Mine Water Solutions 2018

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University of British Columbia
NBK Institute of Mining Engineering
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JUNE 12-15 | VANCOUVER, CANADA
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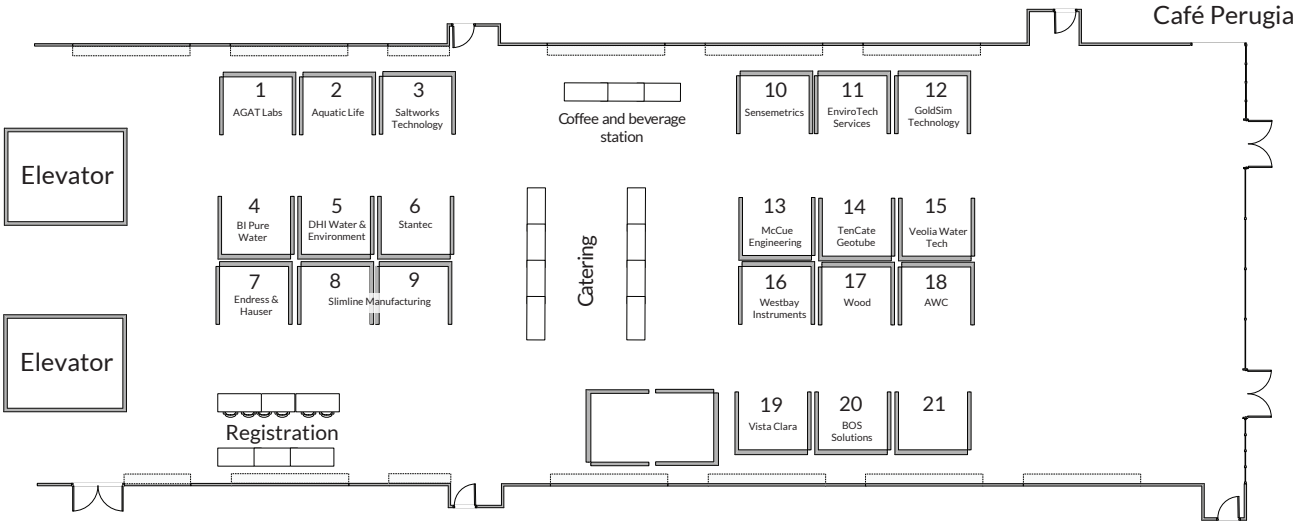
PROGRAM GUIDE

CONFERENCE FUNCTIONS AND LOCATIONS

Function	Location
Short Courses	Angus Building Rooms 291, 292, 293
Keynote Talks	LSC Room 1001
Sessions	LSC Room 1001, CHBE 101, CHBE 102
Trade Show	LSC, West Atrium
Breakfast, Lunch and Breaks	LSC, West Atrium
Speakers' Breakfast Meeting	LSC, West Atrium
"Exclusive Night at MOA"	Museum of Anthropology



BOOTHS

01 AGAT Labs
02 Aquatic Life
03 Saltworks Technology
04 BI Pure Water
05 DHI Water & Environment
06 Stantec
07 Endress & Hauser
08 Slimline Manufacturing
09 Slimline Manufacturing
10 Sensemetrics
11 EnviroTechServices
12 GoldSim Technology
13 McCue Engineering
14 TenCate Geotube
15 Veolia Water Tech
16 Westbay Instruments
17 Wood
18 AWC Water Solutions
19 Vista Clara
20 BOS Solutions

UBC NBK Institute of Mining Engineering

UBC's Department of Mining Engineering has faculty that teaches and mentors graduate students and staff to undertake research in all aspects of mining in order to study and improve the industry for future generations.

Known for being a small, close-knit family, the department is exemplified by the dedication of the faculty and staff who provide a dynamic, hands-on learning experience for both undergraduate and graduate students.

Gifts from alumni, corporations, foundations, students, parents and other friends assist the Keevil Institute in conducting leading edge research, providing outstanding education and contributing to social and economic development.

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C3 Alliance Corp.

At C3 Alliance Corp. we understand that the sharing of information and ideas is vital to gaining insights and developing relationships which, in turn, leads to successful natural resource development. Community members, business people, and government representatives can all benefit from meeting to share stories and knowledge.

C3 employs an expert team of event planners who specialize in conferences and networking opportunities. We benefit from a vast network of professional contacts to organize exciting events that connect people and knowledge across resources sectors, communities and government.

For more information, visit the website at http://www.c3alliancecorp.ca/

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TUESDAY JUNE 12

Location: *Life Sciences Centre, Room 1001*

17:30 - 18:30 **INTRODUCTION & WELCOMING** - Dirk Van Zyl, Organizing Chair, UBC

WELCOMING - Dan Ramey, Freeport McMoRan Inc.

Resilience of Mine Water Solutions and the Origin and Significance of the Conference Series - Andy Robertson, Robertson Geoconsultants

OPENING KEYNOTE - People, Policy and Water
Luke Danielson, Sustainable Development Strategies Group

18:30 - 20:00 Exhibit Hours, Life Sciences Centre, West Atrium Institute (CIRDI)

18:30 - 20:00 Exhibit Hall Welcome Reception, Life Sciences Centre, West Atrium

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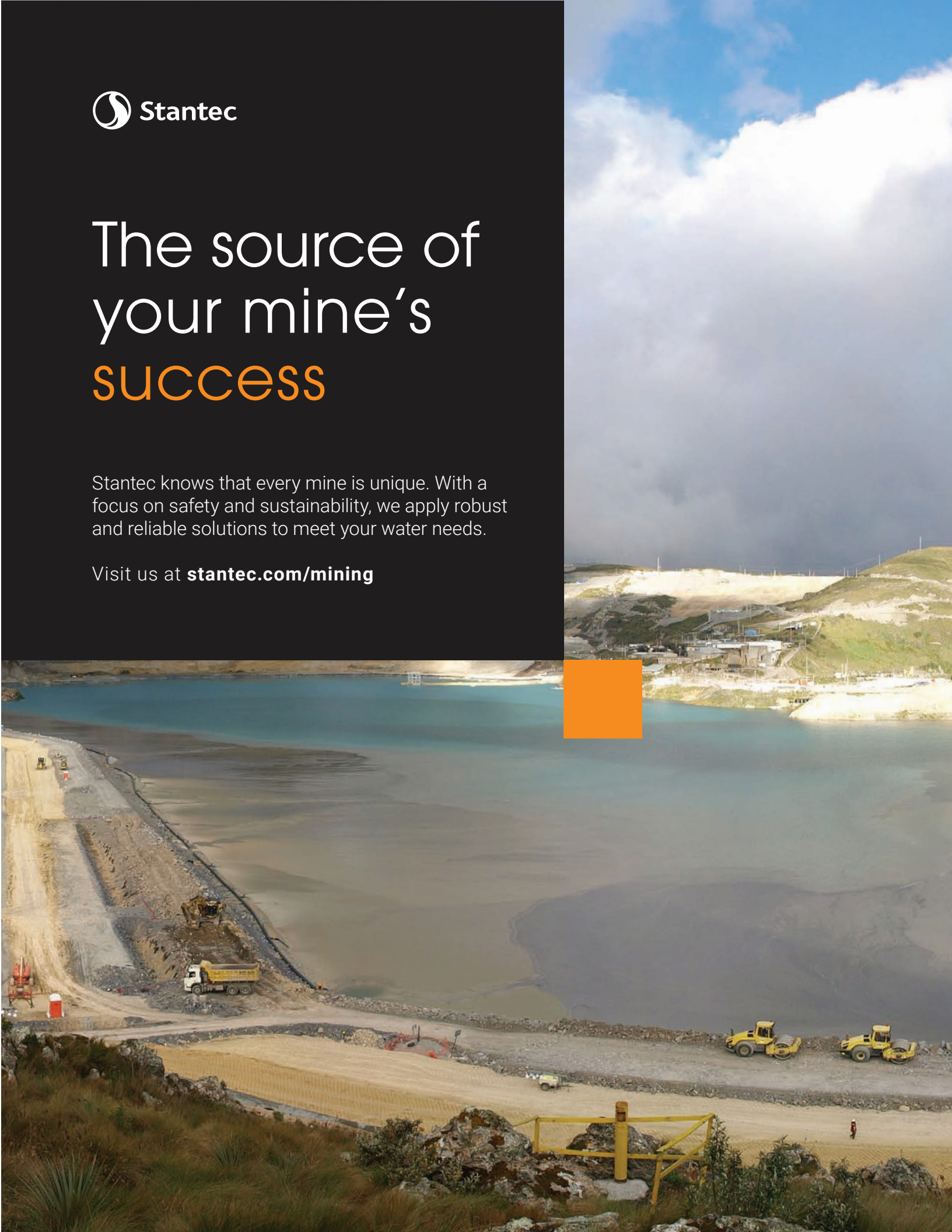

07:00 - 09:00	**Registration and Light Breakfast, Life Sciences Centre, West Atrium**	
08:00 - 08:30	**Speakers Coffee Meeting, Life Sciences Centre, West Atrium**	
09:00 - 17:00	**Exhibit Hours, Life Sciences Centre, West Atrium**	
	Safety Share	
Location:	*Life Sciences Centre, Room 1001*	
09:00 - 10:15	Welcome from Councillor Morgan Guerin, xʷməθkʷəy̓əm, Musqueam Nation Welcome from UBC *The Origin and Significance of the Mine Water Solutions Conference Series*	
KEYNOTE:	**Opportunities at the Confluences Between Technological Innovation, Society, and the Environment |** Dan Ramey, Freeport McMoRan Inc.	
10:15– 10:45	**Refreshment Break - *sponsored by Knight Piesold***	
10:45 - 12:25	**SESSION 1 - Water as a Valued Asset** Chair: Briana Gunn, Newmont	**SESSION 2 - Water Treatment (1)** Chair: Robert Kimball, Wood
Location:	*Life Sciences Centre, Room 1001*	*CHBE Building, Room 101*
	Follow The Money (And The Water) – The Goldcorp Water Valuation Toolbox - Brendan O'Brien, Goldcorp, Inc. USA	Removing Selenium from very low concentration mine waters - Mohsen Barkh, SGS Canada
	A new approach to mitigation banking - Eric McCleary, Stantec USA	Synthetic Water Calibration for Water Quality Parameters & Water Treatment Program Validation - Cecilia Garcia Marra, McCue Engineering, Canada
	Mine Water. A resource for the circular economy in South African Mining communities - Dheepak Maharajh, Mintek, South Africa	Water Use, Quality and treatment at Syncrude's Mineable Oilsands Operation in Northern Alberta - Warren Zubot, Syncrude Canada
	'Don't make waves': desalinated water and the social licence to operate in the Atacama Region, Chile - Cecilia Campero, UBC	Bioremediation-Based Water Treatment for Mine Closure: A Pilot-Scale Study - Leonard Santisteban, Freeport-McMoRan, USA
	From water management to water stewardship in mining regions - Nadja Kunz, UBC	The development of a new peat-based weak anion exchange material that removes sulfate from acidic water - Igor Kolomitsyn, Natural Resources Research Institute, USA
12:25 – 13:30	**Lunch - *sponsored by Eco Mister Evaporator* - Life Sciences Center, West Atrium**	
13:30 -15:10	**PANEL - Innovative Approaches to Mine Water Recovery and Reuse** Chair: Andrew Watson, Stantec	
Location:	*Life Sciences Centre, Room 1001*	
	Getting to good enough: fit for reuse water upscaling (a strategy presentation) Andrew Watson, Stantec	
	Advances in solid-liquid separation - Christian Kujawa, Paterson and Cooke	
	Breakthroughs in value recovery from mine water streams - Brett Waterman, Freeport McMoRan	
	Innovative sulfate removal - Ron Davis, Ecolab	

15:10 - 15:40	**Refreshment Break, Life Sciences Centre, West Atrium**		
15:40 - 17:40	**SESSION 3 - Water Treatment (2)** Chair: Brett Waterman, Freeport McMoRan Inc.	**SESSION 4 - Characterization and Prediction (1)** Chair: Erick Weiland, Freeport McMoRan Inc.	**SESSION 5 - Operational Water Management** Chair: Mike Geddis, KGHM
Location:	*Life Sciences Centre, Room 1001*	*CHBE Building, Room 101*	*CHBE Building, Room 102*
	Alkaline Flush Technology: an In Situ Treatment Method for Mining Impacted Alluvial Aquifers - Olufunsho Ogungbade, Freeport-McMoRan, USA	Characterising the Geochemistry of Soil and Water Using Drone based Hyperspectral Analysis - Jamie Robinson, SLR Consulting, UK	Is water the best option? How to evaluate which fugitive-dust management practice is right for your site - Jeff Ladderud, Freeport McMoRan, USA
	Performance Review of a Passive Treatment System for Fe, As, Mn at the Empire Mine State Historic Park - Neal Gallagher, Golder Associates, USA	Approaches to Water Quality Modeling Using Geochemical/ARD Test Data in Conjunction with Field Analog Data - Madhumitha Raghav, Freeport McMoRan USA	Estimating the Wetting Time for Mine Waste Rock Piles - Mark Steinepreis, Stantec Canada
	Electrocoagulation (EC) for the Removal of Silica in RO Rejects from ARD Water Treatment - Zhong Xie, National Research Council, Canada	Predicted (post-closure) Contaminant Loads and Water Quality Conditions in Myra Creek, Nystra Myra Falls (Canada) - Alex Trapp, Robertson GeoConsultants Inc., Canada	3D Deposition and water balance modelling with Muk3D and GoldSim - Carlo Cooper, MineBridge Software, Canada
	New Zero Water Intake Technology for Chemical Treatment of Mining Tailings - Colin Klein, SNF Canada	The Role of Speciation for Selenium Treatment and Compliance with Site-Specific Aquatic Life Criteria - Ben Wozniak, Brooks Applied Labs, USA	Dust Mitigation using a Water Conservation Program - Steven Clark, Enviro Tech Services, USA
	Containerized Water Treatment for Remote Mine Sites - Veneil Sundar, BQE Water, Canada	Base Mine Lake: The first End-Pit Lake for the Alberta Oil Sands - Dallas Heisler, Syncrude Canada	Biochemical cyanide treatment of gold mine tailings supernatant: Pilot and demonstration trials - James Harrington, Alexco Environmental Group
	In-Situ Treatment of Arsenic in a Pit Lake – Case History - Tom Patterson, SLR International, USA	Estimating Operational Groundwater Inflows to a Proposed Underground Coal Mine on Vancouver Island - Laura-Lee Findlater, Lorax Environmental Services, Canada	A Real Challenge in Mine Water Management in High Precipitation Area, Grasberg Mine - Vladimir Ugorets, SRK Consulting, USA
18:00 - 21:00	**Night at the Museum of Anthropology - *Sponsored by Goldcor***		

07:00 - 09:00	**Registration and Light Breakfast, Life Sciences Centre, West Atrium**		
08:00 - 08:30	**Speakers Coffee Meeting, Life Sciences Centre, West Atrium**		
09:00 - 17:00	**Exhibit Hours, Life Sciences Centre, West Atrium**		
09:00 - 10:00	Introductions and Safety Share, Dan Ramey, Freeport McMoRan		
Location:	*Life Sciences Centre, Room 1001*		
KEYNOTE:	**Goldcorp's Towards Zero Water (H2Zero) Goal** | David Garofalo, CEO, Goldcorp		
KEYNOTE:	**Cerro Blanco Underground Mine: 100+°C Water - Taking Challenges from Risks to Opportunities to Reality**, Jeff Reinson, VP Project Development, Bluestone Resources		
10:00 - 10:20	PLENARY: Current PMP Estimation and Meteorological Parameter Development for Mining Facilities in Data Limited Regions - Bill Kappel, Applied Weather Associates, USA		
	Session Close, remarks and announcements		
10:20– 10:50	**Refreshment Break, Life Sciences Centre, West Atrium**		
10:50 - 12:30	Social Aspects of Mine Water Management Moderator: Luke Danielson, Sustainable Development Strategies Group		
Location:	*Life Sciences Centre, Room 1001*		
	Total Water Management: Canada's contribution to sustainable mine development - Jon Fennell, Integrated Sustainability Consultants, Canada		
	Planning the climate change adaptation practices in watershed ecosystems: What the mining sector is developing? - Gabriel Castillo Devoto, UBC		
	PANEL DISCUSSION		
	Nadja Kunz, Assistant Professor, UBC School of Public Policy and Global Affairs and Norman B. Keevil Institute of Mining Engineering		
	Andre Xavier, Project Manager, Canadian International Resources and Development Institute (CIRDI) Lana Eagle, Lana Eagle - President - Industry Council for Aboriginal Business (ICAB)		
12:30 – 13:30	**Lunch, Life Sciences Center, West Atrium**		
13:30 -15:10	**SESSION 6 - Case Studies (1)** Chair: Hamish Weatherly, BGC Engineering	**SESSION 7 - Characterization and Prediction (2)** Chair: Shannon Shaw, pHase Geochemistry	**SESSION 8 - Water Management in Extreme Climates** Chair: Jennie Gjertsen,
Location:	*Life Sciences Centre, Room 1001*	*CHBE Building, Room 101*	*CHBE Building, Room 102*
	Challenges in containing geochemical risk at the Faro Mine Complex, Yukon - Dustin K. Rainey, Yukon Government, Canada	Use of Adaptive Management Planning in Support of Environmental Monitoring and Permitting Process, Sheldon Smith, Stantec	Incorporating Climate Variability into Water Balance Modelling to Help Inform Water Management Design: The Pebble Mine - Alana Shewan, Knight Piesold, Canada
	Lime Treatment: Advantages of a Proven Technology and Competing Alternatives - Kristina Minchow, Golder Associates, USA	Meteorological time series and natural runoff model in a cold climate environment - Joel W. Trubilowicz, Northwest Hydraulic Consultants, Canada	Effect of Variability of Design Storms on the Galore Creek Project - Charles Masala, Klohn Crippen Berger, Canada
	Hurricane Harvey Rainfall, Did It Exceed PMP and What are the Implications - Bill Kappel, Applied Weather Associates, USA	A New Rapid Brine Release Extraction Method in Support of Lithium Brine Resource Estimation - Jason Keller, GeoSystems Analysis, USA	Hydrogeology of the Coffee Gold Project: groundwater interactions in an area of discontinuous permafrost - Laura-Lee Findlater, Lorax Environmental Services, Canada

13:30 -15:10	**SESSION 6 - Case Studies (1)** Chair: Hamish Weatherly, BGC Engineering	**SESSION 7 - Characterization and Prediction (2)** Chair: Shannon Shaw, pHase Geochemistry	**SESSION 8 - Water Management in Extreme Climates** Chair: Jennie Gjertsen, Goldcorp
Location:	*Life Sciences Centre, Room 1001*	*CHBE Building, Room 101*	*CHBE Building, Room 102*
	New tailings encapsulation methods could "pave" the way toward safe long-term stacking of filtered tailings - Donald J. Lake, Terra CO2 Technologies, Canada	A comparison of predicted groundwater impacts to observed effects at the Victor Diamond Mine, 11 years after the start of dewatering - Simon Gautrey, Amec Foster Wheeler (Wood Plc), Canada	Numerical Groundwater Flow and Thermal Transport Modeling in Cold Regions - Mundzir Basri, Stantec Canada
	Enhanced Reclamation of the Giant Nickel Tailings Storage Facilities in British Columbia, Canada - Allison Brown, Barrick Gold, Canada	Multi-Parameter Time-Lapse Dam Seepage Investigation - Thomas C. Goode, Stantec USA	Changing Effluent Regulations in Canada, Helping Mine Sites to Reach New Limits - Sean Miller, Maxxam Analytics, Canada
15:10 - 15:30	**Refreshment Break**		
15:30 - 17:00	**SESSION 9 - Characterization and Prediction (3)** Chair: Madhumitha Raghav, Freeport McMoRan Inc.	**SESSION 10 - Case Studies (2)** Chair: Alana Shewan, Knight Piesold	
Location:	*Life Sciences Centre, Room 1001*	*CHBE Building, Room 101*	
	Richmond Hill Mine Heap Leach Pad Soil Cover System Evaluation - Johnny Zhan, Barrick Gold, USA	Application of SAGR Bioreactors for Ammonia Treatment in Mining Effluents - Mike Bratty, Golder Associates, Canada	
	Dependence of Predicted Dewatering on Size of Hydraulic Stress Used for Groundwater Model Calibration - Cristian Pereira, SRK Consulting, USA	Towards a Conservative Mine Design Practice through Probabilistic Calibration - John Mayer, SRK Consulting, Canada	
	Novel Use of the Westbay System to Characterize Deep Hydrogeology for a Proposed Underground Coal Mine - Tyler Gale, ERM Consultants, Canada	Mixing Zone Assessment for Mine Effluent Discharges in Receiving Waters: Challenges and Solutions through Best Practices - Mijanur R. Chowdhury, Minnow Environmental, Canada	
	Groundwater Discharge Into Tailings Facility During Intense Precipitation Events, Nyrstar Myra Falls - Christoph Wels, Robertson GeoConsultants, Canada	Investigation of Feed Water Treatment Options in an Arid Area - Mohsen Barkh, SGS Canada	
	Cold Desert Evapotranspiration Cover System Design Evaluation - Jason Keller, GeoSystems Analysis, USA	Implementing a Long-Term Water Management Strategy for Mine Closure in Northwest British Columbia - Michael Dabiri, Klohn Crippen Berger, Canada	

Schedule subject to change

SESSION 1: WATER AS A VALUED ASSET

Follow The Money (And The Water) – The Goldcorp Water Valuation Toolbox

Brendan O'Brien, Goldcorp, Inc. USA

ABSTRACT

Goldcorp's CEO has challenged the company to make significant strides in water reduction over the next 10 years with an aspirational goal referred to as 'Towards Zero Water'. A central question which arises when beginning to plan and prioritize water reduction efforts in pursuit of this goal is "what is the cost of water?" However, the mining industry does not have any standard methods for addressing this topic, and the costs of water management activities do not often fall neatly into their own accounting cost centers.

To address this challenge, Goldcorp has developed a spreadsheet model - the "Water Valuation Toolbox" - to standardize the compilation and presentation of operational costs and planned sustaining capital projects related to water management. This paper describes the development of the model and its subsequent use to create a company-wide set of water costs for the 2016 calendar year.

The project team worked through an iterative process involving both site-based and corporate stakeholders to gain insight into the data available and desired application of the results. Definitions and methodologies were then developed to capture and document a mine site's actual operational and planned future sustaining capital expenditures on water. This material comprised the basis of the Water Valuation Toolbox spreadsheet which addresses the following aspects: definition of the scope and detail of cost (what specifically do we mean by "cost"?), methodology for defining and organizing a site's water activities (what "water" are we talking about?), methodology for combining future sustaining capital costs with current operating costs, tools for compiling and presenting these costs, and metrics for basic data analysis.

The completed spreadsheet model has provided Goldcorp with a useful tool to standardize, compile, and compare water costs across its operating portfolio. The application and population of the model for each operating site has yielded a valuable database of detailed costs to be used as a resource for the company to ensure that water management costs are considered in financial models when analyzing business scenarios. Ultimately, the Water Valuation Toolbox has allowed Goldcorp to answer the driving question of "what is the cost of water?" and will contribute to intelligent discussions and better business decisions.

A new approach to mitigation banking

Eric McCleary, Stantec USA

ABSTRACT

The use of a mitigation bank for ecosystem restoration is being developed as a pilot demonstration project in Western Pennsylvania to restore streams impacted by mine drainage and acid precipitation. Mine drainage and acid precipitation are problematic throughout Appalachia. In Pennsylvania alone, over 5,000 miles of streams have been impacted by these types of pollution. Mine/acid drainage affects ecosystem health typically by having a reduced pH with elevated acidity and metal levels (principally iron and aluminum). The task of restoring streams affected by mine/acid drainage is daunting, especially with reduced state and federal funding sources. The idea of employing mitigation banks, sponsored by private entities (i.e. industry, developers, etc.), to ecologically offset these types of pollution, as "out of kind" mitigation, has yet to be done through the federal mitigation banking program developed by the United States Army Corps of Engineers.

Lyons Run, in Westmoreland County, PA, along with various other streams in the northcentral portion of Pennsylvania, are the pilot sites for this unique approach to mitigation banking. Installation of strategically placed and relatively low-cost passive limestone treatment units, designed to increase alkalinity and remove metals (where applicable), is the core of this restoration effort. Water quality trading, based on both measurable water quality improvement and carbon increases, provide ecological lift that can be objectively measured and traded to offset various environmental impacts. This approach

is receiving favorable support from the State of Pennsylvania, federal agencies, and private parties. The use of private funding to establish mitigation banks (as ecosystem banks) to offset unavoidable ecological impacts, accomplished through existing state and federal permitting programs, is attractive to all parties involved. These programs can produce significant environmental benefits, notably wild brook trout recovery. This presentation introduces the concept, explores the development of the pilot project, covers the concerns of the state and federal agencies, presents the current status of the project (anticipated implementation being summer of 2018), and examines how it could be utilized throughout North America as an ecosystem restoration tool.

Mine Water: A resource for the circular economy in South African Mining communities

Dheepak Maharajh, Mintek, South Africa
Tamsyn Grewar, Mintek, South Africa
John Neale, Mintek, South Africa
Michelle van Rooyen, Mintek, South Africa

ABSTRACT

South Africa (SA) is one of the 30 driest countries in the world and amongst the most water wasteful. The agricultural sector in SA uses ~70% of the country's total water resources and the average South African uses 60% more water than a global citizen; additionally, our waste water treatment plants are not all efficiently operational. Although the mining sector only uses 3-5% of the water resources these situations increase pressure on the mining sector to deal with mine water pollution as the mine water contaminates ~37 billion litres of fresh water. The mines are also required to develop innovative ways to create jobs while stimulating economic growth in the mining communities. The mining industry in SA is still a major contributor to the economy and any changes to the mine sustainability will have dire impacts on the regional and national poverty levels. These are amongst the major reasons why a sustainable solution for the future of mining is required. A future that allows for a seamless movement of labour from mining into other industries when mines are spent or mechanisation is required. The technology proposed in this paper is still a conceptual integration of technologies and the target is to demonstrate the integrated system during the course of 2018/9. Using mine water as a resource has shown potential to create energy, jobs, food and clean water through an integrated system. The rationale behind the concept is to generate various products by adopting a cradle-to-cradle approach, where the waste from one process technology is the raw material for the next. There are various potential technologies proposed for integration and Mintek is involved in some of these at various stages of development. The concepts include biological sulphate reduction, SAVMIN, algal bioenergy, biogas technologies, concentrated solar power and agriculture. The system delivers energy, fuels, food and jobs while remaining environmentally responsible. The products produced in the system have available markets in the mines and communities. The electricity and food generated will be routed to the community, while the biofuels produced will be supplied to the mines to partially meet their average fuel demand of ~70 ML/annum/mine. The concept will also enable mining companies to mitigate their environmental responsibility by generating a positive NPV through the various interventions. The concept is designed for the mining sector but can be adapted to deliver resources to rural or remote communities.

'Don't make waves': desalinated water and the social licence to operate in the Atacama Region, Chile

Cecilia Campero, UBC

ABSTRACT

Desalination is assumed to be important in overcoming physical resource limits, resolving water scarcity and satisfying water demands associated with productive activities. In Chile the mining industry is leading the drive toward the construction of new desalination plants, followed by water supply companies that are focused on human consumption. This expanding process is confronting governance challenges due to the multiple interests

around desalinated water and the impacts of the process (e.g. ecological, economic and social).

The Atacama Region of Chile, in addition to hosting major mining industries in their territory, is located in the arid, to extremely arid, northern part of the country, which makes water a contested resource with the farming community and indigenous people, affecting its availability even for human consumption. This context presents a challenge for local development and for the structure of governance, which is competing between territorial scales and power to affect decision making. Drawing from company sustainability reports and environmental impact assessments, I examine three mining companies in the Atacama Region that through the incorporation of desalinated water into their water strategy show governance challenges and new interest from local communities. Describing, at the same time, what companies are doing to affect the acceptance of the project SLO.

The broader intellectual objective of the article is, first, to explore desalinated water governance and the different interests pursued by actors. Second, the article considers how desalinated water is strategically articulated through the mining industry´s social licence to operate. Finally, the article presents how companies are responding to new societal interest in desalinated water projects. Analysis of these processes does not only reassert questions over the complex governance of desalination, revealing different interests and concerns, but also reveals the strategies used by both mining companies and social groups to achieve their goals.

From water management to water stewardship in mining regions

Nadja Kunz, UBC

ABSTRACT

Expansion of the mining industry is increasingly constrained by a lack of water, too much water, or social opposition over water-related risks. A lack of water is a global concern with roughly two thirds of the world's largest mines now located in countries experiencing high water scarcity. This can create conflict with surrounding water users and constrain industry access to water. Too much water can prove equally costly for mining firms; for example, the 2010 flooding events in Australia's Bowen Basin led to billion-dollar production losses for the coal mining sector. The floods also prompted regulatory changes due to concerns about the ecological impacts caused by the discharge of contaminated mine water. Gaining a comprehensive understanding of water issues in mining is challenging because the tasks that use water are interconnected and interdependent. This complexity is magnified at the catchment scale because the water system becomes more closely coupled to the climate and the stakeholders who use, impact and/or regulate water are more diverse. This paper provides a high-level overview of key water challenges facing the global mining sector and proposes an organizing framework to distinguish between research needs at two levels: Mine Water Management (within the company fence) and Mine Water Stewardship (beyond the company fence). The former focuses on addressing operational water risks at the mine site level, such as water reservoir optimization and understanding the impacts of water quality changes on flotation effectiveness. The latter explores opportunities to create regional synergies and networks in water provision for mining regions, including working with diverse stakeholders to address water supply and quality issues. It is argued that interdisciplinary thinking is needed at both levels, giving due consideration to both technical and social issues, and that this will be increasingly essential for successful mining companies of the future.

SESSION 2: WATER TREATMENT (1)

Removing Selenium from very low concentration mine waters

Mohsen Barkh, SGS Canada

ABSTRACT

Despite availability of different selenium removal options, removing selenate (SeO_4^{2-}) from diluted mine water is an ongoing industrial challenge for many

projects. The ion exchange process is one of the most effective selenate removal methods which could concentrate selenate and other contaminants in a small reject volume. Waste management method and regeneration frequency are key parameters which determine the feasibility of selenium removal by ion exchange.

One of the best available options for managing selenium waste is returning the element to a stable state by chemical precipitation. In the proposed methodology, the concentration of selenium(VI) was increased through an ion exchange system and the high-concentration regeneration solution was precipitated at low pH using sodium hydrosulfite (sodium dithionite, $Na_2S_2O_4$) as a reducing reagent.

Synthetic Water Calibration for Water Quality Parameters & Water Treatment Program Validation

Cecilia Garcia Marra, McCue Engineering, Canada

ABSTRACT

To support the Environmental Assessment (EA) of a new gold mine project in BC, McCue completed the preliminary design of a mine water treatment plant (WTP) using a water profile modeled by others for the future open pit sump water. The water profile is complex and the treatment plan includes heavy metals removal by chemical precipitation. Plant effluent quality was initially predicted largely based on published theoretical heavy metal solubility data.

To address uncertainty with the treatment process and improve the inputs for the impact assessment model (by others), McCue created a synthetic water sample from field leachate samples and laboratory-grade salts to match the modeled plant inlet water profile. The synthetic water sample was used to validate the water treatment process at a bench scale and provide effluent quality data for impact assessment modeling. The bench scale test program also provided valuable data needed in the future to advance the design of the mine water treatment plant from preliminary to detailed.

Data from the bench scale work reduced uncertainty as to what could be achieved with water treatment at the project site and what impact the treated water would have on the local environment. This was important in satisfying both the regulators reviewing the EA and the project stakeholders, including local First Nations.

The bench scale test results and data from an ensuing full-scale treatment plant at another project site have also contributed to the body of knowledge for heavy metals precipitation treatment performance. For instance, previously, literature indicated that no or negligible removal could be achieved for copper. McCue's work has provided valuable data for copper that could benefit EA work at other mine sites globally.

McCue will present the synthetic sample method, bench scale test program results, and how they related to the detailed design and performance of a full-scale metals precipitation plant that offered an economical treatment program for complex water containing high levels of salts in addition to heavy metals.

Water Use, Quality and treatment at Syncrude's Mineable Oilsands Operation in Northern Alberta

Warren Zubot, Syncrude Canada

ABSTRACT

The oil sands industry, located in northern Alberta, Canada, makes a significant contribution to Canada's economy. In total, the deposits contain an estimated 1.7 trillion barrels of oil, of which 300 billion barrels are recoverable using current technology. Depending on the depth of the deposit, raw bitumen is produced either by in-situ well technology or mining. After mining, bitumen is recovered from the oil sand using a warm water extraction process, generating a tailings material composed of oil sands process water, sand, silt, clay and some unrecovered bitumen.

A key driver for Syncrude's long-term sustainability is improved environmental performance, which includes water management. Water is integral to both

operational and environmental aspects of Syncrude's business with short-term objectives to ensure adequate volumes of process water of sufficient quality are available for process needs. Longer-term objectives include maintaining acceptable water quality to maximize bitumen production, facilitating terrestrial and aquatic reclamation objectives and demonstrating to our stakeholder's prudent and responsible use of the available water resource.

To improve environmental performance, Syncrude has been developing a technology that uses an upgrading by-product, petroleum coke, to treat oil sands process water. Syncrude is constructing a prototype water treatment facility designed to treat oil sands process water (OSPW) to a quality to ensure it can be safely released to the environment in a manner that is protective of ecological and human health. The facility, scheduled for commissioning in the summer of 2018, will build upon a smaller scale pilot completed by Syncrude in 2012 at the Mildred Lake lease. The treatment process is a novel application of known treatment processes and is based upon filtration of the water through a contained deposit of petroleum coke. However, unlike conventional sand filtration, the petroleum coke filtration media is composed of carbon. The 2012 program confirmed previous studies that showed petroleum coke– a byproduct of SCL's Fluid Coking™ process - can be used as activated carbon (adsorption) to reduce concentrations of dissolved organic compounds present in OSPW. The results confirmed that the technology's treatment efficiency exceeded 80% for hydrocarbons components such as naphthenic acids and polycyclic aromatic hydrocarbons and produced treated water that was acutely non-toxic based on a 96-h rainbow trout bioassay. Similar to the 2012 program, the 2018 program will involve the hydraulic deposition of a freshly produced slurry of OSPW and petroleum coke into a large earthen containment cell equipped with engineered underdrainage. This structure will be situated within the southeast quadrant of the Mildred Lake Settling Basin. The treatment is designed to reduce concentrations of suspended solids, free phase hydrocarbons, and dissolved organic compounds present in OSPW.

The intent of the field pilot study is to provide additional information to assess the water treatment process and validate at a prototype scale. The quality of the OSPW will be chemically monitored throughout the treatment. The final treated water produced will be evaluated using a triad approach that will include chemical testing, whole effluent toxicity testing, and standard chronic testing. Chronic toxicity testing will be conducted using commercial laboratories, and on-lease using a mobile test facility equipped with outdoor mesocosms to evaluate biological effects in real-time.

Syncrude produces about 20 kg of product petroleum coke per barrel of synthetic crude oil produced and, based on the current state of knowledge, the technology has a commercialization potential to treat between about 8 and 12 Mm3 of OSPW per year. This presentation will review Syncrude's water use and quality and discuss this novel water treatment process including key results of the 2012 field program and the 2018 program.

Bioremediation-Based Water Treatment for Mine Closure: A Pilot-Scale Study

Leonard Santisteban, Freeport-McMoRan, USA
Ilsu Lee, Freeport-McMoRan, USA
Shane Hansen, Freeport-McMoRan, USA
Erick Weiland, Freeport-McMoRan, USA
Dan Ramey, Freeport-McMoRan, USA

ABSTRACT

Metal mines approaching end of active operations must prepare for the potential long-term treatment of mining-influenced water (MIW). It is therefore imperative to identify options for cost-effective treatment technologies and strategies. Biologically-based passive remediation technologies, for example, are a proven, cost-effective option for treating mild to moderately-impacted waters at low- to moderate-flow rates. Yet, their applicability to highly-impacted waters are less understood. The objective of this project was to conduct a pilot-scale test for optimizing the design criteria of sulfate-reducing biochemical reactors and treating wetlands for improving the quality of highly-impacted MIW.

A pilot-scale bioremediation treatment system

was constructed to treat MIW emerging from a historical mine facility located in the southwest U.S. The acidic (pH ~3 s.u. and 8,500 mg/L acidity as $CaCO_3$) water contained elevated concentrations of aluminum (>900 mg/L), iron (>150 mg/L), copper (>900 mg/L), manganese (>500 mg/L), zinc (>300 mg/L), and sulfate (>16,000 mg/L), which was higher than what is typically treated using passive bioremediation. The treatment system consisted of three stages: pre-treatment, primary treatment, and post-treatment. The pre-treatment stage was designed to decrease iron and aluminum concentrations. The primary treatment stage consisted of a sulfate-reducing biochemical reactor (SRBR) to remove remaining metals and sulfate. The post-treatment wetlands were designed to remove manganese (Mn) and impart a final water quality polishing step. The treatment system was operated from July 2014 to November 2015.

Results indicated that metals and sulfate removal met treatment goals. Both calcium hydroxide [$Ca(OH)_2$] and limestone [$CaCO_3$] pre-treatment options effectively removed aluminum (>91%), iron (>99%), and copper (>72%), and significantly reduced the acidity and metal content of water to be treated by the SRBR. SRBRs removed iron, copper, uranium, cobalt, cadmium, and nickel below detection limits, in addition to removing up to 65% of sulfate. Post-treatment wetlands removed 70% of Mn, with the majority of the remaining metals sequestered in the wetland sediments. The results indicated that SRBRs and treatment wetlands are a viable option for highly-impacted waters characterized by elevated metal concentrations, significant metal acidity, and low pH.

Our findings also corroborate the conclusions drawn by other practitioners indicating that treating this type of MIW requires a very large footprint. It is therefore worth noting that inclusion of either pre-treatment option resulted in a >67% reduction in SRBR size required compared to no pre-treatment. Regardless, bioremediation systems are a viable technology for the treatment of a wide range of water chemistry on mine sites approaching closure. Furthermore, this study indicates that managing long-term MIW liabilities using passive treatment technologies at a site is a feasible option.

The development of a new peat-based weak anion exchange material that removes sulfate from acidic water

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ABSTRACT

Peat is a slowly renewable resource. Because of its limited availability, it is essential to add value to products that are produced from peat. Recently, we reported the development of three peat products for the removal of dissolved heavy metals: APTsorb II™, APTsorb III™, and APTsorb II*Na™ with Cd^{2+} breakthrough capacities of 13 mg/g, 16 mg/g, and 22 mg/g correspondingly. This research describes the development of a new peat-based weak anion exchange material that effectively removes sulfate and other anions from very acidic waters. For instance, such water can be found as a result of oxidation of pyritic materials producing acid mine drainage. The new material (APTsorbNH2) is created using the Duff reaction under modified conditions. We demonstrated that a reaction of a prepared surface of peat granules with hexamethylenetetramine formed amine groups instead of expected aldehyde groups. Moreover, a reaction of the prepared peat surface with an adduct of alkyl aldehyde and alkyl amine formed amine groups as well. Thus, a reaction of peat granules with an adduct of acetic aldehyde and methyl amine in water at 120°C for 17 hrs resulted in increase of nitrogen concertation from 3.1% to 5.28%. A reaction of peat granules with hexamethylenetetramine in water at 120°C for 17 hrs resulted in increase of nitrogen concertation from 3.1% to 7.12%. The new material has a measured total anion exchange capacity between 60 to 80 mEq/100g using both batch and column methods. The weak anion exchange properties were demonstrated in column experiments by loading the new material with a 0.1N solution of H_2SO_4 in water and successfully regenerating with a 0.1N solution of NaOH in water. It is believed that a lignin fraction of peat is responsible for a successful reaction of hexamethylenetetramine or an adduct of alkyl aldehyde and alkyl amine with the peat surface. A reaction mechanism and a new technique for measuring anion exchange capacity, as well as performance data using synthetic water, will be presented.

SESSION 3: WATER TREATMENT (2)

Alkaline Flush Technology: an In Situ Treatment Method for Mining Impacted Alluvial Aquifers

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ABSTRACT

Alkaline Flush (ALF) technology is a potential in situ remediation strategy for treatment of alluvial aquifers impacted by acid rock drainage (ARD) and historical mining activities. ALF involves introducing solutions with elevated alkalinity into alluvial aquifers to adjust groundwater and sediment pH, as well as modify the surface chemistry of sediments to limit the mobility of constituents of concern. Along with the reduction of acidity associated with groundwater and sediment, this technology may precipitate constituents of concern into stable mineral forms significantly reducing their aqueous concentrations over both the short- and long-term. Application of ALF technology may provide "enhanced attenuation" and "resiliency." Enhanced attenuation is the acceleration in treatment time achieved with ALF compared to natural attenuation, whereas resiliency is the capacity of the remediated system to resist future impacts after ending ALF treatment.

ALF has been extensively tested in the laboratory on alluvial sediments impacted by acidic and metal-rich waters using lab-scale column and pilot-scale tank experiments. The experiments consisted of three stages: equilibration of the sediments with mining-influenced water (MIW), treatment with an alkali-enhanced water, followed by a MIW/circumneutral rinse. The equilibration stage re-equilibrated the impacted sediments to site conditions (both sediments and water were collected from the same site). The treatment stage evaluated the effectiveness of alkalis and circumneutral waters in treating impacted sediments. The rinse stage was performed to evaluate the response of the treated sediments when a source of impacted or non-impacted water is introduced into the system after it has been treated. This final stage quantifies the acid and metals buffering capacity imparted to the sediments during the treatment stage. Alkali reagents such as sodium sesquicarbonate, sodium hydroxide, and calcium hydroxide, and circumneutral ground waters with alkalinity (expressed as equivalents of $CaCO_3$) range of 130-240 mg/L were tested in these experiments.

Based on the column test results, the potential benefits of using ALF technology are 1) reduced remediation time required to reach remedial action objectives and 2) resiliency of the treated system to resist re-acidification in the presence of MIW after treatment has been terminated. Laboratory results showed the effectiveness of ALF technology at neutralizing alluvial groundwater and sediment acidity as well as reducing aqueous metal concentrations to levels below remedial action objectives. This technology offers an opportunity for remediation of alluvial aquifer systems that may provide time and cost savings over those associated with other potential remedial alternatives.

Performance Review of a Passive Treatment System for Fe, As, Mn at the Empire Mine State Historic Park

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ABSTRACT

Empire Mine, located in Grass Valley, California, was one of the richest hard rock gold mines in California. Over its 106 year life, the mine produced nearly 5.6 million ounces of gold before it closed in 1956. The mine property is operated by the California Department of Parks and Recreation as Empire Mine State Historic Park and contains 367 miles of now flooded underground workings. While the mine was active, the Magenta Drain Tunnel (portal) was used to dewater the underground workings. Following the mine's closure, mining influenced water (MIW) continues to discharge from the portal. Flow rate from the portal varies seasonally and contains arsenic, iron, and manganese in excess of Federal and State primary and secondary drinking water standards. National Pollutant Discharge Elimination

System (NPDES) permit limits for arsenic, iron, and manganese from the portal flow are 10, 300, and 50 micrograms per liter (µg/L) respectively. A full-scale passive treatment system (PTS), which has been in operation since November 2011, was designed and constructed to treat MIW from the portal to meet the NPDES permit limits. The PTS consists of a 0.5 acre settling pond, followed by a 1 acre aerobic wetland, and a 1.2 acre horizontal-flow manganese removal bed (MRB). PTS flowrate varies seasonally, and has averaged 155 gallons per minute (gpm) with a peak of 1,200 gpm. Metal removal results in the system have improved over time, since startup, corresponding with maturation of the PTS. Since February 2013, the PTS has provided effective removal of permitted metals to trace levels. During this time arsenic, iron, and manganese in PTS influent averaged 75 µg/L, 5,492 µg/L, and 2,385 µg/L, respectively. PTS effluent averaged 3 µg/L, 34 µg/L, and 11 µg/L, respectively. In addition to metals removal, flow through the PTS has also provided the benefit of increased pH, increased dissolved oxygen, and reduced turbidity. Site background information and a review of PTS performance with respect to arsenic, iron, and manganese is presented.

Electrocoagulation (EC) for the Removal of Silica in RO Rejects from ARD Water Treatment

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ABSTRACT

Conventional chemical processes, such as lime treatment, are often employed for treatment of acidic rock drainage (ARD) streams. In certain cases, further treatment by a membrane separation, e.g. reverse osmosis (RO) or nanofiltration (NF), is necessary. Although high levels of water recovery can be achieved with NF/RO, a high salinity concentrate stream remains to be managed and/or treated.

During the NF and RO process, ions in the concentrate stream become increasingly concentrated. NF/RO concentrates from the treatment of acid rock drainage (ARD) water contain high levels various impurities—depending on the geochemistry of the waste rock and the treatment processes applied. Presence of cross-linked fine colloidal particles, especially silica, at certain levels in NF/RO concentrate streams can cause membrane fouling, a significant operational and water management challenge.

Electrocoagulation (EC) is a mature technology for many types of industrial waste water treatments. The technology can remove metal ions, colloidal suspensions, fine particles, and soluble inorganic pollutants from aqueous solution by introducing highly charged polymeric metal hydroxide species. In this paper, EC is explored as a treatment option for concentrated ARD water with focus on silica removal. Fe metal plates were employed as sacrificial electrodes. The experiments systematically investigate the influence of pH, dissolved oxygen (DO), current density (CD), and duration on the formation of green rusts (GRs) and silica removal. Batch tests have proved the concept that EC is a viable approach for silica removal from 80% RO reject water. Silica can be reduced from ~14 ppm down to ~3.0 ppm under 25mA/cm^2 current density for 60 minute or 12.5 mA/cm^2 for 120mins. This level of silica removal can alleviate the membrane fouling during subsequent NF/RO treatment. The DO level in solution has important influence on pH and water chemistry. It also governs ferrous or ferric or ferrous/ferric mixed GR generation and impacts the removal of silica in RO rejects from ARD water treatment. EC with ferrous green rust formation under lowest DO level is best for silica removal.

New Zero Water Intake Technology for Chemical Treatment of Mining Tailings

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ABSTRACT

Treatment of mine tailings commonly utilizes polymer flocculants and/or coagulants to enhance solid-

liquid separation. The preparation of these polymer solutions requires significant volume of water which, depending on the application, is recovered very slowly or may not be recovered due to evaporative losses. In addition, low quality (high fine solids content) water can potentially have a detrimental effect on polymer performance due to, for example, polymer being consumed by the fines in the water.

As a solution to this challenge, SNF has developed a new tailings treatment process which rapidly recovers a high volume of water from treated tailings. This process uses a combination of flocculants with different properties added in sequence to enhance dewatering performance as compared to a single flocculant treatment. The test results conducted on oil sands mature fine tailings have shown that initial (immediate) net water release was positive. It means that within a very short period of time, volume of water released from the treated tailings is higher than the volume of water used in the flocculant solution to treat the tailings. Furthermore, a quality of the water released was high with little to no fine solids and its reuse for preparing new polymer solutions has no negative impact on polymer performance. Water chemistry has also been found to be unaffected by this process. These potentially allow water to be recycled an unlimited number of times without affecting flocculant performance. As a result, high quality water is readily available to be recycled for preparation of more polymer solution. This new zero water intake approach effectively eliminates the need for water from other sources to be used for the polymer make-down, offering significant reductions in water consumption and capex and opex related to pipeline and water pumping energy. Finally, the Environmental impact of polymers used in the new zero water intake technology, particularly cationic polymer, is also discussed.

Containerized Water Treatment for Remote Mine Sites

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ABSTRACT

Although lime treatment remains the most common treatment method for mine impacted waters, there are instances where it is neither a good fit from a technical performance perspective nor is it the most cost effective solution. Depending on site specific requirements, the shortcomings of lime treatment can be any one of the following: difficulty to achieve ultralow discharge limits for certain metals and metalloids, inability to be deployed in a modular/ containerized fashion and high cost of managing waste sludge.

This paper describes the water treatment that was implemented at the Silvertip Mine located in a remote area of Northern British Columbia (BC). Although lime treatment was originally envisaged, the site water quality and discharge requirements combined with constraints in footprint and overall capital cost led to the adoption of sulphide precipitation as the treatment process of choice.

Sulphide precipitation is known to be a highly effective tool for achieving ultralow discharge limits in mining effluents and offers the possibility of a containerized mine water treatment design which:

- Minimizes capital costs and the need for skilled labour trades at remote project sites
- Reduces water treatment plant footprint
- Reduces the quantity of residue produced during treatment and enables possible value recovery

The Silvertip project was able to take advantage of all these benefits. The treatment process underwent regulatory reviews and performance demonstration which was required because the application at Silvertip was the first sulphide precipitation treatment system to be applied in BC. The success of Silvertip removes the need for pilot demonstrations for future projects where sulphide treatment may be considered.

To help reduce project risks and costs, BQE Water accepted full responsibility for water in the project, from the initial evaluation of treatment options and bench scale testing, through permitting, to the full scale implementation.

In-Situ Treatment of Arsenic in a Pit Lake: Case History

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ABSTRACT

Treatment and discharge is a fairly common element of mine water management plans. During closure and the post-closure period, it is preferable to eliminate or minimize treatment requirements. The former Royal Mountain King (RMK) Mine in California, in closure since 1994, requires long-term active water management. The water management plan includes storage of mine water in a pit lake with seasonal release of pit lake water under a discharge permit. The constituents of concern are Total Dissolved Solids (TDS) and arsenic.

To manage TDS, water is discharged using an automated system that precisely proportions the discharge flow to the flow of the receiving stream so that receiving water standards are met. Arsenic can largely be managed in the same way but because of pit lake concentrations and effluent limits, it controls how much water can be discharged. Therefore, reducing pit lake arsenic concentrations is necessary to maximize water released from the pit each year.

An in-situ treatment process for the pit lake was developed and has been in use since 2011. The treatment process is based on mixing a solution of ferrous sulphate into the pit lake. Treatment has been effective in reducing the arsenic concentration from 120 µg/L to less than 50 µg/L, which is approximately the concentration where TDS controls the discharge. Since 2011, there have been several refinements and improvements to the process, and some challenges to overcome.

This paper describes the water management and treatment processes, and identifies some of the more noteworthy refinements and solutions to challenges that we have experienced. In particular, this paper provides a discussion of the influence of pit lake stratification and arsenic speciation on the performance of treatment.

SESSION 4 - CHARACTERIZATION AND PREDICTION (1)

Characterising the Geochemistry of Soil and Water Using Drone based Hyperspectral Analysis

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ABSTRACT

Geochemical analysis through field samples and laboratory testing is a well-trodden method for understanding the composition of a soil and its contaminants. The limitation of this approach is in the spatial extrapolation of these diagnostic point-location samples. Over large areas such as operational and closed mine sites, sampling can be labour intensive and present potential Health, Safety and Environment protection issues associated with the sampling. Hyperspectral image analysis has been shown to identify an object's spectral composition and discretise it from its surroundings. This has the potential to aid the interpretation of mine water chemistry by interrogating the source-pathway-target relationship.

SLR Consulting Limited have been developing a methodology to assess the chemistry of soil and surface water using mounted hyperspectral sensors and to combine these to provide greater accuracy and precision insights across sites with known mine water contamination issues. The use of UAV-mounted Visible Near Infrared (VNIR) and Short-Wave Infrared (SWIR) sensors aims to deliver superior spatial and spectral resolution outcomes, compared to multispectral satellite or manned fixed-wing airborne hyperspectral data acquisition.

Through the use of case studies in Ireland and the US, SLR will seek to demonstrate the application of drone based hyperspectral analysis and also provide insight into the potential problems associated with the technique and how these can be overcome. The case studies present real data which has been successfully correlated with ground based analysis to such an extent that large areas can be surveyed. Preliminary studies compared RBG data with hyperspectral data

and demonstrate the difference which can be seen beyond the variation in colour detect in normal light.. In addition, interpretation of the data provided an initial assessment of elements which might be present in the waste rock and tailings, subject to the ground truthing.

The studies have shown that the use of drone based hyperspectral sensors provide an excellent potential for the surveying of mining land-use and mining legacy sites. The surveys provide benefits in supporting soil and water geochemical investigation at active and historic mining sites both in data acquisition and also area coverage. The application of change analysis to time variant surveys can also provide validation of mine closure plans, stability assessment and, in some cases, contaminant migration. The technique is also being considered for application in assessing closed landfill sites, radiation surveys and potential Unexploded Ordnance (UXO).

Approaches to Water Quality Modeling Using Geochemical/ARD Test Data in Conjunction with Field Analog Data

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ABSTRACT

Prediction of long-term water quality from mining operations is a critical component of environmental liability management at any mine site. Acid rock drainage (ARD) alone is estimated to contribute over US$100 billion in total worldwide liability associated with current and future remediation, with neutral/ alkaline metal impacted waters only driving these costs higher. The value that reliable water quality predictions can bring to a mining project beyond regulatory compliance (permitting and environmental impact assessments) is often underappreciated. Water quality modeling can guide the early implementation of effective materials (overburden, development rock, tailings, and heap leach materials) and water management practices as well as facilitate the design of water treatment plants at closure, thereby potentially reducing the overall project risks and future liabilities.

Various approaches to water quality predictions are viable depending on the mine lifecycle stage, site-specific conditions/risks, and objectives of prediction. These include, among others, development of spreadsheet models to predict elemental mass loadings, geochemical models, and coupled water balance/water quality prediction models. Prediction models are developed based on available geochemical/ARD test data (Net Acid Generation test leachate data, humidity cell elemental release rates, mineralogy, elemental composition, etc.).

The water quality predictions from these types of models, generally need to be 'scaled up' based on field data to provide estimates that are more representative of actual field conditions. Water quality data from field test pads provide excellent analog data to understand the scaling factors between the lab and field studies. However, these types of field-scale tests are time, labor, and cost intensive, and may not be an option for a given mine site or stage of the project. Depending on what data are available for a given site/stage of a project, the objectives of water quality predictions and the overall conditions/risks associated with the project, other types of field analog data may be effectively applied. These may range from seepage water quality from an existing stockpile within the site to mine water quality from another mine within the same mining district (similar lithology, alteration, and mineralogy). It may be possible to start with scoping-level water quality predictions when limited data are available and refine these initial estimates as additional field data become available.

The authors demonstrate through examples, a few approaches they have employed for water quality prediction using geochemical/ ARD characterization test data in conjunction with field analog data.

Predicted (post-closure) Contaminant Loads and Water Quality Conditions in Myra Creek, Nystra Myra Falls (Canada)

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Christoph Wels, Robertson GeoConsultants, Canada
Alexander Trapp, Robertson GeoConsultants, Canada
Nicole Pesonen, Nyrstar Myra Falls, Canada

Nyrstar Myra Falls (NMF) is an underground zinc mine on Vancouver Island, B.C. (Canada). In 2016, Robertson GeoConsultants Inc. (RGC) developed a water and contaminant load balance model to support the closure planning for the Old Tailings Disposal Facility (TDF) and a closure cover design for the embankment berm of the active Lynx TDF. The model was used to (i) simulate current impacts to groundwater and Myra Creek by Metal Leaching (ML) and Acid Rock Drainage (ARD) and (ii) predict future, post-closure water quality conditions as closure and progressive reclamation proceeds. This paper will describe RGC's conceptual load balance model and a numerical load balance model that was developed with the software GoldSim. The numerical model was calibrated to daily zinc (Zn) loads in Myra Creek from 2012 to mid-2016 and water quality data collected from within the mine site. Once calibrated, the model was used to simulate the improvement in water quality conditions in Myra Creek during the future operation of the Lynx Seepage Interception System (SIS) and after the Old TDF has been closed and the Lynx TDF berm has been raised to its final height and covered.

The Role of Speciation for Selenium Treatment and Compliance with Site-Specific Aquatic Life Criteria

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ABSTRACT

It is well-known that for many elements, static water quality guidelines can be over- or under-protective for aquatic life. A variety of site-specific factors may either inhibit or enhance the uptake and bioaccumulation of an element into aquatic organisms like algae, invertebrates, and fish. Regulators have recognized this issue for decades, promulgating guidance for the generation of site-specific contaminant limits and, especially in the case of selenium, tissue-based criteria that may be adopted by states or provinces. The Aquatic Life Criterion for Selenium released by the USEPA in 2016 recommends adoption of a multi-component standard for regulatory management of water quality, including limits on selenium concentrations in water, whole fish, fish muscle, and fish eggs or ovaries. While similar regulations in Canada remain under development, provinces like British Columbia have established tissue-specific guidelines for selenium. These criteria can add a high degree of complexity to controlling selenium discharge for companies involved in mining activities, particularly if measured tissue concentrations indicate that impairment is occurring. In such cases, investigations into the cause and potential corrective actions (treatment) are typically necessary. The mobility, treatability, and extent to which selenium is bioaccumulated in aquatic organisms are directly impacted by the molecular forms of selenium in solution. In chemistry terms, the different molecular forms an element can be present as is referred to as "species". Selenite and selenate (collectively referred to as inorganic selenium) are the most abundant, naturally-occurring soluble selenium species in most aquatic environments. Mining activities may release these species into wastewaters and, if left untreated, receiving waters. While conventional physical/chemical treatments are effective for selenite removal, biological treatment has been identified as the preferred treatment method for selenate by the USEPA. Such treatment systems can, depending on the operating conditions, induce formation of organic selenium species that bioaccumulate at levels significantly greater than those of the initial inorganic selenium species. Proper selection and maintenance of the treatment technology are therefore facilitated by speciation analysis, and in turn increase the likelihood that site-specific selenium criteria will be met. Furthermore, speciation analysis can elucidate the viability of applied preparatory and analytical methods for the measurement of total selenium.

Estimating Operational Groundwater Inflows to a Proposed Underground Coal Mine on Vancouver Island

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ABSTRACT

The Quinsam Coal Mine, located 20 kilometres west of Campbell River on Vancouver Island, was operated as an open pit and underground thermal coal mine between 1998 and 2014. In 2013, the operator sought to expand the existing 7 South underground mine into a new area termed 7 South Area 5 (7SA5). The expansion proposed to mine the No. 4 Coal Zone within the Dunsmuir Member of the Comox Formation via conventional room-and-pillar mining methods. The proposed mine resides in the eastern limb of the Quinsam Syncline, the north and south extents of which are truncated by regional scale faults. Depth of cover over the mine ranges from 28 to 90 metres. Exploration drilling logs indicated that a number of drill holes intercepted water bearing features with airlift yields ranging from 0.1 to 3.8 litres per second (l/s). These features were found to occur above the No. 4 coal seam in the southern portion of the mine, which, along with initial slug tests on monitoring wells, raised concerns about potentially large groundwater inflows to the development.

To facilitate estimates of potential mine inflows, a three-day 1.9 L/s pumping test was undertaken in the 7SA5 footprint which created widespread drawdown (anisotropy at "fault scale" producing an elongated drawdown pattern). The drawdown data were analysed using AQTESOLV and found to be most accurately represented by the Gringarten-Witherspoon analytical solution for fractured bedrock. Fracture hydraulic conductivity was estimated at $2x10^{-6}$ m/s while bulk rock hydraulic conductivity was estimated at $3x10^{-7}$ m/s. Given the relatively high permeability of bedrock in the 7SA5 area, it was considered probable that the hanging rock will dewater during mine development.

As such, the approach taken for predicting potential groundwater inflows during mine development was to determine how much pumping would be required to lower the hydraulic head in the mining footprint to within +/-10 metres of the No.4 coal zone within 100 days. Drawdown from the 3-day pumping test was projected to 100 days and recontoured to simulate the effect of a single well pumping 100 days. The 100-day drawdown cone was replicated over the mine domain, and through the principle of superposition, used to estimate the effect of multiple pumping wells. Ultimately, it was found that 5 wells pumping 1.9 L/s for 100 days would be sufficient to dewater the area above the workings, for a total pumping rate of 8 to 10 L/s.

SESSION 5 - OPERATIONAL WATER MANAGEMENT

Is water the best option? How to evaluate which fugitive-dust management practice is right for your site

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ABSTRACT

Throughout the mining industry, fugitive dust emissions may present various health and safety challenges, such as limited visibility and/or respiratory problems, and are therefore the subject of regulation at the local, State, and Federal levels. The use of water trucks has been a go-to method for controlling fugitive dust emissions on unpaved roadways and other source areas such as tailings facilities. However, as water becomes an increasingly scarce resource, is it always the best option? Several families of topical dust suppressants are commercially available, including resins, polymers, lignosulfonates, salts, and asphalt emulsions. There are also non-chemical management practices available including mulching, capping, and the implementation of administrative controls such as speed limits. Navigating the available options presents a challenge for mine-site decision makers.

This paper reviews several dust management strategies for light duty and haul roads, and tailings beaches. Drawing upon the author's experiences, it outlines a framework for evaluating the effectiveness and costs of alternative dust-management strategies. These include stakeholder discussions, laboratory tests for compatibility of any chemical dust suppressants with metal extraction processes and the environment, various field experimental design and evaluation techniques, and financial considerations. It is important to include as many voices as possible at stakeholder discussions. Dust management decisions

affect many departments within any mining operation and all need to buy in for a practice to be successful. It is imperative that any new suppressants used on site not adversely affect metal recovery or the environment (primarily air and water quality). Flotation and SX/EW compatibility testing on a laboratory scale look at metal recovery impacts while flux chamber and leaching procedures detect possible air or water pollution from dust suppressants. Field trials of dust suppressants are an important step in evaluating their overall performance within a given operation. However, the careful design of such trials is important to account for the many confounding variables present. The quantitative and qualitative metrics that can be used to judge product performance are discussed. Finally, it is important to recognize that dust management requires striking a balance between life cycle expenditures and regulatory compliance. Therefore, an accounting of direct and indirect dust management costs using water compared to other strategies will ultimately dictate whether an alternate management practice is worth pursuing.

Estimating the Wetting Time for Mine Waste Rock Piles

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ABSTRACT

Waste rock pile seepage effluent is typically of low quality and the timing of infiltration breakthrough has potential implications to site-wide water balances and costs associated with water management infrastructure such as effluent treatment plants. Flow through waste rock piles consists of surface runoff and infiltration into the body of the pile, and estimating the resulting flow beneath the pile is a challenging component of site-wide water balances. Runoff coefficients are often used to estimate the percentage precipitation that will be surficial and sub-surficial flow, however waste rock piles will typically go through a period of 'wetting-up' prior to breakthrough across the basal area of the pile. This wetting-up process typically takes many years and occurs as infiltration is initially stored within the pore space of the material. Steady state flow will occur once the infiltration and the unsaturated hydraulic conductivity profile of the material reach an equilibrium.

As water balances are required during feasibility and environmental assessment phases, site specific data are generally not available. Unsaturated flow modeling is required to estimate the 'wetting-up' times, and input parameters include soil moisture characteristic curves and unsaturated hydraulic conductivity functions. Material models have been estimated by others for waste rock piles and the variability of both has been observed, even within the same site. This paper presents a method of estimating the wetting time of a waste rock pile using 2-dimensional unsaturated flow analyses to for a feasibility study for a prospective gold-producing mine in Manitoba, Canada, with limited available material properties.

This work indicates that 2-dimensional analyses are useful to estimate the timeframe for pile wetting up, however early models will need to be confirmed using site specific unsaturated hydraulic conductivity parameters for the waste rock. These models can be obtained from particle size distribution data when available. Photographic procedures for estimating particle size distribution of waste rock have recently been proposed and may be useful where laboratory testing is not available or not practical.

3D Deposition and water balance modelling with Muk3D and GoldSim

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Miguel Palape Reyes, MineBridge Software S/A, Chile

ABSTRACT

GoldSim is a widely used simulation package that is frequently used in the modelling of water balances for mine sites and Tailings Storage Facilities (TSF). One limitation of GoldSim is that TSFs can only be represented as 2D structures using the available GoldSim modelling tools. Currently, water balance models of the TSF pond assume a constant tailings storage shape, notably a conical shape or the stage-area-volume curve of the last survey. They can also be comprised of a set of

stage-storage curves for the pond & tailings that are based on deterministic modelling. This is then applied to a long duration model. The result is that elevations and volumes predicted by the TSF model may not accurate and or relied on as a realistic prediction. Muk3D is a 3D modelling tool that simulates the filling of TSF's based on the geometric representation of tailings behaviour. As tailings surfaces are formed within the model, the interaction with the pond and the underlying topography is simulated, leading to more realistic deposition surfaces that can better predict TSF behaviour than 2D models. Muk3D does not include a water balance component in its modelling toolkit and so has always relied on the user entering relevant data about the behaviour of the pond when developing tailings plans.

This paper discusses how GoldSim and Muk3D have been integrated allowing for 3D tailings deposition to be incorporated into an existing water balance model. The difference in results between the 2D models for a TSF used in GoldSim and the same models run using a 3D deposition model are explored, and advantages & limitations of this approach are discussed.

Dust Mitigation using a Water Conservation Program

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ABSTRACT

When it comes to controlling dust at your operation, whether a mine, a batch plant or ancillary area, what are the options? We know watering alone is not the answer, but at the same time, we have an obligation to keep dust from flying to ensure a safe environment and keep our skies clear of pollution, for both regulatory requirements and our neighbors. Employing a water conservation program instead of looking to buy the first dust control product off the shelf is a first step to controlling dust and conserving water. Application calibration and methodology development at mining sites (Cripple Creek Victor Gold, Spence BHP Chile, and New Caledonia Nickel) provided test results that lead to the successful development and implementation of a water conservation program. With ease of access to a haul road for dust meter measurements, a water conservation case study in Larimer County Colorado provided quantitative results. This study is a collaboration of data collection and methodology refinement. Deployed in arid, semi-arid, and humid climates, the program results in water saving of 50 - 70 % as compared to dust mitigation by only water.

Biochemical cyanide treatment of gold mine tailings supernatant: Pilot and demonstration trials

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ABSTRACT

Two factors combine to make Kumtor's Tailings Management Facility (TMF) fairly unique: 1) the cyanide (CN) destruction circuit is located downstream of the TMF pond rather than in the mill; and, 2) water is not reclaimed from the TMF pond back to the mill due to the distance (~8 km) and elevation difference (~350 m). While the INCO SO2/ Air cyanide destruction process employed at the Effluent Treatment Plant (ETP) has been effective for 20 years, the ammonia produced by this process makes it challenging for Kumtor to comply with its Total Ammonia discharge criterion. To address this, the authors explored the viability of a biochemical cyanide treatment process referred to herein as the "cyanohydrin process". The primary benefit of the cyanohydrin process for Kumtor is that, unlike many other cyanide destruction methods, this process destroys cyanide without producing ammonia or nitrate. While Alexco has employed the cyanohydrin process at 15 heap leach sites, the authors are not aware of any full-scale application in tailings facilities. The cyanohydrin process occurs in two stages: first is the reaction of cyanide with aldehydes or ketones, where the carbon in the cyanide forms a covalent bond with the carbon in the aldehyde or ketone. The resulting cyanohydrin compound no longer measures as free, weak-acid dissociable (WAD), or

total cyanide. The second reaction is cyanohydrin degradation by microbes that subsequently use the cyanohydrin for both a carbon and nitrogen source to support their growth. By incorporating nitrogen from cyanide into microbial biomass, formation of ammonia is prevented while still effectively degrading the cyanide. This is different from conventional biological cyanide destruction which focusses on oxidative degradation of cyanide into ammonia.

Following preliminary testwork, the authors set up a series of pilot-scale tests at the mine site in 200 L covered barrels and 1 m3 Intermediate Bulk Container (IBC) totes exposed to the atmosphere in July 2017. The containers were filled with a mixture of tailings (fresh slurry from the pipeline with some mature solids and water from the TMF as a microbial inoculum), then dosed with varying amounts of glucose, fructose, and phosphorus; controls were also established. Over approximately 75 days of monitoring, barrels treated with amendments showed ~75% to ~90% removal of total cyanide (from ~60 mg/L to 14.5, and <5 mg/L), without the production of ammonia or nitrate. It is important to note that neither nitrite nor nitrate was formed, as these could represent degradation byproducts of ammonia. Moreover, dissolved oxygen measurements through the trials confirmed that the systems remained in aerobic, oxidizing ranges, confirming that ammonia was not converting to nitrate and then elemental nitrogen gas.

For the purpose of this manuscript, a representative trial that gave approximately 75% removal is presented as a typical conservative case. Trends for total cyanide degradation were similar to those of CN-WAD, therefore, discussions of cyanide in this paper are made in the context of CN-T and understood to be reflective of CN-WAD and overall treatment of cyanide. Throughout this manuscript, cyanide or CN refer to total cyanide. Following the pilot-scale testing in barrels and IBC totes, the authors undertook a full-scale cyanohydrin test in August 2017, with fructose and phosphorus being mixed and dosed in the mill, and all tailings produced in the mill during the 7.5-day test setup period (~170,000 m3) were deposited into an “Isolated Pond” within the permitted footprint of the TMF. This setup period was followed by 30 days of monitoring prior to freezing of the pond surface. Data from the Isolated Pond displayed the same trends as the barrels, if not accelerated. Cyanide concentrations were reduced by approximately 39% (from 91 mg/L to 56 mg/L). Of equal significance, ammonia concentrations in the Isolated Pond are essentially unchanged despite the substantial cyanide destruction. On the strength of the results of these studies, Kumtor implemented the cyanohydrin process at full-scale early in 2018. Performance will be evaluated later in the year.

Base Mine Lake: The first End-Pit Lake for the Alberta Oil Sands

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ABSTRACT

Alberta’s oil sands are among the largest petroleum deposits in the world, containing 300 billion barrels of proven reserves. Extraction of bitumen from surface mined oil sands generates significant quantities of fluid fine tailings (FFT) and oil sands process water (OSPW). Managing the inventory is critical to the sustainability of the surface mineable oil sands industry and has been subject to escalating focus by industry, regulators and stakeholders. One technology for managing both FFT and OSPW involves placing these materials into a mined-out pit, forming an End-Pit Lake (EPL).

More than 20 years of research, small-scale piloting in the Syncrude Test Ponds, and input from external experts has been used to design Syncrude’s Base Mine Lake (BML). BML is the first full-scale demonstration of water capping tailings technology, containing 186Mm^3 of FFT and 32Mm^3 of OSPW in a 50m deep, 7.7 km^2 mine pit. This presentation will provide an overview of BML and the monitoring program with subsequent presentations covering specific components of the BML Research program.

A Real Challenge in Mine Water Management in High Precipitation Area, Grasberg Mine

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ABSTRACT

The Grasberg Mine is the world's largest gold mine and one of the largest copper producers in the world. The mine poses a real challenge for hydrogeologists due to its size and complex hydrogeological setting, including structurally controlled groundwater flow. The mine sits in a mountainous area with rainfall of up to 5 meters per year. The site geology features highly undulated sedimentary rocks and vertical intrusions hosting the mineralization. Karstification exists in the area and influences structural control of the groundwater flow path in the vicinity of the open pit and underground mines.

The applied mining method for the Grasberg intrusive complex (GIC) also complicates water management. The existing open pit is approximately 1.5 kilometers deep and a block cave operation is under development approximately 400 meters (m) below the pit bottom. Block caving will propagate to the pit bottom eventually and will create a highly transmissive cave zone, which will connect drawpoints to the bottom of the open pit. Near the GIC, the East-Ertsberg skarn system (EESS) has been mined since 1982 by systems of five vertical block caves (GBT1, GBT2, IOZ, DOZ, and DMLZ). The implemented dewatering systems for both the GIC and EESS areas, with a total flow of approximately 41,000 gallons per minute (gpm) or 2.6 m^3/s, allows lowered water levels in vicinity of the open pit and underground mines by discharging groundwater via gravity by a system of upward drainholes drilled from the underground drifts.

To assist in the development of dewatering and mine water management strategies for the remaining life of mine, a comprehensive groundwater flow model was developed by using the finite-element MINEDW code and calibrated to the available flow and water level data collected over a 20-year period of active mining.

SESSION 6 - CASE STUDIES (1)

Challenges in containing geochemical risk at the Faro Mine Complex, Yukon

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ABSTRACT

Beginning in 1969, three decades of open pit mining and milling of pyritic sulfides at the abandoned Faro lead-zinc-silver mine produced long-term geochemical risk in the form of 55 million tonnes of acid generating tailings that are retained in a valley-fill impoundment. Geochemical risk from the tailings manifests not only as acid rock drainage that could progressively degrade receiving water quality over the course of years and decades, but also as low probability-high consequence events such as a flood-induced dam breach that would release geochemically reactive mine waste to the downstream environment. The Intermediate Dam, which is 650 meters long and 32 meters high, is the main geotechnical that ensures tailings and contact water do not migrate off site. Construction began in 1981, with the most recent raise completed in 1991, leaving a spillway that does not have the ability to pass a moderate or major flood without potentially overtopping and failing the dam. A project initiated in 2013 to design and implement an upgrade to the emergency spillway was unsuccessful because of insufficient integration between design and operations. The proposed spillway design eliminated critical storage capacity for contact water, increasing the likelihood of short-term environmental non-compliance.

Lime Treatment: Advantages of a Proven Technology and Competing Alternatives

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ABSTRACT

Precipitation of metal hydroxides using lime has traditionally been one of the most common treatment technologies used at mines sites for treatment of mining-impacted water. While lime treatment continues to have a place in the water treatment arsenal for mining applications, evaluation and implementation of other technologies is on the rise.

These alternative technologies include treatment processes that are proven in other applications but are “innovative” and “emerging” technologies for mine water treatment. Alternative technologies include membrane treatment, sulfide precipitation, electrocoagulation, and passive treatment, are increasingly being evaluated and implemented at mining sites. This paper compares lime treatment to alternative technologies for mine water treatment and presents a summary of indicator factors that can be used when considering alternative technologies. The drivers for lime treatment alternatives include regulatory changes to meet lower limits, limits on constituents not previously regulated, cost and operational factors, and technology improvements.

Even though lime remains a viable process compared to alternative technologies, and may provide an advantage over alternative technologies on a gross removal and cost basis, lower regulatory limits require evaluation of technologies that have not historically been considered or required for mining impacted waters. This paper presents the continued advantage of lime treatment for mining-impacted waters, such as: simplicity, chemical cost, and system flexibility. Where lime treatment alone used to be sufficient as a single-treatment approach, it is now often paired with additional treatment steps to accommodate lower regulatory limits. Increasingly stringent discharge limits may also result in treatment requirements for relatively clean sources of water that have historically not required treatment.

This paper touches on the need for additional treatment steps in less constituent-heavy water as an area where alternatives to lime treatment can be evaluated. The impacts of lime treatment versus other technologies on secondary waste, safety, and other operational factors is included in the discussion.

Hurricane Harvey Rainfall, Did It Exceed PMP and What are the Implications

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ABSTRACT

Rainfall resulting from Hurricane Harvey reached historic levels over the coastal regions of Texas and Louisiana during the last week of August 2017. Although extreme rainfall from this type of landfalling tropical system is not uncommon in the region, Harvey was unique in that it persisted over the same general location for several days, producing volumes of rainfall not previously observed in the United States and most of the world. Devastating flooding and severe stress to infrastructure in the region was the result. Coincidentally, Applied Weather Associates (AWA) had recently completed an updated statewide Probable Maximum Precipitation (PMP) study for Texas. This storm proved to be a real-time test of the adequacy of those values. AWA calculates PMP following a storm-based approach. This same approach was use in the Hydrometeorological Reports developed by the National Weather Service and is recommended by the World Meteorological Organization and Canadian Dam Safety. Therefore inclusion of all PMP-type storms is critically important to ensuring that appropriate PMP values are produced. This presentation will discuss the analysis of the Harvey rainfall using the Storm Precipitation Analysis System (SPAS) program used to analyze all storms during AWA PMP development, compare the results of the Harvey rainfall analysis against previous similar storms, and provide comparisons of the Harvey rainfall against previous and current PMP depths. Discussion will be included regarding the implications of the storm on previous and future PMP estimates, dam safety design, and infrastructure vulnerable to extreme flooding.

New tailings encapsulation methods could “pave” the way toward safe long-term stacking of filtered tailings

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ABSTRACT

Mine tailings are often stored underwater behind earthen dams; this is effective in the short term, but failure of these structures typically causes significant environmental damage. Dry stacking of filtered tailings is a promising alternative to traditional slurry tailings storage facilities, but with use-cases limited mostly to very arid locations. A widely applicable fail-safe solution is needed. Siderite ($FeCO_3$) encapsulation of tailings is one such alternative that may prevent filtered tailings from contaminating water in a broader range of climates by buffering alkalinity and preventing oxidation of the tailings.

To evaluate the preliminary feasibility of carbonate coating tailings, we synthesized siderite coatings (~10 µm) at room temperature using a novel system. We coated glass rods (100-200 µm) and assessed the stability of siderite coating material. As an indicator of water quality, we analysed iron content and pH of leachate from siderite immersed in sulphuric acid solutions (pH 2-4) for 300 days. This paper presents our findings and further research that will be required to evaluate this technique.

We were able to coat glass rods with siderite, which is a first step towards coating complex mineral surfaces. We found that the leachate from aqueous storage of siderite had moderate pH and extremely low total iron concentrations when the starting pH was 2.5 or greater and the water:rock ratio was 37.5. In both acidic aqueous and air storage, the siderite oxidized to goethite and ferrihydrite within a period of 300 days. In conclusion, siderite is a promising coating material that merits further investigation.

Future studies will need to consider the impact on coating integrity of anoxic storage and siderite conversion to ferrihydrite with oxic storage. During the transition of siderite to ferrihydrite there is potential for significant cation adsorption, which may have implications for improving water quality, but it is not yet known whether cation adsorption affects the maturation of ferrihydrite to more stable iron oxide phases that we consider likely to be suitable for long-term tailings encapsulation.

Enhanced Reclamation of the Giant Nickel Tailings Storage Facilities in British Columbia, Canada

Allison Brown, Barrick Gold, Canada

ABSTRACT

The Giant Nickel Mine (Giant Nickel) is located approximately 10 km north of the community of Hope, British Columbia, Canada and comprises a closed underground copper and nickel mine, mill and waste disposal facilities which were operated from 1959 to 1974. The Upper and Lower tailings storage facilities (TSFs) ceased operation in the mid-1970s and contain an estimated 4 to 5 million tonnes of mill tailings. A soil cover was placed on the tailings surface in 1995 and the site was revegetated with volunteer native plant species and deemed to be in a 'passive closure' state requiring no active management and limited monitoring. Barrick Gold Corporation (Barrick) acquired the closed property in 2002 as part of a merger with Homestake Mining Company (Homestake).

In recent years following the Mount Polley tailings dam failure, the British Columbia Ministry of Energy, Mines and Petroleum Resources (BC MEMPR) has required all active and closed TSFs in the province be evaluated for compliance with current dam safety requirements. In response to this directive Barrick initiated a holistic evaluation of the Giant Nickel TSFs and is updating the site closure plan to reflect the company's overarching goal of creating a stable, non-polluting landform with a beneficial end use. This evaluation focuses on several unique but related aspects, including: dam safety; tailings and construction material geochemistry (e.g. metal leaching and acid rock drainage potential); water balance; predictive long-term water quality; and, contaminant flow paths.

Results from environmental monitoring, water quality modelling and geochemical characterization are also being used to design a passive water treatment feature to polish perennial seepage from the Upper TSF prior to release. This represents an important improvement on previous reclamation efforts which considers input from regulators, community members and First Nations.

This project demonstrates that reclamation of older, closed mine sites can be enhanced, according to modern standards and best available technologies, to meet the social, environmental, and economic needs of the surrounding communities.

SESSION 7 - CHARACTERIZATION AND PREDICTION (2)

Use of Adaptive Management Planning in Support of Environmental Monitoring and Permitting Process

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Michelle Fraser, Stantec Consulting., Canada
Walter Sencza, Newmont Canada, Canada
Stephen Lines, Greenstone Gold Mines, Canada

ABSTRACT

An adaptive management plan (AMP) is an iterative decision making process that includes assessing the problem, designing a management plan, implementing the plan and monitoring, followed by evaluating and adjusting the plan based on the results. Involving the use of an AMP early in the permitting process allows the continuous re-evaluation of the monitoring program throughout the regulatory process and all phases of mine life in an effort to optimize the program by allocating resources to areas that are most informative.

In mining, it often takes time for environmental effects to be fully realized. During which, scientific knowledge and economic conditions change and technical solutions that might not have been economically or scientifically feasible at the time of the Environmental Assessment may now be practicable. Because of the uncertainties with changing economics and scientific knowledge, defining the triggers that require additional investigation and the decision-making process associated with trigger exceedances is critical for the protection of the environment. Subsequently, adaptive management planning can be used to determine the most effective contingency measures available at the time.

This paper will explain what an AMP is and how it could be used to provide flexible decision-making in the face of uncertainties. The use of the AMP over nearly four decades at the Newmont Golden Giant Mine and how it was used to adapt to changing phases of mine life (operation to closure), emerging issues, and to mitigate potential environmental effects from dam seepage will be presented. The content of a modern day AMP will be highlighted through examples of the Greenstone Gold Mines Hardrock Project.

Meteorological time series and natural runoff model in a cold climate environment

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ABSTRACT

Common issues with water supply estimation in remote mine sites, and with hydrology in general, are 1) a lack of observation data and 2) limited understanding of the uncertainty in results. These issues are addressed in a surface water runoff model at a mine site in central Yukon. Water management and water balance models require records of temperature and precipitation through local observations. The challenges faced in extreme weather environments often means increased missing data in the observational record. To address this challenge, a model was developed to patch and extend local weather observations and estimate the vertical temperature and precipitation gradients, using regional weather stations combined with reanalysis sources. Seasonally-dependent temperature gradients provide dynamic changes to temperature and more accurately model the common mid-winter valley inversions in the Yukon. The improved meteorological time series' were used to drive a semi-distributed, conceptual hydrologic model in the Raven platform to predict natural runoff to the mine site. The highly flexible Raven platform allowed for the selection of the most appropriate hydrologic processes for the mine site region. Even with better certainty in the meteorological input data, there is considerable uncertainty in the output of hydrologic models. This is often due to an incomplete characterization of the subsurface processes, and inaccurate representation of spatial variability of meteorological datasets. One way to quantify these uncertainties is through the Generalized Likelihood Uncertainty Estimation (GLUE) method. The GLUE method was applied to the hydrologic model for the Yukon mine site to produce hydrologic outputs which can generate upper and lower bounds of potential natural runoff. This uncertainty-based framework provides greater confidence in the predicted hydrologic impacts of climate change and forest disturbance on natural runoff at the mine site.

A New Rapid Brine Release Extraction Method in Support of Lithium Brine Resource Estimation

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ABSTRACT

Lithium brine mining via groundwater extraction and concentration in large evaporation ponds accounts for approximately half of the world's lithium production. Lithium brine mineral resources and reserves are typically located in large lacustrine evaporite closed basins (salt pans or salars) associated with high-angle faulting and hydrothermal fluids containing lithium migrating into the basins where they are concentrated by up to 2 orders of magnitude. Lithium concentrations can vary laterally and vertically across a lithium deposit and the host aquifers typically consist of highly heterogeneous layered sediments. Thus, knowledge of the relative lithium concentrations and the drainable porosity and potential flow contribution from the different lithological facies is essential for the resource estimation and to support groundwater modeling.

As a first step in determining economic viability, the lithium brine deposit is evaluated using statistically representative measurements of depth specific brine sample lithium concentrations, as well as core samples to determine drainable porosity (specific

yield) of the host aquifer materials. Whereas aquifer pumping tests can provide data on large-scale aquifer hydraulic characteristics, results typically cannot resolve explicit estimates of mineral grade and drainable porosity for multi-layer aquifer systems - such as lithium concentrations and specific yield of fine-grained hydrogeologic units versus coarse-grained hydrogeologic units. Consequently, brine mineral resource estimation requires supporting data from both field and laboratory testing programs to estimate the lithium concentrations associated with the various lithologies in concert with the ability to drain brine from the various lithological layers.

We present a rapid brine release (RBR) test based on a modified soil water characteristic curve (SWCC) method to determine specific yield characteristics of core samples collected during exploration drilling. The laboratory method takes less than one week and dozens of samples can be run simultaneously using various core sample types (i.e., sonic, HQ, PQ wire line diamond drill core,). To date this method has been used to determine specific yield characteristics on hundreds of samples from eight different brine deposits in North and South America. Case studies from Clayton Valley Lithium Project, Nevada, USA (Pure Energy Minerals) and Minera Salar Blanco (Maricunga Joint Venture Project), Chile are presented.

A comparison of predicted groundwater impacts to observed effects at the Victor Diamond Mine, 11 years after the start of dewatering

Simon Gautrey, Amec Foster Wheeler (Wood), Canada

ABSTRACT

The Victor Diamond Mine is an open pit mine located in the James Bay Lowlands, approximately 90 km west of the community of Attawapiskat and 120 km east of the Ring of Fire. Since early 2007, operation of the mine has been supported by dewatering of the limestone aquifers that surround the Victor kimberlites, but now the mine is about to close. Monitoring throughout the period of active mining documented the response of the local groundwater system to mine dewatering and can be compared to predictions of groundwater impacts made as part of the pre-mining Environmental Assessment process. This presentation will provide a summary of predicted groundwater impacts made prior to mining and compare them to the observed effects towards the end of mine life. The comparison will be used to assess how well hydrogeological investigations completed between 2004 and 2007 predicted impacts to the groundwater environment.

Cold Desert Evapotranspiration Cover System Design Evaluation

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Monisha Banerjee, GeoSystems Analysis, USA
Michael Milczarek, GeoSystems Analysis, USA
Clay Self, Round Mountain Gold Corp., USA

ABSTRACT

Round Mountain Gold Corporation (RMGC) mine is located in central Nevada, USA at an elevation varying between 1,770 m and 2,070 m above mean sea level. The climate is characteristic of a cold desert climate, with cool winters and hot summers. Average annual precipitation is 16.1 cm, approximately 10 times less than the calculated average annual potential evapotranspiration (PET) of 160 cm. RMGC constructed evapotranspiration (ET) cover system test plots in 2012 to evaluate the effectiveness of 0.3 m, 0.9 m, and 1.5 m thick monolayer ET cover systems in minimizing net percolation of precipitation into underlying waste rock. Each test plot is approximately 200 m2 and includes three cover system performance monitoring stations consisting of sensors placed at approximately 0.6 m intervals along a vertical profile in the cover and waste rock to a maximum depth of 2.4 m. The sensors measure soil matric potential, temperature, water content, and direct net percolation water flux. Soil water content and matric potential data are used to evaluate the cover systems' capacity to store infiltrated precipitation and to remove water via ET. Direct net percolation flux measurements are collected below the estimated depth of ET and these measurements provide a point estimate of net percolation flux into the waste rock. The site-specific seed mix applied to the test plots did

not establish, thus test plot vegetation is primarily comprised of invasive annuals Russian Thistle (Salsola tragus) and Halogeton (Halogeton glomeratus).

Annual precipitation from 2012 through 2017 was representative of long-term average precipitation conditions. Wetting was observed to a maximum depth of 1.2 m at the 0.3 m and 1.5 m ET cover system test plots. The deepest wetting (1.8 m) was observed in the 0.9 m ET cover system test plot due to focused run-on at the location of two of the three monitoring stations. At all test plots, drying of the soil profile occurred in late spring and early summer in response to decreased precipitation and increased ET. Net percolation flux into the waste rock was calculated based on measured soil water matric potential data and also directly measured via water flux meters. The average annual calculated and measured net percolation flux over the monitoring period was zero for the 0.3 and 1.5 m ET cover systems and 0.8% and 0.2% of precipitation for the 0.9 m cover system, most likely due to run-on to the test plot. The establishment of native vegetation, particularly deeper rooting shrub type vegetation, is expected to decrease the amount of net percolation. Results to date indicate no difference in the effectiveness of 0.3 m, 0.9 m, and 1.5 m ET cover system thicknesses in minimizing net percolation of precipitation into underlying waste rock.

SESSION 8 - WATER MANAGEMENT IN EXTREME CLIMATES

Incorporating Climate Variability into Water Balance Modelling to Help Inform Water Management Design: The Pebble Mine

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Jaime Cathcart, Knight Piésold, Canada

ABSTRACT

Water plays a key role in the operation of mining projects, and it is essential that water management facilities be designed to manage the inflows and outflows required for proper operations, as well as accommodate any unpredictable runoff resulting from storms events. The amount of water available varies by year, season, and day, so how do you design for this? Establishing a predictive water balance model during the mine design stage is one of the most important considerations for minimizing water management problems from occurring during the operation and closure stages for a project. The water balance model needs to simulate mine operations under normal climate conditions but also under unusually wet and dry periods of varying durations. Key water management planning may be driven by the spring melt of a winter snowpack in cold regions, the variation in snowpack accumulation, and the timing of the freshet season.

The current industry standard for introducing climate variability into water balance modelling is to model monthly precipitation values as distributions, which are typically based on the mean and standard deviation values of historical monthly precipitation. The water balance model is then run for thousands of iterations using Monte Carlo simulation techniques to produce a large range of potential precipitation conditions and corresponding results. This procedure is effective, but it has a major shortcoming in that it simulates precipitation in every month as being completely independent of precipitation in any proceeding or following month. Areas that experience strong climate cycles resulting in extended dry or wet periods may not be correctly represented by this type of modelling.

This paper presents a case study for the proposed Pebble Mine Project (Pebble) in Alaska and highlights the importance of a climate variable water balance model for informing the water management plan and design. The Pebble water balance model utilizes a 68-year monthly time-series of temperature and precipitation that was developed using a long-term regional dataset in combination with the extensive hydrometeorological dataset collected for Pebble. The time-series data were stepped through the model incrementally by year for the planned life of the project, thereby preserving the inherently cyclical nature of the climate record including wet and dry cycles, while creating 68 unique sets of water balance results for each month of each year of the project. The results were used to develop a robust

water management strategy that supplies sufficient water to maintain full mine operations, even during prolonged dry periods, and maintains downstream flow requirements for aquatic habitat and resources.

Effect of Variability of Design Storms on the Galore Creek Project

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Andrew Thrift, Teck, Canada
Yapo Alle-Ando, Teck, Canada.

ABSTRACT

The Galore Creek project ("the Project") is in Northwest British Columbia, within the territory of the Tahltan First Nation, an area characterized by significant spatial variability in precipitation. In this region, it is not uncommon for precipitation to vary more than 100% within a short distance. For Galore Creek watershed (Galore Watershed), which has a catchment area of approximately 140 km^2 and annual precipitation ranging from 1,300 mm to 2,500 mm, spatial variability of precipitation can have a significant implication on water management design parameters (design parameters). Therefore, the design storms on the site should consider, and incorporate, spatial variability of precipitation and resulting stream flow.

Spatial variability of precipitation at the Project is influenced by both regional and local factors. Regional factors are influenced by the Pacific Ocean and coastal mountains. The air masses from the Pacific Ocean bring precipitation to the coast. As storm air masses move inland, they are forced to rise due to the presence of coastal mountains along the windward slopes, resulting in widespread precipitation. This results in a regional trend of decreasing precipitation from southwest to northeast. On a local scale, precipitation is influenced by local topography and orientation of the Galore Watershed.

This paper focuses on the variability of rainfall. The local spatial variability of rainfall was measured using tipping bucket rain gauges and project meteorological stations. For Galore Watershed, rainfall decreases along a southwest to northeast direction, like regional precipitation. Based on the assessment, two sets of design storms were identified and estimated for the Galore Creek watershed, which could serve as input for estimating engineering design parameters for the project.

Hydrogeology Of The Coffee Gold Project: Groundwater Interactions In An Area Of Discontinuous Permafrost

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ABSTRACT

The Coffee Gold project is a proposed gold mine located in the White Gold District of west-central Yukon, approximately 130 kilometres (km) south of the City of Dawson. The Project comprises a complex of four open pits positioned at the height of land in an area of discontinuous permafrost. Multiple hydrogeological and geotechnical programs have been undertaken at the site to characterize the groundwater and permafrost regimes to support estimation of operational water management and effects assessment in the receiving environment. The well-developed monitoring network includes 7 Westbay systems, 11 conventional monitoring wells, 12 thermistor/vibrating wire combination installations, plus standalone thermistor strings and vibrating wire piezometers. The data indicate permafrost thickness ranging from largely absent on south facing slopes to over 160 metres thick on north facing slopes, with permafrost thickness decreasing with elevation. Groundwater levels in ridge areas, coincident with mine infrastructure, range from 220 metres below ground surface to artesian conditions. Groundwater level hydrographs are observed to fluctuate by up to 30 metres at some locations. Hydraulic conductivity data range over several orders of magnitude, typical of a fractured bedrock system. Mineralized structures and creek traces represent areas of enhanced hydraulic conductivity. The data from these programs and others have been used to develop a conceptual model of groundwater flow at the site. This conceptual model has informed the

development of a steady-state groundwater model developed using MODFLOW-2005. The permafrost distribution was incorporated into the structuring of the groundwater model which was calibrated to water levels and creek baseflows. The results of the groundwater model indicate that seepage losses from pit lakes to groundwater are modest (4 litres per second or less) during post-closure with pit groundwater inflows influenced by runoff accumulation in nearby pits. Overall, impacts to baseflow in receiving drainages is small and within measurement accuracy.

Numerical Groundwater Flow and Thermal Transport Modeling in Cold Regions

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ABSTRACT

Groundwater inflow estimation to mine pits in cold regions is one of the many challenges in mine development projects. Pit groundwater inflow can be estimated using a numerical groundwater flow model that is developed for the mine site. Such groundwater flow modeling is commonly simulated under steady state conditions. In northern cold regions, groundwater flow modeling approach for estimating pit inflow is difficult due to freezing of the pit wall during winter periods. Sub-zero air temperatures can freeze the pit wall, which, in turn, reduces the hydraulic conductivity the pit wall to practically zero. The frozen ground with near zero hydraulic conductivity will prevent groundwater inflow into the mine pit.

The paper discusses application of a freezing and thawing module built in a three-dimensional groundwater flow and thermal transport FEFLOW model to predict groundwater inflow rates into the mine pit. A series of simulation runs from simple one dimensional steady-state modeling to more complex three dimensional, transient, variably saturated groundwater flow and thermal transport modeling with water-ice phase change was completed. The following four modeling scenarios were evaluated: steady state saturated unconfined aquifer, transient saturated groundwater flow, transient variably saturated flow, and transient variably saturated flow and thermal transport with freezing-thawing module. The results of groundwater inflow simulations obtained from one excavation site in Winnipeg area and an open pit mine in Northern Manitoba are presented and discussed in this paper. Significant reduction in pit groundwater inflow estimation was observed for the open pit mine using frozen walls in comparison to the standard groundwater flow modeling approach.

Changing Effluent Regulations in Canada, Helping Mine Sites to Reach New Limits

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ABSTRACT

In 2018 Environment and Climate Change Canada (ECCC) is planning to release the final version of the Metal Mining Effluent Regulations (MMER). This will be the first extensive update to the MMER since they were conceived in 2002. The updated regulations have new or more restrictive limits for key contaminants of concern to many mining operations in Canada. These include un-ionized ammonia, arsenic, cyanide, lead, and others. As well, changes to evaluating the toxicity of effluents being discharged to saline waters are being considered.

Analytical laboratories play an important role in supporting mining activities in Canada. Laboratory test results are used to demonstrate and record regulatory compliance, and to make critical decisions during mine operation and mine closure. To adequately support mining operations and meet the regulatory requirements governing them, the need to measure metal concentrations in a variety of sample matrices at ultra-trace (sub-part per billion and in some instances, sub-part per trillion) levels continues to challenge the industry. With the new limits being proposed in the MMER updates, mine sites may need to include ultra-trace analytical capabilities in their monitoring programs.

New analytical technologies that support higher sensitivity (lower detection limits), increased data reliability, and lower costs, are available. The demand for ultra-trace level metal analyses has spawned new analytical technologies: ICP- mass spectrometry (ICP-MS); and ICP-tandem mass spectrometry (ICP-QQQ). A review of these technologies and their applications will help mine sites to choose what will work best for a specific site or monitoring program.

New challenges that could impact the compliance of regulatory monitoring programs are emerging along with the demand for lower detection limits and new technologies. Contamination of samples and diligent protocols for sample handling and processing will be important to mine sites that are required to meet more stringent discharge limits.

SESSION 9 - CHARACTERIZATION AND PREDICTION (3)

Richmond Hill Mine Heap Leach Pad Soil Cover System Evaluation

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ABSTRACT

LAC Minerals operated the Richmond Hill mine located in the northern Black Hills from 1988 to 1993 using conventional heap leach technology. Following active mining, LAC Minerals began reclamation actions in 1994.

The mine facilities were located in an area of relatively rugged terrain. Annual and daily temperature variations can be extreme. Annual precipitation and potential evapotranspiration average about 0.73 and 0.90 m (29 and 36 inch) per year, respectively.

The Richmond Hill Mine heap leach pads (HLPs 1&2, and HLP 3) were reclaimed in 1996 using a three-layer evapotranspiration (ET) cover designed to limit meteorological infiltration through the facilities. HLP seepage outflow rates have been measured on an approximately weekly basis from December 1996 to present. Large seasonal and wet/dry outflow cycles have been observed. Several years after the cover system installation, increased HLP drainage rates were observed, which could be due to increased permeability of the compacted layer in response to pedogenic processes such as wetting/drying, freeze/thaw, and root development.

The estimated net infiltration rate through the multilayer cover system during the monitoring period is about 34% of precipitation, which is well within the range of observations from other studies. To evaluate the cover system efficiency, a monthly time-step, spreadsheet based, parsimonious water balance model was created. The model considers close inter-relation between precipitation, ET and cover net infiltration on a monthly scale and continuous feedback of water movement in the soil-plant-atmosphere continuum. The model accurately reproduces the recorded seepage rates for the monitoring period after pedogenic processes ceased.

The revegetated and reclaimed Richmond Hill Mine heap leach pads have been monitored for a relatively long term period. Results from 20 years of cover system monitoring provide a general review of ET cover system performance for closure of other comparable facilities, and offer guidance for ET cover system requirements in other areas with similar climate.

Dependence of Predicted Dewatering on Size of Hydraulic Stress Used for Groundwater Model Calibration

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ABSTRACT

Accurate predictions of long-term dewatering requirements by groundwater models depend on the quality of calibrated hydraulic parameters and boundary conditions. The latter is very important for large scale dewatering projects when drawdown

propagates a significant distance away from the mine area and predicted mine inflow/dewatering rates predominantly depend on the hydrogeologic behavior of the model boundaries.

This paper presents the results of a multiyear data collection and groundwater modeling study to define large scale dewatering requirements for a mine project in a complex hydrogeologic setting characterized by large bedrock transmissivity and groundwater storage, high recharge from precipitation, and the presence of leaky lateral and vertical boundaries. Over a period of 5 years, dewatering requirements were evaluated for scoping, pre-feasibility, and feasibility studies using a groundwater model calibrated to various hydraulic stresses including short-term hydrogeologic testing in geotechnical boreholes, 2 to 3 day airlift tests, 5 to 14 day pumping tests in prototype dewatering wells, one year of highly variable flow and water level data obtained during exploration decline (initial mine) dewatering, and observations of groundwater recovery once dewatering ceased.
Based on the size and length of the hydraulic stress applied to the groundwater system and observed responses, a series of conceptual and numerical models were developed for the project.

When new data were obtained, an iterative approach was used to evaluate the robustness of the model calibration, assess the validity of the conceptual model, and revise to the predicted dewatering requirements. In total, the groundwater model was recalibrated five times to account for new data. The process required revising the conceptual model with regards to transmissivity, vertical hydraulic conductivity, groundwater storage, recharge from precipitation, and boundary conditions. Dewatering predictions were completed for two mining methods (block cave and open pit) and the high variation in predicted dewatering requirements highlights the importance of understanding vertical recharge to the groundwater system and the hydrogeologic role of lateral model boundaries. In complex hydrogeologic systems, these two factors cannot be precisely evaluated based on short to intermediate-term hydraulic testing; model calibration to long term testing provided superior input to the conceptual models and resulted inore defensible mine dewatering predictions. Predictability of the final version of the model was verified by reproducing groundwater recovery observed during flooding of the exploration decline.

Novel Use of the Westbay System to Characterize Deep Hydrogeology for a Proposed Underground Coal Mine

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ABSTRACT

A deep hydrogeology site investigation was recently completed for a proposed underground coal mining project in northeastern British Columbia. Central to the study was the installation and operation of two MP38 Westbay Multilevel Groundwater Monitoring System Completions (Westbay Systems™), one 980 m long and the other 716 m long. Innovative uses of the Westbay Systems provided for efficient hydraulic testing and collection of groundwater samples.

Shut-in methods were used to conduct hydraulic tests in lower hydraulic conductivity zones in the Westbay Systems. A theoretical foundation for shut-in testing has been established in the literature, and in this article we describe an adaption of this theory for use in the plastic Westbay System. Performing hydraulic tests under shut-in conductions allowed estimation of hydraulic conductivity over a range from 10-8 m/s to 10-12 m/s in a small fraction of the time required under open water column conditions.

The primary challenge confronting collection of groundwater samples in deep boreholes is the level of effort required to remove drilling circulation fluid first. In our study, we made use of the natural vertical hydraulic gradient to purge drilling fluid from borehole intervals near the depth of mining into a shallower “dump” zone. The purging process occurred without operational or maintenance needs for several weeks, followed by collection of depth-representative groundwater samples. The deep groundwater was shown to have elevated salinity, which resulted in mine inflow water quality being a significant consideration in discharge water quality predictions and site water management planning.

Groundwater Discharge Into Tailings Facility During Intense Precipitation Events, Nyrstar Myra Falls

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ABSTRACT

Nyrstar Myra Falls (NMF) is an underground zinc mine on Vancouver Island. In 2014, groundwater discharge was observed at surface along the northeastern perimeter of the Old Tailings Disposal Facility (TDF). Flows of groundwater occurred at several discrete locations, including the so-called "Main Spring". Flows from the Main Spring flooded a portion of the Old TDF and were identified as a potential dam safety issue to be addressed for closure of the facility. A hydrogeological investigation was therefore conducted in 2015 to determine the factors controlling the discharge of impacted groundwater during periods of intense and prolonged rainfall.

The groundwater flow regime in the natural hillside along the northern perimeter of the Old TDF is highly transient due to steep gradients and rapid recharge from the upper catchment during high precipitation events. During high precipitation events (say >50 mm), the capacity of the natural soils and mine waste on the northern hillside to transmit groundwater downslope is temporarily overwhelmed and groundwater levels rise quickly. When this occurs, mine waste materials are flooded after the storage capacity of natural soils has been reached. This effect is pronounced in areas where tailings, which have very low permeability and essentially no available storage, were placed directly against the natural hillside, and therefore represent a hydraulic barrier. This rapid rise in groundwater levels behind the tailings deposit gives rise to significant discharge (up to 100 L/s) of groundwater impacted by contact with mine waste material. The findings of this study informed the design of improved operational water management and closure planning for the Old TDF.

Multi-Parameter Time-Lapse Dam Seepage Investigation

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ABSTRACT

A mine water seepage investigation on a small collection reservoir and dam utilized multiple lines of evidence during a baseline and rising head test to increase levels behind the dam to determine seepage pathways. A baseline sweep of measurements (groundwater elevations, water quality sampling, electrical resistivity surveys) was completed prior to starting the rising head testing. The monitoring sites consisted of multiple well locations and electrical survey lines downstream of the dam as well as along both abutments and up gradient of the reservoir. The rising-head test consisted of a series of six distinct step changes to the reservoir level occurring over a time frame of approximately one month. The step changes ranged from 0.5 meter rise (at the beginning of the test) to 1.5 meters for the last step. Water levels and water quality were monitored at the wells continuously during testing and weekly electrical resistivity surveys were completed.

Results of the testing included changes in water levels and water quality at downstream wells over time that mimicked changes in reservoir elevations. Time-lapse changes observed in subsurface resistivity (resulting from changes in water level as well as fluid conductivity) highlighted the spatial extents of the seepage beneath and around the dam. Two primary mechanisms were subsequently identified as controlling the overall flow of groundwater in the vicinity of the dam. 1) Dam Bypass: Some impacted groundwater migrates downstream of the dam along fracture pathways that are not in communication with the reservoir. 2) Direct Seepage: The cause of seepage is not related to a distinct defect or weakness in the dam structure. Instead, seepage from the reservoir is occurring along multiple flow paths. Seepage migrated around the right abutment, beyond the extent of the grout curtain as well as through the central and possibly right upper portions of the grout curtain. Additional seepage pathways were identified beneath the grout curtain. Based on the findings from the seepage investigation, installation of pumping containment systems both upstream and downstream of the dam were recommended. The system consists of three downstream and four upstream pumping

wells and six monitoring wells. These wells will reduce groundwater flow bypassing the dam, and capture seepage coming directly from the reservoir. The spatial extent of the seepage from around the dam, as identified by the geophysics, guided the ultimate placement of the seepage collection wells.

SESSION 10 - CASE STUDIES (2)

Application of SAGR Bioreactors for Ammonia Treatment in Mining Effluents

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ABSTRACT

Ammonia treatment is a growing concern in the mining industry. Ammonia is commonly found in mining effluents as a byproduct of cyanide degradation, and as a residual of blasting compounds. This paper explores the application of the Submerged Attached Growth Reactor (SAGR) in mining effluents, in particular in cold climates, exploring the fundamental principles and related experience from other sectors. The SAGR under construction at the subject site of this paper will be the first implementation of the technology in a mining context.

Towards a Conservative Mine Design Practice through Probabilistic Calibration

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ABSTRACT

Conventional groundwater model calibration is typically a deterministic process, whereby a set of unknown inputs are adjusted to minimize the difference between the measured and modelled outputs. The product is often a single, calibrated model used for subsequent decision analysis. However, However, such an approach can result in overfit models due to the stochastic nature of the inputs, and the state of incomplete information (i.e. limited number of hydraulic tests, variable recharge, etc.). To deal with this uncertainty, alternative Bayesian approaches are available that utilize stochastic learning techniques to find the probability distribution of both the inputs and outputs.

This paper explores the concept of probabilistic groundwater model calibration using the stochastic learning technique known as Markov Chain Monte Carlo (MCMC). Examples of the approach are presented for groundwater models at the preliminary economic assessment (PEA) and pre-feasibility study (PFS) levels, to predict both long-term inflow and drawdown trends. Results suggest that improved predictive abilities can be achieved using the proposed approach, with uncertainties explicitly quantified through the generation of multiple calibrated models. The broader implications of the Bayesian approach are then discussed, with the idea of ultimately applying it across the multiple disciplines involved in a mine design study.

Mixing Zone Assessment for Mine Effluent Discharges in Receiving Waters: Challenges and Solutions through Best Practices

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ABSTRACT

The assessment of a mixing zone is an important component of the aquatic impact assessment of effluent discharges from different water management facilities (e.g., tailings ponds, sedimentation ponds, pit lakes) of proposed, existing, and legacy mines into receiving waters. A mixing zone is an area adjoining the discharge point where the water quality objectives for one or more parameters, based on chronic exposure, may be exceeded locally. Mixing zone assessment for a discharge entails the evaluation of its physical extent, and biological and chemical

influence of the discharges in the zone. Different regulatory agencies provide standard technical guidance for conducting a mixing zone assessment by devising a field program and/or using modelling tools. However, there are key challenges associated with the practical application of the technical guidance using either approach (i.e., a field program or modelling); these challenges can be successfully navigated through the use of best practices.

This study describes several case studies of mixing zone assessments for different types of mine effluent discharges that include two types of discharge configurations (e.g., shore-line discharge through a channel and a multi-port diffuser), two receiving water types (lakes and rivers), and different chemical compositions of the effluent. Standard effluent plume delineation techniques, such as field tracer study (adding a tracer or using a tracer that is already present in effluent) and mixing zone models were applied in these studies. An analysis of the challenges and possible best practices to implement these studies in different mine sites are also presented. Further, research on the development of new modelling tools that will streamline the mixing zone assessment is identified.

Investigation of Feed Water Treatment Options in an Arid Area

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ABSTRACT

A water treatment option was required to provide feed water for a mine in an arid area in Africa. The required feed water needs to have a quality of 200 mg/L or less of chloride with a flowrate of 1,200 m3/hr. Constraints existed not only with respect to the available source of raw water, but also in terms of the available alternatives for the ultimate disposal of waste streams.

The two technically and economically viable options, Ion Exchange (IX) and Reverse Osmosis (RO), were compared. Two types of source water, brackish water RO (BWRO) and sea water RO (SWRO), were selected and investigated. The waste disposal alternative with the least environmental issues is the Zero Liquid Discharge (ZLD) arrangement. Different variations of ZLD including an evaporator, crystallizer, and solar evaporation pond were investigated. The evaporator of choice is a vertical falling film mechanical vapor compression type. Vertical falling film evaporators have a very good reputation in industrial areas. Mechanical vapor compression was selected as the source of energy for evaporation because steam was not available at site.

To determine if the solar evaporation was a viable system, the evaporation rate in the area was estimated and the precipitation records were obtained. A decision matrix was developed to quantify the advantages and disadvantages of the different options. A partial ZLD system (Low Liquid Discharge system) including an evaporator and crystallizer was adopted for the design.

Implementing a Long-Term Water Management Strategy for Mine Closure in Northwest British Columbia

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ABSTRACT

The Premier Gold Mine, near Stewart, British Columbia, ceased mining operations in 1998. Since then, closure activities have included stabilization and revegetation of waste rock dumps, treatment of discharge from the underground mine, and upgrades to the Tailings Storage Facility (TSF). This paper focuses on the on-going implementation of a long-term water management strategy for the TSF and related components, in a wet environment, receiving an average of 2,200 mm of annual precipitation. Additional consideration is given to treatment of underground mine discharges and management of the resulting water treatment sludge.

Site-specific challenges include (a) ML/ARD from contemporary and historical mining activities on the site dating back to the 1920s, as well as PAG tailings and waste rock, (b) a wet environment subject to extreme

storms and high peak flows, and (c) topographic and geologic constraints, including scarcity of construction materials and geohazard risks associated with steep, rocky terrain. Sources of ML/ARD for the site were characterized through site-wide hydrologic and water quality modelling assessments. These were used to identify and quantify sources of chemical mass loading from historical and contemporary mining activities, and to assess the impact of proposed water management plans and external influences such as upstream hydroelectric developments and climate change. Measures that mitigate ML/ARD risks include (a) design and implementation of a water cover and rockfill blanket to prevent oxidation and mobilization of tailings within the TSF, (b) reconstruction of water treatment sludge clarification ponds, and (c) on-going development of a long-term water treatment sludge management plan that accounts for the possibility of perpetual water treatment from underground workings. Flood management measures include design and construction of a TSF closure spillway in bedrock, implementation of stabilizing measures on the TSF dam and decommissioning the existing fuse plug spillway. These measures are designed to safely route peak design flows in excess of 500 m^3/s without compromising dam stability. Much of the site is characterized by high geohazard risks due to steep, rocky terrain and frequent rockfall. The water management plan was designed to (a) eliminate reliance on diversion channels and access roads that are subject to risk of failure due to rockfall, and (b) facilitate safe monitoring and sampling in key discharge areas. This includes construction of an upgraded TSF seepage monitoring system, allowing safe measurement and sampling of seepage, as well as scaling and ongoing monitoring of high-risk rock surfaces.

Geohazards, steep topography and scarcity of suitable granular construction materials introduced additional challenges to the design and construction of water management infrastructure. However, the development and on-going implementation of water management solutions at the Premier Gold Mine has achieved the desired outcomes, by meeting challenges with suitable solutions.

NOTES

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