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PanAust Limited's Approach to Mine Waste and Tailings Stewardship

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ABSTRACT

PanAust Limited (PanAust) has successfully constructed and commissioned two mining operations in Lao PDR over the past decade and undertaken major studies for three new mine developments. The management of potentially acid generating mine waste and tailings in close proximity of local communities sensitive to water discharge quality have been recurring themes that have confronted PanAust's project study, development and operational teams. Further compounding challenges, such as the effects of intense annual tropical monsoonal conditions, staging of embankment raises and regular lifting of spillway structures, integrating mine waste and tailings management into production plans and ensuring the long term stability of structures, have been addressed by implementing leading practice management solutions.

A recognition of the criticality of managing the substantial business risks associated with these crucial activities led to the early establishment of a governance structure to ensure that the highest standards are embraced for planning and execution. Importantly, these are guided and monitored by a panel of highly experienced and qualified international specialists reporting directly to PanAust's Managing Director – the Tailings Independent Review Panel. The stewardship process has been effective in identifying potential shortcomings in management systems and has led to enhanced executive commitment to risk informed designs, assurance and overall process rigour.

INTRODUCTION

PanAust Limited (PanAust) is a leading copper and gold producer in Laos with pre-development and exploration opportunities in Laos, Papua New Guinea (PNG), Myanmar and Chile. The company's producing assets are the 90% owned Phu Kham Copper-Gold Operation (Phu Kham) and the Ban Houayxai Gold-Silver Operation (Ban Houayxai) in the Lao People's Democratic Republic. PanAust's major development project is the 80% owned Frieda River Copper-Gold Project in Papua New Guinea (PNG) which is the subject of a feasibility study and environmental impact assessment.

The company is focused on a sustainable business model associated with the production and sale of copper, gold and silver, delivery of production goals and astute responsible growth. PanAust's strategy is to maximise returns from its producing assets while advancing projects that offer potential to sustain and grow the business in the long-term. The responsible management of mine waste rock and tailings is an important component of PanAust's sustainable business model.

PanAust operates two large Tailing Storage Facilities (TSFs) in Laos and is proposing to construct a very large Integrated Storage Facility (ISF) in Papua New Guinea. All three facilities utilise subaqueous deposition to contain and encapsulate potential acid forming (PAF) mine waste rock and process tailings. The Ban Houayxai TSF holds process tailings only. The Phu Kham TSF stores process tailings and mine waste rock. Both facilities operate with a small water cover to limit final embankment build height and construction cost. The Frieda River Project ISF is unique in that it is designed to integrate the storage of process tailings and mine waste while maximising the water cover to allow generation of hydroelectricity. Interestingly, the final embankment height is driven by the opportunity to maximise hydroelectric power rather than minimise embankment construction cost. Salient features of each facility are listed in Table 1.

TABLE 1

Features of PanAust's tailings storage facilities.

	Unit of Measure	Ban Houayxai	Phu Kham	Frieda River
Status		Operating	Operating	Study
Embankment Height[1] - Current	m	83	170	-
Embankment Height[1] - Final	m	89	179	185
Embankment Volume	Mm3	0.6	60	26
Storage Volume	Mm3	33	155	4,400
Crest Length	m	286	1,880	720
Annual Rainfall	mm/year	2,400	2,400	7,600

[1] Embankment height relative to downstream toe elevation

All facilities are of a scale where any significant failure could threaten the safety of communities, cause severe and irreversible long term harm to the environment, and ultimately, threaten PanAust and its subsidiaries' reputation and licence to operate. In simple terms, their design, construction, operation and closure is of major importance to PanAust's Managing Director.

The efficient design, construction and operation of these facilities is a key factor contributing to the success of the business, especially given the substantial initial and sustaining capital expenditure required to build these Facilities and the operating expense associated with their use.

PanAust is committed to providing a level of stewardship that is commensurate with the risks associated with these facilities and is consistent with leading global practice. Stewardship is considered to be a shared responsibility across all parties contributing to the design, construction, implementation, operation and closure of the facilities including management, employees, contractors and consultants. PanAust's Managing Director is ultimately responsible for ensuring that stewardship is managed effectively. This recognition led to the formation in 2011 of an independent technical panel of internationally renowned specialists who provide PanAust's Managing Director with an unfiltered and objective assessment of the company's TSF stewardship performance.

The stewardship program, and its accompanying systems and processes, has provided a strong, well-structured and supportive environment for the design, engineering, construction and management teams to perform effectively and efficiently. The program empowers and acknowledges the importance of, and PanAust's commitment to, its TSF and waste rock storage facilities. Expectations are established and clearly defined while governance recommendations and review actions allow and enable the required physical and financial resources to be allocated in a proactive manner for the facility life cycle. The stewardship program provides the necessary forums for the continued development and contribution of staff and external consultants. The program is highly valued, does not burden the organisation and enables and empowers people.

DEFINITIONS

PanAust has adopted the following definitions in relation to its management of mine waste rock and tailings.

Facilities: TSFs, ISFs and various other dams and structures that are considered Large Dams based on the definition by the International Commission on Large Dams (ICOLD).

Governance: the organisational structure, systems and process which underpin our commitment to risk management, social licence to operate, sustainability and reporting for the design, construction, operation and closure of the facilities.

Stewardship: the non-technical approach of the company beyond the technical design and construction of the facilities. PanAust's stewardship commences with Executive Management commitment and includes

independent review by an expert panel that comprises up to five international, industry leading tailings and geotechnical specialists reporting directly to PanAust's Managing Director.

Material Risk: risks that may have a significant economic, environmental and/or social impact on the business that could substantively influence the assessment and decisions of stakeholders.

MINE WASTE AND TAILINGS FACILITIES

PanAust has constructed and commissioned two mining operations in Laos over the past decade and undertaken major studies for new mine developments in PNG, Laos and Chile.

Ban Houayxai Gold-Silver Operation

The Ban Houayxai Operation is located approximately 160 km north of the Lao capital Vientiane and 25 km west of the Phu Kham Operation (Figure 1). The Operation, which commenced commercial production in 2012, comprises an open pit mine, carbon in leach (CIL) process plant and associated facilities. The mine uses conventional drill, blast, load and haul methods to deliver ore to the process plant and waste rock to permanent storage facilities. The ore processing plant uses crushing, grinding, gravity separation and CIL processes to recover gold and silver into a saleable doré which is transported and sold to an offshore refinery. Production from Ban Houayxai in 2017 was 14.7 Mt mined and 5.0 Mt processed.

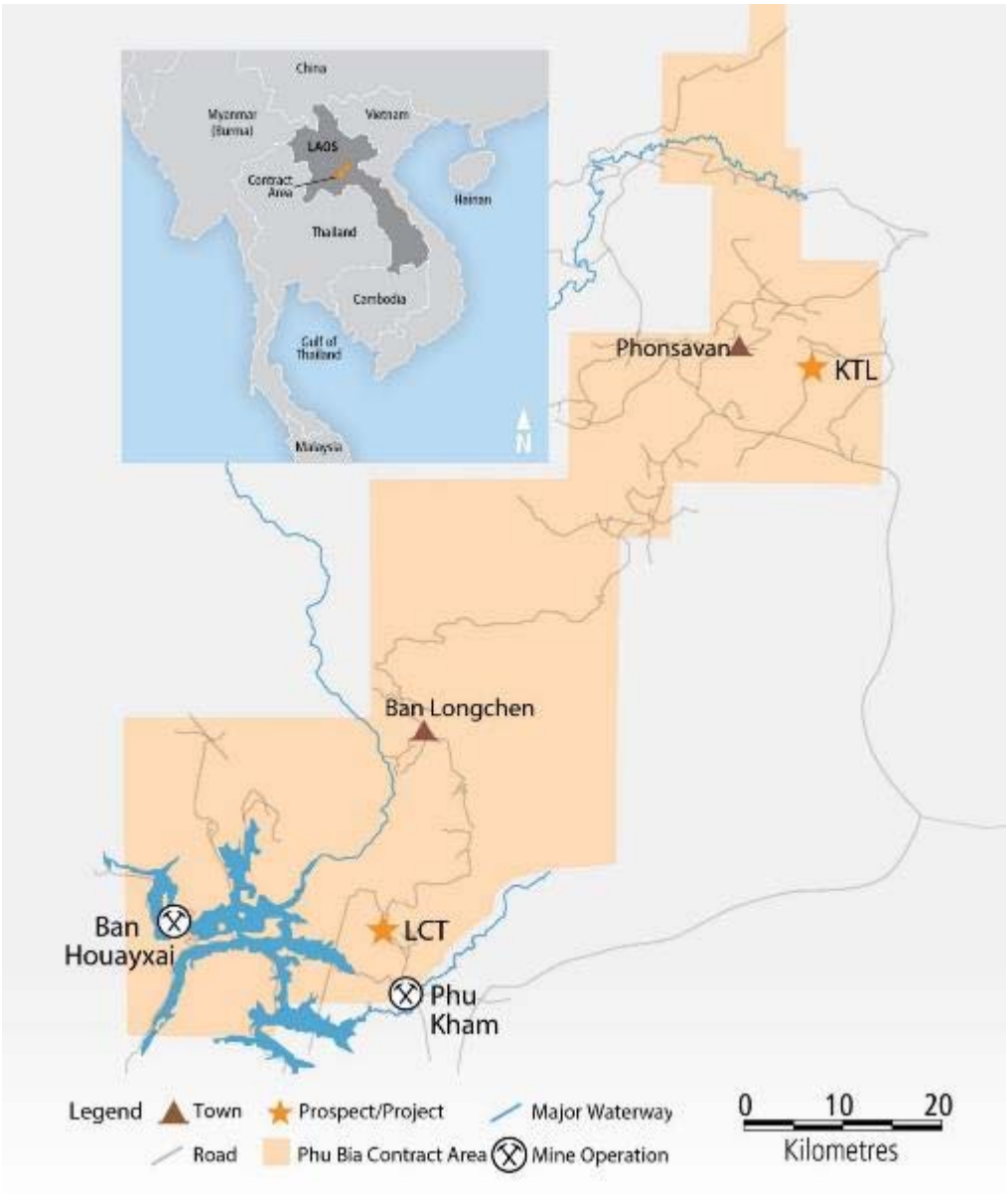

FIGURE 1 - Phu Kham and Ban Houayxai location map

Waste Rock Storage

Waste rock from the operation is placed in an engineered waste rock dump adjacent to the open pit. Backfilling of the North and Central open pits will provide additional waste rock storage later in the mine life.

The waste rock consists primarily of oxidized and transitional material. Primary sulphide material constitutes approximately 10% of the waste rock. Pyrite represents the main sulphide mineral in the waste rock and encapsulation is used to minimise the ingress of oxygen into the dump and thereby prevent acid rock drainage (ARD) generation. Encapsulation is achieved by construction of an impermeable compacted oxide waste rock layer around the PAF rock.

The waste rock dump is a valley fill design constructed with a basal underdrainage system in the spines of the valley. A bottom-up construction sequence is used. Three metre tip heads were used initially, when the waste material was predominantly oxide and transitional waste, to ensure sufficient dump compaction was achieved to promote the geotechnical stability. In 2014, when the general waste became coarser and was predominantly gravelly materials and rockfill, the lift height constraint was relaxed to allow the placement of general waste rock in lift heights of up to 5 m to reduce the potential for segregation (Figure 2).

FIGURE 2 - Ban Houayxai waste rock dump construction

At the toe of the dump a small sediment pond has been constructed with an earthen embankment which discharges through a gabion cascade to a second sediment pond. The second sediment pond has been constructed as a flow through waste rock embankment and is located in the impoundment area of the Nam Ngum II reservoir.

Tailings Storage

Detoxified process tailings are pumped to a TSF through a tight-liner, twin lined pipeline (outer steel/inner HDPE pipe) which is buried along its entire length. An automated pneumatically controlled variable choke station maintains non-slack flow of the tailings slurry within design velocity requirements to minimise line erosion. The choke station is monitored from the central site control room. The purpose built engineered

TSF is located approximately 7 km southwest of the pit and processing areas. The TSF is a valley fill bounded by a zoned rockfill dam wall. Tailings are deposited from a floating pipeline into the valley and stored under water. There is no under-drainage located within the facility as this could allow the tailings to drain, become unsaturated and allow sulphide oxidation to occur. An operational spillway adjacent to the embankment discharges through sediment dams along a natural water course that empties into the Nam Ngum II hydroelectric reservoir. The TSF wall height is raised intermittently using rock from an adjacent quarry.

PanAust is a signatory to the International Cyanide Management Code for the Manufacture, Transport and Use of Cyanide in the Production of Gold (the Cyanide Code) and the Ban Houayxai facility has been designed, constructed and operated in accordance with the guidelines contained in the Cyanide Code.

TSF Design

The Ban Houayxai TSF embankment comprises a zoned rockfill dam with a low permeability core protected by filters on the downstream side and a broadly graded transition zone on the upstream side (Figure 3). Construction of the TSF to its current configuration occurred in three stages comprising a starter embankment and subsequent downstream raises. A weir constructed in a large channel excavated through a rock ridge adjacent to the embankment forms the operating spillway. The water in the TSF flows continuously over the spillway.

FIGURE 3 - Ban Houayxai TSF embankment, construction quarry and spillway with tailings in foreground

Phu Kham Copper-Gold Operation

The Phu Kham Operation is an open pit mine and ore processing facility located in Laos approximately 120 km north of the capital Vientiane (Figure 1). The Operation commenced commercial operations in 2008 and comprises a large multistage open pit mine, ore processing plant and associated facilities. The mine uses conventional drill, blast, load, and haul methods to deliver ore to the process plant and waste rock to permanent storage facilities. The process plant uses crushing, grinding and flotation circuits to recover copper and precious metals into a saleable concentrate which is transported and sold to offshore smelters. A single tailings stream is produced from the processing plant which flows by gravity to the TSF through HDPE pipelines. Phu Kham achieved ex-pit production of 55.5 Mt in 2017 with 18.5 Mt of ore delivered to the concentrator.

Waste Rock Storage

Selected open pit waste rock is placed in various zones of the TSF embankment wall according to its geotechnical properties and geochemical characteristics. Material is either placed directly from mine waste rock that is hauled from the open pit or rehandled from stockpiled material according to the construction plan.

Waste rock is geochemically characterised based on its potential to generate acid drainage and mobilise metals to the environment. Five categories of waste rock have been defined: acid neutralising (blue), non-acid-forming (NAF), low sulphur potentially acid-forming (low PAF), medium PAF, and high PAF. Blue waste, such as limestone, is utilised in a PAF neutralising capacity while NAF waste rock is used for the bulk TSF embankment construction. PAF waste rock is placed in five metre lifts within the TSF impoundment and is progressively and permanently covered by tailings and submerged under water as the embankment is raised. NAF waste rock is utilised for TSF embankment construction and, depending upon clay content, PAF encapsulation. Depending on embankment construction requirements, any remaining NAF waste rock is placed separately in an engineered waste rock dump. The mine's mobile fleet management system (FMS) provides real time monitoring of material placement. The FMS alerts the central control room of any deviation from the placement plan to ensure waste rock is placed at its designated location.

Staged backfilling of the pit at the end of the mine life will provide additional waste rock storage.

Tailings Storage

Tailings from the Phu Kham ore processing plant are stored in a purpose-built TSF, designed as a cross-valley impoundment, located approximately 2.7 km west of the process plant site and approximately 3.5 km southwest of the Phu Kham open pit. Tailings are transported and deposited using pipelines that allow the controlled placement and distribution across the impoundment area (Figure 4). Tailings are deposited using a combination of subaerial spigots from the main embankment, to develop a saturated beach along the embankment, and subaqueous deposition using floating deposition lines.

FIGURE 4 - Phu Kham TSF tailings pipeline deposition system with waste rock dump in lower right

The embankment is constructed in stages with annual lifts of the low permeability and filter zones being performed by a specialised earthworks contractor. The structural embankment is progressively constructed by the mining fleet as part of the mine waste rock placement operations from the open pit (Figure 5).

Additional borrow pits at the TSF are available to provide low permeability homogenous materials to augment mine waste rock placement in the TSF embankment.

FIGURE 5 - Phu Kham TSF embankment downstream construction with waste rock dump in upper right

Phu Kham's tailings are classified as PAF. The TSF is therefore operated largely as a subaqueous facility with the embankment designed and constructed to more exacting standards as a water retaining structure. Cyclical deposition is regularly performed to maintain saturation of the tailings where subaerial deposition occurs. There is no under-drainage located within the facility as this could allow the tailings to drain, become unsaturated and allow sulphide oxidation to occur. All tailings are contained in the TSF together with PAF waste rock which is co-disposed upstream of the embankment (Figure 4 and Figure 5).

Decant water is reclaimed from the TSF using a floating pump system and reused in the process plant. The TSF impoundment also receives contact water from open pit dewatering activities and runoff water from the area surrounding the facility. A positive water balance requires excess water to be discharged from the TSF prior to, and at the conclusion of, the annual monsoonal season (May to September).

A two stage passive water treatment system treats the embankment filter zone seepage flow (Hedin et al, 2015). The first treatment stage removes sediment and increases the oxygen concentration to levels required to support aquatic life. The second stage precipitates manganese, which naturally leaches from the TSF basin, to concentrations below the regulatory release requirement.

TSF Design

The Phu Kham TSF dam is designed for staged construction using the downstream method with an upstream low permeability zone, a chimney drain and filters. TSF development has been performed annually since the construction of the starter embankment in 2007.

Frieda River Copper-Gold Project

The greenfield Frieda River Project lies in rugged jungle-covered upland terrain of Sandaun Province in north west PNG (Figure 6). The site is located approximately 180 km from the nearest coastline. The area is remote with no road access or power supply.

FIGURE 6 - Frieda River Project location map

PanAust is evaluating the development of the Project as a long life large-scale conventional open pit operation. Crushed ore will be conveyed from the open pit to a conventional comminution and flotation process plant that will produce a copper-gold concentrate for export to smelters. PAF mine waste rock and tailings will be stored subaqueously within a large ISF to avoid adverse downstream environmental impact. Additionally, the river flow through the ISF will be used to generate hydroelectric power for the Project.

Waste Rock Storage

Opportunities to construct and operate safe and stable waste rock dumps are limited by the rugged local terrain and climatic conditions. Most mine waste rock will therefore be placed and contained within the ISF. Waste rock production is expected to peak at 65 Mtpa.

Mine waste rock has been classified as either PAF or NAF. In general, the PAF and NAF waste will be stored subaqueously to limit the potential for PAF waste rock to generate acid. Waste rock will be trucked to primary crushers then conveyed to a barge loading station where it will be stacked, reclaimed and loaded into 5,000 t split hopper barges. The barges will transport and deposit the waste rock within the ISF.

A surface waste rock dump upstream of the ISF will store organic pre-strip material and selected NAF waste rock.

Tailings Storage

Thickened process tailings will be pumped via a dedicated pipeline from the process plant for subaqueous storage within the ISF. Tailings will be discharged at depth using a floating pipeline and tremie pipe system. This method was selected to prevent the suspension of discharged tailings and limit the concentration of suspended solids. Waste and tailings will be segregated within the facility to limit the potential of a rock mass failure under water.

ISF Design

The Frieda River ISF will be located in the Frieda River Valley approximately 16 km downstream of the mine site (Figure 7). The ISF will store water, mine waste rock, process tailings and sediment. The nature of the site dictated that the dam be a rockfill structure to ensure constructability in wet conditions and longevity considering the availability of local construction materials. As such, the ISF is being designed as a water dam rather than a conventional tailings dam and will be constructed to its final height at the time of first mine production.

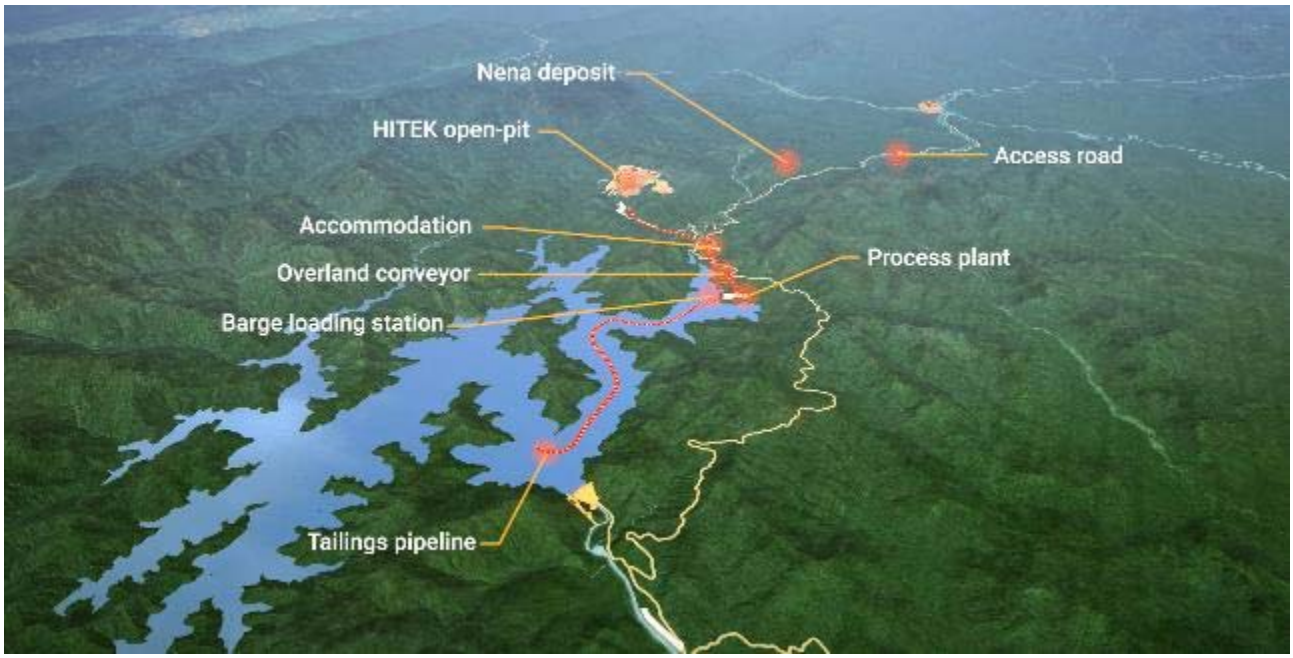

FIGURE 7 - Frieda River Project site layout showing facilities and ISF impoundment area (blue)

The embankment will be constructed from engineered rockfill with a vertical impermeable asphalt core. The ISF design incorporates a spillway and hydroelectric infrastructure including tunnels, turbines and electrical transmission infrastructure. The ISF will provide a total storage capacity of approximately 4,400 Mm^3.

DESIGN, ENGINEERING OPERATIONAL AND CLOSURE CONSIDERATIONS

Mine waste rock and tailings management at PanAust's operating and development sites considers a range of challenges during design, construction, operation and closure.

Climate

PanAust's waste rock and tailings facilities are located in tropical climates with substantial rainfall. Tropical weathering leads to variable geotechnical conditions that require extensive ground investigation, considered site selection and robust designs that account for the engineering properties of local materials.

The Lao operations are subject to a tropical monsoonal climate with distinct seasons from May to September (wet season) and October to April (dry season). The area receives approximately 2,400 mm of rain annually and monthly rainfall can exceed 1,000 mm during the wet season. Embankment raises and spillway construction typically occur during the dry season to maximise productivity and quality outcomes.

The Frieda River Project site is classified as wet tropical with average annual rainfall in excess of 7,600 mm. The rainfall pattern has very weak seasonality with almost daily rainfall. Seismicity and the high and frequent rainfall were major factors influencing the selection of an asphalt core rockfill dam as it is one of the few dam types that can be constructed under these conditions.

Topography

The Phu Kham, Ban Houayxai and Frieda River sites are characterised by mountainous terrain, forested hillsides and generally dense secondary growth vegetation. The topography varies between steeply sloping hills and narrow river valleys with limited flat areas.

Steep topography is favourable for cross-valley TSF/ISF embankment construction but also concentrates rainfall runoff. This requires the upstream diversion of water, through a purpose built channel at Phu Kham for example, or an ability to discharge surplus water from engineered emergency spillways when pump system capacity is exceeded. At Frieda River, the high rainfall runoff will be harnessed to generate hydroelectric power.

Waste rock dump siting and construction is challenging given the desire to locate these facilities adjacent to the open pit and a need to construct underdrains and use controlled “bottom up” construction lifts to provide PAF encapsulation and geotechnical stability.

Stability

For PanAust the consequences of large scale embankment failure are extreme given the potential impact on down river villages at the Frieda River ISF site and the proximity of local communities to the Phu Kham Operation. Designs for PanAust’s facilities therefore consider embankment stability under static and seismic conditions. An array of safety monitoring instrumentation, including vibrating wire piezometers, inclinometers and extensometers, are installed in waste rock dumps and TSFs.

The Phu Kham and Ban Houayxai TSFs are designed to ANCOLD standards based on a “High” dam failure consequence category (ANCOLD, 2012a). The Frieda River ISF is being designed to ANCOLD and ICOLD standards using an “Extreme” consequence category (ANCOLD, 2012a).

Closure

Closure performance is an important consideration in PanAust’s facility designs. Waste rock dump and TSF structures are designed to remain physically stable and non-polluting for perpetuity to meet closure objectives defined in the company’s Closure Standard. Progressive waste rock dump rehabilitation has commenced at both Lao operations in support of these closure objectives (Figure 8).

FIGURE 8 - Progressive rehabilitation of the Ban Houayxai waste rock dump

Acid Rock Drainage

PanAust’s approach to ARD management is considered leading practice across the global mining industry and has been documented as a case study in the Australian Government’s *Preventing Acid and Metalliferous Drainage: Leading Practice Sustainable Development Program for the Mining Industry* (Commonwealth of Australia, 2016).

PanAust actively manages the potential for ARD from the early stages of mine planning through to operations and closure. At both Phu Kham and Ban Houayxai, the management strategy to address the potential for ARD commenced well before mine operations with sulphur modelling undertaken as an integral component of orebody modelling and mine planning processes (Miller et al, 2012). The sulphur modelling facilitated detailed characterisation of rock types based on geochemistry test results and their acid forming potential which informed the development of an integrated ARD life of mine plan.

The ARD Management Plan provides strategies for the identification, control and monitoring of mine waste and is regularly updated with any relevant changes in sulphur modelling. Waste rock is classified using assay results from grade control drilling and, after classification, ARD rock type materials are marked up in the field and the boundaries incorporated into the fleet management system which tracks load movements and provides alerts in the event of placement at an incorrect destination.

Geochemistry testing for the Frieda River Project has indicated that the tailings and waste are likely to be net acid forming with exposure of the tailings or sulphidic waste rock to oxygen likely to cause mildly acidic conditions that could lead to elevated metal release.

The Phu Kham TSF provides subaerial and subaqueous storage for both tailings and waste rock in a manner that minimises exposure for oxidation and acid generation. On closure, a water cover with a minimum depth of one metre and an average depth of two metres will be maintained over the subaqueous tailings and waste rock with a NAF cap constructed over the subaerial tailings beaches. Waste rock above the water cover will be encapsulated.

The Ban Houayxai TSF provides subaerial and subaqueous storage for tailings only. Tailings have been categorised as NAF which allows a partial subaerial beach and pond arrangement on closure. Waste rock encapsulation has been demonstrated to limit the potential for ARD and provides a geochemically stable final landform.

Tailings and waste rock at the Frieda River ISF will be managed in a similar manner as the Phu Kham TSF but with subaqueous deposition only.

Water

The construction, operation and closure of waste rock dumps and TSFs in high rainfall environments presents several challenges. High rainfall requires the selection of suitable embankment types, for constructability, construction materials and, where possible, scheduling to avoid construction during wet periods. Wet cover and spillways are maintained at PanAust's TSFs which require careful planning and sequencing of embankment and spillway raises.

Operating freeboard levels comply with the recommendations of the ANCOLD (2012b) guidelines. At Phu Kham, the overall strategy for spillway construction is such that the spillway invert will need to be raised simultaneously with each main embankment raise in order to maintain TSF storage capacity that includes retention of the 1 in 250-year annual return interval (ARI) annual rainfall sequence plus the 1 in 100-year 72-hour storm event. The Frieda River ISF is being designed to store and release water from a probable maximum flood (PMF) event, equating to 30 000 m^3/s, through a concrete lined permanent spillway.

The positive water balance at PanAust's sites requires discharge of runoff, supernatant and seepage to local water bodies. Management of water chemistry and sediment loading is especially important to achieve ambient water quality standards and protect the aquatic ecology. Modelling is used to predict water quality including limnology modelling to inform the design of the Frieda River ISF given its depth and deposition methods. A range of operating and physical controls are implemented to meet discharge standards. Routine monitoring activities are performed to confirm compliance and trigger preventative actions.

Waste rock dumps at the Lao operations are designed and constructed to divert surface water to catchment areas and prevent water contact with PAF rock. The waste dumps are progressively rehabilitated where possible (Figure 8). Long term stable landforms will be prepared by contouring, ripping of compacted material, and drainage construction to minimise erosion and allow vegetation regrowth.

Construction

TSF embankments and spillways at PanAust's Lao operations are constructed in stages by the downstream method during the dry season. Placement of mined waste rock in the embankment at Phu Kham requires careful integration with the open pit mine plan and schedule to ensure that sufficient quantities of suitable rock are available primarily during the dry season. TSF embankment construction at Ban Houayxai occurs

on a campaign basis, which requires the mobilisation of a contractor fleet for rock quarrying and placement. TSF spillways are raised concurrently with embankment lifts and require significant civil construction activity.

ISF construction at Frieda River will occur continuously for several years until the embankment reaches its final height. Coffer dams and tunnels will be used to divert the Frieda River to provide a dry construction area for the main embankment and associated work zones. A deep cut-off will be installed prior to the construction of the asphalt core and rockfill embankment. The spillway, hydroelectric tunnels and power generation and transmission facilities will be constructed concurrently with the embankment.

Year round waste rock placement occurs at Phu Kham and Ban Houayxai. Dumps are developed in a bottom-up sequence with rock placed by mine haul trucks in 5 to 15 metre vertical lifts to create a terraced landform subject to ARD management plan requirements.

Deposition

Tailings are deposited at locations that are several kilometres from the process plant sites. Pipeline transport and deposition methods were selected to reduce transport and placement costs. Floating pipeline segments allow tailings deposition in distant reaches to maximise the use of storage volume in the facilities (Figure 4). Terrestrial pipelines and spigots allow tailings placement against the TSF embankments to reduce water seepage through the embankment zones.

Waste rock is placed using mine rigid body and articulated haul trucks at the Lao operations. The placement of PAF rock into the Phu Kham TSF requires careful control and sequencing with tailings deposition to maintain waste rock dump stability. Waste rock placement over tailings is avoided because loading of the saturated tailings is likely to lead to slumping and potential failure. Additionally, dozer push is used at tip heads to limit exposure to any slumping of the dump toe caused by saturated submerged rock.

The need for subaqueous PAF rock placement, large lateral transport distance and annual waste rock movement of up to 65 Mtpa led to the selection of a barge transport and deposition method for the Frieda River Project. Key drivers in the selection process were system volumetric capacity, sensitivity to material characteristics, capital and operating cost, sediment generation and suspension, and lateral placement capability. Waste rock will not be deposited over tailings and gentle underwater slopes will be maintained to prevent potential material sloughing from creating large water displacement. Tailings can be placed over waste rock. Solids placed into the ISF will be at an elevation that is well below the hydroelectric turbine intake.

Production Planning

The Phu Kham mine operates an integrated TSF whereby the profitable extraction of valuable metals relies on the successful placement and deposition of waste rock and tailings.

Production planning and materials placement uses the plan-execute-review-implement (PERI) process that underpins PanAust's Production Management System (PMS). The process ensures that TSF and waste rock dump concepts and plans are translated into engineered designs with clear specifications and timing requirements. Planning services are provided by the open pit mine planning section in consultation with the TSF engineering team and mine services group who perform the construction activities. The planning approach uses a top-down model that cascades life of mine strategic objectives, annual budget and build profile to more granular quarterly, monthly and weekly plans. Daily planning and review meetings consider waste rock dump development and TSF construction activities.

The Phu Kham operation has addressed numerous planning considerations and challenges.

- Ensuring open pit wall cutbacks, sequencing and mine production schedules are optimised to safely generate the necessary metal production and cash flow whilst simultaneously supplying sufficient NAF waste rock to construct the TSF embankment wall in line with annual tailings deposition and waste rock dump storage profile requirements. Production planning clearly defines, reconciles and reports the various waste classifications.
- Balancing mined material availability with TSF embankment construction. This will become more challenging as the open pit strip ratio reduces and hard NAF rock areas are depleted while conversely an increase in PAF waste rock occurs as the operation becomes ore bound. It has become critical to maximise waste rock delivery to the TSF embankment whilst there remains a plentiful supply of NAF material.

- The sequencing of multiple open pit wall cutbacks at different vertical horizons relative to the more distant downstream TSF construction build. Open pit production is haulage fleet constrained so the operation must carefully manage haul distances and maximise opportunities for short haul dumping of waste rock on the dump close to the open pit exit.
- Waste rock placed into the TSF embankment must meet the design fragmentation and grading specification. Waste rock blasting is closely managed to ensure the required fragmentation is achieved for the embankment build, especially as out of specification waste rock can lead to a shortfall of suitable construction materials. Blast designs aim to minimise oversize rock and achieve a sub 300 mm P80 for NAF construction material sourced from the open pit.
- Maximising embankment wall construction during the dry season in conjunction with progressive spillway lifts. During the monsoon season the TSF build is minimal and truck availability is plentiful providing an opportunity to haul PAF waste rock to the extremities of the dump.
- Delivering significant sand and pebble filter zone material quantities to meet annual build requirements. Significant plant and infrastructure has been deployed to mitigate potential TSF construction schedule risks whilst also delivering quality material for the equally important mine road base and concrete aggregate needs.

Skills and Capability

PanAust has progressively developed significant capability and skills in the construction and successful operation of TSFs and waste rock dumps. At the commencement of the Phu Kham operation there were limited human resources with mining skills in Laos and a heavy dependency on expatriate technical and supervisory resources. Construction of the Phu Kham TSF commenced before the larger mine fleet arrived which required local earthworks contractors to undertake the majority of the embankment builds using a relatively unskilled workforce.

Lao personnel have been very eager and successful in improving their mining and civil construction skills. The development of skilled personnel involved significant investment in training programs, setting high expectations, applying a disciplined approach and retaining knowledge within the organisation. The PERI process captures key learnings from each completed build so that corrective actions and improvements are implemented during the next construction season. Over time personnel have been trained so that they are skilled in all areas of TSF construction.

PanAust has established several important skills and capabilities within its Lao operations.

- A significant supervisory capacity comprising expatriate and Lao personnel supported by a site based TSF engineering team and an extensive in-house soil testing laboratory facility servicing the needs of both Phu Kham and Ban Houayxai operations with standardised processes and no duplication of resources.
- Survey teams providing construction support, bathymetrical and aerial drone survey for tailings and waste rock storage and efficiency assessment.
- The retention of the design consultant from Stage 1 construction in 2007 to the present has enabled a strong working relationship which supports construction and operational compliance and provides third party review.
- PanAust has persisted with the development of local contractor capability for various TSF civil construction activities that require smaller equipment. The partnership with local contractors, while challenging at times, has forged strong relationships and allowed the advancement of both the contracting organisations and their employee's capability.

Collectively, these actions have allowed high construction standards to be established and maintained across multiple construction stages.

Stakeholder

PanAust has developed strong and enduring relationships with community and government stakeholders. Whilst the Ban Houayxai operations has no immediate local communities, the Phu Kham operation is in close proximity to two villages that predated mine development. The purity of water and plentiful supply of healthy aquatic species is central to village life and Lao cultural heritage. Hence the government and local

population have a heightened awareness of, and sensitivity to, the environmental conditions and regulatory compliance of the Phu Kham TSF.

Construction and operation of the TSF in a sustainable manner has required a number of initiatives.

- Demonstrating a healthy aquatic environment. PanAust has implemented water health indicators that are visible to local stakeholders with fish "canary" cages installed at monitoring locations. The fish cages are additional to the extensive water sampling programs that occur upstream, downstream and within operating Facilities.
- Education and capacity building with respect to TSF. PanAust has continuously worked with the government to improve its capacity to understand and regulate the construction, operation and monitoring of TSFs. A particular focus has been to build the technical understanding that allowed the Phu Kham operation to move from a negative to positive water balance discharge facility. The company has supported the government to conduct independent reviews, forums and workshops that address matters such as corporate governance and controls, construction and operational practices, international good practice and standards. Annual reviews are performed by PanAust's Tailings Independent Review Panel (TIRP) which considers the interests of all stakeholders during operations through to closure.
- Community engagement. Strong relationships have been established from weekly TSF discharge inspections that are jointly conducted by PanAust representatives, local community leaders and government agency personnel.
- Environmental management closely linked to the community engagement processes to ensure a transparent means of communication, ensuring that any grievances are known and actioned appropriately.
- TSF discharge. Supernatant water discharge from the impoundments must satisfy Lao national environmental standards and site specific compliance requirements. Discharge is controlled under strict conditions and in consultation with the government.
- Adherence to the agreed process for compensation of impacted land. A compliance process verifies that local villagers do not undertake further agricultural activity on compensated lands within the TSF operational area. Disturbances caused by agriculture may pose safety risks, increase suspended solids in water run-off from deforested land caused by farming or increase the risk of local land slips around the periphery of the mountainous TSF facilities.

The reliance of downstream villages on the river system for their livelihood, and a history of riverine and marine disposal of mine waste rock and tailings in PNG, has raised community and regulatory interest in the proposed Frieda River ISF. Community consultation has provided an opportunity to illustrate the waste rock and tailings storage method, demonstrate PanAust's success in Laos and respond to concerns. The Project's feasibility study and environmental impact assessment will include extensive technical assessment and independent reviews that will be considered under PNG's mining and environmental permitting process.

GOVERNANCE FRAMEWORK

PanAust recognises the Material Risk and associated responsibility for managing mine waste rock and TSFs. Accordingly, the company has established a comprehensive governance framework that encompasses organisational resourcing, systems and processes to support its sustainable business model. Figure 9 provides a representation of PanAust's mine waste and tailings governance framework.

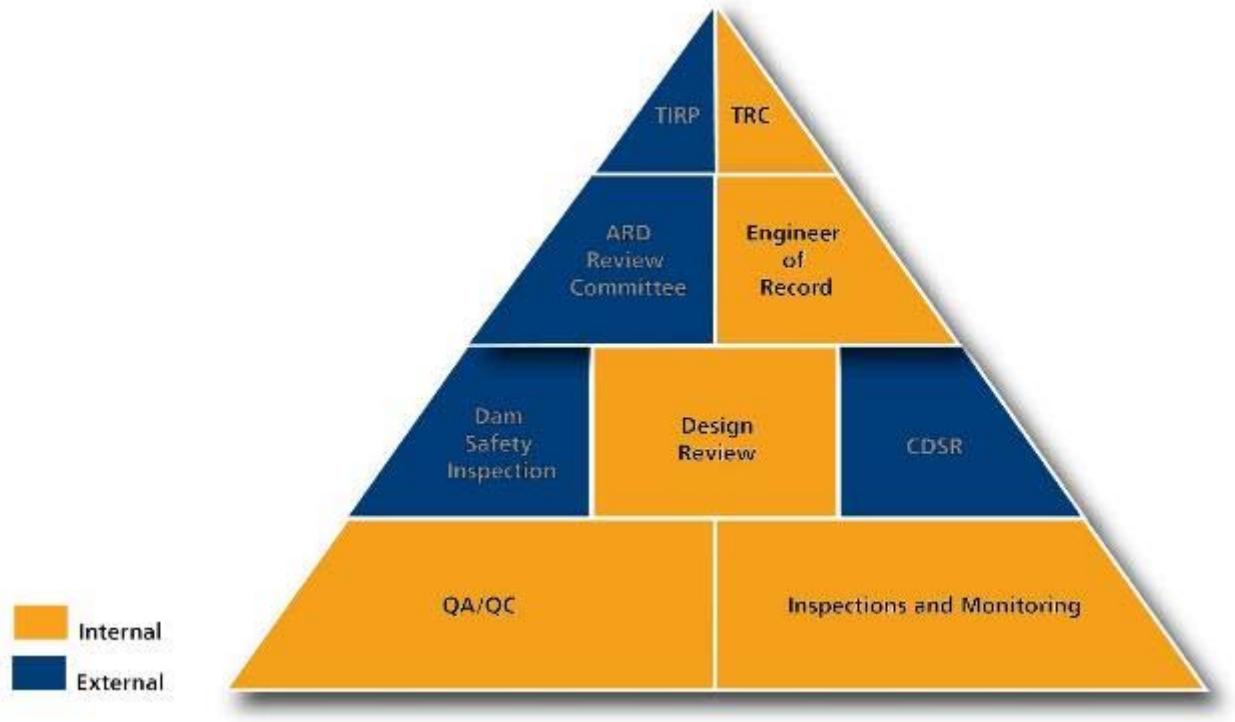

FIGURE 9 – Waste rock and tailings governance framework

Tailings Review Committee

PanAust's Managing Director has instituted a Tailings Review Committee (TRC) whose membership includes the Managing Director, internal experts on tailings engineering and risk management, and executives with organisational accountability for facility planning, design, construction and operation.

The objectives of the TRC are to:

- inform the Managing Director of Material Risks associated with the Facilities and the appropriateness and effectiveness of action plans intended to mitigate the identified risks
- oversee the implementation of actions related to Material Risk management and continuous improvement in relation to facility management
- ensure that the Tailings Independent Review Panel (TIRP) completes annual reviews of the design, construction, operation and closure of PanAust's Facilities
- provide executive management support and associated resources for identified actions arising from TIRP reviews
- evaluate the plans proposed by operational management to act on matters arising from the TIRP reviews to ensure that they are appropriate, practical and make efficient use of resources and funds
- update the relevant risk registers for each business unit annually.

The TRC performs an important stewardship function, enables executive accountability and demonstrates commitment to the responsible management of PanAust's Facilities.

Engineer of Record

PanAust has appointed an Engineer of Record (EOR) as the approver of all designs, as-built construction, operations and performance monitoring of the company's Facilities. The EOR is an individual who may be a PanAust employee, an employee of a consulting organisation or an individual consultant that meets requirements of the EOR. A consulting company may be the contracting organisation to provide an EOR but the EOR is a named individual who will satisfy the requirements of the EOR. PanAust's Principal Tailings Engineer currently acts as the EOR for the company's Facilities.

Tailings Independent Review Panel (TIRP)

The TIRP is an important element of PanAust's governance program. The TIRP comprises three eminent experts in the disciplines of tailings, geotechnical and water who collectively provide independent review and advice on Material Risks that may arise during the design, construction, operations and closure of the company's Facilities. The TIRP's membership is expanded, as needed, to draw on specialist expertise in disciplines such as hydropower generation.

The TIRP members must not have any conflict of interest issues with their commission. Specifically, they must not be involved in any other work for PanAust's operations that would require review by the TIRP as part of the commission. TIRP members must also be independent from the day to day operations and design activities.

The TIRP conduct annual facility inspections and provide independent confirmation to the Managing Director that all aspects of the company's Facilities are being managed appropriately. Recommendations arising from the TRIP's reports are transferred to action plans that are monitored by the TRC. Responsibility for acceptance and implementation of the TIRP's advice and recommendations remains with PanAust and its nominated design consultants and construction contractors.

ARD Review Committee

High level governance of ARD management is provided through PanAust's ARD Review Committee which comprises internal management and specialist external consultants. The Committee verifies that management strategies are effective in limiting the potential for generation of ARD during construction and waste placement and that these strategies will continue to be effective following mine closure. Functions of the Committee include to:

- provide technical support to evaluate risks operation of TSFs using the PanAust Enterprise Risk Management criteria
- highlight any new risk issues identified during the review period and ensure the risks are appropriately captured on the site risk register
- provide guidance on procedures that ensure ARD management and closure planning will be in conformance with current international good practice and standards, legal requirements and operating licenses
- review the geochemical aspects of the tailings, waste rock and construction materials, particularly with respect to ARD and metals leaching potential
- provide input on design, construction, operational and closure activities that may have long-term stability or other critical performance implications on ARD management
- review health, safety, environmental and social risks associated with ARD management and ensure they are appropriately addressed in accordance with design, construction, operation and closure plans.

Consultant reviews of ARD management at Phu Kham and Ban Houayxai are performed routinely. These reviews confirm that the programs are highly developed and effective. The programs are consistent with methods described in the Global Acid Rock Drainage Guide (INAP, 2014).

Assurance Activities

Multiple assurance activities are used to verify the performance of PanAust's Facilities throughout their life cycle.

Design Review

Facility designs are subject to a stage gated review and approval process. Designs are typically peer reviewed by a group of internal specialists and/or external independent experts to confirm that the design can be released to the next, more detailed, stage of work.

Quality Control and Assurance

Site laboratories perform material testing for quality control and quality assurance of construction materials. The site laboratories are audited every two years by an independent auditor. Independent testing activities are undertaken at an accredited external laboratory for validation of quality control activities.

Routine Inspection and Monitoring

Daily, weekly and monthly inspections and monitoring is performed by trained PanAust employees reporting to the site based Tailings Superintendent. Monitoring of dam seepage and embankment deformation is undertaken along with inspections and audit programs to ensure that monitoring equipment is operational and functioning correctly. The EOR reviews the inspection and monitoring reports on a monthly basis.

Quarterly TSF dam inspections are performed by PanAust's corporate Principal Tailings Engineer and/or Senior Tailings Engineer.

Monitoring and control of the Phu Kham water discharge occurs using a settling pond that forms part of the discharge infrastructure and strict controls accompanied by live fish cage monitoring, fish tissue analysis and biodiversity surveys.

Water quality from the waste rock dumps is monitored to ensure that any acidic and/or metalliferous drainage is controlled and managed. Instrument probes are installed to measure the ingress of oxygen into the Ban Houayxai waste rock dump with test pits used for monitoring at Phu Kham.

Dam Safety Inspections

PanAust engages competent and experienced consulting organisations to perform the role of Design Engineer. The appointed Design Engineer has responsibility for preparing engineered designs, as directed by company representatives, for approval by the EOR. An annual audit of each facility is conducted and documented by an independent expert engineer.

Comprehensive Dam Safety Reviews

Comprehensive dam safety reviews (CDSRs) were recently initiated following a recommendation arising from an internal "Deep Dive" audit of tailings dam management in late 2015. These reviews will be performed at five-yearly intervals and other critical project milestones. The first review was completed in early 2018.

The CDSRs are performed in conjunction with comprehensive inspections of the Lao TSFs. The reviews are undertaken by a "suitably qualified and experienced person in relation to high risk tailings dams", in accordance with the ANCOLD Guidelines. The review is undertaken, as a minimum, based on the key ANCOLD guidelines:

- Guidelines on Dam Safety Management (ANCOLD, 2003)
- Guidelines on the Consequence Categories for Dams (ANCOLD, 2012a)
- Guidelines on Tailings Dams, Planning, Design, Construction, Operation and Closure (ANCOLD, 2012b).

The CDSR process provides a valuable assessment of the design, construction and operations performance of these Facilities with an emphasis on identifying Material Risk factors.

PANAUST ROLES AND RESPONSIBILITIES

Corporate

PanAust employs a Principal Tailings Engineer and Senior Tailings Engineer who are both based in the Brisbane corporate office. These individuals have extensive experience in the design, construction and operation of TSFs.

The Principal Tailings Engineer is the discipline leader and subject matter expert for all company owned and operated Facilities. Supported by the Senior Tailings Engineer, the role evaluates and recommends design and construction outcomes from the Design Engineer while ensuring alignment to overall business requirements, risk profile and leading practice management of the Facilities. These corporate roles define the strategy, framework and design outcomes for site activities.

Site

PanAust employs experienced site based personnel with responsibility for both Phu Kham and Ban Houayxai TSFs. These roles include TSF Superintendent, Senior Tailings Engineer, geotechnical engineers, materials testing technicians and construction supervisors.

The TSF Superintendent leads a team with responsibility for the implementation of, and compliance with, designs approved by the EOR. The role encompasses construction oversight, quality assurance and control activities, tailings and water management, and monitoring activities (dam safety and environmental). The TSF Superintendent also manages detailed design work to ensure field adjustments are incorporated into the final design and the Issued for Construction (IFC) drawings are fit for purpose.

Embankment and spillway construction is performed by contractors under the direct supervision of PanAust personnel. The Phu Kham Mining Department coordinates embankment construction and is responsible for rockfill placement in the embankment's downstream structural zone and production of engineered sand and aggregate material. Spillway construction at both Lao operations is performed by the site Infrastructure and Road Maintenance Department.

STEWARDSHIP OUTCOMES

PanAust's stewardship process has been effective in identifying potential shortcomings in management systems and has led to enhanced executive commitment to risk informed designs, assurance and overall process rigour. The following examples illustrate outcomes achieved from the stewardship process.

- Independent expert review. The April 2016 TIRP review was conducted immediately prior to the annual monsoon season and highlighted slippage against the just-in-time Phu Kham TSF embankment construction schedule and insufficient resources to complete the Ban Houayxai weir raise. The review occurred when a large annual embankment build was required concurrent with a significant open pit expansion that placed competing demands on the organisation's resources. The review findings provided a turning point in how the company addressed such a critical activity.
    - Personnel capacity and continuity: the TIRP review findings provided the impetus to mobilise additional technical specialists for continuous, senior level engineering coverage, bolster organisational construction capacity, and share personnel between the Phu Kham and Ban Houayxai sites.
    - Physical resources: significant initiatives were undertaken to improve the crushing and concrete batch plant reliability, availability and productivity. This has proven to be even more profound in 2018 when a significant ramp-up in capacity was required to meet concurrent weir and spillway concrete demands.
    - Process: lessons learned from the 2015/16 TSF build seasons provided a number of improvement opportunities and led to more stringent project management controls and the allocation of more resources. The benefits of these actions were realised in the early completion of the 2017 embankment construction at Phu Kham and timely completion of spillway and embankment raises at both Lao sites in 2018.
- Executive commitment. The TRC provides a forum to prioritise corrective and improvement actions arising from the annual TIRP and periodic internal company reviews, assign appropriate resources from different business units and monitor progress. Action completion is monitored by the TRC such that actions are typically completed within 12 months of each TIRP review. The TRC has also established a heightened organisational awareness of the criticality of TSFs at the most senior levels of the PanAust organisation.
- Internal verification. A Deep Dive audit in late 2015 was performed by a PanAust team to validate and verify facility performance at Phu Kham and Ban Houayxai. The Deep Dive identified several opportunities for improvement including the commissioning of the CDSR.
- In-house expertise. PanAust has recognised the necessity of directly employing personnel who have specific skill and knowledge of TSF design and construction, especially given the major risk exposure that these facilities represent. The company has developed and sustained significant expertise at senior engineering levels complimented by a highly capable construction management team. The expense of employing specialist personnel has been more than justified by the quality of facility design and engineering, high construction standards, and schedule efficiencies that delivered significant cost savings and de-risked build programs.

- Staged design review. The Frieda River ISF design is subject to staged design reviews by the TIRP. The review process is used to identify potential issues and provide recommendations prior to the design advancing to more detailed engineering. The process allows time for investigation, data collection and analysis prior to final design decisions. Consequently, the design process has become more efficient, with less rework, and advances in a more cost effective and timely manner.
- TIRP and TRC composition. The TIRP and TRC comprise a core membership that provides retained knowledge and continuity. Both groups are typically supplemented from time to time with specialists who provide additional expertise. This approach has been valuable in the design of the Frieda River Project's ISF through the contribution of specialists in hydroelectric dam engineering and geotechnical engineering.
- Accountability, responsibility and competency. PanAust has documented the roles, responsibilities and competencies required of its personnel and its design consultants. A RACI matrix defines whether each role is Responsible, Accountable, Consulted or Informed on decisions relating to PanAust's Phu Kham and Ban Houayxai Facilities. This approach has clarified the functions of internal and external contributors who work across multiple jurisdictions and timeframes.
- Risk registers. Risk assessment has provided a valuable tool for knowledge retention and proactive management action. Risk registers are regularly reviewed and updated to assess changed conditions and capture the outcomes of lessons learnt reviews. Furthermore, the risk controls allow more informed and rational debate about annual budget expenditure and the implementation of additional measures.
- Stakeholder assurance. The stewardship program inclusive of the TIRP provides a transparent and formal platform that is accessible to community, government and external parties. For example, Lao government representatives accepted the opportunity to receive feedback from, and engage with, the panel of independent industry experts following the 2018 TIRP review. PanAust's International Finance Corporation (IFC) safety and sustainability auditor, ARD Review Committee and insurance risk engineer draw upon the findings and acknowledge the company's proactive approach under the stewardship program. This process has contributed to improved IFC audit scores and reduced insurance premiums.

CONCLUSIONS

PanAust has developed considerable experience in the design, construction and operation of TSFs in challenging environments. Technical challenges have been effectively addressed with solutions that represent leading practice. The knowledge gained from this experience is being transferred to new projects such as the Frieda River Project in PNG.

A recognition of the criticality of managing the substantial business risks associated with these crucial activities led to the establishment of a governance structure that provides independent reviews and assurance that the highest standards are embraced for planning and execution. The TRC, EOR, TIRP and ARD Committee, supported by a range of assurance activities and strong organisational capability, demonstrate PanAust's commitment to governance and stewardship practices for the effective management of mine waste and tailings. Ultimately, this approach provides PanAust's Managing Director with confidence that these facilities are being managed appropriately.

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