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CONSULTING ENGINEERS & SCIENTISTS

Giant Mine Remediation
Yellowknife, NWT

FINAL Report

Fugitive Dust Assessment

Project R.014204.349

RWDI #1600705
May 4, 2016

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1. INTRODUCTION

RWDI AIR Inc. (RWDI) was retained by Indigenous and Northern Affairs Canada (INAC) to assess dust management options for tailings areas as part of the Giant Mine Remediation project in Yellowknife, NWT. This included the provision of a preliminary analysis for dust management options on site.

2. GIANT MINE SITE

Figure 1 is a generalized map of the project site and tailings areas. Areas assessed as part of this study (labeled in red and outlined in blue) include the Northwest Tailings Pond (NWTP), North Tailings Pond (NTP), Central Tailings Pond (CTP) and South Tailing Pond (STP).

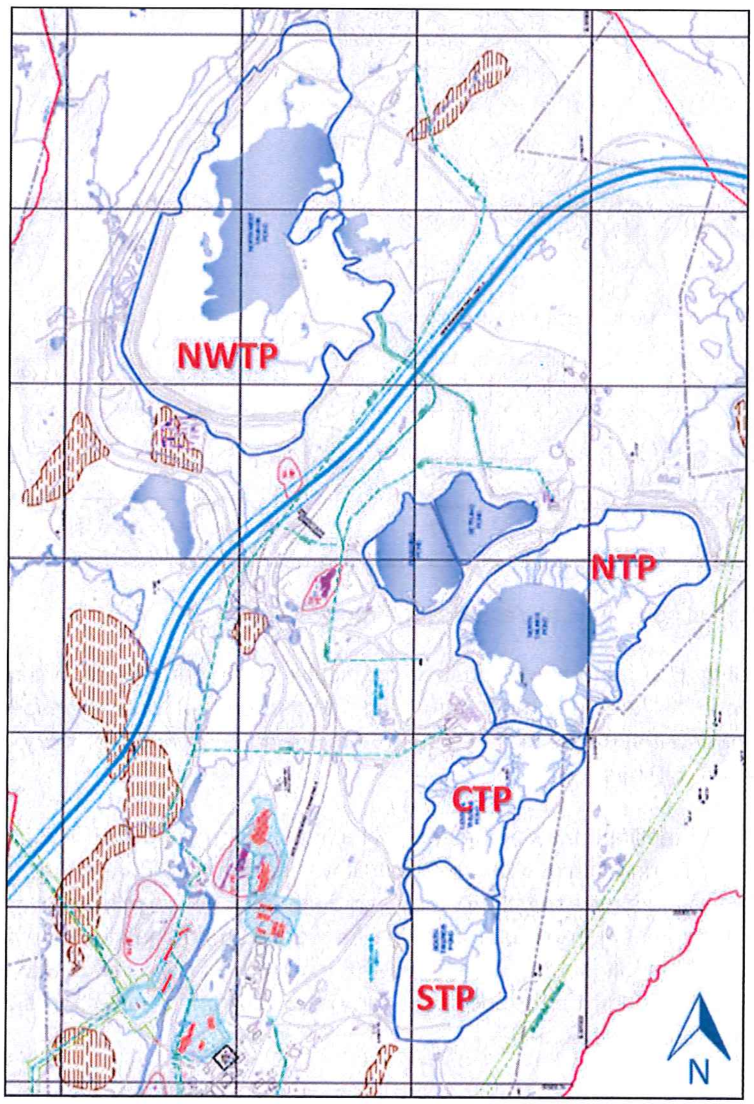

Figure 1. Location of tailings areas at the project site.

Historical meteorological data from Yellowknife Airport were analysed to support the analysis of wind-blown dust issues at the site. Annual wind statistics for the 1992 to 2012 period are shown in Figure 2.

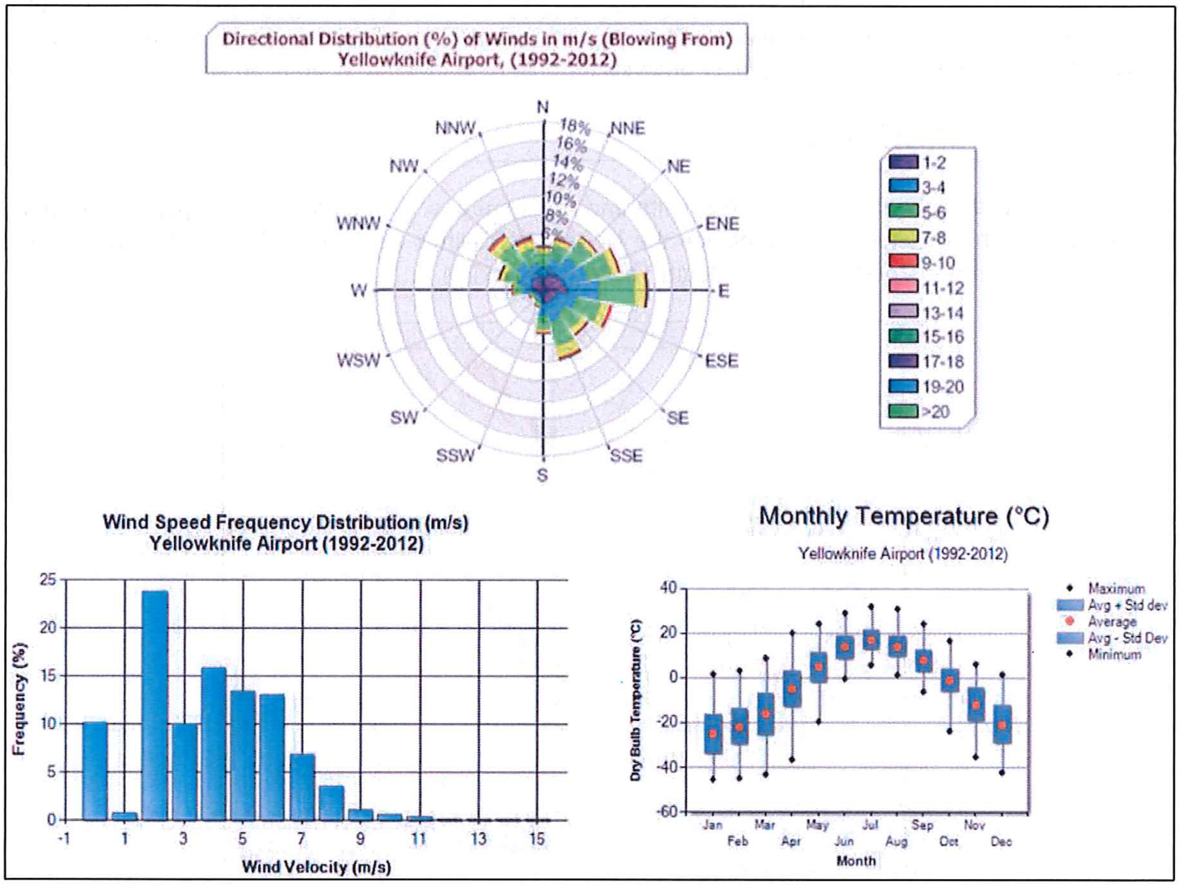

Figure 2. Meteorological conditions at Yellowknife Airport (1992-2012).

It is our understanding that wind-blown dust, in particular as it pertains to offsite impacts, is most problematic during mid to late May and early June under current dust management practices as described below. Untreated surfaces are a concern from the entire period from May through October for winds greater than about 5.0 m/s.

Figure 3 depicts a 2014 satellite image of the site, including locations of the tailings ponds (labeled), and locations of ambient monitoring stations at the Great Slave Sailing Club (Marina Stn.) and on Sikyea Tili Rd. (Ndilo Stn.). Wind roses for the months of May and June from Yellowknife Airport for the years 2003-2015 are also presented to orient the reader as to the frequency and magnitude of winds during this early spring period. It is noted that although the frequency of occurrence is low, winds during this time blowing from the north-northwest through north tend to be strong (> 8.0 m/s); more than sufficient to generate wind-blown dust from unprotected surfaces.

During this period, the temperature is typically too low to apply Soil Sement (the chemical surfactant currently applied to tailings on site), yet the surface is no longer snow covered and hence exposed and subject to high winds. By early June the ambient temperature is often warm enough (≥ 5 °C) to apply Soil Sement on tailings surfaces, after which wind-blown dust has been perceived to be adequately reduced for the remainder of the season, with snow cover typically reappearing by October. Historically a new application of Soil Sement has been required after each spring thaw. On average, approximately 130 barrels of Soil Sement are required annually, at a cost of approximately $700 USD per barrel or ~$91,000 USD per year (Pers. Comm., INAC).

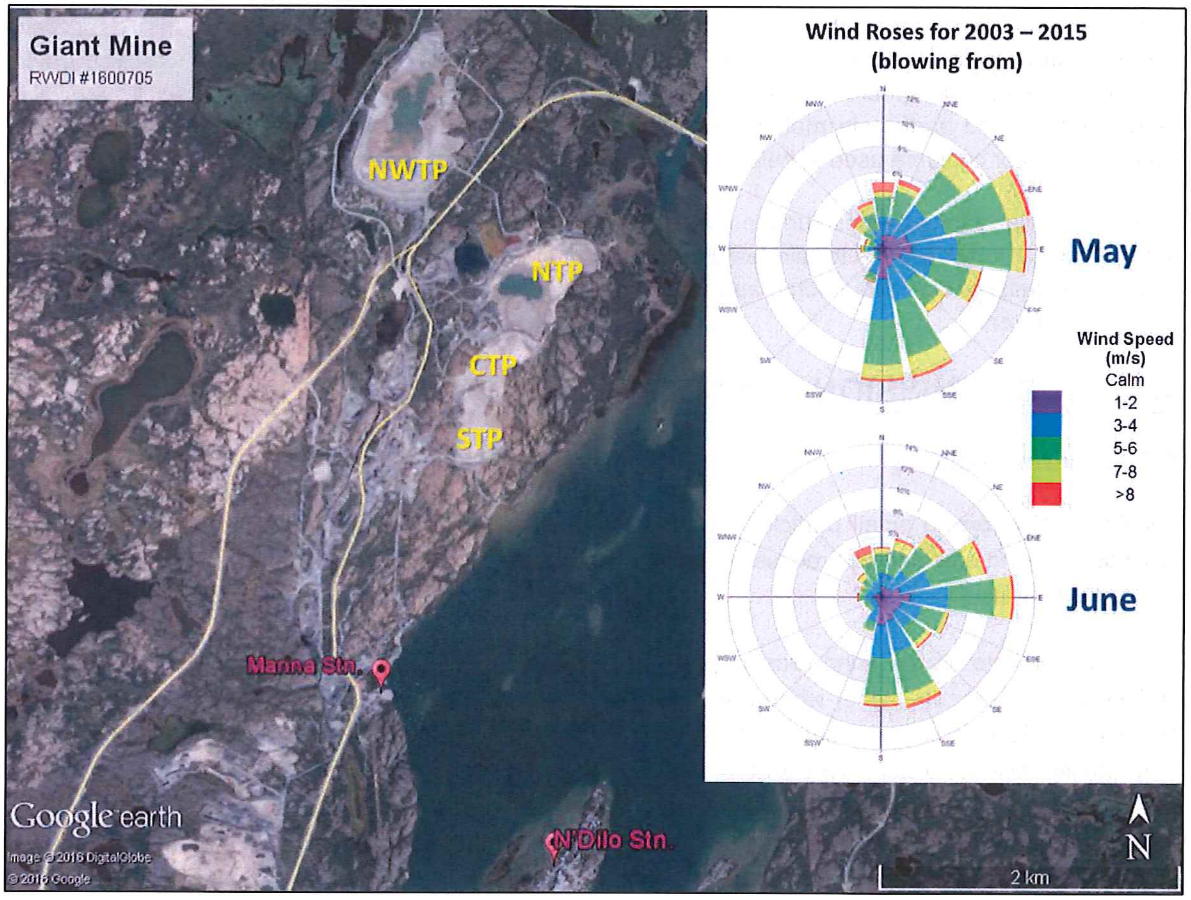

Figure 3. Location of tailings ponds and ambient monitoring stations alongside wind roses depicting the frequency of winds by direction (blowing from) and by wind speed bin for the months of May (top) and June (bottom) at Yellowknife Airport (2003-2015).

3. SITE VISIT

A site visit was performed by Mr. Wayne Boulton (M.Sc. Aeolian Geomorphology, Senior Consultant / Principal of RWDI) on Tuesday, March 8th, 2016. Informal technical discussions were held with various INAC and Public Works personnel at INAC's offices in Yellowknife on the afternoon of Monday, March 7th and again on the morning of Wednesday, March 9th.

While on site, Mr. Boulton visited key features of the mine property, including:

- The Mine Site and former Roaster Complex
- West tailings dam and east end of the Northwest Tailings Pond
- North, Central, and South Tailings Ponds
- Norseman shed south of the Tailings Reprocessing Plant (or TRP)
- The fenced Material Storage Area (or MSA) built on the Central Tailings Pond housing the arsenic-impacted waste from the 2013-2015 demolition of the Roaster Complex.

A cursory visual inspection of the area around the Townsite ambient monitoring station at the Great Slave Sailing Club (Marina Stn.) and monitoring station located on Sikyea Tili Rd. (Ndilo Stn.) was also made. Although outside the specific scope of this assessment, a high-level review of publically available meteorological and particulate matter data from the Marina Stn. was performed to learn whether data from this monitor could be used to help assess dust emissions at the site.

A detailed review of the tailings surface material was not possible due to abundant snow cover. However, it was possible to assess the terrain features surrounding the tailings ponds, locations of residences and monitoring stations, etc. Site photographs taken the previous summer were provided by INAC personnel for further reference.

4. DUST EMISSION SOURCES

4.1 Wind Erosion

Fugitive dust refers to small particles that become suspended in the atmosphere due to mechanical processes. Wind erosion is a process whereby loose particles are picked up by the wind as it blows over an erodible surface.

The emission rate from a wind erosion process is highly dependent on the properties of the erodible surface but is generally higher when it is made up of very fine particles. Particle emission rate is also highly dependent on the wind speed. Below a certain wind speed, known as the wind speed threshold, wind erosion will not occur. This wind speed threshold, typically in the range of 5.0 m/s for most mine tailings materials, is dependent on the properties of the erodible surface. Generally, more coarse materials will have a higher wind speed threshold. Once the wind speed threshold is met, the rate of wind erosion increases following roughly a power-law relationship.

Since wind erosion occurs over the entire erodible surface, the total emission rate is proportional to the total erodible surface area. It should also be noted that wind speeds over a 30-45° inclined (sloped) surface are about 1.5 to 2.0 times greater than they are over a flat, level surface. Emissions from a sloped surface can therefore be an order of magnitude higher than emissions from an equivalent flat surface. The relatively flat surfaces of tailings at the site are therefore favourable and should be maintained as such.

4.2 Mine Tailings

Tailings are a by-product of mining operations and refer to the materials left over after the valuable fraction of an ore has been extracted. Tailings are generally produced as a slurry of fine particles in water that are pumped to an outdoor waste area. When the water drains off and the slurry dries, these fine particles can become a significant source of fugitive dust.

Based on discussions with INAC personnel there are a number of unique challenges to the site as it pertains to wind-blown dust mitigation from the tailings. The following discussion is broken out into the different areas of concern, namely the: Northwest Tailings Pond (NWTP); North Tailings Pond (NTP); Central Tailings Pond (CTP); and, South Tailings Pond (STP).

4.3 Northwest Tailings Pond (NWTP)

It is our understanding that the surface of the Northwest Tailings Pond (NWTP) remains unworked and generally unaltered. The wet area is defined as the area covered with water as well as the surrounding beach where the surface moisture context is >5% by volume. The spatial extent of the wet area changes seasonally and on a year over year basis.

The NWTP is used as an overflow reservoir into which water from the underground mine cavity is pumped to maintain a constant, subterranean water level at -750 feet. Given the long period during which ambient air temperatures remain below zero, there is a limited period during which water can be pumped out of the tailings pond and into the water treatment facility. As such, the water level is pumped down to low levels during the summer to allow for maximum mine water storage capacity in the pond without affecting the integrity of the tailings dam. Unfortunately, the lowering of the water levels and associated reduction of wet area results in a greater risk for dust to be emitted during high wind events.

The NWTP sits approximately 10 to 15 m higher than most of the surrounding terrain, including the two public roads (Hwy. 4 and V-Lake Rd.) that run approximately two thirds of the way around the southern perimeter of the pond. Observations of elevated dust emissions from the NWTP blowing from a various directions have been noted by INAC staff at different times of the year. Specifically, dust from the NWTP has reportedly been seen blowing across both Hwy 4 and V-Lake Rd.

The NWTP has a particularly large, dry and erodible area. It is also located close to public transportation routes and is exposed to high winds from multiple directions throughout the spring through summer period. As such, any successful mitigation for this surface will likely need to be particularly robust and applicable to multiple wind directions.

4.4 North Tailings Pond (NTP)

The NTP was noted by personnel on site as being an area where there are few (if any) historic or current concerns as it pertains to wind-blown and fugitive dust. It is believed that this pond is typically wetter and therefore less prone to wind erosion. It is also believed to be somewhat more protected by local terrain features from winds both from the northeast and southwest.

Given these characteristics it is likely that somewhat less prescriptive dust mitigation measures may be sufficient for the NTP.

4.5 Central Tailings Pond (CTP)

Tailings material in the CTP has recently been excavated / extracted, screened, stockpiled, and used in the production of paste fill as part of Site Stabilization activities. This activity has resulted in the CTP forming a shallow depression (approximately 3-5 m deep) relative to both the NTP and STP. Once screened, tailings are transported by truck to the Norseman shed south of the Tailings Reprocessing Plant (or TRP) and stockpiled. Specifics as to the size of the actively worked area versus tailings material remaining in situ was unavailable to RWDI at the time of this assessment but would need to be quantified as part of any future mitigation strategy development.

The fenced Material Storage Area (or MSA) is situated on the southeastern edge of the CTP. The MSA houses the arsenic-impacted waste from the 2013-2015 demolition of the Roaster Complex in stacked shipping containers (Sea-Cans).

Personnel at the mine have observed dust emissions occurring at the CTP under modest to high wind conditions. It is expected that these emissions are the result of a combination of both wind-blown processes plus material handling activities; the relative contribution from each is unknown.

Tailings in situ will likely need to be managed in a manner that allows for considerable operational flexibility and the ability to excavate material for making paste in future. This will necessitate the selection of not only a cost-effective solution, but one that is also practical given the relative uncertainty as to future activities in this area.

Dust emissions associated with tailings extraction and paste manufacturing are best managed through the adoption of a robust, site-specific fugitive dust management plan (FDMP) and standard operating procedures (SOPs). It is RWDI's understanding that there are SOPs governing material handling processes as they pertain to mitigating wind-blown and fugitive dust emissions for these activities. A review of these SOPs was not included in the context of this assessment and so the specific technical content of those SOPs (and whether or not they are adhered to on a day-to-day basis) are unknown. Issues such as the management of stockpiles (for example) should include site-specific guidelines pertaining to pile height, slope angles, pile orientation, surface covering, excavation and stockpiling strategies, etc. Guidelines pertaining to the alteration or cessation of activities during adverse weather conditions should also be included in material handling SOPs. Lastly, it is unknown whether SOPs for the CTP are consistent with other material handling procedures adopted at the site. An assessment of the current SOPs and their adequacy is recommended.

4.6 South Tailings Pond (STP)

There is uncertainty as to both the short-term and long-term plans for tailings in the STP area. Specifically, there remains uncertainty as to whether the tailings material will need to be extracted to create paste in the same way as in the CTP. There was also discussion of the potential use of tailings material to fill open pits around the mine site as part of the long-term closure plan. As such, a permanent solution for the STP is not viable or even desired at this time. Rather, a solution that allows for the ability to access tailings material in the future but that provides protection from dust emissions in the immediate term is required.

The STP is the closest source of wind-blown dust emissions relative to the 'Old Town' neighbourhood of Yellowknife and the monitoring station located on Sikyea Tili Rd. (Ndilo Stn.). The distance between the southwestern-most edge of the STP tailings dam and the Ndilo Stn. is approximately 2.75 km; the distance from the STP to the nearest residence is approximately 2.5 km.

The STP impoundment is essentially full and hence the surface is within one to two meters of the top of the dam. Beyond the dam there are no physical obstructions between it and Old Town. The approximate difference in elevation between the tailings pond surface and Great Slave Lake is 30 m, allowing for transport and deposition of wind-blown dust across the lake to occur under specific meteorological circumstances.

5. WIND EROSION CONTROL TECHNOLOGIES

As noted previously, wind erosion occurs when wind travels over an erodible surface and picks up loose particles which become suspended in the air. The emission rate from these processes is dependent on the wind speed over the surface and on the properties of the surface material. Thus, fugitive dust from wind erosion can be controlled by reducing the energy (speed) of the wind as it flows over the surface, by changing the properties at the surface of the erodible material to suppress the formation of dust, or by minimizing the surface area exposed to wind erosion. A wide range of approaches and technologies have been developed and used to control wind erosion at mine sites the world over as discussed in the following sections.

Although not assessed specifically as part of this work it is noted that both the CTP and STP are being considered by the project as potential sources of fill for several of the open pits at the mine site. For these reasons, and in support of the potential need to leverage tailings material in manufacturing paste, mitigation strategies that allow for the mitigation to be removed, reused / repurposed as part of the long-term management strategy are considered desirable.

5.1 Wind Control

Wind control refers to techniques that limit wind erosion by altering or impeding the wind blowing over the erodible surface. These are generally physical barriers or objects placed on or near the erodible surface.

5.1.1 Vegetation

Vegetation growing on the tailings would control wind erosion by absorbing part of the momentum from the wind and thereby protecting the erodible surface. Over time the roots from vegetation also help to stabilize the surface material. Planting salt tolerant grasses such that its vertically projected area ratio is greater than 15% has been found to effectively eliminate wind erosion of sand [1]. Although some vegetation may die in the winter, dead vegetation provides similar protection to living vegetation, as long as it remains intact. Living vegetation is most often the preferred approach in situations where it can grow of its own accord on mine tailings. However, the relatively harsh climate and characteristics / chemistry of the tailings themselves are expected to make this option less untenable.

In situations where vegetation cannot be grown, crop residue or straw mulch can be used as a surrogate. Straw mulch can be applied as a surface covering without any physical anchoring to the soil, although it is sometimes pre-mixed as a slurry with water or a tackifier in a manner similar to hydro-seeding. This is done more often in agricultural settings where dust management goes hand in hand with encouraging vegetation growth. Crop residue or mulch placed flat such that 30-60% of the surface is covered can provide 80-90% emission control efficiency [2].

However, if the vegetation is placed standing up (i.e., replicating crop stubble), the same level of control can be reached with a vertically projected area ratio of only 5% [2]. The process of straw crimping has been used at agricultural and industrial sits to produce an artificially 'planted' surface. This process involves first distributing loose straw over the erodible surface and then physically anchoring it to the ground by crimping. Straw crimping involves the use of a notched plow disc designed to essentially fold and push longer strands of straw into the surface, forming a row of straw plugs that resemble a field of natural crop stubble. This method has been shown to provide approximately 80-90% control, similar to using vertically standing vegetation as described above.

Crop residue and / or crimping materials and machinery (crimping discs) would need to be acquired and imported from outside the region and straw would also need to be imported and likely replaced on a regular basis (e.g., annually). It should also be noted that the ability of the tailings to hold crimped straw in place is unknown (tailings having unique physical properties that are dissimilar to natural soils).

5.1.2 Non-Erodible Roughness Elements

Covering an erodible surface with non-erodible elements causes the elements to absorb part of the momentum from the wind and thus protect the erodible surface. If the density of non-erodible elements is sufficiently high, they will absorb the majority of the momentum from the wind and the emissions from the protected erodible surface will be minimized. Note that this discussion evolves around larger elements, typically several 10's of centimeters to meters in cross-sectional and frontal area. Total coverings that provide essentially a fully armored surface is discussed in a subsequent section.

The required density of non-erodible elements over a tailings surface is dependent on the shape and surface area of the element being used. To achieve adequate surface protection, their vertically projected area ratio (the ratio of the frontal area visible to the wind to the total erodible surface area) should be approximately 2-5% [3]. This allows for the creation of a stagnant zone or 'pocket' in the lee of individual elements. A wide variety of non-erodible elements have been used at mine sites, including tires, straw bales, and rocks. This method can provide >90% control but is highly dependent on the size of the non-erodible elements and density of placement over the erodible surface.

Non-erodible elements have been used to control wind erosion emissions at numerous industrial facilities; what element is used is typically dependent upon cost and local availability. For example, straw bales are not as readily available in Yellowknife as they are in other regions. However, rocks of different sizes can be generated on site and as such are a potential option. Given that are also a fairly large number of disposed tires on site (> 1,000), and possibility of obtaining more from other sources (e.g, municipal landfill), the use of tires as non-erodable elements may be worth consideration.

Another form of non-erodible roughness element is the use of wind rows. This type of mitigation works along the same principles of other non-erodible roughness elements but in linear rows as opposed to a random placement that is typically adopted for discrete elements such as large rocks or straw bales. Wind rows are sometimes used at active mine sites where waste rock is being generated actively. Instead of dumping waste rock in a pit or pile it is deposited in rows on the tailings surface. Given the linear nature of wind rows, this approach lacks effectiveness for winds that are not essentially perpendicular to the row in the same way that wind fences are limited (as discussed in the next section). As rocks on site must be generated through blasting and crushing it is felt that if this level of effort is going to be employed it is likely more practical to deposit material in a thin layer across the entire surface than it is to generate wind rows as the former is expected to provide greater overall efficiency.

5.1.3 Wind Fences

Porous wind fences can be an effective means of reducing wind speeds and hence wind erosion downwind of the fence. Over flat ground, a 50% porous wind fence reduces the wind speed by more than 50% on the leeward side at distances of up to 12 or 15 times the height of the fence [4]. However, at farther downwind distances from the fence, the wind speed will increase back to its nominal (undisturbed) value.

There are generally two different types of wind fences: those that are very large, engineered structures in excess of 10 m tall with a fabric or mesh suspended between large poles or stanchions; and, those that are much smaller (on the order of 2 m tall or less) and used as snow fences or similar purposes.

The former kind of fence requires significant engineering (and often significant cost) in design and installation from the perspective of wind loading, stanchion installation, fabric, etc. Per the ratios provided above, a 10 m tall fence can reduce near-surface wind speeds in the lee by on the order of 50% for a distance of up to 120 or 150 meters. These types of fences are typically installed in space limited areas (e.g., along docks or property lines) where other options are not feasible and where winds tend to be unidirectional.

Smaller porous structures such as snow fences offer protection to dust emitting surfaces through the same basic principles as larger fences. For greatest effectiveness, several wind fences typically need to be placed in rows at separation distances of up to 20 fence heights apart to cover the entire erodible surface area (i.e., rows of four foot tall snow fence can be installed up to 80 feet apart). Decreasing the separation distance to approximately 15 heights or 60 feet apart can provide further conservatism in terms of area protected and achieve on the order of 75-95% reduction in dust emissions over the protected surface.

Note that with both types of fences, the rated effectiveness is only valid if the wind is blowing perpendicular to the fence(s). The relative effectiveness decreases drastically as the wind angle to the fence decreases, which supports the option of decreasing the spacing between rows. To provide mitigation in areas where there are two or three primary wind directions of concern, snow fencing installed in a saw tooth or 'zig-zag' pattern is sometimes used to mitigate both sand and snow drifting issues. However, there is no known report detailing how well this type of configuration might work for mitigating wind-blown dust. Further review and testing through field trials, physical wind tunnel testing, or numerical simulation would likely be needed before further consideration for this type of approach is warranted.

There are some other inherent benefits to exploring the use of snow fences that are worth consideration. Rough calculations suggest that several kilometers of fencing would likely be required to cover a given tailings area. However, the cost is relatively low for the fence material (averaging in the range of $1.60 per linear foot for a four foot tall fence), as are the steel posts (about $10 per post) and mounting hardware. Although time consuming to install, the work can be done using light duty vehicles and involves primarily manual labour. All considered, the costs for snow fencing may be relatively modest.

Another benefit to snow fencing is its ability to trap wind-blown snow within the tailings areas, resulting in a deeper snowpack and hence extension of the period during which snow cover protects the surface. This may also play a minor role in increasing the wetted area of the tailings for a short period during the spring thaw.

One potential downside to snow fencing is the need for relatively frequent maintenance to replace sections of fence, re-install posts, etc. It is also likely that the fencing material would have to be replaced after several years in the field. The expected frequency for replacement of fencing in Yellowknife is unknown but most likely available.

Although used in different configurations at a wide range of industrial sites, the effectiveness of snow fences tends to be quite specific to the surface being protected (e.g., pile, material handling area, flat open surface), and wind regime (specifically the range of wind directions of concern). Nonetheless, it was considered worthwhile to present a potential snow fence option in the subsequent options analysis.

5.2 Physical Coverings

Covering dust emitting surfaces with a non-erodable material would provide total (i.e., 100%) protection from wind erosion. As long as the covering remains intact, the wind would pass over the cover and the tailings below would be completely protected.

The use of granular material such as gravel or cobbles as a surface coating or 'armoring' presents an option that can be very highly effective (> 95% efficiency). In active tailings areas rocks are prone to sink into the tailings matrix or be covered by fresh tailings slurry. However, because the tailings areas are all 'static' and undisturbed (other than the CTP presently), this is not an issue at the site.

Because rocks of essentially any size would need to be generated on site, options for both gravel and cobble-sized materials are assessed further as part of the options analysis. Some of the key benefits to using rocks are that they are native to the site, they can be screened out fairly readily if a decision is made in future to extract tailings for paste or other products, and they are permanent and in no need of maintenance. In addition, rocks could be reused / repurposed as fill material as part of future long-term closure plans if so desired.

Another option to sealing or covering the tailings surfaces that was discussed with personnel on site is the application of a thin cover of a low-grade tailings paste. As described previously, paste is being manufactured from screened tailings for application as cemented backfill in the underground mine. An option to generate a lower-grade paste from unscreened tailings and applying that to the tailings surface with an application depth of approximately 2.0 cm was felt to be worth further assessment in the options analysis.

Once cured, the expectation is that a fairly thin (i.e., 2.0 cm deep) layer of paste would create a cemented, non-emitting surface. At this time there are uncertainties with this approach, including a lack of understanding of the physical properties of the paste in terms of how it will behave when applied to the surface and allowed to undergo weathering and freeze-thaw cycles, whether a 2.0 cm thickness would be sufficient from a resilience / structural perspective, etc.

5.3 Dust Suppressants

Dust suppressants are compounds that can be applied to an erodible surface to hold it together such that it will resist wind erosion. Water can be considered a dust suppressant, but there are also several commercially available chemical suppressants that can minimize wind erosion for extended periods.

5.3.1 Water

When a tailings area is wet, the water adheres to the particles, thereby increasing their effective mass and surface tension forces. This has the effect of significantly decreasing the erodibility of a surface. The application of water can also result in the formation of natural aggregates and surface crusts that often persist after the water has evaporated [5].

Emissions from wet tailings (> 5 to 10% moisture content) are typically >95% lower than for dry tailings [6]. Therefore, the watering of a tailings area can be assumed to provide complete control over that area as long as its entirety can be kept moist constantly. To accomplish this, the rate of water application must be at least equal to the rate of water evaporation and infiltration. The actual amount of water application required can be computed from available weather records and will vary depending on the surface material, air temperature, wind speed, humidity and cloud cover.

However, given the challenge of needing to mitigate dust during the thaw period when there is no snow cover but temperatures are near or below freezing, water applications are expected to be problematic. This is further complicated by the need to actively manage water levels in the ponds, and in particular in the NWTP, as noted previously. Both the Polishing Pond and North Pond water levels also require active management by the Care and Maintenance Contractor.

5.3.2 Chemical Dust Suppressants

There are a variety of chemical dust suppressants available commercially. Most act very similarly by either agglomerating or binding fine particles together, or by forming a crust over the erodible surface thus preventing wind erosion of the underlying material. Some examples of commercially available chemical suppressants include Soil Sement (as is being used on site currently), ENTAC, EcoAnchor (formerly branded as 'RhinoSnot'), Durasolution, Posi-Shell, EA-DC, GreenPac, Hydrotac, etc.

The effectiveness of chemical suppressants is highly variable depending on the product but is generally at a maximum immediately following its application and then degrades with time. This rate of degradation is increased if the surface is disturbed, such as by vehicles driving on the crusts, or through surface cracking from freeze-thaw cycles.

Options for the use of Soil Sement, EcoAnchor (formerly branded as 'RhinoSnot'), and ENTAC are presented in the options analysis as three commonly used suppressants in mining applications in Canada.

Salts such as magnesium or calcium chloride have also been used at facilities to keep tailings moist when snow or ice is present at temperatures as low as around -10°C. Applying these salts to the tailings area can help keep them moist for longer periods of time. They also allow the surface to absorb moisture at relative humidity levels above 50% [5]. Similar to watering, this method can be assumed to control wind erosion by as much as 95% over the areas that can be kept moist.

Salts however will eventually wash away with runoff from precipitation events and would need to be replenished. Salt content in the runoff would also have to meet appropriate discharge limits. For these reasons salts are not considered a desirable option for the site.

5.4 Snow and Ice Cover

In the winter, snow cover can reduce fugitive dust, as long as the erodible surface remains covered and the snow does not drift, which may leave some areas exposed (unprotected). Mechanically compacting the snow covering the tailings area can increase the effectiveness of snow cover by preventing the snow from drifting and also allowing it to melt more slowly in the spring, thus extending the protection period. The application of additional snow on the tailings from snow removal at the facility can also be used, as can snow making machines.

Snow and ice covering provides protection against wind erosion emissions from most facilities for which snow and ice form naturally. Other mines in Canada have been known to apply additional snow to tailings areas and mechanically compact it to extend the season for which it provides control. Others have also been known to apply water using a heated water cannon, to promote ice formation on tailings surfaces during winter months.

A snow or ice covering can be assumed to provide complete control over the area that it covers. Given constraints over water management in the ponds as previously mentioned, increasing the snow cover or adding a layer of ice to tailings pond surfaces is not considered to be a practical solution.

6. OPTIONS ANALYSIS

As part of this assessment a preliminary options analysis was performed. Given the preliminary nature of the work a number of fundamental assumptions were made:

1) No specific emission reduction targets were set or prescribed at the outset of the assessment. It was therefore agreed, in consultation with INAC personnel, that each option should provide a minimum 75% emission reduction efficiency over a 10 year period. This value was selected to allow for a comparison of options based on a realistic expectation of what might be achievable on site. Each option selected has the ability to achieve a minimum of 75% efficiency; some may be able to achieve 90% or greater. However, it is noted that the actual efficiency achieved is often highly dependent upon installation / application, maintenance, etc. and therefore the 75% efficiency should be thought of as an overall target over the entire 10-year period.

2) Calculations for total tailings and dry beach areas (provided by INAC) are approximate only and can change on a year to year basis depending on water levels, use of tailings in paste manufacturing, etc.

3) Volumes and material quantities for mitigation measures are rough estimates only do not include material losses, inefficiencies in application / installation logistics, etc. In general, volume and material quantity calculations are expected to be in the range of ±10 %.

4) Although included in the area calculations, it is likely that a portion of the CTP area will continue to be actively worked as part of the paste making process and therefore require some other form(s) of mitigation specific to material handling activities. It is also noted that other tailings areas could be used for paste and / or filling open pits on site in future.

5) Costs are approximate and provided as 'ballpark' estimates only. Unless otherwise indicated, costs do not include the transport or application / placement / installation of mitigation measures. Cost estimates are expected to be in the range of ±15 %.

An Excel spreadsheet developed to compile the data presented in the options analysis was provided to INAC as a separate deliverable under this scope of work.

OPTIONS ANALYSIS

Option	Mechanism	Longevity / Permanency	Maintenance Requirements	Ease of Removal / Repurposing	Advantages	Risks / Challenges / Uncertainties	Cost
Soil Sement	Chemical Dust Suppressant	Annual re-application required x 10 years	• Minimal once applied	• Non-permanent; relatively fragile • No repurposing possible	• Cost-effective • Known entity that has been proven to work once applied	• Can only apply > 5 °C • Past exceedances (mid to late May) • Unknown if could affect quality of paste	$ 910,000 USD (product only)
ENTAC	Chemical Dust Suppressant	Up to 24-month application Assumed 5 applications over 10 years	• Minimal once applied	• Non-permanent; relatively fragile • No repurposing possible	• Cost-effective • Widely used across Canada • Similar application to Soil Sement • Heavier application reported by vendor to sustain freeze/thaw cycles	• Can only apply > 5 °C • Unknown if could affect quality of paste	$ 2,499,000 USD (product only)
EcoAnchor (RhinoSnot)	Chemical Dust Suppressant	24-48 month applications possible Assumed 4 applications over 10 years	• Minimal once applied	• Non-permanent; less fragile than other surfactants • No repurposing possible	• Cost-effective • Similar application to Soil Sement • Heavier application reported by vendor to sustain freeze/thaw cycles	• Can only apply > 5 °C • Unknown if could affect quality of paste	$ 924,000 USD (product only)
Tailings Paste	Physical covering	Permanent Assumed 10 years - see uncertainty	• Minimal • Re-application in damaged / exposed areas	• Moderately easy • Crushable for repurposing or removable as broken sheets	• Relatively well-known entity • Existing site experience and equipment • Maximizes use of on site materials (no introduction of new chemicals, etc.)	• Uncertainty as to long-term efficacy / resiliency in environmental conditions • Means of application untested on site	$ 1,960,000 (product only)
Gravel (2" D)	Physical covering	Permanent	• Minimal	• Moderately easy • Stone can be excavated and screened as needed • Stone can be repurposed	• On site experience and equipment required to generate material • Stone can be incorporated into long-term closure plan / capping material	• Blasting and crushing required to generate material • Material needs to be placed fairly evenly ~5 cm deep – logistics of application may require more material than estimated	$ 1,575,000 ($1,050,000 material + $525,000 installation)
Cobbles (6" D)	Physical covering	Permanent	• None	• Easy • Stone can be readily excavated and easily screened (more so than gravel) • Stone can be repurposed	• On site experience and equipment required to generate material • Stone can be incorporated into long-term closure plan / capping material	• Blasting required to generate material • Assumed greater volume required than technically necessary due logistics as easier to cover a surface than space out cobbles 75 cm apart	$ 4,803,750 ($3,202,500 materials + $1,601,250 installation)
Tires	Non-erodible roughness elements	Permanent	• None	• Easy • Tires can be readily retrieved and repurposed	• Existing materials on site • Re-use of on site waste • Can be used in smaller areas where more local protection is required (e.g., excavation area of CTP)	• Insufficient tires available on site (even adding those from municipal landfill) • Typical truck tire provides protection for ~9.5 m^2	No capital cost – installation / placement costs only
Snow Fence	Wind fence (wind speed reduction)	Semi-permanent Assumed full reinstall 3 times over 10 years	• Modest • Regular, ongoing maintenance	• Moderately difficult to remove posts and fencing. • Can be repurposed	• Cost-effective • Can be used in smaller areas where more local protection is required (excavation area of CTP) • Can extend the snow cover period and increase surface moisture content	• Time consuming / manual installation but no heavy machinery required • Effective for a narrow range of wind directions • Geotechnical constraints for fencepost installation in tailings unknown • Longevity / maintenance needs of fencing unknown	Linear installation $ 945,000 (materials) ZigZag installation $ 1,417,500 (materials)

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Northwest Tailings Pond (NWTP)

As the NWTP is used to balance water levels in the mine, as described previously, the wind fence option, which would enhance snow accumulation, is unlikely to be viable at this location. The area is also too large to consider the use of tires as a surface roughness enhancing option. Lastly, Soil Sement has been proven to be effective but not for the full period of concern, making it inadequate as a long-term solution.

The preferred options for the NWTP are therefore limited to a more resilient chemical surfactant or rock covering.

7.2 North Tailings Pond (NTP)

The NTP was noted by on site personnel as being an area where there are few (if any) historic or current concerns as it pertains to wind-blown and fugitive dust. It is believed that this pond is typically more wet and therefore less prone to wind erosion. It is also believed to be somewhat more protected by local terrain features from winds both from the northeast and southwest.

For these reasons the use of snow fences in a zig-zag pattern over dry tailings areas is considered a highly cost-effective option worth further consideration. The application of a surface covering of gravel or cobble sized rocks would also be well suited to this pond, although likely considerably more expensive. Lastly, the application of a resilient chemical surfactant would also be well suited to this surface.

7.3 Central Tailings Pond (CTP)

Tailings material in the CTP is currently being extracted, screened, stockpiled and used for paste. In areas where these activities take place it is recommended that site and activity specific SOPs be established to actively manage dust emissions on day-to-day basis.

Parts of the CTP that are not being actively worked on the other hand will need some form of more passive management. Due to the expected need to excavate material though the means selected will need to be readily removable. This limits the effectiveness of options such as snow fences. The application of large cobbles would likely be practical as they are expected to be easier to remove and redeploy elsewhere on an as-needed basis. The application of a resilient chemical surfactant would also be well suited to this surface.

Lastly, for tailings areas not being actively worked, but that are expected to be needed as a source of material for paste in a given year, it may prove more efficient to use a chemical surfactant, or, if the area is sufficiently small, non-erodible roughness elements such as tires.

7.4 South Tailings Pond (STP)

Like the non-worked areas of the CTP, the STP is another difficult area in that there is a potential future need to gain access to tailings for manufacturing paste and / or filling open pits. However, the timing and even need for these activities is unknown.

Given the physical orientation of this pond and its relative proximity to the community, a more conservative and aggressive approach to dust mitigation likely warranted.

Successive rows of snow fences installed in a zig-zag pattern across the dry tailings area may prove effective in that there are fewer wind directions during which dust emissions are expected to result in off-site impacts (e.g., winds blowing from the north-northwest to northeast).

The application of a resilient chemical surfactant would also be well suited to this surface.

Alternatively, covering the dry tailings area with rock (either gravel or cobbles) would also prove effective, although more costly. The merits and disbenefits of these different options will need to be considered carefully not only in terms of cost, logistics, and efficacy of control, but also in consideration of sensitives to dust emissions from this source in particular.

8. RECOMMENDATIONS FOR FURTHER STUDY

The following recommendations are provided for consideration.

1. Conduct a short-course / webinar for INAC personnel to provide more in-depth training concerning the physics of wind-blown dust and its management than what is contained herein, using this report as a case study.

2. Short-list the options for each tailings pond and perform a more detailed costing and engineering design exercise in order to reduce some of the inherent uncertainties contained herein prior to spending capital on any specific measure.

3. Review and assess the appropriateness of the SOPs being used at the CTP and elsewhere on site to ensure they are suitably customized to the local environment and activities taking place on site and therefore provide a sufficient level of control.

4. Assess historical ambient monitoring station records for fence line and on site monitoring stations for overall representativeness. The placement of some stations (e.g., portable station on the knoll above the mine dump site at the northeastern edge of the NWTP) may prove more beneficial to assessing dust emissions if relocated. These portable stations could be re-purposed to assess the efficacy of different mitigation measures by recording ambient dust levels (and coincident meteorological conditions) both before and after the installation of different options.

9. REFERENCES

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