Similarities in Mine Water Management Challenges in Polar and Desert Climates: Two Case Studies

Houcyne El Idrysy

SRK Consulting (UK) Ltd, 17 Churchill Way, Cardiff, United Kingdom, hidrysy@srk.co.uk

Abstract Water resources availability and management in extreme climates are usually challenging for mining projects. The present paper focuses on two extreme conditions: the desert and the polar (Tundra subtype) climates. Despite the obvious difference between these two extreme conditions, water resources availability and management for mines in both climates show some striking similarities that may seem surprising. Such similarities relate to the following aspects especially:

- Atmospheric precipitation patterns
- Water inflows into mines
- Tailings management
- Water supply and groundwater quality

This paper illustrates the above similarities with two case studies.

Key words Extreme Climate, Permafrost, Desert, Mine Water Management, Water Supply.

Introduction

Water management in polar and dry climates (Belda et al. 2014) entails specific challenges to mining projects. The rainfall scarcity and sharp seasonal fluctuation in these climate conditions make mine water supply difficult and therefore the mine project development requires rigorous measures to minimise the use of water and maximise its recycling to fulfil the water demand. Such stringent requirement has a direct effect on the selection of the appropriate approach to tailings management, as well as the identification of the water supply source.

To illustrate the mine water management challenges and similarities in these two climates, this paper presents a polar climate project in Russia and a dry climate project in the Sahara Desert. To ease reference for the reader, since the project in Russia is in a polar (Tundra subtype) climate with a thick permafrost layer present, the project will be referred to here as the "permafrost" project and the second project will be referred to as the "desert" project.

Discussion

Project location and summary

The locations of the two projects presented in this paper are shown in Figure 1 and photographs of the landscape of each site are presented in Figure 2. This paper is based on the findings of the mine development Feasibility Study (FS) for both projects.

The permafrost project (the Mangazeisky Silver Project) is located some 400 km north of Yakutsk in Russia (Figure 1). It is a combined open pit and underground mining operation with the open pit mining comprising a small open pit of approximately 90m depth and a few narrow trenches up to 30 m deep. Topographic elevations in the project area range from approximately 1240 m above sea level (masl) at the high ridge near the proposed mine, to 840 masl at the adjacent valley floor (Figure 2). The streams are characterised by steeply dissected valleys. The site catchment belongs to the basin of the Yana River, which flows north into the Laptev Sea. Surface water flow in the area ceases during the winter season due to the freezing temperatures, which cause the formation of ice along the river and stream beds.

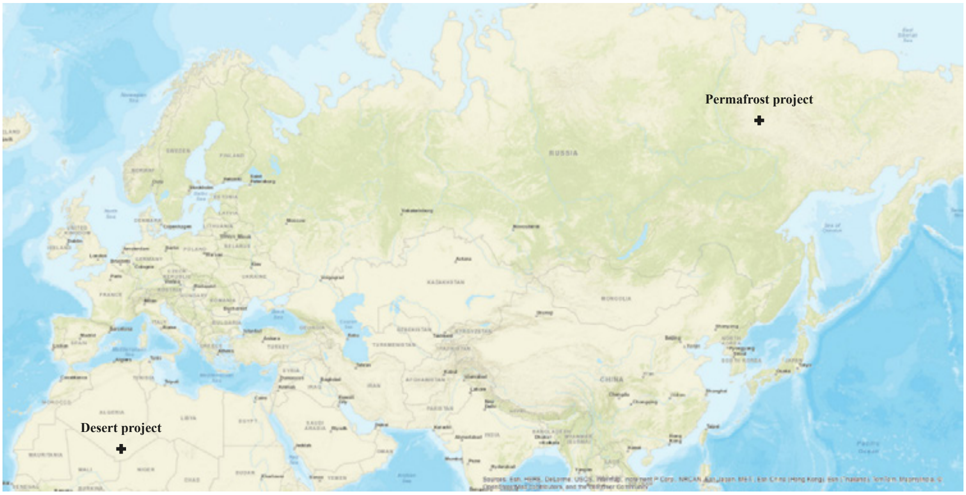

Figure 1 *Approximate locations of the two projects*

The desert case study is the Nahda Tungsten underground mine Project, located in the barren Tanezrouft region of far southern Algeria, a region that extends along the borders of Niger and Mali, west of the Hoggar mountains. The terrain of the desert project is generally flat and sandy with some rocky outcrops in the north-western part of the concession (Figure 2). The elevation of the permit area varies between 545 and 728 m above mean sea level (masl). Wadis in the local area serve as witness to historic water erosion when the Sahara Desert's climate was wetter. Wind erosion is currently the main driver of the landscape structure and due to the absence of dense vegetation the landscape is more prone to erosion.

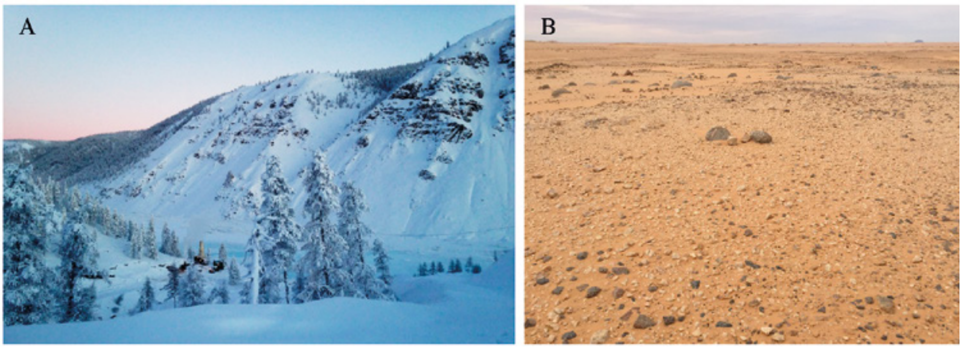

Figure 2 *Views of the two sites: (a) the permafrost site in February and (b) the desert site in January. (source: Author's photos from site visits)*

Atmospheric precipitation pattern

A global map showing the pattern of average annual precipitation worldwide is presented in Figure 3 (Evans 1996). This map illustrates the striking similarities between the desert and polar Tundra subtype climates with respect to atmospheric precipitation over the year which is very low in both regions.

Accordingly, the desert climate, which occurs in arid areas such as the Sahara, is characterised by high air temperature and low atmospheric precipitation. The permafrost areas, which have a polar type of climate in cold regions such as Siberia and north of Canada and Alaska, also show low atmospheric precipitation but low air temperature. Weather station records show that the amount of rainfall is less than 250 mm per year in both the permafrost and desert areas. The annual average rainfall in the Algerian Desert is generally below 100 mm in the northernmost part. The scarcity of rainfall is aggravated by its irregularity. The presence of slow but constant winds exacerbate the dryness and aridity of the Sahara by causing enhanced rates of evaporation.

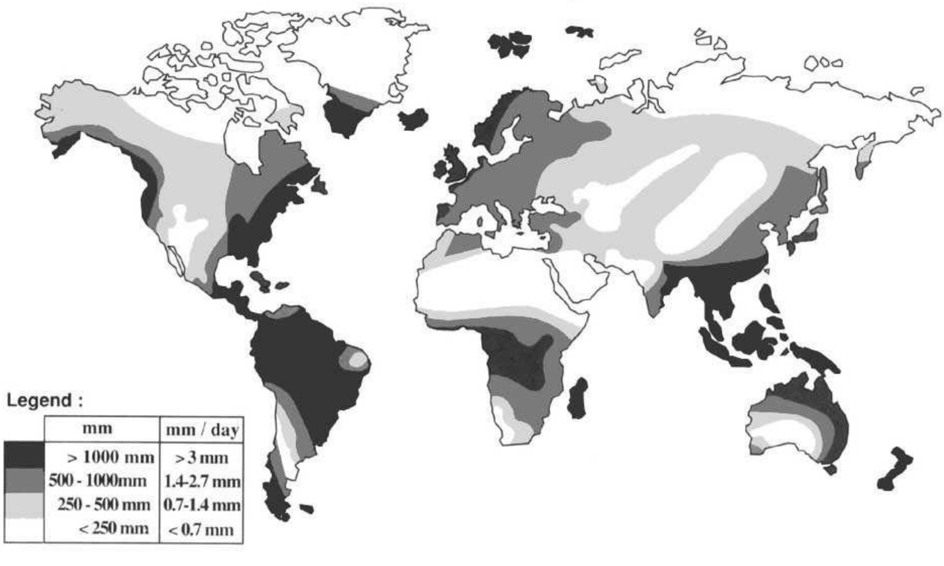

Figure 3 *Global map of average annual precipitation (source: http://www.fao.org/docrep/w5183e/w5183e01.jpg).*

The nearest weather station precipitation and temperature data from the Global Historical Climatology Network (GHCN) were used in the analysis for both projects. The data were obtained via the U.S National Oceanic and Atmospheric Administration (NOAA) website (NOAA, 2015).

In the permafrost project area the two weather stations of Sebyan-Kuel and Syuryen-Kyuyel, located 45 and 80 km respectively from the project, are the nearest stations with longterm precipitation records. The average annual precipitation at the Sebyan-Kuel and Syuryen-Kyuyel weather stations is 203 mm and 337 mm, respectively. More than 60% of the precipitation occurs during the warm season. The highest average amount of precipitation occurs in June and July (59 mm and 76 mm, respectively) and the lowest in the winter months, from November to March.

Table 1 *Average monthly precipitation for both projects, based on the nearest station data, mm.*

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Permafrost Project (Sebyan-Kuel)	3	3	3	8	12	59	39	31	25	13	3	4	203
Desert Project (In Guezzam)	11.4	0.9	2	3	5.2	13.2	15.7	8	20.9	0	0	0	80.3

The climate characterization for the desert project was based on data from the nearest station, In Guezzam, located some 140 km south of the project site. The data consist of a total of 20 years of monthly climate data and 20 years of daily rainfall data. The average monthly and annual precipitation recorded in the nearest weather stations for both projects are presented in Table 1.

The estimated magnitudes of 24h storm events for both project are shown in Table 2. 24h storms are commonly less than 25 mm in the permafrost project area and are not expected to be much higher than 60 mm for events of 50-year return period or more. For the desert project the maximum 24h rainfall recorded over the 20-year monitoring period from 1996 to 2015 was 60 mm. The frequency analysis suggests a maximum 24h rainfall magnitude of around 70 mm for 50-year return period and 90 mm for 100-year return period events.

Table 2 *Estimated extreme Event 24-hour Rainfall Storms for both projects*

Return Period (year)	**Estimated 24-hour Extreme Rainfall Depths (mm)**	
	Desert site	**Permafrost site**
5	22.6	36.24
10	34.5	43.15
20	48.5	49.77
50	70.6	58.34
100	90.4	64.76

Expected water inflows into the mine

Because of the scarcity of atmospheric precipitation (and the presence of an impervious permafrost layer in the case of the polar site) inflows of groundwater and surface water runoff into mines in these two climate conditions are commonly low and therefore manageable using in-pit sump pumps rather than active dewatering from outside the mine.

Permafrost project

The hydrogeology of the site is characterised by the presence of the following formations:

- An active layer, where the temperature levels during the warm season reaches thawing point;
- The underlying permafrost layer: the permanently frozen ground; and
- Bedrock beneath the permafrost, which has the potential to contain groundwater.

The measured downhole temperature profiles, obtained from full year temperature monitoring, indicate a maximum thawing soil thickness of 1.75 to 2.75 m, reached in late August. Such a thin active layer, which remains frozen for most of the year, has a very limited storage capacity.

Using a geothermal gradient obtained from the temperature monitoring in deep boreholes, the thickness of the permafrost layer was estimated to be between 190m in the river valley to 400m in the top of the hills. Considering the significant thickness of the permafrost in the project area, the sub-permafrost aquifer is located far below the weathered layer, and groundwater flow seems to be mainly driven by geological structures (faults and fracture networks).

Six deep boreholes were drilled to investigate the sub-permafrost aquifer along the river valleys, and airlift and pumping tests carried out to assess the aquifer potential and estimate its hydraulic parameters. The results showed that the aquifer is highly confined, with all boreholes being artesian. The highest pumping rates achieved ranges from 1 L/s to less than 3 L/s (10 m^3/h).

Due to the pit and underground mine being located fully in the permafrost layer, groundwater inflow into the mine was estimated to be negligible. The average surface water runoff into the proposed pits over the mine life was estimated to vary between 440 and 1700 m^3/day due to rainfall events in the summer time.

Desert project

Hydrogeological investigations in the desert site revealed the existence of a small confined aquifer comprising a fractured horizon in the crystalline bedrock. The recharge area for the aquifer is believed to be the Atakor mountains, which are located more than 250 km north of the site at an altitude of 2000 masl, whereas the approximate elevation of the project area is 500 masl.

Of 44 boreholes drilled at the early stage of exploration on site only 9% were hydraulically productive. The borehole tests indicated a strong anisotropy of the fracture network. The most productive well, where the static groundwater level was recorded at 52 meters below ground level, produced an average flow rate of 126 m3/day (1.45 L/s). A pilot mine shaft of 6 m^2 section constructed in the past at the site to a depth of 100 meters showed a static water level of 40m below ground. The shaft was hydraulically tested at a rate varying from 15 to 37 m^3/day, inducing a drawdown of 18 m; a level that did not stabilise indicating low aquifer yield and limited storage capacity. The aquifer properties, the low rainfall in the area and the remote location of the recharge zone indicate that aquifer yields and therefore groundwater inflows into the proposed mine will be very low.

Tailings management

Ore processing for the permafrost project is expected to produce some 805,000 tons of tailings over the 8 years Life of Mine (LoM). For the desert project the amount of tailings expected from ore processing over the 6 years of mine life is around 900,000 tons. Due to the difficulties of water supply for ore processing all year round, water conservation in both projects is an important driver in selecting the tailings disposal technology. Based on such criteria, a filtered tailings design was developed for both projects. The similarity of the tailings Feasibility Study design criteria for both projects is illustrated in Table 3 (SRK, 2016 and 2017).

Table 3 *Tailings management Feasibility Study design criteria for the two projects*

Tailings Management Design Criteria	Permafrost project	Desert Project
Tailings Deposition Type	Filter press dewatered tailings or 'filter cake'.	Filter press dewatered tailings or 'filter cake'.
Tailings Facility Capacity	805,000 tons	900,000 tons
Tailings Facility Design Life	8 years	6 years
Tailings Moisture Content	15%	15%
Tailings Deposited Dry density	1.77 t/m^3	1.4 t/m^3
Tailings Design Storm (considering 100y return period 24h duration)	65 mm	90 mm

Filtered tailings are typically produced in a two-step process using a high-density thickener and vacuum or pressure filters in series. This allows the solids content by mass (w/w) of the tailings material to be raised above 85%. Using this method allows a recovery of up to 95% of the process water in the tailings. Furthermore, filtered tailings material present a lower risk of instability and environmental impact compared to wet tailings, and they are typically transported by trucks or conveyors and deposited in successive lifts to form a dry stack.

Water supply and groundwater quality

Owing to the thickened tailings technique and water recycling, the estimated fresh water demand for the desert and permafrost projects were reduced to around 130 m^3/day and 260 m^3/day, respectively, including the processing plant and mine camp water requirements.

Due to the precipitation and temperature patterns in both desert and polar climates, water supply must rely on a groundwater resource, which is often 'fossil' (paleo) water due to minimal recharge of the aquifers. Over the years such low recharge has led to an increase in salt concentration in groundwater.

The sub-permafrost aquifer is the only potential water source for the permafrost project during the cold period of the year when surface waters are frozen. Using aquifer parameter data obtained from borehole tests, in addition to geological and permafrost information, a groundwater model was developed and scenarios of long term borehole pumping for water supply simulated to assess the availability of the required amount of water in the aquifer for various pumping rates and patterns. The model results indicated the existence of enough water storage to supply the mine for the project life with the required amount of water. Subsequent testing of actual water supply wells, which is still ongoing, is corroborating such findings.

Borehole tests at the desert project suggested very low storage capacity of the small local aquifer. Therefore, water supply is envisaged from another groundwater source some 80 km from the site. In such a location, historic water wells have been operating for a long time and appear to guarantee the water supply for the project. Due to the selected tailings management technique, water recycling is maximised and the water supply needs are reduced to the minimum. Therefore, the small amount of makeup water required for the project over such a distance will be transported to site by track.

pH and salinity of groundwater at both sites are shown in Table 4 (SRK, 2016 and 2017).

Table 4 *Summary of groundwater quality*

Site	Groundwater quality parameters		
	pH	Salinity (TDS) mg/L	Comment
Permafrost site	7.3-7.5	~2,270	Water can be used for ore processing but needs treatment to become drinkable
Desert site	6.7	2,260-2,550	Water can be used for ore processing but needs treatment to become drinkable

Conclusions

The water management elements in a mining project are linked through the project water balance, which often reflects either a need for additional water supply, water treatment or discharge into the environment. This paper illustrated the striking similarities that can be observed in both the polar (Tundra subtype) and desert climate conditions using two case studies.

Whilst the scarcity of both rainfall and groundwater (and extreme temperature fluctuations) in the permafrost and desert locations result in low and manageable inflows of water into the mines, this also leads to a shortage in water resources and dictates specific water management measures to be taken to fulfil the mine project needs. Thus, the use of filtered tailings was envisaged in both the presented case studies to maximize process water recovery within the processing plant and reduce makeup water demand. Fossil groundwater remains the main source of water supply for these mine projects, but due to its high salinity such water requires treatment before it can be used as a potable supply.

Acknowledgements

The author would like to thank the Clients of both the Mangazeisky and Nahda projects for allowing this paper to be presented in the IMWA 2017 Conference and colleagues that contributed to either of the FS, namely Samantha Barnes, Lenar Sultanov, and David Cooper.

References

Belda et al. 2014, Climate classification revisited: from Köppen to Trewartha. CLIMATE RESEARCH (Clim Res). Vol. 59: 1–13, 2014. doi: 10.3354/cr01204.

Evans, T. E., (1996) The effects of changes in the world hydrological cycle on availability of water resources. http://www.fao.org/docrep/w5183e/w5183e04.htm

NOAA (2015), Global Historical Climatology Network (GHCN) data, from National Climatic Data Center: https://www.ncdc.noaa.gov/oa/climate/ghcn-daily/

SRK Consulting (UK) Ltd (2016) Mangazeisky hydrogeological FS report.

SRK Consulting (UK) Ltd (2017) Nahdha Project Climate Study and TSF interim report.