CASINO PROJECT: INTERACTIVE DESIGN OF A LARGE TAILINGS DAM TO ACHIEVE MINE WASTE MANAGEMENT OBJECTIVES

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ABSTRACT:

The Casino Project is a proposed copper-gold-molybdenum mine in the southwest Yukon. The deposit will be mined using open pit methods with a nominal mill throughput of approximately 125,000 tonnes per day of ore over a 22 year operating life. The climate at the project site is characterised by long, cold, dry winters and short, warm, wet summers. Permafrost is discontinuous over the Tailings Management Facility embankment area.

A waste and water management plan has been developed that considers geotechnical and geochemical characteristics of the various waste materials produced over the operating life of the mine. Waste rock and tailings will be selectively placed to provide subaqueous disposal of potentially acid generating materials, mitigate metal leaching potential and ensure long-term water quality and geotechnical performance objectives are achieved. The waste management strategy and dam design are being optimised during successive design stages as a better understanding of the geotechnical conditions and geochemical characteristics of the waste materials is obtained. The mine waste materials will be placed in a valley impoundment and constrained by a zoned embankment dam. The embankment will be constructed in stages using the centreline method, reaching a maximum height of over 280 metres at the end of mining operations. Mine tailings will be de-pyritized and cycloned to provide suitable sand fill for construction of the embankment shell zones. Design considerations include integration of the mine production schedule with construction of the Tailings Management Facility embankment and placement of waste rock, the impact of the cold climate on dam construction and facility operations, the impact of discontinuous permafrost foundation conditions on dam stability and integrity, and the effect of high confining stresses on the strength and permeability characteristics of the embankment construction materials.

RÉSUMÉ :

Le projet Casino est une mine de cuivre, d’or et de molybdène dont l’exploitation est planifiée dans le Sud-Ouest du Yukon. L’exploitation se fera à ciel ouvert et la production sera de 125 000 tonnes de minerai par jour durant sa durée de vie anticipée de 22 ans. Le climat sur le site est caractérisé par de longs hivers froids et secs ainsi que de courts étés chauds et humides. Du pergélisol discontinu se retrouve sous la zone de remblai du parc à résidus miniers.

Un plan de gestion des stériles miniers et de l’eau a été élaboré et il tient compte des caractéristiques géotechniques et géochimiques des divers résidus produits durant le cycle de vie de la mine. Il est proposé d’entreposer par confinement subaquatique les stériles et les résidus miniers afin de prévenir les risques de lixiviation des métaux et de drainage acide ainsi que d’assurer l’atteinte des objectifs à long terme de qualité de l’eau et de performance géotechnique. La stratégie de gestion des déchets miniers et la conception de la digue seront optimisées au cours des phases successives de conception au fur et à mesure que les caractéristiques géotechniques et géochimiques des stériles seront recueillies. Les stériles et les résidus miniers seront confinés dans une vallée par un barrage zoné. La digue sera construite par étapes selon la méthode du centre-ligne et elle atteindra une hauteur maximale de 280 m à la fin des opérations. Les stériles seront dépyritisés et lavés par cyclone afin que le sable puisse servir à la construction du noyau de la digue. Les considérations de conception incluent l’intégration de l’échéancier de production de la mine avec la construction du remblai du parc à résidus et la mise en place des résidus; l’impact du climat froid sur la construction de la digue et de l’exploitation du site; l’impact des fondations en pergélisol discontinu sur la stabilité et l’étanchéité de la digue; les effets des contraintes de confinement élevées sur les caractéristiques de résistance et de perméabilité des matériaux de construction du remblai.

INTRODUCTION

The Casino Project is a venture by Casino Mining Corporation (CMC) to develop a copper-gold-molybdenum mine in the Yukon Territory, Canada. The project is located in the Dawson Range Mountains of the Klondike Plateau approximately 300 km northwest of Whitehorse, as shown on Figure 1.

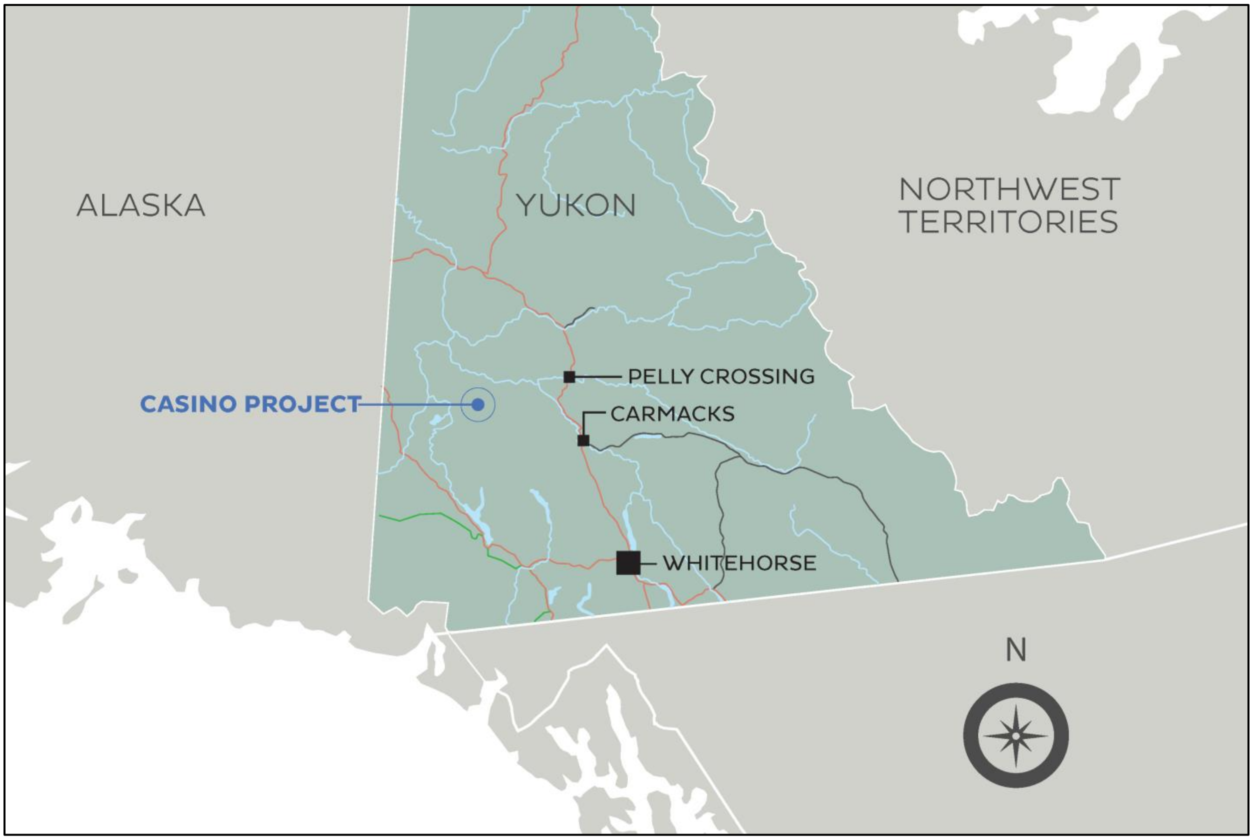

Figure 1: Project Location

The deposit will be mined using open pit methods with a nominal mill throughput of approximately 125,000 tonnes per day over a 22 year operating life, resulting in approximately 965 million tonnes of milled ore. Additional mined ore will be processed at a Heap Leach Facility located uphill of the proposed Tailings Management Facility (TMF). A general layout of the project site is presented on Figure 2.

A waste and water management plan has been developed that considers the geotechnical and geochemical characteristics of the various waste materials produced over the operating life of the mine. The slurry tailings resulting from the milling process and reactive waste rock will be placed in an impoundment located in Casino Creek valley and constrained by the Main Embankment and West Saddle Embankment. Waste materials will be selectively placed in the impoundment to provide subaqueous disposal of potentially acid generating materials, mitigate metal leaching potential and ensure long-term water quality and geotechnical performance objectives are achieved. Any non-reactive waste rock and overburden materials produced from mining activities can be used in embankment construction.

The embankments will be constructed as water-retaining zoned structures with a low permeability core zone. The Main Embankment will be developed in stages using the centreline method, reaching a maximum height of over 280 metres at the end of mining operations. The West Saddle Embankment will be constructed at the southwestern corner of the TMF. This embankment will be built prior to the start of operations to provide a pipeline corridor for tailings delivery to the TMF.

Ongoing site investigations and mine waste characterisation studies have improved the understanding of the dam foundation conditions and the geotechnical and geochemical characteristics of mine waste materials and potential construction materials. The waste and water management strategy and tailings dam design have been optimised during successive design stages as a better understanding of the waste characteristics and site conditions was obtained. The development of the TMF design and resulting key embankment dam design considerations are discussed in this paper.

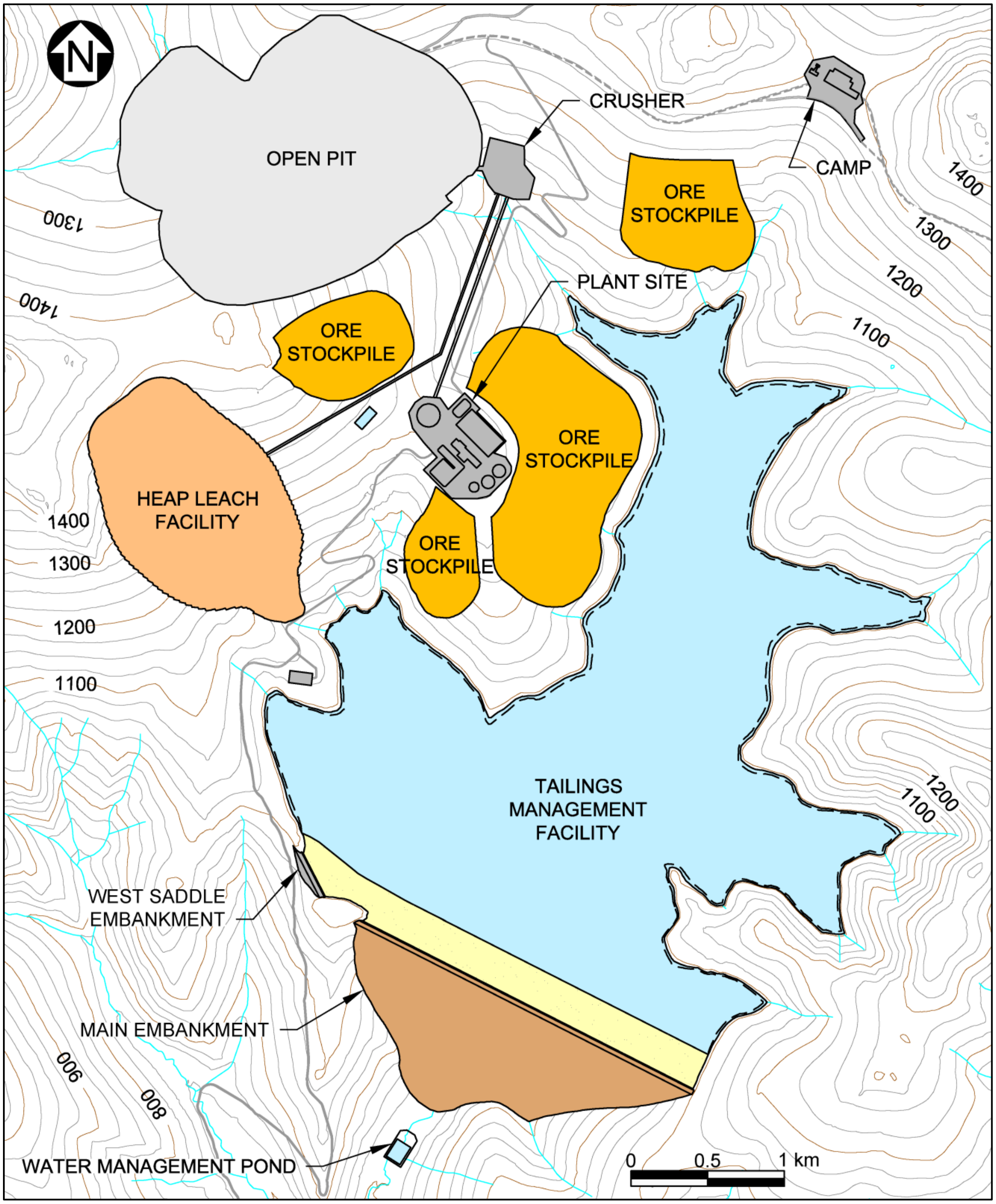

Figure 2: General Arrangement

SITE CONDITIONS

The characteristic terrain features at the project site are smooth, rolling topography, with moderate to deeply incised valleys.

The climate is characterised by long, cold, dry winters and short, warm, wet summers, with conditions varying according to altitude and aspect. Permafrost is discontinuous over the TMF embankment area, and is primarily present at the valley bottom, north-facing slopes and shaded areas. Permafrost is characterised by thin ice lenses in fine grained colluvium, interstitial ice crystals in residual soils, and small ice wedges in broken rock.

The tailings basin area is sited within Casino Creek valley. The valley bottom has impeded drainage and prominent permafrost features such as palsas and hummocky tussock fields. Casino Creek drains in a south-westerly direction to Dip Creek, eventually discharging into the White River, which is a tributary of the Yukon River.

The overburden generally comprises in situ weathered residual gravelly sands and well graded colluvial veneer along valley ridges and upper slopes. The lower slopes and valley bottom are characterised by fine grained organic colluvial apron with coarse alluvium near Casino Creek. No glacial till is present in the project area as the region was not glaciated during the Wisconsin Advance.

Bedrock primarily comprises intrusive rock from the Dawson Range Batholith (Mid-Cretaceous), and is dominantly granodiorite in composition with less abundant quartz monzonite and diorite. Gneiss, quartzite and metadiorite from the Yukon Metamorphic Group are present locally. This older suite of rock was intruded by the Dawson Range Batholith. The depth to bedrock varies from typically 2 metres along ridges and valley slopes up to 23 metres in the Casino Creek valley bottom.

The site is situated in a region of low historical seismicity and moderate seismic hazard. The seismic hazard for the project site is predominantly from shallow crustal earthquakes in the region of the southern Yukon, but it is also influenced by the potential for larger magnitude earthquakes occurring farther from the site in the seismically active region of southeast Alaska.

DEVELOPMENT OF MINE WASTE MANAGEMENT STRATEGY

Pre-Feasibility Design Studies

An initial Pre-Feasibility study was completed for the Casino project in 2008, resulting in the project layout shown on Figure 3. The majority of the tailings were assumed to be potentially reactive, requiring subaqueous disposal to maintain the tailings deposit in a saturated state, inhibiting oxidation and potential reactivity. Approximately two-third of the waste rock was also considered to be potentially reactive, requiring co-disposal with the tailings and submergence by the tailings and supernatant pond to satisfy long term water quality objectives.

The remaining one-third of the waste rock was assessed to be geochemically innocuous and suitable for use in embankment construction. The non-reactive rock fill from the open pit was selected as a cost-effective source of construction material for the TMF embankments. The Main Embankment would be developed in stages as a centreline dam with a low permeability core zone and adjacent filter zones. The embankment shell zones would be constructed with random fill comprising non-reactive waste rock and overburden from open pit stripping operations at a 2H:1V downstream slope.

The production schedule indicated that more non-reactive waste rock would be produced than required for the staged development of the TMF embankments. Any remaining non-reactive waste rock would be stored on surface within a designated area south of the open pit.

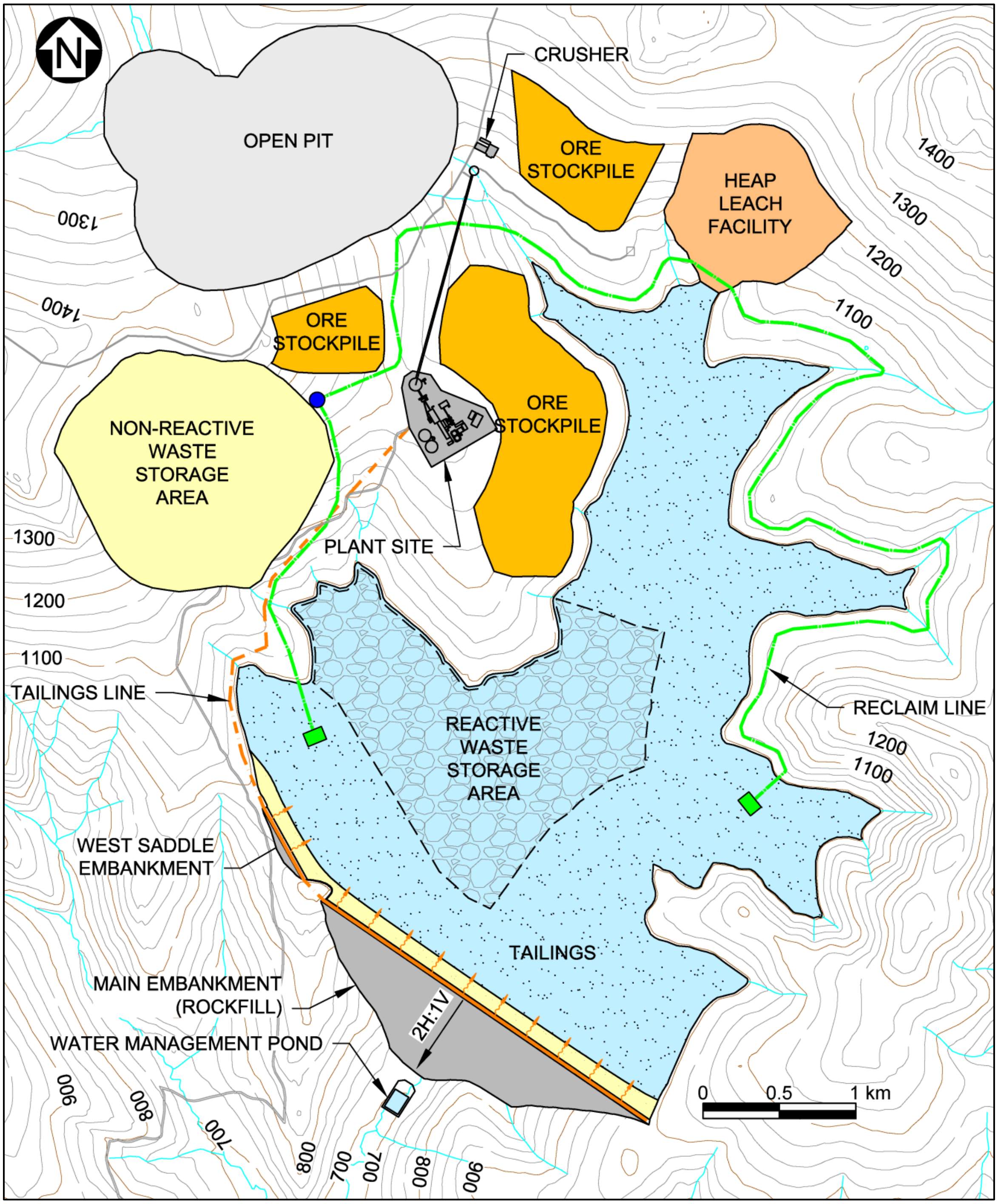

Figure 3: General Arrangement for Initial Pre-Feasibility Study

Subsequent geochemical characterisation studies indicated that all of the mine waste material may be potentially acid generating (PAG) or metal leaching (ML), and therefore not suitable for embankment construction. Consequently, a revised Pre-Feasibility study was carried out in 2011 to evaluate alternative embankment construction options. Embankment construction using cyclone sand in the shell zone was determined to be the most efficient and cost effective design concept. The downstream slope was flattened to 3H:1V to facilitate cyclone sand cell placement and to satisfy embankment stability requirements under static and seismic loading conditions. The revised layout of the project site is presented on Figure 4.

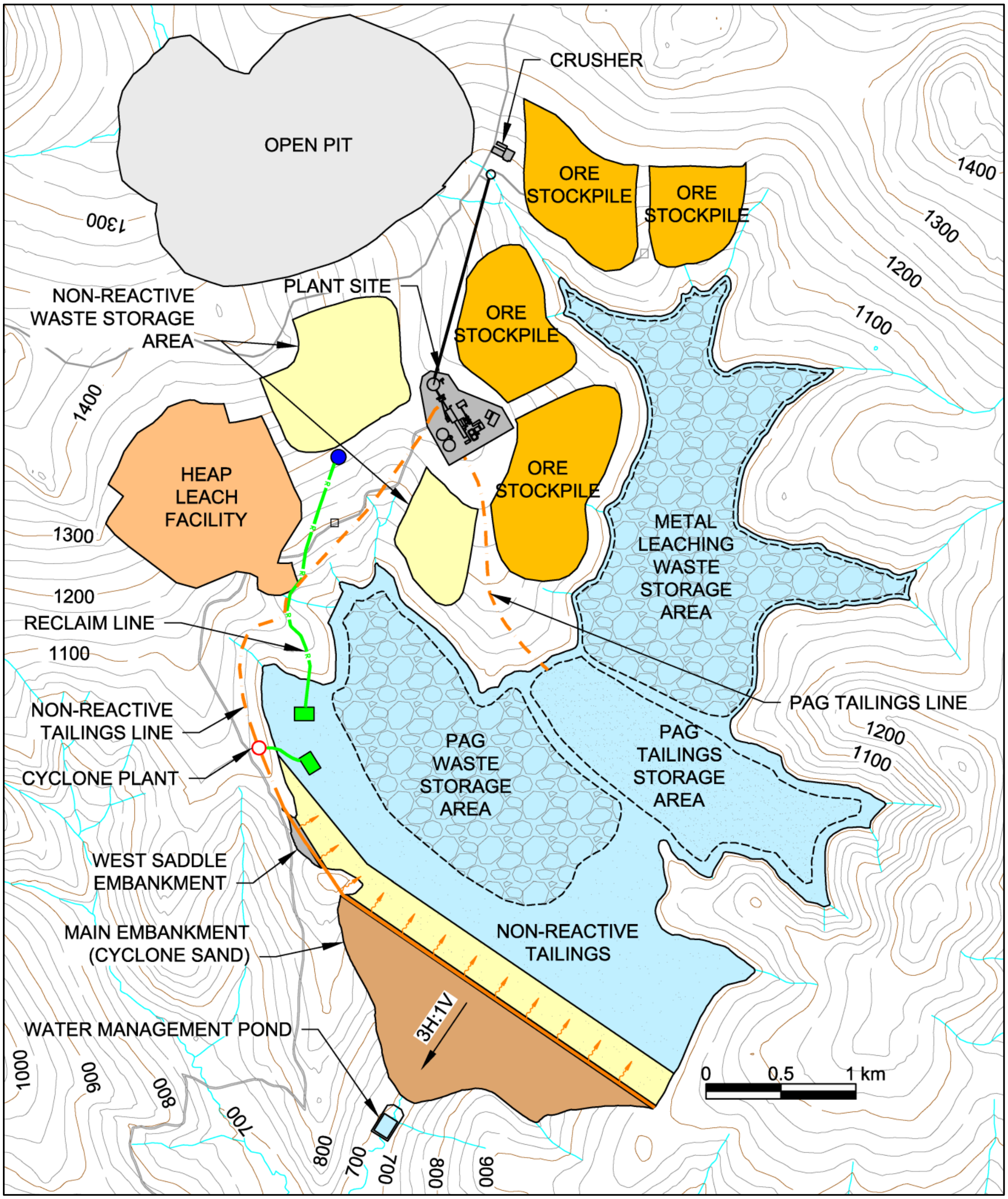

Figure 4: General Arrangement for Revised Pre-Feasibility Study

The use of cyclone sand fill material requires removal of the pyrite content from the bulk tailings to create a non-reactive tailings stream that is suitable for use in embankment construction. These non-reactive tailings (approximately 80% by mass) will then be passed through a cyclone station to produce suitable sand fill material. A smaller PAG stream (approximately 20%) requires complete subaqueous disposal in the TMF. Fine tailings (overflow) produced from the cycloning operation will also report to the TMF for disposal. Bulk non-reactive tailings will be discharged into the TMF when cycloning operations are suspended and when freezing climatic conditions preclude sand fill placement.

Cyclone sand production will likely not provide sufficient material to satisfy the complete demand for fill in the embankment shell zones over the entire operating life of the Main Embankment. Rockfill from open pit stripping (if available and geochemically innocuous) and suitable fill material from local borrow sources or quarries will be required to make up any shortfall of embankment fill material.

Potentially reactive waste rock and overburden would be hauled to the TMF for co-disposal with tailings and submergence by the tailings and supernatant pond. It was anticipated that the ML fraction of the reactive waste rock would be stored in a separate area to the PAG waste rock. The ML waste storage area was scheduled to be developed in the northern section of the TMF. The PAG waste rock and reactive tailings would be placed in the central region to minimise exposure time before submergence and saturation by the supernatant pond (thereby inhibiting oxidation and potential reactivity).

Feasibility Design Studies

A Feasibility Study was conducted in 2012 based on an updated production schedule, and incorporating the findings of additional geotechnical site investigations, laboratory testing and geochemical characterisation studies.

Site investigations revealed the presence of ice-rich overburden at the proposed location of the Main Embankment. These soils are unsuitable for the dam foundation and will be excavated before embankment construction. The alignment of the Main Embankment was revised from previous studies to minimise the volume of unsuitable material requiring excavation in the embankment footprint, while maintaining TMF storage requirements. The new alignment also reduced the size of the Starter Embankment, and reduced predicted seepage flows from the TMF. The general arrangement developed for the Feasibility Study is presented on Figure 5.

Preliminary design studies for the cyclone sand operation estimated that approximately 50% of the non-reactive tailings stream can be recovered as suitable low fines sand material when the cyclone station is operating.

Proposed revisions to the placement of mine waste materials in the TMF included development of the PAG tailings deposit in a separate central region of the TMF by discharging the tailings from the north-western side of the TMF, close to the Waste Storage Area. Deposition in this area will keep the PAG tailings between the Waste Storage Area and the non-reactive tailings. This will minimise seepage from the PAG tailings and ensure that they remain in a subaqueous state.

Potentially reactive waste rock will be hauled to a Waste Storage Area in the northern section of the TMF, upstream of the PAG tailings deposit. This placement strategy results in longer seepage flow paths and smaller predicted seepage rates from the potentially reactive waste rock, which benefits water quality downstream of the TMF. Geochemical and water quality studies have indicated that selective placement of the waste rock and tailings materials enhances beneficial flow-path reactions and minimises potential flushing of leachable waste rock materials.

Studies to determine the geotechnical and geochemical characteristics of mine waste rock, tailings, and potential construction materials are ongoing. The waste management strategy will continue to be refined in future design studies as the characterisation of the mine waste and construction materials is enhanced.

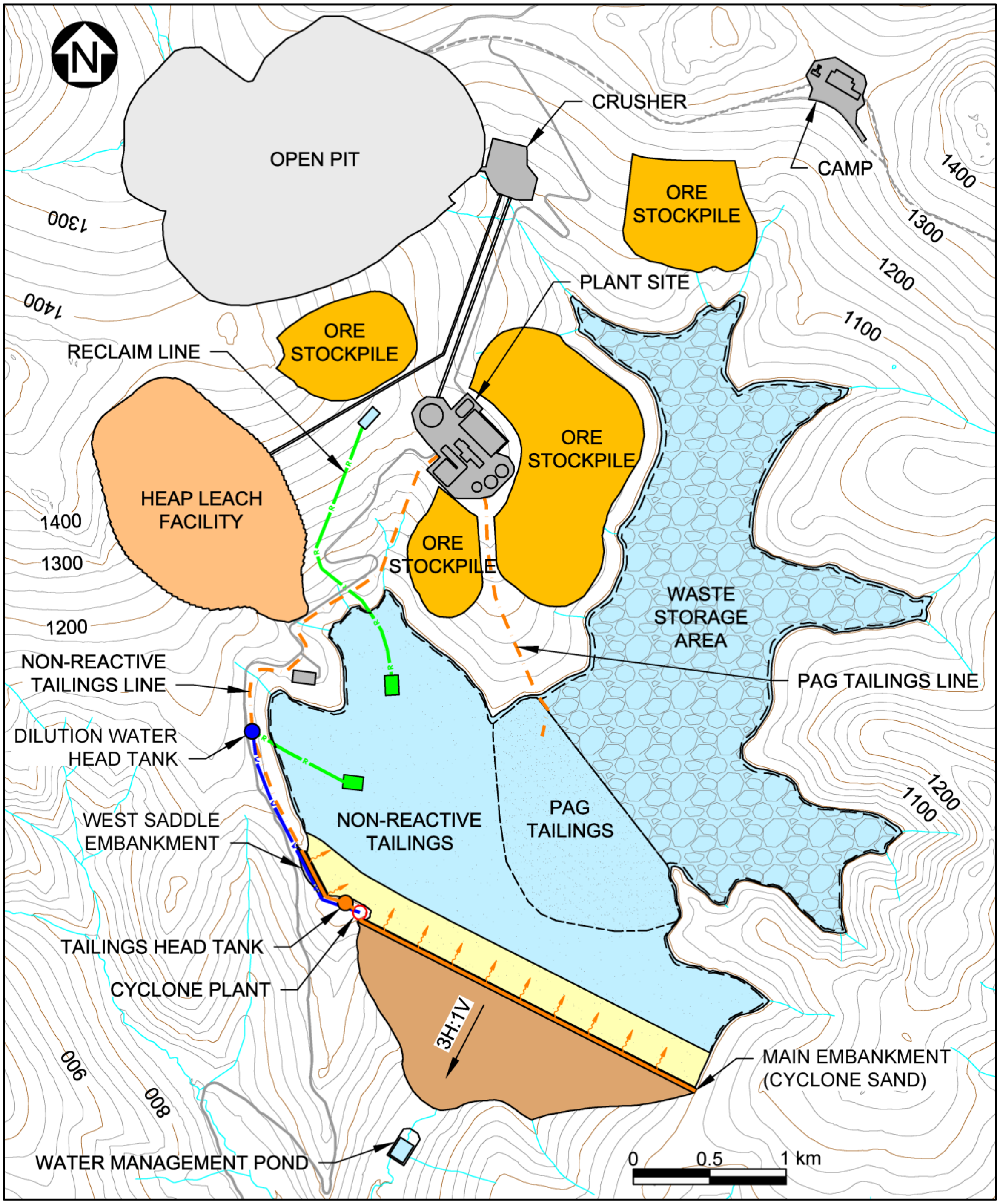

Figure 5: General Arrangement for Feasibility Study

MAIN EMBANKMENT DESIGN

The Main Embankment will be developed in stages as the storage requirements for mine waste materials increase throughout the life of the mine. The embankment will be a water-retaining zoned structure with a low permeability core zone. Appropriate filter and transition zones will be constructed from the core zone to the coarse shell zone materials and adjacent tailings deposit to prevent downstream migration of fines and to limit differential settlements. The core zone will include a seepage cut-off keyed into competent rock in the foundation. Seepage losses from the TMF are reduced further by an upstream low permeability blanket beneath the Starter Embankment. An under-drain system below the downstream shell of the embankment will collect seepage water and promotes drainage of the rockfill and cyclone sand shell zones. Seepage water from the TMF will be collected in a water management pond located downstream of the Main Embankment and pumped back into the TMF during operations.

The Starter Embankment will provide capacity to store runoff as a source for mill start-up water and accommodate initial tailings and potentially reactive waste rock production for approximately one year of operations. Ongoing expansion will comprise centreline dam raises. The development of a sufficient tailings beach area will be required between the supernatant pond and the embankment to provide a stable upstream construction surface for the centreline embankment raises, minimise seepage and ensure dam stability. The final Main Embankment will be over 280 metres high at the deepest section of Casino Creek valley. A typical section illustrating the staging of the embankment is shown on Figure 6.

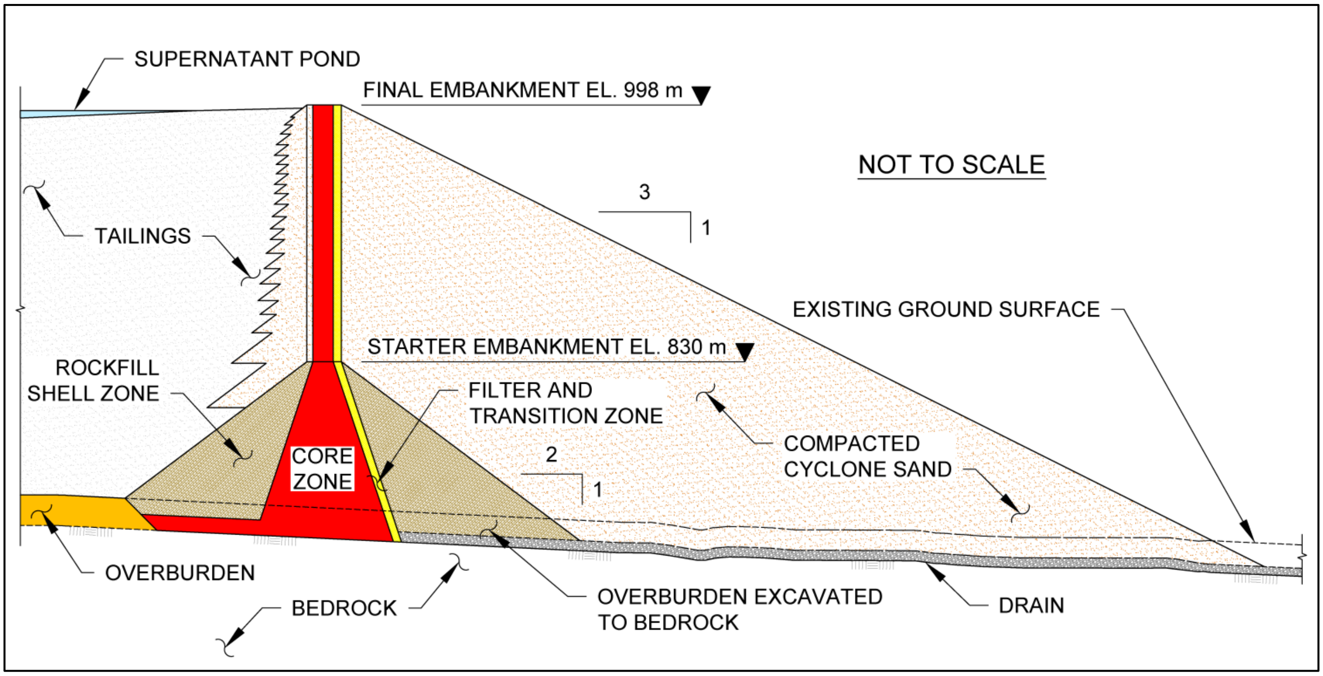

Figure 6: Typical Main Embankment Cross-Section

The consequence classification assigned to the proposed dam is HIGH, based on the CDA Dam Safety Guidelines (2007). The dam classification included assessment of the potential environmental consequences of dam failure using the methodology presented by Eagen and Greenaway (2010, 2011), which considers the potential impact to fish species and habitat present in downstream watercourses. An appropriate Inflow Design Flood event was selected based on the HIGH classification. A spillway will be provided at closure to facilitate control and discharge of excess water accumulation within the TMF and to provide long term protection against overtopping of the dam. The Probable Maximum Flood event has been adopted for design of the closure spillway. The stability of the dam during seismic loading was assessed using the 1 in 2,500 year return period earthquake. Seismic loading for the 1 in 10,000 year earthquake was also considered to demonstrate the robustness of the embankment design, and to ensure an appropriate design for long-term closure conditions.

CYCLONE SAND DESIGN CONSIDERATIONS

The particle size distribution of the Casino mill tailings is a key consideration for determining the suitability of the bulk non-reactive tailings to provide cyclone sand of suitable quality and in sufficient quantity. Coarser tailings are preferred, as a higher sand fraction or 'split' can be realized. Clean sand with sufficiently low fines content (% passing a #200 sieve) will be required for placement, in order to facilitate rapid drainage and subsequent compaction. The large embankment height associated with the Main Embankment limits the sand placement options and likely necessitates construction using sand cells. The cyclone sand fill material will require compaction to provide adequate strength for embankment stability and to ensure the material is not susceptible to cyclic softening or flow liquefaction under seismic loading.

Experience from existing large cyclone sand dams indicates that the sand fill should have an in situ permeability equal to or greater than 2×10^{-4} cm/s (Barrera, Valenzuela and Campana, 2011). This will ensure the rapid drainage of construction water (following cyclone sand placement), seepage water and direct precipitation. Cyclone sand from copper tailings with a fines content in the range of 15 and 20 percent typically have a sufficiently high permeability for adequate drainage. This criterion continues to be valid provided the sand grain size is not significantly changed by particle crushing, due to high confining stresses imposed by dams of large height. Chilean experience for large copper cyclone sand tailings dams indicates that high confining stresses do not significantly affect the sand grain size.

Permeability and strength testing has been conducted on a laboratory generated sample of cyclone sand material, generated from the anticipated bulk tailings stream. The testing did not indicate evidence of particle crushing, and measured permeability values were greater than 2×10^{-4} cm/s, even at high confining stresses. From consideration of the large height and size of the Main Embankment, the current design requires that the fines content of the cyclone sand be less than 15%, in order to ensure adequate compaction, strength and drainage characteristics.

Placement of additional rockfill in the downstream shell of the Main Embankment will be used to supplement any shortfall of the cyclone sand, and to provide additional structural support and drainage, if required, during on-going expansion of the facility. Suitable earth or rockfill materials will also be required to provide erosion protection for the cyclone sand embankment.

COLD CLIMATE DESIGN CONSIDERATIONS

Numerous mines have constructed and operated tailings facilities under severe winter conditions. However, specific design and operating requirements will need to be considered to ensure appropriate construction and operation of the facility. Disturbance or removal of the vegetative cover to initiate construction may result in the melting of permafrost and the development of unstable conditions. Frozen overburden and bedrock that are underlying part of the proposed tailings impoundment and embankments are expected to thaw over time, as the tailings and water stored in the TMF will act as a heat source. All ice-rich and unsuitable overburden encountered during construction will therefore be removed along the entire foundation of the TMF embankments. Ground ice is not expected to be significant in bedrock which will likely provide a stable foundation for the embankments. Preferential seepage paths may develop when ice filled discontinuities thaw. Bedrock may need to be steamed and grouted if the potential for this to occur is identified.

Cold winter conditions may reduce the construction period for cyclone sand placement, due to the potential for freezing and ice entrainment in the sand fill or from snow drifting into sand placement cells. Mine operations that have utilised cyclone sand fill for dam construction include the Kemess, Gibraltar and Highland Valley mines in British Columbia. The construction season at these mines is reduced to accommodate cold operating conditions in the winter months. A similar reduced construction season for cyclone sand placement is anticipated for the Main Embankment, and has been accounted for in the design studies.

CONCLUSIONS

The Tailings Management Facility for the Casino Project has been designed to permanently store PAG and non-reactive tailings, as well as PAG, ML and non-reactive waste rock materials. Waste rock and tailings will be selectively placed to provide subaqueous disposal of potentially acid generating materials, mitigate metal leaching potential and ensure long-term water quality and geotechnical performance objectives are achieved. The dam design and allocation of waste materials has been optimised during successive design stages as a better understanding of the geotechnical conditions and geochemical characteristics of the waste materials was obtained.

Design considerations include integration of the mine production schedule with construction of the TMF embankments and placement of waste rock, the impact of the cold climate (freezing conditions) on dam construction and facility operations (including cyclone sand production), the impact of discontinuous permafrost foundation conditions on dam performance, consideration of dam stability and integrity (including potential differential settlement) and the effect of high confining stresses on the strength and permeability characteristics of the embankment construction materials.

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