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Project Memorandum

To:	**SWCA Environmental Consultants**		
Attention:	**Chris Garrett, P.HGW**		
From:	**Robert (Nick) Enos, CPG**	**Date:**	**July 14, 2020**
Subject:	**Resolution Copper Project EIS – Subaqueous Disposal of Pyrite Tailings**		
Project No.:	**1704007**		

1.0 INTRODUCTION

1.1. Project and Environmental Impact Statement

Resolution Copper Mining (RCM) is proposing to develop the Resolution Copper Project (Project), an underground copper mine located approximately two miles east of the town of Superior, Arizona. Tonto National Forest (TNF) issued the Draft Environmental Impact Statement (DEIS) for the proposed Project on August 9, 2019 (USFS, 2019). The DEIS identified the preferred Tailings Storage Facility (TSF) alternative as Alternative 6 – Skunk Camp. As part of Alternative 6, RCM proposes subaqueous deposition and water cover of pyrite tailings during mine operations in order to reduce the risk of acid rock drainage (ARD) and metal leaching (ML). The purpose of this memorandum is to summarize the available information supporting this approach, some considerations in managing pyrite tailings, the available guidance and best practice, other examples of subaqueous tailings disposal, and to generally comment on the applicability for this Project.

1.2. Scope and Objectives

BGC Engineering USA Inc. (BGC) is providing geological and geotechnical expertise to SWCA Environmental Consultants (SWCA) and the TNF. As part of the DEIS, BGC has performed a desktop review of available information pertaining to tailings management provided by RCM and their consultants. In order to address public and agency comments on the DEIS, BGC has also participated in a "Water Workgroup" (Workgroup) facilitated by SWCA and the TNF. The Workgroup considered the proposed management of pyrite tailings in the context of the public and agency comments on the DEIS, and industry best practice and guidance.

The objectives of this memorandum are to:

- Summarize the information provided by RCM and reviewed by BGC and the Workgroup
- Describe key considerations, as well as available guidance and best practice in the industry for subaqueous disposal of reactive tailings
- Comment on the applicability of subaqueous disposal in an arid environment.

This memorandum does not address other technical aspects of the proposed TSF and does not include an independent assessment of the minimum water cover requirements, or the associated make-up water requirements necessary to ensure adequate water cover.

1.3. Information Reviewed

In response to Workgroup data requests pertaining to the management of pyrite tailings, the following information was provided by RCM:

- *"Case studies for Resolution-technologies.pdf"*. Originally submitted to TNF on November 6, 2018 and re-submitted on April 7, 2020. This document provides a table of example mine sites and mine projects that incorporate subaqueous disposal. (RCM, 2020a).
- *"Case studies for Resolution - 2020 Update.doc"*. Submitted to TNF on April 17, 2020. This document is an updated version of the table of example mine sites and projects that utilize subaqueous disposal. The updated version includes additional examples from arid environments. This information is included in Table 1. (RCM, 2020b).
- *"March 26th 2020 Water Working Group: Geochemistry Notes"*. Submitted to TNF on April 7, 2020. These are notes from RCM that accompany the presentation during the March 26, 2020 Workgroup meeting and include RCM's detailed response to a DEIS public comment by Buka Environmental suggesting a lack of site-specific geochemical testing to support the plan for subaqueous disposal of pyrite tailings. (RCM, 2020c).

The following documents provide additional background, and are applicable to this review:

- Design Guide for the Subaqueous Disposal of Reactive Tailings in Constructed Impoundments (MEND, 1998)
- Global Acid Rock Drainage (GARD) Guide (INAP, 2014)
- Resolution Copper Mining LLC, Resolution Copper Project, DEIS Design for Alternative 6 – Skunk Camp, Rev. 1 (KCB, 2018)
- Resolution Copper Mining LLC, Resolution Copper Project, Skunk Camp TSF Reclamation Plan, Rev. 0 (KCB, 2020).

2.0 PROPOSED TAILINGS MANAGEMENT OVERVIEW

The Project is proposing to produce about 132,000 dry tons per day (tpd) of tailings, with a cumulative 1.37 billion tons over the proposed 41-year mine life. Processing will result in the separation of two distinct types of tailings: 1) "scavenger" or "low-pyrite" tailings, and 2) "pyrite" or potentially acid generating (PAG) tailings (USFS, 2019). Based on geochemical characterization studies to date, the scavenger (low pyrite) tailings are characterized by a low average concentration of pyrite relative to the more enriched "pyrite" tailings. Although scavenger tailings show a range of sulfide sulfur concentrations (reported as between 0.01 and 1.09 weight percent), geochemical studies indicate a geometric mean of 0.07 weight percent sulfide sulfur (Duke HydroChem, 2016). These low pyrite tailings are estimated to account for approximately 84 percent, or approximately 1.15 billion tons, of the tailings that will be produced during the life of mine. In contrast, the enriched pyrite tailings will contain a significantly higher amount of pyrite (typically greater that 20 weight percent sulfide sulfur; Duke HydroChem, 2016) and will account for 16 percent, or approximately 0.22 billion tons, of the estimated tailings that will be produced during the life of mine.

These two very distinct types of tailings, and the management requirements for each, is a fundamental aspect of the proposed project design. The proposed Skunk Camp TSF (Figures 1 and 2) will consist of two pyrite tailings storage cells upstream of a scavenger tailings beach and TSF main embankment. The ultimate TSF configuration at the end of mine operations is shown on Figure 2.

2.1. Management of Pyrite Tailings

Management of the pyrite tailings during mine operations, and their location within the facility post-closure, are intended to reduce the risk of ARD and ML. Geochemical characterization studies consistently demonstrate that pyrite tailings are PAG, meaning that if allowed to weather in an oxidizing environment, they may be expected to generate acidic conditions and produce drainage with elevated metal/metalloid and sulfate/total dissolved solids concentrations (Duke HydroChem, 2016). In order to limit the generation of ARD and ML, RCM proposes that pyrite tailings be deposited subaqueously (i.e., beneath a “water cover”) in two low-permeability “pyrite cells”, contained by independent downstream-raised compacted cycloned sand embankments (KCB, 2018). Additional information regarding the engineered low-permeability layer for containment in the pyrite cells is further discussed in KCB (2018). Pyrite Cell 1 (Figure 2) will receive tailings from startup to about Year 15 and will be subsequently covered with scavenger tailings starting in about Year 16. Once covered with scavenger tailings, a water cover will not be maintained on the pyrite cell. A thick sequene of scavenger tailings fines will replace the water cover and will serve to limit infiltration and oxygen ingress long-term (KCB, 2020). Pyrite Cell 2 construction will start prior to Year 15 and will receive pyrite tailings from Year 16 to Year 41. Towards the final years of operations, scavenger tailings will be progressively deposited into Pyrite Cell 2 to gradually cover the area of pyrite tailings and reduce the final remaining area that will need to be covered and reclaim pond managed at the end of operations (KCB, 2020). It is important to note that this approach will require rigorous operational planning to ensure that pyrite tailings remain fully saturated prior to final cover by scavenger tailings. Details about the timed staging, deposition, and closure of these cells is provided in an Updated Tailings Staging and Deposition Plan, included in Appendix II of KCB, 2020.

Pyrite tailings will be deposited from a floating barge or pipelines into the cells, which will be operated with a minimum 10-foot (3 m) water cover with additional flood storage and freeboard allowance (KCB, 2018). During operations water in the pyrite cell will serve as a reclaim pond for reuse in processing. During times of a negative water balance, additional water will be pumped into the pyrite cells to maintain the required minimum water cover (KCB, 2018).

Closure of the pyrite cells will include covering the pyrite tailings with 10 ft (3 m) of scavenger tailings, topped by a 2 ft (0.6 m) “soil-like” cover sourced from the local Gila Conglomerate (KCB, 2020). The long-term post-mining closure goals for the TSF are to have a physically stable facility and to limit the generation and potential release of poor water quality seepage. The 10 ft (3 m) thickness of the scavenger tailings cover material is to limit oxygen ingress into the pyrite tailings, with the soil cover designed to reduce net infiltration and support vegetation (KCB, 2020). In short, this closure cover plan is intended to serve a similar purpose in closure as the water cover is intended to serve during operations, that of limiting oxygen ingress into the pyrite tailings. Once the pyrite cells are reclaimed, there are no plans for maintaining a water cover post-closure. However, in the case of a temporary or interim closure during operations, the pyrite cell operating pond would need to be maintained and monitored to ensure adequate water cover (KCB, 2020).

2.2. Considerations for Subaqueous Disposal

Water covers, in the case of subaqueous disposal, act as a barrier to significant oxygen ingress into tailings (INAP, 2014). Subaqueous disposal of mine tailings has been demonstrated to be an effective method of suppressing sulfide mineral oxidation, as documented by MEND (1989), Fraser and Robertson (1994), and MEND (1996). In practice, MEND (1998) describes design criteria up to 1998 and Larkins (2020) describes more current practices in constructed impoundments. This approach has been approved in several jurisdictions, including Canada (Buttle and Benson Lakes, and Wolverine Mine, British Columbia; Anderson and Mandy Lakes, Manitoba, McArthur River Saskatchewan), Indonesia (Grasberg), Papua New Guinea (Ok Tedi) and the USA (Thompson Creek, Idaho) (RCM 2020b). The primary purpose of a water cover is to limit the exposure of reactive tailings to oxygen. Subaqueous management of sulfidic tailings is supported by studies demonstrating extremely low dissolved metals in interstitial pore water, verifying reduced reactivity due to submerged conditions (Fraser and Robertson, 1994). However, there are important considerations in the application of subaqueous disposal.

Sufficient depth of water must be provided to account for mixing and resuspension of waste material due to wind and wave action (INAP, 2014 and MEND, 1998). While only shallow water covers are needed to prevent oxygen diffusion, INAP (2014) suggests that thicker covers of 3 ft (1 m) to 10 ft (3 m) are needed to limit resuspension of fine tailings due to wave action. More specific guidance on minimum depth is provided in the Mine Environment Neutral Drainage (MEND) program's *Design Guide for the Subaqueous Disposal of Reactive Tailings in Constructed Impoundments* (MEND, 1998).

The design of the impoundment should also ensure that the minimum depth of the water cover is maintained throughout the hydrologic year as part of water balance calculations (MEND, 1998). In a hot and arid environment, such as in Arizona, water losses due to high evaporation typically result in a significant negative water balance. This means that sufficient make-up water must be secured in order to continuously maintain the minimum water cover over the pyrite cell. It is beyond the scope of this memorandum to quantitatively assess the makeup water requirements, but it is noted that this an important consideration for life-of-mine water consumption. RCM provides a DEIS-level water balance, including evaporation and make-up water requirements for the pyrite cells, in Appendix III of KCB (2018).

2.3. Site Specific Testing

As described in the previous section, subaqueous disposal of mine tailings has been demonstrated and documented to be an effective method of suppressing sulfide mineral oxidation (MEND, 1989, 1996; Fraser and Robertson, 1994). The fundamental chemistry involved, that of severely limiting the access to oxygen to drive the reaction, is not site-specific and is applicable anywhere in which sulfide minerals are underwater. However, there are site-specific testing data available for tailings material at Resolution that demonstrate this fundamental chemistry (Duke Hydrochem, 2016). Column tests were conducted that measured the rate of oxygen consumption by tailings. Tests were run with variable percentages of the pyritic tailings submerged in water and the results clearly demonstrate that as greater amounts of pyritic tailings are submerged the rate of oxygen consumption, and therefore sulfide mineral oxidation, decreases. This testing is consistent with previous documentation in the MEND (1989, 1996) and Fraser and Robertson (1994) reports. The diminished reactivity of sulfide minerals upon submersion in water by restricting the rate of oxygen supply has been demonstrated and practiced for some 30 years in both lake settings and engineered impoundments.

3.0 CASE EXAMPLES

Table 1 (Project Case Histories – Subaqueous Deposition) provides examples of other mining projects and operations that incorporate subaqueous deposition. The 28 examples in the table provide a variety of case sites across various geographic and climatic conditions. All the examples in Table 1 include engineered and managed facilities, and not natural impoundments such as lakes. Some include disposal in former open pits (e.g., Key Lake and Rabbit Lake). As discussed in the previous section, the fundamental chemistry of subaqueous deposition is not site-specific and is applicable anywhere sulfide minerals are underwater. However, it is recognized that there are currently no examples of subaqueous deposition in the US southwest desert at a scale of what is proposed by RCM. Except for the proposed project in Western Australia cited in Table 1, none of the other examples are in geographic locations analogous to Arizona's hot and arid climate. The primary difference for consideration is in the loss of water due to high evaporation rates, and the corresponding need to supplement make-up water to maintain a minimum water cover. In other words, there are many examples demonstrating that water covers are effective, but no examples that demonstrate maintaining a water cover at the scale and climatic conditions of the Project.

4.0 COMMENT AND SUMMARY

BGC has reviewed the information provided by RCM supporting their proposed approach of managing pyrite tailings through subaqueous disposal during mine operations. BGC has also reviewed the industry guidance, best practice, and case examples of subaqueous disposal. As discussed previously, subaqueous disposal has been clearly demonstrated to be an effective method of suppressing sulfide mineral oxidation, and therefore in reducing the risk of ARD and ML. However, the effectiveness of this approach requires that a sufficient depth of water be maintained throughout the life of mine, and that the design of the impoundment ensure that the minimum depth is maintained throughout the hydrologic year as part of water balance calculations. In the hot and arid climate at the Project site, this will require securing and managing enough makeup water to balance evaporative losses. BGC has not quantitatively assessed the water balance requirements to meet this need but assumes that information will be addressed outside the scope of this memorandum. This approach will also require rigorous operational planning for tailings deposition to ensure that pyrite tailings remain saturated until final cover placement prior to closure.

In summary, subaqueous disposal provides an applicable and industry-tested approach for the Project to manage pyrite tailings during mine operations. Water covers are an effective method of suppressing sulfide mineral oxidation and managing the risk of ARD and ML generation from tailings. However, the effectiveness of this approach hinges on maintaining a minimum water depth and is only applicable at the Project assuming that a sufficient volume of water can be maintained. While there are many case examples demonstrating that water covers are effective, there are no current examples in arid environments, like the desert of the Southwestern United States, that demonstrate maintaining a water cover at the scale and climatic conditions of this Project.

5.0 CLOSURE

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Yours sincerely,

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Attachments: Table 1 – Project Case Histories – Subaqueous Deposition
Figure 1 – Skunk Camp Location Plan;
Figure 2 – Skunk Camp DEIS TSF Overview

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TABLE

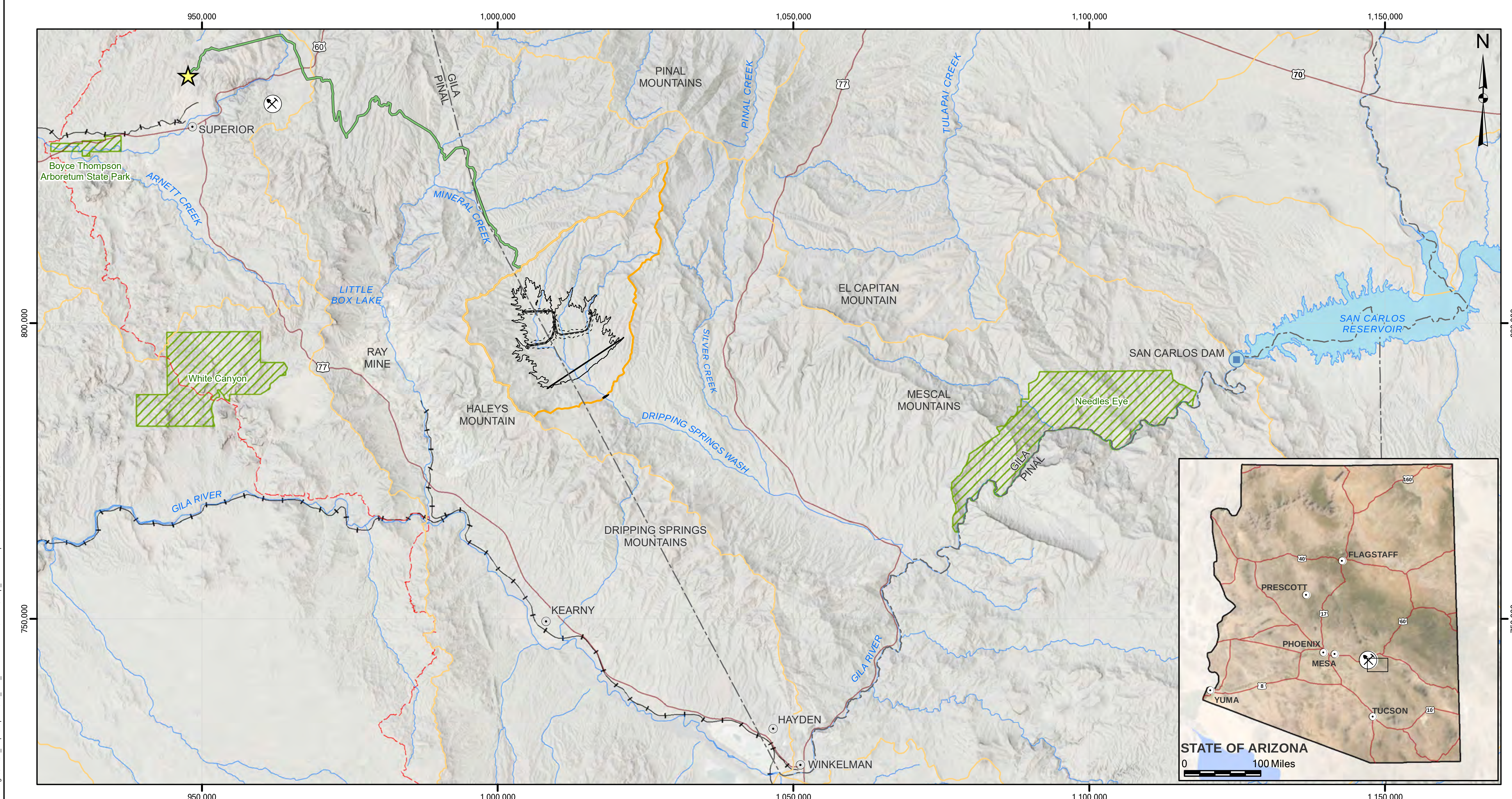
Table 1 Project Case Histories – Subaqueous Deposition

Project Case History	Location	Owner/Operator	Description	Climate
Red Dog	Alaska, US	Teck	Subaqueous disposal during winter.	Cool and wet (snowfall)
Thompson Creek	Idaho, US	Centerra Gold	Centerline construction cyclone sand dam with subaqueous deposition of pyritic tailings	Warm summers and humid
Mt. Milligan	British Columbia, Canada	Centerra Gold	Facility with multiple cells, including cleaner tailings cells that are subaqueously deposited.	Cold to Temperate and wet
Rabbit Lake In-Pit TMF	Saskatchewan, Canada	Cameco	Subaqueous deposition of tailings	Arid northern climate
Key Lake Deilmann TMF	Saskatchewan, Canada	Cameco	Subaqueous deposition of tailings	Arid northern climate
McClean Lake	Saskatchewan, Canada	Orano	Subaqueous deposition of tailings	Arid northern climate
Vale Thompson	Manitoba, Canada	Vale Canada Limited	Subaqueous deposition of tailings	Cold to Temperate and wet
Strathcona Tailings	Ontario, Canada	Glencore	Subaqueous disposal of high Po tailings	Cold to Temperate and wet
Vale Sudbury	Ontario, Canada	Vale Canada Limited	Subaqueous deposition of tailings	Cold to Temperate and wet
Elliot Lake	Ontario, Canada	Rio Algom	Subaqueous deposition of tailings	Cold to Temperate and wet
Louvicourt Mine	Quebec, Canada	Legacy	Subaqueous disposal of tailings	Cold to Temperate and wet
Caribou Mine	New Brunswick, Canada	Trevali	Subaqueous disposal year-round, floating line	Cold to Temperate and wet
Lisheen	Ireland	Vedanta Resources Zinc International	Subaqueous disposal of tailings via floating pipeline.	Temperate oceanic
Kevitsa	Finland	Boliden	Pyrite separation and subaqueous deposition of tailings	Cold (Subarctic)
Kylylahti	Finland	Boliden	Pyrite separation and subaqueous deposition of tailings	Cold to Temperate
Aitik	Sweden	Boliden	Pyrite separation and subaqueous deposition of tailings	Cold (Subarctic)
Cobre Panama	Panama	First Quantum Minerals	Subaqueous deposition of high-PAF cleaner tailings fraction.	Tropical and Wet
Rosebery	Tasmania, Australia	MMG Limited	Subaqueous disposal of hard rock metal deposits (zinc). Coning of subaqueous deposition in the pond requires frequent moves of the discharge.	Temperate to Warm and wet
ERA Ranger Mine	Queensland, Australia	Energy Resources Australia (Rio Tinto)	Downstream construction uranium dam with subaqueous deposition for dust management	Tropical (wet/dry seasons)
Ok Tedi	Papua New Guinea	Ok Tedi mining Ltd	High-pyrite tailings and subaqueously deposited and kept saturated in a pond.	Tropical and very wet
Pond 2A, Niobium Tailings Dam	Goias, Brazil	China Molybdenum Co (CMOC)	Subaqueous disposal of tailings	Tropical and wet
Nueves Corvo	Somincor, Spain	Somincor (Lundin Mining)	Originally subaqueous deposition of pyrite tailings modified to paste deposition using upstream stacking to maintain saturation and reduce acid generation potential	Hot (Mediterranean)
Morrison (proposed)	*British Columbia, Canada*	*Pacific Booker Minerals*	*Subaqueous disposal of tailings*	*Cold to Temperate and wet*
KSM (proposed)	*British Columbia, Canada*	*Seabridge Gold*	*Large copper tailings facility proposed and permitted that include PAG cells (subaqueous deposition) and NPAG cells operating adjacent to each other separated with splitter berms or dams.*	*Cold and wet*
Patterson Lake South Property (proposed)	*Saskatchewan, Canada*	*Fission Uranium Corp.*	*Uranium tailings facility proposed, but not yet permitted, that includes subaqueous deposition with a pervious surround and underdrain system. Proposed to be a hybrid facility (i.e., partially excavated, partially above ground)*	*Arid northern climate*
Kvanefjeld (Proposed)	*Greenland*	*Greenland Minerals Inc.*	*Subaqueous deposition of tailings via floating pipeline.*	*Cold (Subarctic)*
Mulga Rock Uranium Project (proposed)	*Western Australia*	*Vimy Resources Ltd.*	*Uranium tailings facility proposed and permitted but not started. Includes an initial above-ground TSF with subaqueous deposition of tailings. Once a void has been created, tailings will be deposited back into the unlined pit and capped with non-mineralized overburden.*	*Warm and dry (Desert)*

Green: Arid or semi-arid
Orange: Cool/temperate and wet
Red: Tropical/wet climate

Reference: Adapted from RCM 2020b

FIGURES



LEGEND

- PROPOSED CONCENTRATOR SITE (WEST PLANTSITE)
- RESOLUTION OREBODY
- SKUNK CAMP TSF
- SEEPAGE COLLECTION DAM
- SKUNK CAMP TSF - WEST PLANT PIPELINE CORRIDOR AND TUNNEL
- MAJOR CATCHMENT BOUNDARY
- TSF CATCHMENT BOUNDARY
- WILDERNESS AREA AND STATE PARK
- SAN CARLOS DAM
- TOWN OR CITY
- COUNTY LINE
- HIGHWAY
- EXISTING RAILWAY
- ARIZONA NATIONAL SCENIC TRAIL (ARIZONA TRAIL)
- NATURAL WATERCOURSE

NOTES:
1. NAD83, ARIZONA STATE PLANE CENTRAL, COORDINATES IN FEET
2. IMAGERY PROVIDED BY ESRI/BING AERIAL IMAGERY
3. TERRAIN AND IMAGERY DATA SOURCE: ESRI

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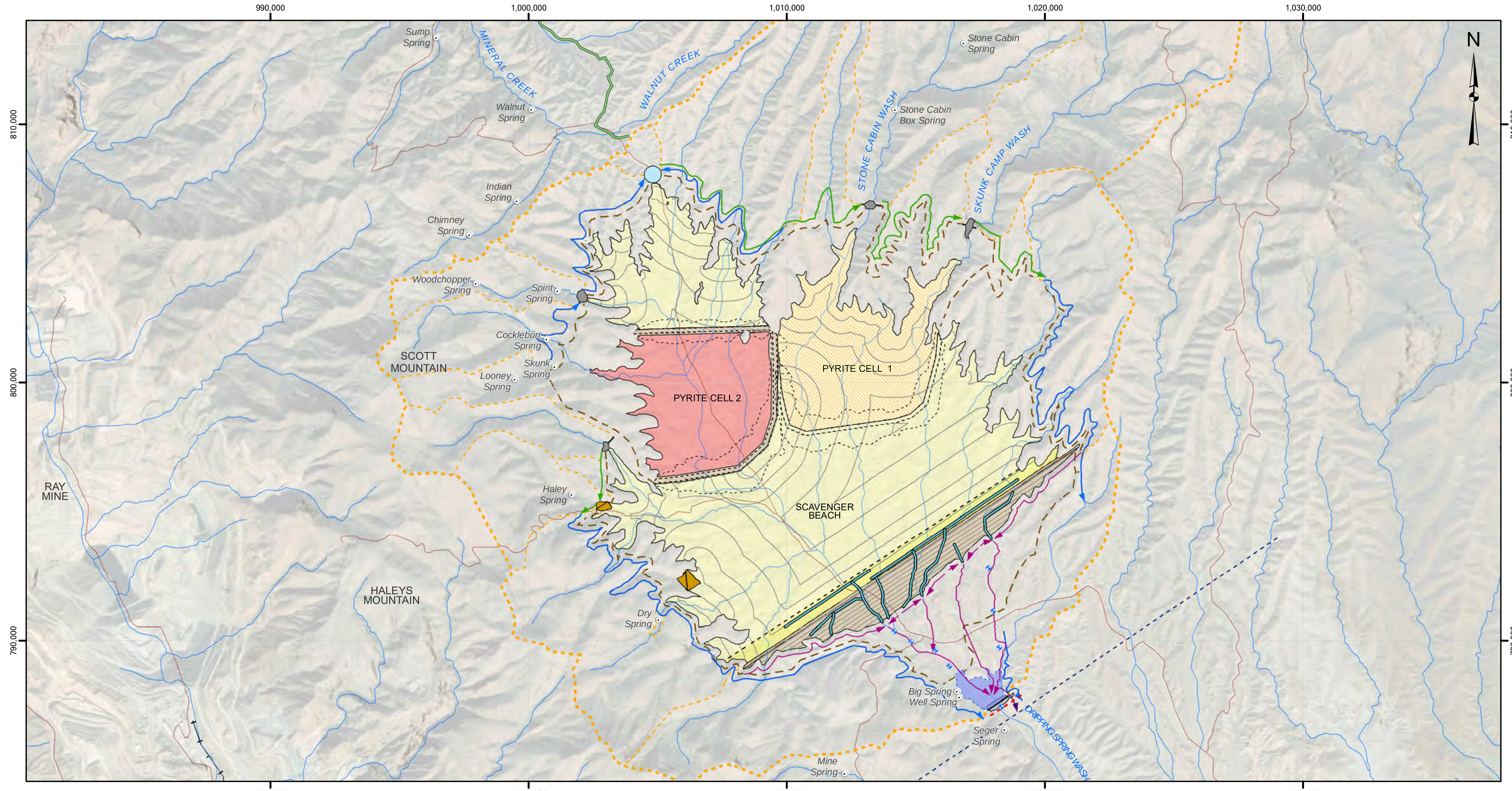
CLIENT	PROJECT	
RESOLUTION COPPER / KCB Consultants Ltd.	RESOLUTION COPPER PROJECT SKUNK CAMP TSF RECLAMATION PLAN	
	TITLE: SKUNK CAMP LOCATION PLAN	
	PROJECT No. UM09441A23	FIG No. 1

Reference: From KCB 2018



LEGEND

- MAIN EMBANKMENT -CYCLONED SAND
- NEAR DAM SCAVENGER BEACH
- SCAVENGER BEACH
- PYRITE TAILINGS
- PYRITE TAILINGS UNDER SCAVENGER BEACH
- PYRITE CELL EMBANKMENT FOOTPRINT
- CONTAINMENT DAM
- SKUNK CAMP TSF - WEST PLANT PIPELINE CORRIDOR AND TUNNEL
- PROPOSED ROAD
- SPRING
- TSF CATCHMENT BOUNDARY
- SUB-CATCHMENT BOUNDARY
- SURFACE WATER DIVERSION DAM DRAWDOWN PIPELINE
- OPERATIONAL UPSTREAM DIVERSION CHANNEL
- CONTACT WATER COLLECTION DITCH
- SCP EMERGENCY SPILLWAY
- FINGER DRAIN
- SHALLOW ALLUVIAL PUMPBACK WELL
- GROUT CURTAIN
- POINT OF COMPLIANCE LOCATION
- SURFACE WATER DIVERSION DAM
- SEEPAGE COLLECTION DAM
- SEEPAGE COLLECTION POND
- STORM RETENTION POND
- EXISTING ROAD
- EXISTING RAILWAY
- RIVER OR MAJOR DRAINAGE

NOTES:
1. NAD83, ARIZONA STATE PLANE CENTRAL
2. TERRAIN AND IMAGERY DATA SOURCE: ESRI
3. CONTAINMENT DAM REQUIRED FOR AVOIDANCE OF SPRINGS

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KCB Consultants Ltd.

PROJECT: RESOLUTION COPPER PROJECT SKUNK CAMP TSF RECLAMATION PLAN

TITLE: SKUNK CAMP DEIS TSF OVERVIEW

PROJECT No.	FIG No.
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Reference: From KCB 2018