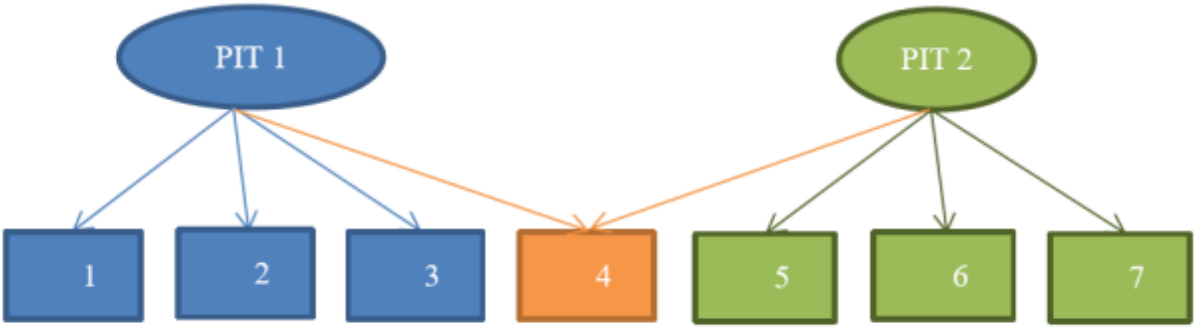

Figure 1: Scheme of a mine operation considering 2 pits and 7 deposition areas.

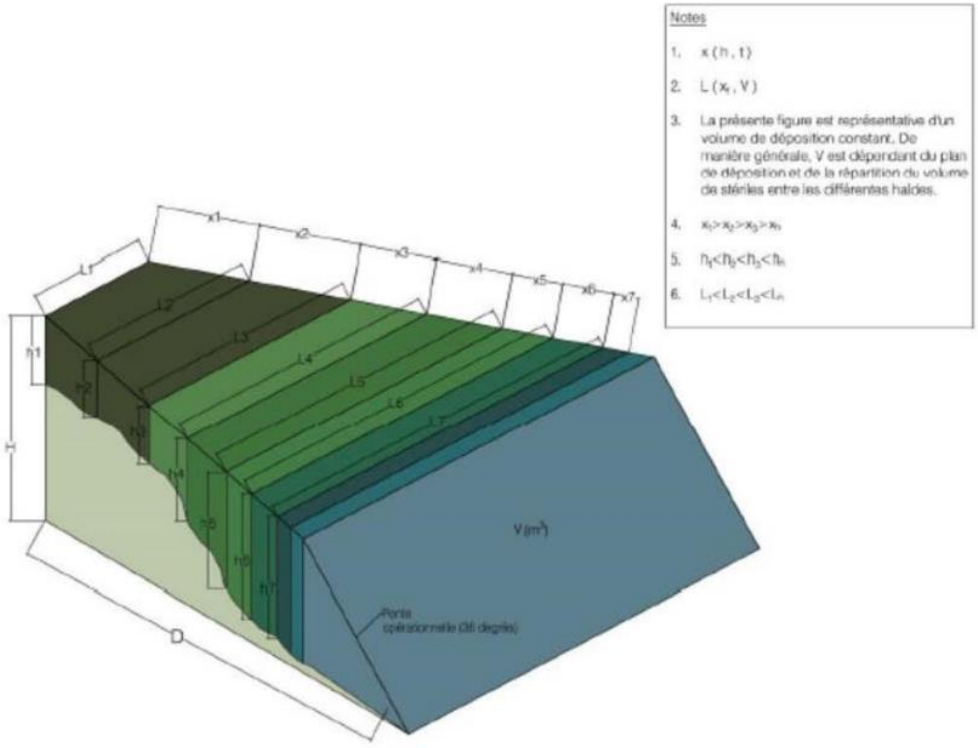

Figure 2: WRSF construction parameters and advancement rate (figure to be translated).

As an example, a multi-variable graph was prepared for a coarse waste material deposited on a medium quality foundation. The graph is shown Figure 3, and provides a

rate of advance and resulting volume per linear meter at the deposition front, for a range of heights between 70m and 250m.

When managing multiples stockpiles, with one or multiple waste streams, taking into account the rate of advance, can be logistically challenging. Equation 1 below can be used for each of the waste streams. The total volume (Vt) should be balanced to the overall volume being handled at a particular time. In the mine scheme shown at Figure 1, if a rate of advance is a constraint to placing the required volumes at a particular time, the length of the deposition front should be increased.

$$Vt = \sum_{x=1}^{n} \mathrm{Vx} * \mathrm{Lx}$$

Where:

H_x = Height (m) of a particular pile

n = number of stockpile in construction at a given time, t

V_x = Volume per linear meter of deposition front advance (m3 / lm)

L_x = Length of the deposition front crest (m) of a particular stockpile advanced at a given period,t

V_t = total volume of material to be deposited per day for a given period, t n, Lx and Vt are time dependent and, as such, become the key parameters required to establish an operational deposition plan.

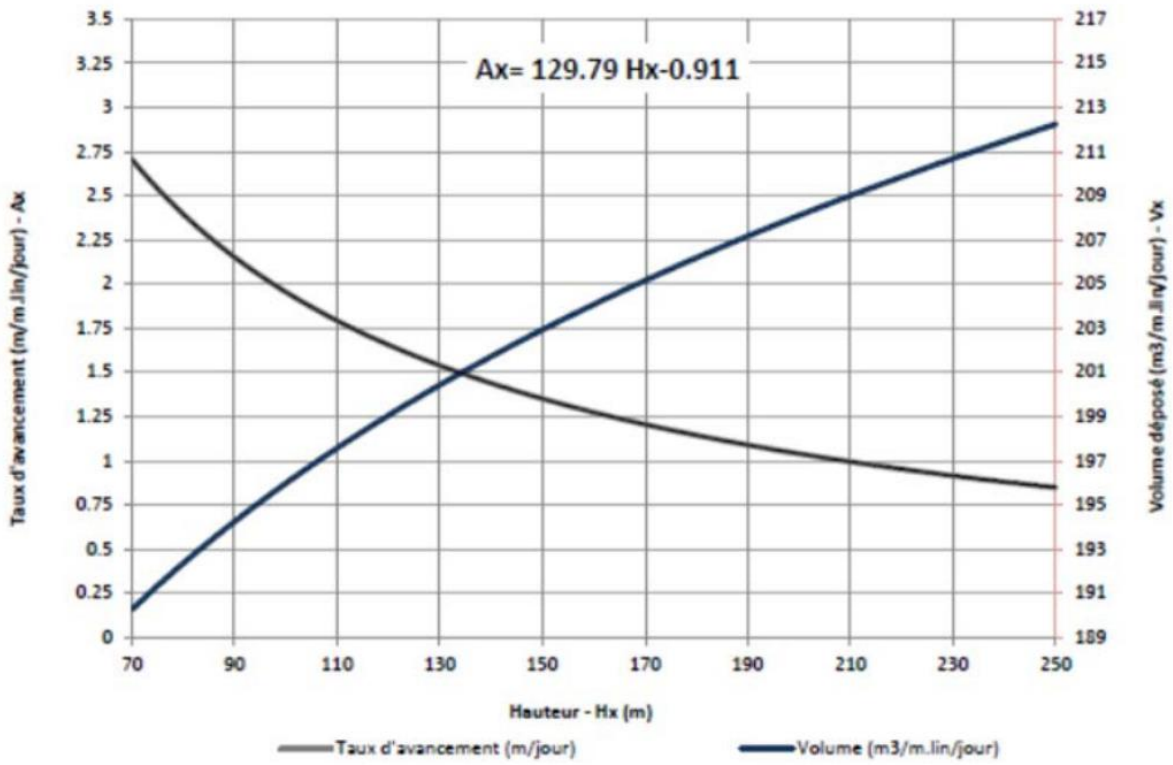

Figure 3: Coarse WRSF – Relation between stockpile height and advancement rate (to be translated).

Segregation

Material types entering the WRF can vary over time. Given the marked difference between the angle of internal friction of fine and coarse waste rock, it is generally recommended to deposit these materials in separate stockpiles. From a design perspective this will eliminate or reduce input design parameter variability.

Experience has shown that at times (i.e. during a push-back on a pit wall) larger quantities of fine grained waste will likely be generated. If these materials are placed over the face of a coarse grained waste, which are also free draining, water levels within the stockpile will rise. The rising water levels can initiate a failure, particularly in the finer material. This has been modeled, and shown in Figure 4.

Where smaller quantities of fine grained material are produced alternatives using free dumping techniques remain a possibility. The management of fine materials can be accomplished by various means. They can continue to be managed in separate stockpiles or by a designed codeposition. Managing the fine material in separate stockpiles may not be cost effective if small quantities are involved. A proper co-deposition method offers some advantages with respect to cycle times and overall simplification to planning and coordination. It can also ensure the stability of the stockpile. In this example, we present a co-deposition method in which the fine materials are deposited in separate layers within the stockpile body between coarse materials and maintaining setbacks from the slope crest. Figure 5 shows a possible configuration using free dumping of fine material within a coarse stockpile. Figure 6 illustrates the resulting 3D seepage model of the configuration and shows that will proper design the water table within the stockpile can be kept low.

Figure 29. Nappe phréatique dans une HSG (k_{sat}=1x10^{-4} m/s) avec une face en matériaux fins (k_{sat}=1x10^{-7} m/s)

Figure 4: 2D Seepage model- Fine grained material over the face of a coarse grained stockpile (Piciacchia et al., 2018a).

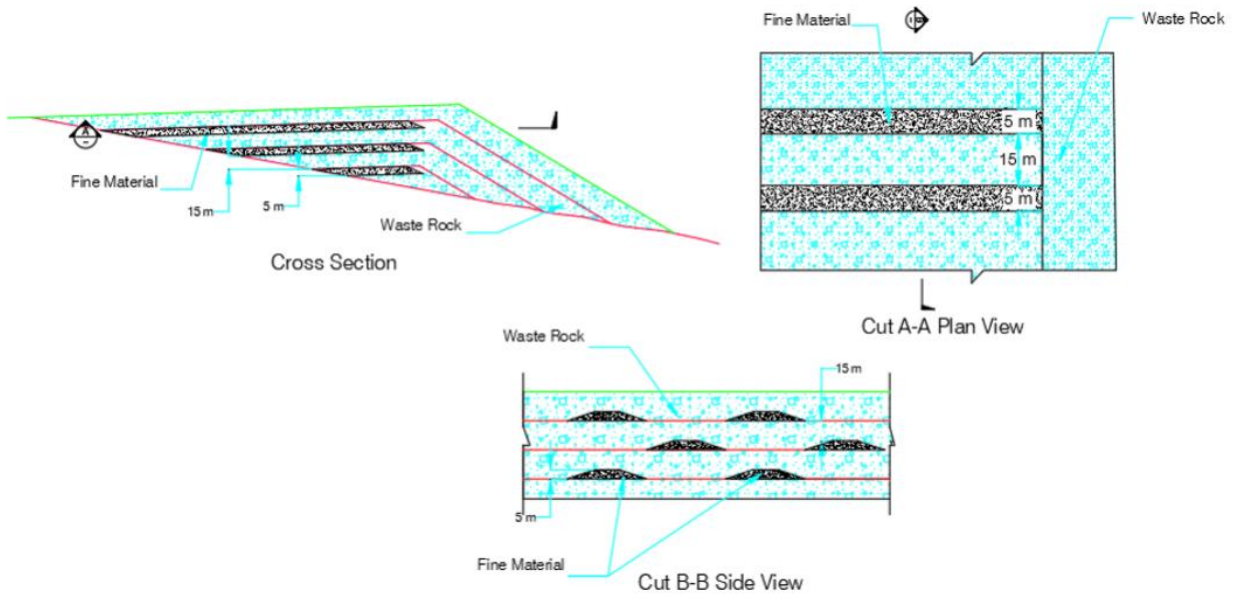

Figure 5: Cross-section, plan and side view for the proposed co-deposition method (Piciacchia et al., 2018a).

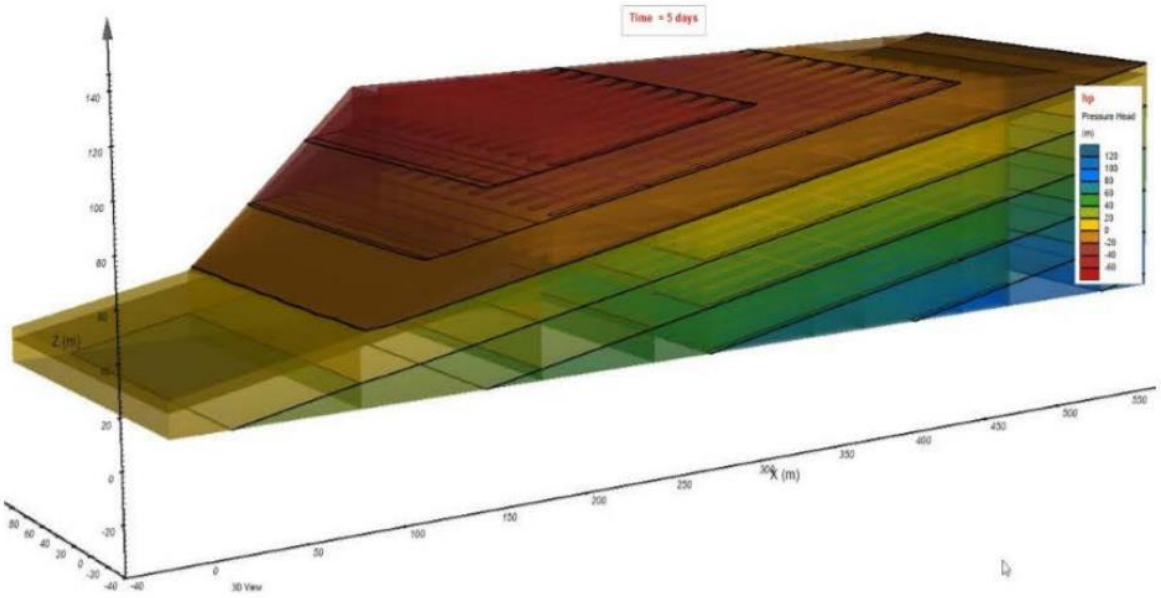

Figure 6: 3D seepage analysis result (Piciacchia et al., 2018a) (Figure to be upgraded).

Depositions plans

WRSF are complex structures whose operating criteria change over time, including the quantity and quality of materials to be managed at a specific time. In addition, the construction of these structures must be harmonized with all other mining and engineering activities. As such, waste rock deposition plans are essential management tools that orient mining operations. They allow operators to evaluate and prioritize, proactively, the design and construction needs aligned with the mine plan.

It is recommended to prepare deposition plan, for various stages of the mine life. These plans should be updated in a regular basis as recommended below:

- Long term considering closure prediction: updated each 5 years;
- Short-term (5 years horizon) considering global planning: updated annually;

- Immediate-term (1-2 years horizon) for operational purposes: updated annually.

Should significant changes occur in the operation, the impact on the deposition plans must be evaluated at that time. This process is similar to that which is undertaken for TMF.

Operation Manual

The Operation, Management and Safety (OMS) manual allows for the clarification of individual responsibilities, decision-making processes, guidelines for design and possible modifications, instrumentation, monitoring and the development of environmental protection measures and emergency plans for the WRF. Operational guidelines must take into account both longterm and short-term operational needs. The operating manual is a master document that standardizes the operating procedures at the mine and should be updated to include any changes in the operation. The implementation and application of an OMS manual has a direct impact on the long term continuity and performance of the WRF overtime. An OMS manual should cover as a minimum the following management categories:

- **Roles and responsibilities:** the organisational structure should be described with the overall responsibility being clearly identified. The level and frequency of training required for individuals entrusted with the facilities should also be documented. Personnel turnover and revised staff assignments will require this section of the document to be updated on a regular basis. This section may also include the nomination of an engineer of record to ensure compliance with design criteria and operating standards.
- **Facility description:** this section of the manual aims to put a framework for the WRSF. A detailed description of the facility, as well as maps, layouts, and plans showing detailed information of the facility are required. Historic data with regards to topography, environment, and other baseline information must be recorded and organized in such a document. Design reports, construction drawings, as-built drawings, construction reports, and all documents related to the development of the facility must be maintained.

- **Construction and operation**: this section should include a description of the mine plan under which the WRSF is to be operated, including the details of the deposition plans, aligned with the exploitation plan. In addition, it should include chapters which cover environmental protection, risk management, health and safety, snow management (if applicable) instrumentation and inspection, foundation preparation, waste classification and management, and water management. This provides a brief list of some of the key element that should be include, mine operators should tailor the list of operational KPIs which they deem most appropriated for their operation.

Conclusion

This paper has attempted to demonstrate some key changes that need to be implemented as WRSF go from being considered simple dumps to engineered structures. Regulation established by legislators demonstrates their recognition that WRSF are in a fact structures. Thus they need to be designed and managed as such.

WRSF are by the nature of the waste streams, which vary in quantity and quality over time, are more complex, from a management perspective, than TMF. In addition, the number of failures, albeit less consequential, which had being recorded during the past 40 years in BC alone far surpasses the high profile failures in tailings facilities over the same period. Yet the amount of rigor presently employed in the design and operation of WRSF is significantly less than with TMF design. Recognition of these facilities as structures will change the approach to their design, planning and operation.

References

1. Hawley, Mark, and John Cunning 2017. Guidelines for Mine Waste Dump and Stockpile Design.
2. Piciacchia, Luciano, Marefat, Vahid and Mosquera, Jenyfer, 2018. The use of 3D models and analysis in support of waste stockpile design and operations. 18th Tailing and Mine Waste Conference, The Department of Civil and Environmental Engineering at Colorado State University.

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Dr. Luciano Piciacchia, P.Eng., Ph.D., is an experienced mining engineer with 30 years of solid geotechnical and environmental experience. He has worked on numerous site characterisation and decontamination projects as well as mine tailings impoundment design and waste management. He has been responsible for the planning, execution or supervision of laboratory and field investigations. Dr. Piciacchia has further been involved in numerous complex decontamination projects requiring specialised methods such as the requirement for sheet piling, bacteriological remediation and on-site encapsulation. His involvement has extended to tailings impoundment planning from the standpoint of scoping, pre-feasibility and feasibility perspectives. He has been involved in the design, site supervision and project management for earthworks, roads and dams for a number of mining sites including Bloom Lake, Mont Wright, Kearl, Mine Aurizon to mention some of the more recent assignments.

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Dr. Vahid Marefat is a skilled professional with more than 12 years' of experience in the domain of geotechnical and geoenvironmental engineering and hydrogeology. He has worked on numerous geotechnical projects including 3D and 2D slope stability analysis, tailings and earth dam design, seepage analysis, foundation and earth structure design, excavation stability analysis and sheet piling, instrumentation, site investigation, as well as construction projects. Dr. Marefat's research and expertise centered on the slope stability and seepage analysis of waste rock piles and tailings/rockfill dams. His expertise has also extended to geotechnical engineering and hydrogeology of the Champlain Clay. Dr. Marefat has also led and supervised several complex research projects on geotechnical instrumentation, regional hydrogeology, geotechnical field and laboratory tests, grouting and climate impact on the foundation engineering in the laboratory of Geotechnical and Geoenvironmental Engineering and in the laboratory for Hydrogeology and Mining Engineering in Montreal, Quebec, Canada.

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Mr. Vides is a Civil Engineer with more than 13 years of experience in civil and environmental engineering. As Project Manager and Engineer, he has participated in several prefeasibility, feasibility and detailed engineering studies as well as construction projects in Canada and around the world in the mining, oil and agriculture sectors. He has worked on the design and construction of numerous systems, such as water management, tailings management and land use systems (water management infrastructure, drainage systems, irrigation systems, access roads, landscaping, and buildings). He has led multidisciplinary and multicultural engineering teams, in both the office and on site and has carried out and managed several field studies.

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