Mine Waste Rock Storage Facilities Design, Construction, and Operation as Engineered Structures

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Executive Summary

Waste rock storage facilities (WRSF) are massive structures that make part of mining environments, landscape, and layouts. Instabilities in these structures can impact nearby mining infrastructure, equipment and personnel as well as the surrounding environment 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, engineered construction, supervision and monitoring, stockpile deposition planning, site characterization or operations. It is only when we look at the long-term that the increased apparent costs of planning, design, construction and operation of a WRSF is put into perspective. It is therefore important that the current mindset regarding WRSFs evolves and becomes more holistic by considering not only short term needs but include proper fit to purpose engineering and construction of these structures. This paper provides an example of an optimized design along with consideration for constructability where existing stockpiles need to be brought to code for long term stability.

- 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 is an important waste stream generated in all open pit and underground mining operations. The amount of waste rock produced depends on the commodity being mined, the mining method employed, and the geometric orientation of the orebody. Waste rock needs to be managed according to the type, quantity, geochemical and geotechnical characteristics of the waste material being produced, as well as of the geotechnical characteristics of the foundation on which the WRSF will be deposited.

Typical methods for managing mining waste, which may include rock altered to varying degrees, sand, till and organics materials, are deposited directly on natural ground. The materials are normally transported by truck and deposited by one of three methods:

- **End dumping:** consist on depositing waste rock over the face of an existing waste rock pile or from the crest of a natural ridge. This method usually results in particle size segregation down slope towards the toe of the waste rock pile. Particle size generally increases from the top to the bottom. The end dumping method might be beneficial for coarse waste rock as larger fragments accumulating at the toe will form a natural drain, making the waste rock pile self-draining.
- **Push dumping**: consists of depositing waste rock from trucks onto the waste rock pile platform, followed by leveling and pushing by tractors and shovels over the waste rock pile face. This method also results in particle size segregation, with finer waste rock at the top and coarser waste rock at the toe of the waste rock pile. Push dumping has a similar self-draining effect at the base of the waste rock pile as that described for the end dumping method. However, push dumping has the added benefit of providing an extra degree of safety to workers as large trucks do not approach the crest of the waste rock pile during waste rock placement.
- **Free dumping:** this method is similar to push dumping, but instead of pushing waste rock over the slope of the existing pile, the material is spread of over the platform with tractors and shovels. The result is a better graded in place waste rock material with minimal particle size segregation. This is an ideal method for ascending waste rock pile construction or for co-deposition of fine and coarse waste rock.

Mine waste rock piles configurations tend to take advantage of the topography in which they are situated. Common classification for such configurations has been described by Hawley and Cunning (2017), as follows: valley-fill, cross-valley, side-hill, ridge, or heaped. Within a particular topography the method of deposition and construction are typically governed by economic aspects of the project and often result in either an ascending or descending configuration.

Where topography permits, descending construction method tends to be the most costeffective. It is important to note that by using a descending construction method, the platform elevation remains constant and the deposition front advances towards the final footprint. On sloping ground the slope height increases with the waste rock pile advancement. As such, the factor of safety associated with the pile will decrease with the advancing front. For granular materials, the theoretical factor of safety will never be less than one (1) if the WRSF is built on a competent foundation (Piciacchia et al., 2018a). However, the regulatory requirements for waste rock piles design specifies that an overall factor of safety 1.5 should be maintained for long term stability (MERN, 2017). Within limiting heights, using descending construction methods alone will result in waste rock piles that do not conform to legislation.

On sites where foundations conditions are considered to be less than ideal or where the overall pile height are the driving factors for stability, the ascending construction method should be considered. This method offers the potential to control the incremental loads placed on noncompetent foundations. It further offers a means of controlling the geometry of large waste rock piles and therefore the overall factor of safety. However, ascending construction is a more costly method.

Material considerations in the design of waste rock piles

Overburden and blasted rock (waste rock) are the two primary waste streams generated during orebody exploitation before any milling and grinding processes occurs. The overburden portion usually consists of organic material followed by coarse grained soils such as sand and till, and/or fine-grained and cohesive materials such silt and/or clay. Waste rock grain size, shape, and degree of fragmentation varies from coarse to fine depending on the type of rock and the method used for its extraction (blasting and ripping).

These two waste streams have drastically different design properties. Parameters such as permeability, water retention capacity, angle on internal friction (Ø) and cohesion (c) can vary significantly for the various waste streams. If the overburden and waste rock are to be managed within the same waste rock pile, the degree of heterogeneity will be proportional to the amount of each type of material in the pile at any given time. Spatial and temporal uncertainty of mine waste rock properties are the biggest management challenges for mine operators and designers. These challenges can be mitigated, in part, by adopting good practices such as material sorting at the point of origin and by managing the waste streams in separate piles (Vides et al., 2018).

The properties of soil in the foundation are also governing factors in waste rock stability assessment. The result of conventional geotechnical investigations of the foundation is a basic input that must be integrated into the waste rock design. Three dimensional numerical modelling is useful tool for a more realistic identification of critical sections within a waste rock pile, (Piciacchia et al., 2018b), as it helps visualize materials interactions in different directions.

Design Criteria

Waste rock pile guidelines and regulations such as the one proposed by MERN, 2017, requires that different factors of safety need to be maintained under varying operating conditions including the closure stage of a WRSF. Table 1 presents factors of safety used in WRSF design.

Table 1. Stability analysis - Minimum values for factor of safety

Condition	Factor of safety (FS)
Bearing capacity of the foundation under WRF	1.5 to 2.0
Local stability of the piles (for each bench)	
Short term static analysis*	1.0 to 1.1
Long term static analysis	1.2
Overall stability, for deep failures or failures pass through Foundation	
Short term static analysis *	1.3 to 1.5
Long term static analysis	1.5
Pseudo-static analysis	1.1 to 1.3

* According to risk and uncertainty

Case study

Description

A practical example of implementing a proper design approach for an existing WRSF is summarized below. The WRSF closure configuration has an overall strike length in excess of 10 km and measures between 200m to 300 m in height. The WRSF has a width of 2 km and will store over 2 billion m3 of coarse waste rock at closure.

This facility operates a number of open pits in a synchronized fashion. Deposition areas are built and operated in sequence. The main criterion for defining areas of deposition is transportation distance between the pit and the waste rock stockpile. End dumping and push dumping methods account for the majority of the deposition methodology. Stockpile development proceeds using descending construction.

Over the years, some geotechnical characterisation has been performed at the site of the study area. Foundation could be described as competent, and are characterised by shallow deposits of glacial till to a maximum depth of 6m, overlaying bedrock. The overall waste rock deposition can be considered a side hill fill configuration, on a moderated sloping topography (about 15 degrees). The stockpiles currently under construction are mainly composed of coarse material; this includes gravels, cobbles and boulders with less than 5% of fines. Stockpiles in place appear to be in equilibrium, with angles of repose equal to the angle of internal friction of approximately 35-37 degrees. The factor of safety evaluated for the current operation and stockpile configuration is 1.0.

In order for the facility to meet regulatory requirements, a generalized overall slope of 26 degrees will be required at closure. In addition, bench heights and widths will need to be designed in order to meet local stability design criteria (Piciacchia et al., 2018). Descending construction method alone can therefore not be used to meet closure configurations. The facility has advanced to this point, meeting regulatory requirements for short term stability.

Looking ahead plans needed to be developed in order for the operators to meet long term regulatory requirements. Figure 1 summarizes the most important features of the current operation.

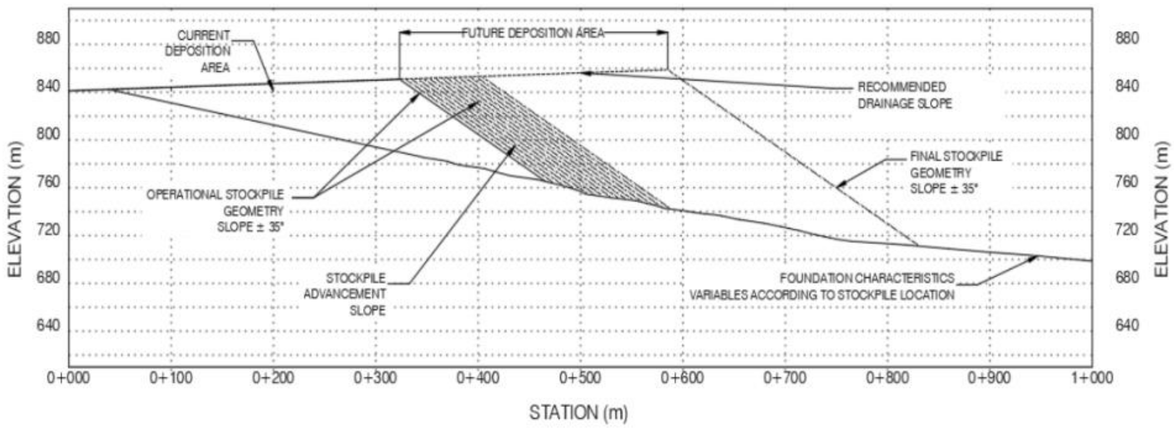

Figure 1: Typical waste rock pile of the study area.

Configuration approach and design

The final configuration required for the pile can be met by different construction approaches. Figure 2 presents one of the proposed construction alternatives required to attain a long term factor of safety equal to 1.5. This option is essentially an ascending construction method commencing from the final toe of the proposed waste rock pile and built in lifts.

As shown in figure 2, the first level of the pile is built to the prescribed elevation and then backfilled to natural terrain. Subsequent benches are built maintaining a design setback. The number of benches built in this fashion would be governed by the final elevation of the existing waste rock pile and the design bench height. In essence this approach would require mine operators to move completely away from a descending construction method in favour of ascending construction method. It was determined that such a drastic modification would not only be disruptive to operations, but would be extremely costly due to a significant increase in truck cycle times. This cost increase would impact both the capital and operational costs of the project as the current fleet of trucks would need to be increased.

An alternate approach to construction is shown in Figure 3. This option maximizes the use of the descending construction method and limits ascending construction to a minimum limiting such construction to the containment structure (buttress) located at the final foot of the waste rock pile. This confinement structure is built before the current deposition front comes in proximity to the footprint of the designed buttress structure.

The construction sequence also allows for the confinement structure to be built safely and reduces the volume of ascending construction required, from 100% in the first option to about 25% in the construction of the buttress.

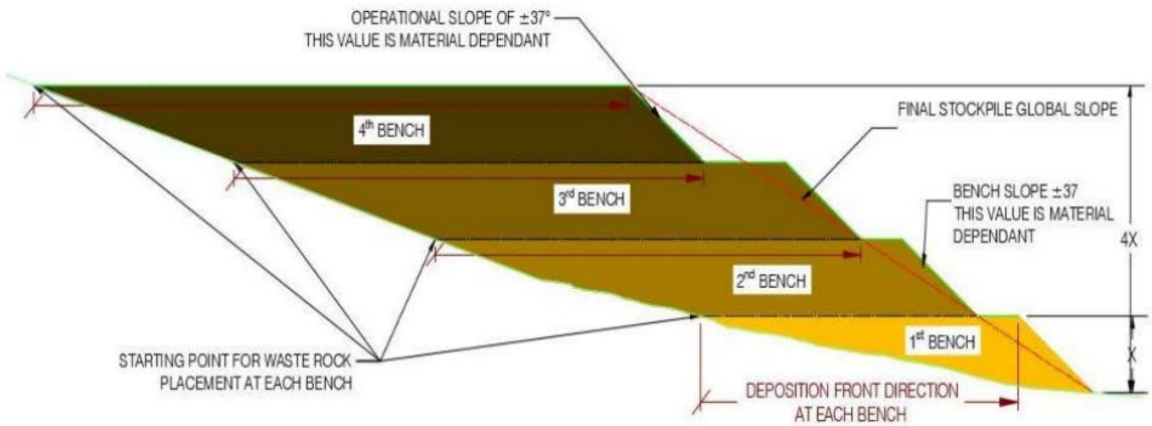

Figure 2: Waste rock pile construction Method – Alternative 1.

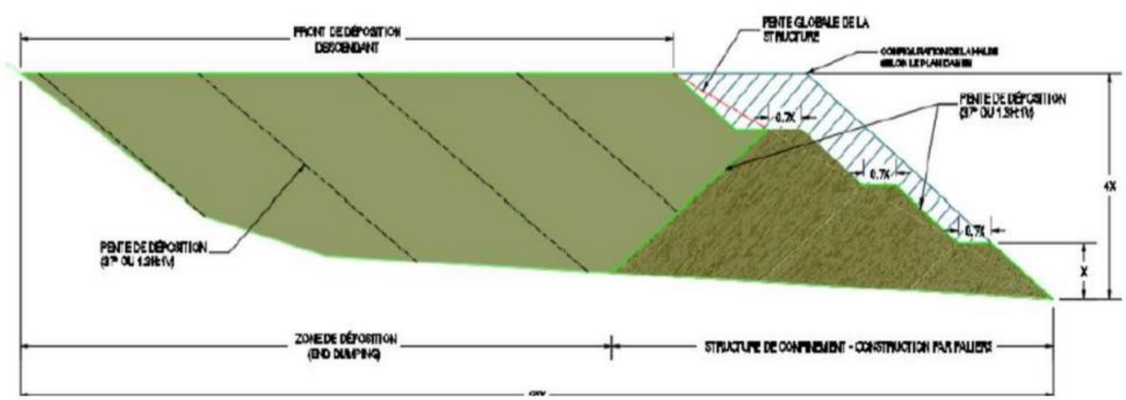

Figure 3: Waste rock pile construction method – Alternative 2.

In order to reduce the volume required for the construction of the confinement structure, a maximum bench height for the recommended configuration was defined. Bench width was determined using analytical calculations and the safety factor was validated using 2D and 3D numerical models. The maximum height for a bench comprising a waste rock with an Ø of 36° is 50 m, as developed by Piciacchia et al. (2018). This geometry required a bench width of 35 m in order to attain an overall FS=1.5, and a local FS=1.2. Figure 4 presents a typical cross section applied along the strike on the entire deposition area. Figure 5 presents a plan view of the resulting 3D application of the typical cross section.

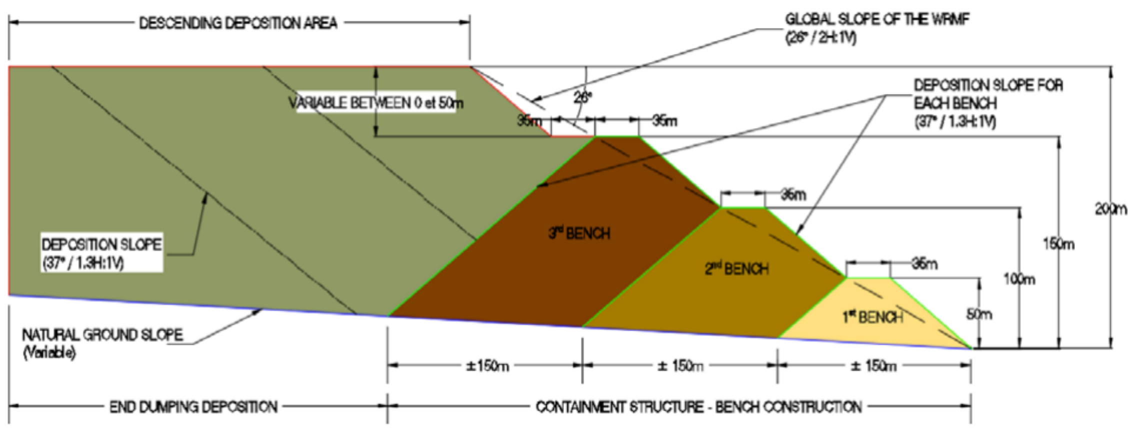

Figure 4: Typical design cross section applied on the deposition area.

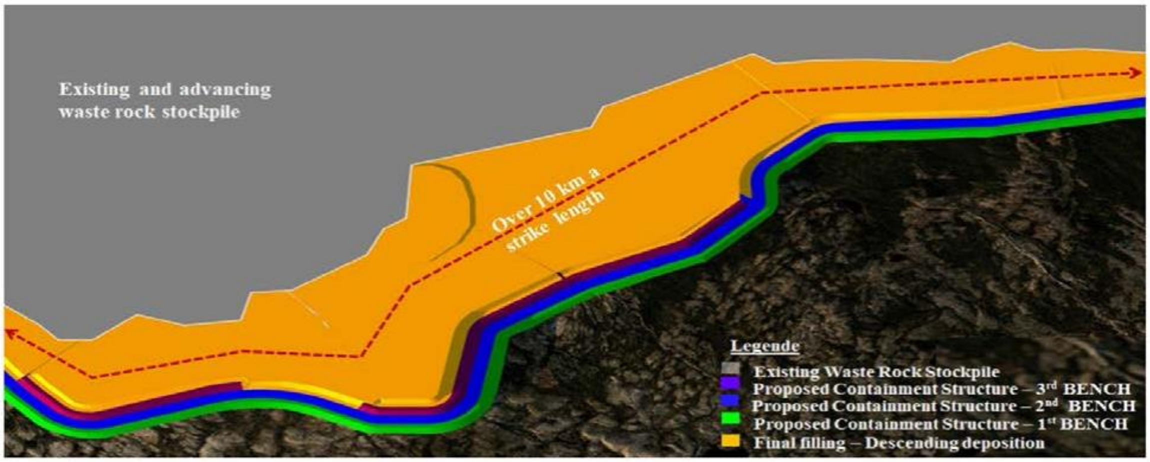

Figure 5: Resulting 3D model of the recommended solution.

A verification of interferences between the proposed final configuration and existing infrastructure and environmental constraints was conducted to ensure feasibility of the construction method and configuration proposed. Hybrid solutions are often needed in cases where interferences cannot be mitigated in the short term. The hybrid solutions should be aligned with the needs of the mine development plan.

Constructability

Constructability entails assuring access to the construction site, availability of the quantity and quality of materials required for construction, assessment of construction drawings, preparation of a construction schedule in alignment with operational needs, and a detailed sequence of each construction stage. The availability of the construction material can be ensured by developing deposition plans which are synchronized with the mine development plan including the volumes and material specifications required for buttress construction.

Options for access to the construction site of the confinement buttress have been considered including a ring road at the toe of the WRSF. However, such roads would not only be costly to build, but will increase truck cycle times. As such, access roads were incorporated into the confinement structures themselves. Figure 6 illustrates the resulting configuration of such an approach.

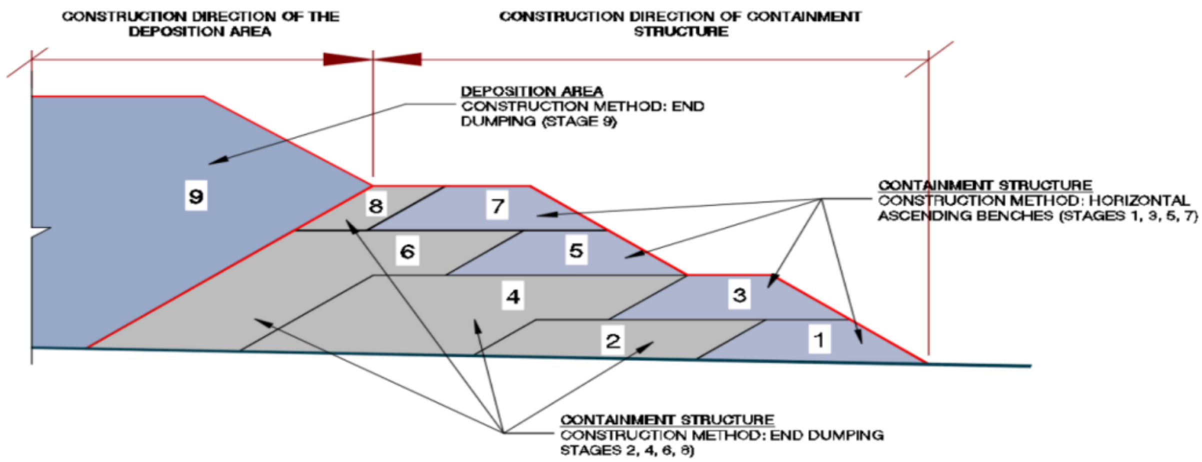

Figure 6: Access roads and containment structure approach.

With the construction of each bench the platform area should extended beyond the design bench width in order to accommodate the base of the following bench. The construction of individual benches could be achieved by one or multiple lifts depending on overall dimensions and degree of compaction required. Figure 7 illustrates a sequence in which each bench is built in two lifts.

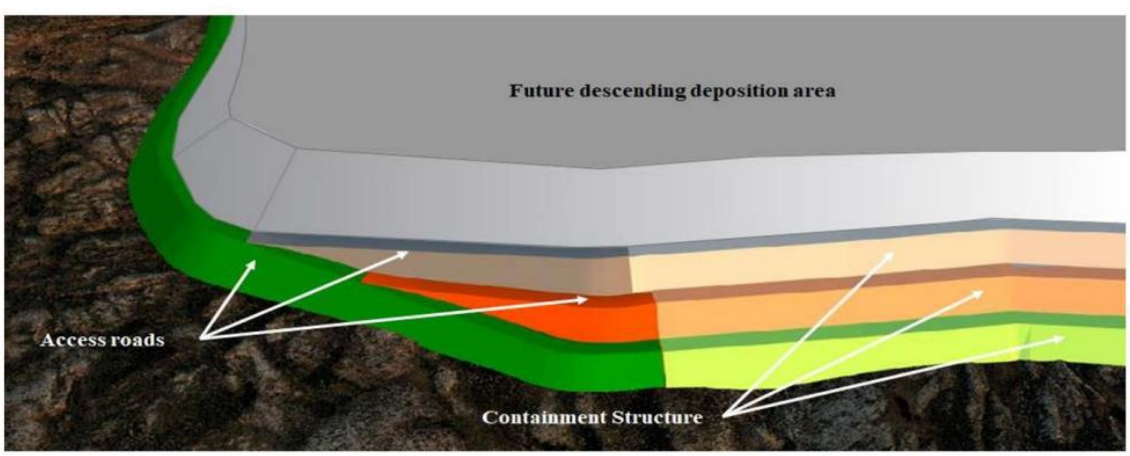

Figure 7: Construction sequence for benches of the containment structure.

The construction phases shown in Figure 7 can be undertaken using ascending or descending construction methods. For this particular, stages 1,3,5,7 were recommended to be done using ascending construction, while 2, 4, 6, 8 and 9 using descending construction method.

Conclusion

This paper has presented a design approach which attempts to find the balance between operational needs, constructability, safety and compliance. WRSF should be considered as engineered structures instead of dumps and should be given the attention that structures of this size, magnitude and importance demand. This paper provides an example of the complex nature of WRSF design and the need to adapt to changing design input parameters. Flexibility in design is essential and needs to account for operating constraints as well as regulatory requirements. Special attention should be given to the design nuance between the operational factor of safety and the factor of safety required at closure.

Given the long life of WRSF, it is essential to conduct proper planning, scheduling and sequencing of the construction. Likewise, waste rock deposition plans are important management tools that aid in the planning, operation and construction of WRFS. Planning should be done to varying levels of precision accounting for the special and temporal variability of the waste rock properties.

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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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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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