Appendix 3I Calculation of Emission Factor (Mitigated Scenario)

Calculation of Watering Efficiency

With reference to Cowherd et al., "Control of Open Fugitive Dust Sources, EPA-450/3-88-008, U.S. Environmental Protection Agency, Research Triangle Park, NC, percentage of dust mitigation efficiency is calculated from Equation (3-2) :

$$C = 100 - 0.8\ p\ d\ t / i$$

where
p = Potential average hourly daytime evaporation rate, mm/hour = 0.23676 [1]
d = Average hourly daytime traffic rate per hour = 7 per hour [2]
t = time between application in hour
i = Application intensity = 0.16 L/m^2 [3]

Notes:
[1] p = 0.0049 x 48.3189 inch, where 48.3189 inch is equivalent to the total evaporation of 1227.3mm obtained from Hong Kong Observatory (https://www.hko.gov.hk/en/cis/normal/1981_2010/normals.htm)
[2] Estimated by Engineer
[3] The assumptions provided are for the purpose of assessment predictions only. Actual figures would be defined in the detailed design stage.

By applying the Equation (3-2) with the above assumptions,

Dust suppression efficiency =
= 100 - 0.8 x (0.23676 x 7 x 1) / 0.16
= 91.7

Therefore,

For watering once per hour , the estimated dust suppression efficiency is 91.7%

(A) Consturction works outside cavern

1.) Site formation for Portal Enclosure and Auxiliary Buildings, Actively operating area / Water mains laying works

1.1 Heavy Construction

TSP emission factor (Mg/hectare/month of activity)	2.69	*from AP-42, S13.2.3, 1/95 ed.*
TSP emission factor ($g/m^2/s$)	2.0756E-04	*Assume 30 working days per month and 12 working hours a day during unit conversion*
RSP/TSP Ratio	0.473	*from USEPA AP-42, 5th ed. 11/06 ed. S13.2.4*
FSP/TSP Ratio	0.072	*from USEPA AP-42, 5th ed. 11/06 ed. S13.2.4*
% of dust suppression	91.7%	*Assuming watering once per hour.*
Mitigated **TSP emission factor ($g/m^2/s$) =**	**1.7228E-05**	
RSP emission factor ($g/m^2/s$) =	**8.1487E-06**	
FSP emission factor ($g/m^2/s$) =	**1.2404E-06**	

1.2 Wind Erosion

TSP emission factor (Mg/hectare/yr)	0.85	*AP-42, 5th ed., Table 11.9-4*
TSP emission factor ($g/m^2/s$)	2.6953E-06	*Assume 365 days per year and 24 hours a day during unit conversion*
RSP/TSP Ratio	0.473	*from USEPA AP-42, 5th ed. 11/06 ed. S13.2.4*
FSP/TSP Ratio	0.072	*from USEPA AP-42, 5th ed. 11/06 ed. S13.2.4*
TSP emission factor ($g/m^2/s$) =	**2.6953E-06**	
RSP emission factor ($g/m^2/s$) =	**1.2749E-06**	
FSP emission factor ($g/m^2/s$) =	**1.9406E-07**	

(B) Construction works within cavern

2.) Rock Crushing

2.1 Truck Unloading - Fragmented Stone

RSP emission factor (kg/Mg)	8.0000E-06	*from EPA AP-42, 5th ed. 8/04 ed., S11.19.2 Table 11.19.2-1*
Loading rate (ton/hr)	3.8750	*from engineer (maximum 93 ton/day)*
TSP/RSP Ratio	2.1	*from EPA AP-42, 5th ed. 8/04 ed., S11.19.2 Table 11.19.2-1*
Mg/ton	1	
tonne/ton	1.10231131	
% of dust suppression	95%	*Dust collector will be provided at the exhaust of the rock during rock crushing, for typical removal efficiency for Dust Collector inside Enclosure Control Techniques for Particulate Emission from Stationary Sources Vol.2, Section 9.7.1.2.2. The typical efficiency is found to be at least 99%, but a conservative approach of 95% is chosen.*
TSP emission rate (g/s)	**8.2025E-07**	
RSP emission rate (g/s)	**3.9059E-07**	
FSP emission rate (g/s)	**3.9059E-07**	*adopt RSP emission factor as upper limit*

2.2 Tertiary Crushing

TSP emission factor (kg/Mg)	0.0027	*from EPA AP-42, 5th ed. 8/04 ed., S11.19.2 Table 11.19.2-1*
RSP emission factor (kg/Mg)	0.0012	*from EPA AP-42, 5th ed. 8/04 ed., S11.19.2 Table 11.19.2-1*
Crushing rate (ton/hr)	3.8750	*from engineer*
Mg/ton	1	
tonne/ton	1.10231131	
% of dust suppression	95%	*Dust collector will be provided at the exhaust of the rock during rock crushing, for typical removal efficiency for Dust Collector inside Enclosure Control Techniques for Particulate Emission from Stationary Sources Vol.2, Section 9.7.1.2.2. The typical efficiency is found to be at least 99%, but a conservative approach of 95% is chosen.*
TSP emission rate (g/s)	**1.3183E-04**	
RSP emission rate (g/s)	**5.8589E-05**	
FSP emission rate (g/s)	**5.8589E-05**	*adopt RSP emission factor as upper limit*

2.3 Fines Screening (controlled with wet suppression)

TSP emission factor (kg/Mg)	0.0018	*from EPA AP-42, 5th ed. 8/04 ed., S11.19.2 Table 11.19.2-1*
RSP emission factor (kg/Mg)	0.0011	*from EPA AP-42, 5th ed. 8/04 ed., S11.19.2 Table 11.19.2-1*
Crushing rate (ton/hr)	3.8750	*from engineer*
Mg/ton	1	
tonne/ton	1.10231131	
% of dust suppression	95%	*Dust collector will be provided at the exhaust of the rock during rock crushing, for typical removal efficiency for Dust Collector inside Enclosure Control Techniques for Particulate Emission from Stationary Sources Vol.2, Section 9.7.1.2.2. The typical efficiency is found to be at least 99%, but a conservative approach of 95% is chosen.*
TSP emission rate (g/s)	**8.7884E-05**	
RSP emission rate (g/s)	**5.3707E-05**	
FSP emission rate (g/s)	**5.3707E-05**	*adopt RSP emission factor as upper limit*

Total emission from Rock Crusher (2.1) + (2.2) + (2.3)

TSP emission rate (g/s) =	**2.2053E-04**
RSP emission rate (g/s) =	**1.1269E-04**
FSP emission rate (g/s) =	**1.1269E-04**

3.) Blasting (USEPA AP-42, Section 11.9, Table 11.9-1)

$E = 0.000014 (A)^{1.5}$ .....(1)

where

E = emission factor in lb/blast

A = horizontal area (ft^2)

Assumptions:

A = $165m^2 = 1776\ ft^2$

frequency = 1 blasting per day (7am to 7pm - Monday to Saturday (subject to condition))

$E = 0.000014 (1776)^{1.5}$

E = 1.0478E+00 lb/blast

E = 1.3203E-01 g/s (only one blast in one hour)

TSP emission rate (g/s) =	**1.3203E-01**
RSP emission rate (g/s) =	**6.8654E-02**
FSP emission rate (g/s) =	**3.9608E-03**

RSP/TSP Ratio 0.52 *from USEPA AP-42, Section 11.9, Table 11.9-1*

FSP/TSP Ratio 0.03 *from USEPA AP-42, Section 11.9, Table 11.9-1*

4.) Wet Drilling (USEPA AP-42, Section 11.19.2, Table 11.19.2-1)

TSP: $E = 4.0 \times 10^{-4}$ kg/Mg ..... (2)

RSP: $E = 4.0 \times 10^{-5}$ kg/Mg ..... (3) *from USEPA AP-42, Section 11.19.2, Table 11.19.2-1*

Assumptions: handling rate = 21 m^3/hr x 2700kg/m^3 x 0.001 Mg/kg = 56.7000 Mg/hr

TSP emission rate (g/s) =	**6.3000E-03**
RSP emission rate (g/s) =	**6.3000E-04**
FSP emission rate (g/s) =	**6.3000E-04**

adopt RSP emission factor as upper limit

5.) Materials Handling (USEPA AP-42, Section 13.2.4.3)

$E = k (0.0016) (u/2.2)^{1.3} /(M/2)^{1.4}$ .....(5)

where

E = emission factor in kilograms per Megagram (Mg)

k = particle size multiplier

u = wind speed in metres per second

M = material moisture content in percent

Assumptions:

k = 0.74 for TSP; 0.35 for RSP; 0.053 for FSP

M = 0.7 % (USEPA AP-42, Table 13.2.4-1)

u = 0.1 m/s (air flow rate within cavern provided by engineer)

handling rate = 21 m^3/hr x 2700kg/m^3 x 0.001 Mg/kg = 56.7 Mg/hr

TSP: $E = 0.74 (0.0016) (0.1/2.2)^{1.3} /(0.7/2)^{1.4}$

E = 9.2578E-05 kg/Mg

E = 5.2492E-03 kg/hr

E = 1.4581E-03 g/s

RSP: $E = 0.35 (0.0016) (0.1/2.2)^{1.3} /(0.7/2)^{1.4}$

E = 4.3787E-05 kg/Mg

E = 2.4827E-03 kg/hr

E = 6.8964E-04 g/s

FSP: $E = 0.053 (0.0016) (0.1/2.2)^{1.3} /(0.7/2)^{1.4}$

E = 6.6306E-06 kg/Mg

E = 3.7595E-04 kg/hr

E = 1.0443E-04 g/s

Mitigation efficiency : 91.7 % *Assuming watering once per hour.*

Mitigated

TSP emission rate (g/s) =	**1.2102E-04**
RSP emission rate (g/s) =	**5.7240E-05**
FSP emission rate (g/s) =	**8.6678E-06**

6.) Vehicle movements on unpaved road (USEPA AP-42, Section 13.2.2.2)

$E = k\,(s/12)^a\,(W/3)^b$ .....(6)

where k, a, and b are empirical constants and

E = size-specific emission factor (lb/VMT) Note: 1 lb/VMT = 281.9 g/VKT (g per vehicle kilometer traveled)

s = surface material slit content

W = mean vehicle weight (tons)

Assumptions:

s =	8.5	% (Table 13.2.2-1 of USEPA AP-42, Section 13.2.2.2)		
W (loaded)=	30	tonnes (from engineer)	k = 4.9 for TSP;	1.5 for RSP; 0.15 for FSP (Table 13.2.2-2 of USEPA AP-42, Section 13.2.2.2)
=	33.07	ton		
W (empty)=	10	tons (from enginner)	a = 0.7 for TSP;	0.9 for RSP; 0.9 for FSP (Table 13.2.2-2 of USEPA AP-42, Section 13.2.2.2)
=	11.02	ton		
Truck flow =	3.5	veh/hr (one way)	b = 0.45 for TSP;	0.45 for RSP; 0.45 for FSP (Table 13.2.2-2 of USEPA AP-42, Section 13.2.2.2)
distance traveled	750	m (oneway)		

6.1 For trucks with loading

TSP: $E = 4.9\,(8.5/12)^{0.7}\,(33.1/3)^{0.45}$

E = 11.3344 lb/VMT

E = 2.3298E+00 g/s

RSP: $E = 1.5\,(8.5/12)^{0.9}\,(33.1/3)^{0.45}$

E = 3.2385 lb/VMT

E = 6.6568E-01 g/s

FSP: $E = 0.15\,(8.5/12)^{0.9}\,(33.1/3)^{0.45}$

E = 0.3238 lb/VMT

E = 6.6568E-02 g/s

Mitigation efficiency : 91.7 % *Assuming watering once per hour.*

Mitigated		
	TSP emission rate (g/s) =	**1.9337E-01**
	RSP emission rate (g/s) =	**5.5251E-02**
	FSP emission rate (g/s) =	**5.5251E-03**

6.2 For trucks without loading

TSP: $E = 4.9\,(8.5/12)^{0.7}\,(11.02/3)^{0.45}$

E = 6.9134 lb/VMT

E = 1.4211E+00 g/s

RSP: $E = 1.5\,(8.5/12)^{0.9}\,(11.02/3)^{0.45}$

E = 1.9753 lb/VMT

E = 4.0603E-01 g/s

FSP: $E = 0.15\,(8.5/12)^{0.9}\,(11.02/3)^{0.45}$

E = 0.1975 lb/VMT

E = 4.0603E-02 g/s

Mitigation efficiency : 91.7 % *Assuming watering once per hour.*

Mitigated		
	TSP emission rate (g/s) =	**1.1795E-01**
	RSP emission rate (g/s) =	**3.3701E-02**
	FSP emission rate (g/s) =	**3.3701E-03**

Dust Filter

Mitigation measures (watering) within the interior space of cavern will be only applied to material handling and vehicles movement on unpaved road.
The total emission originated from inside cavern construction will be emitted via a ventilation shaft in the tunnel portal. A dust collector will be provided at the exhaust.
According to the catalogue of the proposed dust filter, the minimum efficiency is 80%.

The final values after mitigated by this dust filter can be found in Appendix 3F.