September 2012

FINAL REPORT

Determination of Natural Winter Mitigation of Road Dust Emissions from Mining Operations in Northern Canada

Submitted to:
De Beers Canada Inc.

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REPORT

Golder Associates

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1.0 INTRODUCTION

Fugitive dust or particulate matter emissions from mining activities have a long being one of the concerns in the Canadian arctic and sub-arctic regions, due to the potential linkages to the health of migratory wildlife (e.g., caribou). Road dust generated when mining vehicles travel on unpaved haul roads are typically the largest source of fugitive dust emissions from mining operations.

Air quality modelling and assessment efforts on mining projects in the Canadian arctic and sub-arctic regions are often undertaken using a set of assumptions regarding road dust emissions emanating from haul trucks year-round. The degree to which dust emissions are mitigated based on winter conditions has often been estimated, but has not been succinctly, publically disseminated. Common assumptions include the potential for road dust emissions during the summer season or dry season to be substantially mitigated by adhering to a regimen of road watering. During the winter or wet season, road watering or other dust suppression techniques are neither practical nor safe. A common assumption is that there are next to no road dust emissions during the winter, when road dust emissions are effectively mitigated by snow or rain. However; monitoring, photographic and other anecdotal evidence suggests that some dust emissions may still be present during winter.

Because of the ongoing concern around dust emissions and deposition in northern Canada, and the challenges (i.e., unique site conditions, weather) associated with directly quantifying winter road dust emissions, Golder Associates Ltd. (Golder) was retained by De Beers Canada Inc. (De Beers) to design and conduct a study to link the relatively lesser-known winter road dust emissions with the better-known summer road dust emissions. The study was conducted in Fall/Winter of 2011/2012 at two De Beers diamond mines in Canada. The details of the study are presented in this report. Although the scope and the design of the study was limited, it is assumed that the findings of this study can still contribute to the general understanding of the road dust emissions at mining operations in the Canadian arctic and sub-arctic regions.

2.0 STUDY OBJECTIVES AND DESIGN

The primary objective of the study was to reveal and articulate the relationship between summer road dust mitigation effectiveness and the effectiveness of natural mitigation due to winter conditions. The objective of the study involved tracking mine haul trucks using a pickup-truck (chase vehicle) mounted dust sampler (a nephelometer) under typical summer conditions (e.g., warm and dry) and typical winter conditions (e.g. cold and frozen). The chase vehicle was to pull in behind a haul truck en route between regular loading and unloading locations. The haul truck was followed for a predetermined length of the haul road, at a set distance (50 metres [m]) behind the haul truck before pulling off the road to wait on the return trip, where the sampling was completed in the opposite direction. Fifty metres (50 m) is the shortest distance behind the haul trucks allowed by the De Beers' mine site traffic safety rules. To determine the effectiveness of road watering, the first chase was timed to immediately follow the passage of a water truck along the haul road. Monitoring behind haul trucks then continued until data indicated that road dust emissions had reached a maximum and plateau (indicating the road surface had dried out). This was expected to occur over the period of several hours. In addition, dust monitoring was conducted throughout the night to determine if the day time or night time conditions have any discernable effect on the road dust emission rates.

2.1 Monitoring Sites Overview

The study was conducted at two De Beers mines: the Victor Mine in northern Ontario and the Snap Lake Mine in the Northwest Territories. The locations of the mines are shown in Figure 1.

The Victor Mine is located in the James Bay Lowlands of Northern Ontario, approximately 90 kilometres (km) west of the coastal community of Attawapiskat First Nation. It is the first diamond mine in Ontario and second in Canada for De Beers. The Victor Mine is an open-pit mine and has been in production since 2008. The layout of the Victor Mine is shown in Figure 2. Ore and mine rock are extracted from the mine pit and transported to the primary crusher and mine rock dump via the main haul road. The majority of the road dust emissions were expected to come from this main haul road. The haul trucks used at the Victor Mine are primarily Caterpillar 777s and 773s, with gross machine weights of 163 and 100 gross tonnes, respectively.

The Snap Lake Mine is De Beers' first mine in Canada. Built on the shore of Snap Lake, 220 km northeast of Yellowknife, this mine is an underground operation. The Snap Lake Mine has been in production since 2008. A layout of the Snap Lake Mine is presented in Figure 3. Because the ore is directly transported from the underground mine to the processing plant via covered conveyors, the majority of the haul truck traffic at the mine is associated with transportation of overburden and processed kimberlite. This material is hauled primarily by Komatsu HM350 articulated haul trucks (63 gross tonnes) on the main mine road and during the sampling program, on the Sump 5 road.

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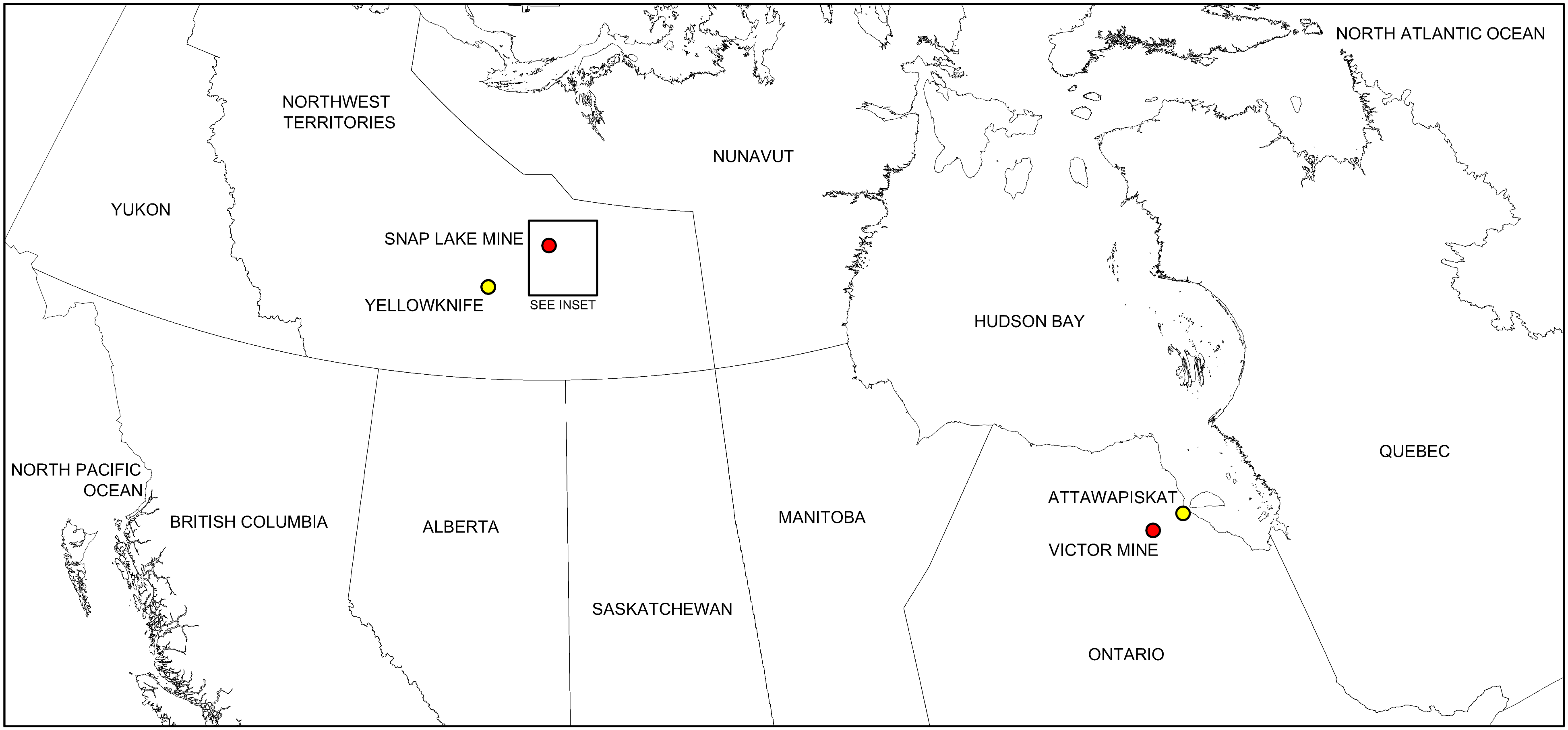

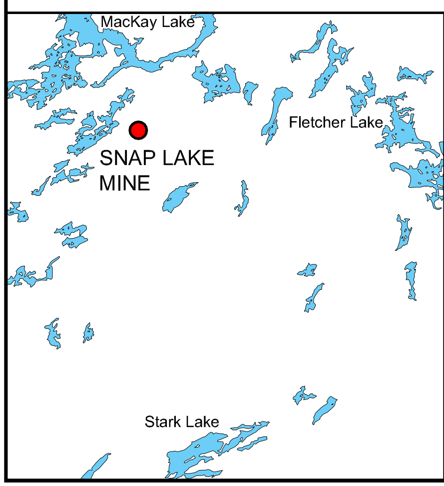

LEGEND

- DE BEERS MINE
- CLOSEST POPULATION CENTRE

INSET
SCALE:
1:3,000,000

ROAD DUST EMISSIONS STUDY

LOCATION OF DE BEERS SNAP LAKE MINE AND VICTOR MINE

PROJECTION: UTM Zone 12	DATUM: NAD83
SCALE: 1:20,000,000	
FILE No:	DATE: August 15, 2012
JOB No: 11-1365-0012	REVISION No: 0
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DE BEERS CANADA

Figure 1

LEGEND

1	CONTRACTOR CAMP	10	PRIMARY CRUSHER
2	PERMANENT CAMP	11	MINE PIT
3	OFFICE BUILDING	12	WASTE MANGEMENT AREA (LAND FILL)
4	STORAGE BUILDING	13	"SPIDER" INTERSECTION
5	PROCESSED KIMBERLITE TOWER		
6	MAIN PROCESSING BUILDING		
7	MECHANICAL SHOPS		
8	POWER GENERATORS		
9	FUEL DUMP		

NOTES
Base Data source:

SCHEMATIC ONLY, NOT TO SCALE

ROAD DUST EMISSIONS STUDY

VICTOR MINE LAYOUT

PROJECTION: UTM Zone 12	DATUM: NAD83		DE BEERS CANADA
SCALE: AS SHOWN			
FILE No:			DATE: August 15, 2012
JOB No: 11-1365-0012	REVISION No: 0		Figure 2
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LEGEND

1	SURFACE OPERATIONS AND MAINTENANCE	10	SUMP
2	POWER HOUSE	11	WEATHER STATION
3	PROCESSING FACILITIES	12	MINE SUMP
4	PERMANENT WORK CAMP	13	LAY DOWN AREA
5	FUEL DUMP	14	WASTE MANAGEMENT AREA
6	STORAGE BUILDING	15	AIR STRIP
7	ICE ROAD ACCESS	16	GRAVEL QUARRY
8	WATER MANAGEMENT AND SURGE POND		
9	CONSTRUCTION CAMP		

NOTES
Base Data source:

SCHEMATIC ONLY, NOT TO SCALE

ROAD DUST EMISSIONS STUDY

SNAP LAKE MINE LAYOUT

PROJECTION: UTM Zone 12		DATUM: NAD83	DE BEERS CANADA
SCALE: AS SHOWN			
FILE No:			DATE: June 27, 2012
JOB No: 11-1365-0012	REVISION No: 0		Figure 3
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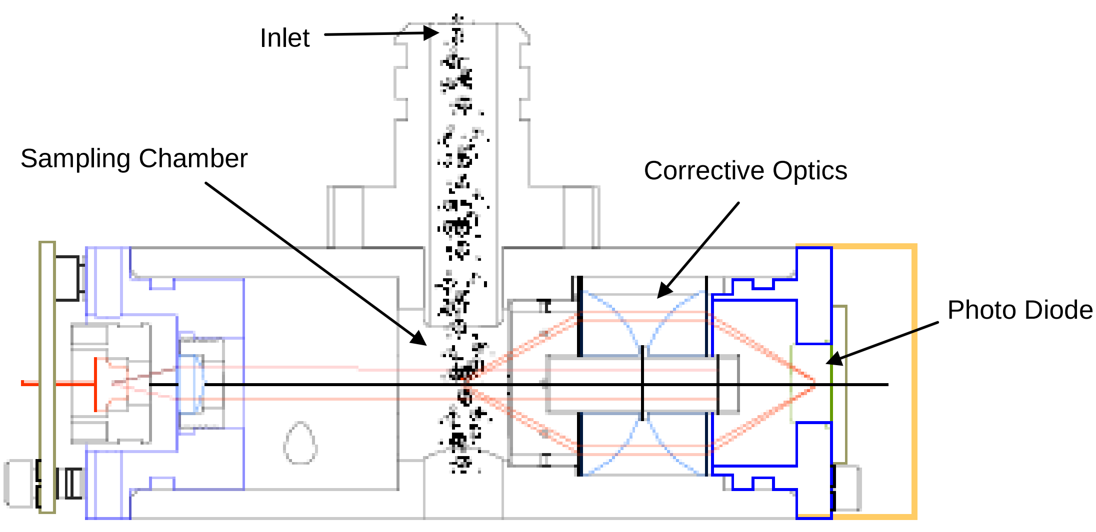
2.2 Instrumentation

2.2.1 Met One Instruments Inc. E-Sampler

The primary instrument used in the study was the Met One E-Sampler fitted with a Total Suspended Particulate (TSP) inlet. The sampling basis of the E-Sampler is to analyze the total amount of light scatter from suspended particulates to provide a continuous real-time measurement of airborne particulates. The portability and adaptability of the use of the device in remote sites while being powered with a 12-volt (V) direct current (DC) source lent itself to the needs of the study.

The light scatter measurement is made by collimating an internal visible spectrum laser diode through a chamber of sample air drawn into the instrument, known as a nephelometric measurement. Flow is maintained by a flow controlled vacuum pump at 2 litres per minute (L/min). In a clean air flow, absent of airborne particulates, the beam from the laser diode is extinguished in a light trap. If airborne particulates are present, the laser beam then will be scattered in the sampling chamber. The scattered light is then collected via correcting optics in the sampling chamber and focused on a photo diode that converts the scattered light to a proportional electrical signal (Figure 4). Forty measurements are made each second which are time averaged to ensure stable readings. The E-sampler has an internal logger which records 1-minute time averaged data of airborne particulate concentration. The E-sampler also has a raw data output voltage which was recorded by a Campbell Scientific CR10X data logger during the study.

Figure 4: Light Scatter by Airborne Particulate in the E-Sampler



The voltage output from the photo diode is linearly proportional to airborne particulate mass up to and beyond 100 milligrams per cubic metre (mg/m^3). The levels recorded in the study were generally from 1 to 5 orders of magnitude below this range, and thus well within the linear region of the instrumentations capabilities. The specifications for the E-sampler are provided in Appendix A.

High relative humidity (RH) can cause aggregate clumping of the airborne particulate and inaccuracy of the estimated airborne mass density of the particulate. To compensate for this, the E-sampler has a heater coil with an internal RH sensor on the inlet that will dry the air prior to entry into the sample chamber. The user can vary the set point that the heater coil turns on to dry the air. For the study, the RH set point was well below ambient humidity levels as to effectively run the heater coil continuously and to prevent high RH from affecting the concentration readings.

2.2.2 Campbell Scientific CR10X Data Logger

For the truck mounted on-board E-Sampler, sample-averaged data were recorded with the Campbell Scientific CR10X data logger. The CR10X is a rugged low-power measurement and control system that is often used for remote data acquisition. The CR10X runs off of a 12 V DC power source such as a deep cycle battery or 12V power outlet. The units used for the study were rated to -55 degrees Celsius (°C), and so were appropriate for this study as they are able to withstand the cold of northern Canadian winter.

2.3 Haul Truck Dust Emissions Tracking

The method for measuring dust generated by the haul truck passage on the haul roads at the mine sites was to follow the haul trucks in a pick-up truck at a set distance while recording the airborne particulate concentration measured with a E-sampler mounted on the outside of the pick-up truck. A range finder was used to establish the constant following distance (50 m) behind the haul trucks. This was the minimum safe distance to follow a haul truck. A CR10X recorded the concentration output from the E-sampler, while the sampler operator noted relevant conditions for each haul truck transit along the haul roads, also referred to in this study as a “sampling run”. Immediate quality control and general analysis was performed by viewing the real-time data on a laptop connected to the CR10X. The entire equipment setup was powered by the vehicle’s on-board 12 V outlet.

The E-sampler instrument inlet was plumbed to a truck-mounted TSP sample inlet to facilitate iso-axial sampling (i.e., sampling in which the flow of the sampler inlet is moving in the same direction as the flow being sampled) of the dust plumes. From a practical standpoint, the TSP inlet is capable of passing 30 micron (µm) particles with high efficiency; however, particle losses become significant at larger sizes due to their rapid settling velocity (Baron and Willeke 2001).

The inlet head was projected above the front passenger side window to sample the haul truck plume without interference from the dust emissions of the pick-up itself (Figure 5). Test runs were done at each site by traversing the haul truck route with only the pick-up truck on the haul truck route to establish a baseline measurement and to verify that the E-sampler was not sensing dust related to the position of the inlet.

For the summer segment of the study, the primary goal was to determine the extent of the degradation of the road watering effectiveness on the mitigation of haul truck road dust emissions. It was hypothesized that immediately after road watering, dust concentrations measured would be minimal and that dust emissions related to haul truck passage would slowly increase over time as the road surface dried out. It was further theorized, that the dust emissions would reach a peak level (plateau) when the road base had dried to a depth sufficient for watering to lose its mitigative effect. When this water-related mitigation profile had been established, the winter measurements would be referenced to it to assess the effective level of natural mitigation of winter conditions versus active summer watering mitigation.

Figure 5: E-Sampler with TSP Inlet Head Mounted on Pick-Up Truck

To test the hypothesis, De Beers allowed the segments of the haul roads that Golder was using for the study to dry prior to initiation of the study. At the commencement of the summer segment at each mine site, a water truck watered the roads per normal dust mitigation on site. A "wet" data sampling run was acquired immediately after the road watering had completed. Haul trucks continued to traverse the haul roads, and were tracked by the chase vehicle, which measured the ever-increasing dust concentrations as the haul roads dried out until a plateau dust concentration was reached. On two occasions during the Victor Mine summer study, the dry roadbed was watered and then the chase truck resumed sampling behind haul trucks. During the Snap Lake Mine summer study this procedure was carried out once.

Haul road surface material samples were collected for laboratory particle size distribution analysis. Shallow excavations in the road base material were also made intermittently to visually assess the depth of drying. These observations were considered when assessing the dust concentrations recorded by the E-sampler.

For the winter sampling program, average dust concentrations were measured on the same sections of the haul road used during the summer monitoring effort. "Average" conditions were required at each site to ensure that the measurements reflected true winter baseline natural dust mitigation on the haul roads. Typical winter conditions were considered to be:

- recent snowfall;
- no accumulating snowfall during the measurements;
- moderate wind; and
- sub-freezing temperatures.

Consistent conditions at each of the sites were expected to lead to reasonably consistent, average winter dust concentration value at each of the sites. These average observed concentrations would then be referenced to the concentration curve that was built from the summer sampling data, and reflect a natural winter mitigation percentage. Consistent with the summer program, haul trucks were tracked by the chase vehicle along the same haul road segments using the same monitoring method. The haul truck tracking continued for day and night time runs at each mine site until enough data had been acquired to establish that the concentrations being measured were reasonably consistent, and could be justifiably compared to the summer data.

The location of the haul road segments used in the winter and summer study programs at the Victor Mine and Snap Lake Mine are shown in Figures 6 to 9. A pictorial comparison of the difference in dust emissions from the haul trucks at Victor Mine can be seen in Figure 10. Note that the visible plume in winter is primarily comprised of condensed water vapour from the vehicle exhaust, rather than dust.

LEGEND

⨂ SUMMER ROAD SAMPLE POINT

HAUL TRUCK TRACKING ROUTE

NOTES

Base Data source:

SCHEMATIC ONLY, NOT TO SCALE

ROAD DUST EMISSIONS STUDY

VICTOR MINE SUMMER ROAD DUST SURVEY

PROJECTION: UTM Zone 12	DATUM: NAD83
SCALE: AS SHOWN	
FILE No:	DATE: June 27, 2012
JOB No: 11-1365-0012	REVISION No: 0
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DE BEERS CANADA

Figure 6

LEGEND

- ⊗ WINTER ROAD SAMPLE POINT
- HAUL TRUCK TRACKING ROUTE

NOTES

Base Data source:

SCHEMATIC ONLY, NOT TO SCALE

ROAD DUST EMISSIONS STUDY

VICTOR MINE WINTER ROAD DUST SURVEY

PROJECTION: UTM Zone 12		DATUM: NAD83	DE BEERS CANADA
SCALE: AS SHOWN			
FILE No:			DATE: June 27, 2012
JOB No: 11-1365-0012	REVISION No: 0		Figure 7
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LEGEND

SUMMER ROAD SAMPLE POINT

HAUL TRUCK TRACKING ROUTE

NOTES

Base Data source:

SCHEMATIC ONLY, NOT TO SCALE

ROAD DUST EMISSONS STUDY

SNAP LAKE MINE SUMMER ROAD DUST SURVEY

PROJECTION: UTM Zone 12	DATUM: NAD83		DE BEERS CANADA
SCALE: AS SHOWN			
FILE No:			DATE: June 27, 2012
JOB No: 11-1365-0012	REVISION No: 0		Figure 8
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LEGEND

HAUL TRUCK TRACKING ROUTE

NOTES

Base Data source:

SCHEMATIC ONLY, NOT TO SCALE

ROAD DUST EMISSIONS STUDY

SNAP LAKE MINE WINTER ROAD DUST SURVEY

PROJECTION: UTM Zone 12	DATUM: NAD83		DE BEERS CANADA
SCALE: AS SHOWN			
FILE No:			DATE: June 27, 2012
JOB No: 11-1365-0012	REVISION No: 0		Figure 9
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Figure 10: Victor Mine Comparison of Summer Dust Plumes and Winter Dust Plumes (including Condensed Water Vapour)

3.0 MONITORING RESULTS AND ANALYSIS

3.1 Meteorology

The primary objective of the study was to evaluate the natural mitigation of haul truck dust emissions due to winter conditions. The assumption is that in northern climates, the year can be broken down into two seasons with respect to the expected impact on haul truck dust emissions: summer and winter, or snow-free and snow seasons. During the summer or snow-free season, the primary mitigation controls impacting road surface dust production are rainfall and active road watering, both of which mitigate dust production only as long as the road surface remains wet.

The study was performed during normal climatic conditions representative of summer and winter as defined primarily by temperature and snow cover, and during a period without major precipitation that would prevent any dust emissions from being measured. Essentially, the conditions required were warm, windy, and dry during summer; and cold, windy, and dry with snow present on the ground during winter. To ensure that these weather conditions were met during both field surveys, the summer survey was initially postponed for several weeks due to an extended period of rainfall at both mines. The winter survey was also delayed for one week at Snap Lake Mine due to a blizzard, after which both surveys commenced under appropriate study conditions.

3.1.1 Victor Mine

Road dust monitoring was undertaken at the Victor Mine during the summer period from September 6th to 12th, 2011. The winter monitoring period was between January 16th and 20th, 2012. The meteorological parameters that may affect the road dust emissions, such as temperature, wind speed and relative humidity, observed during each of these periods were compared to the monthly conditions observed at the Victor Mine in 2011 (Figures 11 to 13). The basis for both the monthly conditions and study period conditions was the daily averages at the on-site meteorological station. In general, weather conditions during the study were in line with the typical monthly conditions during the year. The range of daily averages during the study was as follows:

- Temperature: 8.1 °C to 17.0 °C (summer)
  -10.5 °C to -31.8 °C (winter)
- Wind speed: 2.0 metres per second (m/s) to 5.5 m/s (summer)
  1.8 m/s to 5.2 m/s (winter)
- Relative Humidity: 55.3 % to 97.4 % (summer)
  72.4 % to 85.9 % (winter)

Figure 11: Comparison of Monthly Temperatures Recorded at the Victor Mine (2011) and Temperatures during Victor Mine Surveys

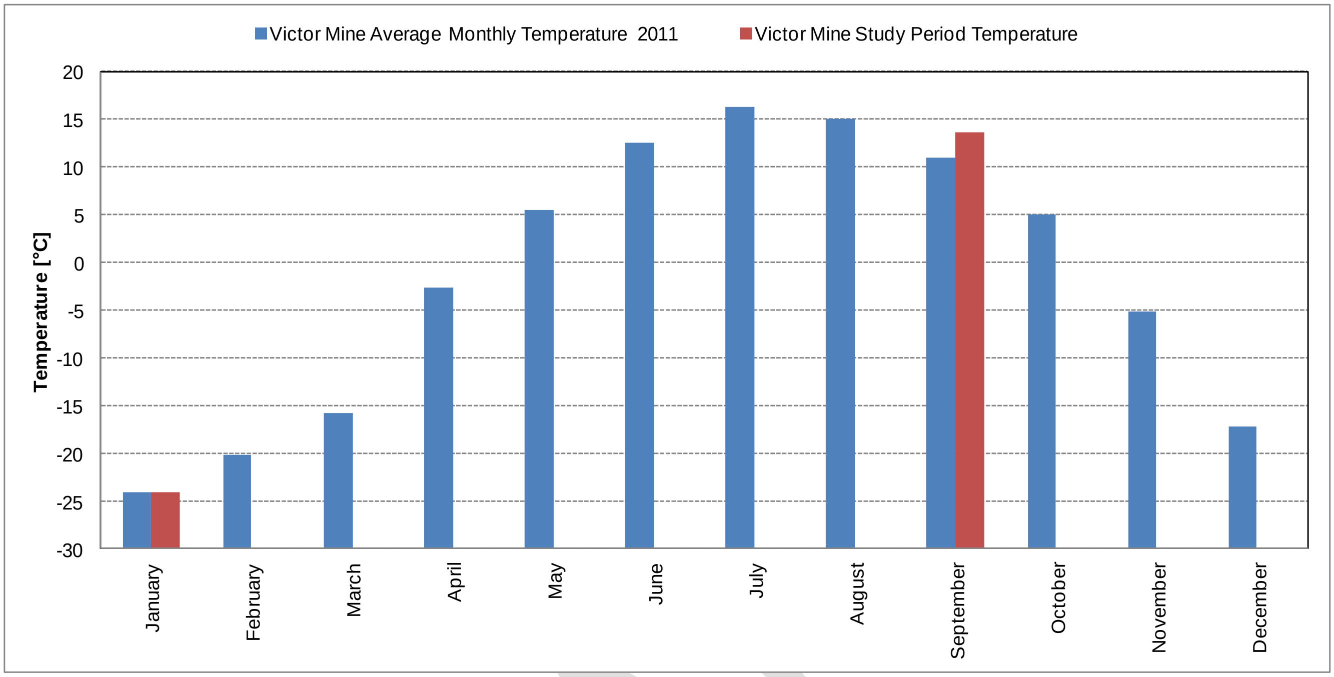


Figure 12: Comparison of Monthly Wind Speeds Recorded at the Victor Mine (2011) and Wind Speeds During Victor Mine Surveys

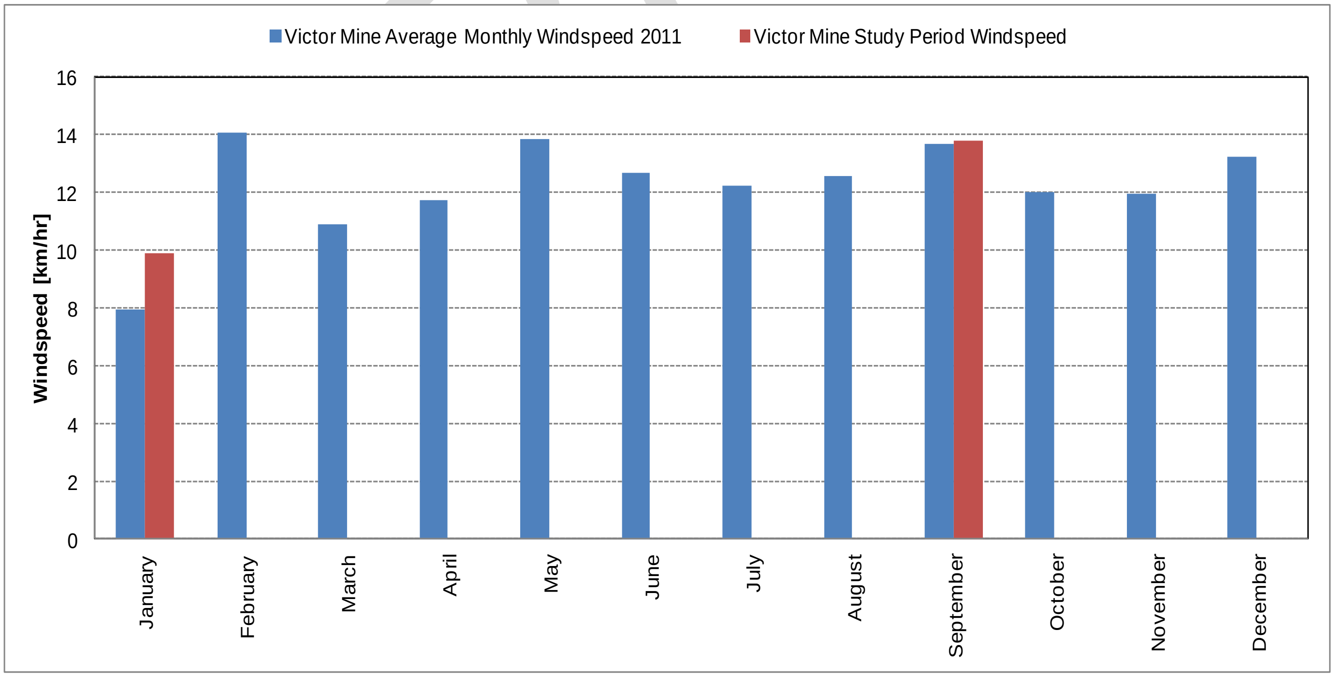
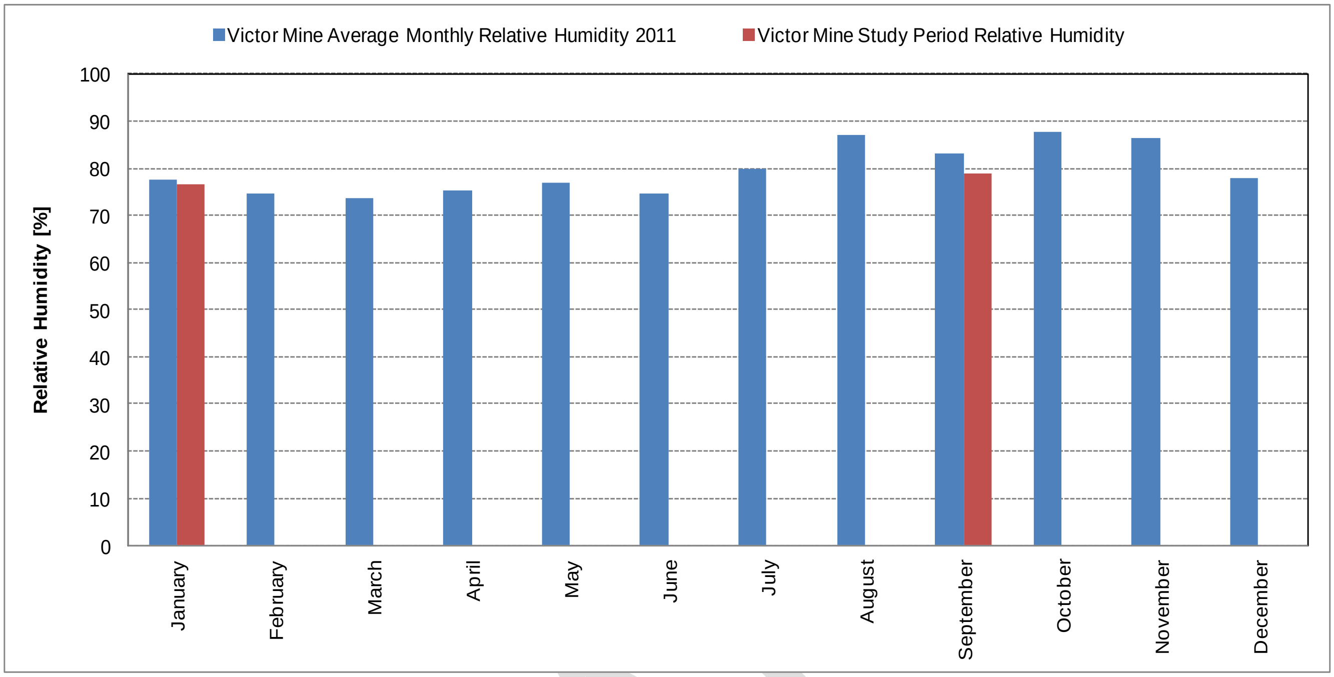


Figure 13: Comparison of Monthly Relative Humidity recorded at the Victor Mine (2011) and Relative Humidity during Victor Mine Surveys



3.1.2 Snap Lake Mine

Road dust monitoring was undertaken at the Snap Lake Mine during the summer period from August 23rd to 29th, 2011. The winter monitoring was conducted between February 2nd and 6th, 2012. Key meteorological parameters that may affect road dust emissions, such as temperature, wind speed and relative humidity, measured during the Snap Lake surveys were compared to the climate normal data from Yellowknife (Environment Canada 2012). These comparisons are shown in Figures 14 to 16. The basis for the monthly conditions was the 1971-2000 climactic averages at the Environment Canada meteorological station in Yellowknife, while the Snap Lake study period data were based on the daily averages at the on-site meteorological station. The analysis shows that the conditions during the summer study period are typical of August. The conditions during the winter study period are representative of a warmer than usual February, with higher temperature, wind speed and relative humidity. The range of daily averages during the study was as follows:

- Temperature: 10.1 °C to 14.1 °C (summer)
  -3.0 °C to -18.9 °C (winter)
- Wind speed: 2.0 m/s to 5.5 m/s (summer)
  6.7 m/s to 9.5 m/s (winter)
- Relative humidity: 68.2 % to 80.1 % (summer)
  78.3 % to 95.2 % (winter)

The figures also indicate that February and August are representative of snow (October to April) and snow-free (May to September) seasons.

Figure 14: Comparison of Average Temperatures based on Yellowknife Climate Normal (1971-2000) and Temperatures during Snap Lake Mine Surveys

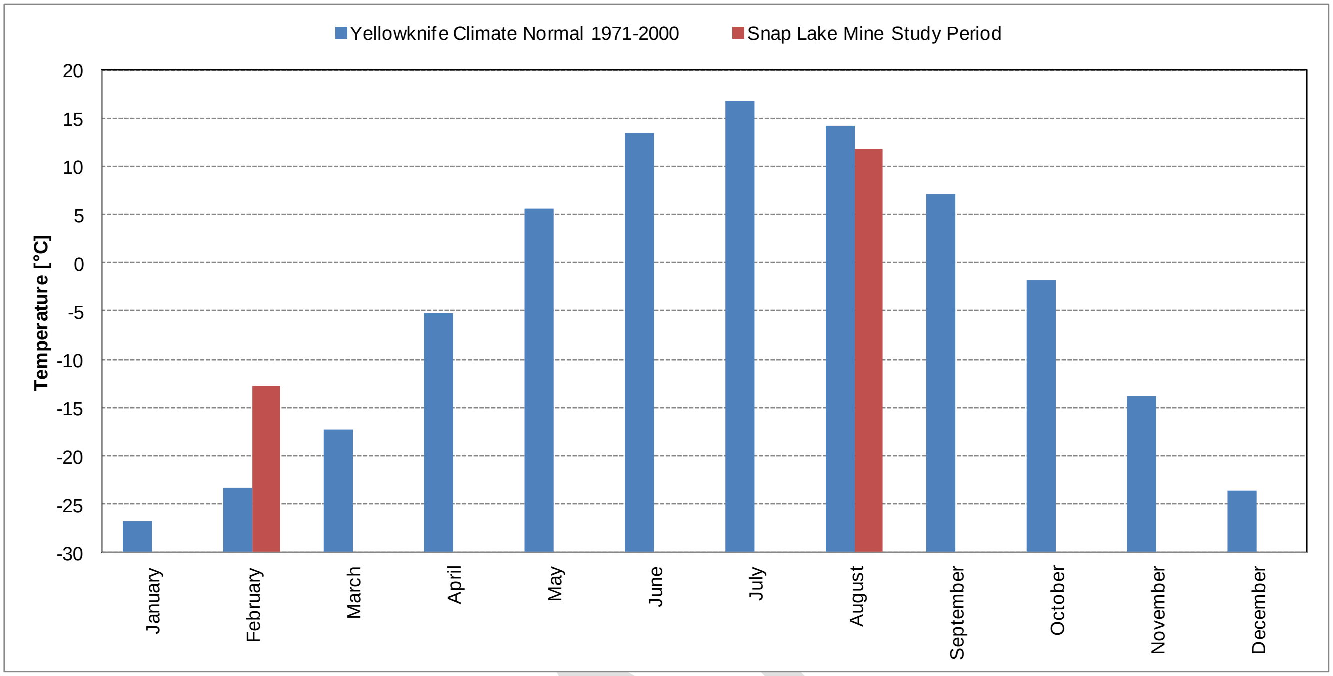


Figure 15: Comparison of Average Wind Speed Based on Yellowknife Climate Normal (1971-2000) and Wind Speed During Snap Lake Mine Surveys

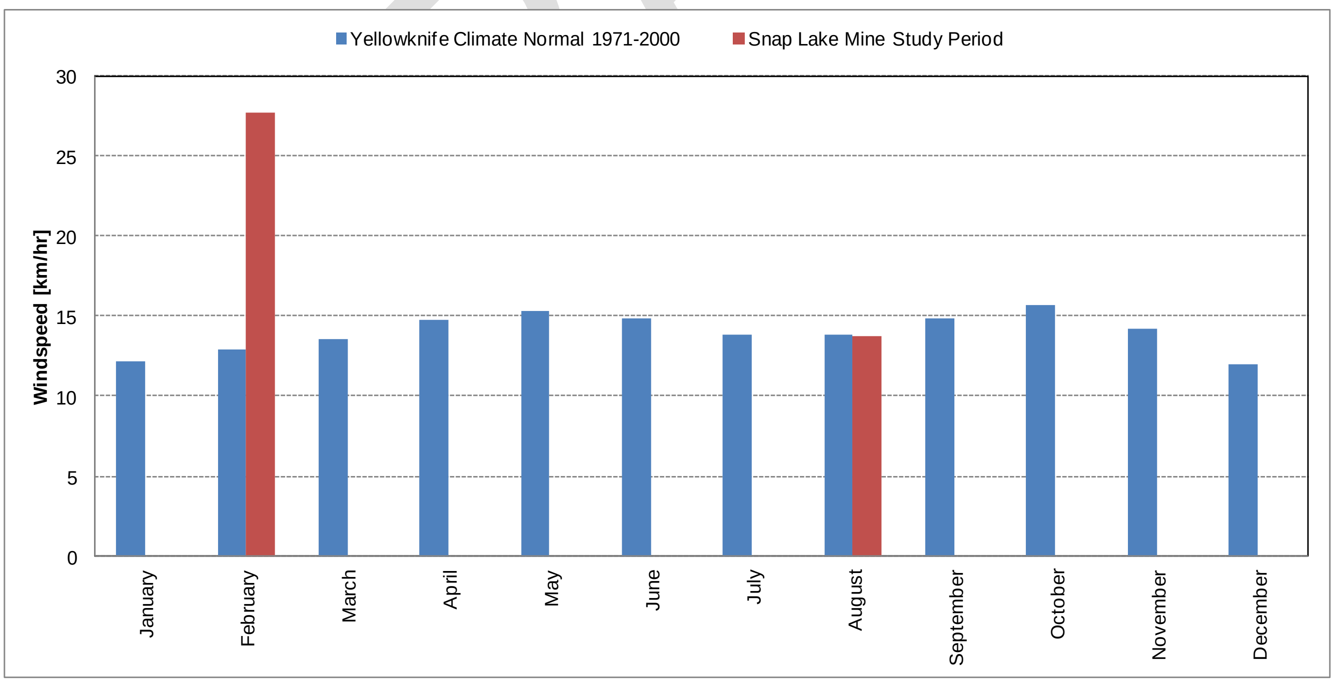
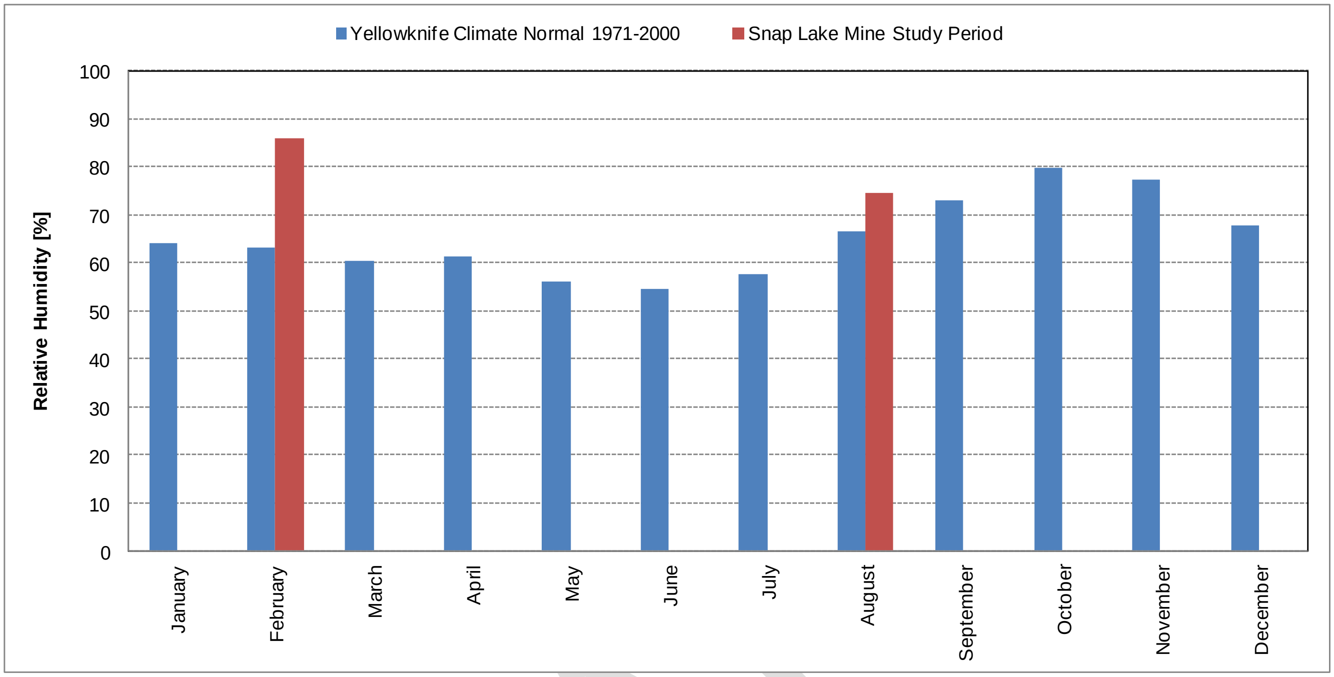


Figure 16: Comparison of Relative Humidity Based on Yellowknife Climate Normal (1971-2000) and Relative Humidity during Snap Lake Mine Surveys



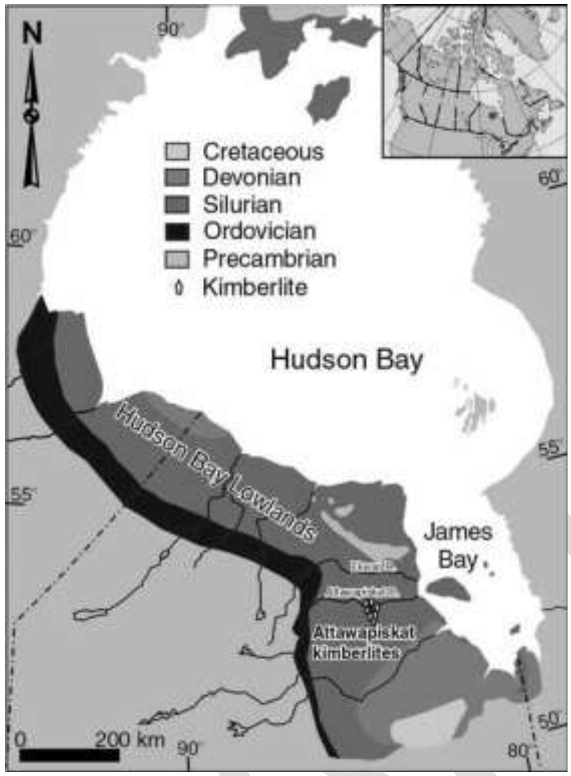
3.2 Road Material Analysis

3.2.1 Victor Mine

3.2.1.1 Road Material

The road surface material at the Victor Mine site was sourced from the mine during the summer monitoring study. The material is predominantly limestone and dolostone with some clastic material, all of which are mid-Ordovician to mid-Silurian in age. These rock types overlay and surround the diamond bearing Kimberlite pipes to a thickness averaging 300 m in the vicinity of the Victor Mine (Bellefleur et al 2005). The regional geological setting of the rock types can be seen in Figure 17.

Figure 17: Geology of Hudson's Bay Lowlands (Sader et al, 2005)



The limestone belongs to the Attawapiskat and Ekwan/Severn formations, while the dolostones belong to the Bad Cache Rapids formation (Bellefleur et al 2005). In the vicinity of the mine, the predominant rock that outcrops is the Attawapiskat limestone, which has been described as reefal (bioherm) limestone composed of fossil remains of marine organisms and corals (Sader 2011). The texture of this material is described as karstic, which is readily erodible and dissolvable carbonate rock, prone to rapid weathering.

3.2.1.2 Road Base Life Cycle

The limestone rock mined from the pits is stockpiled and crushed into road material on site. The material is typically crushed to an approximately 25-millimetre (mm) diameter and spread on all the roads at the mine as the primary road bed. The rock, however, is prone to chemical and mechanical weathering processes, induced by heavy vehicle pulverization (i.e., haul trucks and grading operations) and by precipitation and road watering. This weathering reduces the average particle size further, making it prone to dust generation during dry periods. As the material is eroded, more crushed material is added to the road bed, and the cycle of erosion continues. A photo of the road surface material at the Victor Mine is shown in Figure 18.

Figure 18: Victor Mine Road Limestone Material with Fine Grained, Cemented Character (Photo: A. Pickup, 2011)

Note: A camera lens cap 50 mm in diameter was placed in the photo to provide a size reference.

3.2.1.3 Sediment Analysis

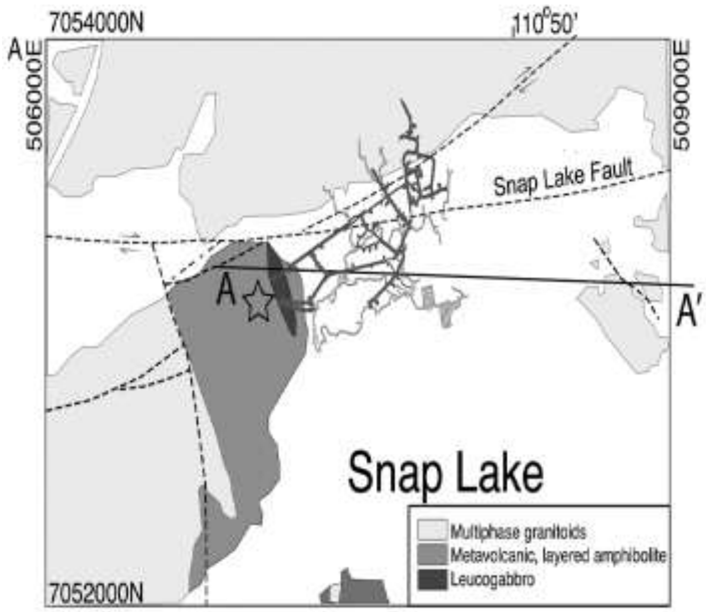
Two samples of the limestone road bed material were taken at the site and analyzed at Golder Geotechnical Lab in Calgary. A particle size analysis consisting of dry sieving and hydrometer tests was conducted on all samples from the mine site, using methodology ASTM-D422, which includes the silt test sieve method of ASTM-C-136. Fine silt fractions for the limestone material passing a US #200 mesh sieve (0.075 mm) ranged between 14.7 and 22.0% (Appendix B; Figures A1 and A2). This provides an average silt fraction of about 18.3 % overall for the road surface. The typical measured values for silt content in mine roads ranges between 2.4 and 16%, with an average of 10% for stone quarrying (U.S. EPA 2006a). The analysis of the Victor Mine's road base material demonstrates that these road surfaces are above average in terms of their potential for road dust emissions based on silt content.

3.2.2 Snap Lake Mine

3.2.2.1 Road Material

Similar to the Victor Mine, the source material for road building at the mine is mine rock from the site. The material used at Snap Lake Mine for the road building is primarily granitic and/or metavolcanic rock (Kopylova et al, 2010). The rocks are Pre-cambrian, or 2.4 billion years in age, and part of a geological complex known as the Slave Craton (Kopylova et al 2010). The region has never been overlain by sedimentary rock (Caro & Kopylova 2004). Granitic rocks are primarily coarse grained, igneous rocks composed mostly of quartz and feldspars. The regional geology of Snap Lake can be seen in Figure 19.

Figure 19: Geology of the Snap Lake Area (Source: Kopylova et al 2010)



3.2.2.2 Road Base Life Cycle

Mine rock material from the mine is crushed on site to supply road base material. The material is typically crushed to an approximately 25-mm diameter and added to the roadways. Owing to the high degree of quartz and feldspar minerals comprising the granite, the rock is more resilient to mechanical and chemical weathering, compared to the limestone material used at the Victor Mine. The Snap Lake Mine granitic material is subject to pulverization from heavy equipment and haul trucks on the roads at the mine site. The finer sized material likely results from mechanical abrasion brought about by the heavy vehicles. The road bed can be seen in Figure 20. Because granite is physically resistant to erosion and given the difficulty of mechanically generating particulate sizes less than 10 µm in diameter, the proportion of silt in the road surface material at the Snap Lake Mine is lower than that of the Victor Mine.

Figure 20: Snap Lake Road Granitic Material Showing Pulverized Material and Depth of Moisture Retention below Surface (Photo: A. Pickup 2011)

3.2.2.3 Sediment Analysis

Three samples of the granite road surface material were collected during the summer survey program at the Snap Lake Mine. These samples were sent to the Golder Geotechnical Lab in Calgary for particle size analysis, using standard dry sieve and hydrometer tests. The results from three road samples showed an average fine silt fraction of 7.3% with a range of 5.9 – 8.5% passing a #200 mesh sieve (Appendix B; Figures A3, A4 and A5).

3.2.3 Factors Affecting Road Dust Emissions

3.2.3.1 Victor Mine

3.2.3.1.1 Summer

The haul roads at the Victor Mine are different than those at the Snap Lake Mine in terms of their emission characteristics as described in Section 2.1. The high silt content of the road base at Victor Mine typically gives rise to higher emissions from wheel entrainment by vehicles as is evidenced in published emission factors (US EPA 2006b). The fine silt fraction of the road surface material was observed to be prone to rapid drying in the summer season. Water trucks regularly wetted the surface material to a depth of approximately 2 to 3 centimetres (cm) (Figure 21). Field observations during the summer survey found the surface layer to dry out within three to four hours under generally sunny and winter conditions. Anecdotal information from equipment operators at the site report dust emissions returning to non-wetted emission rates within this time frame.

Observations made during sample collection of the road material demonstrated that a concrete-like hard pan is evident, which is created by repetitive watering and drying of the roads (Figure 21). Surface water from precipitation or road watering dissolves the carbonates forming a lime mud which dries to a hard consistency. This cemented layer is durable against picks and shovels and appears to limit water penetration, which likely limits watering effectiveness by limiting water retention. Overall the road contains a high fraction of fine material in combination with the road bed characteristics, predisposes the Victor site to a high dust emission potential in the summertime. Traffic speeds at the Victor Mine are set at 50 kilometres per hour (km/h) and the trucks are primarily in the 100 and 163 tonne classes. These two combined factors of speed and mass are known to be the primary factors in influencing the amount of suspended dust generated (US EPA 2006b).

Figure 21: Victor Haul Road Showing Durable Lime Mud Hard Pan, Pen Denotes Area Excavated With a Steel Pick Axe (Photo: A Pickup)

3.2.3.1.2 Winter

During the winter, the haul roads change in terms of their emission characteristics. Owing largely to snow and ice and prolonged sub-zero conditions, the road materials become freeze-dried. The fine silt fraction appears to combine with ice and becomes bound to the larger pieces of aggregate in the road. The result is that the bound fine material becomes unavailable for lofting via wheel entrainment. Additionally, the entire aggregate matrix becomes a solid, frozen mass, which seems to limit airborne dust production (Figure 22). The frozen and consolidated nature of the road material during the wintertime results in an obvious visual reduction in road dust production (compared to summer), as noted by the study team while on-site.

Figure 22: Victor Mine Roadbed Showing Frozen, Consolidated Aggregate in Wintertime [total depth ~4cm] (photo: A Pickup)

3.2.3.2 Snap Lake Mine

3.2.3.2.1 Summer

Road bed silt content at the Victor Mine is approximately 2.5 times higher than the road bed silt content at Snap Lake Mine. Higher roadbed silt content can result in greater road dust emissions. The finer materials also have slower gravitational settling rates meaning that the dust remains suspended for a longer period of time.

Vehicle weight and speed also influence road dust production. At the Victor Mine, haul trucks are predominantly Caterpillar Model 777 trucks (empty weight 72 tonnes; full weight 163 tonnes), while the Snap Lake Mine primarily uses Komatsu Model HM350 haul trucks (empty weight 31 tonnes; full weight 63 tonnes). Haul truck speeds at the Victor Mine are typically 50 km/h, whereas haul truck speeds are limited to 30 km/h at Snap Lake. Higher vehicle weight and speed typically result in higher road dust emissions (US EPA 2006b).

Similar to the observations at the Victor Mine, the road material at the Snap Lake Mine was also observed to be prone to drying in about three to four hours after road watering under partly cloudy and windy conditions. On a visual basis, the trucks at Snap Lake Mine were often visible while sampling their dust plumes, whereas the larger haul trucks at Victor Mine were often totally obscured by their dust plumes. These field observations suggest that the finer material produced by faster and heavier equipment at the Victor Mine has greater potential to be transported downwind compared to road dust generated at the Snap Lake Mine.

3.2.3.2.2 Winter

Similar to the Victor Mine, the roads at the Snap Lake Mine became ice-bound solid during the winter months. The granite aggregate becomes bonded to the fine fraction with frost and ice, effectively limiting emissions from wheel entrainment.

Observations suggest that the entire roadway becomes a solid mass with limited loose material on the surface. Small excavations of the roadbed show that during the sampling, there was about eight to ten centimetres of frozen aggregate underlain by ice and the crushed rock of the road base. Figure 23 below shows a small excavation in the road surface.

The character of both road beds from summer and winter demonstrated that the fine silt fractions of the road materials became ice-bound during the winter months. The aggregate materials in the road had a strong tendency to consolidate into a singular mass. The underlying road beds became completely frozen in the winter period. In total, the transformation of the roads in terms of dust emission potentials becomes highly constrained during the winter period, with the majority of the material becoming ice-bound and unavailable for wheel entrainment.

Figure 23: Snap Lake Road Bed Profile Showing Frozen Aggregate and Solid Ice Layer Below (A. Pickup)

3.3 Truck Monitoring Results and Analysis

3.3.1 Gravitational Settling During Truck Sampling

The gravitational settling velocity (V_{grav}) of airborne particulate is an exponential function of particle geometric diameter[1]:

$$V_{grav} \cong 3 \times 10^{-8} \rho_p d_g^2 \qquad \text{(Equation 1)}$$

Where, ρ_p is the particle density (2,560 kilograms per cubic metre [kg/m³]) and d_g is the particle's geometric diameter in µm (Equation 4-29; Baron and Willeke 2001). The time varying gravitational loss of dust particulate for a static parcel of air can be estimated by multiplying the size-resolved mass distribution of particulate by Equation 1.

The size-resolved mass distributions (i.e. frequency distributions) for the Snap Lake Mine and Victor Mine road dust can be derived from the cumulative mass distributions obtained during the ASTM D422 sediment analysis (Appendix B). This derivation assumes that the frequency distribution of dust particulate in the dust plume generated by haul road traffic is identical to the particle size distribution found in the road bed material. The frequency distributions are calculated as the derivative of the ASTM D422 cumulative distributions (Equation 22-1 to 22-3; Baron and Willeke 2001). However, it is important to note that:

1) the cumulative distributions below 150 µm have been normalized by the percentage of the mass passing the 150 µm sieve stage such that the integral of all the frequency distributions are equal to unity (i.e. 1 µg/m³) to facilitate comparison among the frequency distributions;
2) the sieve diameters from the sediment analysis represent "bin edges", whereas for a frequency distribution, the distribution was plotted as it relates to the "bin center"; and
3) particulate distributions tend to follow log-normal rather than normal distributions (i.e. their logarithm is Gaussian) requiring that bin centers be computed as the geometric average[2] of the "bin edges".

Figure 24 plots the average mass distribution for the Snap Lake Mine and Victor Mine in $dM/d_{log}d_g$ versus $d_{log}d_g$ format; where dM represents the mass concentration over the interval $d_{log}d_g$. In the figure, the integral or, "area under the curve", is equal to the total mass concentration expressed in µg/m³, i.e. it is the sum of the product of $dM/d_{log}d_g \times d_{log}d_g$ over each $d_{log}d_g$ interval.

Having established the initial size-resolved mass distributions and the mass concentration at time zero (C_o at t_o), the reduction in particulate mass concentrations (C_n/C_o) due to the effects of gravitational settling at any future time (t_n) can now be calculated. For this calculation, it was assumed:

- a maximum dust plume height of 5 m; and,
- a sampling elevation of 2 m.

During the dust study at the Victor Mine, the sampling vehicle trailed the haul trucks at 50 m while traveling at 50 km/h. This results in a sampling lag-time of approximately 3.6 seconds (s) during which time the particulate

[1] Geometric diameter corresponds to the actual physical diameter of the particle, assuming it is spherical.

[2] Geometric mean value is the antilog (10^x) of the average of the base-10 logarithm of the bin edges [$x = (\log(d_1) + \log(d_2))/2$]

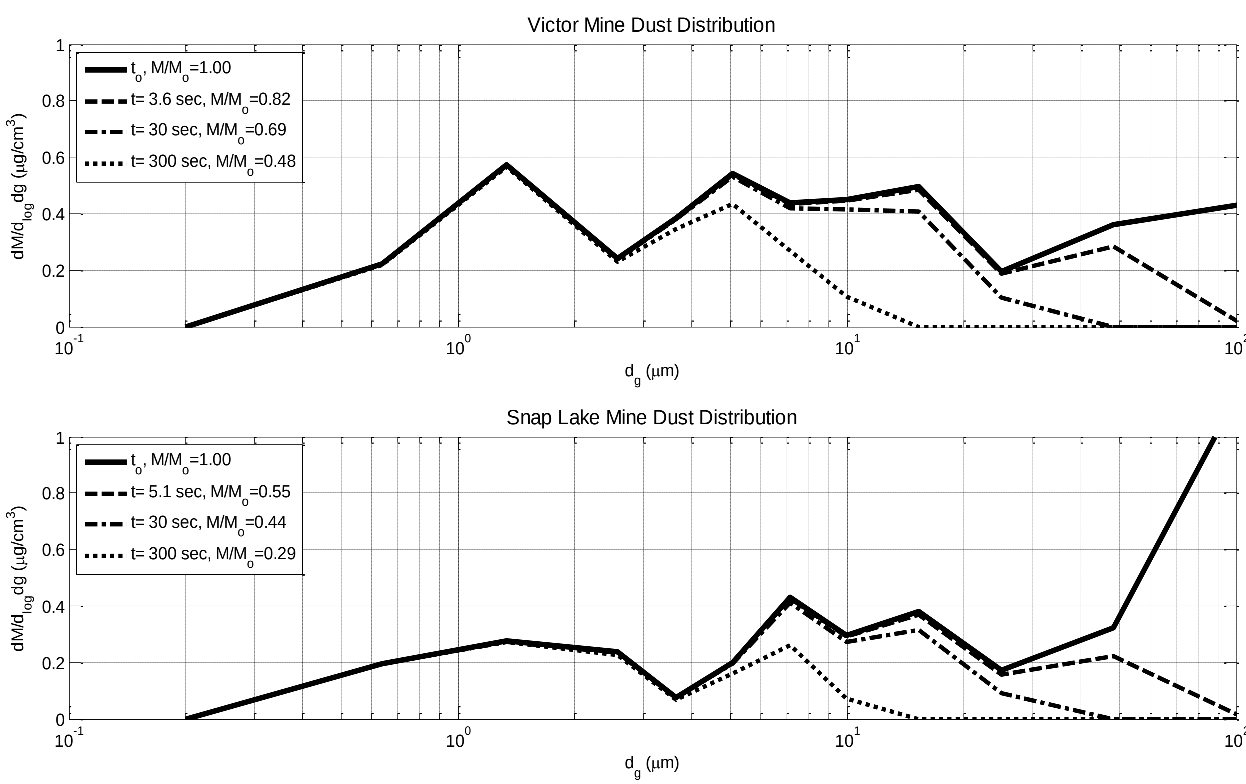
concentration is reduced by approximately 18%. After two hypothetical sampling times of 30 s (t_2) and 5 minutes (t_3 = 300 s), the particulate concentrations are reduced by 31% and 52% at the Victor Mine.

During the Snap Lake Mine dust study, the sampling vehicle trailed the haul trucks at 50 m while travelling 35 km/h. This results in a sampling lag-time of approximately 5.1 s during which time the particulate concentration is reduced by approximately 45%. After 30 s and 300 s, the concentrations at Snap Lake Mine are reduced by 56% and 71% compared to the initial concentration.

As Figure 24 illustrates, the Victor Mine road dust contains a higher proportion of particles below 10 µm in geometric diameter. Theoretical gravitational settling velocities for particles lesser than 10 µm are low over these short time periods. As a result, the dust mass concentrations theoretically sampled approximately 30 s after dust generation are predicted to be approximately 1.6 times higher for Victor Mine than for Snap Lake Mine. When evaluated in terms of the actual sampling lag during the experiment, the Victor Mine data are expected to be enhanced by a factor of approximately1.5 compared to Snap Lake Mine.

Note that the time varying, size resolved particle losses represent idealized conditions for a static parcel of air and without mixing or entrainment. In reality, light winds, small-scale turbulence and interaction with the local environment can enhance, reduce or eliminate gravitational losses for particles lesser than 10 µm. Mixing with ambient air during plume transport will substantially reduce measured dust concentrations (i.e., dilution).

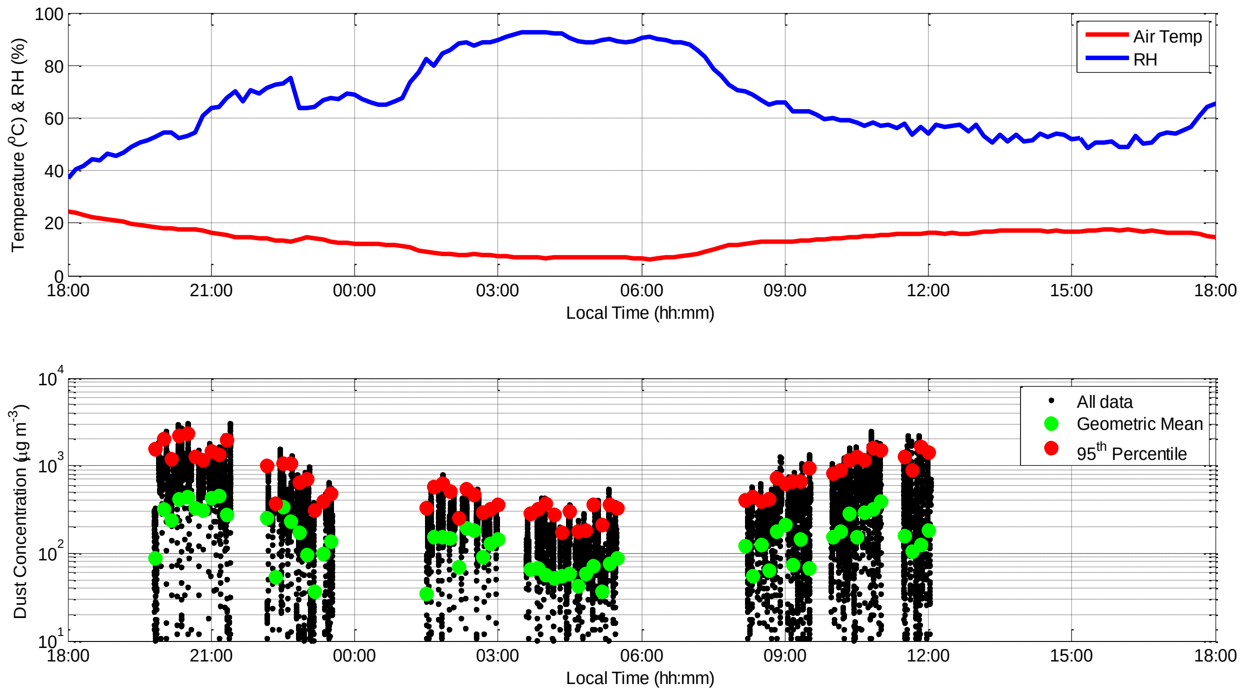
Figure 24: Simulated, Size Resolved Gravitational Losses for Road Dusts Generated at Victor Mine (Top) and Snap Lake Mine (bottom).



3.3.2 Road Dust Production at Victor Mine

Atmospheric RH is primarily controlled by temperature, pressure and the concentration of atmospheric water vapour (Figure 25). During the summer field observations, temperature varied between 6.4°C and 25.8°C with an average value of 15.0°C. RH measured at 2.5 m height varied between 37% and 96% with an average value of 65% over the same time period.

Figure 25: Victor Mine Time Series of (Top) Air Temperature and Relative Humidity and (Bottom) Dust Concentrations: 10-Minute Geometric Average and 10-Minute 95th Percentile Values



The lower panel of Figure 25 plots the summertime series of dust concentration measurements (logarithmic scale) made from on board the chase vehicle (post-road-watering data have been eliminated from the figure). Dust concentrations measured every second (1 Hertz [Hz]) were geometrically averaged to 10 minute averages (n = 61) and to compute 10-minute 95th percentiles. The 10 minute average corresponds to the same sampling interval as the meteorology data. These corresponding 10 minute summer and winter data are provided in Tables C-1 and C-2 in Appendix C. The geometric averages are plotted as green circles and the 95th percentiles as red circles in the lower panel of Figure 25. The results show that there is a strong, non-linear dependence between road dust concentrations and ambient relative humidity and/or temperature. The question becomes what is the cause of this effect?

Pure limestone ($CaCO_3$) is relatively insoluble in pure water and not typically hygroscopic. The Victor Mine road bed material is predominantly composed of limestone and dolomite. In-situ chemical weathering from the application of on-site water, as well as interactions with atmospheric acids found in natural and polluted precipitation (i.e., sulfuric acid [H_2SO_4], nitric acid [HNO_3]), leads to heterogeneous chemical reactions and the formation of more soluble and hygroscopic calcium salts (e.g., calcium sulphate [$CaSO_4$], calcium nitrate

[$CaNO_3$]) (McNaughton et al. 2009). The presence of even a small weight percentage (wt%) of these salts on silt-grade particulate can lead to non-linear hygroscopic growth of particle geometric sizes at relative humidity above approximately 40% (Sullivan et al. 2009). Thus the presence of these hygroscopic salts could result in an apparent suppression of road dust at the Victor Mine due to enhanced gravitational settling of the particles suspended at high RH.

Alternatively, in their chapter on fugitive dust emissions, Watson et al. (2000) note “water adhering to soil particles increases their mass and surface tension forces, thereby decreasing suspension and transport” and that, “cohesion of wetted particles often persist after the water has evaporated due to the formation of aggregates and surface crusts”. The presence of soluble salts, discussed in the preceding paragraph, enhances soil particle cohesion implying that at high RH the production of dust from the road surface is suppressed. However, the haul truck tires mechanically destroy these aggregates implying that the suppression of dust by surface cohesion is limited to areas dominated by wind erosion, i.e. the road surface adjacent to the tires. Thus, the observed reductions in dust concentrations at high RH are likely caused by a combination of factors and the presence of soluble salts would likely enhance the effectiveness of either mechanism.

To evaluate the relationship between dust concentrations and ambient atmospheric relative humidity, the 10 minute geometric average dust concentrations and the 10 minute 95th percentile concentrations are plotted versus relative humidity in Figure 26. A linear regression of the base-10 logarithm for the geometric average and 95th percentile dust concentrations to RH are then performed and the results plotted as solid green and red lines (Figure 28). The regression of the 95th percentile concentrations against RH are relatively robust (r^2 = 0.676), whereas the regression for the geometric averages are not well constrained (r^2 = 0.317). The relation between the geometric mean airborne particle mass is described by the non-linear equation:

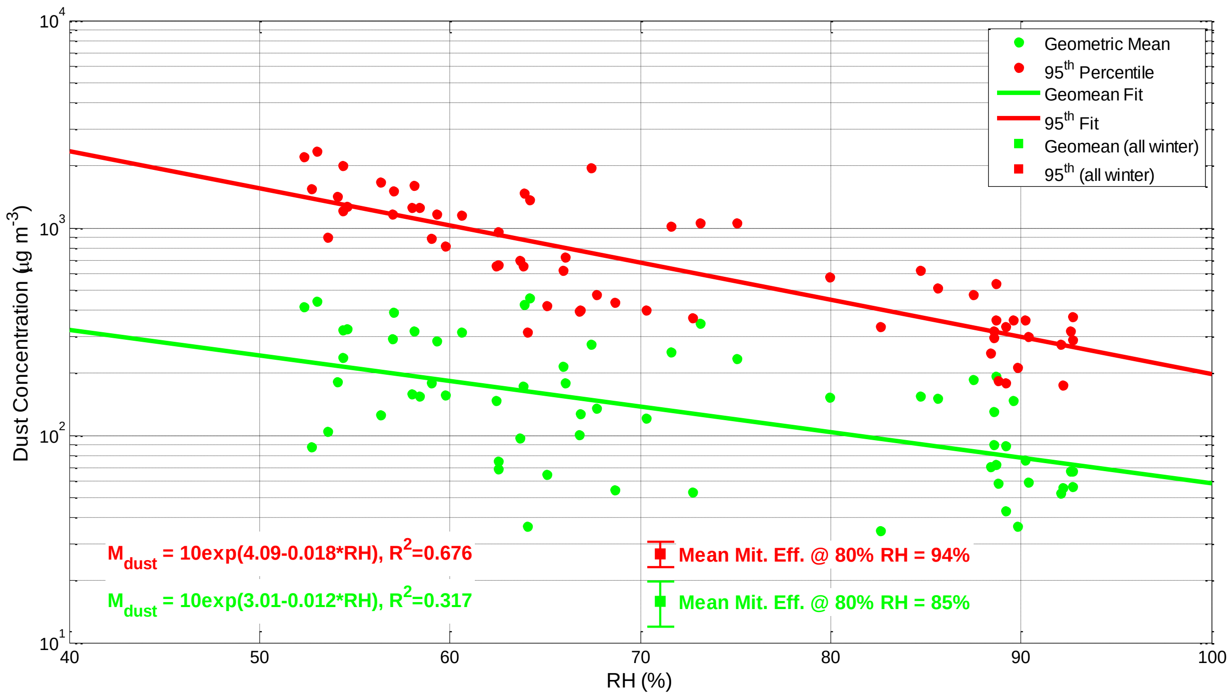
$$Mass_{dust} = 10^{(3.01-0.012\times RH)} \quad \text{(Equation 2)}$$

where RH is expressed in numerical percentage (0 to100). The relation for computing the 95th percentile from ambient RH is described by the equation:

$$Mass_{dust} = 10^{(4.09-0.018\times RH)} \quad \text{(Equation 3)}$$

It is noted that these relationships pertain to the dust concentrations measured behind the haul trucks within approximately 5 seconds of their suspension and entrainment. The relations are also only valid over the observed range of RH ~50 to 95%. The data may be extrapolated to approximately 40% RH; however, below 40% RH the relationship between RH and dust production is likely flat, i.e. no further increases in dust production with decreasing RH, as below 40% RH hygroscopic salts typically effloresce (i.e. crystallize).

Figure 26: Victor Mine Dust Concentrations as a Function of Ambient Relative Humidity.



During the winter study at the Victor Mine, air temperatures ranged from -32.1 to -25.5°C, with an average of -28.2°C. Relative humidity varied from 61% to 77% with an average value of 71%. No trends in dust concentrations with either air temperature or relative humidity were observed. Dust concentrations measured every second (1 Hz) were geometrically averaged to 10 minute averages (n = 22). The 10 minute average dust concentrations ranged between 10.3 and 25.4 µg/m^3, with a mean value of 15.8 µg/m^3. The range of 95th percentile dust concentrations were 14.5 to 45.9 µg/m^3, with an average of 26.9 µg/m^3.

In this study, the natural mitigation efficiency due to winter conditions is calculated by dividing the wintertime dust concentration by representative unmitigated summertime values and then subtracting this ratio from unity and converting to a percentage as shown in the equation below.

$$E_m = 100\% \left(1 - \frac{w}{s}\right)$$

Where:

E_m = mitigation efficiency (%)
w = wintertime dust concentration (µg/m^3)
s = unmitigated summertime dust concentrations (µg/m^3)

However, though wintertime concentrations do not show a trend when plotted against meteorological variables, summertime dust concentrations have a non-linear dependence with ambient RH. Thus, mitigation efficiency has to be reported at a single value of RH. For this study, Golder has chosen a RH of 80% to conservatively estimate the natural mitigation efficiency. This value was chosen based on the RH observed during the Snap Lake Monitoring Program. Choosing a lower RH would appear to increase the mitigation efficiency, whereas choosing a high RH would appear to decrease the mitigation efficiency.

Wintertime geometric average and 95^{th} percentile dust concentrations are 15.8 and 26.9 µg/m^3, respectively. The summertime geometric average and 95^{th} percentile dust concentrations predicted by Equations 3 and 4 at 80% RH are 112 and 447 µg/m^3. Using this approach, the geometric average mitigation efficiency is ~85%, i.e. 100% × (1-15.8/112) and the 95^{th} percentile mitigation efficiency is ~94%, i.e. 100% × (1-26.9/447). The correlation between dust concentration and RH is stronger based on the 95^{th} percentile measured dust data; consequently, the Victor Mine result can be summarized in the following sentence:

- The natural wintertime mitigation efficiency on dust concentrations is 94% when comparing to unmitigated summertime dust concentrations, at 50 m behind the haul trucks and 80% relative humidity.

3.3.3 Road Dust Production at Snap Lake Mine

Figure 27 plots the time series of ambient air temperature and relative humidity during the summertime road dust study at the Snap Lake Mine. The Snap Lake meteorology data were only collected hourly. This sample frequency is very coarse compared to the 1 Hz sampling rate for the chase truck making road dust measurements. As a result, the RH data were resampled using linear interpolation to 20-minute intervals to facilitate better comparison (Figure 27). The corresponding 20 minute summer and winter data are provided in Tables C-3 and C-4 in Appendix C. The lower panel of Figure 27 plots the dust mass concentrations, the 20 minute geometric means, and the 20 minute 95^{th} percentile dust concentrations. Consistent with the monitoring data from Victor Mine, a strong relationship between road dust production and ambient relative humidity is apparent.

The road bed material at Snap Lake Mine consists of pulverized igneous bedrock. Crushing for use as road bed material exposes mineral surfaces that would have been subject to little chemical weathering. These freshly exposed surfaces will contain significant weight percentages of oxides of potassium (K_2O), sodium (Na_2O), calcium (CaO), iron (FeO, Fe_2O_3), magnesium (MgO) and phosphate (P_2O_5) (Press and Siever, 1986). These compounds have a range of solubilities in pure water but are readily wettable. As a result they may form cohesive aggregates at the road surface at high RH or, once suspended, could undergo sufficient hygroscopic growth to enhance their gravitational settling.

Figure 28 plots the linear regressions of the base-10 logarithm of the geometric means and 95^{th} percentile dust concentrations versus relative humidity for the summertime Snap Lake Mine measurements. As expected the regressions are robust (r^2 = 0.622, 0.720) and exhibit a steeper dependence with respect to relative humidity compared to the finer, less hygroscopic road bed material used at the Victor Mine.

Figure 27: Snap Lake Mine Time Series of (Top) Air Temperature and Relative Humidity and (Bottom) Dust Concentrations: 20-Minute Geometric Average and 20-Minute 95th Percentile Values

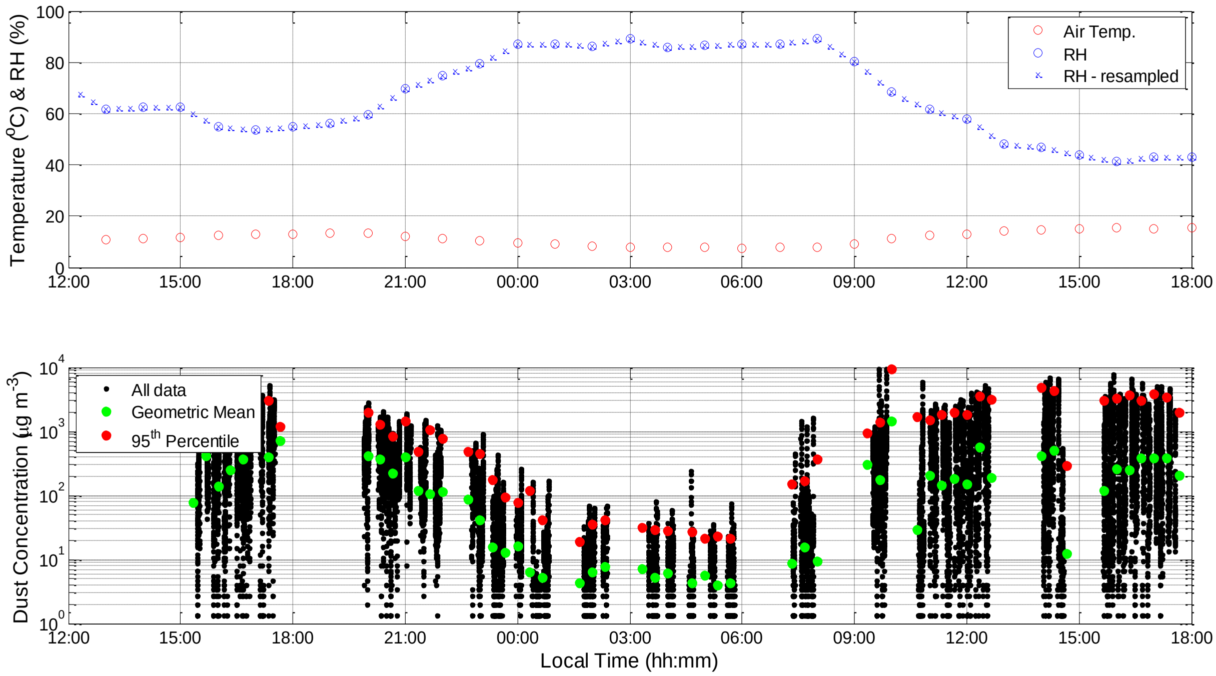
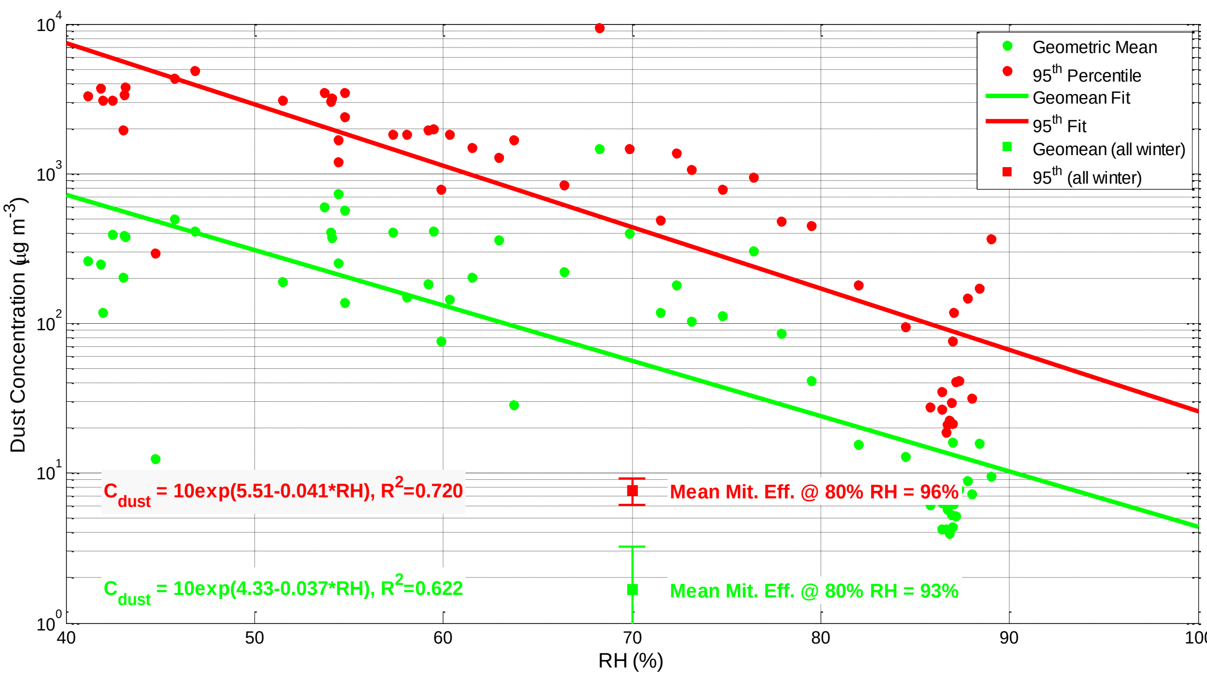


Figure 28: Snap Lake Mine Dust Concentrations as a Function of Ambient Relative Humidity.



The non-linear dependence of the geometric mean as a function of relative humidity can be expressed according to:

$$Mass_{dust} = 10^{(4.33-0.037\times RH)} \quad \text{(Equation 4)}$$

While the 95th percentile can be expressed according to:

$$Mass_{dust} = 10^{(5.51-0.041\times RH)} \quad \text{(Equation 5)}$$

Wintertime temperatures during the Snap Lake Mine measurements varied between -7.5 and -1.7°C with an average of -4.3°C. Relative humidity with respect to water varied from 69% to 97% with an average value of 84%. No dependence of dust concentrations with temperature or relative humidity were observed for the wintertime Snap Lake Mine study. The 20 minute geometric average dust concentrations varied between 1.5 and 4.7 µg/m^3 with an average value of 2.5 µg/m^3 (n = 6 after 3 concentrations of 0 µg/m^3 removed). The 20 minute 95th percentile values varied from 2.9 to 14.5 µg/m^3 with an average value of 7.7 µg/m^3 (n = 9). When compared to the observations of summertime dust concentrations at Snap Lake Mine (Equation 4), the natural wintertime mitigation efficiency is ~89%, i.e. 100% × (1-2.5/23.4). Based on the 95th percentiles (Equation 5), the natural wintertime mitigation efficiency is ~96% when computed at a RH of 80%, i.e. 100% × (1-7.7/170). The final natural wintertime mitigation efficiency for Snap Lake Mine is determined based on 95th percentile values to be consistent as the approach used for the Victor Mine. The Snap Lake Mine result can be summarized in the following sentence:

- The natural wintertime mitigation efficiency on dust concentrations is 96% when comparing to unmitigated summertime dust concentrations, at 50 m behind the haul trucks and 80% relative humidity

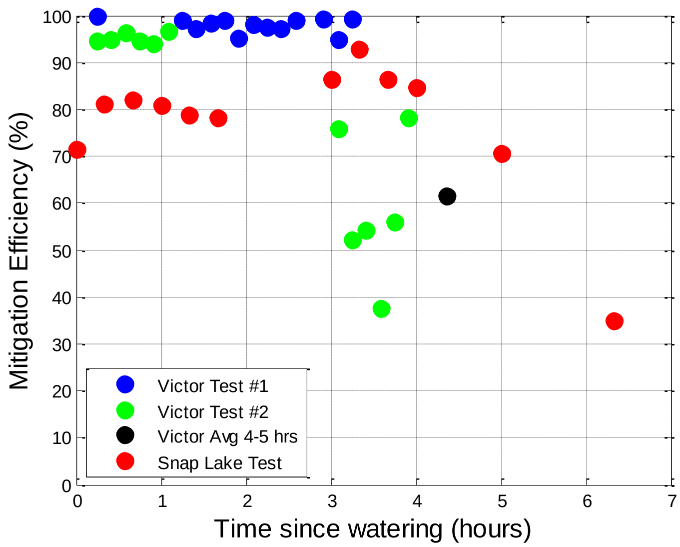
3.3.4 Mitigation Efficiency of Road Watering as a Function of Time

The mitigation efficiency of watering was evaluated as a function of "time since watering". Here mitigation efficiency is expressed as a percentage and is defined as *one minus the observed concentrations of dust after watering, divided by the expected concentrations of dust*. The expected concentrations of dust were calculated from the Victor Mine and Snap Lake Mine regressions of ambient dust concentrations as a function of ambient relative humidity. The regression equation employed is that corresponding to the geometric mean, not the 95th percentile, so as to keep the estimated road watering mitigation efficiency more conservative.

The results of the mitigation efficiency as a function of time since watering are summarized in Figure 29. For the Victor Mine, approximately 80% or greater mitigation efficiency persists for approximately three hours after watering. After three hours, the data indicate that mitigation efficiencies can drop below 50% and at least two data points from Victor Mine collected more than four hours after watering show dust levels at or above their pre-watering concentrations, i.e. there is no longer any effective mitigation of dust production. These values are consistent with the study team's anecdotal observations that *"visually it took 3-4 hours for road dust levels to reach their pre-watering values"*. The Snap Lake Mine data did not return to pre-watering levels within the seven hour time period allotted for the investigation. However, mitigation efficiency is reduced from approximately 80% at four hours to approximately 50% at five to six hours.

These results indicate that to achieve greater than 80% mitigation efficiency the haul road emissions at these locations should be watered approximately 4 to 6 times per 24 hour period of mine operations. However, this is highly subjective depending on the mine operation activities (e.g., amount of traffic on the haul road) and local meteorology (e.g., relative humidity, solar radiation).

Figure 29: Mitigation Efficiency as a Function of Time since Road Watering.



4.0 CONCLUSIONS AND RECOMMENDATIONS

A road dust monitoring study was conducted at De Beers Snap Lake Mine and Victor Mine to determine the level of natural mitigation associated with, or afforded by, winter conditions (i.e., snow-covered road surface and freezing temperatures) on the road dust emissions from the haul roads at the mines. Analysis of the haul truck monitoring data showed that based on the observed 95th percentile values, the wintertime road dust emissions are naturally mitigated with an efficiency of 94% (Victor Mine) to 96% (Snap Lake). The results also indicated that 80% mitigation efficiency of road dust emissions can be achieved for four to six hours after water is applied to the haul roads. However, the results are highly dependent on mining activities (i.e., haul truck traffic) and meteorological conditions at the sites. Beside the typical factors that govern road dust emissions, such as silt content of the road bed material, vehicle weight and vehicle speed, the study found that the measured ground-level dust concentrations is also strongly dependant of ambient relative humidity.

5.0 CLOSURE

We trust this report meets your present needs. If you have any questions or require additional details, please contact the undersigned.

GOLDER ASSOCIATES LTD.

Report prepared by:

Dennis Chang, B.Sc.
Air Quality Scientist

Cam McNaughton, Ph.D.
Environmental Scientist

Andrew Pickup, B.A., B.Sc.
Air Quality Scientist

Graham Tyler B.Sc., B.A.Sc.
Air Quality EIT

Report reviewed by:

Chris Madland, B.Sc.
Senior Air Quality Scientist

John Faithful, B.Sc. (Hons.)
Associate, Senior Water Quality Specialist

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APPENDIX A

Instrument Specifications

Specifications

Specifications

Concentration Ranges (Auto-ranging)	0-0.5, 0-1, 0-10 0-65 mg/m3
Laser	670 nm, 5 mW
Sensitivity	0.001mg/m3
Sample Period	1 sec
Sample Flow Rate	2 LPM
Pump Type	Diaphram 10,000 hr
Accuracy	8% of NIOSH 0600
Precision	0.003 mg/m3 or 2% reading
Particle Size Sensitivity Range	0.1-100 micron
Long term Stability	5% reading
Sensor Type	Forward Light Scatter
Average Period	1 – 60 minutes
Display	4X20 LCD
Internal Battery (Optional)	12 VDC 12 Amp-Hr, lead acid
Power Consumption	350mA (no heater) 1.1 A (w/heater)
Internal Battery Operation, no heater	>30 Hours
with heater	10 Hours
Battery Type	Lead Acid
Size	10.5 (267) X 9.25 (235) X 5.7 (145) inches (mm)
MOI Service Period	2 yrs
Programmable Auto-Zero	15min to 24 hours
Programmable Auto-Span	15min to 24 hours
Traceable Testing	Gravimetric
Sample Line Heater	Configurable RH Con trolled
Outputs	Analog 0-1,0-2.5, 0-5VDC, RS232
Data Storage Capacity	12000 Records
Temperature Compensation	Standard
Temperature Range	-10 deg to 50 deg C
RH Measurement	Internal
Ambient Temperature	-30 deg to 50 deg C
Ambient Pressure	1040 to 600 mbars
Alarm	Contact Closure
Available Cut Points	TSP, PM10, PM2.5, PM1

Standard Equipment
Universal Voltage Power Supply
Battery Charger Internal
47 mm Filter Holder
Comet Software
TSP Inlet
Inlet Heater
Digital Output Cable
Instruction Manual

Options
PM10, PM2.5, PM1 Sharp-Cut Cyclone
Extra 47 mm Filter Holders
Aluminum Tripod
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Phone Modem
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- Auto-ranging (1 to 65000 µm/m3)
- Automatic Flow Control Protocol
- Internal Battery (30 Hours Operation without heater & 10 Hours with heater.)
- Laser-Diode Precise Optical Engine
- Integral 47mm Analysis Filter
- Ambient Pressure and Temperature
- Internal Datalogger
- PM_{10}, $PM_{2.5}$, PM_1, TSP Monitoring
- Aluminum Weatherproof Enclosure
- Sheath-Air protected Optics
- Completely Self-Contained
- No Tools Filter Replacement

Applications
- Ambient Air Monitoring
- Remediation Site Perimeter Monitoring
- Indoor Air Quality Monitoring
- Source Monitoring
- Visibility Monitoring
- Mobile Monitoring

Met One Instruments, Inc.

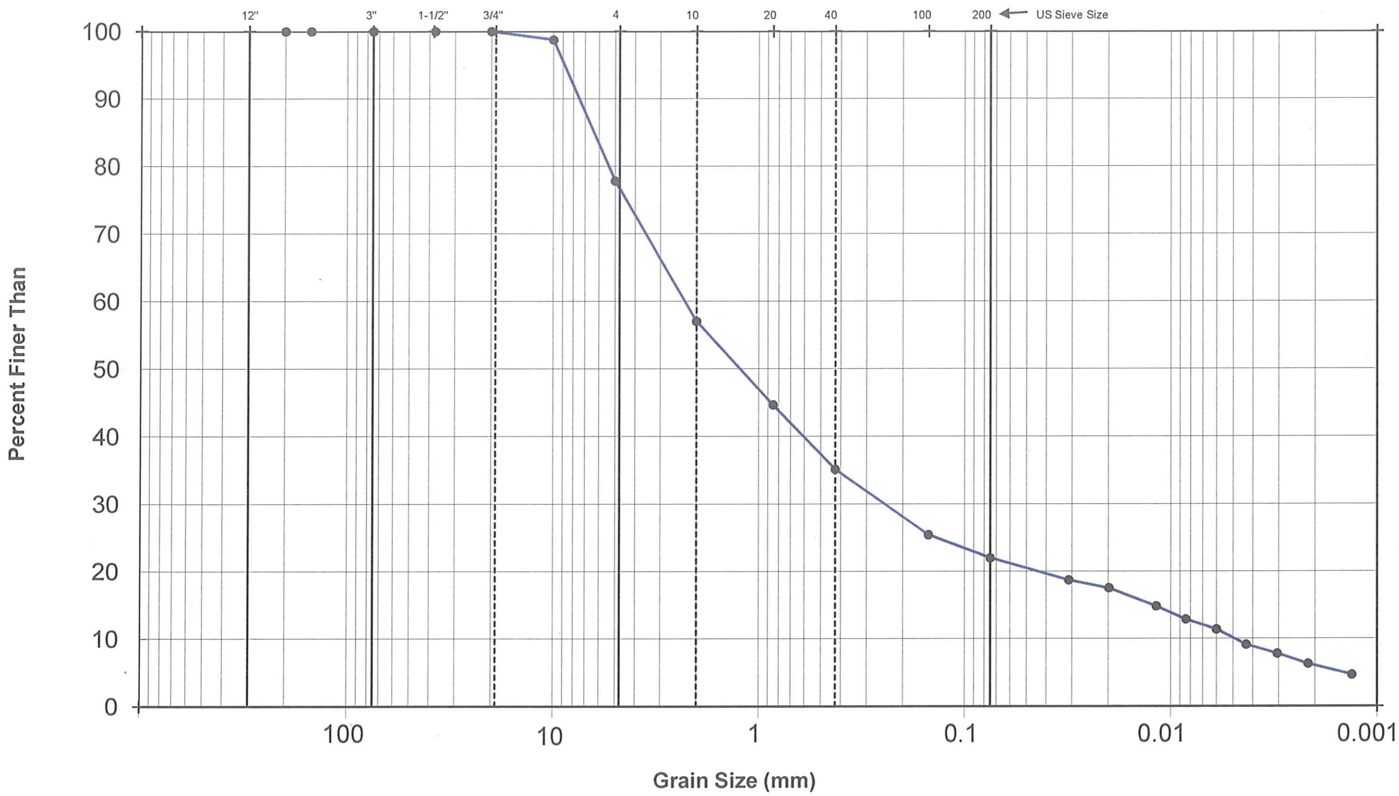
APPENDIX B

Segment Curves

Golder Associates

PARTICLE SIZE ANALYSIS OF SOIL
(ASTM D422)

Project No.:	11-1365-0001	Lab No.:	1058901
Project Title:	GK Dust Study		
Borehole:	Victor SRB-1	Sample No.:	1
Depth:	-		
Date Tested:	27-Sep-11	By:	CG/AR



Boulder Size	Cobble Size	Gravel Size: Coarse	Gravel Size: Fine	Sand Size: Coarse	Sand Size: Medium	Sand Size: Fine	Silt and Clay Size

Diameter of Sieve (mm)	Percent Passing (%)
200.0	100.0
150.0	100.0
75.0	100.0
37.5	100.0
20.0	100.0
10.0	98.8
5.00	77.9
2.0	57.1
0.850	44.7
0.425	35.2
0.150	25.4
0.075	22.0
0.031	18.7
0.020	17.5
0.012	14.8
0.008	12.9
0.006	11.4
0.004	9.1
0.003	7.8
0.002	6.3
0.001	4.7

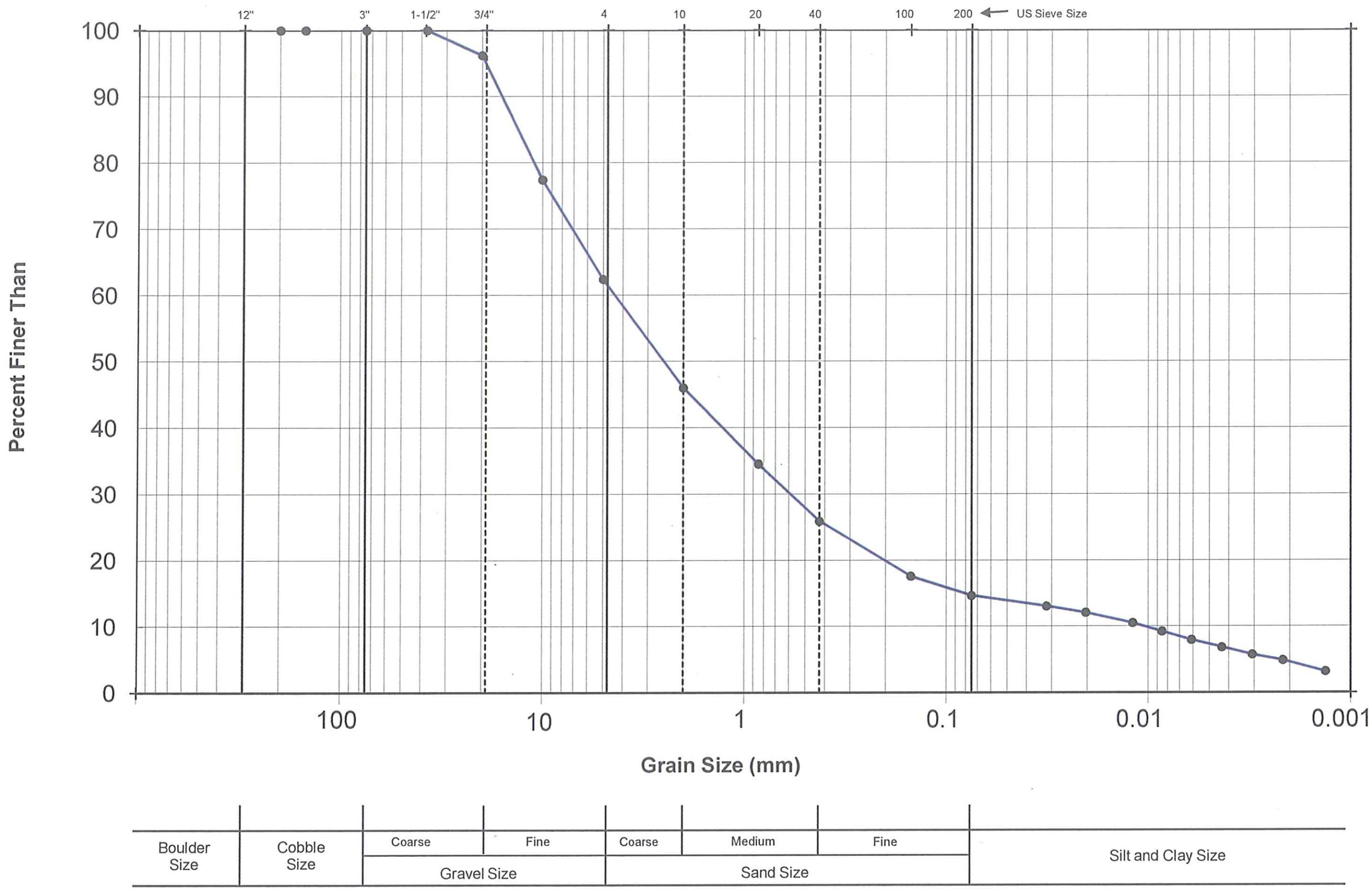
Comments:

Reviewed: [signature]

Golder Associates

PARTICLE SIZE ANALYSIS OF SOIL
(ASTM D422)

Project No.:	11-1365-0001	Lab No.:	1058902
Project Title:	GK Dust Study		
Borehole:	Victor SRB-2	Sample No.:	2
Depth:	-		
Date Tested:	27-Sep-11	By:	CG/AR



Diameter of Sieve (mm)	Percent Passing (%)
200.0	100.0
150.0	100.0
75.0	100.0
37.5	100.0
20.0	96.2
10.0	77.4
5.00	62.4
2.0	46.0
0.850	34.5
0.425	25.9
0.150	17.6
0.075	14.7
0.032	13.0
0.020	12.1
0.012	10.5
0.009	9.2
0.006	8.0
0.004	6.8
0.003	5.7
0.002	4.9
0.001	3.2

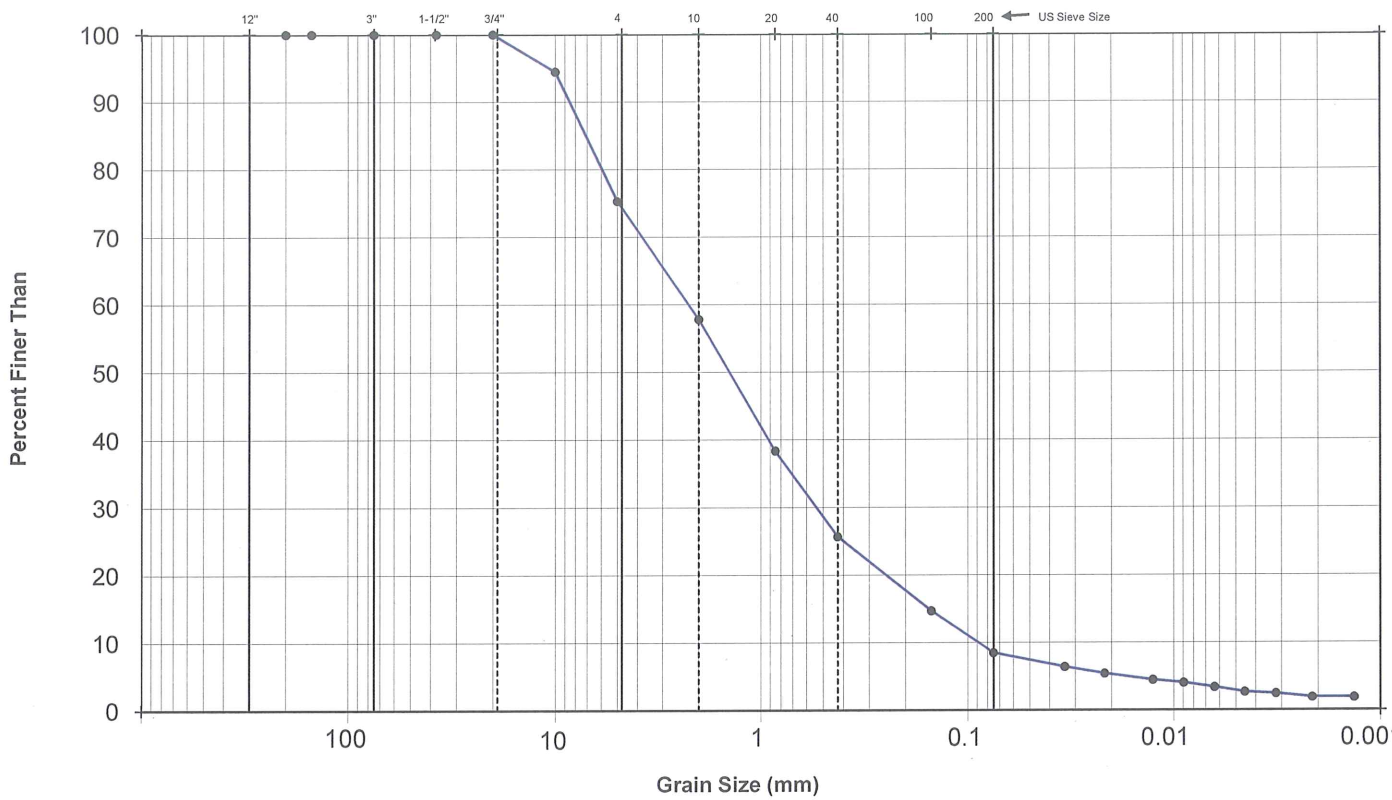
Comments:

Reviewed:

Golder Associates

PARTICLE SIZE ANALYSIS OF SOIL
(ASTM D422)

Project No.:	11-1365-0001	Lab No.:	1057501
Project Title:	Haul Truck Dust Emission Study		
Sample:	SRB-1	Depth:	Surface
Source:	Road sample - Snap Lake		
Date Tested:	12-Sep-11	By:	CG/AR



Boulder Size	Cobble Size	Gravel Size: Coarse	Gravel Size: Fine	Sand Size: Coarse	Sand Size: Medium	Sand Size: Fine	Silt and Clay Size

Diameter of Sieve (mm)	Percent Passing (%)
200.0	100.0
150.0	100.0
75.0	100.0
37.5	100.0
20.0	100.0
10.0	94.5
5.00	75.3
2.0	57.8
0.850	38.3
0.425	25.7
0.150	14.7
0.075	8.5
0.034	6.4
0.022	5.4
0.013	4.4
0.009	4.0
0.006	3.3
0.005	2.6
0.003	2.4
0.002	1.9
0.001	1.8

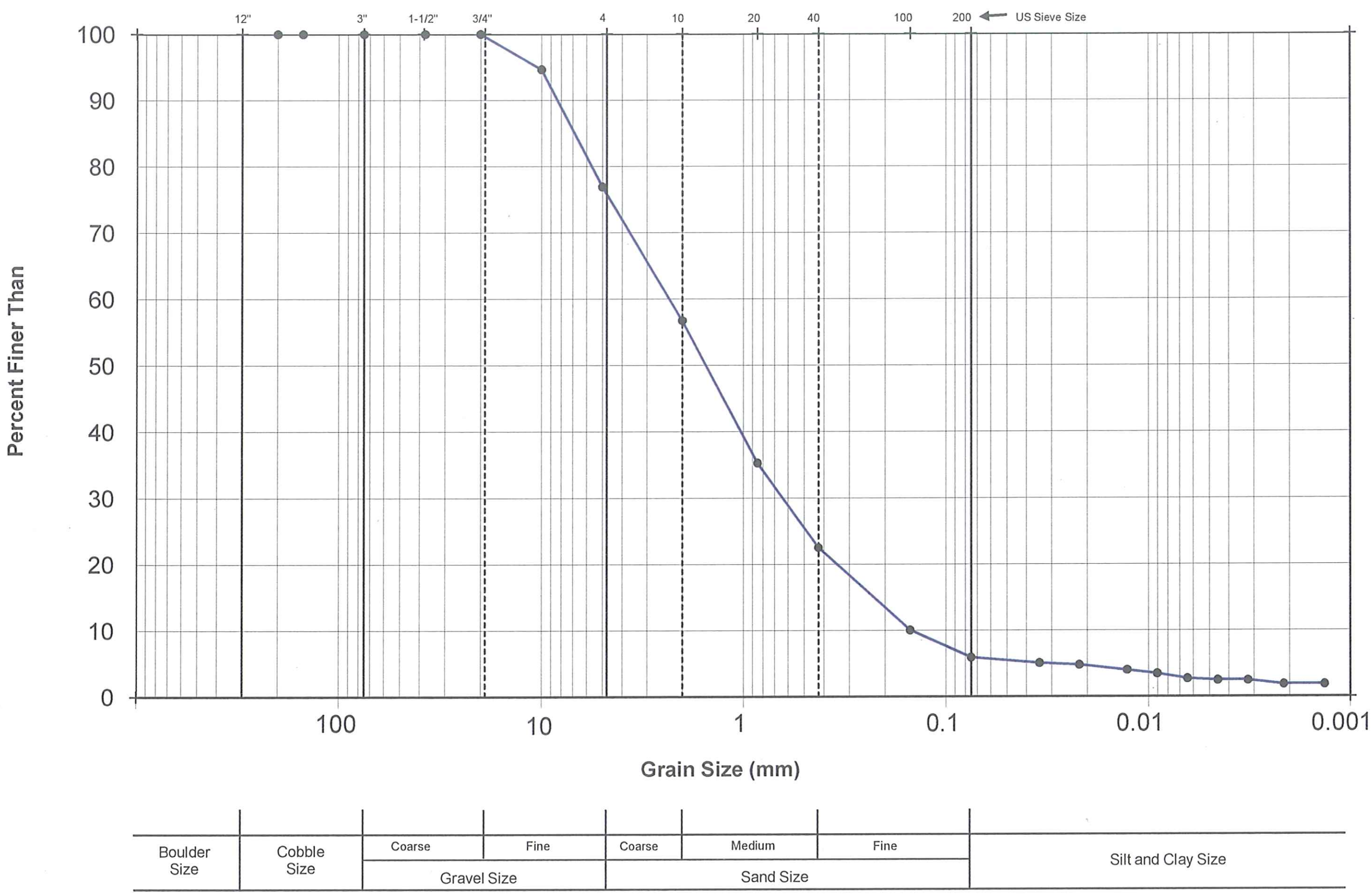
Comments:

Reviewed: [signature]

Golder Associates

PARTICLE SIZE ANALYSIS OF SOIL
(ASTM D422)

Project No.:	11-1365-0001	Lab No.:	1057502
Project Title:	Haul Truck Dust Emission Study		
Sample:	SRB-6	Depth:	Surface
Source:	Road sample - Snap Lake		
Date Tested:	12-Sep-11	By:	CG/AR



Diameter of Sieve (mm)	Percent Passing (%)
200.0	100.0
150.0	100.0
75.0	100.0
37.5	100.0
20.0	100.0
10.0	94.7
5.00	76.9
2.0	56.8
0.850	35.3
0.425	22.5
0.150	10.0
0.075	5.9
0.035	5.1
0.022	4.8
0.013	4.0
0.009	3.4
0.006	2.7
0.005	2.5
0.003	2.4
0.002	1.8
0.001	1.8

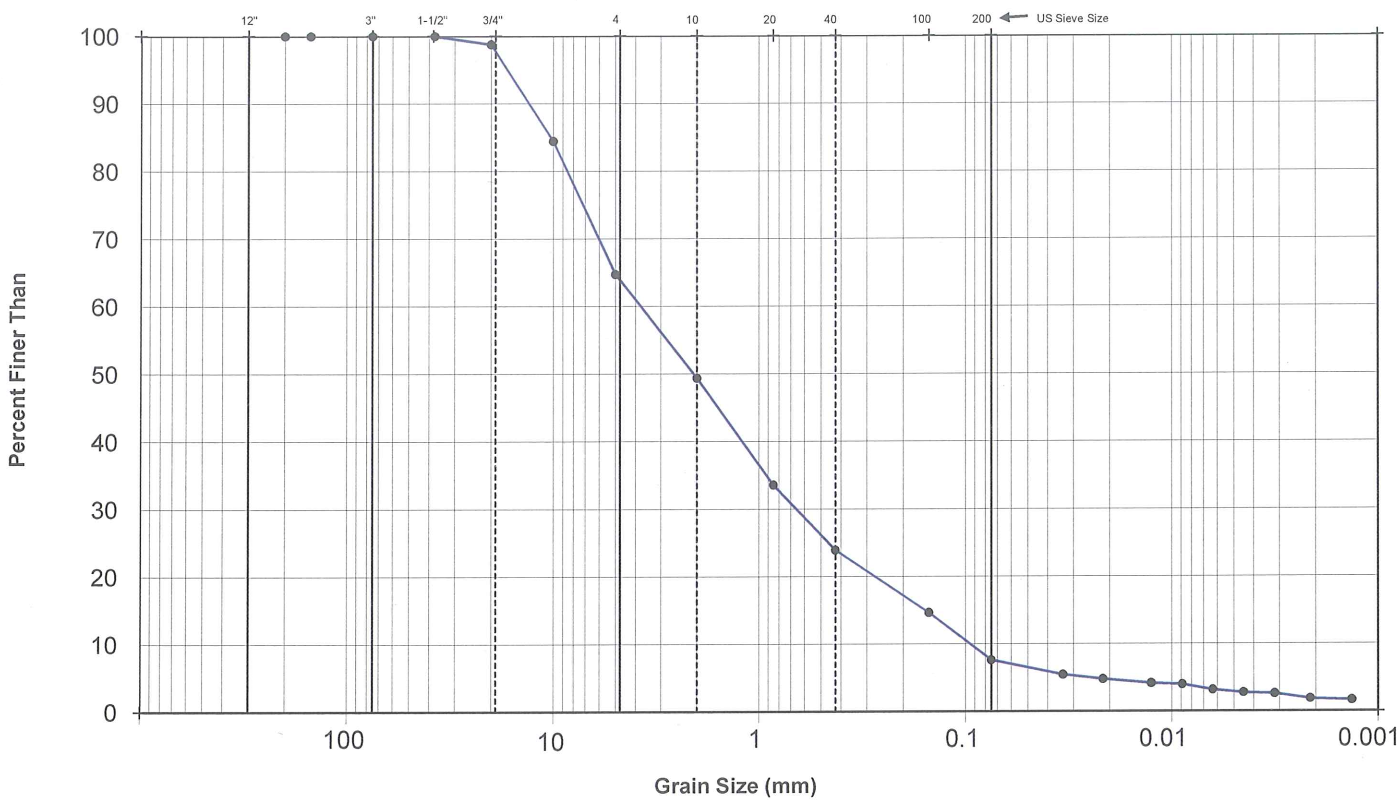
Comments:

Reviewed:

Golder Associates

PARTICLE SIZE ANALYSIS OF SOIL
(ASTM D422)

Project No.: 11-1365-0001 Lab No.: 1057503
Project Title: Haul Truck Dust Emission Study
Sample: SRB-8 Depth: Surface
Source: Road sample - Snap Lake
Date Tested: 12-Sep-11 By: CG/AR



Boulder Size	Cobble Size	Gravel Size		Sand Size			Silt and Clay Size
		Coarse	Fine	Coarse	Medium	Fine	

Diameter of Sieve (mm)	Percent Passing (%)
200.0	100.0
150.0	100.0
75.0	100.0
37.5	100.0
20.0	98.8
10.0	84.5
5.00	64.8
2.0	49.4
0.850	33.6
0.425	23.9
0.150	14.6
0.075	7.6
0.034	5.4
0.022	4.8
0.013	4.1
0.009	3.9
0.006	3.2
0.004	2.7
0.003	2.6
0.002	1.8
0.001	1.6

Comments:

Reviewed:

APPENDIX C

Corresponding Dust Concentrations and Meteorological Data

Table C-1: Victor Mine Summertime Dust Measurements in 10-Minute Intervals

Julian Day	Ambient Temperature [°C]	Relative Humidity [%]	10-minute Geometric Average Dust Concentration [μg/m³]	10-minute 95th Percentile Dust Concentration [μg/m³]
251.8264	18.5	52.7	88.0	1544.2
251.8333	18.1	54.4	320.3	2003.4
251.8403	17.9	54.4	237.8	1204.3
251.8472	17.8	52.3	415.0	2216.4
251.8542	17.6	53.0	445.6	2356.0
251.8611	17.4	54.6	325.7	1273.4
251.8681	17.0	60.6	313.9	1153.4
251.8750	16.3	63.9	425.4	1465.4
251.8819	15.7	64.2	458.3	1365.8
251.8889	15.3	67.4	274.9	1946.2
251.9236	14.0	71.6	252.2	1019.0
251.9306	13.4	72.8	53.3	369.6
251.9375	13.2	73.2	345.0	1054.5
251.9444	13.1	75.1	235.3	1050.4
251.9514	13.7	63.8	173.0	655.8
251.9583	14.7	63.7	97.4	699.6
251.9653	14.3	64.1	36.3	312.8
251.9722	13.6	66.8	100.4	394.3
251.9792	13.0	67.7	135.4	478.4
252.0625	9.0	82.6	34.8	334.4
252.0694	8.7	80.0	152.4	582.8
252.0764	8.2	84.7	154.9	624.0
252.0833	8.2	85.6	150.2	512.2
252.0903	8.0	88.4	70.3	250.3
252.0972	7.9	88.7	193.4	536.0
252.1042	8.1	87.5	186.1	474.5
252.1111	8.0	88.6	90.5	295.1
252.1181	7.7	88.6	130.4	318.6
252.1250	7.5	89.6	147.7	358.0
252.1528	6.9	92.7	66.8	288.0
252.1597	6.8	92.6	67.5	316.3
252.1667	6.7	92.7	56.9	373.5
252.1736	6.9	92.1	52.3	273.4
252.1806	6.9	92.2	56.1	173.6
252.1875	7.0	90.4	59.4	299.7
252.1944	7.1	89.2	43.0	178.8
252.2014	7.0	88.8	58.9	184.2
252.2083	6.8	88.7	72.3	361.6
252.2153	6.8	89.8	36.3	211.5
252.2222	6.8	90.2	75.5	361.1
252.2292	6.9	89.2	88.9	334.6
252.3403	12.1	70.3	121.1	401.0
252.3472	12.4	68.7	54.8	439.3
252.3542	12.7	66.9	126.6	399.5
252.3611	12.8	65.1	64.8	419.6
252.3681	12.9	66.1	178.7	720.2

Table C-1: Victor Mine Summertime Dust Measurements in 10-Minute Intervals (continued)

Julian Day	Ambient Temperature [°C]	Relative Humidity [%]	10-minute Geometric Average Dust Concentration [µg/m³]	10-minute 95th Percentile Dust Concentration [µg/m³]
252.3750	12.9	66.0	214.0	620.8
252.3819	13.1	62.6	75.0	659.8
252.3889	13.2	62.5	146.9	658.1
252.3958	13.5	62.5	68.7	952.7
252.4167	14.0	59.8	155.4	813.4
252.4236	14.2	59.0	179.6	893.3
252.4306	14.5	59.3	283.3	1168.3
252.4375	14.7	58.4	153.9	1254.8
252.4444	15.0	57.0	292.2	1171.6
252.4514	15.1	58.1	318.7	1598.4
252.4583	15.4	57.0	390.4	1502.5
252.4792	15.8	58.0	158.7	1254.9
252.4861	15.9	53.6	104.7	900.0
252.4931	15.9	56.4	125.3	1662.3
252.5000	16.3	54.1	181.4	1424.2

Table C-2: Victor Mine Wintertime Dust Measurements in 10-Minute Intervals

Julian Day	Ambient Temperature [°C]	Relative Humidity [%]	10-minute Geometric Average Dust Concentration [µg/m³]	10-minute 95th Percentile Dust Concentration [µg/m³]
17.4931	-27.5	74.5	22.0	34.8
17.5347	-25.9	69.5	22.7	38.2
17.5417	-25.5	68.5	19.9	29.7
17.5486	-25.5	68.4	19.9	34.0
17.8681	-29.5	76.6	12.4	25.8
17.8750	-29.5	76.6	16.2	23.0
17.8889	-29.1	76.2	25.4	45.9
17.8958	-28.9	76.3	16.6	33.0
17.9028	-28.6	76.1	14.5	25.1
17.9097	-28.3	76.2	15.3	23.1
17.9167	-28.0	76.3	14.5	19.1
17.9514	-27.3	76.1	14.7	31.5
17.9653	-27.7	75.9	15.2	24.3
17.9722	-27.7	76.0	11.8	27.5
17.9792	-27.6	76.1	13.9	25.2
18.4444	-32.1	71.5	10.3	14.5
18.5556	-28.9	63.4	11.7	23.3
18.5625	-28.7	62.6	13.7	24.7
18.5694	-28.6	62.0	13.6	22.8
18.5764	-28.5	62.0	14.0	24.7
18.5833	-28.4	61.6	14.5	21.4
18.5903	-28.2	61.2	14.0	20.5

Table C-3: Snap Lake Mine Summertime Dust Measurements in 20-Minute Intervals

Julian Day	Ambient Temperature [°C]	Relative Humidity [%]	20-minute Geometric Average Dust Concentration [μg/m³]	20-minute 95th Percentile Dust Concentration [μg/m³]
238.6389	11.8	59.9	76.7	785.4
238.6528	12.1	57.3	408.5	1842.5
238.6667	12.3	54.8	137.4	2404.1
238.6806	12.6	54.4	252.5	1683.1
238.6944	12.8	54.1	373.1	3183.4
238.7083	13.0	53.7	597.0	3449.8
238.7222	13.0	54.1	407.1	3061.8
238.7361	12.9	54.4	728.7	1206.6
238.8333	13.2	59.5	415.6	2007.3
238.8472	12.8	62.9	362.8	1277.2
238.8611	12.4	66.4	222.8	837.6
238.8750	12.0	69.8	400.4	1470.8
238.8889	11.7	71.5	117.6	493.7
238.9028	11.3	73.1	104.1	1057.1
238.9167	11.0	74.8	113.3	790.1
238.9444	10.5	77.9	86.3	483.9
238.9583	10.3	79.5	41.2	453.3
238.9722	10.0	82.0	15.7	179.6
238.9861	9.7	84.5	12.9	95.7
239.0000	9.5	87.0	16.1	76.6
239.0139	9.4	87.1	6.3	117.7
239.0278	9.3	87.1	5.2	41.0
239.0694	8.6	86.7	4.2	18.8
239.0833	8.4	86.4	6.4	35.1
239.0972	8.2	87.3	7.8	41.7
239.1389	7.7	88.0	7.3	31.5
239.1528	7.7	86.9	5.3	29.7
239.1667	7.7	85.8	6.2	27.8
239.1944	7.7	86.4	4.3	26.9
239.2083	7.7	86.7	5.8	21.2
239.2222	7.6	86.8	3.9	22.7
239.2361	7.5	87.0	4.4	21.5
239.3056	7.9	87.8	8.9	147.8
239.3194	7.9	88.4	15.9	172.5
239.3333	8.0	89.0	9.5	370.0
239.3889	9.8	76.4	304.1	952.8
239.4028	10.6	72.3	179.3	1372.7
239.4167	11.3	68.3	1465.7	9446.9
239.4444	12.0	63.7	28.8	1695.1
239.4583	12.3	61.5	203.1	1505.0
239.4722	12.5	60.3	144.2	1827.9
239.4861	12.7	59.2	185.0	1968.0
239.5000	13.0	58.0	149.3	1832.1
239.5139	13.3	54.8	565.5	3489.9
239.5278	13.7	51.5	190.1	3106.8

Table C-3: Snap Lake Mine Summertime Dust Measurements in 20-Minute Intervals (continued)

Julian Day	Ambient Temperature [°C]	Relative Humidity [%]	20-minute Geometric Average Dust Concentration [μg/m^3]	20-minute 95th Percentile Dust Concentration [μg/m^3]
239.5833	14.6	46.8	411.3	4912.4
239.5972	14.8	45.8	498.9	4338.3
239.6111	14.9	44.7	12.6	296.0
239.6528	15.3	42.0	118.7	3096.9
239.6667	15.5	41.2	262.0	3330.8
239.6806	15.3	41.8	247.1	3708.4
239.6944	15.2	42.5	391.5	3100.8
239.7083	15.1	43.1	379.6	3772.7
239.7222	15.2	43.1	389.2	3380.8
239.7361	15.3	43.0	204.8	1942.2

Table C-4: Snap Lake Mine Wintertime Dust Measurements in 20-Minute Intervals

Julian Day	Ambient Temperature [°C]	Relative Humidity [%]	20-minute Geometric Average Dust Concentration [μg/m^3]	20-minute 95th Percentile Dust Concentration [μg/m^3]
34.8333	-7.5	95.3	1.8	5.6
34.8750	-6.6	96.0	2.5	14.5
34.9583	-4.3	96.7	1.5	2.9
35.0000	-2.7	95.9	0.0	9.5
35.3333	-1.7	70.6	0.0	9.6
35.3750	-2.4	72.1	4.7	9.0
35.4583	-3.0	69.4	2.2	5.5
35.7917	-5.7	81.5	0.0	7.0
35.8333	-5.2	80.4	2.4	5.6

https://capws.golder.com/sites/capws2/1113650001posteissubmission/tsw and eis update/2010 - air quality/hual truck emission report/september 2012 reports/external_version/appendix c.docx

Golder Associates Ltd.
102, 2535 - 3rd Avenue S.E.
Calgary, Alberta, T2A 7W5
Canada
T: +1 (403) 299 5600

Golder Associates