RESOLUTION COPPER MINE
PRE-FEASIBILITY STUDY
REFRIGERATION AND VENTILATION STRATEGY

BBE Report 7211

For	Resolution Copper Mine
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Revision Notes

	Date	Description	Source
A	Sept 2011	First PFS report version.	SB, RM, FvG.
B	Oct 2012	Update following VAB 6, RCM/BBE meeting end April 12, revised schedule, new shaft sizes, dual u/c levels, no Magma return.	SB, RM, FvG

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1 INTRODUCTION AND SCOPE OF REPORT

RCM is compiling the Pre-feasibility Study for the project life-of-mine. In preparing this Pre-feasibility documentation, numerous ventilation and refrigeration studies have been carried-out over a period of time with the aim of:

- Establishing the heat loads and the cooling, ventilation and refrigeration requirements.
- Providing preliminary ventilation distribution layouts.
- Identifying suitable refrigeration and ventilation strategies.
- Providing information on ventilation and refrigeration power requirements.

The status of this preparatory work has been summarised in the following documentation:

- Ventilation and refrigeration report, BBE 0407, rev F, Sept 2010.
- Proceedings of Ventilation Advisory Board No.5, Oct 2010.
- Third-party review reports, MVS Inc in Nov 2010 and Nov 2011.

This present pre-feasibility report has built-on this earlier work and has now been updated to account for:

- Updated design criteria [e.g. shaft sizes, locations, No.9 Shaft timing, etc].
- Feedback from GAP analysis and third-party reviews.
- Life-of-mine profiling of heat loads, refrigeration, ventilation, power and water needs.
- Increased number of simultaneously open extraction drives.
- Engineering designs or equipment selection and specification [at pre-feasibility level].
- Construction scheduling [at pre-feasibility level].
- Capital estimation and cash-flow profiling [at pre-feasibility level].
- Change design of Undercut level to double-level undercut concept
- Ventilation allocation regarding diesel exhaust dilution
- More details on design attention to DPM issues.
- More detail on dust control strategies to address the high-silica issues.
- Bench-marking the primary ventilation factor against other block-cave operations.
- Examining in greater detail the construction work needs in mine development scenarios.
- Definition of service ventilation allocations for ‘fixed’ infrastructure facilities.
- Examining the level-of-automation, control and monitoring to be provided-for in estimate.
- Modelling heat and cooling of additional development scenarios.
- Providing more information on broken rock temperatures.
- Design of cooling systems for shaft sink[s].
- Definition and scheduling of conveyor drift development and permanent phase.
- Increase in service water allocation to 150 l/s.
- Underground service water dam located at No.13 Shaft 50 m above the upper undercut elevation
- New shaft sizes:
  No.14 - 10m; No.13 - 11m; No.12 - 10 m; No.11 - 10 m; No.10 - 8.5 m; No.9 - 6.7 m

The report structure is such that it first examines the ventilation and refrigeration needs for the fully established life-of-mine scenarios and thereafter examines the project development phases.

The two main criteria from the ventilation system design are dust [high silica] and heat and the general modus operandi of the ventilation design work has been as follows:

- Build-up the ventilation allocation by audit of various zones and specific requirements.
- Provide adequate ventilation for extracting dust [generally reporting direct to return].
- Determine heat load - cooling duty energy balance with VUMA modelling.
- Iterate around the above three points.
- Carry-out pre-engineering of main equipment centres.

2 ASSUMPTIONS AND GENERAL MODELLING CRITERIA

2.1 General

The mining method will be an advance undercut block-cave operation using single panels with one cave front. The mine will employ three hoisting and service shafts and three upcast shafts and, within the mining block, the basic levels will include undercut level, production level, intake vent level, return vent level, haulage level and crusher conveyor level. Electrical loaders will be used for production but diesel equipment will be used for development and undercutting. There will be an electrical rail haulage system delivering rock from ore-passes to the crushers from which a conveyor belt will report to the hoisting shafts loading facilities. There will be mid-shaft skip discharge and, from that location, another conveyor system will deliver the ore to the surface plant.

The shaft system will have the following sizes:

Downcast shafts

- No.11 Shaft [hoisting shaft] 10.0 m Ø
- No.12 Shaft [hoisting shaft] 10.0 m Ø
- No.13 Shaft [service shaft] 11.0 m Ø

Upcast shafts

- No. 9 Shaft 6.7 m Ø
- No.14 Shaft 8.5 m Ø
- No.10 Shaft 10.0 m Ø

The rock will have very high silica content [20% to 50%] which will create very serious dust control challenges and thus dust issues dominate the design evaluations The depth of the production-extraction level will be >2000 m and the virgin rock temperature will be >80°C and thus thermal issues also dominate the design evaluations. While DPM management issues will be important, there is no indication of significant extraneous strata gas emission potential and the ventilation rates based on the dust and heat criteria will, under normal operating conditions, satisfy acceptable gas standards. However, there are other issues such as radon, fibres, flammable strata-gas etc. that might affect the final ventilation design and these will need to be considered at the appropriate time in the future.

The important design criteria for the present work are highlighted below.

2.2 Silica/Quartzite Levels

Analyses of rock samples from exploration bore-holes indicate a range of quartz content of 20% to 50% for the Diabase formations and 40% to 80% for other formations. These values are particularly high and hence respirable dust [and silica] is a significant ventilation engineering design issue.

This is an important design criterion and the best practice in terms of dust control measures will need to be applied. These will include extensive use of water sprays [which will also assist in controlling high dry-bulb temperatures] and relatively large quantities of ventilation exhausted from dusty areas direct to return [e.g. crushers, transfer points, skip loading, skip discharge, etc]. Where possible and practical, this will be applied in conjunction with hoods, enclosures and dedicated duct systems. Although scrubbers and filters will find limited application in specific problematic local areas, the general strategy will be to use water sprays and exhaust of adequate quantities direct to return. Extensive use will need to be made of PPE and personnel will need to be trained in the control of exposure to respirable dust. Formal respirable dust sampling programmes will need to be implemented and monitored.

Addendum H presents a review of dust design criteria and, as a general design criterion, respirable crystalline silica must be less than 0.1 mg/m^3.

This pre-feasibility work makes provision in terms of allocating liberal ventilation quantities direct to return and in terms of hoods, ducts, fans, nozzles and other engineering components estimate.

2.3 Virgin Rock Temperatures

The general geothermal gradient will be 2.7°C per 100 m and the virgin rock temperatures will be particularly high and hence thermal issues are regarded as the other [with dust] primary ventilation and engineering design issue. The following reference virgin rock temperatures will apply:

- Pump level 1395 mbc
- Undercut level 2030 mbc 78.84°C
- Production level 2045 mbc 79.24°C
- Intake vent level 2075 mbc 80.05°C
- Rail Haulage level 2090 mbc 80.46°C
- Return vent level 2110 mbc 81.00°C
- Crusher-to-conveyor level 2180 mbc 82.89°C

2.4 Geothermal Properties

The following geothermal properties have been applied:

- Original geothermal data apply for the Apache Leap Tuff which exists to depth of 550 m.
- Original geothermal data for the 'Quartzite/Diabase' apply the shaft host rock to depth of 1550 m.
- New geothermal data [Nov/Dec 2008] apply below 1550 m in terms of a mixed mean value. But, in identified quartzite rich areas [see Figure 2.1], the quartzite rich data apply.

Table 2.1 Geothermal Properties

	Apache Leap Tuff	Quartzite/Diabase	Mixed-mean below 1500m	Quartzite rich areas
Thermal conductivity	1.95 W/m°C	3.90 W/m°C	4.83 W/m°C	6.55 W/m°C
Specific heat capacity	1.14 kJ/kg°C	0.95 kJ/kg°C	0.80 kJ/kg°C	0.80 kJ/kg°C
Density	2.10 t/m^3	2.80 t/m^3	2.72 t/m^3	2.69 t/m^3
Diffusivity	0.8x10-6 m^2/s	1.5x10-6 m^2/s	2.2x10-6 m^2/s	3.0x10-6 m^2/s

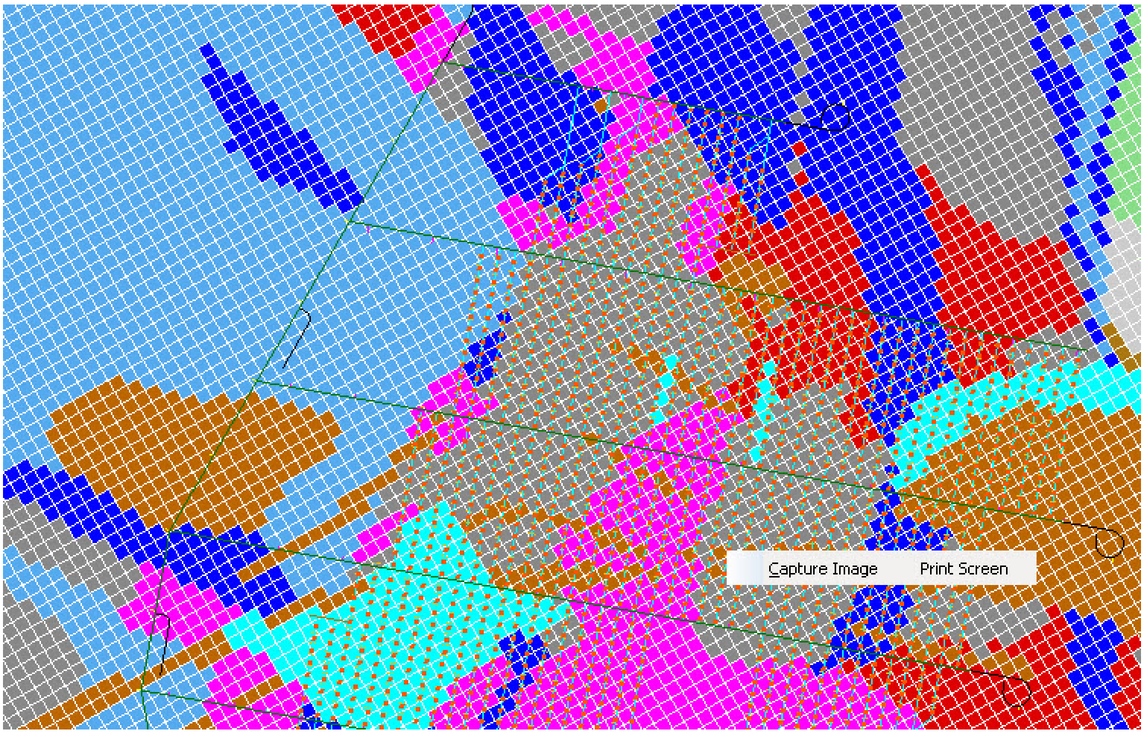


Figure 2.1 Layout Showing Quartzite Rich Areas [dark blue]

2.5 DPM Exposure Management

Another important design issue, along with heat and dust, will be that of DPM management. Controlling employee DPM exposure to less than the current TLVs and potential future values will be addressed by management plans including, but not necessarily limited, to the following:

- Underground diesel equipment will use modern tier 3 or 4 engines and all units will be purchased under tight specifications.
- High quality, low sulphur fuel will be used with the option to use alternatives such as biodiesel if required.
- Exhaust conditioning, over and above that provided normally on engines will be applied [this technology is available].
- Operators of a large portion of diesel equipment will be in air conditioned cabins with filtered air conditioned intake.
- Series ventilation of work places employing diesel equipment will have to be minimised or avoided altogether due to heat considerations.
- All diesel vehicles will be operated according to a site specific, risk assessed DPM Control Plan and an emissions-based maintenance program, incorporating regular exhaust testing, will be employed to identify problems in a pro-actively.

As will be seen, the life-of-mine ventilation capacity is some three times that required to operate the diesel fleet at 100% load. There will be however, times during the development phase where control over diesel locations will have to be exercised to ensure appropriate ventilation rates are employed at point of operation. This control will include monitoring of DPM concentrations and ventilation rates.

2.6 Service Water Usage

There is no definitive clarity* [at this stage] on the expected service water consumption to be supplied from surface. However, it is logical to use service water, in all phases of development and production, as a supplementary cooling and dust suppressant medium. It must be chilled on surface and supplied underground in an insulated pipe network system.

For this present work, it is assumed, somewhat subjectively* that, at full 120 kt/d production, the average service water demand from surface will be 150 l/s [24 hr ave, 0.1 ton/ton]. Service water flow rates for other production scenarios are determined on a pro-rata basis.

In the absence of further detailed information, the service water consumption for the development activities is taken as 10 l/s [24 hr ave] in the early development regimes.

* This important issue should be addressed in detail when more information is available on the expected service water consumption. It is understood that detailed water balance evaluations are being carried-out by RCM.

2.7 Ambient Weather Data

The surface design ambient temperature conditions will be **21/37°Cwb/db** [88 kPa barometric press], see Figure 2.2 and Addendum A.

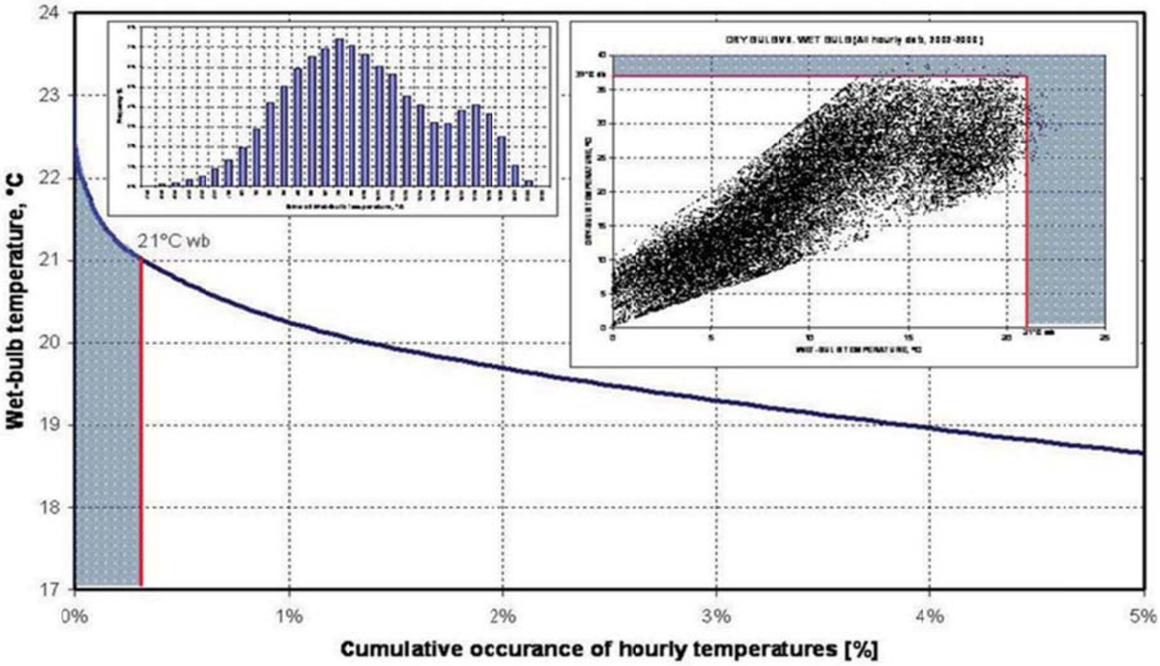


Figure 2.2 Mine Weather Data

2.8 Underground Temperature Conditions

The underground design reject conditions will be 30/40°Cwb/db. But, in select areas, the design criteria will be 27.5/37.5°Cwb/db, see Addendum B.

2.9 Note on High Dry-bulb Conditions

Due to the depth of mining and related auto-compression and exacerbated by high rock temperature there will be potential for high dry-bulb temperatures in certain areas. This potential will be most prevalent on the Production level. The ventilation and heat simulations assume that liberal amounts of water will be used at draw-points and ore passes. This will be required for dust suppression purposes anyway but this is also an important part of the cooling system design. The modelling indicates that, with reasonable amounts of moisture, the dry-bulb temperatures can be practically kept below 35°C [without water sprays this could exceed 42°C].

2.10 Note on Possible Underground Fissure Water

At this stage, one of the significant assumptions in the design criteria is that there will be no significant deep fissure water encountered. This is a fundamentally important assumption that could affect project costs should fissure water be encountered at depth. This will have potential to increase the mine heat loads dramatically and the probability of encountering fissure water must be reviewed continuously as more information becomes available. To demonstrate the magnitude of this possible problem, consider the following possible fissure water flow rates and their potential order-of-magnitude heat load effects:

- 38 l/s or 600 gpm [24 hr ave] 7.5 MW
- 76 l/s or 1200 gpm [24 hr ave] 15.0 MW
- 152 l/s or 2400 gpm [24 hr ave] 30.0 MW

As will be seen later, the overall heat load on the mine will be of the order of 100 MW and these additional loads could be very significant.

2.11 Note on Pumping Strategy

When No.10 Shaft sink is complete, a pump station will be established at No.10 Shaft below the Characterization level and, throughout the mine development period, return water will be pumped in a column in No.10 Shaft to the intermediate pump station on Pump level and hence to surface [via No.10 Shaft]. Once the mine has been established, the main pump station will be near No.13 Shaft bottom and return water will be pumped in the shaft column to Pump level where it will be routed across to the original intermediate pump station at No.10 Shaft. The discharge from the No.10 Shaft pump station will then be routed back to No.13 Shaft from where it will report to surface. Bearing in mind that No.10 Shaft will be an upcast shaft, there will need to be a ventilation allocation provided for the Pump level equipment which will report direct to the upcast shaft.

2.12 Note on Reactive Ground and SO_2 Production

The risk related to the reactivity of sulphide ores was discussed during the course of this work. If the ground is relatively reactive, there will be a risk of oxidation reactions which will generate heat, SO_2 [and acidic water]. This would be exacerbated in the presence of ground water or fissure water. This potential problem has been identified as such, but, on the basis of available information, it is not possible to quantify these effects with any level of confidence. It has thus been recommended that specialist scientific consultants be engaged to carry out appropriate evaluations and relevant modelling work at the appropriate time.

Another related issue would be the possibility of sulphide dust explosions. It is considered that this will be largely mitigated by the comprehensive dust management strategies discussed in this report. However, there may be merit in examining this in more detail at the next level of design detail.

2.13 Note on Single Egress Scenario

There are major questions of escape and rescue related to the possible early development work with a single egress scenario - that is until No.9 Shaft is holed. This problem is critical during early development and characterization work which will take place before project approval. Thus this problem is being addressed outside the scope of this particular work - indeed there are numerous evaluations being undertaken related to emergency refuge stations and escape methodologies with detailed risk assessments. For the present purposes, this entire subject is purposely excluded from this report. This subject will be given much detailed attention and will be documented in a different forum.

2.14 Note on Air Density

The density of the ventilation air will vary significantly through the mine. For example, air into the main surface upcast fans will be 0.95 kg/m^3 while the cold downcast underground intake air will be 1.20 kg/m^3. Because of this, flow rates quoted as 'volume flow' will change significantly throughout the mine. Hence, in general, this report makes use of mass flow basis [kg/s].

2.15 Note on Heat-Moisture Ratings

The heat transfer processes generally combine dry [sensible heat] and wet [latent heat] heat flow. For example, pure sensible heat would arise from electrical substations while pure latent heat would be associated with water spray systems. Each heat source has its own characteristics which can be described by an enthalpy/moisture ratio. Because of the many different possible heat processes in mines, this issue is addressed using VUMA rating categories ranging from dry [Cat.1] to wet [Cat.5]. For example, heat derived from diesel machines generally falls into Cat.4.

3 FEATURES OF FULLY ESTABLISHED MINE YEAR 2031

The purpose of this section is to describe the basis and rationale for the fully established production circuit design.

3.1 Selection of Critical Production Scenario

The snap-shot scenario at year 2031 in the life-of-mine is shown in Figure 3.1. This scenario was selected as the critical design year for sizing the ultimate ventilation and refrigeration needs and this is the basis of the detailed VUMA mine modelling. Other scenarios towards the end-of-life-of-mine are examined by extrapolation from this scenario. The development phases were modelled separately and are presented in Section 12.

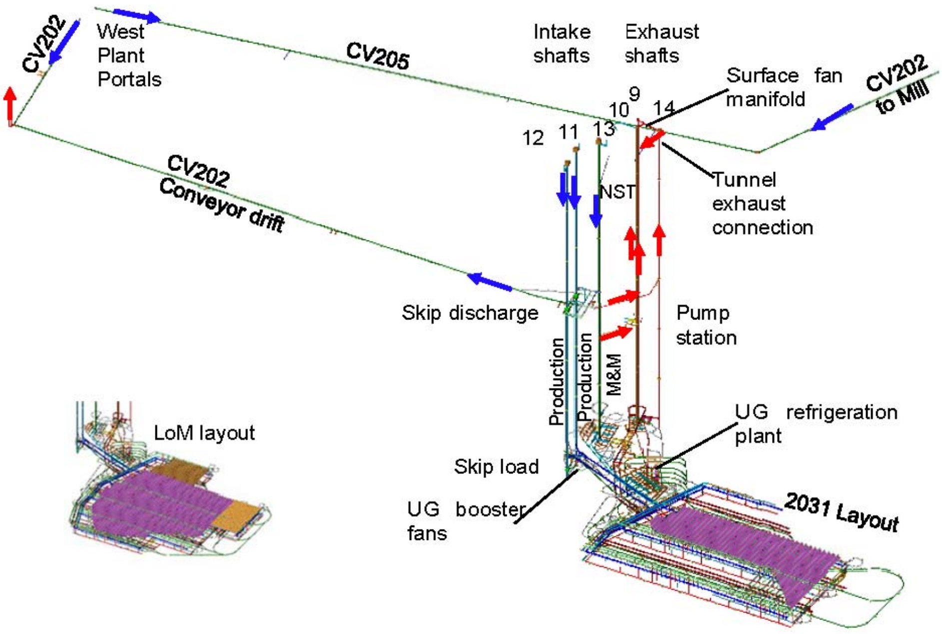


Figure 3.1 Snapshot at Design Condition 2031

The life-of-mine planning includes exploiting six main mining panels of varying size. Figure 3.2 shows the production build-up and the production profile for each panel.

The snap-shot at year 2031 relates to the period when Panel 1 is approaching completion and Panel 2 is starting production. This was considered to be appropriate because of the relatively high mix of development tonnage, the duplicity of a number of excavations and the fact that the workings are furthest from the main infrastructure.

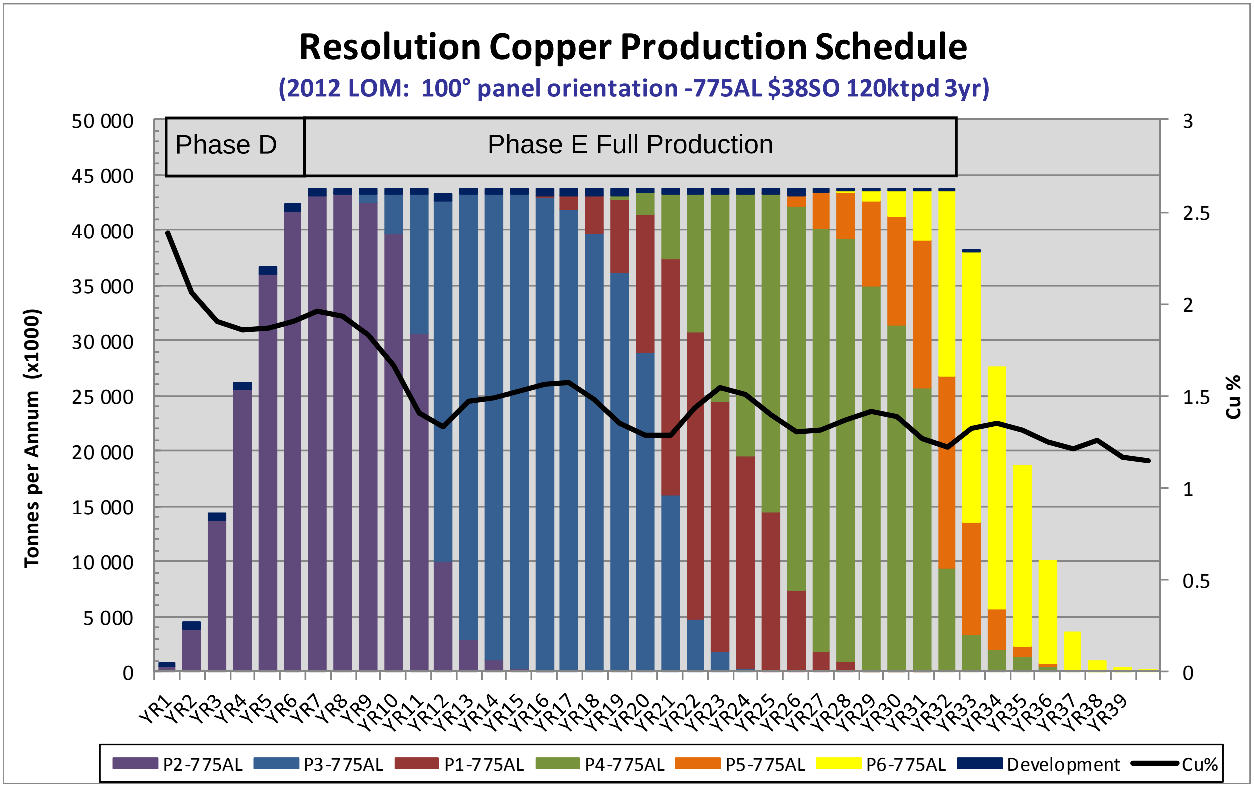


Figure 3.2 Production Build-up Profile

The production during this period will include about 7% from ‘quartzite rich’ zones. The other main ‘quartzite rich’ zones will include the third panel development and areas toward the end of life-of-mine when production is depleting.

Towards the end-of-life-of-mine there is a scenario where three different panels are working and some of production is ‘quartzite rich’. This scenario was considered as a candidate for the critical design scenario but the panels are relatively small at that stage. As noted, this scenario is examined by extrapolation from the base year 2031 snap-shot.

3.2 Activities and Working Zones in Mining Block

The modelling work has addressed the workings in reasonable detail and this section defines some of the main activities and zones, Table 3.1:

740 Undercut level

Undercut headings [retreating]

11 off retreating using 2 diesel LHDs
Broken rock from development and surrounding rock heat
Other heat: aux vehicles, aux fans, dill rigs, lights

Undercut development and rim tunnel development headings

5 off in u/c development + 2 off in rim tunnel development using 2 diesel LHDs
Broken rock and surrounding rock heat
Other heat: aux vehicles, aux fans, dill rigs, lights

760 Undercut level

Undercut headings [retreating and mucking swell

11 off retreating and mucking swell using 2 diesel LHDs
Broken rock and surrounding rock heat
Other heat: aux vehicles, aux fans, dill rigs, lights

Undercut development and rim tunnel development headings

5 off in u/c development + 2 off in rim tunnel development using 2 diesel LHD
Broken rock and surrounding rock heat
Other heat: aux vehicles, aux fans, dill rigs, lights

Production extraction level

Production-crosscut zone

70 off active 150 m production crosscuts using 30 electric LHDs
Broken rock and surrounding rock heat
Other heat: aux vehicles, dill rigs, lights

Production-crosscuts in draw-pt construction

2 off crosscuts with through flow vent using 2 diesel LHDs
Broken rock and surrounding rock heat
Other heat: aux vehicles, dill rigs, lights

Production-crosscut development and rim tunnel development headings

1 off in crosscut development, 2 off in rim tunnel development using 1 diesel LHD
Broken rock and surrounding rock heat
Other heat: aux vehicles, aux fans, dust sprays, raise-bore rigs, dill rigs, lights

Intake vent level [haul trucks, development drives and ‘background’ activities]

2 off developing drives using 1 diesel LHD
Broken rock and surrounding rock heat
Other heat: haul trucks aux vehicles, aux fans, dill rigs, lights

Rail haulage level [development drives and ‘background’ activities]

4 off developing drives using 1 diesel LHD
Broken rock and surrounding rock heat
Other heat: aux vehicles, aux fans, dill rigs, lights, elec [trolley] locos, dust sprays, dust control equipment

Return vent level [development drives and ‘background’ activities]

2 off developing drives using 1 diesel LHD
Broken rock and surrounding rock heat
Other heat: aux vehicles, aux fans, dill rigs, lights

Table 3.1 Summary of Active Crosscuts and Headings in Mining Block and LHD Deployment

	No	LHDs
740 Undercut level		
Number of headings in undercut retreat	11	2 diesel
Number of headings in undercut excavation development	5	2 diesel
Number of headings in undercut level rim tunnel development	2	
760 Undercut level		
Number of headings in undercut retreat [mucking swell]	11	2 diesel
Number of headings in undercut excavation development	5	2 diesel
Number of headings in undercut level rim tunnel development	2	
Production extraction level		
Number of full active 150 m production crosscuts	70	30 elec
Number of production crosscuts in construction [draw-pt preparation]	2	2 diesel
Number of headings in production crosscut development	1	1 diesel
Number of headings in production level rim tunnel development	2	
Intake vent level		
Number of headings in intake vent level development	2	1 diesel
Rail haulage level		
Number of headings in haulage level development	4	1 diesel
Return vent level		
Number of headings in exhaust vent level development	2	1 diesel

3.3 Diesel and Electric Mobile Equipment

The underground equipment and its deployment are given in Table 3.2 for the year 2031. Note that this is a full production life-of-mine scenario that does not reflect the mine construction/development phase [see later] in terms of, for example haul trucks and concrete trucks. Also, these lists will change as the mine design process evolves but, for the present purposes, these data are used in the established mine heat load analysis. In summary, the main statistics are as follows:

- Diesel auxiliary and service vehicles will have total rating of about 7.99 MW this will relate to heat generation of 4.79 MW on a general overall average basis.
- Diesel loaders and diesel rock breakers will have total rating of about 4.15 MW this will relate to heat generation of 7.32 MW on a general overall average basis.
- Electrical loaders on the extraction level will have total rating of about 4.62 MW this will relate to heat generation of 2.82 MW on a general overall average basis.
- Drill rigs [and blind borers and raise borers] will have total rating of about 4.11 MW. For the diesel engines with some of these drill rigs, the total diesel rating will be about 1.86 MW. The electrical [and diesel] heat will relate to heat generation of 1.16 MW on a general overall average basis.

The total heat load related to vehicle and mobile equipment will be about 16 MW. An important aspect of the ventilation plan will be to provide sufficient volumetric capacity for the mobile fleet, Figure 3.3.

3.3.1 DPM Exposure Management

Unlike potential exposures to respirable silica and heat, there is nothing extraordinary concerning DPM management in proposed design parameters for the project. Controlling employee DPM exposure to less than current TLVs, and potential future TLVs, is not expected to be problematic for the following reasons:

- All diesel vehicles will be operated according to a site specific, risk assessed DPM Control Plan.
- Underground diesel equipment will use modern Tier 3 or Tier 4 engines and all units will be purchased under the control and specification of RCM.
- An emissions-based maintenance program incorporating regular exhaust stream PM testing will be employed to identify problems in a pro-active manner.
- Life-of-mine ventilation capacity is some three times that required to operate the diesel fleet at 100% load. However, there will be times during the development phase where control over diesel locations will be needed to ensure that adequate ventilation rates are employed at point of operation. This control will include monitoring of DPM concentrations and ventilation rates.
- High quality, low sulphur fuel will be used with the option to use alternatives such as biodiesel if required.
- If required, exhaust conditioning, over and above that provided for on engines is available and will be applied.
- Other than remotely controlled units, operators of most diesel equipment [certainly all >200kW units] will be in air conditioned cabins with filtered air conditioned intake.
- Series ventilation of work places employing diesel equipment will have to be minimised or avoided altogether due to heat considerations.

Table 3.2 Year 2031 Equipment List

RESOLUTION MOBILE EQUIPMENT LIST
DESIGN SCENARIO YEAR 2031, rev October 2012

DIESEL AUXILIARY AND SERVICE VEHICLES [excl drill rigs, LHDs]						
		General location	Diesel		Number	Total
			rated		units	rating kW
	Scissor lifts - Getman A64	All	130 kW		6	780
	Scissor lifts Miller w man basket	All	104 kW		7	728
	Fuel and lub trucks - Getman A64	All	130 kW		3	390
	Crane trucks - Getman A64	All	130 kW		3	390
	Crane trucks - Miller Toyota	All	104 kW		3	312
	Water trucks - Getman A64	All	130 kW		2	260
	Grader Cat - 120H	All	104 kW		2	208
	Man haul personnel carriers - Miller Toyota	All	104 kW		11	1144
	Service truck	All	130 kW		2	260
	UG Skid steer loader	All	60 kW		1	60
	UG Dozer	All	104 kW		1	104
	Flat deck truck	All	104 kW		3	312
	Conveyor maintenance vehicles	Conveyor	104 kW		2	208
	Explosive loading units - IT 62	Development	86 kW		7	602
	Shotcrete sprayers	Development	86 kW		5	430
	Shotcrete trucks enclosed cab	Development	104 kW		8	832
	UG Haul trucks 40 tonne	Development/Intake vent level	354 kW		2	708
	LHD generator truck	Extraction	86 kW		3	258
					71	7986

DIESEL / ELECTRIC DRILL RIGS						
			Diesel	Elec	Number	
			rated	rated	units	
	Drill Jumbo, 2-Boom, E/H drills on developn	Development	110 kW	140	5	
	Drill Jumbo, 1-Boom, E/H drills on rock bolti	Development	74 kW	42	5	
	Drill Jumbo, 1-Boom, E/H drill on cable bolti	Extraction	110 kW	78	1	
	Drill Jumbo, 1-Boom, E/H drills on productio	Extraction / Undercut	55 kW	70	5	
	Medium reach rig	Extraction	110 kW	140	1	
	Robust rig	Extraction	110 kW	140	4	
	Blind hole borers electrical	Extraction		134	2	
	Raise bore machines	Extraction/Development		300	2	
	Fixed secondary rock breakers	Extraction		30	40	
			1855 kW	4106	65	

DIESEL LOADERS						
			Diesel		Number	Total
			rated		units	rating kW
	LHDs 1.1m3 [1.5yd] EJC65	Conveyor	100 kW		2	200
	LHDs 4.6m3 [6yd] LH514	Development	256 kW		7	1792
	LHDs 2.5m3 [3.5yd] LH307	Development	150 kW		2	300
					11	2292

DIESEL MECHANICAL ROCK BREAKER						
			Diesel		Number	Total
			rated		units	rating kW
	Mobile rock breakers	Extraction	224 kW		7	1568

ELECTRIC LOADERS						
				Elec	Number	Total
				rated	units	rating kW
	LHDs 6.4m3 [8.5yd]	Extraction		132 kW	30	3960

ELECTRIC LOCOMOTIVES						
				Elec	Number	Total
				rated	units	rating kW
	Locomotive electrical trolley 40 tonne	Haulage		179 kW	8	1432

Note: Although not reflected above, cement and concrete trucks will be used extensively during the mine construction phase. For example, the RCM table indicates that in 2020 there will be 15 shotcrete trucks and 15 shotcrete sprayers. It is presumed that these will be carrying cement and concrete for bulk civils as well. The heat effects of the trucks and the hydration effect of the cement are addressed in the heat load analysis.

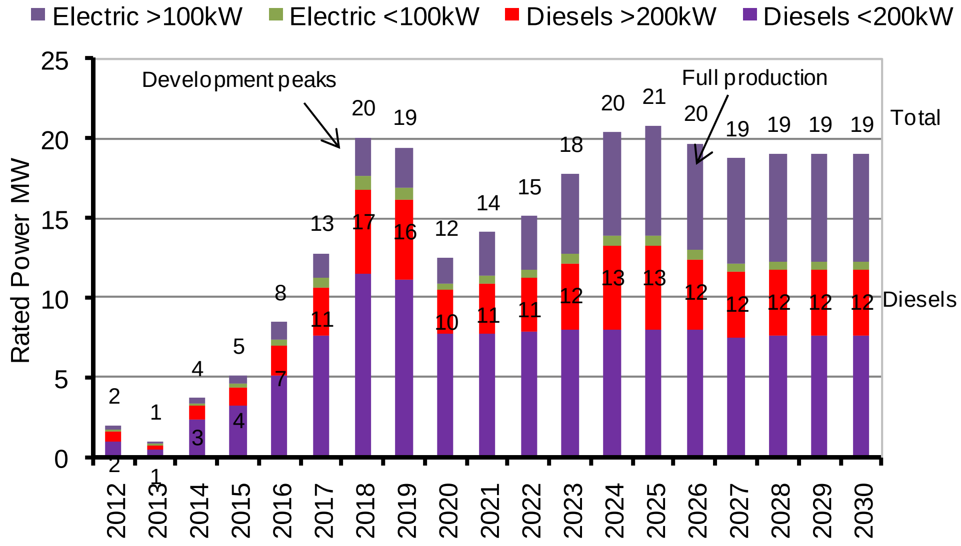


Figure 3.3 LoM Diesel and Electric Mobile Rated Power Profile

3.4 Infrastructure 'Centres'

Apart from the active zones in the mining block, the following other general 'infrastructure' centres/zones, such as workshops, pump stations, crushers, etc, are accounted-for in the modelling.

3.4.1 Workshops, Warehouses and Batch Plants

In the workshops, warehouses, batch plant, etc. the heat loads will be due to the surrounding rock as well as the equipment/activities such as fans, lights, diesels, welding, etc.

The equipment list gives the following specific facilities and motor ratings:

- Maintenance shop for locos and rail cars 150 kW
- Mobile equipment maintenance shop 190 kW
- Underground batch plant 150 kW
- Shops/warehouses/offices 220 kW
- Warehouse underground 370 kW

For the modelling purposes, it is assumed there these facilities will be as follows:

- Maintenance shop for locomotives and rail cars located as shown on Figure 3.4 with ventilation to return, assumed to have equivalent of 200 m of 25 m^2 excavations with 0.2 MW equipment heat.
- Mobile equipment maintenance workshop located as shown on Figure 3.4 with ventilation to return, assumed to have equivalent of 200 m of 25 m^2 excavations with 0.2 MW equipment heat.
- Fuel and tyre store located as shown on Figure 3.4 with ventilation to return, assumed to have equivalent of 120 m of 25 m^2 excavations with 0.1 MW equipment heat.
- Satellite work shop at far end of panel 1 with ventilation to return, assumed to have equivalent of 80 m of 25 m^2 excavations with 0.1 MW equipment heat.

Thus the total heat load related to the equipment in these facilities will be about 0.6 MW. In general, these heat loads are applied in the modelling at VUMA moisture Cat.3.

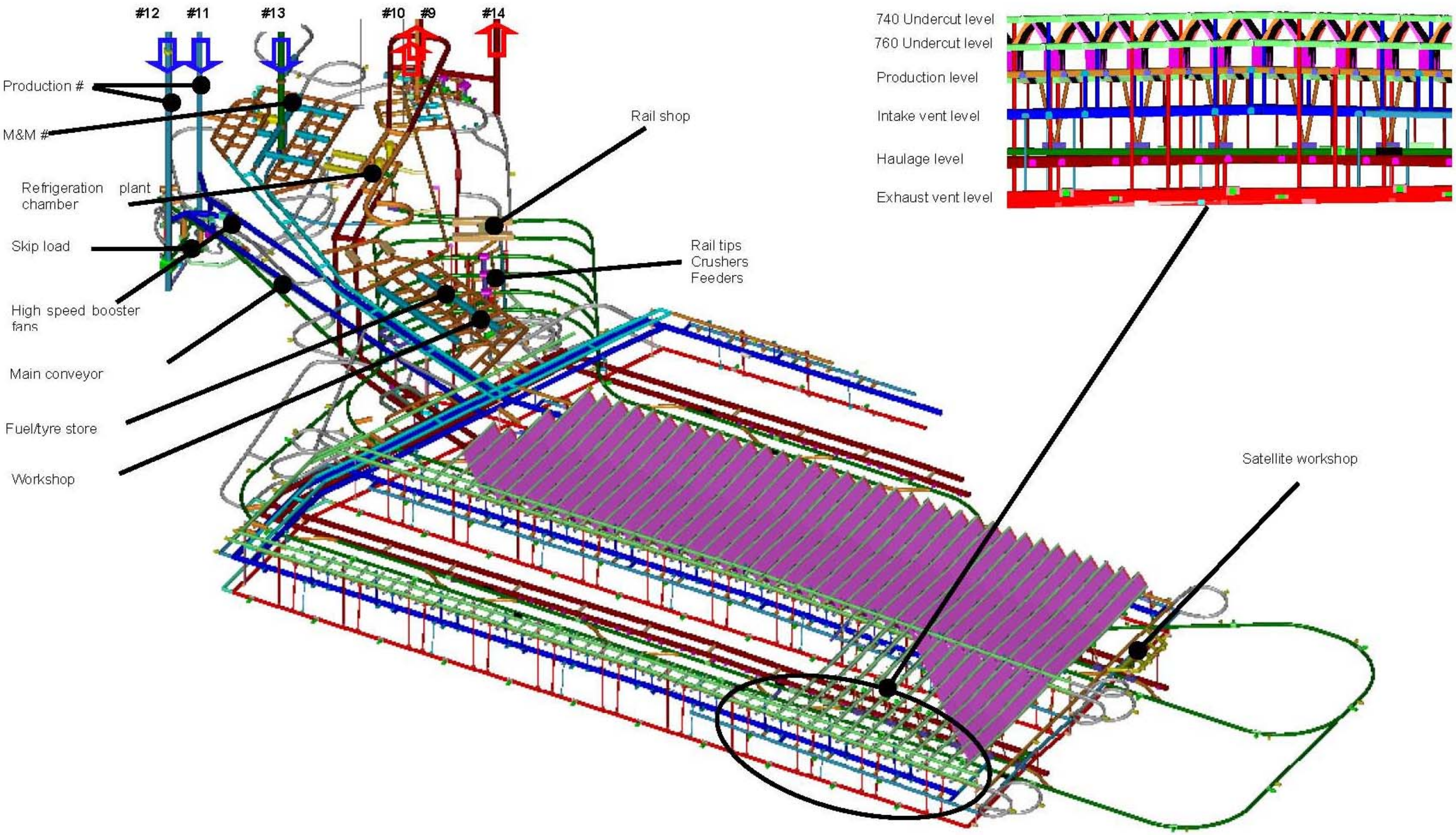


Figure 3.4 General Layout Showing Infrastructure Centres

3.4.2 Pump Stations

In the pump stations, the heat loads will be due to the surrounding rock as well as the equipment/activities such as pumps, fans, lights, etc. The equipment list gives the following specific pumping facilities and motor ratings:

- Pump station [4100 level] 370 kW
- Feed pumps [4100 level] 40 kW
- Pump station [6210 level] 370 kW
- Feed pumps [6210 level] 40 kW
- Pump shaft bottom 90 kW
- Development pumps 40 kW
- Development pumps 10 kW
- Service water pumps 10 kW

For the modelling purposes, it is assumed that the pump facilities will be as follows:

- Shaft bottom area small pump facility with insignificant excavation but with 0.1 MW overall equipment heat.
- Main pump station [No.11/No.12 Shaft] including settling arrangements, mud handling, etc. assumed to have equivalent of 80 m of 25 m^2 excavations with 0.2 MW overall equipment heat.
- Mid-shaft pump station 4100 level [No.11/No.12 Shaft] assumed to have equivalent of 80 m of 25 m^2 excavations with 0.2 MW overall equipment heat.
- At mining block [haulage level]: relatively small pump station, assumed to have equivalent of 30 m of 25 m^2 excavations with 0.1 MW equipment heat.

Thus the total heat load related to the equipment in the pump facilities will be about 0.6 MW. In general, these heat loads are applied in the modelling at VUMA moisture Cat.4.

3.4.3 Refrigeration Plant Chamber

The refrigeration plant chamber will be located near the mining block [on the west side] off the ventilation level. The heat loads in the plant chamber will be due to the surrounding rock as well as the equipment/activities such as compressors, pumps, fans, lights, etc. The refrigeration plant chamber will be assumed to comprise the equivalent of 200 m of 80 m^2 excavation with 0.8 MW equipment heat. In general, these heat loads are applied in the modelling at VUMA moisture Cat.4.

3.4.4 Conveyor Belt System to Hoisting Shaft Facilities

This note relates to the conveyor belt system reporting to shaft bottom loading facilities [not the near-surface conveyor system to the West Plant which is discussed in Appendix D]. This overall facility will comprise the belt system from the mining block to the hoisting shafts as well as the secondary belts related to hoisting shaft loading arrangements. The conveyor belt system will use significant electrical power, part of which manifests itself as heat along the length of the conveyor tunnel [heat load from the broken rock on the belts is discussed in Section 6 and Addendum C].

The equipment list gives the following specific conveyor belt facilities and motor ratings:

• Off crusher apron feeders	783 kW [2x261]
• General vibratory feeders	120 kW [8x15]
• Skip bin apron feeders	448 kW [4x112]
• Stockpile apron feeders	783 kW [4x261]
• Take away belt conveyor	3357 kW
• Tilt belt conveyor	112 kW
• Belt conveyor sections	300 kW [10x30]
• Miscellaneous	35 kW
	5938 kW

For the modelling purposes, it is assumed there that these belt facilities will be as follows:

Belt system from mining block to hoisting shaft loading

Main belt facilities from crusher transfer point to shaft loading will have an electrical rating of 5.5 MW and the related heat load over the length of this conveyor ramp will be 1.38 MW [25% of rated electrical].

Secondary belts related to hoisting shaft loading arrangements

Secondary belts and accessories related to the No.11 and No.12 Shaft loading arrangements will have 0.5 MW total electrical rating and the related heat load will be 0.13 MW [25% of rated electrical].

Note, at this stage the 25% assumption is subjective. This issue needs further definition from the conveyor system designers-suppliers regarding power and load profiles. In general, these heat loads are applied in the modelling at VUMA moisture Cat.2

3.4.5 Crusher Station

There will be one crusher station with three gyratory crushers each equipped with 800 hp [600 kW] motors. Heat generating equipment in the crusher stations will include the crusher motors, dust collection, fans, secondary belts, etc. [apron feeders will be categorised under conveyor systems]. The equipment list gives the following specific motor ratings for crushing and related facilities:

• Gyratory crushers [3x597kW]	1800 kW
• Dust collectors [3x22kW]	66 kW
• Miscellaneous [lights, rock breaker, others*]	243 kW
	2109 kW

*. Hydraulic pumps, lub pumps, trolleys, winches, etc.

For modelling purposes, it is assumed that the crusher station will have an overall rating of 2.1 MW and the related heat load applied will be 0.5 MW [VUMA moisture Cat.3].

3.4.6 Electrical Substations

Electrical substations can generate heat at a rate up to 5% [max] of electrical load. For the present purposes, and in the absence of specific information on the overall electrical power use, it is assumed that the total heat load from electrical substations will be 2.0 MW [VUMA moisture Cat.1]. This has been distributed at strategic locations in the heat load model, as: No.11 and No.12 Shaft stations 0.7 MW; mining block near crusher station 0.7 MW and mining block extraction level 0.6 MW.

3.4.7 Summary Total Heat Load Equipment and Facilities

In summary, the heat load due to all the equipment and facilities discussed in Section 3.4 is about 6 MW.

4 PRIMARY VENTILATION SYSTEM

This section describes the fully developed ventilation circuit in terms of capacity and distribution. The development and production ramp up phases are discussed Section 12.

4.1 Primary Ventilation System Flow Rates

The density of air will vary significantly through the mine and the reference conditions used for the proposed peak life-of-mine ventilation distribution [2760 kg/s or 2345 m^3/s to underground workings] are shown in Table 4.1.

Table 4.1 LoM Distribution and Psychrometric Properties of Air at Key Points

Location	Pressure kPa	WB C	DB C	Density kg/m3	ASV m3/kg	**Mass kg/s**	Quantity m3/s	**Calculation Logic**
#11,12,13 intake shaft bottom	110	21.3	26.0	1.27	0.80	**2760**	2,196	**A**
Conveyor drift portal intake	88	21.0	37.0	0.98	1.03	**60**	62	**B**
Tunnel to mill portal intakes	88	21.0	37.0	0.98	1.03	**150**	154	**C**
#11,12,13 shaft return to conveyor drift	98	17.0	22.0	1.15	0.88	**160**	141	**D**
To No.14 shaft from skip horizon	98	17.0	22.0	1.15	0.88	**180**	158	**E**
To No.10 shaft from pump horizon	98	17.0	22.0	1.15	0.88	**20**	18	**F**
Surface ambient (total intake)	88	21.0	37.0	0.98	1.03	**3330**	3,428	**Sum (A.F)**
Chilled intake mix at #11,12,13 collars	88	12.0	14.0	1.06	0.95	**3120**	2,964	**A + D + E + F**
Underground returns	106	29.0	29.0	1.21	0.85	**2760**	2,345	**=A**
#9,10,14 exhaust shaft collars	83	24.0	24.0	0.95	1.05	**3110**	3,268	**=A + C + E + F**
Conveyor drift exhaust shaft	86	28.0	35.0	0.96	1.07	**220**	235	**=B + D**
Total exhaust shafts						**3330**	3,503	

In general terms, the overall primary ventilation allocation is as follows;

- Underground workings from main intake shafts will be up to 2760 kg/s [2345 m^3/s at UG air density]
    - o Development crew allocations are based on 2 separate active faces per crew with exhaust vent raises installed to limit force duct lengths to <500 m. Detailed analyses of ventilation phase requirements indicate that this allocation will be in excess of that needed when 2 faces can in fact employ the same duct [e.g. raise bore stubs and passing bays].
    - o Undercut and draw bell levels involve both development and mucking of swell from the pile.
    - o Extraction drive allocation [12 kg/s or 9.5 m^3/s per location] is for remotely controlled electric loaders only and will not change for standing [secondary] work in terms of heat management.
    - o Construction will initially involve large excavations such as refrigeration plant chamber for which variable allocations will be required - value shown is an average for all construction activities.
    - o Workshop allocations are only for ventilation reporting directly to return airways [e.g. from fuel bays] and not the entire ventilation rate employed in such places that is then re used elsewhere.
    - o Raise bore location ventilation will be reused and is therefore not an additional load.

- Skip discharge, pumps and main conveyors [CV201,2,5,6]
    - o Dust management based on a capture velocity of 2.0 to 2.5 m/s applied to cross sectional area of capture point. Rates will be reviewed once final geometry of capture points are decided upon.
    - o Mid shaft skip discharge points require a robust dust capture strategy to avoid contaminating No.11 and No.12 Shaft intake ventilation and an additional return connection to No.14 exhaust shaft has been provided for this purpose.

Based on ventilation allocations, number of mining activities and ventilated locations, a nominal summary of ventilation requirements from start of production in Phase V.10 or D [prior to No.12 Shaft completion] is shown in Table 4.2 and summarised in Figure 4.1 and Figure 4.2. The exact distribution of ventilation at any one time will depend on distributional control and specific location requirements.

Table 4.2 Production Phase Ventilation Rate Allocation

	Allocation		Phase V.10		Full Prod		Plan Year		Peak LoM	
			2024	2024	2026	2026	2031	2031	2042	2042
Location or activity	m3/s	kg/s	No.	kg/s	No.	kg/s	No.	kg/s	No.	kg/s
Development Crews (2 locations each)	44	55	5	275	5	275	5	275	5	275
ROWA crews	60	75	0	0	0	0	0	0	0	0
Raise bore crews	0	0	3	0	2	0	2	0	2	0
Undercut and draw bell crews	40	50	2	100	2	100	2	100	2	100
Undercut swell muck & standing places	120	150	1	150	1	150	1	150	1	150
Undercut and draw bell crews	40	50	2	100	2	100	2	100	2	100
Undercut swell muck & standing places	120	150	1	150	1	150	1	150	1	150
Construction crews	40	50	3	150	2	100	1	50	1	50
Active production areas	9.6	12	8	96	17	204	36	432	36	432
Active extraction drive (half side)	9.6	12	4	48	0	0	12	144	34	408
Active rail drives	100	125	1	125	1	125	2	250	2	250
Rail tips	20	25	1	25	2	50	3	75	3	75
Crusher (development jaw)	20	25	0	0	0	0	0	0	0	0
Crushers (LoM main)	40	50	1	50	2	100	3	150	3	150
Conveyor load points	28	35	1	35	2	70	3	105	3	105
Main conveyor	120	150	1	150	1	150	1	150	1	150
No.11,12,13 sumps, tilt belt, skip loading	100	125	1	125	1	125	1	125	1	125
Refrigeration plant (to return)	20	25	2	50	2	50	2	50	2	50
Satellite workshop (to return)	20	25	1	25	1	25	1	25	1	25
Main workshop (to return)	24	30	1	30	1	30	1	30	1	30
Rail shop (to return)	24	30	1	30	1	30	1	30	1	30
Leakage (at full production)	84	105	0	0	0	0	1	105	1	105
Total location allocation UG				1714		1834		2496		2760
Development & DB & UC				775		775		775		775
Construction				150		100		50		50
Production				144		204		576		840
UG ore system				385		495		730		730
Workshops & leakage				260		260		365		365
Total requried below skip discharge				**1714**		**1834**		**2496**		**2760**
Available capacity below skip horizon				**1790**		**2760**		**2760**		**2760**
Skip discharge (No.11 & 12 shafts)				120		240		240		240
Conveyor drift				160		220		220		220
Tunnel to mill				0		150		150		150
Total other				280		610		610		610
Overall total				**1994**		**2444**		**3106**		**3370**
Ambient surface density				**2054**		**2517**		**3199**		**3471**

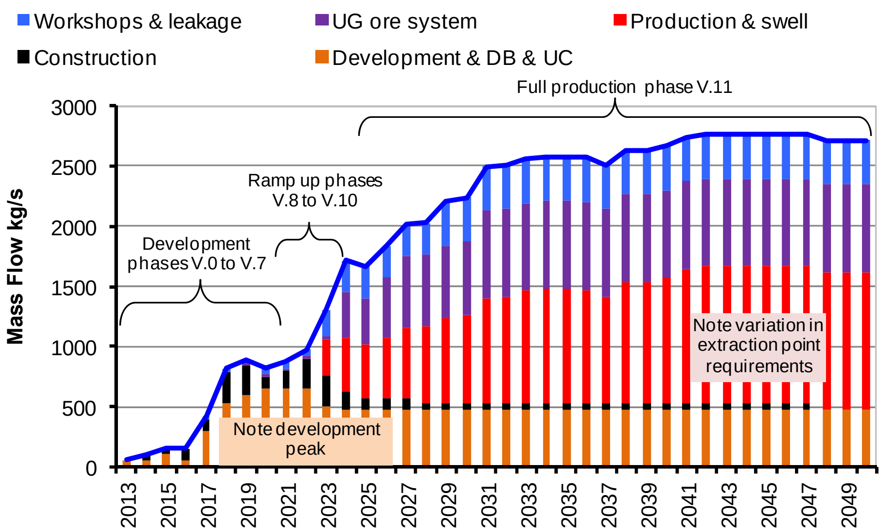


Figure 4.1 Distribution of Ventilation [Below Skip Discharge]

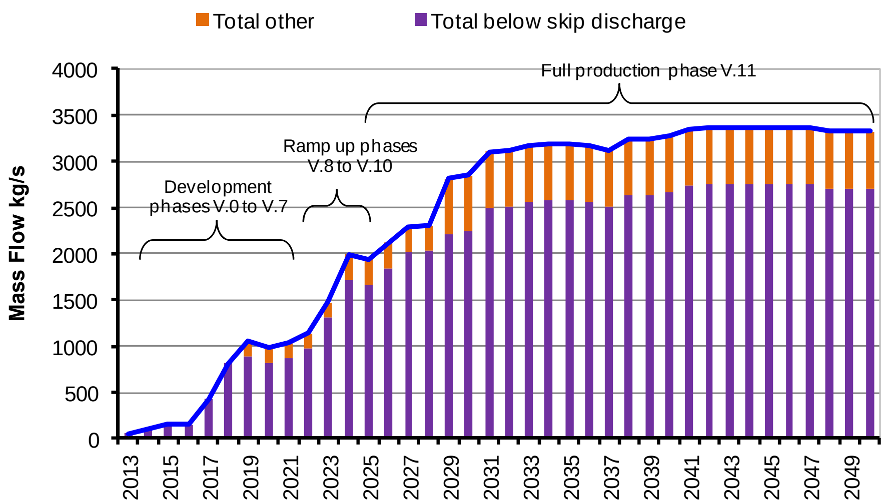


Figure 4.2 Distribution Of All Ventilation

Construction and development activities will initially determine overall ventilation requirements during production ramp up. During full production, the needs will then be dominated by the number of extraction drives which peak in 2042 with about 70 off individual locations at 12 kg/s each with 35 regulated exhaust raises [24 kg/s each].

Comparing total underground ventilation requirements to that available from exhaust shafts indicates that a shortfall could occur during Phase V.6 at the time that development activity increases while only No.9 Shaft is up casting. No.14 Shaft is scheduled to become operational first quarter 2020 at which time full allocation requirements can be met.

4.2 Comparison with Other Block Cave Mines

The comparison between the RCM planned ventilation requirements and those of some other block cave mines are shown in Figure 4.3. Considering the need at RCM to manage high heat loads with refrigeration, to optimise ventilation rates employed and to also provide for mid shaft skip discharge, this somewhat subjective comparison indicates that the planned ventilation rates are consistent with those employed at other block cave mines. It is assumed that ventilation rates reported for other block cave mines are at surface density.

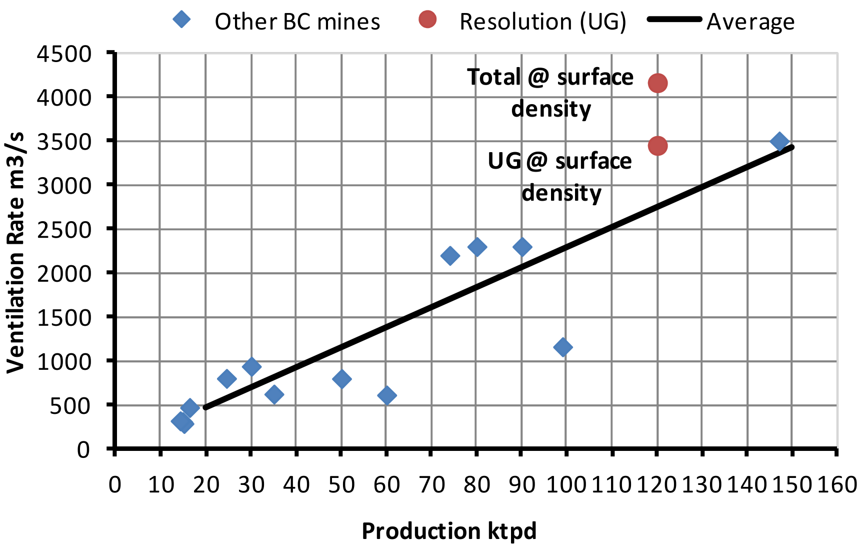


Figure 4.3 Resolution Ventilation Rate Benchmarking

The comparison between these proposed requirements for RCM and the Palabora operation is of interest to illustrate some of the design differences, Table 4.3.

Table 4.3 Comparison Between RCM and Palabora

Factor	Unit	Palabora	Resolution
Total primary ventilation [UG]	kg/s	624	*2760
Total air cooler duty	MW	15	*127
Production	kt/day	33	120
Vent flow factor	kg/s per kt/d	19	23
Air cooler factor	kW per kt/d	455	1060
	kW per kg/s	24	46
Summer day ambient design temp	°Cwb	23	21
Cold mixed downcast temp	°Cwb	16	11
Depth	m	1200	2000
Virgin rock temperature	°C	49	80

* Corrected for surface conveyor and skip discharge return.

4.3 Shafts and Primary Ventilation Infrastructure

Following review of the mine design, the life-of-mine primary ventilation circuit is that shown in Figure 4.4. The base case plan is to downcast No.11, No.12 and No.13 Shafts, upcast No.9, No.10 and No.14 Shafts together with exhaust via the conveyor drift. Provision is also made for a return connection between the skip discharge horizon in No.11 and 12 Shafts to the No.14 exhaust shaft, mid shaft pump station and conveyor tunnel from West Plant to the mill.

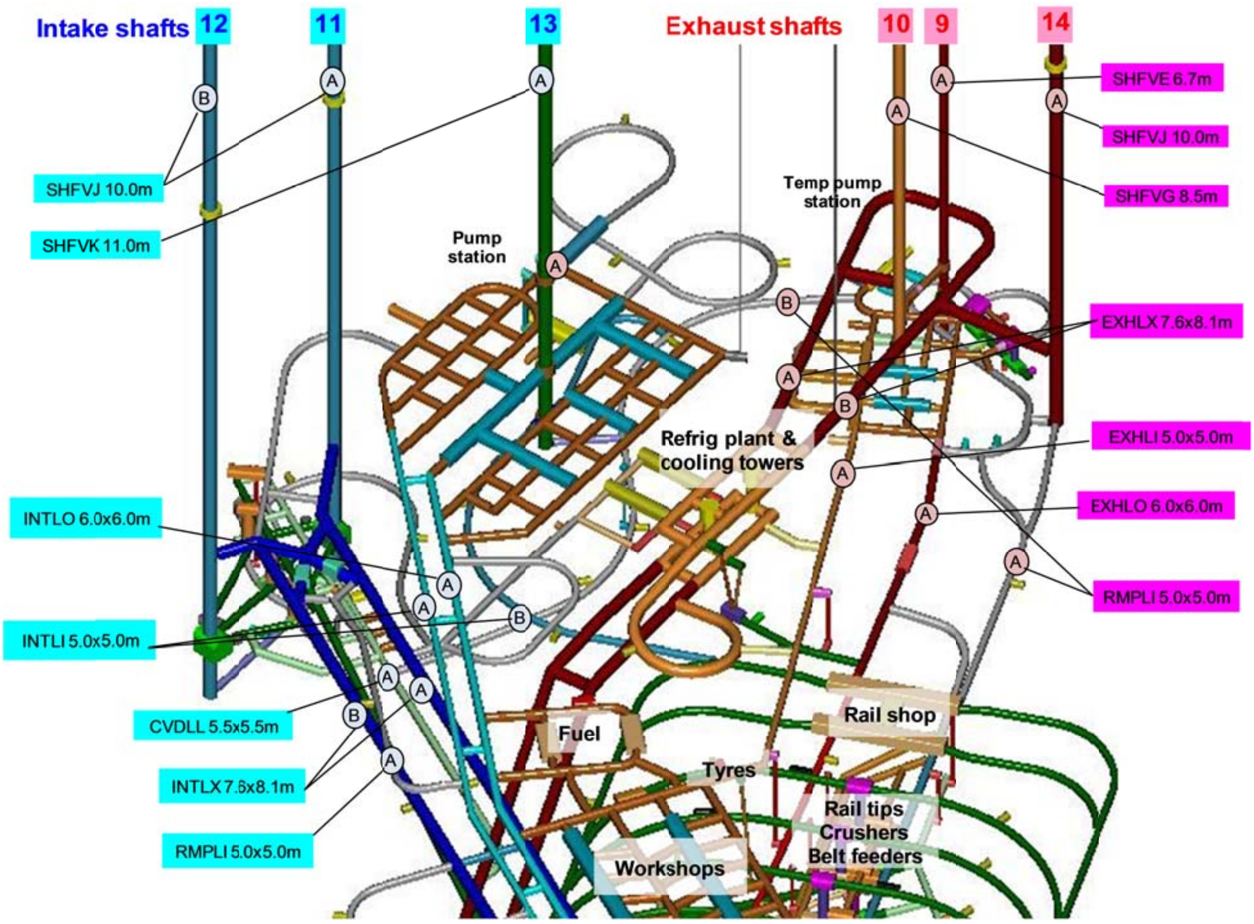


Figure 4.4 LoM Primary Ventilation Circuit

With consideration to airway sizes and industry norms for operational air velocity constraints, the following is an analysis of planned system capacity, identification of limitations and opportunities for increased capacity should it be required. For the purposes of this analysis, the base-case maximum is 2760 kg/s to underground workings and 510 kg/s to mid shaft services as: 180 kg/s to skip discharge, 20 kg/s to shaft pump station, 160 kg/s to conveyor drift and 150 kg/s to mill tunnel.

The ventilation distribution in each airway, with the exception of the conveyor and regulated returns, is based on free splitting at the bottom of shafts and through the workings. That is, it is based on airway resistance with connections made to fully load primary intake and return airways. The life-of-mine ventilation distribution on a mass flow and volumetric basis is shown in Figure 4.5. Note the high speed intake airways with booster fans the function of which is to redistribute ventilation in intake airways and not to boost the entire circuit.

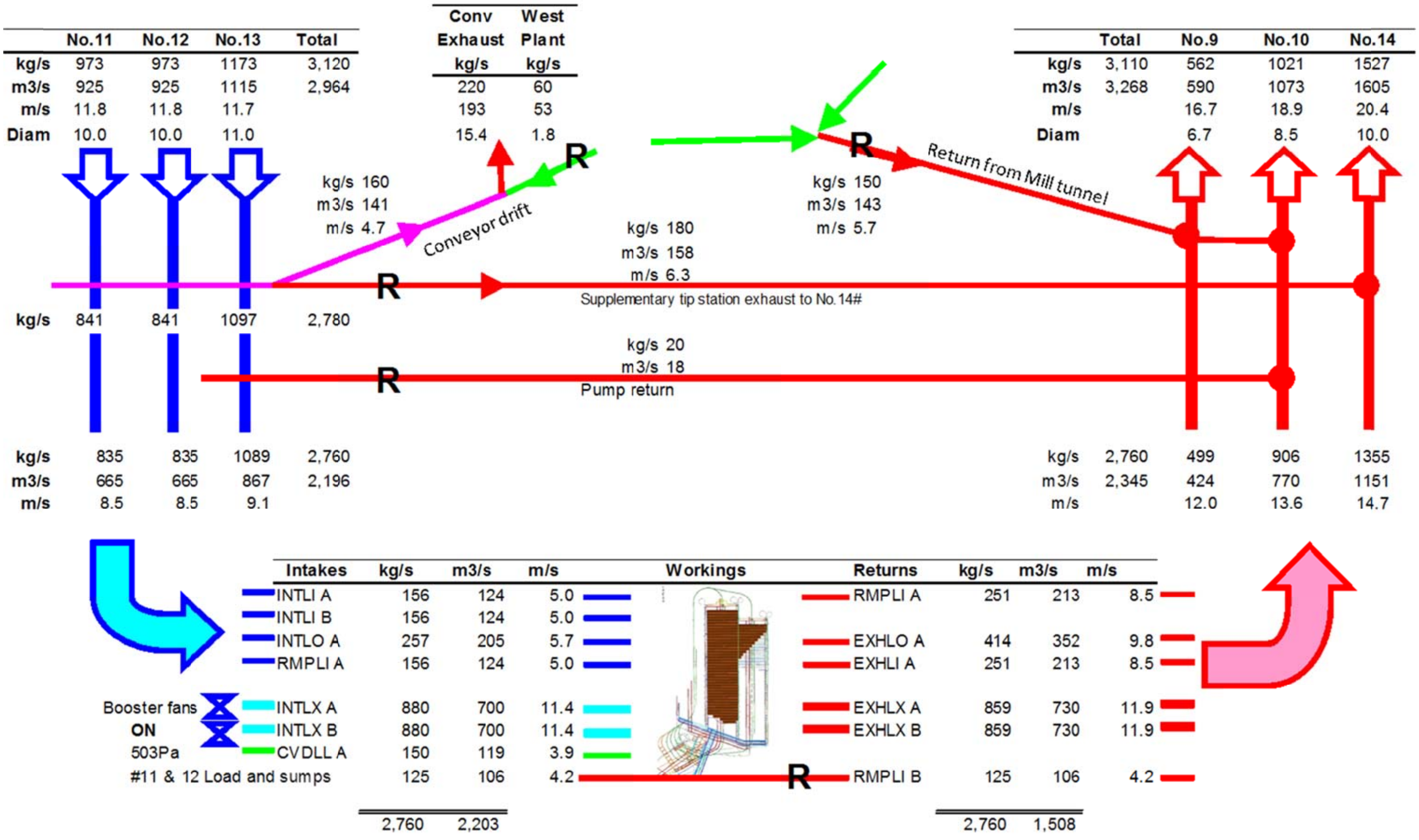


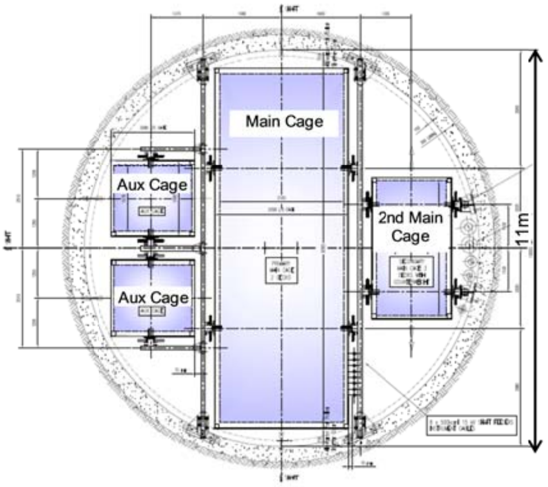
Figure 4.5 Distribution of Ventilation [Booster Fans On]

4.3.1 Intake and Exhaust Shaft Air Velocities

Based on the currently proposed dimensions of intake and exhaust shafts [finished diameters] and distribution of ventilation described above, air velocities at shaft top and bottom are shown in Table 4.4 . Intake shaft conveyance dimensions for hoisting and production shafts are shown in Figure 4.6 and Figure 4.7 respectively.

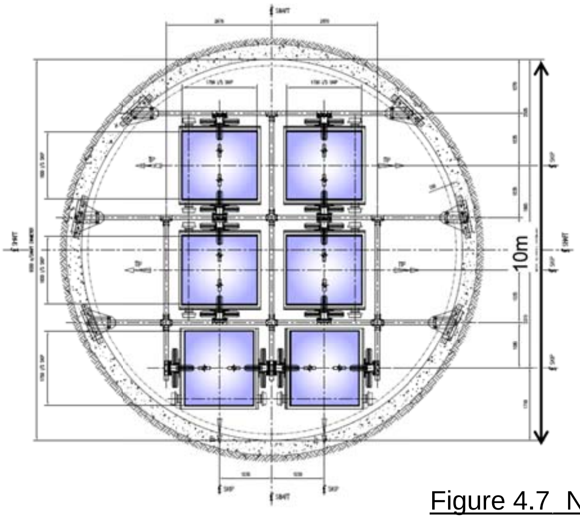
Table 4.4 Main Shaft Velocities [LoM Capacity]

Shaft	Diam m	Area m2	Bottom Velocity m/s	Bottom Quantity m3/s	Bottom Mass kg/s	Top Velocity m/s	Top Quantity m3/s	Top Mass kg/s
Intake								
No.11 Shaft	10.0	78.5	8.5	665	835	11.8	925	973
No.12 Shaft	10.0	78.5	8.5	665	835	11.8	925	973
No.13 Shaft	11.0	95.0	9.1	867	1,089	11.7	1,115	1,173
				2,196	2,760		2,964	3,120
Exhaust								
No. 9 Shaft	6.7	35.3	12.0	424	499	16.7	590	562
No. 10 Shaft	8.5	56.7	13.6	770	906	18.9	1,073	1,021
No. 14 Shaft	10.0	78.5	14.7	1,151	1,355	20.4	1,605	1,527
				2,345	2,760		3,268	3,110



Conveyance	Dimen m	Dimen m	Area m2	Fill %
Shaft	11.00		95.0	
Main cage	3.35	8.79	29.4	31.0
Secondary main cage	2.00	3.40	6.8	7.2
Auxiliary cage	2.03	1.90	3.8	4.0
Auxiliary cage	2.03	1.90	3.8	4.0
			43.9	46.2

Figure 4.6 No.13 Shaft Conveyances



Conveyance	Dimen m	Dimen m	Area m2	Fill %
Shaft	10.00		78.5	
Skip 1	1.75	1.6	2.8	3.6
Skip 2	1.75	1.6	2.8	3.6
Skip 3	1.75	1.6	2.8	3.6
Skip 4	1.75	1.6	2.8	3.6
Skip 5	1.75	1.6	2.8	3.6
Skip 6	1.75	1.6	2.8	3.6
			16.8	21.4

Figure 4.7 No.11 and 12 Shaft Skips

The total potential fill factor for all No.13 Shaft conveyances is 46% although the largest cage has a fill factor of 31%. The total potential fill factor for No.11 and No.12 Shafts is 21% although it is not planned to have more than 3 skips discharging in either shaft at any one time. Provided that these issues and proposed air velocities are taken into account when finalising design of guide spacing and stiffness, then current intake shaft dimensions are deemed acceptable for the LoM ventilation capacity.

Although there will be variations to the actual load reporting to each of the exhaust shafts [e.g. West Plant to Mill and skip discharge exhaust] with common shaft bottom connections and a surface fan manifold, the distribution should be relatively even on a pressure loss basis i.e. common top and bottom node pressures. In this case, shaft velocities close to 12 m/s at the collars which determines the limiting capacity at collars. However, attention needs to be given to air velocities during the development and production ramp-up periods prior to all shafts being available. These issues are discussed in Section 12.

4.3.2 High Speed Intake Airways with Intake Booster Fans

The primary intake ventilation infrastructure will include two large ROWA tunnels [INTLX A, INTLX B] each 61.4 m^2 which will be used as high speed dedicated intake airways. These will be no-go zones with limited or no pedestrian or vehicle access. These airways will each be operated at 11.4 m/s air speed and 700 m^3/s [880 kg/s] and will carry more than 60% of all underground ventilation [below Skip Discharge level].

There will be two booster fan stations for the high speed intake airways, one in each intake ROWA tunnel, to create the special high-speed intakes, Section 7.3. The objective will be to optimise the carrying capacity of these large airways as well as to control air velocity in other trafficable airways. Each of these two underground fan stations will have 880 kg/s [700 m^3/s] capacity and will each comprise four fan motor sets installed in parallel in a bulkhead, Figure 4.8. Each fan will be selected for 175 m^3/s and 1.0 kPa with nominal motor size of 250 kW. Fans will be standard axial flow units with internally mounted directly coupled electric motors. Fan-hub design will allow for manual resetting of the blade pitch in static condition. Each booster fan station will include excavation, bulkhead wall, air lock doors, direct coupled axial fan units, silencers, inlet cones, safety screens, static guide-vanes, diffusers, non-return doors, duct couplings, support civils/structures, etc.

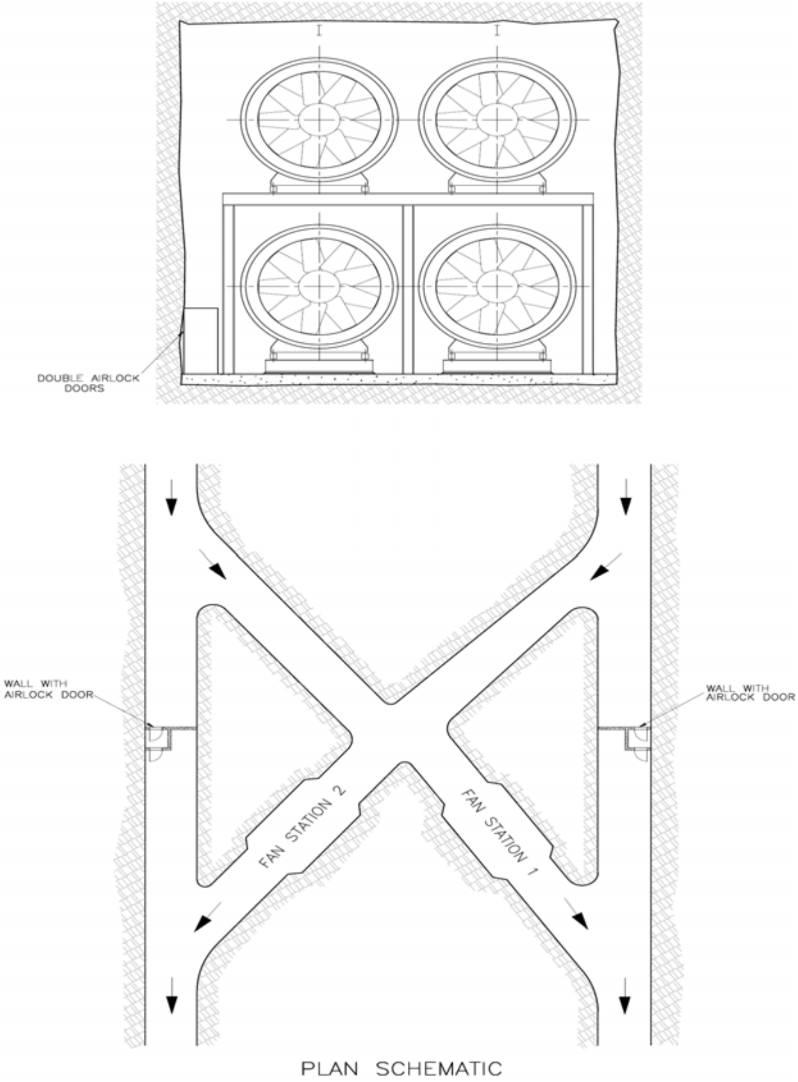


Figure 4.8 General Layout of Booster Fans for High Speed Intakes

It is noted that the rationale for the intake booster fans was not for the purpose of pressure-balancing the cave for control of leakage. This was because of the depth of the cave and the fact that the ore body does not extend to surface i.e. workings are not beneath an open cast pit. Furthermore the buoyancy or natural ventilation pressure effect could cause the cave pile to leak out from the mine rather than in.

4.4 Secondary Ventilation Concepts

For the present purposes, it is necessary to evaluate and understand the secondary ventilation systems and concepts to a level of detail that ensures first, that the required distribution will be possible and second, that the heat load effects are understood [for example: numbers of auxiliary fans, duct sizes and secondary coolers].

The largest diesel equipment will be the 256 kW LHDs and the minimum ventilation quantities for this machine will be 25 kg/s [at point of use]. While this is probably conservative with Tier 3 or 4 engines, it is an appropriate value at the present level of design consideration. See Section 3.3 for note on DPM issues.

There will be a suite of secondary air coolers that will serve the undercut levels, production level and rim tunnel development, see Section 9, Table 9.1and Figure 9.2. The air coolers will be located on the Intake level and deliver chilled air to fresh air ventilation raises reporting to the Production level and the two Undercut levels. The total secondary air cooling duty serving these levels and development will be 30.5 MW at the ultimate design condition.

4.4.1 Undercut Levels

To achieve the required wide inclined undercut for cave initiation an additional undercutting level has been introduced some 20 m above the original Undercut level. The new Undercut level is designated 740 Undercut level and the original Undercut level is now designated 760 Undercut level and is positioned 20 m above the Production level.

The crosscut spacing on the Undercut levels is 30 m and this aligns with the Production level crosscut spacing. The crosscuts on 760 Undercut level will be displaced by 15 m from the crosscuts on 740 Undercut level.

For the 740 Undercut and 760 Undercut levels, intake ventilation raises [3 m] will be established in the rim tunnels at intervals of 120 m [every 4 undercut crosscuts]. Both north and south rim tunnels will be developed towards the panel from the main infrastructures and crosscuts will be developed towards the north, Figure 4.9.

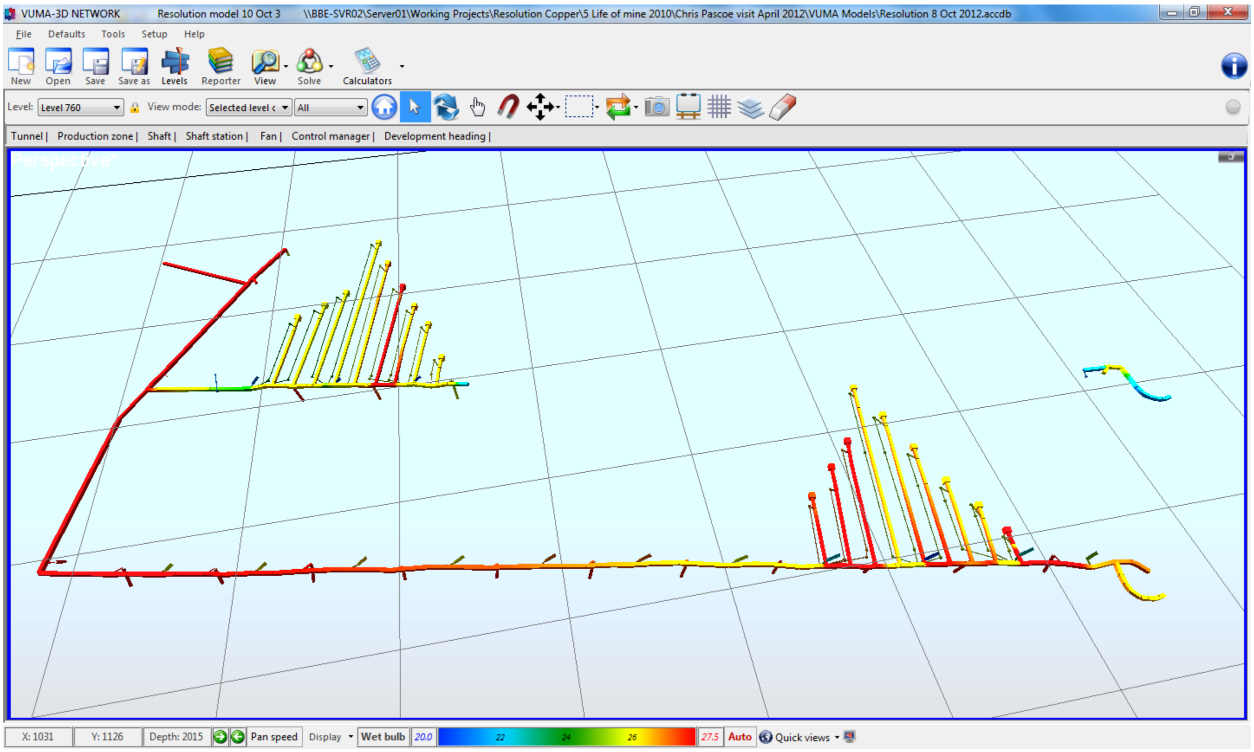


Figure 4.9 760 Undercut level temperature plot [blue on temperature scale = 20 °Cwb; red = 27.5 °Cwb]

Return raises [3 m] from each Undercut level to the Exhaust ventilation level will be established in both rim tunnels at every 120 m [every 4 undercut crosscuts but offset 60 m (2 crosscuts) from the intake raises]. The rate of crosscut development and the angle of the caving 'shadow' will dictate the number of return air raises that will be open at any one time. Regulators will be installed in each ventilation raise for control purposes [from a Central Control facility]. These return ventilation raises will be established down from the Undercut levels bypassing the Production level to the Exhaust ventilation level and connect to the return system along the rim tunnels.

The rim tunnels will be pre-developed and the undercut shadow will retreat back towards the main spine infrastructure. The crosscut headings will be force-ventilated from the rim tunnel with variable speed fans and 1.3 m diameter lay-flat duct systems. The ducts will be carried up to the swell zone and this air will then flow back in the rim tunnel where it will be picked-up and re-used by further force duct systems in the adjacent crosscuts until reporting to the nearest return raise. The crosscut developments will also be ventilated with a fan duct system delivering air to the furthest developing crosscut, the air will then flow back in the rim tunnel where it will be picked-up and re-used by further force duct systems in the adjacent developing crosscuts until reporting to the nearest return raise. At any one cross-section, the rim tunnels must be capable of carrying at least 2 off 1.3 m ducts [excavation size of 25 m²].

It is proposed that variable-speed fans are used in order to selectively control the ventilation distribution to suit the presence of the diesel LHDs and other activities. The control system will be integrated with the monitoring system and, through a Central Control system, feedback-control of conditions in each crosscut and development heading will be possible.

The total number of auxiliary fans [in main ducts] in operation on each Undercut level will be approximately 15 units. Typically, the fans will be rated at 75 kW at full speed.

The following main activities and zones are applied in the modelling, Table 4.5:

740 Undercut level

Undercut headings [retreating and mucking swell]

11 off retreating and mucking swell using 2 diesel LHDs
Broken rock and surrounding rock heat
Other heat: aux vehicles, aux fans, dill rigs, lights

Undercut development and rim tunnel development headings

5 off in u/c development + 2 off in rim tunnel development using 2 diesel LHD
Broken rock and surrounding rock heat
Other heat: aux vehicles, aux fans, dill rigs, lights

760 Undercut level

Undercut headings [retreating and mucking swell

11 off retreating and mucking swell using 2 diesel LHDs
Broken rock and surrounding rock heat
Other heat: aux vehicles, aux fans, dill rigs, lights

Undercut development and rim tunnel development headings

5 off in u/c development + 2 off in rim tunnel development using 2 diesel LHD
Broken rock and surrounding rock heat
Other heat: aux vehicles, aux fans, dill rigs, lights

Table 4.5 Summary of Active Crosscuts and Headings in Undercut Levels and LHD Deployment

740 Undercut level	no.	LHDs
Number of headings in undercut retreat [mucking swell]	11	2 diesel
Number of headings in undercut excavation development Number of headings in undercut level rim tunnel development	5 2	2 diesel
760 Undercut level		
Number of headings in undercut retreat [mucking swell]	11	2 diesel
Number of headings in undercut excavation development Number of headings in undercut level rim tunnel development	5 2	2 diesel

The Undercut levels were examined in particular detail and stand-alone VUMA models were developed, see Figure 4.9. In the modelling, provision was made for dead-end swell mucking [500 t/d], rim tunnel and cross-cut development and cubbies for swell muck dump every 200 m.

The total ventilation allocation to the Undercut levels will be 550 kg/s, of this the major portion will be for dead-end swell mucking. The heat loads per Undercut level are similar and are of the following order:

- Broken and standing rock 3.7 MW
- Diesel background heat 1.1 MW
- Diesel LHDs 0.5 MW

Note, that the heat from blasting will be inconsequential.

As noted, secondary air coolers will be located on Intake level at the raises and air will generally be available at about 23°Cwb.

4.4.2 Production Level

The fully active production crosscuts and those under draw-point construction will be through-ventilated. Intake raises [3 m] to the Production level will be established every 120 m into the intake rim tunnels [both north and south]. Ventilation will flow in the production crosscuts to return raises [2 m] in each crosscut located at the centre of the panel [150 m from either rim]. Thus each production crosscut will have its own regulated return raise connecting down to the Return vent level. In addition, there will also be an ore pass located in each cross-cut at the centre of the panel. Typically a pair of production crosscuts will have 24 kg/s of ventilation.

The rim tunnels will be pre-developed and the production section will retreat back towards the main infrastructure. The crosscut developing headings will be force-ventilated from the rim tunnels with variable speed fans and 1.3 m diameter lay-flat duct systems. Fan duct systems will deliver air to the furthest developing crosscut, the air will then flow back in the rim tunnel where it will be picked-up and re-used by further force duct systems in the adjacent developing crosscuts until reporting to the nearest return raise. At any one cross-section, the rim tunnels must be capable of carrying at least 2 off 1.3 m ducts and an excavation size of 25 m² has been assumed.

Once steady production has been achieved, there will be up to 70 off open, 150 m long production crosscuts [single production crosscut is defined as extending from the rim tunnel (north or south) to the return raise/orepass at the centre of the panel]. Of these, it has been assumed that 35 production crosscuts will be active [35 electric loaders will be available for mucking] and 35 production crosscuts will be available for operation. The air flow required for dust and heat dilution has been determined as 12 kg/s per production crosscut whether loader is present or not. The air will be distributed to open production cross-cuts by regulators in the return raises, controlled from the central control station. This is a relatively low air allocation and the ventilation distribution will present a challenge in terms of equal distribution and leakage and this subset of the VUMA model was scrutinized in some detail, Figure 4.10. This 'per production crosscut' allocation alone gives a total ventilation commitment of 840 kg/s [12x70]. However, on the Production level there will be additional ventilation in terms of that being used for rim tunnel development, extraction drive development, construction work and leakage.

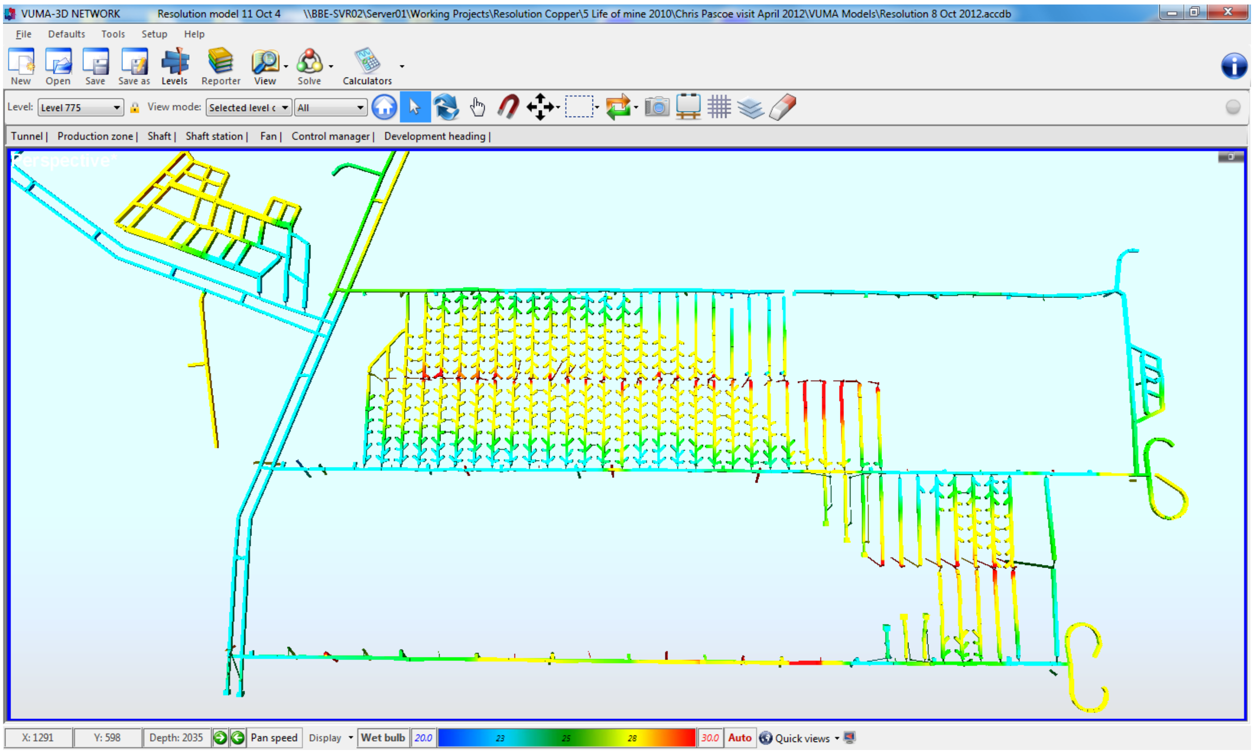


Figure 4.10 Production level temperatures [blue on temperature scale = 20°Cwb; red = 30°Cwb]

As noted, secondary air coolers will be located on Intake level at the raises and air will generally be available at about 23°Cwb.

The potential for high dry-bulb temperatures will be most prevalent on the Production level. The ventilation and heat simulations assume that liberal amounts of water will be used at draw-points and ore passes primary for controlling temperature but this application will assist with dust suppression. The modelling indicates that, with reasonable amounts of moisture, the dry-bulb temperatures can be practically kept below 35°Cdb [without water sprays this could exceed 42°Cdb]. Recall the service water flow to serve this function [amongst others] was set at 150 l/s.

The following main activities and zones are applied in the modelling, Table 4.6:

Production extraction level

Production-crosscut zone

70 off active 150 m production crosscuts using 35 electric LHDs
Broken rock and surrounding rock heat
Other heat: aux vehicles, dill rigs, lights

Production-crosscuts in draw-pt construction

2 off crosscuts with through flow vent using 2 diesel LHDs
Broken rock and surrounding rock heat
Other heat: aux vehicles, dill rigs, lights

Production-crosscut development and rim tunnel development headings

1 off in crosscut development, 2 off in rim tunnel development using 1 diesel LHD
Broken rock and surrounding rock heat
Other heat: aux vehicles, aux fans, dust sprays, raise-bore rigs, dill rigs, lights

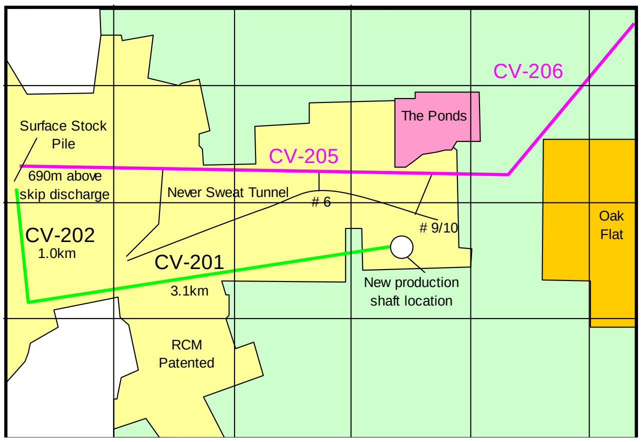
Table 4.6 Summary of Active Crosscuts and Headings in Mining Block and LHD Deployment

Production extraction level	No	LHDs
Number of full active 150 m production crosscuts	70	35 elec
Number of production crosscuts in construction [draw-pt preparation]	2	2 diesel
Number of headings in production crosscut development	1	1 diesel
Number of headings in production level rim tunnel development	2	

4.5 Ventilation of Conveyor Drift and Skip Discharge Level

The conveyor drift will be developed from surface to connect with the Skip Discharge level at elevation 1010 m below collar level and 1170 m above the loading horizon, Figure 4.11.

The conveyor drift will be in two sections [CV-201 and CV-202] and will be about 4.1 km long with a nominal 6.2 m x 5.5m excavation profile. Belt details are given in Table 4.7 using power consumption values at 7800 t/h [132 kt/d for 17 hr per day] effective rate.



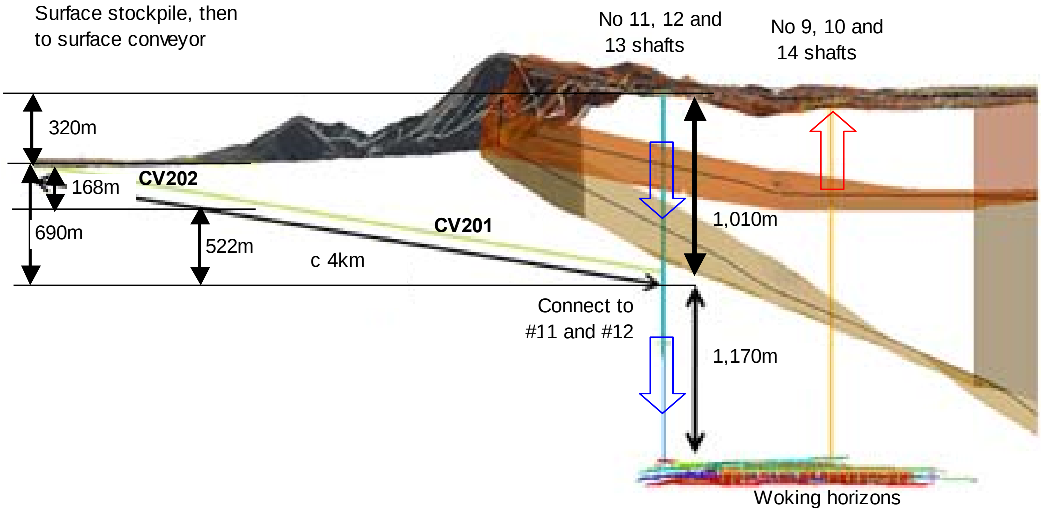


Table 4.7 Conveyor Tunnel Belt Details [6600 tph]

Conv Number	Length m	Lift m	Belting	Drives kW	Number	Total Nameplate kW	Consumed Power kW	Useful Work kW	Potential Heat kW	Potential Heat kw/km
CV-201	3132	522	ST-7800	2500	6	15000	12750	9388	3362	1073
CV-202	996	168	ST-4500	2500	2	5000	3988	3021	967	970
	4128	690				20000	16738	12410	4328	

The heat load from belt drives and roller friction will be about 4.3 MW [estimate], which relates to a linear dry heat source of the order of 1 kW per m. But note this is for the peak rate of 7800 t/h, the overall average will be lower and pro-rata with average production of 120 kt/d.

The heat load from the flow of broken rock is discussed in Appendix C and Section 6. The residence time of rock in this conveyor drift will be about 12 mins [assuming 6 m/s] and, subject to operational experience, it is assumed that the heat load from the broken rock will be about 4.0 MW.

[Two issues complicate this calculation. Firstly, the air entering the conveyor drift will be cooler than that on the haulage horizon and, secondly, it will be flowing in the same direction as the conveyor with lower convective heat transfer and reduced temperature differential with distance. The reduced convection will reduce heat transfer from broken rock in which case the 4.0 MW planning value may be overestimated].

In addition to the connections to No.11 and No.12 hoisting shafts, there will also be an access connection to No.13 Shaft and a return connection to No.14 Shaft. This return connection will be an important part of the ventilation system as it will control the dust discharge at the skip discharge location[s] and 180 kg/s of intake air will be used for this purpose. The dust capture return to No.14 Shaft will also carry heat from broken rock estimated at about 2 MW, Addendum C. Further details of dust management on the Skip Discharge level are provided in Section 0.

The total heat load in the Conveyor Drift will include the above primary sources [4.3 and 4.0 MW] as well as other secondary heat sources due to surrounding rock, lights, cabling, access vehicles and secondary machinery. This heat load will be absorbed by the cold air flow from Skip Discharge level and by the bulk air cooler installed in the Conveyor Drift. The cold air from surface will enter the conveyor system at about 16°Cwb and the air flow of 160 kg/s will have a cooling capacity of 7.5 MW [in heating up to 27.5°Cwb]. This cooling from the primary ventilation will be supplemented by the bulk air cooler of 2.0 MW duty, Section 8.5. The above are estimated requirements based on reasonable assumptions. However it is suggested that, once production starts during the ramp up period, the actual heat loads are measured, and balance of chilled ventilation versus additional refrigeration to the drift optimized. Note the need for additional cooling will increase if larger drives were to be installed for higher production rates.

[The benefits of a separate closed-circuit water system [non-refrigerated] to directly cool the belt drives and couplings [with the heat being rejected on surface] were considered. This system would be an integral part of the conveyor system design and will have cooling benefits that should be evaluated as an optimisation exercise at the next feasibility level of detail. The above approach adopted for this prefeasibility study is conservative].

Thus, to minimise heat and dust contamination of intake air, together with smoke in the event of a fire, the design intent is for the Conveyor Drift to be an exhaust airway using 160kg/s of chilled intake air entering via No.11, 12 and 13 Shafts. The most robust method of exhausting the drift will be with surface fans, either on a raise bore shaft connected to the drift or at the West Plant portal. The raise bore shaft option will reduce duct lengths during the development phase and will also promote bi-directional flow in the tunnel for reduced air temperatures. Thus the base-case will be to install a 5 m exhaust raise near the transfer point of CV201 to CV202 [note that 4 m raise would be sufficient for ventilation, but the planning includes 5 m raise which might also be used for material access]. The recommended ventilation and cooling strategy is as follows, Figure 4.12:

- Provide a ventilation capacity of about 220 kg/s comprising 160 kg/s cold air from Skip Discharge level and 60 kg/s from the West Plant portal.
- Establish an exhaust shaft [5 m] near the transfer point between CV201 and CV202 [this will also reduce the development phase duct lengths, Addendum D].
- Install fan station on surface at exhaust shaft [Section 7] with two operational fans [plus one standby] each providing the duty of 110 kg/s with 200 kW drives.
- Install bulk air cooler [2.0 MW duty] in Conveyor drift at 1.3 km from Skip Discharge horizon [Section 8.5] and supply chilled water to the air cooler from the surface refrigeration facility.

To avoid excessive flow into the conveyor drive from the West plant via CV202, a regulator will be required at the portal. This could take the form of conventional belt seals [conveyor belt 'coffin' seals] but, for the present purposes, the use of surface bins at the portal are proposed. The purpose of the use of surge bins is two-fold. Firstly, this will provide a pressure break that will manage the proposed production rate without excessive leakage and blow-back of fines. Secondly, this will introduce a degree of surge capacity in the rock clearance system. For example, at a production rate of 120 kt/d, a 20 m diameter and 10 m high bin would provide a surge capacity of about 1 hour.

4.5.1 West Plant to Mill Tunnel

The West Plant to Mill tunnel will be developed using a connection to No.9 and No.10 Shaft on the Never Sweat level. It is then the intention to use this connection as a permanent exhaust point for life-of-mine production. For this purpose, a provision of 150 kg/s has been made in surface fan capacity but this is subject to final designs becoming available. The alternative, not proposed at this stage, will be to provide a dedicated exhaust shaft[s] for the tunnel where surface access permits in order to offload the main exhaust shafts.

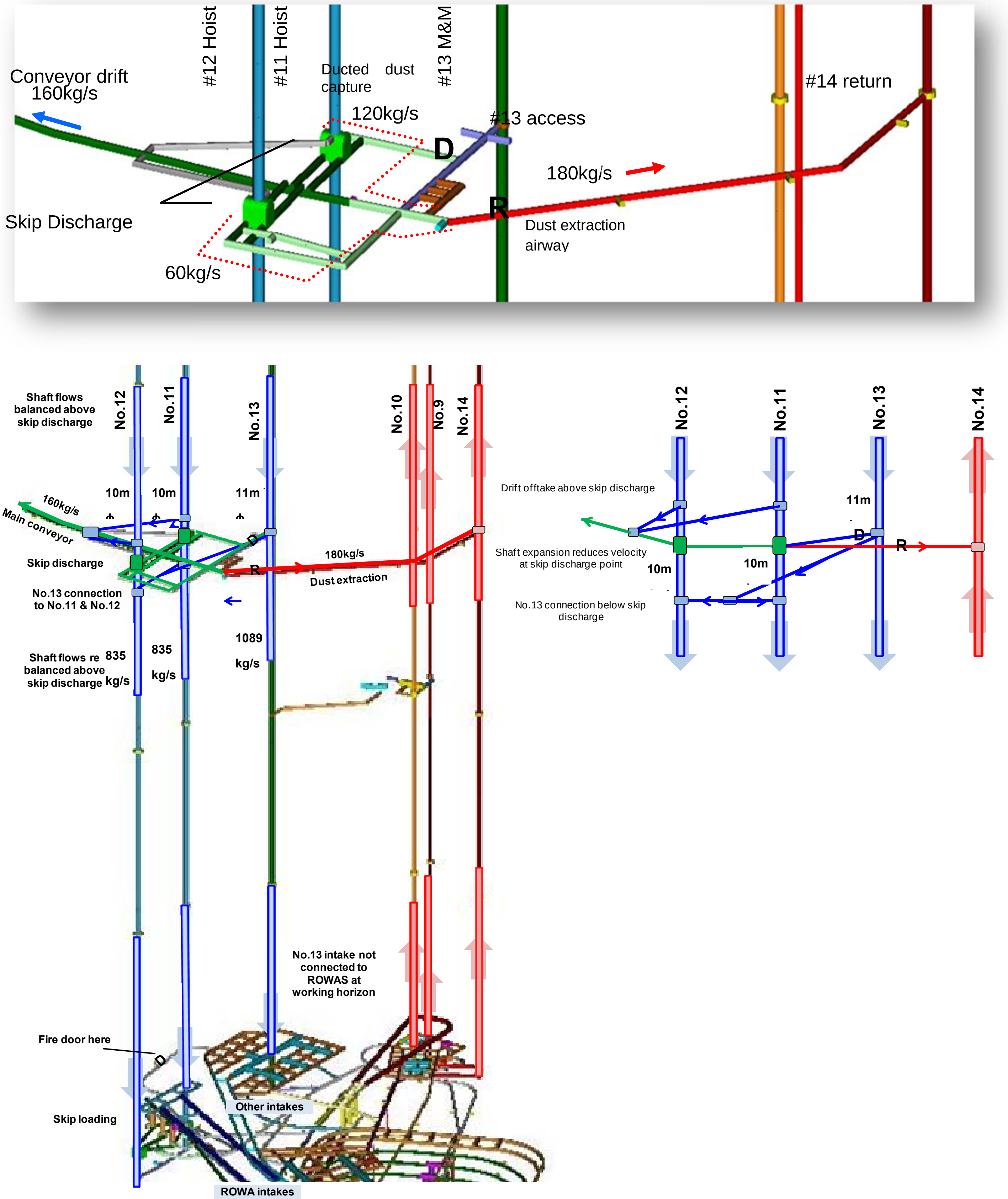


Figure 4.12 Skip Discharge and Surface Conveyors

4.6 Ventilation of Underground Ore Handling System

The sub-system related to the underground conveyor ramp is an important feature of the overall design. The crusher station and rock handling systems will generate significant heat and dust loads and these facilities will be located such that they can be encompassed in this sub-system. There are benefits in isolating this sub-system in its own ventilation district thus ensuring that these heat and dust loads are prevented from entering the main mine workings. This isolation strategy is also sound fire engineering practice. It is proposed to ventilate this sub-system directly to return, Figure 4.13. The overall allocation of ventilation is given in Table 4.8. Further details concerning dust management at various points in his sub system are provided in Section 5.

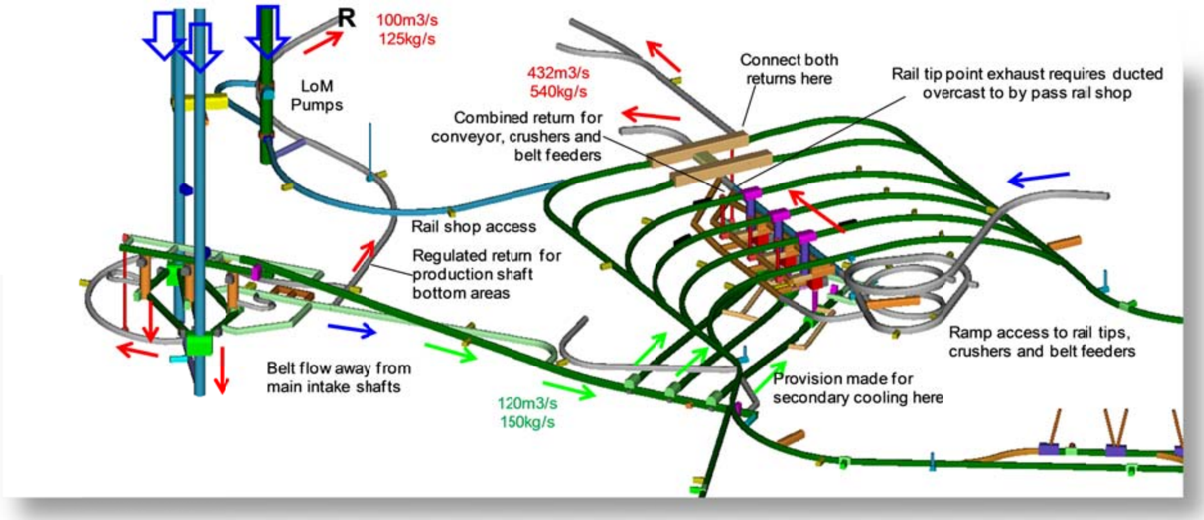


Figure 4.13 Underground Ore Stream Ventilation Distribution

Table 4.8 Below Skip Discharge Ore Stream Ventilation Allocation

Location	Each kg/s	Each m3/s	No	Total kg/s	Total m3/s
Rail (active chutes)	30	24	4	120	96
Rail tips	25	20	3	75	60
Crusher feed level	25	20	3	75	60
Crusher discharge points	25	20	3	75	60
Conveyor feeders	20	16	3	60	48
Conveyor transfer points	15	12	3	45	36
No.11,12,13 shaft bottom	125	100	1	125	100
	Total allocation underground			575	460

4.7 Intake and Exhaust Level Ventilation Circuits

The intake and exhaust level geometry is shown in Figure 4.14 and Figure 4.15 respectively. Note that the rail level main intake point is from below the primary intake level. Using the standard raise diameters, the number of open raises required are determined for acceptable pressure loss [150 Pa at 10 m/s] and, in extraction locations, acceptable distributional control.

The overall operating strategy will be to modify the resistance of raise connections with regulators between the relatively low resistance intake and return levels i.e. controlled parallel paths. In this respect, it will be necessary to balance the differential pressure between the undercut and extraction levels so as to control the magnitude and direction of leakage flows through the pile. The ideal situation would be a near neutral pressure differential but with slight leakage from extraction level through the pile to undercut level returns.

4.8 Rail Level Ventilation Circuit

There will be up to 2 active rail loops at any one time, each allocated 125 kg/s [100 m^3/s], the main ventilation issue will be the control and containment of dust emission from chutes. The proposed rail loop level ventilation circuit is shown in Figure 4.16 and comprises;

- Key issue on the rail level will be that of dust management and this is also discussed in Section 0.
- Level intakes from No.13 Shaft through the rail shop.
- Additional intake balancing raises from the primary Intake level at the start and furthest chute. These provide for control of intake ventilation distribution and provide a source of air uncontaminated by dust from loaded rail cars. Note that the Intake level does not align with the rail loops and therefore cross cuts will be required for additional intake raises.
- Exhaust raises at about 300 to 400 m spacing with actuated regulators which will automatically focus exhaust capacity to loading areas. The first raise will be required for the development phase, with subsequent raises used to control the distribution of contaminated air from rail loading locations i.e. whilst provision will be made to capture and suppress dust at loading chutes, it is likely that there will be dust contamination of air on the return side. The backup strategy provided by this circuit is therefore one of containment.

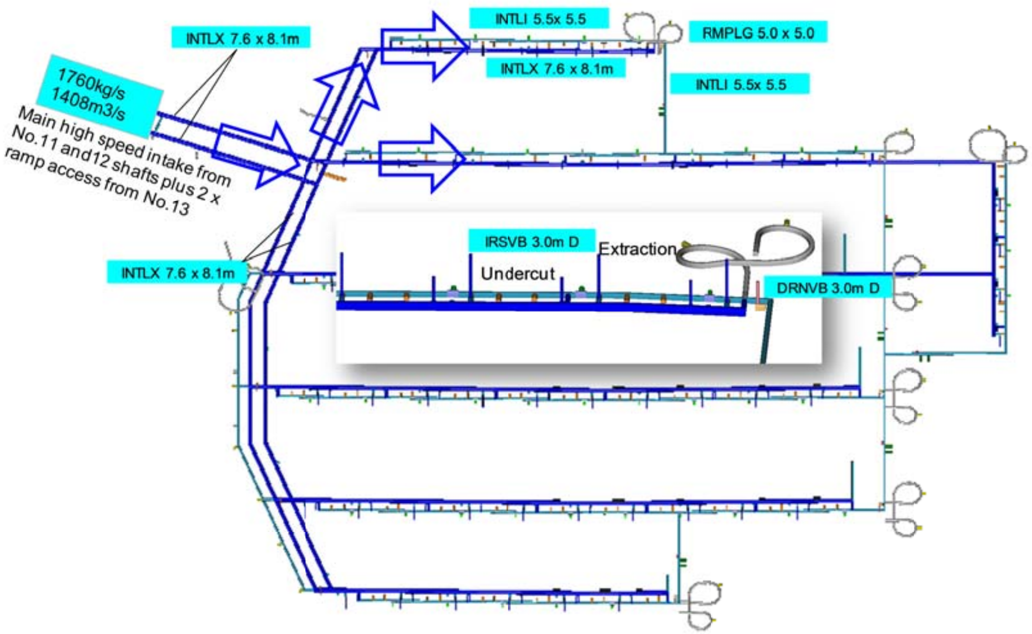


Figure 4.14 Intake Level Ventilation Circuit

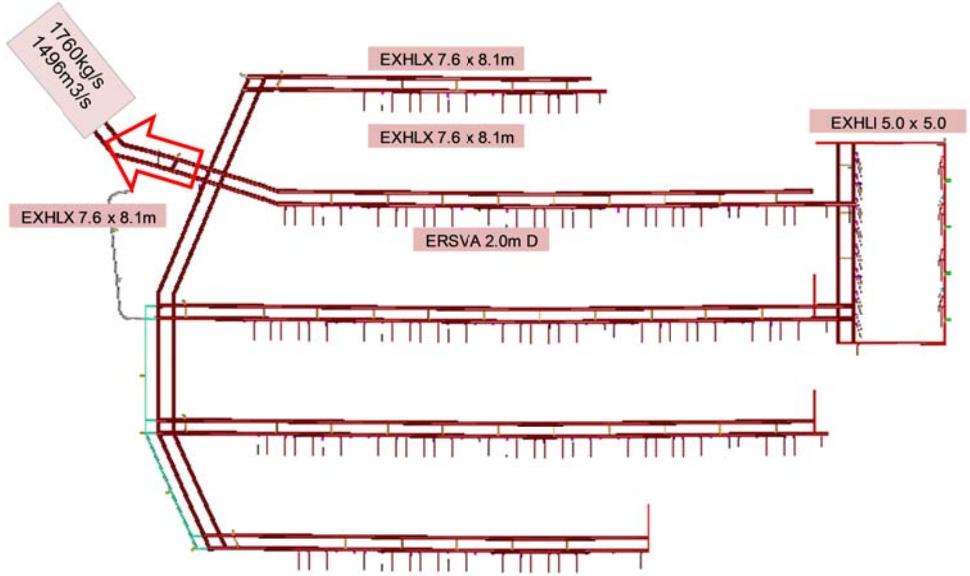


Figure 4.15 Exhaust Level Ventilation Circuit

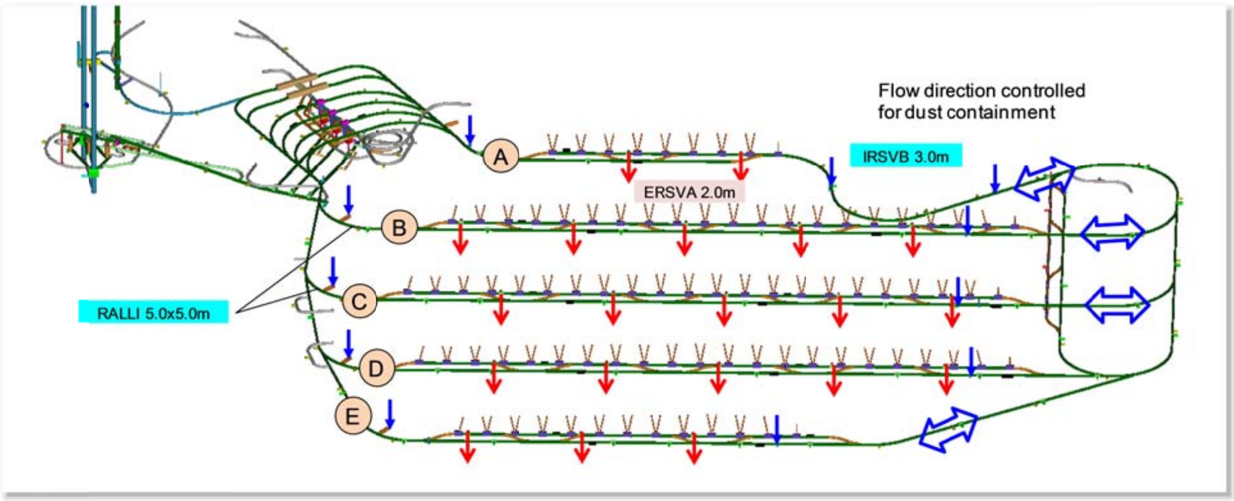


Figure 4.16 Rail Loop Level Ventilation Circuit [not all at same time]

4.9 Exhaust System and Surface Fan Stations

Return ventilation from the mining block will join with return air from the ore handling system and flow in the main return system to the upcast shafts.

Underground return airways should operate at or about limiting air velocities for occasional vehicle or pedestrian access but could be increased further if, for example, the regulated ore system return were to be used for access with the remaining returns operating at higher velocity [>9m/s].

The main fan stations will be installed on surface and will operate in exhaust mode drawing ventilation through the mine in a conventional manner. To allow for phased increase in ventilation capacity [from the first use of No.9 Shaft in Phase V.3], available surface space during sinking and longer term security of production, the proposed plan is to connect all exhaust shafts together in a manifold configuration i.e. all fans connected to all shafts.

The summary of fan operating duties for five installed fans, with one of them as spare, is provided in Table 4.9 with conceptual fan curves in Figure 4.17.

Table 4.9 Surface Fan Duty Points

Phase	Total kg/s	Total m3/s	Fan Static kPa	Fan Power MW	No Fans Installed	No Fans Running	Per fan kg/s	Per fan m3/s	Per fan MW
V.3	241	231	-3.8	1.2	2	1	241	231	1.2
V.4	207	198	-2.3	0.6	2	1	207	198	0.6
V.5	512	490	-3.3	2.2	2	1	512	490	2.2
V.6	515	493	-2.3	1.5	2	1	515	493	1.5
V.7	715	685	-4.1	3.7	2	1	715	685	3.7
V.8	1975	1891	-2.6	6.6	3	2	988	946	3.3
V.9	2035	1949	-2.6	6.8	4	3	678	650	2.3
V.10	2140	2049	-3.6	9.9	5	4	535	512	2.5
V.11	3110	2978	-4.7	18.8	5	4	778	745	4.7

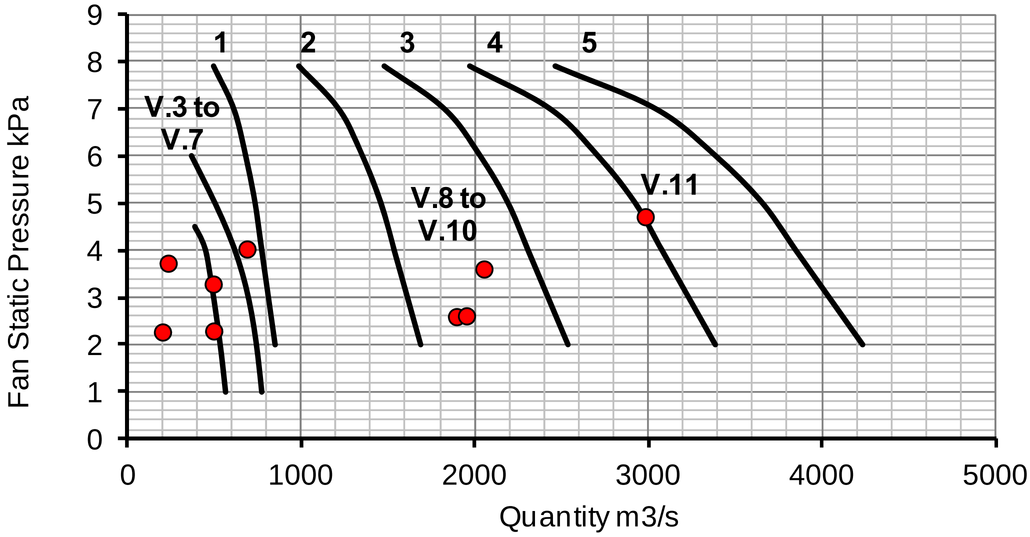
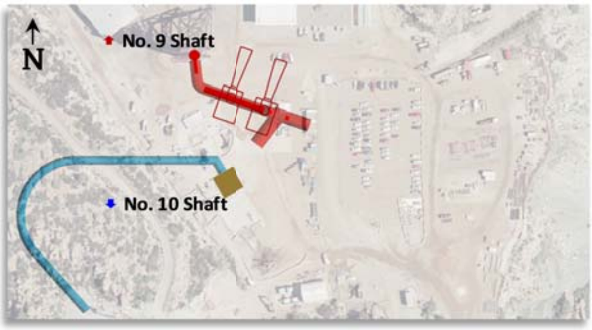


Figure 4.17 Surface Fan Nominal Duty Points and Conceptual Characteristic Curves

Note that fan pressures shown above are nominal and subject to final shaft furnishing designs, installation schedules, network simulation results and provision for shaft bends and surface drift. Further surface fan station engineering details are provided in Section 7. The actual fan equipment selection pressure duty is taken as 5.5 kPa and, typically, for the base-case scenario of four operational units and one standby, the fan motor sets will be 6.0 MW rated units.

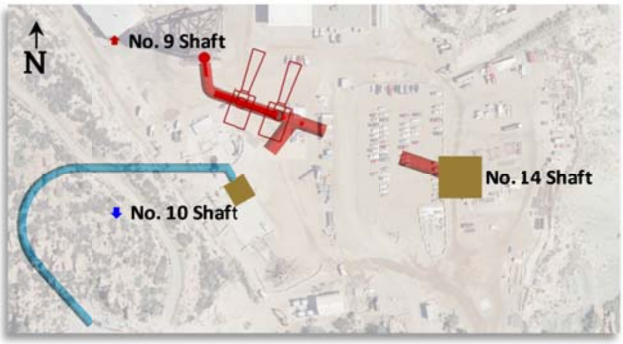
With consideration to the shaft sinking schedule and ventilation requirements during the development phase of the project, the conceptual fan installation sequence is summarised in Figure 4.18 as follows;

- Fans 1 and 2 first to upcast No.9 Shaft [1 on and 1 spare] regime V.3
- Fan 3 when No.14 Shaft complete and head frame removed [2 on and 1 spare] regimes V.7
- Fan 4 when No.10 Shaft complete and head frame removed [3 on and 1 spare] regimes V.9.
- Fan 5 for full production in regime V.10

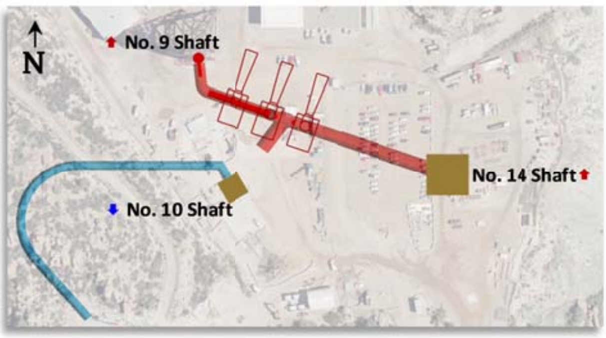


V.3 Feb 2016 1st & 2nd fan stations
To be ready when equipping #9 complete

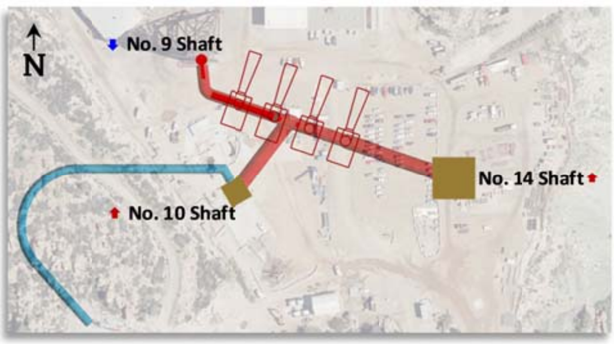
Requires removal of 6ft of #9 collar concrete & installation of hood.



#14 manifold stub
To be excavated during #14 pre-sink

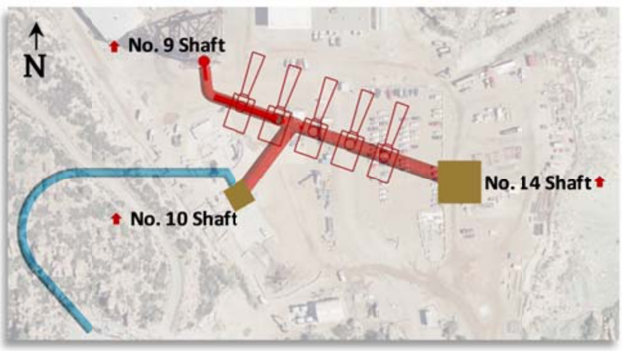


V.7 Jan 2020 3rd fan station
To be ready after stripping #14 complete



V.9 Oct 2022 4th fan station
To be ready after stripping #10 complete

Requires break-in to #10 collar concrete



V.10 Jul 2023 5th fan station
To be ready after stripping #9 complete

Requires hood removed & break-in to #9 collar concrete (integrity of headframe foundation will be compromised)

Figure 4.18 Exhaust Shaft and Surface Fan Installation Sequence

4.9.1 Fan Station Water Management

With respect to water management, all shafts will be maintained at or above 12 m/s during the various phases even if this requires some underground regulation e.g. No.9 Shaft in Phase V6. This means that water droplets will be carried up the shaft to collars and manifold take off points.

The design intent is for the majority of entrained water droplets to be carried through the fans and discharged to atmosphere. However, with all manifold take-offs will be graded down to a central point [at or about the mid connection point], any fallout can be directed to a sump pump for clearance to surface. The simplest approach would be a submersible sump pump[s] that can be retrieved from surface for maintenance.

5 DUST MANAGEMENT

The management of respirable dust in this project is considered to be of high importance due to the presence of significant silica fraction in the ore body and host rocks, Addendum H. Due to depth of workings, provision has not been made for additional exhaust raises to surface dedicated to dust extraction. Therefore all dust will have to be suppressed, captured or report to a return airway.

It is the main objective of the proposed dust management strategy to avoid, as far as practicable, the use of dust filtration [bag filters or scrubbers] to manage respirable dust concentrations in working areas. The main strategy will be to duct or direct contaminated air to return airways for which significant ventilation capacity has been allocated, Table 5.1.

Table 5.1 Ventilation Allocation to Dust Management

Location	Each kg/s	Each m3/s	No	Total kg/s	Total m3/s
Rail (active chutes)	30	24	4	120	96
Rail tips	25	20	3	75	60
Crusher feed level	25	20	3	75	60
Crusher discharge points	25	20	3	75	60
Conveyor feeders	20	16	3	60	48
Conveyor transfer points	15	12	3	45	36
No.11,12,13 shaft bottom	125	100	1	125	100
	Total allocation underground			575	460
Skip discharge (per 3 skips)	40	36	3	120	108
Feeders from skip bin	15	13.5	4	60	54
				180	162
	Total allocation to dust management			755	622

With respect to control of respirable dust in general, the following assumptions are made;

- Provision will be made for industry standard/best practice dust controls, Figure 5.1:
    - Normal mining controls such as wet drilling and wetting broken rock, signs and correct PPE.
    - Water suppression sprays installed in all roadways for routine and controlled wetting.
    - Application of water to maintain at least 2% moisture in ore stream. If 5% can be achieved, this will require 70 l/s total say for dust suppression in the ore stream [note that provision has been made for 150 l/s of chilled service water].
    - Road base maintenance and dust suppression.
    - Dedicated exhaust ventilation systems for crushers and transfer points. Capture velocities of 2.5 m/s will be employed with ventilation needs subject to final designs being available.
    - Remote loading of extraction level with operator location on the intake side.
    - Limited access to return airways.
- Overall system geometry will be configured, as far as possible, to avoid the need for filtration and re-use of previously contaminated air. However, there may be the need for some filtration in locations remote from return airways e.g. transfer points to main conveyor from the three secondary conveyors.
- Employees will be trained in the control of exposure to respirable dust, including PPE.
- Employees will undergo a pre-employment medical with ongoing medical surveillance, including respiratory system and lung function by a suitably qualified medical professional.

- Respirable dust sampling [e.g. personal by task and area gravimetric] regime will be set-up in order to monitor employee exposure to respirable dust. Dust samples will be analysed for composition, including respirable free silica in its various forms.
- Mine to adhere to Rio Tinto occupational health and safety standards of a limit [8 hr day, 40 hr week] of 5 mg/m^3 for general respirable dust [not coal] and 0.1 mg/m^3 for respirable crystalline silica.

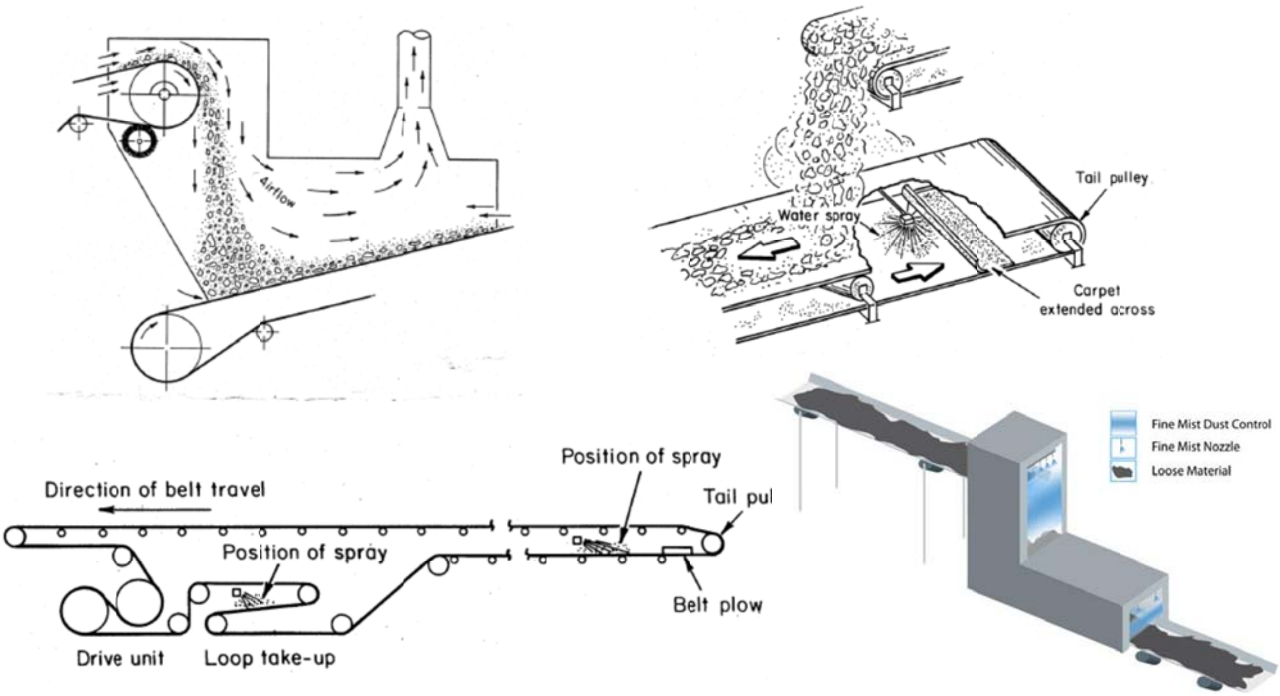


Figure 5.1 Standard Capture and Suppression Methods

5.1 Extraction Level Loader Transport and Tipping

Dust management at loading and tipping points will be managed as follows;

- All development – wet rock prior to load, exhaust raise and dust suppression sprays at ore pass.
- Extraction level production – water suppression at active draw points, tele-remote controlled electric loaders, exhaust raise at central ore pass.
- Road base maintenance with dust suppression sprays installed at appropriate intervals [about 50 m].

Even though the design intent is to operate remote controlled electric loaders on the extraction level, provision for dust suppression needs to be made for visibility issues and to start the ore wetting process.

5.2 Rail Loading Level

Loading of rail cars from chutes can be problematic in terms of dust management because:

- Rock falls from height
- Large volumes of water cannot be applied to the material in the ore pass itself
- Operators need to have line of sight to the chute doors in order to manage various size fractions and to avoid blockages. This aspect may be reduced by improved automation in this project.
- Unlike surface rail loading stations, there will be numerous loading locations each requiring appropriate dust management.
- Overly complex ducted systems are prone to failure in the long term.

- Air velocities required for heat management will reduce effectiveness of sprays used to contain dust.

The proposed strategy is as follows, Figure 5.2 and Figure 5.3;

- Recognise that no dust capture system from chute loading will be totally effective. Therefore employ a ventilation circuit that contains contaminated air to a limited section on the return side of chutes and in which workers will not be located. Consideration should also be given to operators in enclosed filtered cabs with cameras to assist loading.
- Provide 100 m^3/s to each rail tunnel [2.0 m/s for each airway and maximum two operating at once].
- Minimise the fall height and use angled “spoon” feeders or similar to reduce impact velocities.
- Apply actuated dust suppression sprays to wet material as it is released from the chute.
- Additional line of dust suppression sprays to periodically damp surfaces on the return side.
- Consider use of a final foam spray to wet the upper surface of the loaded car.
- Duct extraction hoods [25 m^3/s] from each chute location reporting to exhaust raises at 240 m to 300 m spacing. The final spacing and duct diameter [which will be about 1.0 m] needs to be reviewed for actual train lengths and loading cycles.

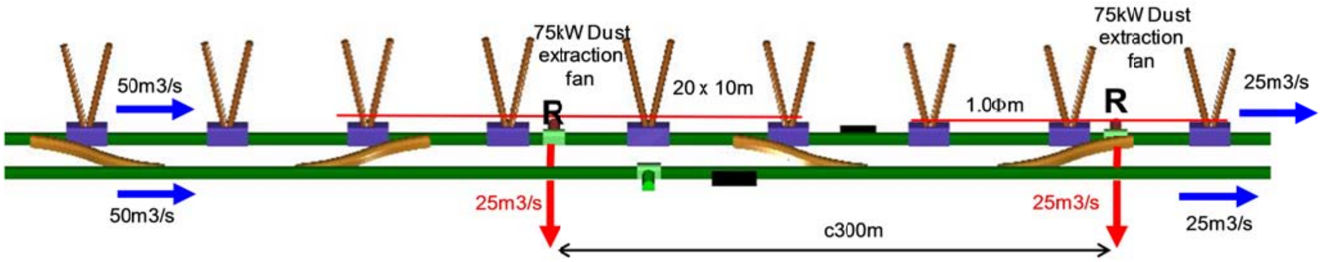


Figure 5.2 Rail Level Ventilation and Dust Management

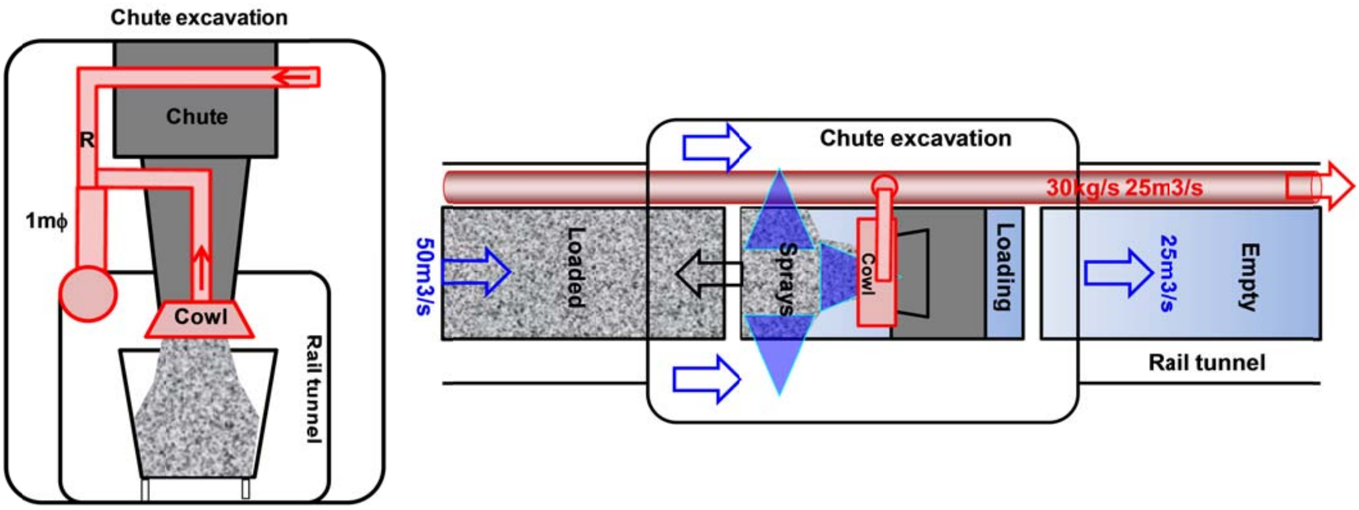


Figure 5.3 Conceptual Chute Loading Dust Management

5.3 Rail Tip to Belt Feeders

Dust control systems in the rail through crushers to belt feed system is summarised in Figure 5.4. All ventilation rates are nominal and based on assumed dimensions of openings. These must be reviewed when final designs become available for an appropriate capture velocity.

5.3.1 Rail Tipping Level

Dust management at the three rail level tipping points will be:

- Draw down through the ore pass collar beneath the tipping rail car [30 kg/s (24 m^3/s) each].
- Captured dust will then be transported to the regulated return discharge point at the rail shop. This could involve an overcast system to facilitate mobile vehicle access or a bypass raise bore as shown.

5.3.2 Crusher Level

Dust management at the three crusher level points will be as follows:

- Draw across feeders [crushers are not to choke fed] will be 30 kg/s (24 m^3/s) each.
- Draw down through the crushers will be 30 kg/s (24 m^3/s) each i.e. total 60 kg/s [48 m^3/s] per crusher.
- Captured dust will then be transported to the regulated return discharge point where it will combine with return air from the belt feeder level return air raises.

Intake ventilation to the crushers will be provided by the access ramp. Final modelling may indicate the need for a supplementary intake raise depending on the intake level split above.

5.3.3 Transfer Conveyor Feeders

Dust management at the three conveyor feeder and three transfer points will be;

- Hooded capture at feeder and transfer points with dust suppression sprays [20 kg/s (16m^3/s) each].
- Additional ventilation will be provided by the main conveyor return including secondary cooling.
- Captured dust will then be transported to the return discharge point where it will combine with the main conveyor return and report to the crusher level return.

Note, a door with regulated opening will most likely be required at the bottom of the access ramp in order to control the distribution of ventilation through the conveyor system [it would otherwise short circuit].

Note, with good enclosure of transfer points, there will be opportunity to reduce ventilation rates.

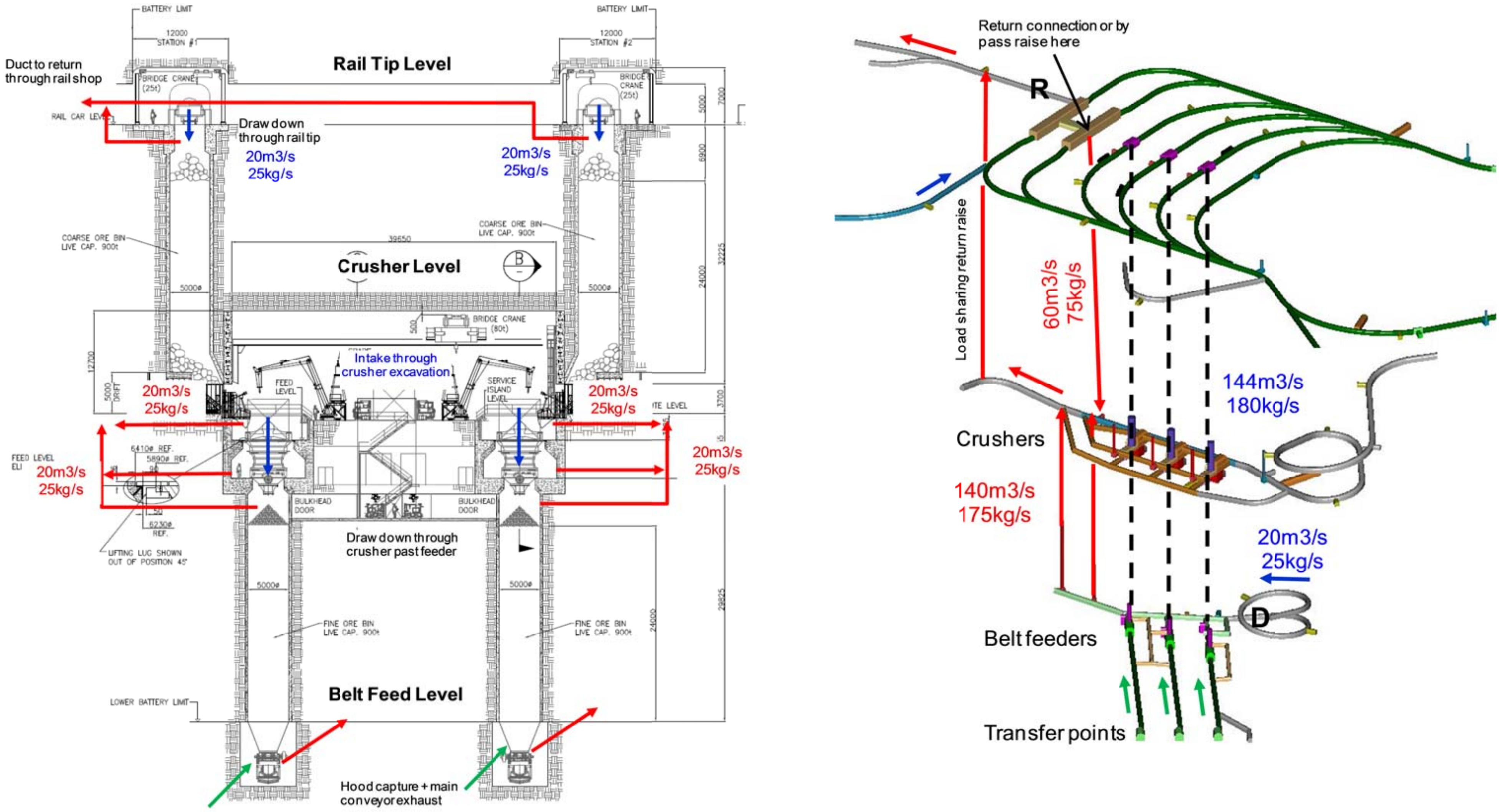


Figure 5.4 Rail Tip Crusher and Belt Feeders

5.4 Skip Loading

The shaft bottom and skip loading areas are shown in Figure 5.7 and the dust management will be:

- Draw down of shaft air to the lower exhaust level past skip loading points.
- Tilt belt and main conveyor transfer point to return via raise.
- Bins to measuring flask transfer belts to return via raise.

Provision has been made for a total 125 kg/s [100 m^3/s] for these areas.

5.5 Skip Discharge

Dust management at the mid shaft skip discharge points for No.11 and No.12 Shafts [Figure 5.8] will include the following:

- Ventilation deflector plates above the discharge point to minimise air turbulence entraining dust into the main intake shafts.
- Exhaust duct system [55 kg/s (54 m^3/s) per 3 skip bin and belt feeder] with actuated dampers to direct flow to the skip[s] being discharged. It is assumed that up to three skips will be discharging at any one time for a total 180 kg/s [although system can provide for 240 kg/s for short periods as required].
- Captured dust will be ducted to the return point to No.14 Shaft.
- Actuated dust suppression sprays to wet rock as it is being tipped.

A number of scenarios of the skip discharge configuration were examined in VUMA. These included variations in the cross-sectional area of the skip dump bypass excavations to reduce shaft velocities in the skip discharge section of No.11 and No.12 Shafts. Figure 5.5 shows the flow distribution with the originally proposed excavation dimensions.

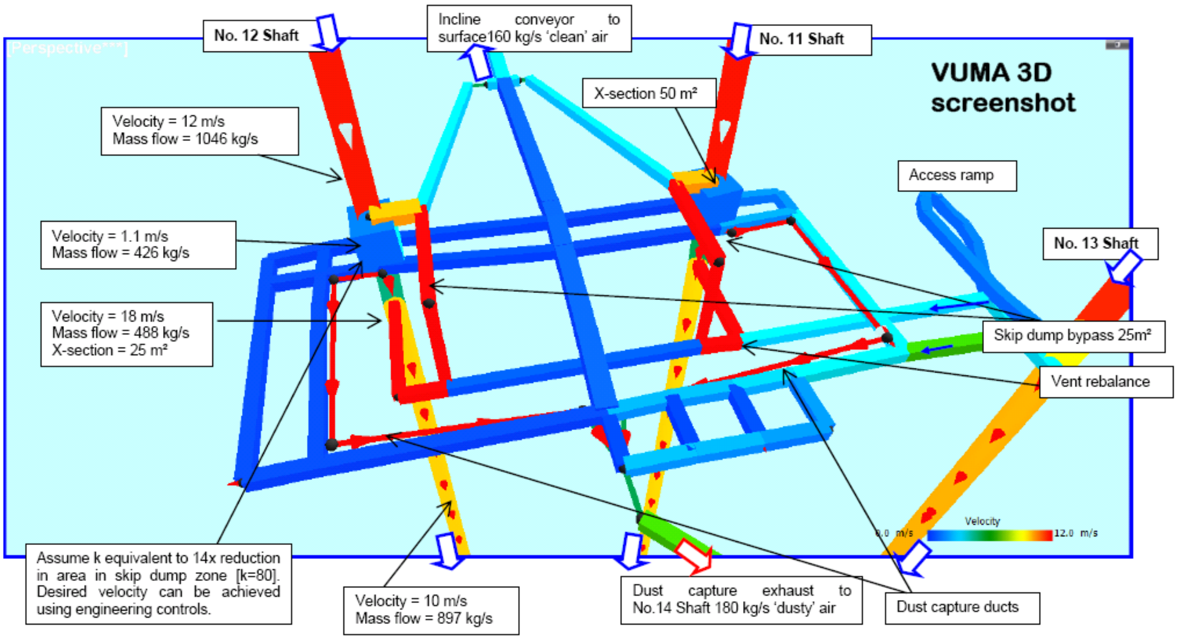


Figure 5.5 VUMA snapshot with originally proposed dimensions [blue in colour scale indicates 0 m/s and red indicates 12.5 m/s]

Figure 5.6 shows the flow distribution with increased dimensions in the skip dump bypass excavations to 50 m². Further work could examine moving the shaft expansion further up above the discharge point. It is also recommended that detailed CFD modelling should be undertaken to show turbulence in the discharge area.

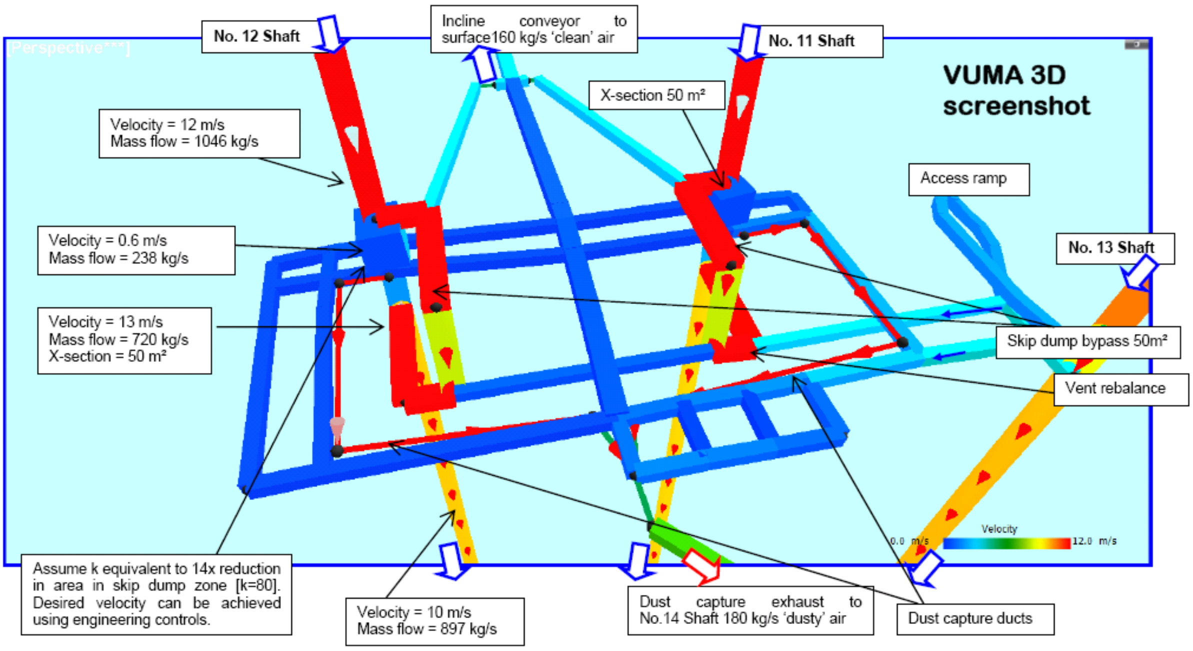


Figure 5.6 VUMA snapshot with increased skip bypass dimensions [blue in colour scale indicates 0 m/s and red indicates 12.5 m/s]

5.6 Shafts to Surface Conveyor Drift

Dust management in the shaft to surface drift will be:

- Dust suppression and belt pile wetting sprays along the length of the drift at 200 m intervals. The intention is for the belt pile to have a moisture content of at least 2.0% at this time although additional sprays will be required to overcome evaporation.
- Hooded capture at the CV201 to CV202 transfer point [15 kg/s, 13 m^3/s] which will be in close proximity to the drift exhaust shaft and report to it.

5.7 West Plant to Mill Conveyor Tunnel

Designs are not yet available for the West Plant to Mill conveyor tunnel although dust management will be essentially the same as that for the drift conveyor system. At this stage, an allocation of 150 kg/s [143 m^3/s] has been made for this purpose. If a significantly higher ventilation rate is required then it is likely that a dedicated exhaust shaft[s] would be justified.

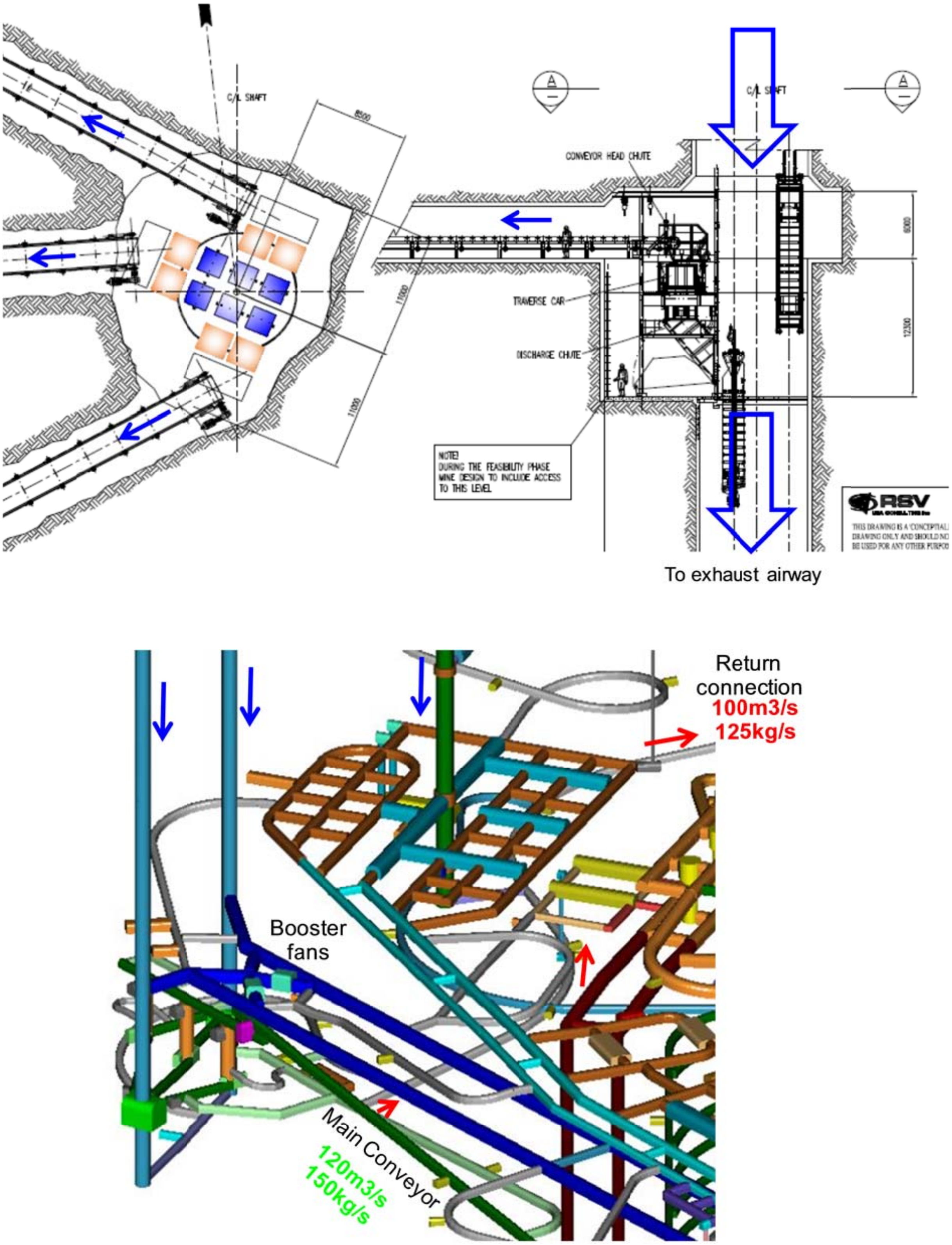


Figure 5.7 Skip Loading

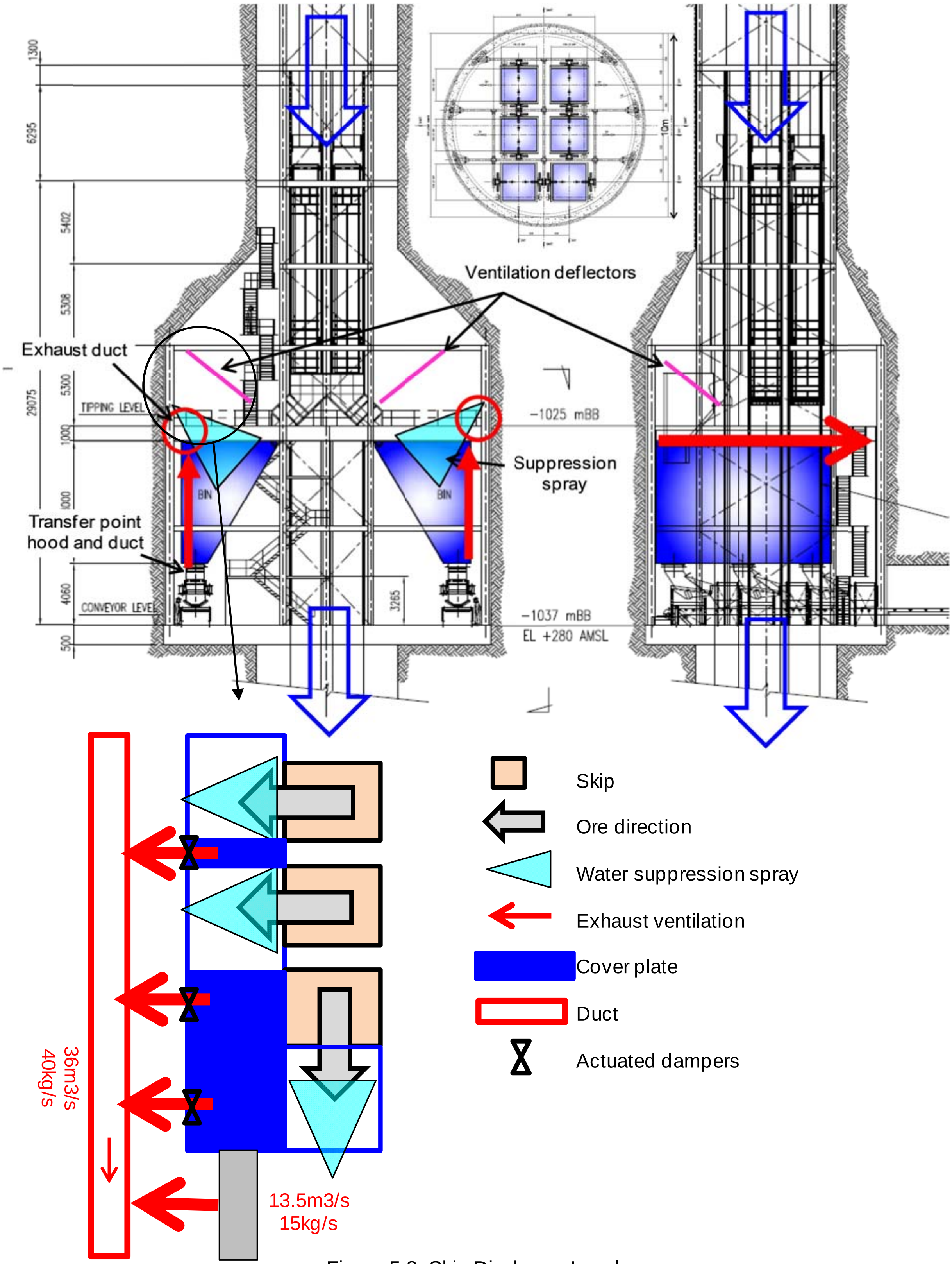


Figure 5.8 Skip Discharge Level

6 ENERGY BALANCE MODELLING

The design process has included the full interactive computer simulation of the heat flow, ventilation and cooling systems to determine the air temperatures, flow rates, heat loads and cooling requirements using VUMA-network software. VUMA-network uses well established, verified algorithms and is considered the best tool available for this function.

The mine-wide global ventilation and cooling balances were evaluated from the main VUMA-network model [Figure 6.1 and Figure 6.2 show some screenshot examples].

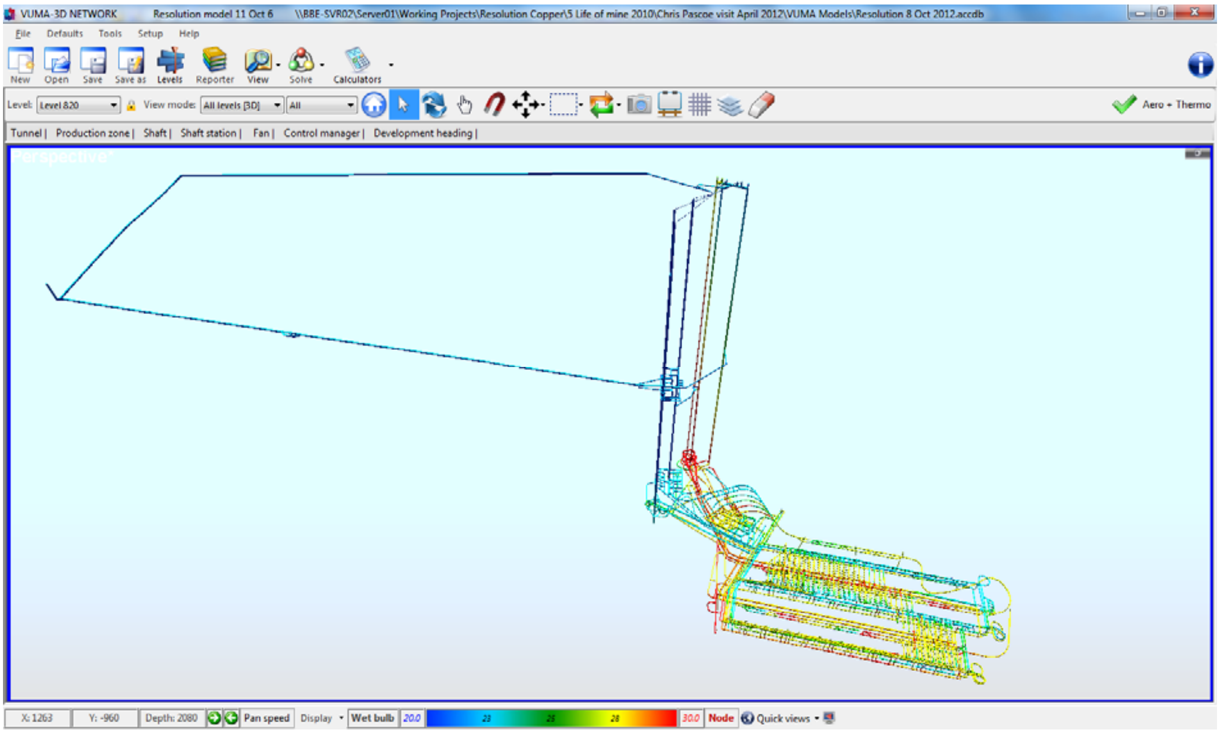


Figure 6.1 Scenario V.6 [B3] VUMA model [blue on temperature scale = 20°Cwb; red = 30°Cwb]

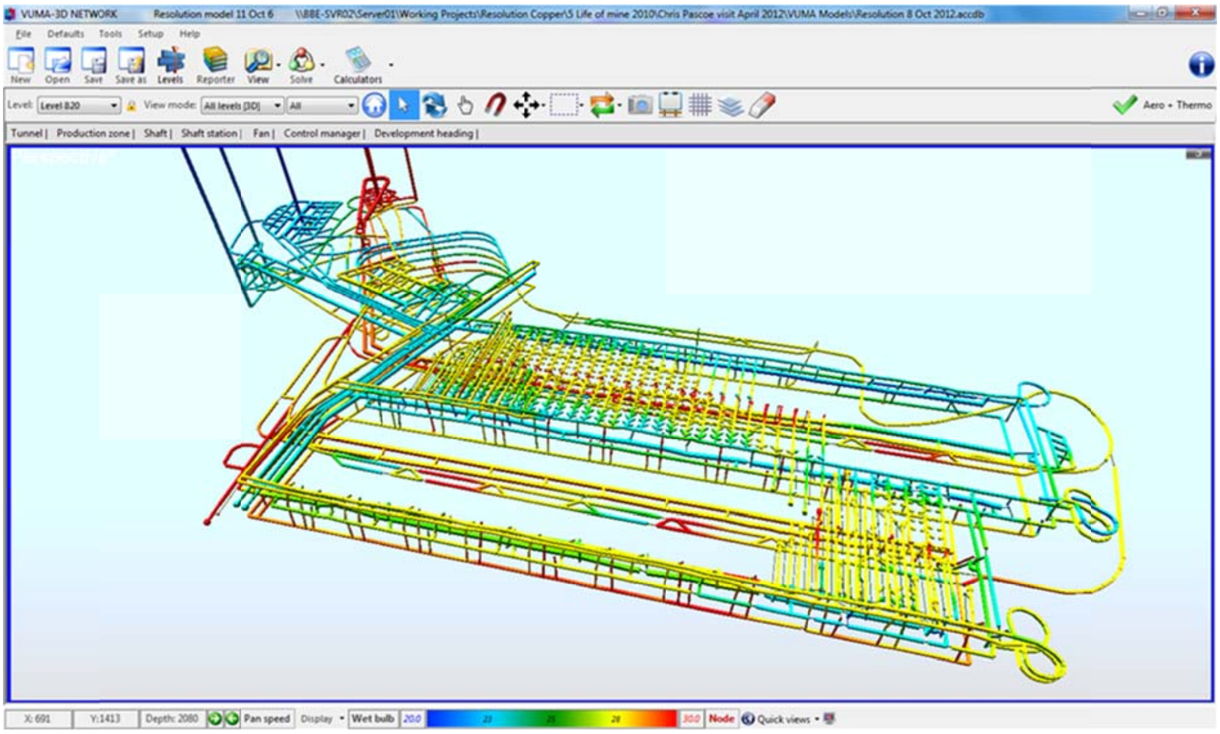


Figure 6.2 Ultimate VUMA model [blue on temperature scale = 20°Cwb; red = 30°Cwb]

This work considers the scenario of 120 kt/d production from a single block for the snap-shot at year 2031 in the life-of-mine. This scenario was selected as the critical design year for sizing the ultimate ventilation and refrigeration needs and is the basis of the detailed VUMA modelling. At this snap-shot, Panel 1 is approaching completion and Panel 2 is starting production. This scenario was considered to be appropriate for sizing the vent/cooling needs because of the relatively high development exposure, the duplicity of some excavations and the fact that the workings are far from the main infrastructure.

The heat load due to all the equipment and facilities, as discussed in Section 3, will be about 23 MW [17 MW mobile and 6 MW static facilities] this was input to VUMA at the relevant nodes and branches.

The heat load analysis has included the effects of the concrete trucks as well as the hydration effect of the cement. This has been applied adequately in both the construction period and the permanent phase.

The heat load from the broken rock flow will be very significant and Addendum C presents an order-of-magnitude conceptual model of this. In summary, the application of this logic in the mine-wide heat load model is taken as:

- Order-of-magnitude of full potential heat source is about 60 MW and of this:
    - 30 MW will manifest itself as a load on the underground mine
    - 2 MW will manifest itself as a load at skip discharge/bin and feeders
    - 4 MW will manifest itself as a load in the surface conveyor system
    - 24 MW remaining leaves the entire mine in a ‘still hot’ condition.

The heat from broken rock flow in the underground mine is assumed to be as follows and this was input to VUMA-network at the relevant nodes and branches.

- Loading level horizon — 12 MW[a]
- Rail level and shaft — 18 MW
    - Characterization level up to crusher — 6 MW[a]
    - Transfer to crusher and belt — 5 MW[b]
    - Conveyor belt system — 2 MW[a]
    - Loading station to hoisting shafts — 3 MW[b]
    - In-shaft No.11 and No.12 Shafts — 2 MW[a]

  18 MW total

[a] Applied as linear heat source across all relevant excavations.
[b] Applied as spot heat source.
Note the rock will generally be wet and the VUMA moisture Cat.5 will apply.

It is emphasized that this assessment is an approximation but the main outcome of this analysis for the present purposes is:

- Underground heat load from broken rock will be very significant and will require appropriate design of the haulage route ventilation and cooling circuits.
- Rock piles in draw points between loading cycles will emit heat which will generate unacceptable air temperatures if ventilation is reduced during these times i.e. this could limit opportunities for a ventilation-on-demand approach to control.

With these and other VUMA-network inputs for excavation branch sizes, connections, age, wetness, geothermal data, etc, the models were established. The modelling has indicated that, for this base-case scenario, and for the base-case energy balance, the mine heat loads will be satisfied with the following resources:

- Primary ventilation flow rate — 3120 kg/s
- Surface bulk air cooler duty — 105.2 MW
- Underground air cooler duty — 38.5 MW [34.5 ac + 4.0 effective pipe loss]

In addition, the surface conveyor drift to the West Plant requires cooling as follows:

- Surface conveyor drift to West Plant — 3.6 MW

In the main mine below the Skip Discharge level, the cooling balance will be achieved by the following:

- Chilled ventilation air of 3120 kg/s downcast at 10.5°Cwb [2760 kg/s will go to deeper underground workings beyond skip discharge horizon]
- Chilled service water of 150 l/s at 4°C
- Underground re-cooling of 38.5 MW air cooler [and effective pipe loss] duty

The base-case design has all three downcast shafts with the same 10.5°Cwb temperature ventilation on surface. However, because of the relatively large outflow of cold air on the Skip Discharge level [for good reasons] there may be merit in making one or two shafts colder than the other. This will form part of a subsequent optimisation study.

The surface bulk air coolers will be served by the surface refrigeration machine system [and thermal store facilities], see Section 8. The underground secondary air coolers will be served by the central underground refrigeration machine system, see Section 9. In addition, the service water to be supplied from surface will be chilled and will create an important cooling effect underground.

The global energy balance can be satisfied by different combinations of higher airflow rates with cool air or lower airflows with colder air. The optimum selection is dictated by issues such as available downcast capacities, capital and running costs of the ventilation and cooling systems, standard equipment capacities and phase-in needs. Following a number of iterations which included the sizing of the shafts, sensitivity studies [of more or less underground refrigeration, use of ice, etc] the above mix of flow rate and refrigeration capacity cooling is considered to be fairly close to optimum. Trade-off studies have been conducted with different splits between surface and underground refrigeration as well as the manner in which the cooling is distributed, Appendix G.

In summary, most of the refrigeration capacity will be on surface however, the underground refrigeration capacity will be extremely important during the development phases and will provide the essential high-positional-efficiency air coolers directly in the workings during production phases.

As noted, this base-case is referenced to the situation of full production in year 2031. Obviously, there will be a phase-in of the vent/cooling resources during the mine construction and the production ramp-up periods. This overall phase-in to the ultimate condition is an important consideration that is discussed in detail later but, an important observation here is that the relatively early installation of the underground refrigeration system will be necessary.

In summary, the underground refrigeration system will comprise:

- Centralized underground refrigeration plant chamber and refrigeration machines
- Suite of underground air coolers and cold water distribution system

In summary, the surface refrigeration system will comprise:

- Central surface refrigeration plant room and refrigeration machines [and thermal store]
- Surface bulk air coolers at each downcast shaft
- Closed circuit air coolers in surface conveyor drift
- Service water refrigeration system to provide chilled surface water to underground

7 FAN STATION ENGINEERING DESCRIPTION

7.1 Main Fan Station

The main fans will be installed on surface and will operate in an exhaust mode drawing ventilation through the mine. The general arrangement will be to connect all the three exhaust shafts to a common sub-surface 'manifold' and each main fan will be connected directly to the manifold. Hence all shafts will be connected to all fans and there will not be dedicated exhaust fans for a particular shaft. In principle, the 'manifold' will be established by open box-cut type excavations on surface which will then be lined and concrete roof cast over the top. At the next detailed level of feasibility study this issue will require detailed aerodynamic design of the shaft bends and the profiles of the fan inlet boxes [including CFD type work]. For the present purposes, it is proposed that there will be four operational main fan units [plus one standby] and the layout of the manifold and the fan sets are shown in Dwgs 060 and 062.

The various operating points for the fans are discussed in Section 4 and the fan selection will have efficient operation around the following process conditions of 5.5 kPa at 778 kg/s. The basic fan designs will be influenced by the relationship between pressure and flow in terms of the Specific Speed no. While this pressure is fairly typical for deep mining operations, the total flow rate of 4 x 778 kg/s [3110 kg/s] is relatively high. This particular application will be well suited to the mixed-flow or centrifugal fan configurations and the mixed-flow approach has been adopted for the present purposes for layouts and cost estimation [Figure 7.1]. However, centrifugal fans and other possible axial arrangements will need to be considered at final design and enquiry-tender stages.

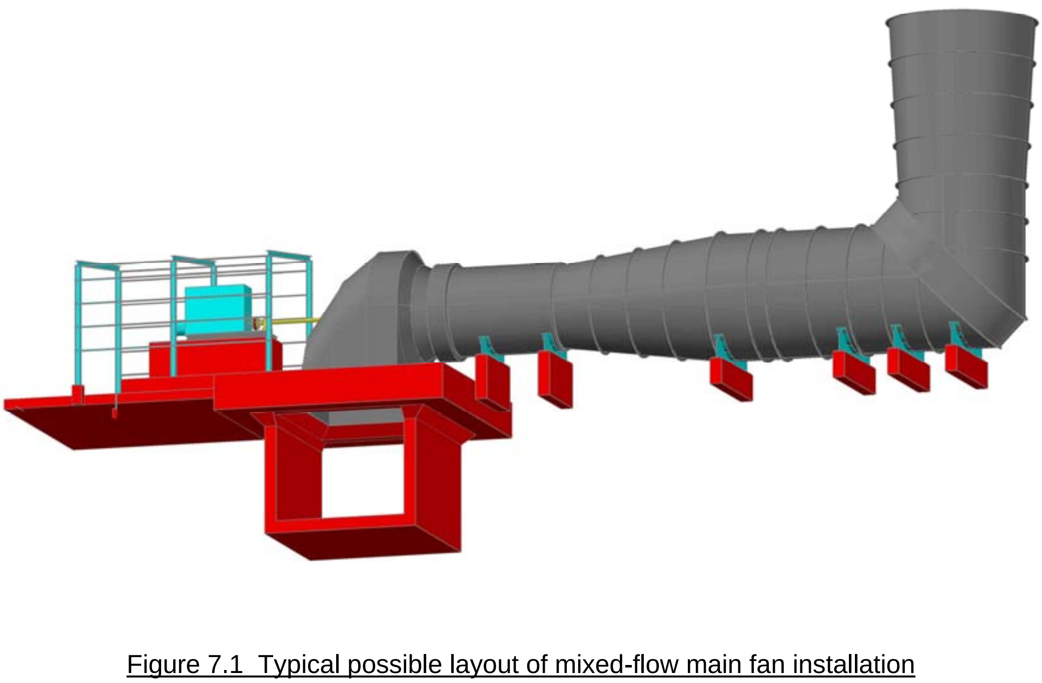


Figure 7.1 Typical possible layout of mixed-flow main fan installation

The ultimate total fan station design flow will be 3110 kg/s [with 4 identical fans in operation and one standby]. The nominal process specification for the each of the fans will be as follows:

- Fan flow rate 778 kg/s
- Volumetric flow 819 m^3/s
- Static pressure differential 5.5 kPa
- Temperature dry/wet-bulb 24/24°C
- Nominal motor selection 6.0 MW [10 pole, 715 rpm, direct coupled]
- Nominal total motor rating [operational] 24.0 MW

Fan design shall be such that the optimum efficiency is achieved at the above process point. The pressure-capacity characteristic curve will rise continuously by at least 15% from the process point to the point of maximum pressure and the higher pressure operation must also have high efficiency performance. The following features are based on a typical fan selection:

- Boxed inlet mixed flow impeller with impeller between bearings directly couple to motor
- Mechanically actuated inlet pre-rotational guide-vanes for energy management
- Removable casing covers for ease of access for impeller cleaning
- Inlet casing streamlined to minimise inlet losses
- Water drain facilities provided in casing for automatic blow-down
- All connections, flanges, gaskets, bolts/nuts and clamps
- Shaft disc brake systems with electrical actuators and interlocking system
- High-stress impeller welds x-ray tested, complete impeller stress relieved after fabrication
- Fans will be dynamic balanced on site to ISO 1940
- Noise levels [total break-out and aerodynamic] with all four fans running at the process design point will be less than 85 dBA at ground level on 30 m radius

The upcast hot humid air will arrive at the fan station in a saturated state which will include water droplets in suspension which will carry-over into the fans for discharge with the exhaust air. The internal and external surfaces of the fan impeller, fan casing, covers, duct legs, discharge diffusers, bends and all structural steelwork and plate-work will have high-level corrosion protection specification.

The discharge diffusers will be designed for optimum pressure recovery at discharge with maximum discharge air speed 16 m/s and overall included angle of diffusion will not be greater than 11°. Diffusers will be manufactured in mild steel with suitable stiffeners. The diffuser bend will be of mitred configuration with corner static guide-vanes [or equivalent]. Each duct leg will incorporate self-closing doors, airlock access facility, flexible duct couplings, safety screens, etc. The duct sections and diffusers will be mounted on steel supports to be assembled on concrete support plinths.

Isolation damper doors will be provided in duct legs and will include a high-level bearing specification and a damping mechanism against slamming. Bearings will be located for ease of access and maintenance. Doors and bearings will be provided with covers and corrosion protection that will resist the effects of the harsh environment. Door assemblies will include manual locking devices and mechanical indicators to show door position. Position proximity switches will be provided to monitor position of doors. Doors will close naturally by gravity using an off-set shaft concept. Detailed design will also need to consider the need for and merits of isolating seals/doors to be installed in each main duct off-take on the fan suction side.

It is noted that these large fans will not be controlled by variable speed drives [this follows team evaluation and various specialist opinions]. The control and energy management will be achieved by mechanically actuated, inlet pre-rotational guide-vanes engineered to a high-level specification. The guide-vanes will be of appropriate aerodynamic and mechanical design to ensure minimum resistance on the system and will be designed to close and open completely. The inlet guide-vanes and actuator assembly will be designed for full continuous modulating operation between the fully closed and maximum open positions. The guide-vane system will be selected for reliability and ease of maintenance and safety when carrying out maintenance.

Each fan motor set will be provided with localised PLC and control panel to be installed near the main fan MCC to assist with fan start-up, interlocks, fan control, energy management, metering and reporting, data collection, monitoring and communication. The energy metering will interface with the mine-wide monitoring system and the PLC will typically supervise and monitor the following:

- Inlet guide-vane actuators
- Energy metering
- Motor winding temperatures
- Fan and motor bearing temperatures
- Vibration sensors
- Fan brake actuator system
- Airflow velocity sensors in each fan duct leg
- Air pressure transducers in each fan duct leg
- Air temperature sensors in each fan duct leg
- Non-return damper door position indicators

7.1.1 Note on 'Hood' at No.9 Shaft Collar

No.9 Shaft will be used for rock hoisting and access throughout the periods of characterization and development. The functioning shaft, winder and headframe will be a critical and integral part of underground mine construction and for this reason, the hood must be designed such that it facilitates maintenance [e.g. skip or rope change out] and does not inhibit secondary egress.. No.9 Shaft will be eventually stripped in 2022/23 and it is only then that possible work can be done to cut into the bank and the shaft lining for the return air drift bend. However, No.9 Shaft will need to upcast in year 2016 with the installation of the first main fan. For this purpose, it is proposed to install a temporary steel hood-bend [Figure 7.2] to connect No.9 Shaft into sub-surface drift work. This arrangement will remain in place until 2022/23 when No.9 Shaft is fully de-commissioned and work can be done on the collar and shaft lining and the permanent fully aerodynamic shaft bend can be constructed.

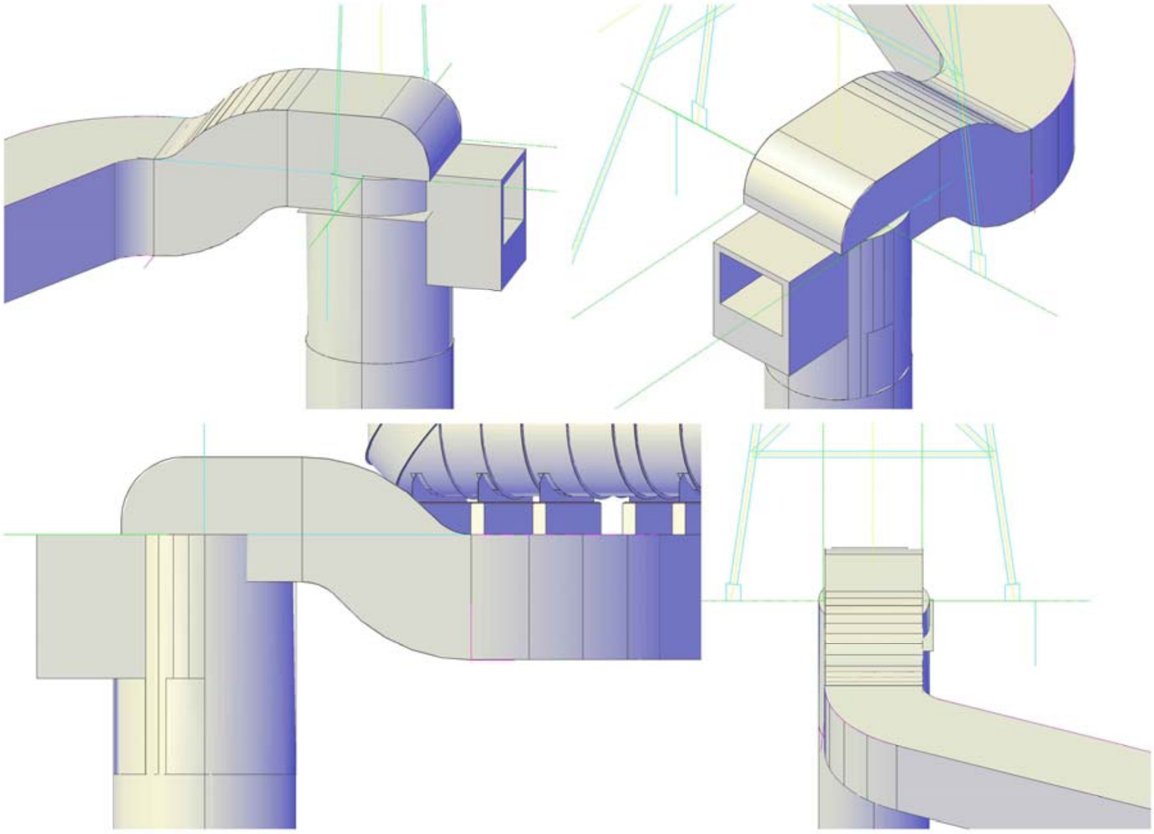


Figure 7.2 Temporary steel hood-bend connecting No.9 Shaft into sub-surface drift

7.1.2 Note on Selection of First Surface Main Fan

There are certain aspects that need to be evaluated in selecting the first surface main fan. In particular, the merits of rather using two half-size units to satisfy the first big fan duty should be considered. The main issues are:

- Use of two half-size units will give redundancy in short term.
- There will be some difficulty in splitting the first fan into two units due to limitation on real estate.
- Half-size 3 MW motors will also not be suitable for VSD and control will still be by guide-vanes.
- Low flow rates for shaft examination will be achieved via drift bypass even with half-size fans.
- Flow needs in the short term, after No.9 Shaft is holed, will vary from about 285 kg/s [40% of one big fan] and 575 kg/s [75% of one big fan].
    - 40% control will be achieved by guide-vanes but at poor efficiency on one big fan.
    - 75% control will be achieved efficiently by guide-vanes on one big fan.

Following discussion, it was proposed to leave the base-case arrangement as four [plus one] big fans for the present purposes. But, at the next level of feasibility examination, it is noted that detailed layouts should be examined for two half-size units and the above points evaluated in more detail.

7.2 Conveyor Drift Fan Station

This conveyor system will be ventilated by 160 kg/s from the Skip Discharge level and 60 kg/s from the West Portal, Section 4. This ventilation system will make use of a 5 m raise-bore-hole exhaust shaft established near the location where CV201 discharges onto CV202. There will be a permanent exhaust fan station established on surface at this shaft drawing ventilation through the conveyor system. The fan station will operate at 193 m^3/s [220 kg/s] and the fan pressure requirement will be about 1.3 kPa. The fan station will comprise two operational fan motor sets and one fully-installed standby set connected to a trifurcated drift. Each fan will be selected for 97 m^3/s air flow [50% of total] and the fans will be standard axial units, Dwg 064 shows proposed fan station layout.

The ultimate total fan station design flow will be 220 kg/s with three identical fan units [two operational and one fully-installed standby]. The nominal process specification for the each of the fans will be:

- Fan flow rate 110 kg/s
- Volumetric flow 97 m^3/s
- Static pressure differential 1.3 kPa
- Temperature dry/wet-bulb 26/28°C
- Nominal motor selection 200 kW [direct coupled]

The fan selection will ensure that optimum efficiency is achieved at this process point and the following features are based on a typical fan station design:

- Shaft top bend and trifurcated drift and symmetrical duct legs
- Bend to include access door for slinging material from time-to-time
- Inlet cones, safety screens, silencers
- Axial flow impeller directly coupled to motor
- Static inlet and discharge guide-vanes for optimum efficiency
- Removable fan casing covers for ease of access
- Discharge diffusers for optimum energy recovery
- Self-closing non-return doors
- Flexible connections
- Structural steel support structure [and anti-vibration mountings as required]
- Water drain facilities provided in casing for automatic blow-down
- Noise levels [total break-out and aerodynamic] with both fans running at the process design point will be less than 85 dBA at ground level on 30 m radius

The upcast hot humid air will arrive at the fan station in a near-saturated state which may include water drops in suspension. The internal and external surfaces, fan impeller, fan casing, covers, duct legs, discharge diffusers, bends and all structural steelwork and plate-work will have a high level corrosion specification. Fans will be standard axial flow fans with internally mounted directly-coupled electric motors. Fan-hub design will allow for manual resetting of the blade pitch. Bearing housings will be constructed to protect the bearings from water, dust and other contaminants.

In order to enable full use of the 5 m shaft ventilation capacity [should it ever be required], the shaft-top bend will be designed for a maximum flow of 330 kg/s. The bend will also include an access door for slinging material from time-to-time. The shaft-top bend, trifurcation section and drift duct legs will be manufactured in mild steel with suitable stiffeners and corrosion protection. The shaft-top bend will include access stairs and handrails for access to instrument ports. The trifurcation and the duct legs will be provided with drainage facilities and will be mounted on steel supports on concrete support plinths.

The discharge diffusers will be designed for optimum pressure recovery with maximum discharge air speed 18 m/s and overall included angle of diffusion <14°. Diffusers will be manufactured in mild steel with suitable stiffeners. Each duct leg will incorporate self-closing doors, airlock access facility, flexible duct couplings, safety screen and converging section into fan inlet.

Non-return damper doors will be provided in the duct legs and will include a high-level bearing specification and a damping mechanism against slamming. Door bearings will be located for ease of access and maintenance. Doors and bearings will be provided with covers and corrosion protection that will resist the effects of the harsh environment. Door assemblies will include manual locking devices and mechanical indicators to show door position. Position proximity switches will be provided to monitor position of doors. Doors are to naturally close by gravity using an off-set shaft concept.

The fan station will be provided with localised PLC and control panel to be installed near the local fan MCC to assist with fan start-up, interlocks, fan control, energy management, metering, data collection, monitoring and communication. The energy metering will interface with the mine-wide monitoring system and the PLC will supervise and monitor the following:

- Energy metering
- Motor winding temperatures
- Fan and motor bearing temperatures
- Vibration sensors
- Airflow velocity sensors in each fan duct leg
- Air pressure transducers in each fan duct leg
- Air temperature sensors in each fan duct leg
- Non-return damper door position indicators

From time-to-time, the shaft will be used as access to supply materials such belt and conveyor drive components underground. For this purpose, the shaft top bend will have removable panels or doors to allow this access and there will be a loading area and a suitable winder installed.

7.3 Booster Fan Station for High Speed Intake Airways

There will be two booster fan stations for the high speed intake airways, one in each intake ROWA tunnel, to create special high-speed dedicated intake airways [no pedestrian or vehicle access], Section 4. The objective will be to optimise the carrying capacity of these large airways as well as to control air velocity in other trafficable airways. Each of these two underground fan stations will have 880 kg/s [700 m^3/s] capacity and will each comprise four fan motor sets installed in parallel in a bulkhead wall [with airlock bypass access] and each fan will be selected for 175 m^3/s air flow [25% of total]*. This operating point is suitable for the selection of axial fan units, see Dwg 71 for proposed layout.

* Full spare fan-motor set [rotor, motor and all ancillaries] will be stored on site.

Each booster fan station will include excavation, bulkhead wall, air lock doors, direct coupled axial fan units, silencers, inlet cones, safety screens, static guide-vanes, diffusers, non-return doors, duct couplings, support civils/structures, etc. Fan blade angles will be manually adjustable in static condition.

For each fan station, with 4 identical fans operational, the nominal process specification for the each of the fans will be as follows:

- Fan flow rate 220 kg/s
- Volumetric flow 175 m^3/s
- Static pressure differential 1.0 kPa
- Temperature dry/wet-bulb 19/28°C
- Nominal motor selection [per fan] 250 kW [direct coupled]
- Nominal total motor rating 1000 kW

The following features are based on a typical fan station and fan selection:

- Excavation and support
- Bulk head wall for fan housing and air lock access bypass construction
- Inlet cones, safety screens, silencers
- Axial flow impeller directly coupled to motor
- Static inlet and discharge guide-vanes for optimum efficiency
- Removable casing covers for ease of access
- Discharge diffusers for optimum energy recovery
- Self-closing non-return doors
- Flexible connections
- Structural steel support structure [and anti-vibration mountings as required]
- Noise levels [total break-out and aerodynamic] with three fans running at process design point will be less than 85 dBA at 30 m distance

The intake ventilation, direct from the downcast shafts will be relatively cool and clean. Nevertheless, in this underground environment the equipment will receive corrosion protection of a high specification.

Fans will be standard axial flow fans with internally mounted directly coupled electric motors. Fan-hub design will allow for manual resetting of the blade pitch. Bearing housings will be constructed to protect the bearings from water, dust and other contaminants.

The discharge diffusers will be designed for optimum pressure recovery at discharge with maximum discharge air speed 18 m/s and overall included angle of diffusion <14°. Diffusers will be manufactured in mild steel with suitable stiffeners. Each duct leg will incorporate self-closing doors, flexible duct couplings, safety screen and converging section into fan inlet.

Non-return damper doors will be provided in each fan discharge and will include a high-level bearing specification and a damping mechanism against slamming. Door bearings will be located for ease of access and maintenance. Doors and bearings will be provided with covers and corrosion protection that will resist the effects of the harsh environment. Door assemblies will include manual locking devices and mechanical indicators to show door position. Position proximity switches will be provided to monitor position of doors. Doors are to naturally close by gravity using an off-set shaft concept.

Each fan station will be provided with localised PLC and control panel to assist with fan start-up, interlocks, fan control, energy management, metering, data collection, monitoring and communication. The energy metering will interface with the mine-wide monitoring system and the PLC will supervise and monitor the following:

- Energy metering
- Motor winding temperatures
- Fan and motor bearing temperatures
- Vibration sensors
- Airflow velocity sensors in each fan duct leg
- Air pressure transducers in each fan duct leg
- Air temperature sensors in each fan duct leg
- Non-return damper door position indicators

7.4 Characterization Level Temporary Fan Station

There will be a critical time [Section 12, Phase V.2] after No.9 Shaft holes on Characterization level during which cold ventilation will downcast in No.10 Shaft, be used in the workings and then upcast in No.9 Shaft. For this purpose, there will be a temporary fan station established on Characterization level designed for a total ventilation flow of 150 kg/s [126 m^3/s]. This temporary fan station will remain operational until the first permanent main fan on surface becomes available [Phase V.3]. The fan pressure requirement has been estimated at about 1.0 kPa. However, this will vary during this operational period and the fans will be provided with variable speed drive facilities.
This underground fan station will comprise three fan motor sets installed in parallel in a bulkhead wall [with airlock bypass access] and each fan will be selected for 75 kg/s air flow [50% of total]. This operating point is suitable for the selection of axial fan units and the proposed layout is given in Dwg 70. Due to the critical nature of this part of the ventilation circuit, a full spare fan set will be installed in the bulkhead wall and will be available for immediate operation.

The fan station will include excavation, bulkhead wall, air lock doors, direct coupled axial fan units, silencers, inlet cones, safety screens, static guide-vanes, diffusers, non-return doors, duct couplings, support civils/structures, etc. Fan blade angles will be manually adjustable at rest and the motors will have VSD facilities. The nominal process specification for the each of the fans will be as follows:

• Fan flow rate	75 kg/s
• Volumetric flow	63 m^3/s
• Static pressure differential	1.0 kPa
• Temperature dry/wet-bulb	28/33°C
• Nominal motor selection [per fan]	110 kW [direct coupled]
• Nominal total motor rating	330 kW

The following features are based on a typical fan station and fan selection:

- Excavation, support and bulk head wall for fan housing and air lock access bypass construction
- Inlet cones, safety screens, silencers
- Axial flow impeller directly coupled to motor with VSD facilities
- Static inlet and discharge guide-vanes for optimum efficiency
- Removable casing covers for ease of access
- Discharge diffusers for optimum energy recovery
- Self-closing non-return doors
- Flexible connections

- Structural steel support structure [and anti-vibration mountings as required]
- Noise levels [total break-out and aerodynamic] with two fans run at design point will be <85 dBA at 30 m distance

The return ventilation flow into the fans will be dusty, hot and humid. The internal and external surfaces, impeller, casing, duct pieces, covers, diffusers and all structural steel and plate work will receive corrosion protection of a high-level specification.

Fans will be standard axial flow fans with internally mounted directly-coupled electric motors. Fan-hub design will allow for manual resetting of the blade pitch [VSD facilities will also be provided]. Bearing housings will be constructed to protect the bearings from water, dust and other contaminants.

The discharge diffusers will be designed for optimum pressure recovery at discharge with maximum discharge air speed 18 m/s and overall included angle of diffusion <14°. Diffusers will be manufactured in mild steel with suitable stiffeners. Each duct leg will incorporate self-closing doors, flexible duct couplings, safety screen and converging section into fan inlet.

Non-return damper doors will be provided in each fan discharge and will include a high-level bearing specification and a damping mechanism against slamming. Door bearings will be located for ease of access and maintenance. Doors and bearings will be provided with covers and corrosion protection that will resist the effects of the harsh environment. Door assemblies will include manual locking devices and mechanical indicators to show door position. Position proximity switches will be provided to monitor position of doors. Doors are to naturally close by gravity using an off-set shaft concept.

The fan station will be provided with localised PLC and control panel to assist with fan start-up, interlocks, fan control, variable speed control, energy management, metering, data collection, monitoring and communication. The energy metering will interface with the mine-wide monitoring system and the PLC will supervise and monitor the following:

- Energy metering
- Motor winding temperatures
- Fan and motor bearing temperatures
- Vibration sensors
- Airflow velocity sensors in each fan duct leg
- Air pressure transducers in each fan duct leg
- Air temperature sensors in each fan duct leg
- Non-return damper door position indicators

8 SURFACE REFRIGERATION SYSTEM

There will be a central surface refrigeration machine facility [and thermal store] from which chilled water will be served to surface bulk air coolers at each of No.11, No.12 and No.13 Shafts. In addition, there will also be a supplementary surface refrigeration system that will provide chilled water to underground to serve closed circuit air coolers in the ‘surface’ conveyor drift and to provide general chilled service water to all workings.

The overall surface refrigeration system will include:

- Refrigeration machines and ice store to serve surface air coolers
- Surface bulk air coolers at each downcast shaft
- Supplementary [independent] refrigeration system to provide chilled water to underground

The overall system is described in the set of pre-engineering drawings prepared for Pre-feasibility design and costing purposes, see Drawing schedule.

The difference between process conditions and the equipment selection specifications must be noted. The latter is a more stringent requirement, which incorporates thermal and physical design safety factors for which the equipment must be supplied and guaranteed. The process conditions describe the actual process design requirements for a specific set of conditions.

8.1 Surface Refrigeration Machines

8.1.1 Refrigeration System to Serve Surface Air Coolers

This refrigeration machine system will comprise main base-load machines pre-chilling the circulating water flow. From these plants, chilled water will then flow to the thermal storage dam containing tube banks through which sub-zero glycol is circulated. Ice will be formed on the outside of the tubes during the cold part of the day and then melted by the circulating water during the warm part of the day. The chilled water will leave the thermal storage dam at temperatures close to 0°C. The thermal storage will allow peak load damping and will also provide energy management facilities.

The combined plant and ice store system for the surface bulk air coolers will provide the following capacity during the hot part of the day [14h00].

- Total surface bulk air cooler duty [at air coolers] 105.2 MW
- Thermal losses and pump effects 4.0 MW
- Total refrigeration effect [including ice dam] 109.2 MW

For this function, there will be five large refrigeration machine modules which will ultimately all be operational. Of the five machines, four will be base-load water chilling units which will pre-chill the circulating water to be delivered to the thermal store ice dam. The fifth machine will be used to refrigerate the circulating glycol which will serve the ice tube banks.

All five refrigeration machines will be similar with interchangeable components [however the glycol plant will have a different gear-speed selection]. The refrigeration machine module will be a standard, factory-assembled and packaged plant with dual single-stage R134a centrifugal compressors, shell-and-tube evaporators/condensers, lubrication systems, piping, cabling and instrument and control systems. The compressor drive-lines will be factory installed, coupled and aligned. The machine will have dual refrigerant compressors operating in parallel on a single set of heat exchangers in order to provide high capacity from a single plant.

The compressors will be single-stage centrifugal-type driven by open-drive electric motors. Capacity control by pre-rotation vanes will be fully modulating from full load down to less than 25% load. Operation of the control vanes will be by external electrical actuators, which will automatically control pre-rotation vane position to maintain constant leaving chilled water temperature. The refrigeration machine will be capable of continuous, reliable operation with entering condenser water temperatures down to 18°C at all load conditions.

The compressor motors [1.8 MW] will be 2-pole units [compressors are internally geared] which will be factory installed, coupled and aligned.

The condensers and evaporators will be shell-and-tube type with water in tubes and refrigerant on shell side. The shells will be manufactured from carbon steel and painted with high specification epoxy coating. The tubes will be 90/10 CuNi [with clad tube sheets in same material] with high efficiency enhanced internal and external surfaces. Design fouling factors used in all calculations are 0.2 m^2°C/kW and 0.1 m^2°C/kW for condensers and evaporators respectively.

Thermal insulation will be applied to the surface of all vessels, piping, flanges, valves and fittings that have potential for condensation. The insulation will be covered by steel sheeting for mechanical protection.

Each plant and the plant building will have access platforms for the refrigeration machine and other equipment. Each plant and the plant building will also include a refrigerant leak detection system.

The four base-load water chilling machines will be arranged in two parallel pairs of lead-lag plants in series. Thus each plant will have differing process conditions however, for example, the lead water chilling plants will have typical specifications as follows:

Evaporator

- Cooling duty — 22.1 MW
- Water flow — 898 l/s
- Inlet water temp — 15.0°C
- Outlet water temp — 9.1°C
- Fouling factor — 0.10 m^2°C/kW
- Evaporating temp — 6.1°C

Condenser

- Duty — 25.6 MW
- Water flow — 700 l/s
- Inlet water temp — 24.0°C
- Outlet water temp — 32.7°C
- Fouling factor — 0.20 m^2°C/kW
- Condensing temp — 36.0°C

Compressor

- Type — Dual single-stage centrifugal
- Rated motor power — 2 x 1.8 MW

The cold water off the two pairs of water chillers will be delivered to the ice dam at 4.3°C. The ice thermal store will make ice during the cold part of the day and this will be melted during the warmer part of the day. For the process condition during warm part of day [at 14h00, summer design], the melting ice and glycol flow will create a cooling effect of some 28.4 MW on the circulating water which will then leave the ice dam at about 0.5°C. During the daily cycle, the glycol refrigeration plant will continue to circulate sub-zero coolant to the tube bank internals and the glycol plant typical specification will be as follows:

Evaporator

- Cooling duty — 14.2 MW
- Glycol flow — 830 l/s
- Inlet glycol temp — -1.5°C
- Outlet glycol temp — -6.0°C
- Fouling factor — 0.10 m²°C/kW
- Evaporating temp — -9.0°C

Condenser

- Duty — 17.6 MW
- Water flow — 700 l/s
- Inlet water temp — 24.0°C
- Outlet water temp — 30.0°C
- Fouling factor — 0.20 m²°C/kW
- Condensing temp — 33.0°C

Compressor

- Type — Dual single-stage centrifugal
- Rated motor power — 2 x 1.8 MW

The overall water chilling effect at 14h00 of the refrigeration system [including ice melt effect] can be summarised as:

- Water chilling ex refrigeration machines — 80.8 MW
- Water chilling ex ice store and glycol — 28.4 MW
- Total — 109.2 MW

The gross refrigeration machine duty and absorbed compressor power will be:

	Duty	**Comp power**
• Water chilling refrigeration machines	80.8 MW	13.4 MW
• Glycol chilling refrigeration machines	14.2 MW	3.4 MW
• Total	95.0 MW	16.8 MW*

*. This relates to the compressor power all the other auxiliary drive [pumps, fans] will add significantly to this, see below.

8.1.2 Refrigeration System to Provide Chilled Water for Underground

The chilled service water will be a very important part of the underground cooling. The chilled service water will be used for dust control, localized cooling sprays and mine service needs and will provide effective localised cooling wherever it is applied. The underground system is discussed in Section 9.9. However on surface, in addition to the refrigeration system above [serving the surface bulk air coolers], there will be a separate independent surface refrigeration system that will provide general chilled service water to all the underground workings as well as chilled water to serve the closed-circuit air cooler in the surface conveyor drift and to provide, see Dwg 51.

The chilled water required for the closed-circuit air coolers in the surface conveyor drift will be 75 l/s and the general service water design criteria has been taken as 150 l/s [24 hr ave for 120 kt/d production, Section 2]. This total flow of 225 l/s will be chilled on surface to about 4°C and delivered to a surface chilled water dam at No.13 Shaft head for supply underground.

This overall chilled-water-for-underground cooling system will comprise a pre-cooling tower in which return-water from underground [and make-up water] is pre-cooled in an atmospheric cooling tower. Following the pre-cooling tower, the water will be chilled in a conventional standard refrigeration module. Following the refrigeration plant, the water will be delivered to an enclosed surface chilled service water dam [5 Ml]. This system will remain separate and independent of the bulk air cooler[s] refrigeration system.

The pre-cooling tower will be located above a dam of about 5 Ml which will be compartmentalised into a return water section and a cooled water section. During the cold periods of the day, this water will be circulated from the return water compartment through the pre-cooling tower at a relatively high rate [with back-pass flow]. The pre-cooling tower will be in the form of a single mechanical draft, packed, counter-flow type tower [splash-grid type pack]. The tower will be constructed in reinforced concrete and will be assembled above the dam and sized for the following process specification:

- Water flow — 350 l/s
- Water temperature on — 29.0°C
- Water temperature off — 23.5°C
- Ambient condition — 21°Cwb at 88 kPa
- Pump-motor set rating — 110 kW
- Fan motor rating — 110 kW

This will be a high thermal efficiency cooling tower with relatively high air flow [water/air ratio < 0.75] as well as relatively large fill depth [factor of merit > 0.65]. The service water-cooling tower operation will simply circulate water from the service water dam to the tower and back. The average service water demand will be less than the through flow and hence the tower will operate in recirculation mode. It will also be possible to operate the tower only during the colder part of the daily cycle, thus maximising performance in an energy intelligent manner.

From the pre-cooling tower, the water will be pumped to and chilled in a conventional standard refrigeration module identical to those used for base-load for bulk air cooling, and the general description given above will apply. This particular plant will have the following process specifications:

Evaporator

- Cooling duty 18.4 MW
- Water flow 225 l/s
- Inlet water temp 23.5°C
- Outlet water temp 4.0°C
- Fouling factor 0.10 m²°C/kW
- Evaporating temp 1.0°C

Condenser

- Duty 21.6 MW
- Water flow 700 l/s
- Inlet water temp 24.0°C
- Outlet water temp 31.4°C
- Fouling factor 0.20 m²°C/kW
- Condensing temp 34.4°C

Compressor

- Type Dual single-stage centrifugal
- Rated motor power 2 x 1.8 MW

8.2 Plant Room Considerations

There will be a total of six similar refrigeration machine modules installed in the plant room [4 x base load chillers and 1 x glycol chiller for surface air coolers and 1 x chilled-water-to-underground machine]. The plant room will be located centrally on the shaft complex bank in order to effectively serve the surface bulk air coolers and the chilled water supply dam near No.13 Shaft head

The refrigeration machine for the chilled-water-to-underground will be located on the west side of the plant building. The four main base-load water chilling refrigeration machines will be located in the centre of the building and these machines will be arranged in two parallel pairs of lead-lag plants in series. The glycol chilling machine will be located on the east side of the building next to the ice storage dam, which will be immediately adjacent on the east side of building.

The machine room will be sheeted structural steel construction with translucent IBR sheeting used extensively for natural lighting. The building will be ventilated with roof-apex mechanical ventilators and, in addition, the electrical rooms will be ventilated and cooled using split air conditioning sets. Mechanised roller-doors will be provided for access. Internal drainage facilities will be included for spillages inside the plant these will report to a sump and oil trap arrangement. There will be 30 ton bridge crane serving the length of the plant room. The bridge crane will be accessed via a cat ladder with a platform at one end and there will be a walkway along the length of the crane beam.

The electrical rooms will be constructed at the west end of the machine room. The electrical room will have a concrete roof and a raised floor for bottom entry cable installation. Access to the electrical rooms will be from inside the plant building while access for equipment installation will be through a transformer door from outside. The transformer bay will be constructed adjacent to the electrical room.

There will be refrigerant pump-down facilities which will be permanently piped-in and capable of holding refrigerant charge of two machines. Each refrigeration machine and the plant building will also include a refrigerant leak detection system. Each item of equipment will have access platforms for ease of maintenance.

8.3 Surface Heat Rejection System

The surface heat rejection system will serve all six refrigeration machine modules in parallel and will be in the form of wet direct-contact packed cooling towers.

As part of the greater pre-feasibility study, an assessment was done comparing dry and wet cooling tower systems. The alternative dry-cooling tower approach will save water. However, this approach would introduce higher condensing temperatures and as a result a greater capital cost for refrigeration machines and cooling towers and greater power cost for refrigerant compressors [and carbon issues]. These costs are orders-of-magnitude higher than that of water consumed in equivalent wet systems and, even acknowledging the secondary environmental issues, there remains a compelling motivation to use the conventional wet system approach [dry systems were examined but the wet systems are clearly favoured].

The condenser cooling towers will be in the form of mechanical draft, packed, wet, counter-flow type towers in six large cells. The cooling towers will be arranged in two banks of three cells on the north side of the plant building. The cooling towers will be constructed in reinforced concrete on top of concrete water basins. The towers will include internal concrete beams [note there will be no painted steel beams]. The tower design will provide easy access to the nozzles, drift eliminators and packing with access doors installed at the top of each tower cell. The fill-pack will be of the splash-grid type and the tower will have a design air speed not exceeding 3 m/s.

The cooling tower construction will have an extended basin lip and inlet air louvers [in polycarbonate material] will be fitted across the inlet openings to assist inlet air flow, prevent water spraying out and prevent accidental personnel entry to sump. Cooling tower floor design will cater for suitable grading to facilitate occasional maintenance. Cooling tower cell construction, splash-grid type pack and water distribution features are all selected to ensure minimum maintenance.

The cooling towers will include special enlarged discharge diffusers in order to maximise pressure recover and minimise fan power costs and to ensure minimum recirculation of hot air or nuisance carry-over to shaft buildings. The fan motor drives will be variable speed drives with 220 kW, 4-pole motors via a reducing angled gearbox which will be selected with an appropriate service factor.

The main water supply to each cooling tower cell will include automatic control valves. The make-up water supply, piping and control system will be included to provide for evaporation losses.

The condenser cooling tower system will be sized for the following process specification:

- Total heat rejection 135.0 MW
- Total condenser water flow 4200 l/s
- Number of cells 6 off
- Water flow per cell 700 l/s
- Fan motor rating per cell 220 kW
- Water temperature on 31.7°C
- Water temperature off 24.0°C
- Ambient condition 21.0°Cwb at 88 kPa

Equipment procurement specifications will allow for thermal ‘safety’ factors in water temperature.

8.4 Surface Bulk Air Cooler System

Each of the downcast shafts [No.11, No.12, No.13] will be served by bulk air coolers and each bulk air cooler will have three parallel cells. At each downcast shaft, the total mixed downcast will be made-up of air flow from the air cooler and a bypass of about 8% from the surface bank.

Each air cooler cell will be a horizontal spray heat exchanger in which the air is forced through an intense rain of chilled water in a horizontal concrete tunnel. In the spray chamber, cold water will be sprayed vertically upwards in a flat V-pattern into the warm air. Within the sprays, heat exchange will occur directly across the large surface area of the spray drops. Uniform distribution of water is achieved by the correct selection and direction of nozzles. Two stages of spraying will be used: cold water from the plant is sprayed in the first stage and then collected and re-sprayed in the second stage prior to returning to plant. The two stages will be arranged in counter-flow to the air flow to achieve high thermal efficiencies.

Ultimately, in subsequent phases, the bulk air cooler cells may well be upgraded into three-stage configurations for greater duty and producing colder downcast air. Thus the air cooler design will include 'real estate' for this purpose and this feature will allow versatility and flexibility in operational management and expansion possibilities in the future.

For the present purposes, the base-case has been designed to keep the downcast temperature at each of the shafts the same temperature 10.5°Cwb. However, as previously noted, because of the different draw-offs from each of the shafts at different depths for different purposes, there may be merits in producing colder-than-average air at one or two of the shafts. The expansion possibility to three stages will allow this to be done relatively easily. This will be examined as an optimisation opportunity at the next level of design detail. For the present purposes, the total downcast flow will be cooled to 10.5°Cwb in-shaft mixed condition.

The spray chambers will be constructed in concrete and will include doors for easy access to the internal manifolds. The water level in the chamber will be such that personnel can walk through chamber in water-proof boots. Bulk air cooler and floor design will cater for suitable grading with wash sumps. Bulk air cooler construction, spray system and mist eliminator format have all been selected for ensuring minimum maintenance. Water distribution will be achieved by manifold piping and multiple spray nozzles with relatively large orifice diameters to ensure that blocking is not a problem.

Where the cool air emerges from the chamber, mist eliminators will be installed to ensure that no water is carried out. Mist eliminator blades will be housed in stainless steel frames and will be of corrugated blade configuration with vertical vane-type profiles down which captured water will drain. Mist eliminators will provide 100% separation for drop sizes down to 17 μm at the design air speed. The drain system will be adequately sized to carry the full water load without re-entrainment. Access facilities for the mist eliminators will be included in detailed design.

The downcast shaft sizes and total downcast airflows will be:

• No.11 Shaft	10 m	973 kg/s
• No.12 Shaft	10 m	973 kg/s
• No.13 Shaft	11 m	1175 kg/s
Total		3121 kg/s

No.11 and No.12 Shaft bulk air coolers will be similar and each will be designed for 900 kg/s through the air cooler [with 8% drawn from surface bank]. Whereas the No.13 Shaft bulk air cooler will be larger and will be designed for 1087 kg/s through the air cooler [again with 8% drawn from surface bank]. However, wherever possible, the same equipment and mechanical modules will be utilised.

No.11 and No.12 Shaft bulk air coolers will have the following process specification [summer day 14h00]:

- Air cooler air duty [from after fans] 32.8 MW
- Air cooler air flow 900 kg/s
- Air temperature onto fans [ambient air] 21.0°Cwb
- Air temperature onto air cooler [after fans] 21.2°Cwb
- Air temperature off air cooler 9.5°Cwb
- Ambient air from above brow 73 kg/s
- In-shaft mixed air temperature at surface 10.5°Cwb

No.13 Shaft bulk air cooler will have the following process specification [summer day 14h00]:

- Air cooler air duty [from after fans] 39.6 MW
- Air cooler air flow 1087 kg/s
- Air temperature onto air cooler fans [ambient air] 21.0°Cwb
- Air temperature onto air cooler [after fans] 21.2°Cwb
- Air temperature off air cooler 9.5°Cwb
- Ambient air from above brow 88 kg/s
- In-shaft mixed air temperature at surface 10.5°Cwb

Bulk air cooler fans will force air flow through the air coolers and into the shaft and will provide for the pressure drop requirements of the air cooler, drift and bend/entry into the shaft. For each air cooler cell, the required air flow rate will be provided by 2 off fan units located at the air inlet side. The fans will be relatively low pressure, axial flow units with direct-coupled in-line motors complete with inlet cone and safety screen, silencers, self-closing doors, fan-motor sets, outlet diffuser ducting and support structures. Fan blade angles will be manually adjustable. Fan motor drives will be variable speed drives with direct-coupled, 6 pole IP 55 motors. The fan impeller blades will be manufactured from high-grade cast aluminium. To maximise energy efficiency, the fan casing will include a set of post-impeller static guide vanes. The fan casing will also be provided with a discharge diffuser for optimum pressure recovery and high efficiency. Noise level will not exceed 81 dBA at 6 m from fans.

No.13 Shaft bulk air cooler will be larger than those at No.11 and No.12 Shafts, however the fan selection must be such that the same fan-hub arrangements are applied to all units but the No.13 Shaft installation will have slightly larger motors [and blade angle set].

No.11 and No.12 Shaft bulk air coolers fans will have the following process specification:

- Total air flow at bulk air cooler 900 kg/s
- Number of cells 3 off
- Number of fan units per cell 2 off
- Air mass flow per fan unit 150 kg/s
- System total pressure nominal 0.6 kPa [at outlet from diffuser]
- Fan diameter 2 500 mm
- Motor 160 kW [6-pole]

No.13 Shaft bulk air cooler fans will have the following process specification:

• Total air flow at bulk air cooler	1087 kg/s
• Number of cells	3 off
• Number of fan units per cell	2 off
• Air mass flow per fan unit	181 kg/s
• System total pressure nominal	0.6 kPa [at outlet from diffuser]
• Fan diameter	2 500 mm
• Motor	200 kW [6-pole]

In total, with the three shafts and three bulk air coolers, there will be 18 off identical fan impellers with 12 off with 160 kW motors and 6 off with 200 kW motors. This includes a conservative over-sizing for resetting blades and upgrading duty should this ever be required.

8.5 Surface Conveyor Drift [CV201, 202] Air Cooler System

The surface conveyor drift to the West Plant will be cooled by 160 kg/s of refrigerated air from surface diverted from the downcast shafts at the Skip Discharge level. This will be supplemented with 60 kg/s of non-refrigerated air from the portal, see Section 4.5. In addition, provision will be made in the surface refrigeration facilities for chilled water supply to the bulk air cooler in the conveyor drift.

From the surface refrigeration plant, chilled water will be pump-fed down No.13 Shaft in an insulated 8" pipe, fed out on the mid-shaft Skip Discharge level and routed to the conveyor drift. Within the conveyor drift, the insulated pipe system will distribute chilled water to the bulk air cooling installation located 1.3 km up the conveyor drift CV-201. In the conveyor drift, the return pipe will be un-insulated to increase the cooling heat transfer. The chilled water flow will be 75 l/s and the cooling balance will be as shown in Table 8.2. The effective air cooling duty achieved underground will be 3.6 MW [see Section 6] made up the air cooler duty plus effective 'losses' from the pipe system.

Table 8.1 Process Conditions of Surface Conveyor Drift Cooling System

Water flow	75	l/s
Supply pipe loss in drift upto air cooler	2.0	°C
Air cooler effect of pipe loss	600	kW
Water temp onto air cooler	8.5	°C
Air cooler duty	2000	kW
Return pipe loss in drift from air cooler	3.0	°C
Air cooler effect of return pipe loss	1000	kW
Total air cooling	**3600**	**kW**

The bulk air cooler will comprise closed-circuit cooling coil modules and will be installed with suitable manifold piping and steel cowlings in permanent structures. Spray-wash systems will be included to minimise external fouling and resultant maintenance. The air cooler fans will be relatively low pressure direct-drive axial flow units with silencers which will force air through the air cooling coil bank.

These air coolers will be of similar design to those that will be deployed in the deeper underground workings and served off the underground plant [Section 9] and will be similar to those shown in Dwg 50C, 50D]. The conveyor drift CV-201 will be 3.1 km and the bulk air cooler will be located at a position about

1.3 km up the drift from the Skip Discharge level. There will be a suitable cubby [5 m wide and 20 m long] excavated on the side of the drift to house the air cooler.

During this prefeasibility study, the benefits were considered of having a separate closed-circuit water system [non-refrigerated] to directly cool the belt drive motors [with the heat being rejected on surface]. This system would then be an integral part of the conveyor system design. This approach would have cooling benefits that will need to be evaluated as an optimisation exercise at the next feasibility level of detail. The above approach adopted for this prefeasibility study is thus conservative.

8.6 Surface Refrigeration System Pumping and Pipe Systems

The following main pumping functions will apply:

- Condenser water pumps
- Glycol pumps
- Chilled water supply pumps to bulk air cooler[s]
- Re-spray pumps at each bulk air cooler
- Chilled water [evaporator] return pumps from each bulk air cooler
- Pre-cooling tower recirculating pumps
- Chilled water [evaporator] pump for chilled-water-to-underground refrigeration system
- Conveyor drift cooling water circulating pumps

In general, the pumps will be horizontal split-case, single-stage, centrifugal sets directly coupled to four-pole motors. Horizontal split-case units will be used because of their general higher efficiency and ease of maintenance considerations. However, the exceptions will be the surface conveyor drift cooling system pumps which will be multistage units. The pumps will all have flooded suctions to avoid cavitation under all circumstances and suction pipes and sumps will be arranged to prevent the formation of vortices.

The pumps will all be fitted with:

- Isolating valves at suction
- Non-return and isolating valves at discharge
- Pressure gauges on delivery header
- Flexible rubber couplings to suction [and discharge] piping
- Drain stopcock for drainage when pump is isolated

The piping will be generally painted steel but within the bulk air coolers it will be hot-dipped galvanised. The main condenser water piping will comprise 2 x 900 m to the cooling towers and 2 x 900 mm back to the condensers. The main chilled water piping overland to each bulk air cooler will be 500 mm supply and return. Other main piping pieces and sections will range from 400 mm to 1000 mm.

All valves, fittings and pipes will be Class 150 [unless pump and valve couplings differ]. With the exception of those on the discharge side of the Conveyor drift cooling water circulating pumps which will be class 250 [unless pump and valve couplings differ]. The following general valve types will be used:

- **Gate valves** will be cast iron, wafer type knife-gate valves with hand-wheel operation.
- **Isolating butterfly valves** will be cast iron, wafer type with manual geared actuators.
- **Check valves** will be cast iron, wafer type swing check valves.

- **Actuated flow control valves** will be installed in the condenser water lines to each machine - these will only be automated isolating valves and not flow control valves.

The pipe thermal insulation will be applied to all piping [and fittings] which have a potential for condensation. For underground piping to the conveyor drift, the general insulation will comprise phenolic foam vacuum-packed in a 4 ply mylar bag which provides a vapour barrier and encapsulated in a steel sleeve for mechanical protection. For surface chilled water piping, the general insulation will comprise a closed-cell nitrile elastomeric product encapsulated in a steel sleeve for mechanical protection.

8.6.1 Condenser Water Pumps

The cooling towers will be arranged in two banks of three cells and each bank will be served by 3 off operational condenser water pumps [plus 1 off piped-in standby pump-motor set]. The condenser pumps will circulate water from the cooling tower sump[s] to the condensers and back to the spray manifolds at top of towers. The required pump pressure will be dominated by the static head of the towers, spray nozzles, strainers and condenser heat exchangers. The total condenser water flow will be 4200 l/s and performance specifications for each pump will be:

- Pressure differential 0.28 MPa
- Water flow rate 700 l/s
- Absorbed power 261 kW
- Nominal motor rating 300 kW

8.6.2 Glycol Pumps

The glycol pumping system will circulate glycol in closed circuit, through the glycol refrigeration machine and the ice tube banks and back to the refrigeration machine. This function will be served by 2 off operational glycol pumps [plus 1 off piped-in standby pump-motor set]. The required pump pressure will be dominated by the ice bank tubes and evaporator heat exchanger. The total glycol flow will be 830 l/s and performance specifications for each pump will be:

- Pressure differential 0.28 MPa
- Water flow rate 415 l/s
- Absorbed power 155 kW
- Nominal motor rating 185 kW

8.6.3 Chilled Water Supply Pumps to Bulk Air Cooler[s] System

The chilled water supply pumps will all be located in the plant house adjacent to the ice dam. These pumps will supply water to the bulk air coolers at each shaft. This function will be served by 3 off operational chilled water pumps [plus 1 off piped-in standby pump-motor set]. The required pump pressure will be dominated by overland pipe friction and spray nozzle requirements. The total flow will be 1796 l/s and performance specifications for each pump will be:

- Pressure differential 0.30 MPa
- Water flow rate 599 l/s
- Absorbed power 239 kW
- Nominal motor rating 275 kW

8.6.4 Re-spray Pumps at each Bulk Air Cooler

These pumps will re-spray water in the bulk air coolers to enhance thermal efficiency and will be located adjacent to each of the surface bulk air coolers. Each bulk air cooler will have 1 off operational re-spray water pump [plus 1 off piped-in standby pump-motor set]. The required pump pressure will be dictated spray nozzle requirements.

For No.11 and No.12 Shaft air coolers, the specifications for each pump will be:

- Pressure differential 0.20 MPa
- Water flow rate 560 l/s
- Absorbed power 149 kW
- Nominal motor rating 185 kW

For No.13 Shaft air cooler, the specifications for each pump will be:

- Pressure differential 0.20 MPa
- Water flow rate 676 l/s
- Absorbed power 180 kW
- Nominal motor rating 220 kW

8.6.5 Chilled Water [Evaporator] Return Pumps [from each bulk air cooler]

The chilled water [evaporator] pumps will be located adjacent to each of the surface bulk air coolers. These pumps will return water to the main base load water chiller evaporators and hence to the ice dam. At each bulk air cooler there will be 1 off operational evaporator water pump [plus 1 off piped-in standby pump-motor set]. The required pump pressure will be dominated by overland pipe friction and the two evaporator heat exchanger in series.

For No.11 and No.12 Shaft air coolers, the specification for each pump will be:

- Pressure differential 0.25 MPa
- Water flow rate 560 l/s
- Absorbed power 187 kW
- Nominal motor rating 220 kW

For No.13 Shaft air cooler, the specification for each pump will be:

- Pressure differential 0.25 MPa
- Water flow rate 676 l/s
- Absorbed power 226 kW
- Nominal motor rating 250 kW

8.6.6 Pre-cooling Tower Recirculating Pumps

The service water make-up will be provided from the regional water supply to the sump of the pre-cooling tower. From this sump the water will be circulated through the pre-cooling tower. This function will be served by 1 off operational pump [plus 1 off piped-in standby pump-motor set]. The required pump pressure will be dominated by the static head of the towers and spray system. The specification for each pump will be:

- Pressure differential 0.20 MPa
- Water flow rate 350 l/s
- Absorbed power 93 kW
- Nominal motor rating 110 kW

8.6.7 Chilled Service Water [Evaporator] Pumps for Water-to-Underground Refrigeration System

These evaporator pumps will be located adjacent to the pre-cooling tower sump will pump water through the dedicated plant evaporators to the chilled service water dam. The general average process condition for these pumps will be 225 l/s [24 hr ave]. However, there will be diurnal variations in service water demand and this system will include a storage dam [5 Ml] for the chilled water. There will be control variations on this flow rate and, for the present purposes, the pump selection flow has been taken as 300 l/s. For this application, there will be 1 off operational pump [plus 1 off piped-in standby pump-motor set]. The required pump pressure will be dominated by overland pipe friction, evaporator heat exchanger and static head in dam. The specifications for each pump will be:

- Pressure differential 0.33 MPa
- Water flow rate 300 l/s [225 l/s 24 hr ave]
- Absorbed power 132 kW
- Nominal motor rating 160 kW

8.6.8 Conveyor Drift Cooling Water Circulating Pumps

The conveyor drift cooling system will require 75 l/s which will be circulated down No.13 Shaft to Skip Discharge level and then into the conveyor drift for 1.3 km to the air cooler and then returned to surface [via the reverse route]. This will in an independent 8" insulated pipe system. This water will be pumped from the surface chilled water dam, flow in closed circuit through the air cooler and report back to the cold pre-cooling tower dam compartment. For this application, there will be 1 off operational pump [plus 1 off piped-in standby pump] and the specifications for each pump will be:

- Pressure differential 2.1 MPa
- Water flow rate 75 l/s
- Absorbed power 210 kW
- Nominal motor rating 250 kW

8.7 Note on Chilled Water-to-Underground Reticulation System

The chilled water-to-underground will be supplied from the cold water dam [5 Ml] on surface and will serve two purposes: water to conveyor drift air cooler and service water to the mining levels. There will be two independent pipe systems.

The first will be the piping for the conveyor drift cooler system which will circulate 75 l/s at constant flow. This will include the pair of 8" insulated pipe columns [supply and return] in No.13 Shaft barrel. This will be a pressurized system with the circulating pump on surface and the water flow will be in close-circuit.

The second will be the service water supply to the main underground service water dam [5 Ml] located at elevation -685 level, off No.13 Shaft. This will provide 150 l/s on average with the flow varying cyclically as the demand dictates. For the present purposes[a], it was decided that this pipe would be an 8" open-ended column [insulated] which will be gravity fed and installed in No.13 Shaft barrel[b]. From the underground service water dam, the service water will be gravity fed to the individual working levels, Section 9.9.

a] At the next level of design detail, consideration should be given to installing a turbine-generator to generate power from this water pressure dissipation. This will require capital for a high pressure column and the turbine-generator equipment but will be attractive from power generation perspective.
b] Pipes in No.13 Shaft barrel will include at least: 2 x 8" water for Conveyor drift cooler, 1 x 8" service water supply, make-up water [un-cooled] to underground, mine water pump column[s].

8.8 Surface Plant Electrical Requirements

The motor and equipment list is given Table 8.2. The total installed rating will be about 31 MW with the major consumers off medium voltage 4.16 kV and the remaining <1% off low voltage 480 V.

The electrical requirements have been considered as required for costing purposes and for determining space requirements. The main MV and LV switchgear will be located in a common, sub-divided, electrical room located on the west side of the plant building. The MV panel will include the main incomers, the refrigerant compressor motor feeders, the main pump motors and the transformer feeders. The MCC will supply the auxiliaries, the pump-out unit, electric overhead cranes and lighting and small power. The control room and PLC equipment will also be accommodated in the same area.

Table 8.2 Surface Refrigeration Plant Motor and Equipment List

SURFACE REFRIGERATION SYSTEM						
MAIN MOTOR LIST	**No. Installed**		**Voltage**	**Rated each**	**Rated total**	**Absorbed summer**
30 Sept 2012						
Refrigeration compressors						
Refrigeration compressors	12		4.16 kV	1800 kW	21,600 kW	20,000 kW
[incl: base-load chillers, glycol chiller + service w ater plant]						
Fans						
Bulk air cooler fans at No.11 and 12 Shafts	12		4.16 kV	160 kW	1,920 kW	1,320 kW
Bulk air cooler fans at No.13 Shaft	6		4.16 kV	200 kW	1,200 kW	797 kW
Condenser cooling tower fans	6		4.16 kV	220 kW	1,320 kW	990 kW
Service water pre-cooling tower fan	1		480V	110 kW	110 kW	83 kW
Pumps						
Chilled water supply pumps to bulk air coolers	3	[+1][a]	4.16 kV	275 kW	825 kW	718 kW
Bulk air cooler return [evaporator] pumps No.11 and 12 Shafts	2	[+2][a]	4.16 kV	220 kW	440 kW	374 kW
Bulk air cooler return [evaporator] pumps No.13 Shaft	1	[+1][a]	4.16 kV	250 kW	250 kW	226 kW
Bulk air cooler re-spray pumps at No.11 and 12 Shafts	2	[+2][a]	4.16 kV	185 kW	370 kW	298 kW
Bulk air cooler re-spray pumps at No.13 Shaft	1	[+1][a]	4.16 kV	220 kW	220 kW	180 kW
Glycol pump	2	[+1][a]	4.16 kV	185 kW	370 kW	310 kW
Condenser water pumps	6	[+2][a]	4.16 kV	300 kW	1,800 kW	1,566 kW
Conveyor drift cooler circulating pump	1	[+1][a]	4.16 kV	250 kW	250 kW	210 kW
Service water plant evaporator pump	1	[+1][a]	4.16 kV	160 kW	160 kW	132 kW
Service water pre-cooling tower pump	1	[+1][a]	480V	110 kW	110 kW	93 kW
Miscellaneous						
Lights, ventilation, services, etc	lot		480 V	varies	70 kW	30 kW
Overhead crane	1		480 V	11 kW	11 kW	
Water treatment pump	1		480 V	3 kW	3 kW	2 kW
Refrigerant pump-out unit	1		480 V	11 kW	11 kW	
Aeration blower	1	[+1][a]	480 V	11 kW	11 kW	7 kW
					31,051 kW	**27,335 kW**
Future expansion						
Third stage re-spray pumps at No.11 and 12 Shafts	2	[+2][a]	4.16 kV	185 kW	370 kW	298 kW
Third stage re-spray pumps at No.13 Shaft	1	[+1][a]	4.16 kV	220 kW	220 kW	180 kW
Note a. Refers to fully connected standby.						

The motors for the refrigeration machine compressors [1.8 MW] and the main drives will all be 4.16 kV. The principal power consumers are the refrigeration compressors, fans and pumps. For the normal duty points, with six machines operating the total power consumption will be about 27 MW_E.

The cooling tower fans and the bulk air cooler fans will have variable speed control and provision will be made for suitable VSD equipment. In addition, the electrical provision will include:

- Fire detection and fire suppression equipment will be provided.
- Earthing and lightning protection equipment
- Battery tripping units [dual charging and multiple batteries]

8.9 Surface Plant Control Philosophy

The instrumentation and control system will include a centralised system-supervisory PLC. Each refrigeration machine will be factory fitted with a dedicated PLC and HMU serving the instrumentation and control functions on that machine. The machine PLCs will communicate with the supervisory PLC and this will be responsible for managing the refrigeration machine and controlling the air cooler fans, cooling tower fans, pumps and the control valves [including blow-down, make-up control, transfer, strainer back-wash, condenser water isolation].

The control will include normal operation, start-up and shut-down as well as all alarms, trips, interlocks and safety devices. Interface with mine-wide monitoring system will be through a fibre-optic link to the System PLC.

The main process controls will include the control of: water transfer from air cooler to condenser water circuit, condenser water blow-down and make-up to maintain acceptable water qualities. Control will be based on instruments measuring water levels in air cooler and cooling tower sumps and instrumentation measuring condenser water salinity [by conductivity].

Refrigeration machine load will be controlled from 100% to 25% by pre-rotational guide vanes. Control of pre-rotational guide vanes will automatically limit maximum absorbed compressor motor power and control the leaving chilled water temperature.

The overall system will be designed for maximum flexibility and will continue to operate successfully in the event of equipment trips or equipment failure. Fully-piped in stand-by pumps will be selected for all critical components and an automatic start of stand-by equipment will be controlled from the central System PLC.

The ice storage dam will be an important part on the control system in terms of energy management. Within the dam, ice will be formed on the outside of the tubes during the cold part of the day and then melted by the circulating water during the warm part of the day. The thermal storage will allow peak load damping and optimisation of power tariff structures. This function will also be controlled from the central System PLC.

8.10 Surface Plant Make-up Water and Water Treatment Considerations

Make-up water for the condenser circuit will be required to replace water lost through evaporation and carry-over in the cooling towers and the water blow-down required to keep the TDS levels below the design water quality criteria, Section 11.

The condenser circuit will typically require corrosion inhibitors, anti-scalant and biocide programs, as well as a blow-down facility to control the TDS levels. The blow-down will be taken from the feed to the cooling towers and routed to the mine service water dam. The chilled water circuit will pick-up pure water condensate in the bulk air coolers and this water quality will generally be excellent. However, depending on local conditions [e.g. pollens etc], a biocide programme may be required. The excess water due to condensation will be transferred to the cooling tower system.

There are indications of relatively high levels of SiO_2 in the surface water supply which could be related to the particularly high quartz content in the underground rock formations. This is presently being investigated by RCM and could result in the need for special water treatment in this regard.

It is anticipated that the mine will engage an outside agency to advise and implement water treatment programs. These companies will usually have an on-going contract to conduct regular sampling and to supply the necessary water treatment chemicals. Where required, continuous monitoring and dosing equipment will be supplied as proprietary packages and will be maintained as part of the contract.

9 UNDERGROUND REFRIGERATION SYSTEM

There will be a single centralised underground refrigeration plant chamber located near the mining block off the Exhaust Vent level. This location will be near the main return ventilation system which will be used for heat rejection from the refrigeration plant. The refrigeration machines will provide cold water in an insulated closed-circuit network to cooling coils distributed singly or grouped into multi-coil bulk air coolers situated strategically throughout the underground workings. Some of the air coolers will remain in one location but many of the units will be moved from time-to-time as the development and production progresses. Thus the underground refrigeration system will comprise two main components: the refrigeration machines and the secondary air cooler system [including distribution system]. As noted, the underground cooling will also be supplemented by the supply of chilled service water which will be used for dust control, localized cooling sprays and mine service needs, see later.

The required secondary air cooler overall duty will be 34.5 MW and the underground refrigeration plant must be capable of providing the following cooling capacity.

- Total refrigeration machine capacity 40.0 MW
- Total secondary air cooler duty [at air coolers] 34.5 MW
- Thermal losses and pump effects 5.5 MW

Part of the ‘thermal losses’ will be from the pipes to the ventilation and this will provide some useful mine cooling effect which is accounted for in the modelling.

The installation will ultimately comprise six 8 MW refrigeration machines [five running, one stand-by]. There will be three plants in each of two machine rooms, six condenser water pumps, six chilled water circulating pumps, two condenser cooling towers [with dam] and a warm water dam for water returning from the closed-circuit network. The layout has been designed such that the plant chambers can be mined and constructed in two distinct phases to suit the build-up in cooling requirements.

The overall system is described in the set of pre-engineering drawings prepared for Pre-feasibility design and costing purposes, see Drawing schedule.

The difference between the process conditions and the equipment selection specifications must be noted. The latter is a more stringent requirement that incorporates thermal and physical design safety factors for which the equipment must be supplied and guaranteed. The process conditions describe the actual process design requirements for a specific set of conditions.

9.1 Underground Refrigeration Machines

There is little or no choice in the type of refrigeration machine for underground operation. The machine will use refrigerant R134a and will include high-speed, multistage, centrifugal compressors and shell-and-tube heat exchangers. These machines are used in the mining industry [mainly South Africa ultra-deep mines] and have a proven track record of reliability.

There will be insignificant seasonal variation in load because of the underground location and the depth. Thus the need for operational flexibility is not dominant and a small number of large machines will be preferred. The maximum size of an individual machine is limited by transportability of the heat exchangers, both in terms of physical size and mass for slinging limitations. The typical large machine will have 8.0 MW refrigeration capacity and will have heat exchangers, with the water boxes removed, of mass of about 16 tons each and will be 8.0 m long, 1.5 m wide and 1.8 m tall [these components will need to be slung down shaft].

Once underground refrigeration is introduced, the required duty of the plant will quickly rise to exceed 50% of the final capacity and thereafter the rate of increase will slow. To accommodate this load profile and the machine size, it is proposed that there will be five operational machines. The reliable operation of this system will be critical and a full spare piped-in machine will be installed to allow for periods of maintenance. Three of these six machines will be installed in a first phase with the other three will be installed later.

The machines will operate in parallel [on both evaporator and condenser sides] and this arrangement will allow the system to adjust to changes in chilled water demand [within limits of minimum water velocity in evaporators]. Long term changes will be accommodated by using different pump impellers, whilst short term changes will rely on flow control valves. For process flow design purposes, a chilled water flow rate of 130 l/s per machine has been selected and the plant temperature drop will be 14.7°C. The refrigeration machines will be identical packaged units including: multi-stage centrifugal compressors, shell-and-tube evaporator and condenser heat-exchangers, lubrication system, interconnecting piping and instrument and control systems. The refrigerant will be R134a and the compressor motors will be factory installed, coupled and aligned prior to disassembly for transport underground. Stable capacity control will be achieved by pre-rotational vanes down to 25% of load. Thermal insulation will be applied to all surfaces that have potential for condensation. The individual machines will have equipment selection specifications as follows:

Evaporator
- Cooling duty — 8.00 MW
- Water flow — 130 l/s
- Inlet water temp — 18.7°C
- Outlet water temp — 4.0°C
- Fouling factor — 0.20 m²°C/kW
- Evaporating temp — 1.5°C

Condenser
- Duty — 10.50 MW
- Water flow — 250 l/s
- Inlet water temp — 38.0°C
- Outlet water temp — 48.0°C
- Fouling factor — 0.30 m²°C/kW
- Condensing temp — 52.0°C

Compressor
- Type — Multi-stage centrifugal
- Absorbed motor power — 2.50 MW

The overall combined machine system duty [total five plants] will be:

Total evaporator chilling duty

- Cooling duty 40.0 MW
- Water flow 650 l/s
- Inlet water temp 18.7°C
- Outlet water temp 4.0°C

Total condenser heat rejection duty

- Duty 52.5 MW
- Water flow 1250 l/s
- Inlet water temp 38.0°C
- Outlet water temp 48.0°C

In the mine development phase, the primary ventilation available for development will be limited to 575 kg/s up to year 2020. Of this, it can be expected that some 500 kg/s [87%] will be available for heat rejection and this flow rate will be adequate to serve the heat rejection of three refrigeration machines.

9.2 Underground Plant Room Considerations

Figure 9.1 shows the general layout of the refrigeration facility.

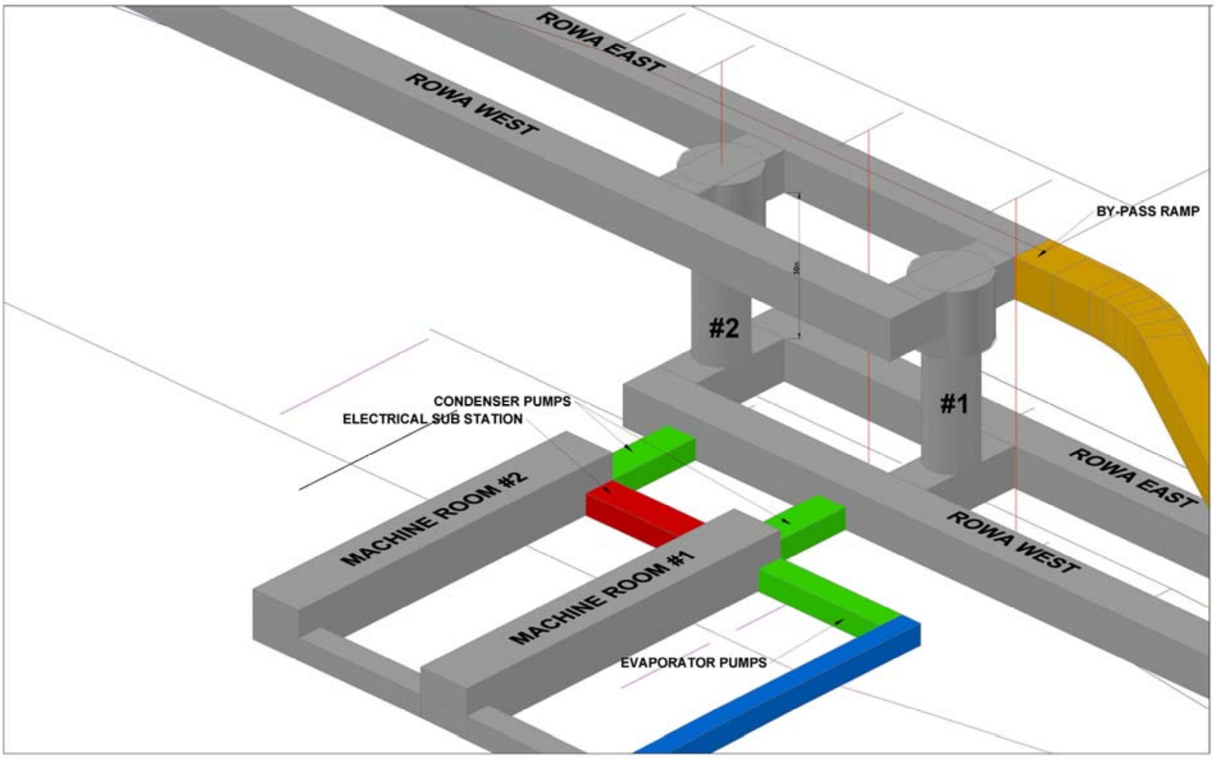


Figure 9.1 Underground Refrigeration Plant Excavation Layout

9.2.1 Plant room layout

Various orientations of the refrigeration machines were investigated, particularly with respect to end clearances of 8 m required for tube maintenance operations and rock mechanic considerations. The most compact layout proved to be two machine rooms each 46 m long x 10 m wide x 9 m high with the machines arranged in line with alternate short [5 m] and long [8 m] gaps between machines. The machines will be connected to water manifolds running the length of each chamber, with chilled water pumps and condenser water pumps grouped in common pump chambers adjacent to their respective dams [as opposed to dedicated pumps at each machine] with associated space savings.

9.2.2 Pump-out unit

There will be one central pump-out unit and receiver to service all the machines in the plant room with a capacity at least 1.2 times the charge in one machine. The pump-out unit will be permanently located in machine room 1 and installed with liquid and gas lines piped in to each refrigeration machine. The dimensions of the receiver will be chosen to suit the spacing of the refrigeration machines.

9.2.3 Gantry and crane

Each machine room will be equipped with a gantry down the entire length carrying an overhead electric travelling crane with a hoisting capacity of 20 tons. The legs of the gantry will also support the main piping manifolds behind the refrigeration machines. The crawls over the chilled water pumps and the condenser water pumps will extend into the machine rooms under the crane gantries to simplify handling. The gantry will also support lighting.

9.2.4 Drainage

The floor of each chamber will be graded towards a drain running longitudinally along the length of the chamber, under the pipe manifold, flowing towards a central sump which will also accumulate water from the two pump chambers.

9.2.5 Ventilation

Although the refrigeration plant will be located adjacent to the return ventilation infrastructure, there will be a direct connection to an airway with a fresh air position nearer the downcast shafts. This will allow for the allocation of cool fresh air to serve the ventilation and cooling of the plant chambers. There will be a large pressure differential between the fresh air and the return airway systems and substantial walls with airlocks for personnel and regulators to control the flow of ventilation air through the machine rooms will be required. It is anticipated that the main compressor motors will be water-cooled, which will greatly reduce the heat load within the refrigeration chamber.

9.3 Underground Heat Rejection System

Heat rejection will be achieved in condenser cooling towers in the form of spray-filled vertical excavations rejecting heat into the return ventilation. The refrigeration plant has been sited adjacent to the two main ROWA return airways which ultimately will carry a flow rate of up to about 1700 kg/s. For heat rejection purposes, some 1200 kg/s [70%] of this air will be utilised in two vertical cooling towers. The vertical towers will be located above a condenser water dam over which the inlet air will flow, turning vertically into the tower barrel and the air will discharge from the towers at a higher [30 m] elevation. The ‘excess’ air flow of about 500 kg/s will bypass the towers through an inclined airway and connect directly to the two upper ROWA airways.

The condenser water pumps will draw cooled condenser water from the large sump under the two cooling towers adjacent to the refrigeration plant room. The water will be pumped through the condensers of the refrigeration machines [arranged in parallel] into a common return line feeding the cooling towers. The system will have two cooling towers as this will provide flexibility in operation yet enjoy the benefits of economy of scale. Each cooling tower will be designed for the heat rejection capacity of three refrigeration machines.

The condenser pumps will be located in two pump chambers, one for each machine room, close to the cooling tower sump. This arrangement has the advantages of saving space, reduces the length of the suction lines yet still provides for a common stand-by pump. Since the sump is very shallow, to avoid overly restricting the air flow into the cooling towers, the floor of the cooling tower sump should be elevated [by about 1 m] to provide a positive suction head on the pumps.

The selection of two towers was based on the available quantity of air and dimension limits imposed by normal rock engineering considerations. This arrangement also provides acceptable turn-down ratios for the spray systems as well as operational flexibility for maintenance purposes. Open towers, as opposed to packed towers, have been selected to keep maintenance down to a minimum. Should maintenance be required on either of the two towers, the system has been designed so that both water and air flow rates can be increased in the remaining operating tower, so that at least three refrigeration machines can continue to operate during the maintenance period.

The diameter and height of the tower were chosen to ensure good contact time for the air and water, good mixing and to keep the rain density within design guidelines for both normal and maintenance conditions. The barrel diameter of each tower will be 10 m and the design air velocity in the main barrel will be about 6 m/s. The minimum functional height below the sprays will need to be 25 m. There will be a drop-out zone above the sprays to reduce the carry-over of water droplets to a minimum. In this zone, the velocity of the air is halved to 3 m/s for a height of 5 m above the sprays, before the air turns and accelerates through the connecting airways into the main return ventilation returns. The functional working height for the towers will be 30 m. The air inlets at the bottom of the towers will be flared for aerodynamic and uniform distribution considerations.

The general process specification for each of the two towers will be:

- Cooling duty 26.3 MW
- Water flow rate 625 l/s
- Inlet water temperature 48°C
- Outlet water temperature 38°C
- Air flow rate 600 kg/s
- Inlet air temperature [wb/db] 30/32°C
- Barometric Pressure 110 kPa
- Air velocity in tower 6.4 m/s
- Factor of merit 0.5

During maintenance, one tower will be shut-down and the operating tower will cope with the heat rejection from three machines. Both the air and water flow rates will increase, which will reduce the tower performance and the return water temperature will increase [hence reducing efficiency and output]. The refrigeration machine specifications will ensure that they continue to operate at these elevated condensing temperatures even if the refrigeration output drops slightly during this period.

Underground cooling towers sometimes have had problems with water spillage at the bottom of the towers. The design of the cooling tower sump arrangement will avoid water containment issues by creating a sump with a footprint much larger than that of the tower. The high air velocities in the intakes to the towers will also assist in containing the water.

It is also proposed to extend one limb of the sump out into one of the incoming airways and help keep the dam shallow. Increasing the plan area of the sump will allow the depth of the sump to be reduced, for the same volume of water, which will reduce excavation and civil construction costs. The sump depth will be 1 m and this will provide a minimum volume of about 500 m^3 [about double the piping capacity]. The floor level under the condenser cooling towers will be elevated to ensure good flooded suction conditions for the pumps.

The specification of the spray systems for the cooling towers will take into account the range of duties to be expected under different conditions, particularly when not all machines are operating. For example, if only two machines operate, the condenser water will be shared between the two towers, to take advantage of the full air quantity available. Although the water distribution will not be as efficient, the water loading in each tower will be less demanding and the net effect will be acceptable. Conversely, during maintenance of one tower, the water flow rate in the other tower will increase by 50%. Therefore, the sprays will be able to cater for flows ranging from 50% to 150% of design and still distribute the water uniformly. This requires the appropriate design of spay manifold and nozzle selection - the ‘nozzle box’ will be anchored onto the ledge created at the top of each tower. The feeder pipes up to the ‘nozzle box’ will stand within the cooling tower barrels and this vertical riser will be supported on a ducks-foot in the sump and will be located laterally by means of clamps bolted into the sidewall of the tower.

In order to conduct maintenance operations in either of the towers, it will be necessary to reduce the airflow through the tower. This will be achieved by restricting the airflow in the horizontal airway at the top of the tower using temporary regulators.

9.4 Underground Secondary Air Cooler System

For the ultimate life-of-mine scenarios, there will be numerous underground secondary air coolers in installations ranging from 0.5 MW to 3 MW with a total air cooling effect of 34.5 MW. Typically these will be made-up of 0.5 MW, 1.0 MW, 1.5 MW, 2.0 MW and 3.0 MW installations. Table 9.1 gives a typical breakdown in air units of different sizes and, in the fully established life-of-mine scenario, there will be about 25 to 30 units. Figure 9.2 shows the typical distribution of these air coolers for the design year 2031 as well as the chilled water reticulation system comprising 500 mm, 250 mm and 150 mm branch piping.

Table 9.1 Underground Air Cooler Unit Distribution

	RATING OF AIR COOLER UNIT						
	0.5 MW	1.0 MW	1.5 MW	2.0 MW	3.0 MW		
Rail level		2					
Rail level		2		2			
Rail level		4			1		
Intake level			2				
Intake level	1		1	2			
Intake level	2	3			1		
Crusher zone rail tips	1						
Railshops		3					
Total units	4	14	3	4	2	27	off
Total rating	2.0	14.0	4.5	8.0	6.0	34.5	MW

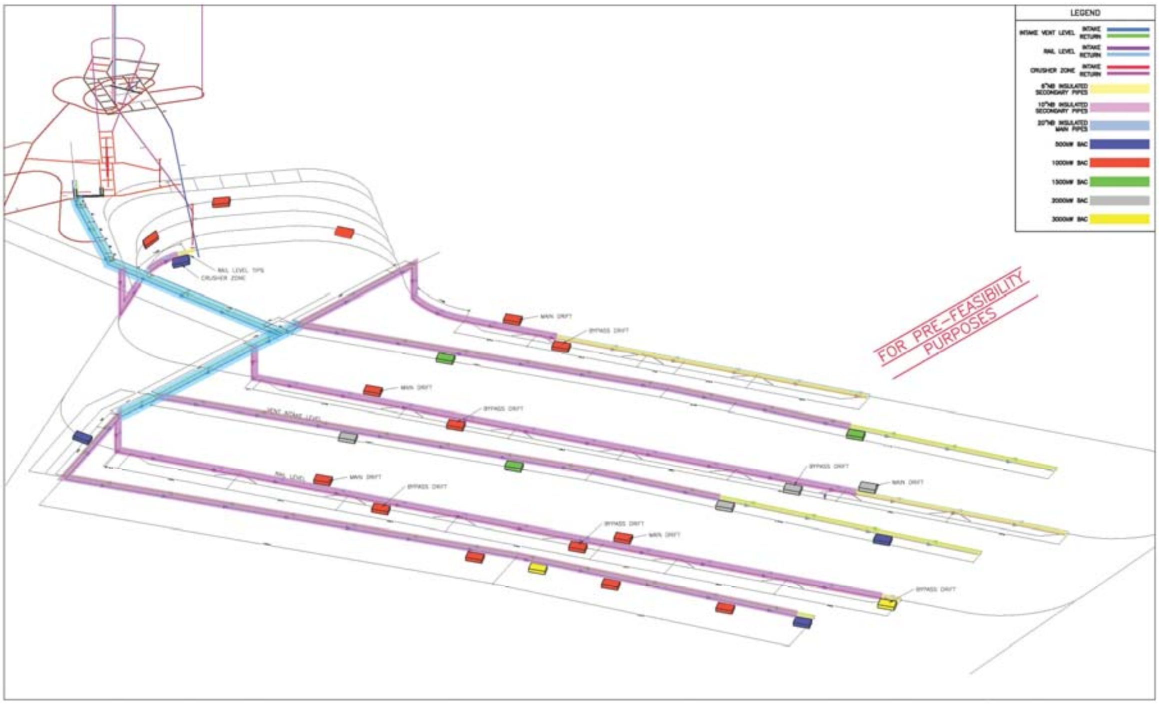


Figure 9.2 Underground Chilled Water Pipe Layout and Air Cooler Locations

These secondary air coolers will be in the form of closed circuit cooling coil modules, Figure 9.3 and Figure 9.4. For each air cooler, multiple coil modules will be installed with suitable manifold piping and steel cowlings in semi-permanent structures. Within the cooling coils, heat exchange will occur across the large surface area of finned tubes. Typically coil tube diameters will be 16 mm with a fin-pitch of 250 per m. Inlet air cooler fans will force air through the cooling coil assemblies - these fans will be relatively low pressure direct-drive axial flow units with silencers. External spray-wash systems will be fitted to minimise external fouling.

Figure 9.3 Multiple-coil air cooler module

Figure 9.4 Cooling coil unit

The main chilled water piping will comprise a 500 mm insulated system near the plants reducing as the network splits-up down to ultimately 150 mm insulated pipe sections. Thermal insulation will be applied to all piping [and fittings, vessels] which have a potential for condensation. The insulation will have a minimum thickness to ensure that no condensation occurs and the general piping insulation will apply 40 mm thick phenolic foam vacuum packed in a 4 ply mylar bag [providing a vapour barrier] and encapsulated in a steel sleeve which provides a mechanical barrier.

The chilled water circulating pumps will draw the return water from a dam adjacent to the refrigeration chamber. For ease of operation, the capacity of the warm water dam should be sufficient to fill the backbone of the underground circuit and the proposed dam capacity will be 800 m^3. Only one chilled water pump will start at a time and the dam volume will be sufficient to contain any transients before a full return flow is established. At full flow [650 l/s], the dam will take about 25 mins to empty. The dam wall height will be 4 m to satisfy both mining and civil construction aspects as well as long term rock engineering considerations.

The water will be pumped through the evaporators of the refrigeration machines, operating in parallel, and thereafter into a single chilled water supply line [500 mm] to the closed-circuit cooling coil system. The chilled water pumps will provide the hydraulic head for the entire network and will have sufficient reserve to meet the ultimate pressure when the network extends to the extremities of the mining area. The backbone will be sized to have a low pressure drop compared to the cooling coils so that flow control devices will be kept to a minimum.

9.5 Underground Refrigeration Pumping and Pipe Systems

There will be two main pump stations: the chilled water [evaporator] pumps and the condenser water pumps [both pump sets include a fully piped in stand-by].

The pumps will be horizontal split-case, single-stage, centrifugal sets directly coupled to four-pole motors. Horizontal split-case units will be used because of their general higher efficiency and ease of maintenance considerations. The pumps will be fitted with:

- Isolating valves at suction
- Non-return and isolating valves at discharge
- Pressure gauges on delivery header
- Flexible rubber couplings to suction [and discharge] piping
- Drain stopcock for drainage when pump is isolated

Pumps will have flooded suctions to avoid cavitation under all circumstances and suction pipes and sumps will be configured to prevent the formation of vortices.

The piping within the cooling towers, including standpipes and nozzle boxes will be stainless steel 304 and all other piping will be hot-dipped galvanised steel. The main condenser water piping will be 800 mm diameter and the main chilled water piping will be 500 mm diameter.

Valves, fittings and pipes on the suction side of all pumps will all be Class 150 [unless pump and valve couplings differ]. Valves, fittings and pipes on the discharge side of all pumps including cooling tower and chilled water ‘field’ piping will all be Class 250 [unless pump and valve couplings differ]. The following general valve types will be used:

- **Gate valves** will be cast iron, wafer type knife-gate valves with hand-wheel operation.
- **Isolating butterfly valves** will be cast iron, wafer type with manual geared actuators.
- **Check valves** will be cast iron, wafer type swing check valves.
- **Actuated flow control valves** will be installed in the condenser water lines to each machine - these will only be automated isolating valves and not flow control valves.

9.5.1 Chilled Water [Evaporator] Pumps

The chilled water pumps will be located in a single pump chamber close to the warm water dam. This arrangement saves space and allows short suction lines. The underground circuit will eventually expand to the extremities of the mining area and the chilled water pumps will have sufficient reserve to meet the ultimate pressure needs. There will be five operating pumps and one piped-in standby. The performance specifications for **each** chilled water pump will be:

- Pressure differential 0.9 MPa
- Water flow rate 130 l/s
- Absorbed power 156 kW
- Nominal motor rating 185 kW

9.5.2 Condenser Water Pumps

The required head on the condenser pumps will be dominated by the static head of the cooling tower, the spray nozzle pressure and the pressure drop across the condenser heat exchanger. When the refrigeration machines are not all operating, the pipe friction will drop and the pressure required for the sprays will drop, causing a slight, but acceptable, increase in flow per machine, with a corresponding increase in the pressure drop across the heat exchanger. Conversely, during maintenance of one of the cooling towers, three condenser pumps will deliver to the other tower and the pressure required on the sprays will double, causing a slight, but also acceptable, drop in flow per machine.

The condenser pumps are located in two pump chambers close to the cooling tower sump and close to each other. This arrangement has the advantages of saving space, operating in fresh air and allows for short suction lines. Suction conditions will be enhanced by raising the floor of the cooling tower basin by about 1 m. Note that these pumps will not be subjected to frequent stopping and starting. There will be five operating pumps and one piped-in standby. The performance specifications for **each** condenser water pump will be:

- Pressure differential 0.6 MPa
- Water flow rate 250 l/s
- Absorbed power 200 kW
- Nominal motor rating 250 kW

9.6 Underground Plant Electrical Requirements

The motor and equipment list is given in Table 9.2. The total installed rating will be about 13 MW with the major consumers off medium voltage 4.16 kV and the remaining <1% off low voltage 480 V.

Table 9.2 Underground Refrigeration Plant Motor and Equipment List

UNDERGROUND REFRIGERATION SYSTEM MAIN MOTOR LIST 30 Sept 2012	No. Installed	Voltage	Rated each	Rated total	Absorbed
Refrigeration compressors					
Refrigeration compressors	5 [+1][a]	4.16 kV	2700 kW	13,500 kW	12,500 kW
Pumps					
Chilled water supply pumps	5 [+1][a]	4.16 kV	185 kW	925 kW	780 kW
Condenser water pumps	5 [+1][a]	4.16 kV	250 kW	1,250 kW	1,000 kW
Miscellaneous					
Lights, ventilation, services, etc	lot	480 V	Varies	40 kW	20 kW
Overhead crane	2	480 V	11 kW	22 kW	
Water treatment pump	1	480 V	3 kW	3 kW	2 kW
Refrigerant pump-out unit	1	480 V	11 kW	11 kW	
				15,751 kW	**14,302 kW**
Note a. Refers to fully connected standby.					

The electrical requirements have been considered as far as required for costing purposes and for determining space requirements. Various layouts were considered for the electrical equipment, bearing in mind proximity to equipment, cable lengths and ventilation, whilst keeping the number of electrical installations to a minimum. The motors for the refrigeration machine compressors [2.7 MW], condenser pumps [250 kW] and chilled water pumps [185 kW] will all be 4.16 kV.

The main MV and LV switchgear will be located in a common, sub-divided, electrical room located between the two machine rooms and in close proximity to the three pump chambers. The MV panel will include the main incomers, the refrigerant compressor motor feeders, the main pump motors and the transformer feeders. The MCC will supply the auxiliaries for the refrigeration machines, the pump-out unit, electric overhead cranes and lighting and small power. It is anticipated that the control room and PLC equipment will also be accommodated in the same area.

The gantries in the machine rooms will be used to support cable racks for power and control and instrumentation cabling as well as fluorescent light fittings.

The principal power consumers are the refrigeration compressors and the two sets of pumps. For the normal duty points, with five machines operating the total power consumption will be about 14 MW.

9.7 Underground Plant Control Philosophy

Each refrigeration machine will be supplied with its own local control panel that ensures the safe operation of the machine and performs all local control and supervisory functions. In addition, there will be a central overall system control PLC supervising the selection, starting and stopping and monitoring of all refrigeration machines, the sequencing and protection of the pumps and the monitoring of the dams.

Each refrigeration machine requires one condenser pump and one chilled water pump to operate. As each pump is started, isolating valves will open on the heat exchangers of the selected refrigeration machine. Both sets of pumps will be arranged on common manifolds so any pump can operate with any machine. The chilled water pumps will draw water directly from the return water dam and the chilled water will be pumped through the evaporator heat exchangers, directly into the cooling coil network, and returned back to the same return water dam.

The condenser system will be a dedicated circuit with hot water returning to the sprayers in the condenser cooling towers and falling into the common dam feeding the two banks of pumps.

The plant operators will need to manually set the number of chilled water circulating pumps [and refrigeration machines] to suit the number of coolers in circuit and hence the flow dependency. The plant room will not be able to detect the exact requirements from any measured variable. The refrigeration machines will respond automatically [PLC control of guide vanes] to achieve a preset outlet water temperature – this set point will change as the underground circuit extends.

9.8 Underground Plant Make-up Water and Water Treatment Considerations

Make-up water for the condenser circuit will be required to replace water lost through evaporation and carry-over in the cooling towers and water bled out of the circuit to keep the TDS levels below the criteria set by the water treatment regime, Section 11. The primary source of make-up water will be un-cooled make-up water from surface. Return mine water will not be used due to its variable and poor quality and neither will chilled service water be applied for thermodynamic reasons.

The condenser circuit will typically require corrosion inhibitors, anti-scalant and biocide programs, as well as a blow-down facility to control the TDS levels. The blow-down can be taken from the feed to the cooling towers and routed to the main pump station for discharge to surface. The chilled water circuit will also probably require corrosion inhibitors, anti-foulant and biocide programs. It is anticipated that the mine will engage an outside agency to advise and implement water treatment programs. These companies usually have an on-going contract to conduct regular sampling and to supply the necessary water treatment chemicals. Where required, continuous monitoring and dosing equipment will be supplied as proprietary packages and will be maintained as part of the contract.

9.9 Underground Chilled Service Water System

The chilled service water will be a very important part of the underground cooling. The chilled service water will be used for dust control, localized cooling sprays and mine service needs and will provide effective localised cooling wherever it is applied.

Due to the depth, auto-compression and high rock temperature there will be potential for high dry-bulb temperatures in certain areas particularly on the Production level. Liberal amounts of chilled service water applied at draw-points and ore passes will be required for dust suppression purposes anyway but this will also be an important part of the cooling system. The modelling indicates that, with reasonable amounts of moisture, the dry-bulb temperatures can be practically kept below 35°C [without water sprays this could exceed 42°C].

As noted, there is no definitive clarity [at this stage] on the expected service water consumption. After some debate, for this present work, it was assumed that the average service water demand from surface will be 150 l/s [24 hr ave] at fully established production. The chilled water flow will have the potential to apply about 10 MW of effective local cooling [as it heats up by say 16°C].

The chilled service water surface refrigeration system plant is discussed in Sections 8.1.2 and 8.7. The chilled service water will be supplied to the underground service water dam [5 Ml] from the cold service water dam on surface. The service water supply will provide 150 l/s on average with the flow varying cyclically as the demand dictates. For the present purposes*, it was decided that this pipe would be an 8" open-ended gravity fed column [insulated] in No.13 Shaft. From the underground service water dam located at elevation -685 level, off No.13 Shaft, the service water will be gravity fed to the individual working levels. The main supply piping from the underground dam will be 16" [insulated] with branch piping getting progressively smaller.

* At the next level of design detail, consideration should be given to installing a turbine-generator to generate power from this water pressure dissipation. This will require capital for a high pressure column and the turbine-generator equipment but will be attractive from power generation perspective.

Note that the service water quality will be reasonable quality industrial water but it will not necessarily be potable water [personnel will use bottled potable water].

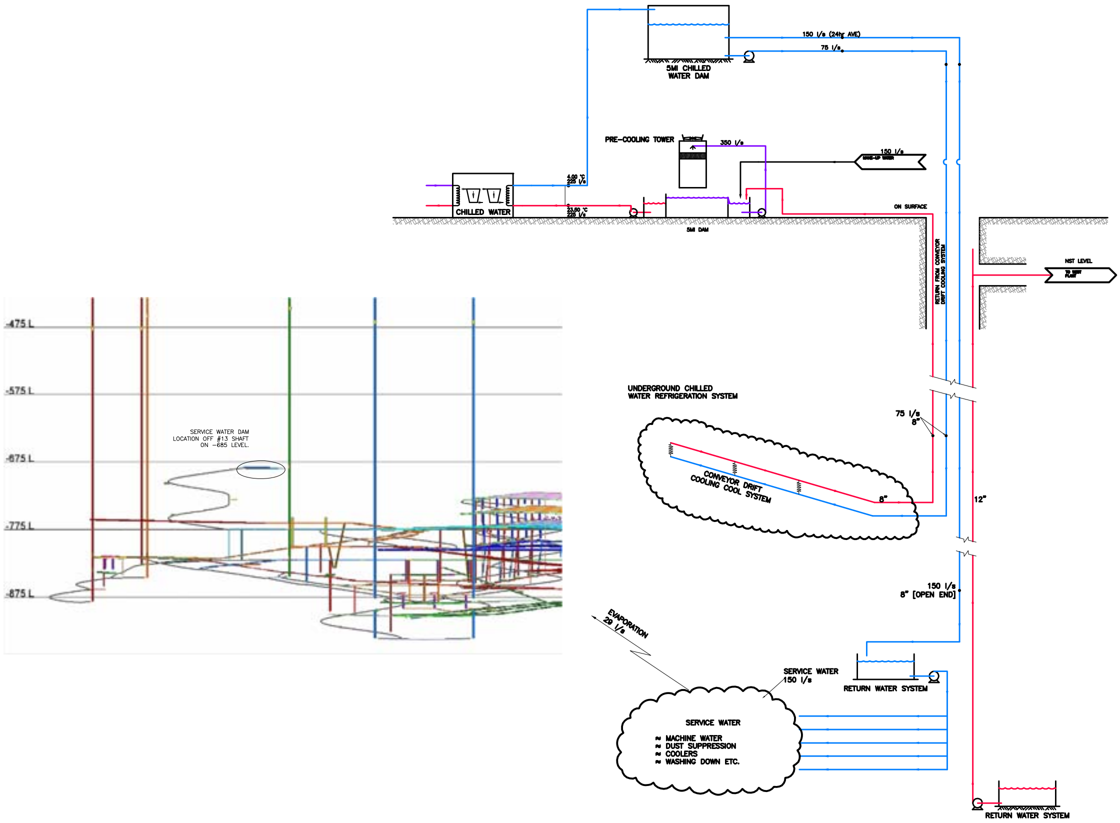


Figure 9.5 Schematic of underground chilled service water system

10 VENTILATION AND COOLING OF SHAFT SINKING OPERATIONS

10.1 General Aspects for all Shaft Sinks [No.11, 12, 13, 14]

No.11, 12, 13 and 14 Shafts will be sunk as follows:

- No.11, 12, 14 Shafts — 10.0 m finished [10.7 m excavated]
- No.13 Shaft — 11.0 m finished [11.7 m excavated]
- Ultimate depth — 2100 m
- Rate of shaft sink [maximum] — 3.4 m/day [97 m/mnth]

The ventilation monitoring system at No.10 Shaft sink [presently in progress] is producing useful data that have been used to update* and calibrate the models. This has established an accurate predictive tool that has been used in the system designs for these new shaft sinks.

*. One example has been the beneficial effect of the rapid placement of shotcrete.

The heat load analyses have used special software routines that allow both the thermo- and aerodynamic effects to be predicted simultaneously, the analyses account for:

- Rock thermal properties for different rock formations
- Heat flow through concrete lining of shaft and the effect of shotcrete
- Heat of hydration from curing concrete
- Heat transfer to chilled water pipe in shaft
- Heat transfer from rock to air flow up shaft barrel [which decompresses in upcasting]
- Heat transfer to air in duct including effects of:
    - radiation from barrel wall
    - convection from air in barrel
    - condensation where it occurs [in upper duct section]

The design criteria state that there will be no significant hot fissure water and the heat analysis limits this to 0.5 l/s [average into workspace typically at virgin rock temperature]. This is a fundamental assumption [and risk] because significant fissure water at depth will increase the heat loads and the probability of encountering fissure water should be reviewed as more information becomes available.

The cooling of the shaft sink operation will be achieved by the following [with a small supplementary cooling effect of the compressed air]:

- Chilled service water used for drilling, washing and muck cooling.
- Chilled air supplied to the shaft bottom by the duct via surface installed shaft sinking fans.

Chilled service water

The chilled service water will be used for drilling, washing and muck cooling. In addition, a water blast spray system will be deployed below the Galloway which will be actuated by the rock blast. The use of chilled service water will play an important role in cooling the work space. This will be highly effective from a positional efficiency point-of-view because the water will be applied where workers are located at the right place at the right time. The chilled water absorbs heat by the mass of water warming up and by evaporation. Typically 4 l/s [with 2% evaporation] will absorb about 400 kW which will be a very important contribution to the overall cooling effect.

Normal service water use [in the absence of heat] will be modest and, in hot rock conditions, the service water consumption will need to be increased to provide adequate cooling. There is obviously a limit to how much water can be managed in terms of baling capacities and, for the present purposes, this limit has been set at 4 l/s [24 hr average] for the ultimate depth scenarios.

Ventilation and air coolers

The shaft sink ventilation system will include an air flow reversal system. The ventilation will normally operate in a forced mode into the face zone. However, just before each blast, the flow will be reversed and the system will operate in an exhaust mode. Thus, at the blast and shortly thereafter, the fumes, smoke, gases, dust, water vapour and heat is directly removed from the working environment. In addition, a water blast-spray system will be deployed below the Galloway which will be actuated at the blast. This approach has two benefits:

- It assists with controlling the temperatures since heat and water vapour are removed directly.
- It minimises the re-entry period of workers returning into shaft after the blast.

There will be gas monitors installed at the bottom and top of the main in-shaft duct column. When the gases are cleared at the bottom, the workers will re-enter and when the gases are cleared at the top, the force flow mode will be re-instated.

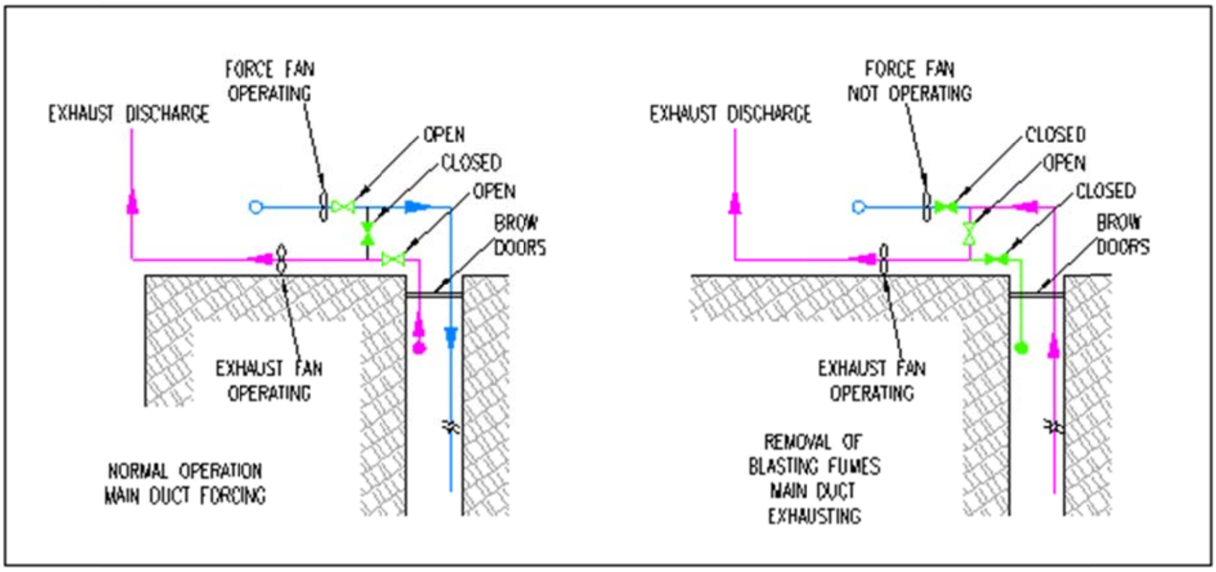


Figure 10.1 General Ventilation Concept for Shaft Sinking

The ventilation system is shown schematically in Figure 10.1. The force fan provides cold fresh air under pressure to the in-shaft steel duct. This air will flow down the in-shaft duct and be delivered to the face zone in a force flow mode. The return air will flow up the shaft barrel where it will be collected just below the brow doors in a short return duct system reporting to the exhaust fan. From the exhaust fan, the return air will be discharged in a vertical 'chimney' to atmosphere. The exhaust fan air flow will be higher

[~10%] than that delivered to the shaft bottom [and returned up barrel] and, as a result, some fresh air will be drawn through shaft doors from the bank.

Where the in-shaft steel duct joins the sinking stage, there will be a cassette arrangement of flexible ducting deployed to allow the advance without extending the in-shaft duct after each blast. From the cassette, duct sections will carry the ventilation to bottom of the Galloway.

The exhaust system will include three isolating duct-gates and when the system is switched-over to main exhaust operation: force fan is switched-off; gate isolating the force fan is closed; gate connecting exhaust fan to in-shaft steel duct column is opened; gate connecting exhaust fan to normal shaft barrel upcast return duct is closed. The exhaust fan will then experience the full system resistance of the in-shaft steel duct and will draw the blast-contaminated, hot, wet air up the in-shaft duct.

The force fan-unit will be required to operate over a range of pressures as the shaft sink progresses and the fans will have variable speed drives. The fan-unit will consist of two axial fan-motor sets arranged in series as two stages. This will allow a phase-in of fan capacity during the shaft sink [as well as providing redundancy capacity]. Initially only one of the fan-motor sets will be installed. The second fan-motor set will be installed when the system resistance becomes critical as the sink gets deeper.

The exhaust fan-unit will have two distinct operating scenarios.

- Under the general operating conditions when force fan is running, the return air will flow up the shaft barrel and report to a relatively short return duct system through the brow doors connecting to the exhaust fan. For this, the exhaust fan-unit will operate against a relatively low system resistance.
- However, when operating in the reversed duct flow mode with the force fan switched-off [and gate closed], the exhaust fan will be connected to the full length of the in-shaft duct. In this situation, this fan-unit will operate against a relatively high system resistance.

In addition to this variation, as the shaft sink progresses, the in-shaft duct column length changes and the fan-unit will be required to operate over a range of system resistances [while in the high-resistance main exhaust mode].

Similar to the force fan-unit, the exhaust fan-unit will consist of two axial fan-motor sets arranged in series as two stages. As with the force fan-unit, these fan-motor sets will be phased-in and each fan will be driven by a variable speed drive motor. In the reverse flow situation after the blast, the contaminated wet air will upcast in the in-shaft duct column, it will decompress and water drops will precipitate. Thus the air fed into this fan-unit will be corrosive, dusty and wet.

The duct leakage will be an important issue and the leakage factors will depend on duct and coupling details as well as installation and maintenance standards. The leakage along the length of the duct will vary with pressure, density and temperature. Based on No.10 Shaft [which has generally been very good from a leakage point-of-view] and other experience, the leakage factor was modelled in terms of typical fixed resistances to leakage flow. These systems will be relatively high pressure operations and the overall leakage rates will be about 25% [of the inlet flow] over the full ultimate depth.

Initially as the sinks progress, more-and-more air flow will be used without refrigeration in order to delay the onset of the refrigeration. This air flow control will be achieved with the variable speed fans. However, the situation will eventually be reached when the fan power is excessive and refrigeration must be introduced. From then on, the duty load on the air coolers will be increased progressively as the shaft sink gets deeper. The refrigeration will be needed at a depth of about 700 m [depending on season and weather conditions].

10.2 Energy and Cooling Balances [No.11, 12, 13, 14]

No.11, 12, 14 Shafts

The shaft diameter will be 10.0 m finished [10.7 m excavated]. The energy/cooling balance analyses require the in-duct air flow to be delivered to the top of the Galloway at 39.4 kg/s and 24.5°Cwb. In order to achieve this, the required flow to be delivered to the ventilation duct on surface will be 52.5 kg/s and 10.7°Cwb into duct at top and this, in turn, requires a temperature of 8.1°Cwb into fan.

The duct size will be 1.83 m [72”] and the force-fan pressure will be 5.3 kPa.

In addition, the overall cooling system will require 4 l/s of chilled service water to be utilized at shaft bottom at the ultimate depth.

No.13 Shaft

The shaft diameter will be 11.0 m finished [11.7 m excavated]. The energy/cooling balance analyses require the in-duct air flow to be delivered to the top of the Galloway at 44.3 kg/s and 24.5°Cwb. In order to achieve this, the required flow to be delivered to the ventilation duct on surface will be 59.0 kg/s and 10.7°Cwb into duct at top and this, in turn, requires a temperature of 8.1°Cwb into fan.

The shaft diameter will be 11.0 m finished [11.7 m excavated]. The energy/cooling balance analysis requires the in-duct air flow to be delivered to the work zone at 44.3 kg/s and 24.5°Cwb. This, in turn, means the flow of 59.0 kg/s and temperature of 10.7°Cwb into duct at top and this, in turn, means temperature of 8.1°Cwb into fan.

The duct size will be 1.93 m [76”] and the force-fan pressure will be 5.1 kPa.

In addition, the overall cooling system will require 4 l/s of chilled service water to be utilized at shaft bottom at the ultimate depth.

10.3 No.14 Shaft Sink Ventilation and Cooling System

The process flow diagram and air cooler general arrangement is shown in Dwgs 35 and 37. It has been assumed that the existing refrigeration machines at the No.10 Shaft sink will be re-used for No.14 Shaft sink [or upgraded similar units]. These machines will provide chilled water flow of 60 l/s to a temporary air cooler to be installed near the No.14 Shaft head via an ‘overland’ 8” pipe system.

The air cooler [Dwg 37] will be in the form of a temporary assembly served by a temporary chilled water system. The air cooler will be a two-stage cross-flow film-pack configuration made-up from standard industrial water cooling tower components that will be factory-assembled, pre-fabricated and delivered to site for installation. Equipment will typically consist of a structural frame and cladding in galvanized steel erected over a concrete basin. The chilled water from the refrigeration plant will be fed to a first stage and then the water will be pumped to a second stage for high thermal efficiency. The air cooler will thus include a restage pump-motor set.

The sinking fan will draw the chilled air off the air cooler and will be installed near the air cooler discharge [ducts, fan casing will be insulated]. Although the force and exhaust fan-units will have different operating duties, it will be logical to use identical fans. Each fan-unit will comprise a two-stage axial fan unit rated at 440 kW [total, 2x220]. The fan assembly will include silencers as well as intake and discharge ducting transition pieces.

In summary, the vent/cooling system for the ultimate scenario for the No.14 Shaft sink will be:

- Duct column diameter — 1.83 m [72”]
- Force fan-unit — 440 kW [2 x 220]
- Duct pressure at surface — 5.3 kPa
- Exhaust fan-unit — 440 kW [2 x 220]
- Air flow to duct at shaft head — 52.5 kg/s
- Air flow from duct delivered to Galloway — 39.4 kg/s
- Temperature airflow into duct at shaft head — 10.7°Cwb
- Temperature airflow delivered to Galloway — 24.5°Cwb
- Bulk air cooler duty — 2.04 MW
- Chilled service water flow — 4 l/s [ave]
- Chilled service water temperature at shaft head — 4°C

10.4 No.11, 12 and 13 Shaft Sink Ventilation and Cooling Systems

The cooling system for No.13 Shaft sink system, although slightly larger because of the larger diameter, will be very similar to those at No.11 and No.12 Shafts and these systems are all described in this section [layouts are shown in Dwgs 30, 33 and 34].

The refrigeration capacity for all three of these air cooler systems will be provided by the first permanent water refrigeration module installed at the central plant room. This plant will serve the first permanent bulk air cooler cells installed at each of the shafts and will be commissioned for the sinking needs. The refrigeration machine will be more-than-capable of producing this capacity and will operate on part load.

The chilled service water to all these shafts will be provided from the permanent service water refrigeration module installed at the central plant and the permanent chilled service water dam system. This system will be commissioned for this purpose and the chilled service water refrigeration machine will only need to operate at part load during strategic periods of the day.

The bulk air cooler cells will deliver the cold air to the drifts that will ultimately deliver the bulk flow to the shaft barrel [about 40 m below bank]. During the shaft sink phase, the sinking fans will be installed in the cold air feeder drift[s] just below surface and the force fan will draw the cold air off the air cooler drift. Although the force and exhaust fan-units will have different operating duties, it will be logical to use identical fans. Each fan-unit will comprise a two-stage axial fan unit rated at 440 kW [total, 2x220]. The fan assembly will include silencers as well as intake and discharge ducting transition pieces.

In summary, the features of the ventilation and cooling systems for the ultimate scenario for each of the No.11, 12 and 13 Shaft sinks will be:

	No.11, 12 Shafts	No.13 Shaft
• Duct column diameter	1.83 m [72"]	1.93 [76"]
• Force fan-unit	440 kW [2 x 220]	440 kW [2 x 220]
• Duct pressure at surface	5.3 kPa	5.1 kPa
• Exhaust fan-unit	440 kW [2 x 220]	440 kW [2 x 220]
• Air flow to duct at shaft head	52.5 kg/s	59.0 kg/s
• Air flow from duct delivered to Galloway	39.4 kg/s	44.3 kg/s
• Temperature airflow into duct at shaft head	10.7°Cwb	10.7°Cwb
• Temperature airflow delivered to Galloway	24.5°Cwb	24.5°Cwb
• Bulk air cooler duty	2.04 MW	2.29 MW
• Chilled service water flow	4 l/s [ave]	4 l/s [ave]
• Chilled service water temp at shaft head	4°C	4°C

11 WATER BALANCE ISSUES

Although there are obviously many other contributing factors in the overall mine water balance, there are two significant water issues associated with the ventilation and cooling systems:

- Service water evaporated underground into the primary ventilation air flow.
- Process water losses [blow-down, net evaporation] in refrigeration and cooling systems.

The purpose of this specific note is to focus on the ventilation and cooling related water balance issues only. But, it is interesting to note that water lost in hoisting rock [taken at say 3% by mass] will be about 40 l/s.

11.1 Water Evaporated into the Primary Ventilation Air Flow

In summer, with the use of surface bulk air cooling, the primary ventilation will enter the mine in a de-humidified condition. In winter, the primary ventilation also enters the mine in the generally dry winter ambient condition. There is little difference in the condition of air downcast into the mine between the seasons - indeed this is one of the functions of surface bulk air cooling.

Service water [chilled] will be used for the normal services and, in addition, this chilled water will be used to suppress dust and reduce high dry-bulb temperatures. Also, because of the nature of the mine heat load, limited amounts of chilled service water will be used for ad-hoc air cooling in open-circuit water-to-drain devices. Thus as the air flows through the mine it absorbs water vapour through evaporation. Then, when upcasting in the ventilation shafts, it will decompress resulting in the ventilation leaving the mine [and entering the main surface fans] in a saturated state. Indeed condensation will take place in the upcast shafts with water fall-out to shaft bottom and some carried into fan drifts.

The return air flow will receive further water vapour in the underground cooling towers however, to avoid double accounting, this is discussed as part of the refrigeration system water balance below.

With the ultimate total primary ventilation flow of 2760 kg/s to the deep underground operations, the amount of water absorbed in this manner is about 31 l/s [500 gpm] on 24 hr average basis. Note that this consumption of water is about 20% of the assumed service water flow.

11.2 Refrigeration System Process Water

The main components of the refrigeration system related water balance are: evaporation from cooling towers, condensation in the surface direct-contact air coolers, cooling tower carry-over, blow-down and make-up flow. Evaporation in cooling towers will always dominate and dissolved salts will tend to accumulate. It is necessary to have a blow-down in order to keep dissolved salts at acceptable levels. The water mass/salt balance is controlled by blow-down [and make-up] flows and, typically, the operating salinities of condenser water will be controlled to about 3000 ppm.

For the water balance prediction below, it is assumed that make-up water will be provided from the ‘regional water supply’ at 300 ppm total dissolved salts [this is basically potable water].

For the **surface refrigeration system**, the evaporation and condensation rates will depend on the weather conditions and cooling duty and will vary seasonally. For the ultimate surface refrigeration requirements at design summer day, the water mass/salt balance requires make-up of 33 l/s [524 gpm] and blow-down of 3 l/s [48 gpm] [24 hr ave during summer day]. These are net values that account for the ‘make of water’ in the surface bulk air coolers. In winter, when the plants are not running, there will be no water consumed in this manner. The overall annual average make-up water flow for the surface plant will be 19 l/s [302 gpm].

For the **underground refrigeration system**, the evaporation [and condensation] will not vary seasonally. For the ultimate underground refrigeration requirements, the water mass/salt balance requires make-up and blow-down rates of 25 l/s [397 gpm] and 3 l/s [48 gpm] respectively. In the underground situation, with a multiplicity of secondary air coolers in the form of cooling coils, it will not be feasible to recover the condensate from the air coolers – it will flow to drain. In addition to the condenser water losses, some consideration must be taken of leakage in the underground chilled water distribution system - somewhat subjectively this will be estimated as 2 l/s [32 gpm] which is 0.3% of circulating flow. The overall annual average make-up water flow for the underground plant will be 27 l/s [429 gpm] [24 hr ave basis].

Thus, for the total overall refrigeration system [surface and underground], for the ultimate scenario, the total make-up requirement will be 60 l/s [952 gpm] in peak summer and 46 l/s [730 gpm] annual average [24 hr basis]. These values relate to 5 180 m^3 per day and 3 970 m^3 per day respectively or 1.37 mil gal per day and 1.05 mil gal per day respectively.

12 DEVELOPMENT AND PRODUCTION RAMP UP VENTILATION STRATEGY

The life-of-mine has a number of distinct phases from shaft sinking to establishing and sustaining full production - these phases are termed V0 to V11. The purpose of this section is to define each of the phases in terms of what ventilation and refrigeration capacity will be available, what can be achieved [in terms of development or production] with these capacities and what key strategies are to be reflected in the planning. There may be practical difficulties in change-over from one regime to the next which also need to be identified at this stage.

The ventilation phases identified from the project schedule are shown in Table 12.1 and Figure 12.1.

12.1 Notes on Ventilation flow Limitations

12.1.1 Note on Return Ventilation Flow to Magma Mine

During certain periods of the development schedule, the primary ventilation flow rate will be limited by upcast air speeds in the No.9 Shaft barrel and in-shaft work activities. It was hoped that this could be alleviated by returning some ventilation into the old Magma mine. However, with recent access having been established on 4000 level off No.9 Shaft and, following inspection, it is clear that it will be very difficult to achieve any return ventilation to the old Magma mine.

The possible merits of spending capital and time to establish a return airway path in the old Magma mine may be considered elsewhere. But this present report now assumes zero return to the old Magma mine. Under these circumstances, the only options to achieve return ventilation to surface would be by upcasting No.9 Shaft barrel or by using ducts to surface or by a brattice compartment.

The brattice wall was considered impractical from the point of view of costs and time to install and then later remove. Regarding ducting to surface in No.9 Shaft, various shapes and sizes were examined and the maximum that could be accommodated was determined to be one oval duct 60”x36” which could carry 32 m^3/s. This was also considered impractical from the point of view of limited air flow, costs and time to install and then later remove and high fan power.

This leaves the option of upcasting the No.9 Shaft barrel [initially above Pump Level] which immediately dictates the use of timed-blasting for Characterization Level development, No.9 Shaft sink and Pump Level development. It also means No.9 Shaft must be sealed [doors and seals] on NST level. These issues along with the re-entry period aspects have been accepted as design constraints.

Table 12.1 Ventilation Regimes

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		Milestone to Commence	Production Project Year From	To	Date From	Date To	Time mths	Main Activities	Waste & Ore Prod t/d	Shaft Configuration # 11	# 12	# 13	# 9	# 10	# 14	Underground Workings kg/s	Other Vent kg/s	Total Vent kg/s	Total Vent m3/s	Surface Refrig' MWR	UG Refrig' MWR
A.1	V.0	#10 holes	-9	-9	23/04/13	15/06/13	1.7	Characterization	500							69	81	150	158	7.7	0.5
								Develop mid shaft pump staion													(6)
	V.1	Mid shaft PST complete	-9	-7	16/06/13	18/02/15	20.1	Characterization Sink#9	500							69	81	150	158	7.7	0.5
A.2	V.2	#9 holes 1 upcast fan on	-7	-6	19/02/15	10/02/16	11.7	Equip #9 Construct main fan stn Limited development	1 600							150	75	225	236	12.2	0.5
B.1	V.3	#9 equipped & 1 upcast fan on	-6	-6	11/02/16	31/07/16	5.6	Equip #10 above mid PST Limited development	1 600							285	95	380	399	19.2	0.5
	V.4	#10 equipped to mid-shaft PST	-6	-6	01/08/16	17/11/16	3.6	Equip #10 below mid PST Limited construction	1 600							285	95	380	399	19.2	0.5
B.2	V.5	#10 equipped fully	-6	-5	18/11/16	03/08/17	8.5	Development	3 000				(1)	(1)		560	30	590	620	22.4	0.5
								Install fridge plant					(1)	(1)							
								Sink #11 #13 #14					(1)	(1)							
B.3	V.6A	UG fridge plant on	-5	-3	04/08/17	01/08/19	23.9	Full development Sink #11 #13 #14	5 300							560	30	590	620	22.4	24
								Conveyor drift holes #11 #13 #14		(2)		(2)			(3)						
	V.6B	#14 holes	-3	-2	02/08/19	03/01/20	5.1	Strip #14 Sink #11 #13								560	30	590	620	22.4	24
B.4	V.7A	#14 stripped	-2	-2	04/01/20	01/06/20	4.9	Sink #11 #13	5 300				(4)		(4)	675	30	705	740	24	24
	V.7B	#11 holes	-2	-1	02/06/20	01/02/21	8.0	Equip #11 sink #13		(5)						1 075	30	1 105	1 160	41	24
	V.7C	#13 holes	-1	-1	02/02/21	15/12/21	10.4	Equip#11 #13		(5)		(5)				1 575	30	1 605	1 685	63	24
B.4	V.8	#11 #13 equipped	-1	0	16/12/21	15/10/22	10.0	Strip #10 Full development	5 300							1 900	150	2 050	2 153	81	24
C	V.9	#10 stripped	0	1	16/10/22	16/07/23	9.0	Strip #9 Full development First production	6 000							1 900	200	2 100	2 205	81	32
D	V.10A	#9 stripped	1	1	17/07/23	01/09/23	1.5	Production ramp up 2023 to 24	12 000							2 300	300	2 600	2 730	102	32
	V.10B	#12 holes	1	2	02/09/23	31/12/24	16.0	Equip #12								2 300	300	2 600	2 730	102	32
E	V.11	#12 equipped	3	7	01/01/25	31/12/29	60.0	Production ramp up 2025 to 29	40 000							2 760	360	3 120	3 276	123	40
			8	39	01/01/30	27/01/61		Full production	120 000												

Key (shaft configuration colours):
- Sinking
- Mixed barrel and ducts
- Intake but stripping or equipping
- Full intake
- Exhaust but stripping or equipping
- Full exhaust

(1) Possible development contraints on underground distribution
(2) Conveyor drift holes #11 #13 skip discharge at this time - requires seperate exhaust circuit
(3) Skip discharge connected to #14 after initial holing #11 #13
(4) Contingency to increase capacity before holing #11 by downcasting #9 with higher volumes exhausting #14
(5) Phase in surface refrigeration for #11 #13 during equipping periods
(6) 0.5MWR UG refrigeration V.0 to V.5 employes chilled service water from surface plant

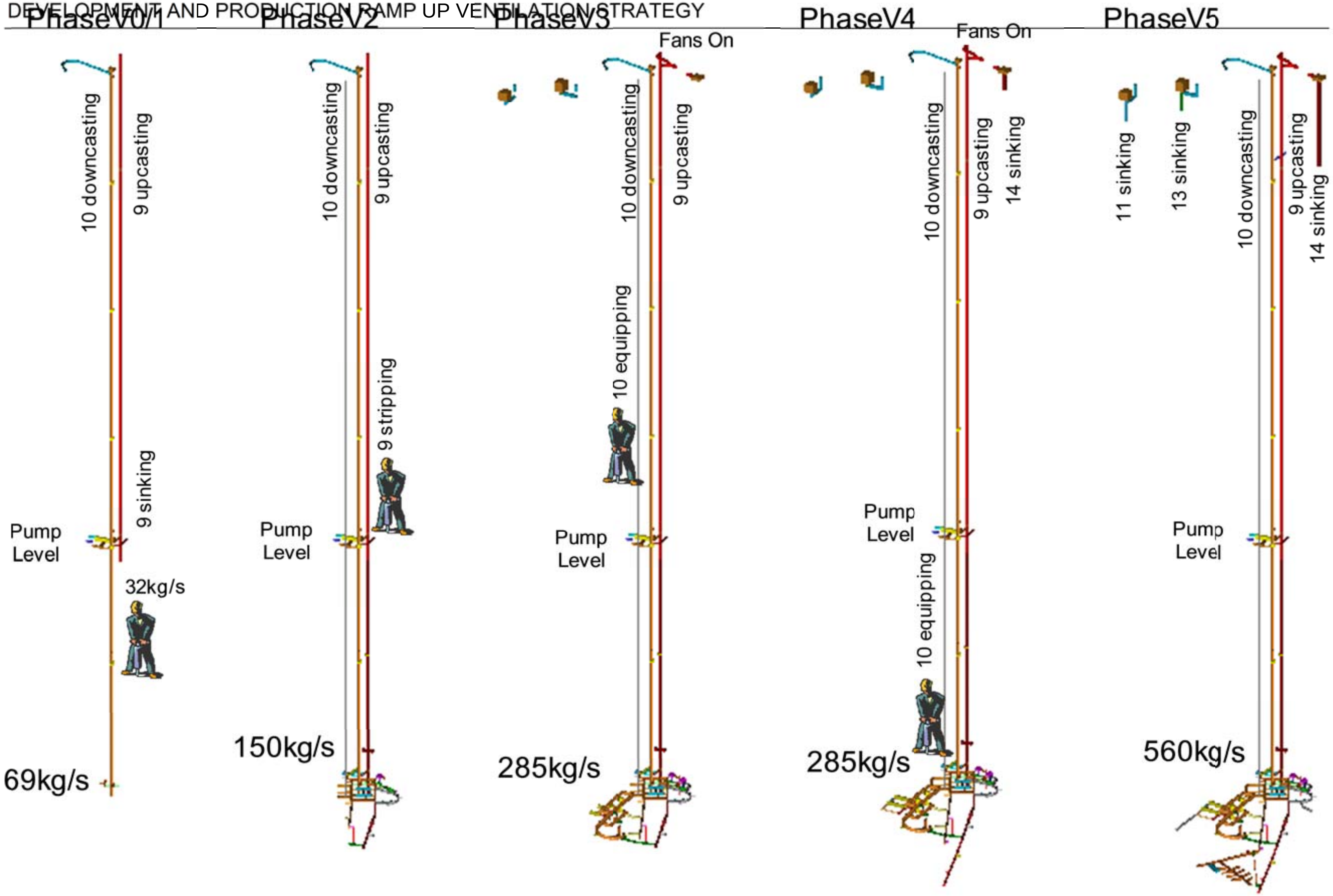


Figure 12.1 Ventilation Regimes – Mine Orbit

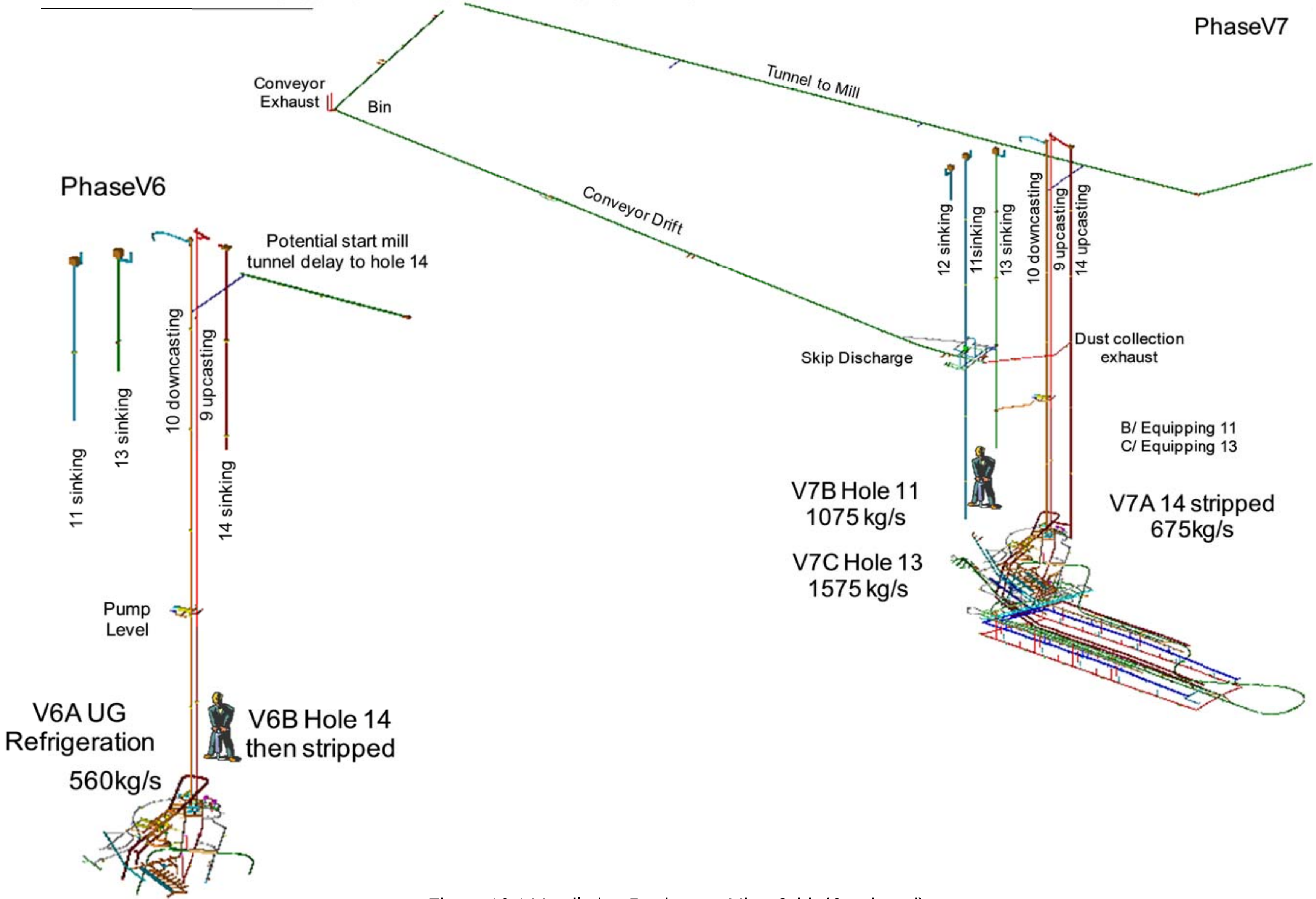
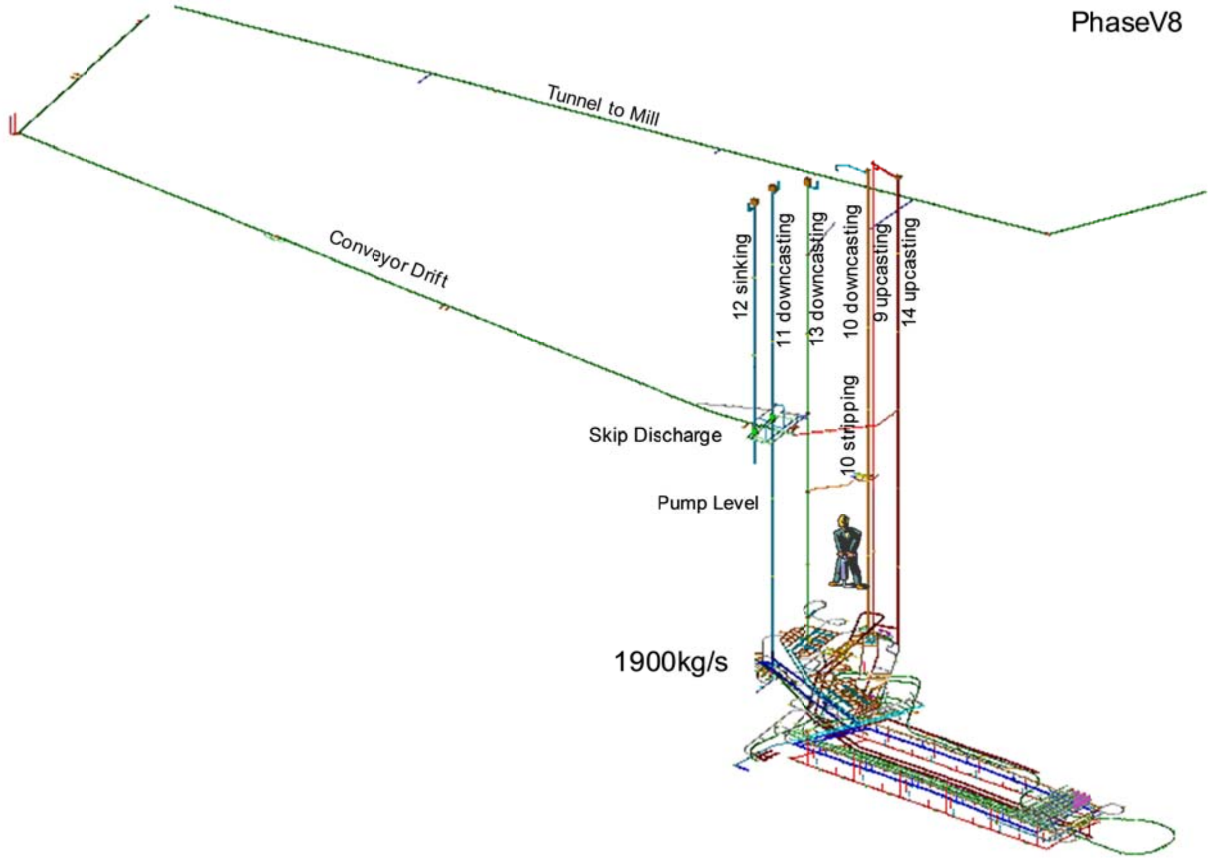


Figure 12.1 Ventilation Regimes – Mine Orbit (Continued)



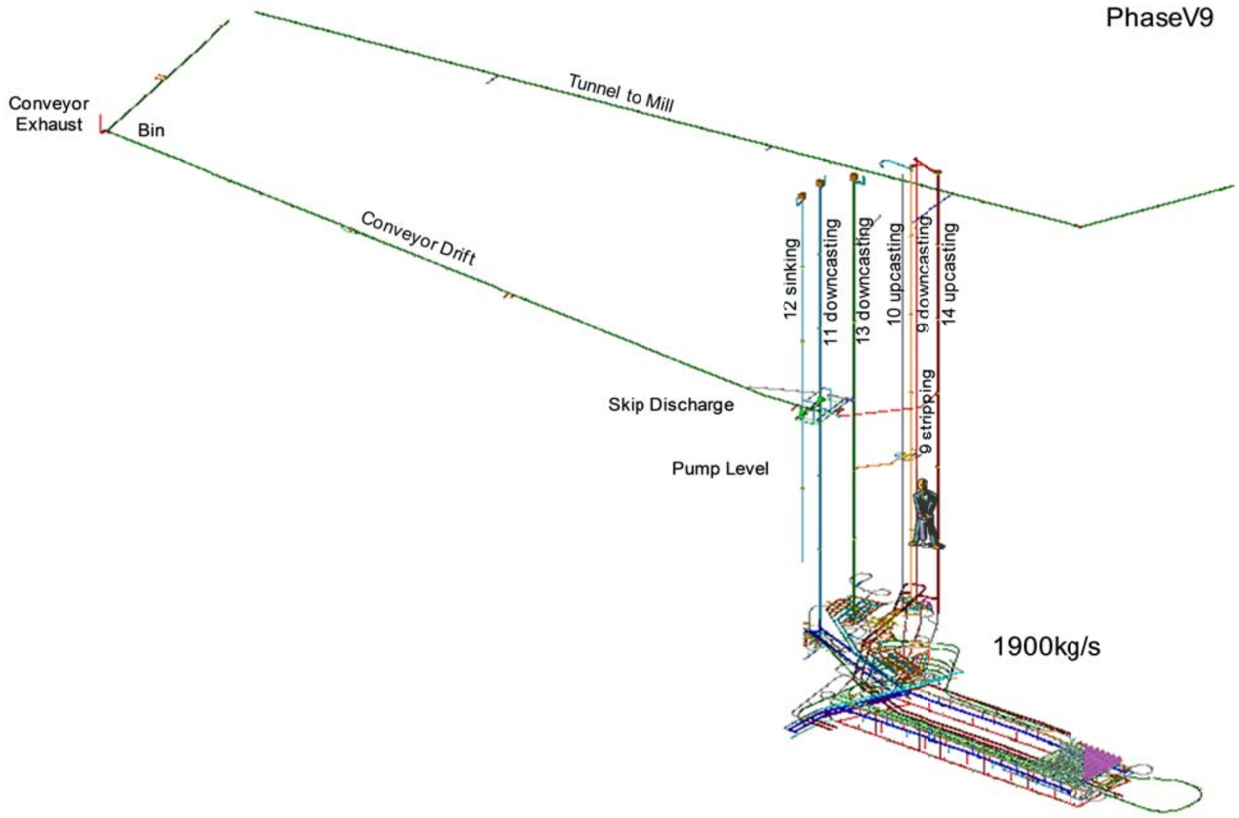
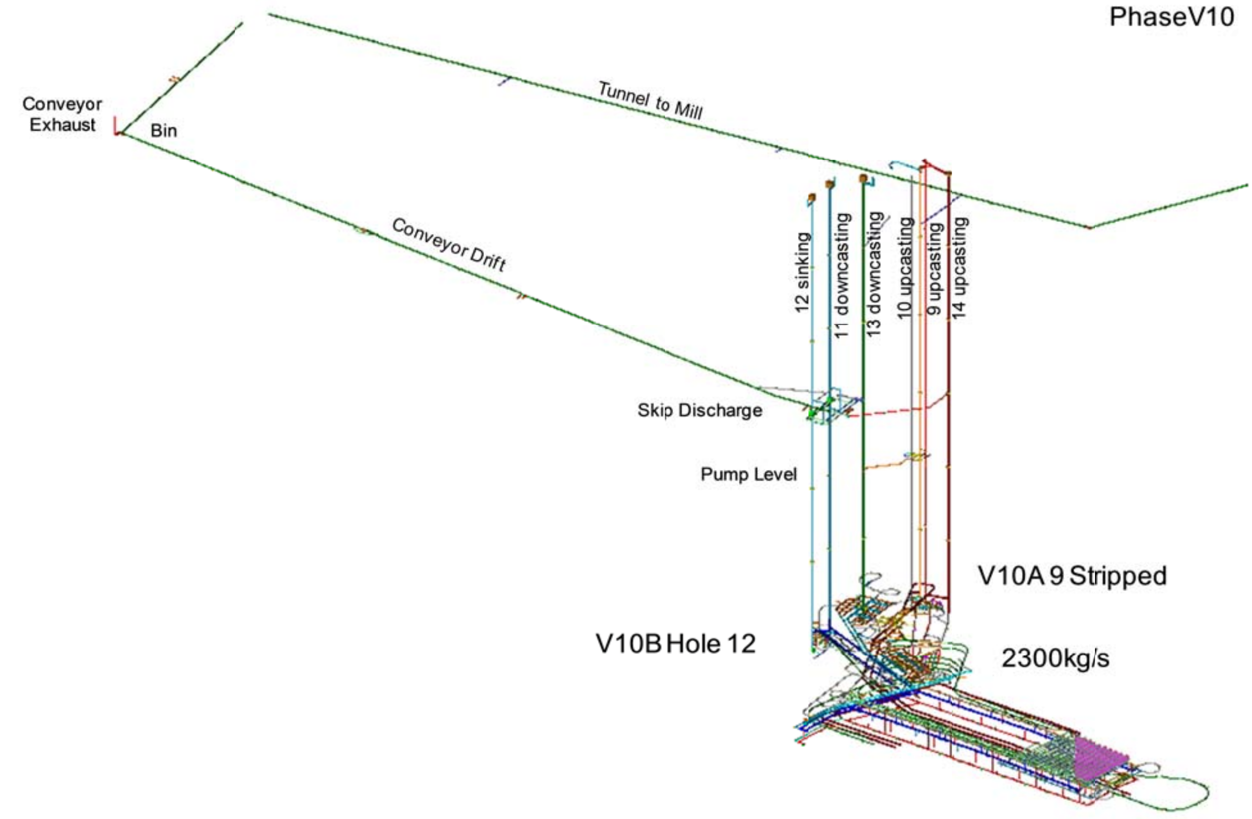


Figure 12.1 Ventilation Regimes – Mine Orbit (Continued)



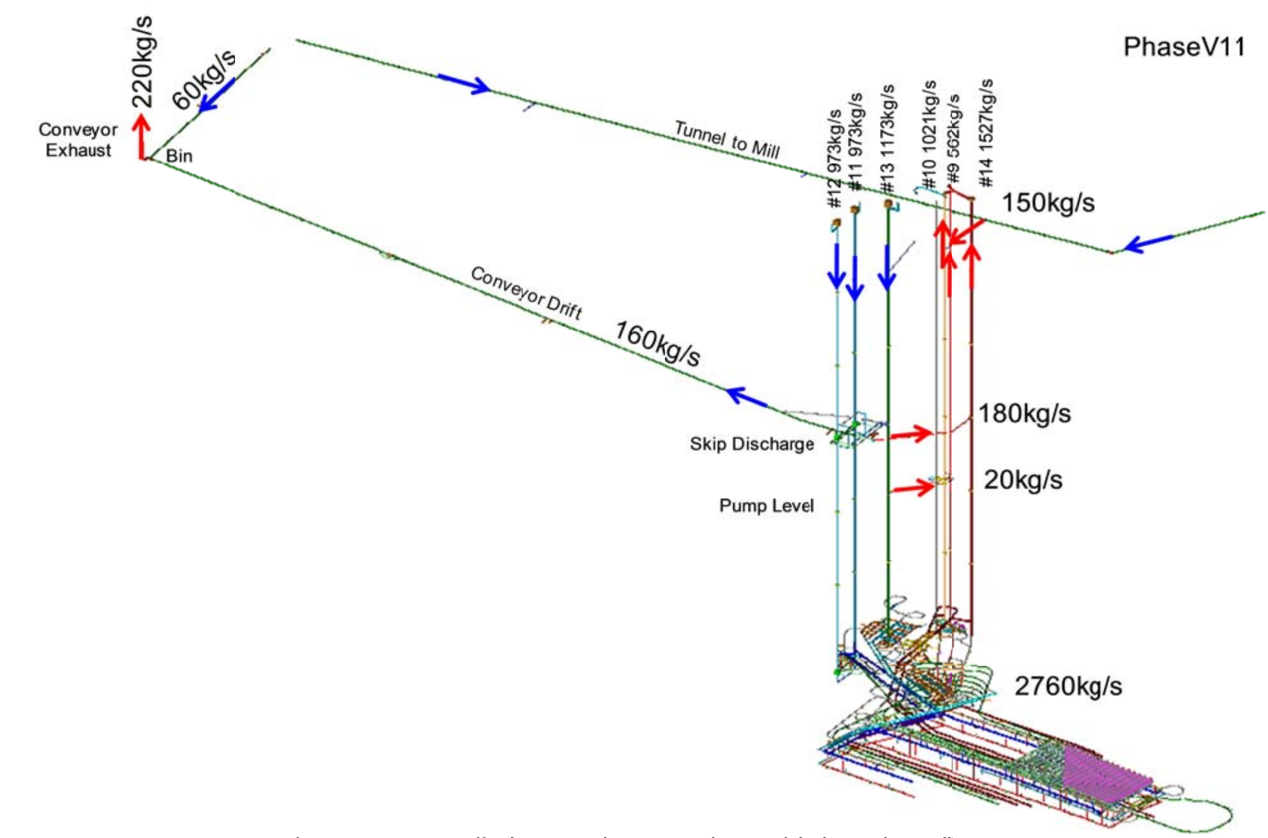


Figure 12.1 Ventilation Regimes – Mine Orbit (Continued)

12.1.2 Note on Limiting Air Flows in Shafts and Main Airways

Equipping No.9 Shaft
When the equipping of No.9 Shaft takes place [Phase V.2], the upcast air speed will be limited to <6 m/s and the maximum flow will be 210 kg/s [in No.9 Shaft barrel above NST level].

Equipping No.10 Shaft
When the equipping of No.10 Shaft takes place [Phase V.3-V.4], the downcast air speed will be limited to <6 m/s and the maximum flow will be 365 kg/s [in No.10 Shaft barrel just below NST level].

Skips in No.9 Shaft
When No.9 Shaft is using skips [on fixed guides] to hoist rock to NST level, the upcast air speed will be limited to <15.5 m/s at NST elevation and the maximum flow will be 575 kg/s [in No.9 Shaft barrel above NST level]. During this time, the system will be exhaust constrained until such time that No.14 Shaft holes or intake constrained until No.11 and No.13 Shafts hole. The timing of these shafts will be critical.

Downcasting No.10 Shaft
When No.9 and No.14 Shafts are available, there is a limitation on downcast capacity in No.10 Shaft and the downcast air speed will be limited to <11.5 m/s above NST elevation and a flow of 705 kg/s [density 1.1 kg/m^3].

Single drive system on Characterization level
When there is a single intake and return drive on Characterization level out to the furthest developments to the south, there is a limitation on ventilation capacity to the furthest workings. The intake and return drive sizes will be 25 m^2 and the ventilation capacity to the furthest workings will be constrained to 220 kg/s. This limitation will exist until the first ROWA drive connects to No.9 Shaft, April 2017.

12.1.3 Note on Underground Refrigeration Plant

The start-up of the underground refrigeration plant is a critical event. But once the plants are operative the return ventilation upcast in No.9 Shaft will be hot and wet due to the underground cooling towers. This means that the underground plant cannot be run until No.9 Shaft equipping work is complete at which time the main upcast fan[s] will start. However, the main fans and flow in No.9 Shaft can only become *fully* operational once the equipping of No.10 Shaft is complete and No.11 and 13 Shafts are available.

12.1.4 Note on Current Status of Equipment at No.10 Shaft

The current status is that No.10 Shaft sink is between Pump level and Characterization level. There will soon be three refrigeration plants installed on surface to serve the No.10 Shaft surface bulk air cooler which will have three bulk air cooler cells each with a capacity of 175 kg/s air flow. This is all temporary equipment that will eventually be decommissioned once No.10 Shaft becomes a permanent upcast. There is a pair of insulated 8” pipes installed in the shaft to reticulate chilled water to cooling cars on NST level and Pump level. These pipes will be carried to Characterization level thus allowing for the possibility of operating cooling cars on Characterization level.

12.2 Regime Ventilation Circuit Schedules

12.2.1 Phase V.0 and V.1: Characterisation Period off 72” Duct

The characterisation period occurs after No.10 Shaft sink is complete and includes the development of exploration drives as well as the characterisation work itself. Characterisation work will include development of two drives towards the refrigeration plant site location and, once the project go-ahead is given, these two drives will enable the immediate development of the plant chamber and rapid installation of the refrigeration machines. Other characterisation activities may include undercut trials, rock stress trial, heat trial, etc. For example, the undercut trial will probably entail two drives off the main development 30 m apart and 50 m long connected by a single drive 110 m long to the main return airway.

For this period, the primary ventilation flow will be established by an in-shaft duct [72”] installed between Characterization level and Pump level [capacity 86 kg/s]. This duct is the dominating constraint in the carrying capacity at this stage. The fan for the 72” duct will be installed on the Pump level and will have 86 kg/s total flow rating with motor size of 200 kW. The total ventilation flow will be 150 kg/s distributed as follows, Figure 12.2:

Intake

• Out down NST	15 kg/s
• Pump level	17 kg/s
• No.9 Shaft sink via Pump level	32 kg/s
• Duct leak	17 kg/s
• Characterization level development	69 kg/s
• **Total**	**150 kg/s**

Return

• Out down NST	15 kg/s
• No.9 Shaft upcast	135 kg/s
• **Total**	**150 kg/s**

Summary

- No.10 Shaft complete to shaft bottom
- 700 m twin heading development
- In shaft duct [1 x 72”] reporting to Pump Level
- 150 kg/s chilled air from surface plus chilled service water, 69 kg/s for development activities
- Air cooling car [500 kW] on Characterization level
- No.9 Shaft sink not yet completed therefore commitment to single entry conditions

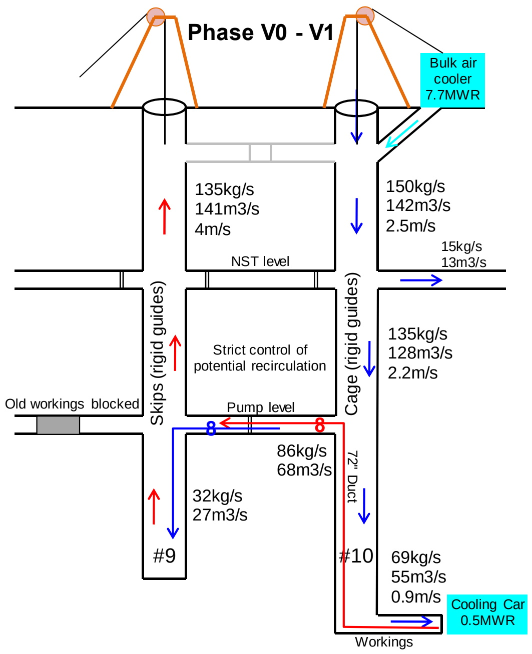


Figure 12.2 Ventilation Regime V0-V1

Refrigeration

The cooling during this period will be achieved by cold air delivered into No.10 Shaft on surface supplemented by chilled service water used for drilling, washing and muck cooling. The downcast flow of 150 kg/s will be cooled on surface to a temperature of 6°Cwb. There will be an air cooling car of 500 kW installed near the workings on Characterization level. The chilled service water flow of 4 l/s [24 hr ave] will be chilled on surface to 4°C. The refrigeration load will be made-up as follows:

- Surface bulk air cooler — 6.7 MW
- Surface chilled service water — 0.3 MW
- Air cooling car — 0.5 MW
- System losses [dams, pipes, pumps] — 0.7 MW
- Total refrigeration machine duty — **8.2 MW**

The surface refrigeration system will use two of the refrigeration modules each rated at 8 MW and during this period, the machines will operate on part-load. The bulk air cooler will use one of the cells of the spray chamber facility at the surface ramp portal.

Capabilities of vent/cooling system

For the characterisation work alone, it can be expected that the 69 kg/s cold intake available on the Characterization level will provide adequate ventilation and cooling resources. The underground cooling car will be introduced in Phase V.1. For example, heat load analyses indicate that this could support:

- Development length — 350 m [toward plant site]
- Development headings — 2 x 25 m^2
- Face advance — 3 m/day, 80 m/month [individual heading]
- Maximum rock production — 500 t/d
- Machinery — LHD [224 kW], drill jumbo, aux vehicles

Obviously there are other combinations and permutations of activities that could be supported – the above is simply an example.

Transition issues
In the transition period after this phase, the following will need to be considered:

- No.9 Shaft sink and connection between No.10 Shaft and No.9 Shaft will have been completed.
- Commissioning of temporary auxiliary bulkhead fans installed on Characterization level must be complete.
- Engineering and tendering for underground refrigeration plant will be complete at end of characterisation period so that the plants can be ordered immediately on project approval.

12.2.2 Phase V.2: After No.9 Shaft Holes but Prior to Running Main Upcast Fan and Prior to Running Underground Refrigeration Plant

During this period, the ventilation limitation is dominated by the air speed in No.9 Shaft that is being equipped. As noted, this maximum air flow will be 210 kg/s in No.9 Shaft barrel. Temporary auxiliary bulkhead fans will be installed on Characterization level to force air up No.9 Shaft. The team doing equipping work in No.9 Shaft will have dedicated ducted fresh cool air [12 kg/s] from NST level and later Pump level reporting to the work stage. The total ventilation flow will be 210 kg/s [plus assume 15 kg/s out down NST] distributed as follows, Figure 12.3:

Intake

• Out down NST	15 kg/s
• Duct dedicated to work equipping team	12 kg/s
• Pump level	48 kg/s
• Characterization level development	150 kg/s
• **Total**	**225 kg/s**

Return

• Out down NST	15 kg/s
• No.9 Shaft upcast	210 kg/s
• **Total**	**225 kg/s**

Summary
- Equipping of No.9 Shaft taking place, not yet hoisting rock in No.9 Shaft.
- Downcast No.10 Shaft with No.9 Shaft utilised as upcast for 210 kg/s.
- Temporary fan in bulkhead on Characterization level delivering return air to No.9 Shaft.
- Allocation to Pump level development and through-flow 48 kg/s.
- Work in No.9 Shaft will need to consider the condensing atmosphere.
- 225 kg/s chilled air from surface plus chilled service water, 150 kg/s for development activities plus air cooling car [500 kW] on Characterization level.
- Main surface fans serving No.9 Shaft will be commissioned at end of period.

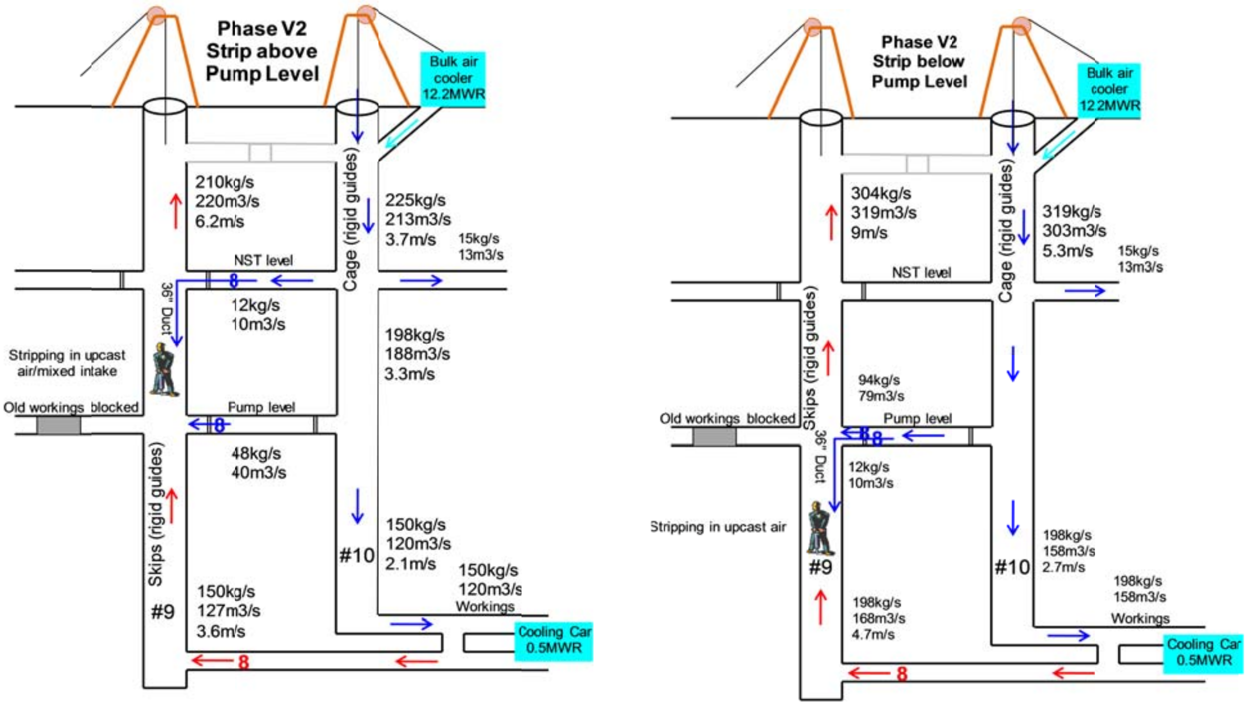


Figure 12.3 Ventilation Regime V2

Refrigeration

The cooling during this period will be achieved by cold air delivered into No.10 Shaft on surface supplemented by chilled service water used for drilling, washing and muck cooling. The downcast flow of 225 kg/s will be cooled on surface to a temperature of 6°Cwb. There will be an air cooling car of 500 kW installed near the workings on Characterization level. The chilled service water flow of 10 l/s will be chilled on surface to 4°C. The refrigeration load will now be made-up as follows

• Air cooler duty [including fans]	10.2 MW
• Chilled service water duty	1.0 MW
• Air cooling car	0.5 MW
• System losses [dams, pipes, pumps]	1.0 MW
• Total	**12.7 MW**

The surface refrigeration system will use two of the refrigeration modules each rated at 8 MW and, during this period, the machines will operate on part-load. The bulk air cooler will use two of the cells of the spray chamber facility at the surface ramp portal.

Capabilities of vent/cooling system

There will be 150 kg/s of cooled primary ventilation available for development on Characterization level. In addition, there will be 10 l/s of chilled service water from surface and the 500 kW air cooling car. The development will be limited to what type of activities these cooling resources can support. For example, heat load analyses indicate that the above ventilation and cooling resources will support a 1.0 kt/d development scenario as follows:

• Number of headings	4 off
• Average heading size	25 m^2
• Bulk excavations	100 kt/d
• Nominal rock production	1000 t/d

- Nominal distance of developments from Characterization level station will be 1.0 km

Transition issues

- The above phase starts when No.9 Shaft holes and ends when No.9 Shaft is equipped.
- The first main upcast fan will be available at start of next phase.
- Temporary auxiliary bulkhead fans on Characterization level to be removed.

12.2.3 Phase V.3 and V.4: Running Main Upcast Fan while Equipping No.10 Shaft and Prior to Running Underground Refrigeration Plant

During this period, the ventilation limitation is dominated by the air speed in No.10 Shaft that is being equipped. As noted, this air flow will be 365 kg/s in the No.10 Shaft barrel. The total ventilation flow will be 365 kg/s [plus assume 15 kg/s out down NST] distributed as follows, Figure 12.4:

Intake

• Out down NST	15 kg/s
• Pump level [for development work]	80 kg/s
• Characterization level development	285 kg/s
• **Total**	**380 kg/s**

Return

• Out down NST	15 kg/s
• No.9 Shaft upcast	365 kg/s
• **Total**	**380 kg/s**

Summary

- Equipping of No.10 Shaft taking place, hoisting rock to NST with skips in No.9 Shaft.
- Downcast No.10 Shaft with No.9 Shaft being upcast with first main fan.
- Upcast speed will be about 10 m/s with condensing atmosphere and possible water drop suspension.
- Relatively large allocation to Pump level development of 80 kg/s.
- 380 kg/s chilled air from surface plus chilled service water, 285 kg/s for development activities plus air cooling car [500 kW] on Characterization level.

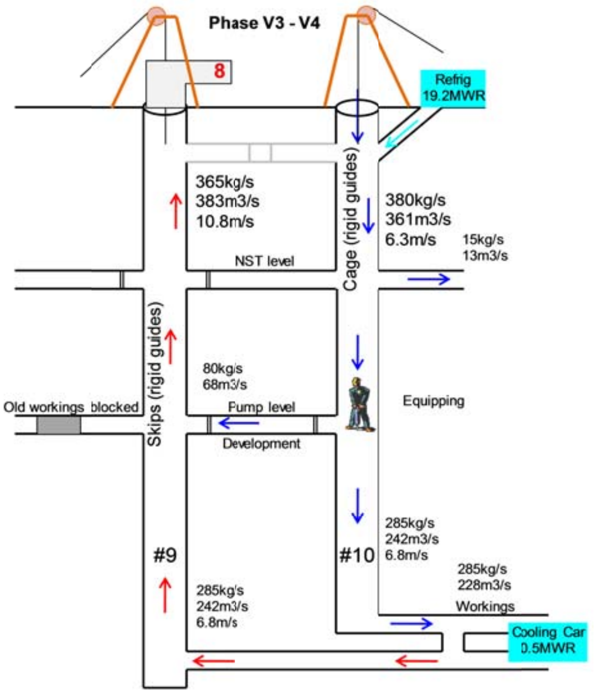


Figure 12.4 Ventilation Regimes V3-V4

Refrigeration

The cooling during this period will be achieved by cold air delivered into No.10 Shaft on surface supplemented by chilled service water used for drilling, washing and muck cooling. The downcast flow of 380 kg/s will be cooled on surface to a temperature of 6°Cwb. There will be an air cooling car of 500 kW installed near the workings on Characterization level. The chilled service water flow of 10 l/s will be chilled on surface to 4°C. The refrigeration load will now be made-up as follows:

- Air cooler duty [including fans] 17.2 MW
- Chilled service water duty 1.0 MW
- Air cooling car 0.5 MW
- System losses [dams, pipes, pumps] 1.0 MW
- Total 19.7 MW

The surface refrigeration system will now use all three of the refrigeration modules each rated at 8 MW and, during this period, the machines will operate on part-load. The bulk air cooler will use three of the cells of the spray chamber facility at the surface ramp portal.

Capabilities of vent/cooling system

There will be 285 kg/s of cooled ventilation available for development on Characterization level. In addition, there will be 10 l/s of chilled service water from surface and the 500 kW air cooling car. The development will be limited to what type of activities these cooling resources can support. For example, heat load analyses indicate that the above ventilation and cooling resources will support a 1.6 kt/d development scenario as follows:

- Number of headings 6 off [+2 contingency]
- Average heading size 25 m^2 [plus 15% over-break]
- Bulk excavations 200 kt/d [total from 2 sites]
- Nominal rock production 1600 t/d
- Maximum distance of developments from Characterization level station will be 1.0 km

Transition issues

- The above period finishes when No.10 Shaft is equipped and the primary air flow is then increased up to the limit set by maximum air speed in No.9 Shaft skip operation.
- The surface fan load will increase from 365 kg/s to 575 kg/s from 47% to 74% rated capacity.
- Work will commence on installing the underground refrigeration plant.
- Development tonnage will build-up to about 5.3 kt/d in next period.

12.2.4 Phase V.5: After No.10 Shaft Equipped but Prior to Underground Refrigeration Plant

During this period, the primary ventilation limitation is dominated by the air speed in No.9 Shaft which will be hoisting rock in skips on fixed guides to NST [with rope through collar seal]. As noted, this air flow will be 575 kg/s in No.9 Shaft barrel. The total ventilation flow will be 575 kg/s [plus assume 15 kg/s out down NST] distributed as follows, Figure 12.5:

Intake

- Out down NST 15 kg/s
- Pump level [through ventilation] 15 kg/s
- Characterization level development 560 kg/s
- **Total** **590 kg/s**

Return

• Out down NST	15 kg/s
• No.9 Shaft upcast	575 kg/s
• **Total**	**590 kg/s**

Although this period now has a significant increase in primary ventilation delivered to the Characterization level [from 285 kg/s to 560 kg/s] there will be development constraints due to limitations in underground ventilation distribution. Although significant development and construction work can take place around the shaft station areas, there will be a limitation on ventilation carrying capacity out to the south where the workshop is being developed. There will be a single intake and return drive [each 25 m^2] out to this zone and the limiting ventilation flow to the furthest workings will be 220 kg/s. This limitation will exist until the first ROWA drive connects to No.9 Shaft, April 2017.

Summary

- Development and construction work on Pump level complete.
- Development tonnage increased on Characterization level, hoisting rock to NST with skips in No.9 Shaft.
- Downcast No.10 Shaft with No.9 Shaft being upcast with first main fan at 74% rated flow.
- Upcast air speed will be <15.5 m/s with condensing atmosphere and water drops will be carried out.
- 590 kg/s chilled air from surface plus chilled service water, 560 kg/s for development activities plus air cooling car [500 kW] on Characterization level.
- Limited carrying capacity for ventilation [220 kg/s] distribution to furthest workings in south.

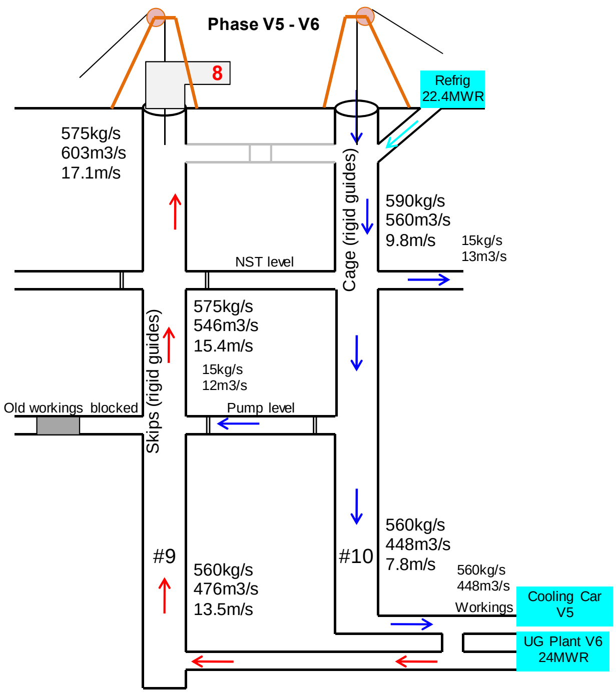


Figure 12.5 Ventilation Regimes V5-V6

Refrigeration

The cooling during this period will be achieved by cold air delivered into No.10 Shaft on surface supplemented by chilled service water used for drilling, washing and muck cooling. The downcast flow of 590 kg/s will be cooled on surface to a temperature of 10°Cwb. There will be an air cooling car of 500 kW installed near the workings on Characterization level. The chilled service water flow of 10 l/s will be chilled on surface to 4°C. The refrigeration load will now be made-up as follows:

- Air cooler duty [including fans] 20.4 MW
- Chilled service water duty 1.0 MW
- Air cooling car 0.5 MW
- System losses [dams, pipes, pumps] 1.0 MW
- Total 22.9 MW

The surface refrigeration system will now use all three of the refrigeration modules each rated at 8 MW and, during this period, the machines will operate close to full-load. The bulk air cooler will use all three of the cells of the spray chamber facility at the surface ramp portal.

Capabilities of vent/cooling system

During this period there will be four development crews, one ROWA crew and two construction crews. While the rock hoisting capability will be 5.3 kt/d, the tonnage will be limited by ventilation and cooling resources. This scenario has been examined in detail with specific VUMA models were set up based on the MineOrbit layout, see Figure 12.6 and Figure 12.7. For example, a representative set of activities would be:

- Number of headings 10 off [+3 contingency]
- Average heading size 25 m^2 [plus 15% over-break]
- Bulk excavations 200 kt/d [total from 2 sites]
- Nominal rock production 3.0 kt/d
- Maximum distance of developments from Characterization level station will be 1.3 km

Figure 12.6 MineOrbit layout for Ventilation Regime V5

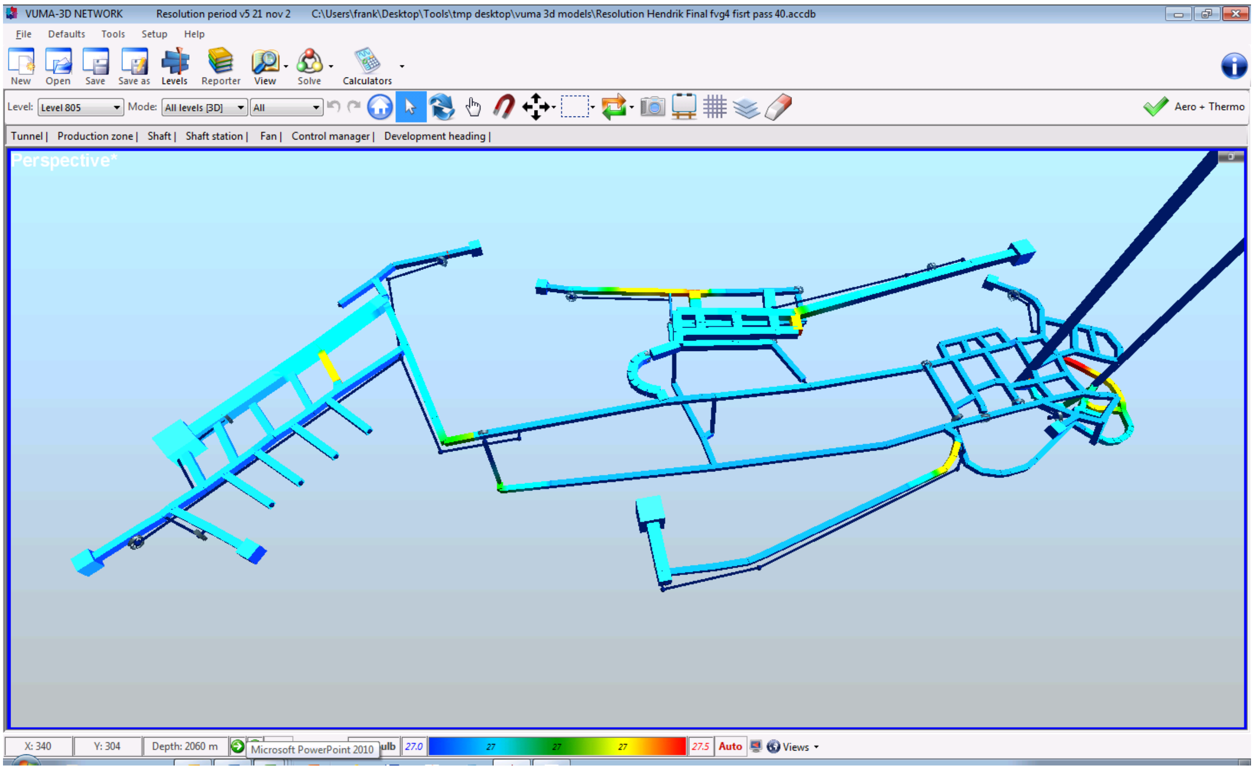


Figure 12.7 VUMA snapshot for Regime V5 [blue on temperature scale = 27.0°Cwb; red = 27.5°Cwb]

The VUMA model shows that temperatures in the development headings will be below the required 27.5°Cwb criterion. The modelling assumes that the air will be cooled to 10°Cwb on surface and an additional 500 kW of air cooling will be provided on Characterization level. The flow to the south is restricted to one intake and one return airway, this limits the airflow for development in the South to 220 kg/s.

Transition issues

- The above period ends when the underground refrigeration system is available and transition work will include start-up of underground refrigeration plant.
- The ventilation constraint to furthest workings in south will be lifted with holing of ROWA drive.

12.2.5 Phase V.6 after Start-up of the Underground Refrigeration Plant

Phase V.6 is a critical design period due to the planned increase in development and construction activities whilst only No.9 Shaft is upcasting [with skip hoisting] and No.10 Shaft is downcasting. No.14 Shaft [upcast] and No.11 and No.13 Shafts [downcast] only become available subsequently, Figure 12.5. The main constraint is the exhaust capacity of No.9 Shaft until No.14 Shaft becomes available. Total development production at this time will be limited to 5.3 kt/d by the temporary hoisting capacity of No.9 Shaft prior to equipping of No.11 Shaft.

The strategy is to maximise ventilation capacity using No.9 Shaft [with surface fans]. At the same time, the combined capacity of surface and underground refrigeration plants will be used to reduce air temperatures below that for LoM stages so that the net cooling capacity kW per kg/s is increased [lower mass flow rates required for the same cooling effect].

As noted, the limiting No.9 Shaft ventilation capacity is taken as 575 kg/s and the total intake at top of No.10 Shaft at this time will be 590 kg/s [at 7 m/s].

To confirm the adequacy of the proposed 575 kg/s to support mining activities, a detailed analysis of the development plan was undertaken with specific VUMA modelling. Figure 12.8 shows the typical [historic] snapshot scenario and Table 12.2 shows the breakdown of allocations to each work centre. This indicates that there will just be sufficient ventilation for the proposed mining activities with a balance of some 155 kg/s for dedicated returns [e.g. crusher or fuel bay] and construction activities. However, it is identified that, during this time, there will be insufficient ventilation capacity to support all development crews in multiple faces or multiple large construction projects. It will be critical to control the distribution of ventilation and to carefully monitor the development and construction schedule until such time that No.14 Shaft becomes available.

The refrigeration system at this time will comprise;

- Surface refrigeration system [total duty 22.4 MW] will provide cold air at 10°Cwb on surface and chilled service water flow [10 l/s] at 4°C on surface.
- Underground refrigeration plant at this stage will be able to provide up to 24 MW capacity with three machine modules. At this time, the capacity of heat rejection on the condensing side limits underground cooling capacity.

The ratio of total cooling capacity [up to 46.4 MW] to total ventilation [590 kg/s] is higher during this time by design in order to increase available cooling capacity.

During this period there will be seven development crews, two ROWA crews and two construction crews. The project constraints during this period will relate to the rock hoisting limit of about 5.3 kt/d and not necessarily the ventilation and cooling resources. These ventilation and cooling resources will support the '5.3 kt/d' development scenario which, for example, may be as follows:

- Number of headings: 22 off [+3 contingency]
- Average heading size: 25 m^2 [plus 15% over-break]
- Bulk excavations: 200 kt/d [total from 2 sites]
- Nominal rock production: 5.3 kt/d
- Maximum distance of developments from Characterization level station will be 1.6 km

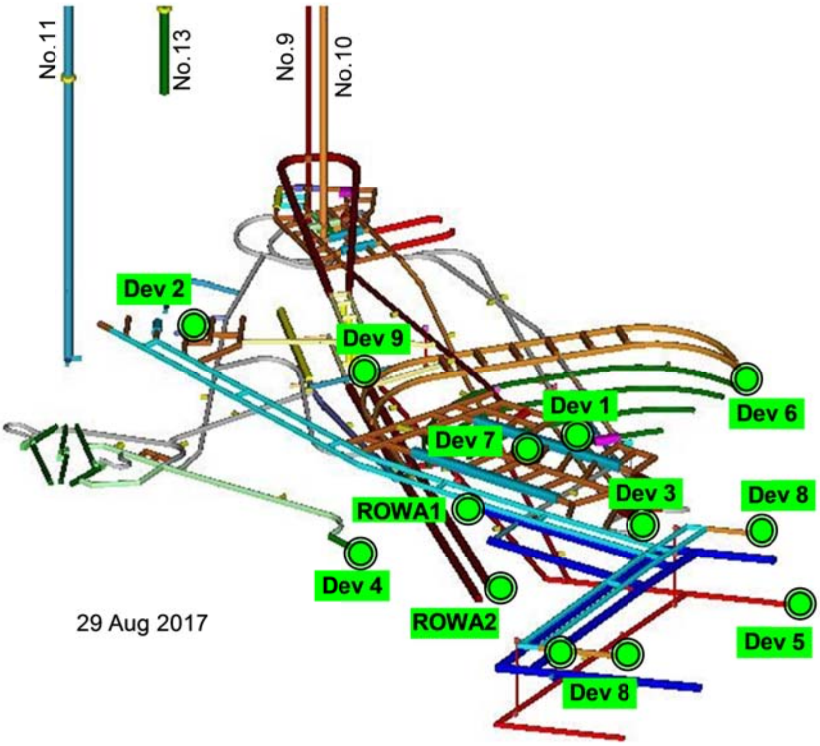


Figure 12.8 Mining Activity Audit

Table 12.2 Ventilation Allocation Audit

Crews	Level	Heading Type		Rate	Type	Active	Loc kg/s	Total kg/s
Dev 1	-870	CRUBW	Crusher Chamber	0.18 m/d	Single	1	25	25
Dev 2	-776	PSSLM	Shaft Station	5.3 m/d	Multi	2	25	50
Dev 3	-870	RMPLG	Ramp	5.3 m/d	Multi	2	25	50
Dev 4	-890	CVDLP	Conveyor Drift	4 m/d	Single	1	25	25
Dev 5	-840	EXHLG	Exhaust Drift	4 m/d	Single	1	25	25
Dev 6	-820	RSHLM	Rail Shop	5.3 m/d	Multi	2	25	50
Dev 7	-820	RALLG	Rail Drift	5.3 m/d	Multi	2	25	50
Dev 8	-775	IRXLR	Intake Raise Access	5.3 m/d	Multi	3		
	-775	PERLG	Perimeter Drift	5.3 m/d	Multi		25	0
	-775	PERLG	Perimeter Drift	5.3 m/d	Multi			
Dev 9	-840	EXHLG	Exhaust Drift	4 m/d	Single	1	25	25
ROWA 1	-840	EXHLX	Exhaust Drift	4 m/d	Single	1	40	40
ROWA 2	-805	INTLX	Intake Drift	5.5 m/d	Multi	2	40	80
					Mining	18		420
				Total available				575
		Balance (crusher/ fuel bays/magazine/leakage)						155

Care has been taken that adequate provision has been made for construction activities including the heat of the concrete trucks and the hydration heat effects of the cement.

12.2.6 Phase V.7A: After No.14 Shaft Holed but before No.11 Shaft Holed

During this period the primary ventilation will be no longer limited by No.9 Shaft upcast constraints because No.14 Shaft upcast will be now available. Rather the limitation will be set by No.10 Shaft downcast air speed constraints. As noted earlier, this limiting air speed was set at 11.5 m/s and the flow in the barrel above NST level will be limited to 705 kg/s and that available for main mine development will be 675 kg/s which is an increase of 20% over the previous period.

The temporary surface refrigeration plant will be now fully loaded at 24 MW and, along with the underground refrigeration capacity of 24 MW, the total cooling capacity will be 48 MW.

Apart from this, the description of this phase will be very similar to that of Phase V.6 above.

This period finishes when No.11 Shaft is available and the constraint on the downcast capacity is partially lifted.

12.2.7 Phase V.7B After No.14 Shaft and No.11 Shaft Holed but before No.13 Shaft Holed

With the availability of No.11 Shaft, and even though it will be undergoing equipping work, an additional downcast capacity of 400 kg/s in No.11 Shaft will become available to the system. The primary ventilation delivered to the Characterization level will now be 1075 kg/s which is an increase of 60% over the previous period.

This period will introduce the first permanent refrigeration machine on surface and the first permanent surface bulk air cooler at No.11 Shaft which will operate at a duty of 17 MW at this time. The temporary surface refrigeration plant will remain fully loaded at 24 MW. The underground refrigeration capacity will be 24 MW at this time.

This period finishes when No.13 Shaft is available and constraint on downcast capacity is further lifted.

12.2.8 Phase V.7C After No.14, 11, 13 Shaft Holed and No.11, 13 Shafts being Equipped

With the availability of No.13 Shaft, and even though No.11 and No.13 will be undergoing equipping work, an additional downcast capacity of 500 kg/s in No.13 Shaft will become available to the system. The primary ventilation delivered to the Characterization level will now be 1575 kg/s which is a 47% over the previous period.

This period will introduce the permanent surface bulk air cooler at No.13 Shaft. No.11 and No.13 Shaft surface bulk air coolers will operate at a duty of 39 MW at this time. The temporary surface refrigeration plant will remain fully loaded at 24 MW. The underground refrigeration capacity will remain 24 MW at this time.

This period finishes when No.11 and 13 Shafts are equipped and No.10 Shaft is being stripped.

12.2.9 Phase V.8: After No.11 and 13 Shaft Available and No.10 Shaft is Being Stripped

During this phase No.10 Shaft will be stripped and first production starts. The total primary ventilation flow will be constrained by upcast capacity of No.9 and No.14 Shafts which will be about 1900 kg/s below Pump level. The total downcast flow will be higher [say 2050 kg/s] because of the needs on Skip Discharge level and Pump level.

With the availability of No.11 and No.13 Shafts, this period will introduce the first permanent surface refrigeration equipment. It also introduces the phase out of the temporary refrigeration equipment that had been serving No.10 Shaft surface air cooler. The general representative overall refrigeration duty would be made up of:

• Temporary surface plant for No.10 Shaft air cooler	5 MW
• Permanent surface plant for No.11 and 13 Shaft air coolers	70 MW
• Chilled service water from permanent plant	6 MW
• Underground plant	24 MW
• Total	**105 MW**

12.2.10 Phase V.9: No.11, 13, 10, 14 Shafts Available and No.9 Shaft Being Stripped

During this phase No.9 Shaft will be stripped and production will continue to ramp-up. The total downcast capacity of No.11 and No.13 Shafts will generally match the upcast capacity of No.10 and No.14 Shafts [with a relatively low flow in No.9 Shaft serving the stripping crew]. No.10 Shaft will no longer be downcasting and the temporary refrigeration system that had served No.10 Shaft will now be de-commissioned. The total primary ventilation flow will still be about 1900 kg/s below Pump level. The total downcast flow will be higher [say 2100 kg/s] because of the Skip Discharge level and Pump level needs.

Due to the ramp-up of the production, this period will introduce the next underground refrigeration module. The general representative overall refrigeration duty will be made up of:

• Permanent surface plant for No.11 and 13 Shaft air coolers	72 MW
• Chilled service water from permanent plant	10 MW
• Underground plant	32 MW
• Total	**114 MW**

12.2.11 Phase V.10: No.11, 13, 10, 14, 9 Shafts Available and No.12 Shaft Being Equipped

During this phase No.12 Shaft will be undergoing equipping, all the other shafts will be operational and production will continue to ramp-up. The total downcast capacity of No.11, 13 and 12 Shafts, with flow retarded in No.12 Shaft for equipping work, will dictate that the total primary ventilation flow will be about 2300 kg/s below Pump level. This phase will introduce the surface bulk air cooler at No.12 Shaft. The total downcast flow will be higher [say 2600 kg/s] because of Skip Discharge level and Pump level needs.

The general representative overall refrigeration duty will be made up of:

• Permanent surface plant for No.11 and 13 Shaft air coolers	88 MW
• Chilled service water from permanent plant	14 MW
• Underground plant	32 MW
• Total	**134 MW**

12.2.12 Phase V.11: All Shafts Available and Final Build-up to Full Production

The ultimate primary ventilation flow will be 2760 kg/s as referenced below Pump level. The total downcast flow will be higher 3120 kg/s because of the Skip Discharge level and Pump level needs.

The ultimate general representative overall refrigeration duty would be made up of:

• Permanent surface plant for No.11 and 13 Shaft air coolers	105 MW
• Chilled service water from permanent plant	18 MW
• Underground plant	40 MW
• Total	**163 MW**

12.3 Summary of Ventilation Circuit and Refrigeration Capacity Profiles

The issues concerning circuit development and refrigeration capacity, described above, are summarised in Figure 12.9 and Figure 12.10. The provision of a higher ratio of refrigeration capacity to ventilation rate in V.6 has been made due to the identified limitation of volumetric capacity prior to availability of shafts 14, then 11 then 13 in phases V.7A to V.7B. With respect to ventilation and diesel power, a comparison between volumetric capacity to underground workings and gross diesel fleet requirements [0.05m^3/s per kW] is shown in Figure 12.11. Prior to and after phase V.6 there is sufficient volumetric capacity to operate, on a mine wide basis, most if not all available diesel equipment. This is certainly the case for the full production phase.

It is identified that during phase V.6 the total diesel fleet [including small service vehicles] would require more ventilation than will be available. However, during phase V.6 it will be possible to operate all larger [>200kW] at 80% potential load with smaller [<200kW] units operating at 40% potential load. Based on operating norms elsewhere this will be adequate for development purposes without compromising exposure standards. Of course, it will be important to monitor use of diesel equipment to ensure that adequate ventilation is provided to each and every working location on a shift by shift basis.

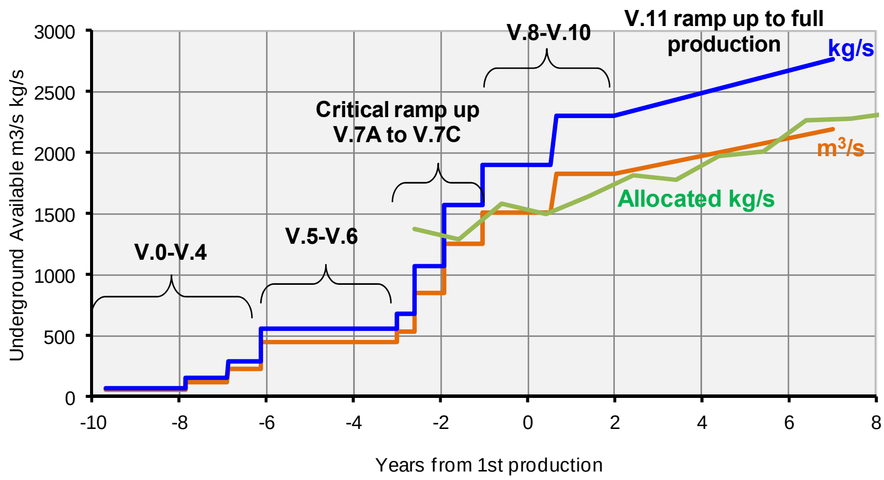


Figure 12.9 Schedule of Ventilation Capacity Profile

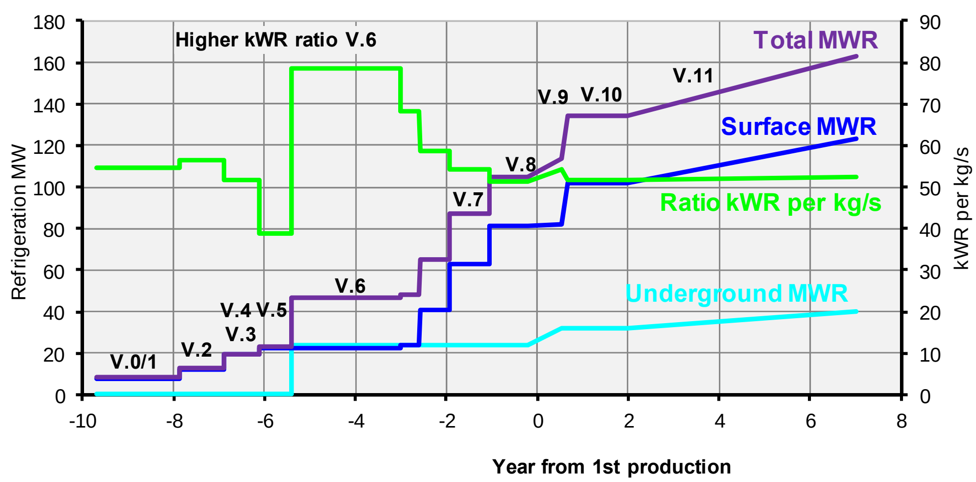


Figure 12.10 Schedule of Refrigeration Capacity Profile

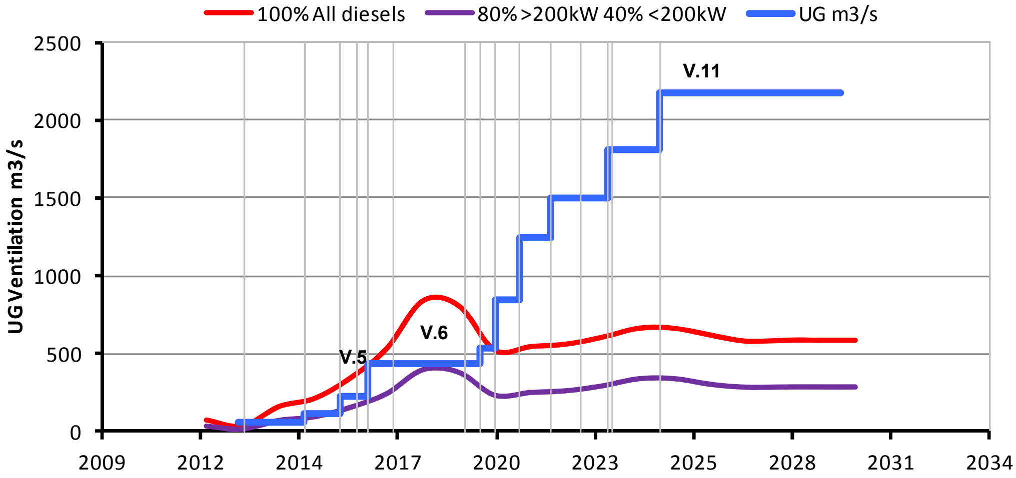


Figure 12.11 Ventilation Capacity and Diesel Fleet Requirements

13 CONTROL AND AUTOMATION STRATEGY

The overall mine will employ both vehicle and personnel tracking and the extraction level loaders will all be remotely controlled. In keeping with the design of a sophisticated modern mining operation, there will be a central control facility that will serve these and many other control functions.

It is thus important to consider and provide-for appropriate control and automation systems within the ventilation and cooling structures. In discussion with RCM the team, it was decided that the basic level of sophistication will be modest and practical in terms will use what is available with current appropriate technology. However, it is important that the development of new technology is tracked and this approach updated as relevant going forward.

The proposed system will include real-time monitoring reporting to 'live' network simulators which will update and calibrate themselves in real-time. The feedback from these systems will be automatically evaluated and prompts reported for manual control intervention. However, some basic-level automatic feedback control will also be applied [e.g. main fan inlet guide-vanes].

The aims of the monitoring and control system will be to enhance health and safety, fire detection, optimise energy management, ventilation on demand and, most importantly, the distribution of ventilation to extraction crosscut exhaust raises all in parallel [up to 35 off].

The purpose of this section is to provide a concept level description of the control and automation strategy for ventilation and refrigeration systems. With consideration to the need for the high refrigeration capacity and high operating pressures of surface fans, there is a need for management of ventilation circuits in order to optimise the capacity and hence minimise operational costs.

13.1 Ventilation System Monitoring and Control

13.1.1 Real time monitoring and network-modelling

The ventilation system will be monitored using a mine wide control strategy, Figure 13.1. The real time monitoring will include:

- Sonic air velocity
- Temperature and relative humidity [hence wet-bulb]
- Absolute and differential pressure transducers
- Auxiliary fan status [PLC control in starter]
- Ventilation door status [open or closed]
- Ventilation regulator settings [fraction open, differential pressure and velocity]
- Smoke or other suitable fire detection system e.g. infra red
- Gases CO, NOx, SO_2
- Surface and booster fan parameters [PLC control in starter]

Real time sensors will be located in intake and return airway splits to provide a mass [kg/s] and heat [kW] balance for each section of the mine together with a means of continuously comparing actual with plan trigger levels. All necessary devices required are readily available and currently employed in the mining industry.

Computer network simulations [e.g. VUMA-live] will be used to correlate real time monitoring data with simulation results in order to update the model and indicate detailed flows in all airways. The mine control system will be equipped to report and archive data, raise alarms and communicate with other software for real time modelling purposes.

13.1.2 Ventilation Surveys

Ventilation surveys will be carried out on a routine basis by ventilation officers to confirm operation of the monitoring system and problem solving. It is intended for the real time monitoring system to provide most of the information required for a mine wide assessment on an ongoing basis. However, section surveys will be required to monitor and audit implementation of ventilation plans e.g. location of ventilation control devices and performance of auxiliary ventilation circuit.

Handheld devices will be used for personal access to all locations deemed to be of high level risk. For heat, this would mean a wet bulb temperature potentially greater than 27°C. For gases, this would mean re entry after blasting or for routine checks on diesel vehicle operating locations. Handheld devices will include:

- Environmental climate monitor
- Gases CO, NOx, SO_2

13.1.3 Personnel Monitoring

For the present purposes, the proposed method for monitoring employee exposure to respirable dust and DPM is by discrete area and personal sampling. This approach is suggested as opposed to the use of a large number of real time sensors. However, this approach should be reviewed periodically to reflect improvements in available future technology.

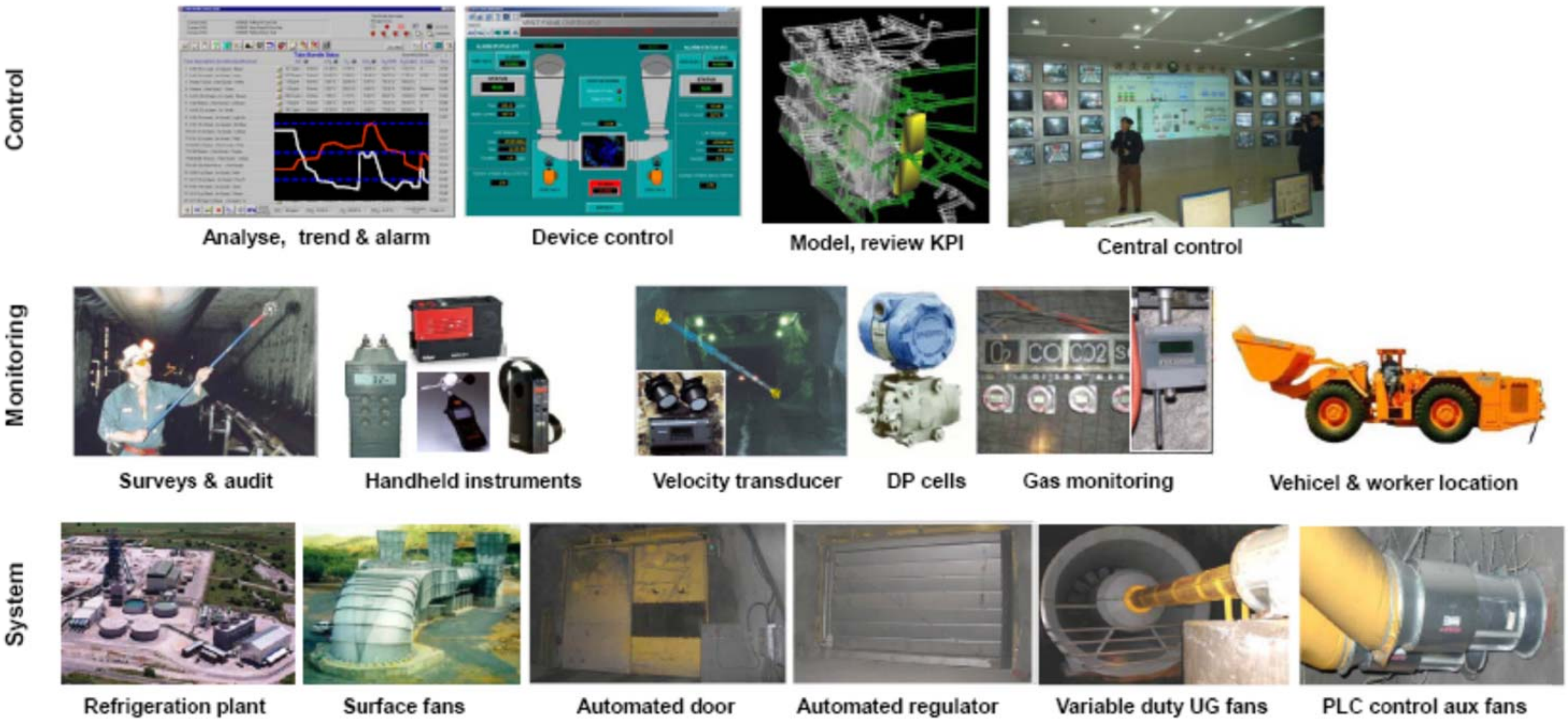


Figure 13.1 Ventilation System Monitoring and Control

13.1.4 Ventilation System Control

The basic hierarchy of ventilation system control in the fully developed mine will be as follows:

- Systems will be operated in accordance with a pre-determined documented plan.
- Surface fans set for primary flow through mine workings, conveyor drift and tunnel to mill.
- Main return regulators set for normal conditions [No.11 and 12 Shaft return, shop returns, refrigeration plant return]. All regulators used to direct ventilation to return from potential sources of fire will have emergency override actuators i.e. a pre determined fully open setting to exhaust smoke to return airways.
- Development headings, in particular those of the undercut level extraction level, will make use of variable speed fans in the duct systems.
- Internal exhaust raises requiring variable control for the extraction level and undercut level will have a high-quality specification automatic regulator system.
- Some key points [e.g. crusher return] will have remote controlled actuators.
- Apart from the above, it is not proposed to have remotely controlled regulators on every return raise although provision will be made to retrofit actuators if proven necessary [e.g. to balance pressure across the cave].
- Other than the potential use of high speed intake fans, the ventilation distribution will be controlled on the exhaust side.
- Data from real time sensors will be collated by the mine control system and reported on standard screens together with dynamic data exchange [DDE] download links to analysis software such as Excel and VUMA-live.
- Given the complexity of the mine circuit, it is assumed that there will be at least one dedicated ventilation officer/controller on each shift who will be responsible for assessing prevailing conditions and responding accordingly.

13.2 Fan Station System Monitoring and Control

The general arrangement of the main surface fans will be that all the three exhaust shafts will connect to a common subterranean ‘manifold’ and each main fan will be connected directly to the manifold. Thus all shafts will be connected to all fans. There will be multiple operational main fan units each equipped with mechanically actuated inlet guide-vanes designed for full continuous modulating operation between the fully closed and maximum open positions. Each main fan motor set will be provided with localised PLC and control panel to assist with fan start-up, interlocks, fan control, energy management, metering and reporting, data collection, monitoring and communication. The energy metering will interface with the mine-wide monitoring system and the system control PLC. The guide-vane control and the multiplicity of fan units will be very versatile control, turn-down and energy management.

The other fan stations will be:

- Surface conveyor drift fan station
- Booster fan station for high speed intake airways
- Characterization level temporary fan station

These fan stations will be provided with localised PLC and control panel to be installed near the local fan MCC to assist with fan start-up, interlocks, fan control, energy management, metering, data collection, monitoring and communication. The energy metering will interface with the mine-wide monitoring system and the PLC will supervise and monitor the following:

- Energy metering

- Motor winding and bearing temperatures
- Vibration sensors
- Airflow velocity, pressure and temperature in each fan duct leg
- Non-return damper door position indicators

In addition, the Characterization level temporary fan station will incorporate variable speed drives.

13.3 Refrigeration System Monitoring and Control

13.3.1 Surface Refrigeration System

The monitoring and control system will include a centralised system-supervisory PLC. Each refrigeration machine will have a dedicated PLC serving the instrumentation and control functions on the machine. The machine PLCs will communicate with the supervisory PLC which will be responsible for managing the refrigeration machines and controlling the air cooler fans, cooling tower fans, pumps and the control valves [including blow-down, make-up control]. This control will include normal operation, start-up and shut-down as well as all alarms, trips, interlocks and safety devices. Interface with mine-wide monitoring system will be through a fibre-optic link to the System PLC. The refrigeration machine load can be controlled by pre-rotational guide vanes set to automatically limit maximum absorbed compressor motor power and control the leaving chilled water temperature.

The ice storage dam will be an important part on the control system in terms of energy management. Within the dam, ice will be formed on the outside of the tubes during the cold part of the day and then melted by the circulating water during the warm part of the day. The thermal storage will allow peak load damping and optimisation of power tariff structures and this function will also be controlled from the central System PLC. On a broad level, the control systems will allow simple load-shedding, energy management, changing set-point temperature of air off the air coolers and the air flow by the variable speed air cooler fans.

13.3.2 Underground Refrigeration System

Each refrigeration machine will be supplied with its own local PLC that ensures the safe operation of the machine and performs all local control and supervisory functions. In addition, there will be a central overall System PLC supervising the refrigeration machines, the sequencing of the pumps and the monitoring of the dams. Each refrigeration machine will require one condenser pump and one chilled water pump to operate and, as each pump is started, automatic valves will open on selected refrigeration machine.

The chilled water will be pumped through the evaporator heat exchangers, directly into the cooling coil network [and back to the return water dam]. The number of chilled water circulating pumps [and refrigeration machines] will need to be set manually to suit the number of coolers in circuit - flow dependent. The plant room will not be able to detect the exact requirements from any measured variable. The refrigeration machines will respond automatically [PLC control of guide-vanes] to achieve the set-point outlet water temperature. On a broad level, the control systems will allow simple load-shedding, energy management, changing set-point temperature and flow of chilled water to the cooling coil network.

14 EMERGENCY PREPAREDNESS

The purpose of this section is to provide a concept level description of the emergency preparedness strategy [pertinent to ventilation and refrigeration systems] which will of course have to be developed further and be subject to appropriate risk assessment. The overall plan is to use an industry best practice approach, including norms with respect to escape and refuge, but with additional consideration to the issues of heat.

The generic issues of concern are:

- Mobile or fixed plant fires e.g. diesel vehicles or conveyor drives.
- Fires associated with stores of flammable material or “hot” work e.g. fuel bays
- Failure of the ventilation system [auxiliary, section through to total mine]
- Entrapment due to falls of ground
- Escape versus refuge [with or without smoke]

The generic and proposed controls are as follows;

- General provisions;
  - A site specific documented and risk assessed emergency preparedness plan
  - A mine plan available to the workforce that clearly demarcates ventilation districts, egress routes, points of refuge and prevailing air temperatures together with heat stress levels [0 to 3].
  - Two way communication system with automatic emergency alert over ride [e.g. PED].
  - Worker and vehicle location system.
  - All workers trained in emergency response procedures.
  - Annual emergency response tests.
  - Established communication pathways to onsite and remote mine rescue/medical resources.
  - Documented and implemented inspection and maintenance system for all mine equipment.
  - Real time monitoring of the ventilation system [gases and heat] with an appropriately qualified engineer on site and in charge of the systems at all times.
  - Dedicated underground mine rescue and fire fighting vehicles.
  - Surface / underground rescue/first aid station with appropriately trained personnel.
  - Appropriate ground support standards and monitoring of geotechnical issues that may arise.

- Fire prevention and fire fighting;
  - On board fire suppression for all mobile vehicles.
  - Dedicated return airways from stores of flammable material/ mine plant and workshop “hot” work areas. This should include “fused” drop door on regulators.
  - Separate ventilation district for ore handling system, including main underground and drift belts. Configured so that potentially contaminated air will not enter other working horizons.
  - Automatic fire suppression at key locations e.g. drive heads and main switch gear.
  - Standards fire prevention practice e.g. house-keeping and material storage in intake airways.
  - CO and smoke detection at appropriate locations [linked with real time monitoring system].

- Escape and refuge
  - All systems configured to promote egress as the first response.
  - Workers PPE [not necessarily worn but in close proximity to work place] must include drinking water and may include a stash of ice jackets. Risk assessment may be employed to determine the quantity of such resources to be employed in different parts of the mine.
  - Sufficient transport vehicles to be available in designated sections of the mine to remove workers to safety.

- Two means of egress from all working horizons established and identified [plans and signs]. This may include escape ladder ways in segregated airways between levels. Restricted access/worker numbers to developing sections of the mine in which a second means of egress has not yet been established.
- Body worn self contained self rescuers with additional stores for replacement and/or refill at appropriate locations based on distance to be travelled.
- Sufficient refuge bays in appropriate proximity to all work places to accommodate all workers underground. These refuge bays should be fitted with means of cooling without external power supply in addition to standard supplies [air/water/food]. The design duration of refuge bays will be subject to risk assessment but is likely to be at least 96 hours.
- Special consideration is to be given to the initial characterisation work if undertaken from No.10 Shaft prior to holing of No.9 Shaft.

ADDENDUM A DESIGN AMBIENT WEATHER DATA

In the course of this work, the most relevant weather data-base that was examined came from hourly data gathered at the mine site. The data consists of hourly measurements over a consecutive period of more than 4 years [March 2002 to June 2006].

The reference data-base file names are as follows [ex Ian Edgar, Sept 06]:

KC2Met 1Jan to 30June06	KC1Met2006 1Jan to 30June06
KC2Met 1Jan to 31Dec05	KC1Met2005 1Jan to 31Dec05
KC2Met 1Jan to 31Dec04	KC1Met2004 1Jan to 31Dec04
KC2Met 1Jan to 31Dec03	KC1Met2003 1Jan to 31Dec03
KC2Met 12July to 31Dec02	KC1Met2002 28Feb to 31Dec 02

Statistical examination of the weather data allows the following observations:

- Raw data is logged as dry-bulb temperature, relative humidity and barometric pressure. Wet-bulb temperature is uniquely defined by these parameters and is calculated accordingly. [Raw data also contains wind speed, wind direction and rainfall].
- For the full data base, the maximum hourly wet-bulb temperature recorded is 23°C [there are only 2 data points above 22.5°C].
- Longest consecutive period when wet-bulb temperature > 20°C is 19 hrs [there were 103 days in 4 years which had data points > 20°, on these 103 days, the average consecutive period was 4.7 hrs].
- Longest consecutive period when wet-bulb temperature > 21°C is 11 hrs [there were 39 days in 4 years which had data points > 21°, on these 39 days, the average consecutive period was 3.2 hrs].
- Longest consecutive period when wet-bulb temperature > 22°C is 5 hrs [there were 4 days in 4 years which had data points > 22°C].

Moreby's analysis [Aug 06] of Phoenix weather data deduced that, of the daily maximum wet-bulb temperatures, 19% were > 21°C but there were zero > 22°Cwb. Note that Phoenix is at a lower altitude and a decreasing correction is relevant.

- For the full data base the maximum hourly dry-bulb temperature recorded is 40°C [there are only 14 data points above 38°C].
- Longest consecutive period when dry-bulb temperature > 36°C is 9 hrs [there were 44 days in 4 years with data points > 36°, on these 44 days the average consecutive period was 3.8 hrs].
- Longest consecutive period when dry-bulb temperature > 35°C is 10 hrs [there were 110 days in 4 years with data points > 35°, on these 110 days the average consecutive period was 4.1 hrs].
- Longest consecutive period when dry-bulb temperature > 34°C is 14 hrs [there were 177 days in 4 years with had data points > 34°C, on these 177 days the average consecutive period was 4.8 hrs].

Faced with this evidence, the appropriate selection for the design surface wet-bulb and dry-bulb temperature and overall ambient surface design condition would appear to be **21/37°Cwb/db** [88 kPa barometric press]. These are the values adopted in this analysis. Figure 2 shows some of these data graphically.

ADDENDUM B HEAT STRESS MANAGEMENT PLAN LIMITS

The purpose of this addendum is to provide a rationale, justification and values for heat stress management plan limits in the Resolution Copper Mine project. A summary of these values and generic management plan contents in is shown in Table B.1 using Australian triggered action response plan terminology.

The overall logic and background to applicable limits are as follows;

1. Subject to surface climate, depth of workings and underground heat loads, a wide range of air temperatures and hence risk of heat related illness may occur in underground mines. For the Resolution project, the known design parameters will lead to levels of risk ranging from negligible to immediately hazardous when compared to custom and practice in the international metalliferous mining industry.

2. There are many decades of heat stress management experience in underground mines for which a number of standards exist for the calculation of rational or notional heat stress indices. In addition to these indices there is also a wide body of evidence to support contents of heat stress management plans with respect to health screening, training in the signs, symptoms and treatment of heat related illness, hydration, acclimatisation, personal protective equipment and appropriate action plan responses. The Resolution project should draw on these standards and supporting material to develop the site's heat stress management plan.

3. There is a need for clear unambiguous values to be used for decision making. These must be safe and justifiable but also operationally practicable and economically realistic.

4. With respect to local mining regulations, the following extract appears to be the only reference to heat stress management requirements;

   Arizona Administrative Code.
   Article 4. Air Quality, Ventilation and Radiation, and Physical Agents
   R11-1-476. Heat stress control
   A. Persons repeatedly exposed to hot environments will be suitably trained to recognize heat disorders and to render first aid for heat disorders.
   B. Work requirements will be adjusted to reduce the risk of heat disorders.
   Historical Note: Adopted effective April 7, 1976 [Supp. 76-2].

   Based on this text this is taken to mean that the Resolution project may select any suitable method for monitoring the thermal environment and is not necessarily compelled to use wet bulb globe temperature [wbGT] and ACGIH work regimen charts. In any event, the ACGIH TLV document makes provision for use of indices other than wbGT in hot environments.

5. This approach would also be consistent with Rio Tinto Occupational Health Standard B6, which states

   3.0 Measurement Techniques
   3.1 Detailed heat stress assessment of identified tasks or jobs must be tiered to:
   [a] Commence with the use of a simple heat stress index as a screening tool; then, if necessary
   [b] Use rational heat stress indices in an iterative manner to determine the 'best' control methods for alleviating potential heat stress; then
   (c) Undertake physiological monitoring when exposure times are calculated to be less than 30 minutes, or where high level PPE that limits heat loss must be worn.

   Rio Tinto standards also provide guidance on the contents of heat stress management plans consistent with custom and practice in hot underground mines worldwide.

6. The normal approach to monitoring and decision making is to use a simple method for determining the status of a working location with respect to transition from Level 0 to Level 1 or Level 2 to Level 3. For example aspirated wet bulb temperature. These provide “lines in the sand” for operational simplicity and do not rely on sophisticated equipment or calculations.

   In addition, for work above Level 0 a more sophisticated heat stress index can be employed to account for parameters otherwise not properly assessed by wet bulb temperature alone, for example air velocity, dry bulb and radiant temperatures. When used, this heat stress index takes precedent over the more simplistic initial wet bulb trigger.

   There are a large number of heat stress indices available world wide with a range of sophistication and applicability to underground mining. The main three indices used in mining are effective temperature [Australia, Europe and historically in South Africa], wet bulb globe temperature wbGT [mainly North America] and air cooling power [South Africa and Australia]. In addition, the international standard ISO 7933:2004 is available for determination of thermal stress using calculated sweat rates or more recently termed predicted heat strain.

   The problem with using aspirated wet bulb or wbGT alone is that the index may over or underestimate the risk. This is a particular issue in the Resolution project where background radiant temperatures will be high and the ventilation circuit design will most likely require routine variation in air velocity for management of ventilation distribution.

   It has been shown that the wbGT method and existing rest regimen charts would result in a significant increase in refrigeration requirements in deep mines. In the main, wbGT charts employed by ACGIH underestimate the effect of air velocity although they do introduce the concept of acclimatisation.

   Air cooling power [ACP] describes limits based on an environment’s ability to cool a person undertaking various degree of work in order to maintain a safe body core temperature. These values are, or can be, calculated from all five thermal environment factors and are therefore as valid as methods described in ISO 7933 providing input parameters for clothing are the same. In this respect, air cooling power and thermal work limit [TWL] developed in Australia represent the similar calculations. It is important to note, in the North American mining context, that air cooling power is also the method described by Dr M McPherson in his text book and peer reviewed publications although various modifications to his original formulation may now be appropriate to match those in ISO 7933 and other similar rational models. An example chart using a more recent Howes method is shown in Figure B.1.

   This view of using alternative rational heat stress indices is supported by ACGIH, Rio Tinto documentation and the International Labour Organisation [ILO] who all reference ISO 7933 and ISO 7243 [wbGT] for comparison. [Note that the ACGIH TLV document includes early ISO 7933 calculations as an appendix].

   It is recommended that the Resolution project employs an air cooling power approach that can be demonstrated to be consistent with ISO 7933:2004. This can also be modified to account for increase in barometric pressure in deep mines.

8. With respect to acclimatisation, the recommended approach is for this to be undertaken in the work place by persons deemed fit for such work by a suitably qualified medical practitioner This examination may include heat tolerance testing and should also specify the length of acclimatisation, typically one week. The period of acclimatisation will include work protocols preventing un acclimatised persons from working or travelling alone in levels 1 to 3 [Table B.1] together with monitoring their health and hydration. Persons will be deemed not to be acclimatised if they have not worked underground in a similar hot environment for a specified period of time, typically two weeks, or have suffered from a heat related illness.

B.1 Design Temperature Standards

It is important to note the distinction between these heat stress management limits and air temperatures employed in refrigeration and ventilation design.

Heat stress management plan limits determine the level of controls to be in place with consideration to the risk of heat related illness. These are based on an average physiological response to working in heat and are therefore guideline values. The rationale being that the combination of hard and soft barriers results in an acceptable degree of risk. For example, the stop work level of ACP = 115 W/m^2 means that, if other systems fail, a person can still safely walk from the work place to a cooler location.

Temperatures used for design of refrigeration and ventilation requirements are set so that, on average, specified work place return air temperatures [reject temperatures] are met. For example, if the reject temperature is set at 27.5°Cwb then return air temperatures may range 26 to 29°Cwb due to the dynamic nature of the mining process superimposed on diurnal variations in surface air temperatures.

The amount of cooling required therefore depends on the design reject temperature with design optimisation balancing resultant heat stress management requirements with cost of refrigeration. For example, at the Resolution project will require about 15 MW_R of refrigeration to reduce the intake air by 1°Cwb.

At this point in time, the recommended design reject temperatures are 27.5°Cwb in development faces when persons are outside air conditioned cabins and 30°Cwb in production crosscuts when equipment is operated remotely. That is, referring to Table B.1, designing for level 1 conditions in development faces and level 2 conditions in production cross cuts.

B.2 Summary

1. A heat stress management plan is required to be developed in accordance with Rio Tinto standards and applicable mine regulations. There is a wide body of appropriate guideline material available for this task including that for medical assessment of fitness for work.

2. Provision should be made [charts, handheld instruments and computer programs] to employ an air-cooling power method as the principal heat stress index for decision making. The basis for calculation of air cooling power, or other rational index, should provide results consistent with those described in ISO 7933 but may be modified as and when appropriate.

3. The recommended trigger levels are those shown in Table B.1 with wet and dry bulb temperatures being used for screening or rapid decision making in the absence of an air cooling power reading.

4. The values provided in Table B.1 are also consistent with air temperatures currently being used for design of Resolution's refrigeration and ventilation systems. If these values were to be reduced then refrigeration requirements would increase by some 15 MW per °Cwb.

Table B.1 Proposed Heat Stress Management Plan Structure

Action Level	Wet & dry bulb temperature wb db °C	Air cooling power ACP W/m^2	Description	Occurrence	Principal controls in place
Level 0	wb < 27 db < 32	200< ACP	Negligible risk of excess heat related illness	At any time	• Generic training in heat stress management and health screening • Provision of adequate drinking water • Appropriate clothing • Heat stress zones marked on mine plan and communicated to workforce • Monitoring the thermal environment – screening using wb & db
Level 1	27 < = wb <29 or 32 < = db <37	200 > = ACP > 145	Potential risk of heat related illness during routine work periods.	Likely in underground work places for most of the year. This is the design status of heat management systems for routine work outside air-conditioned environments.	Level 0 plus, • Use ACP for confirmation of thermal environment status • Limited access to un acclimatised persons • Un acclimatised persons not to work alone. • PPE, work practice and hydration protocols. • Supervision, documentation and worker location monitoring.
Level 2	29 < = wb <32 or 37 < = db	145 > = ACP > 115	Increased risk of heat related illness during routine work periods.	Likely in the vicinity of operating mine development and production equipment.	Level 1 plus, • Workers to be in air conditioned environments other than for short durations. • Persons not to work alone outside air conditioned environments for specified durations. • Redeployment for persons outside air conditioned environments. • Limits on type of work undertaken • Documented remedial actions to improve conditions for work outside air conditioned environments.
Level 3	32< = wb	ACP < = 115	Unacceptable risk of heat related illness	Not designed for but may occur in the event of control system failure.	Level 2 plus, • Work under written permit with additional special precautions.

1. Wet bulb trigger levels rounded for clarity but assume the workplace to be adequately ventilated – used when air cooling power unknown.
2. Wet bulb is the aspirated wet bulb temperature with limits established from regulatory standards elsewhere.
3. Air cooling power method takes precedent when obtained and is calculated from wet bulb temperature, dry bulb temperature, air velocity, radiant temperature and barometric pressure. This can include assumptions regarding average barometric pressure and radiant temperatures.
4. Air cooling power limits established from ISO 7933 [Light activity = 115W/m^2, moderate activity 145W/m^2, high activity 200W/m^2]

Figure B.1 Example Air Cooling Power Chart

AIR COOLING POWER (Howes)

Air velocity = 0.5 **m/s** **Pressure=** 110 **kPa** **Clothing =** 0.69 **icloc**

Dry Bulb \ Wet Bulb	25	25.5	26	26.5	27	27.5	28	28.5	29	29.5	30	30.5	31	31.5	32	32.5	33
50	163	157	151	144	137	130	122	114	105	98	94	90	85	80	74	67	60
	166	160	154	148	141	134	126	118	110	101	96	92	87	81	75	69	61
49	169	163	157	151	144	137	130	122	114	105	98	94	89	83	77	70	62
	172	166	160	154	147	140	133	126	118	109	100	96	90	85	78	71	63
48	175	169	163	157	150	143	136	129	121	113	104	97	92	86	80	73	65
	178	172	166	159	153	146	139	132	124	116	107	99	94	88	81	74	65
47	180	174	168	162	155	149	142	134	127	119	110	102	95	89	83	75	66
	183	177	171	164	158	151	144	137	129	121	113	104	97	91	84	76	67
46	185	179	173	167	160	153	146	139	131	124	115	107	99	92	85	77	68
	187	182	175	169	162	156	149	141	134	126	118	109	100	94	87	78	69
45	190	184	177	171	164	158	151	143	136	128	120	111	102	95	88	79	69
	192	186	179	173	166	160	153	145	138	130	122	113	104	96	89	80	70
44	194	188	181	175	168	161	154	147	139	132	123	115	106	98	90	81	71
	196	190	183	177	170	163	156	149	141	133	125	117	108	99	91	82	72
43	197	191	185	179	172	165	158	150	143	135	127	118	109	100	92	82	72
	199	193	187	180	174	167	159	152	144	136	128	119	111	102	93	83	73
42	201	195	188	182	175	168	161	153	146	138	129	121	112	103	93	84	74
	203	196	190	183	177	169	162	155	147	139	131	122	113	104	94	84	74
41	204	198	191	185	178	171	164	156	148	140	131	123	114	104	95	85	75
	206	199	193	186	179	172	165	157	149	141	132	123	114	105	96	86	76
40	207	201	194	188	181	173	166	158	150	141	133	124	115	106	96	86	76
	209	202	196	189	182	174	167	159	151	142	134	125	116	107	97	87	77
39	210	204	197	190	183	175	167	159	151	143	134	126	117	107	98	88	78
	211	205	198	191	183	176	168	160	152	144	135	126	117	108	98	88	78
38	212	206	199	192	184	177	169	161	153	145	136	127	118	109	99	89	79
	213	207	200	192	185	178	170	162	154	145	137	128	119	109	100	90	79
37	214	207	200	193	186	178	171	163	154	146	137	128	119	110	100	90	80
	215	208	201	194	187	179	171	163	155	147	138	129	120	110	101	91	80
36	216	209	202	195	187	180	172	164	156	147	139	130	121	111	101	91	81
	217	210	203	196	188	181	173	165	157	148	139	130	121	112	102	92	82
35	218	211	204	196	189	181	174	165	157	149	140	131	122	112	102	92	82
	219	212	205	197	190	182	174	166	158	149	141	132	122	113	103	93	83
34	219	212	205	198	191	183	175	167	159	150	141	132	123	113	104	93	83
	220	213	206	199	191	184	176	168	159	151	142	133	123	114	104	94	83
33	221	214	207	200	192	184	176	168	160	151	142	133	124	114	105	94	84
	222	215	208	200	193	185	177	169	160	152	143	134	125	115	105	95	
32	222	215	208	201	193	186	178	169	161	152	144	134	125	115	106		
	223	216	209	202	194	186	178	170	162	153	144	135	126	116			
31	224	217	210	202	195	187	179	171	162	154	145	136	126				
	225	218	210	203	195	188	180	171	163	154	145	136					
30	225	218	211	204	196	188	180	172	163	155	146						
	226	219	212	204	197	189	181	173	164	155							
29	227	220	212	205	197	189	181	173	165								
	228	220	213	206	198	190	182	174									
28	228	221	214	206	199	191	182										
	229	222	214	207	199	191											
27	230	222	215	207	200												
	25	25.5	26	26.5	27	27.5	28	28.5	29	29.5	30	30.5	31	31.5	32	32.5	33

Wet Bulb

Lev	Action
0	Normal precautions
1	Acclimatisation protocols
2	Redeployment
3	Stop work

ADDENDUM C HEAT FLOW FROM BROKEN ROCK

The purpose of this addendum is to review the estimation of heat loads arising from broken rock in the ore transport system using currently available values for geothermal properties of rock.

The need for this analysis arises from the base case potential heat load of some 55MW when ore is being produced at a rate of 120,000 tpd and enters the ventilation system at a virgin strata temperature of c77^{O}C [depending on age of pile].

C.1 Geometry, Thermal and Physical Properties

For the purposes of this analysis the data shown in Tables C.1 and C.2 has been employed. Compared to original data, new geothermal data indicates that, in general terms, there will be less heat in the ore stream, due to lower thermal capacity, but the rate of heat transfer will be greater due to higher thermal conductivity.

Previous analysis of this type indicated a total potential heat load of 50MW with about 65% being emitted in underground workings i.e. about 32MW. The main objective of this analysis is therefore to determine new planning values. To provide a sensitivity analysis the range of properties used will be the mean below 1,500m and those for quartzite rich areas.

Table C.1 Thermal and Physical Properties [New and old]

Item	Symbol	Units	Value	Comments
Thermal conductivity	k	W/m ^{O}C	**4.83** **6.55**	**Mixed mean below 1,500m** **Quartzite rich areas**
Rate of heat transfer will be higher				
Thermal capacity	Cp	J/kg ^{O}C	**800** **800**	**Mixed mean below 1,500m** **Quartzite rich areas**
Amount of heat will be lower				
Thermal diffusivity in situ	α	m/s^2	2.2 x 10^{-6} 3.0 x 10^{-6}	**Mixed mean below 1,500m** **Quartzite rich areas**
Rate of heat transfer will be higher				
Bulk density [in situ and solids]	ρ	kg/m^3	**2,770** **2,690**	**Mixed mean below 1,500m** **Quartzite rich areas**
Little change				

Table C.2 Thermal and Physical Properties

Item	Units	Value	Comments
Bulk density [broken pile]	kg/m^3	1,800	
Swell factor in situ to broken ore	%	55.5	Based on predicted pile density
Mean rock diameter	mm	300	Actual size distribution unknown
Production rate [average]	tpd	110,000	
	kg/s	1,273	
Capacity of loader bucket	m^3	6	
Loader tram speed	km/h	8	
Capacity of rail car	m^3	14	
Speed of rail transport	km/hr	12	
Capacity of shaft skip	m^3	25	
Shaft hoisting speed	m/s	18	
Surface conveyor speed	m/s	4	

C.1 Properties of Broken Rock Piles

Thermal properties provided in Table C.1 above are for solid intact rock. To estimate the thermal behaviour of broken rock, it is necessary to consider the effect of voids and moisture content, refer Figure C.1 and Table C.3.

Figure C.1 Conceptual Thermal Behaviour of Broken Rock

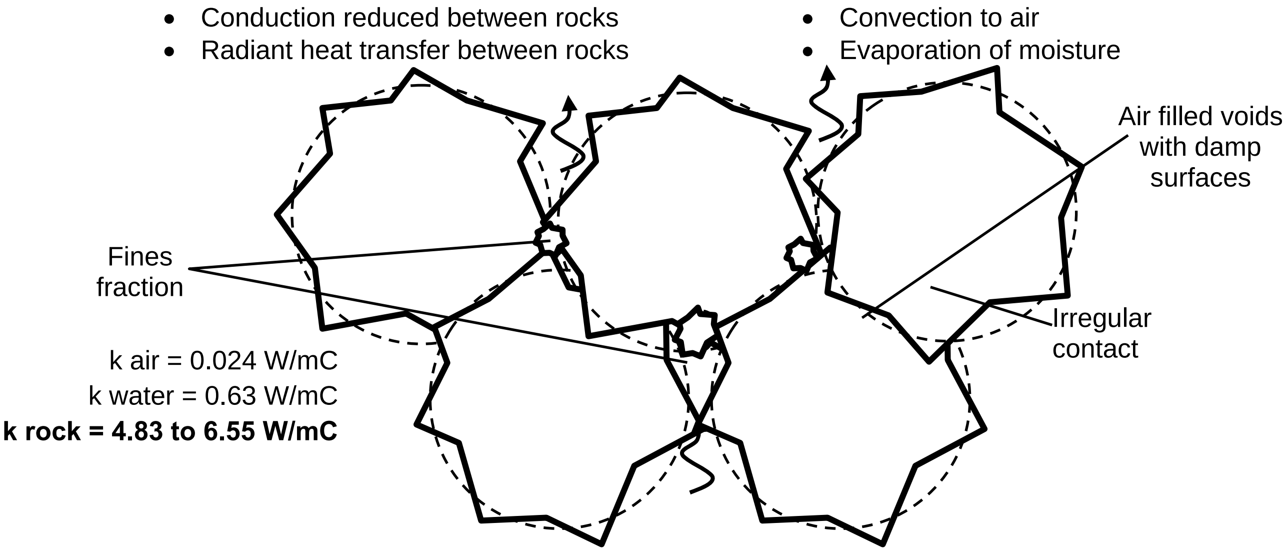


Table C.3 Estimate of Broken Rock Properties

Item	Unit	Mean Below 1500m	Quartzite Rich Areas
In situ rock density	kg/m3	**2,770**	**2,690**
Swell factor	%	55.5	55.5
Broken rock density	kg/m3	**1,781**	**1,730**
Moisture	%	5	5
Per cubic meter basis			
Volume rock	m3	0.64	0.64
Volume voids	m3	0.36	0.36
Mass rock	kg	**1781**	**1730**
Mass water	kg	**89.1**	**86.5**
Mass air	kg	0.31	0.31
Cp rock	J/kgC	**800**	**800**
k rock	W/mC	**4.83**	**6.55**
Cp air	J/kgC	1005	1005
k air	W/mC	0.024	0.024
Cp water	J/kgC	4,183	4,183
k water	W/mC	0.632	0.632
Total density	**kg/m3**	**1,871**	**1,817**
Total thermal capacity	**J/kgC**	**961**	**961**
App thermal cond (estimated)	**W/mC**	**2**	**2**
App thermal diffusivity (estimated)	**m2/s**	**1.11E-06**	**1.15E-06**

The bulk density of a rock pile is given by the total mass [rock, water and air] divided by the volume. Using the site specified swell factor of 55.5% for in situ to broken rock, the broken rock density will be about 1,800kg/m^3. For 5% moisture content, the mass of water would therefore be 86 to 90kg per m^3 and the mass of air about 0.3 kg per m^3. The total mass per unit volume [bulk density] will therefore be 1,817 to 1,871kg/m^3

The total thermal capacity of the rock pile is the sum of thermal capacity of the components weighted by mass percent. For both rock types this is now some 13% less than previously assumed.

The apparent thermal conductivity of the pile is subject to degree of contact between particles and degree of air movement through the pile. This is impossible to calculate with confidence but these effects will reduce thermal conductivity while increased water content will increase thermal conductivity.

Tan & Ritchie [1996] reported values of thermal conductivity for various waste dump material ranging 0.62 to 1.63W/mC but, although they reported bulk density, they did not provide values of the solid material for comparison. Their work also confirms the significance of moisture content on apparent thermal conductivity of broken material.

For the purposes of this analysis a thermal conductivity value of 2 W/m/k is used as an estimate for broken rock piles and also the values for the rock itself assuming that the contact is so great that there is little insulating effect from air in voids i.e. this will provide an operating envelope in which the actual value will fall.

C.2 Base Case Heat Load

The base or worst case heat load arises if all rock enters draw points at tvr = 77^{O}C [mean value of working horizons] and leaves the mine at or about ambient underground intake dry bulb. Ambient underground intake dry bulb temperatures will be tdb = 25 to 35^{O}C i.e. it is assumed that there will be limited heat transfer in shaft conveyances.

Using the thermal properties provided above, the potential heat load is given by Q = m x Cp x dt kW where m is the average mass flow rate in kg/s, refer Table C.4.

Table C.4 Maximum Heat Load kW with Production and Dry Bulb Temperature
Cp= 800J/kg and VRT = 77^{O}C.

Production					**Plan**	
tpd	25,000	50,000	75,000	100,000	**120,000**	140,000
kg/s	289	579	868	1,157	**1,389**	1,620
Dry bulb	Heat MW	Heat kW	Heat kW	Heat kW	**Heat kW**	Heat kW
25	14	27	41	55	66	77
30	12	25	37	49	59	69
35	11	22	33	44	53	62

This provides a potential worst case heat load of, in round numbers, 60MW if all potential heat is transferred from rock to intake ventilation at the anticipated range of intake dry bulb temperatures.

However, this basic analysis cannot indicate how the heat load will be distributed and therefore what heat management controls are required. It does however provide an indication of the order of magnitude involved and the potential effect of mitigation, for example reduced residence times in intake airways or separation of haulage route and crusher ventilation circuits from other main intake airways.

In addition, if rock leaves the mine at a mean temperature above ambient dry bulb then the heat load to the mine reduces but a problem may then arise in the conveyor tunnel. This means that it is also important to estimate the rate at which rock will transfer heat to ventilation as it passes through the ore transport system.

C.3 Ore Transport Flow Chart and Residence Time of Rock

The first step in estimating actual heat loads is to quantify the residence time of broken rock in various sections of the ore transport system. For this analysis it is assumed that the transport flow chart will be similar to that shown in Figure C.2 [new skip discharge horizon] with transport characteristics in Table C.5 and nominal rock residence times in Table C.6. It is emphasised that rock residence times are an approximate average that will of course vary from time to time.

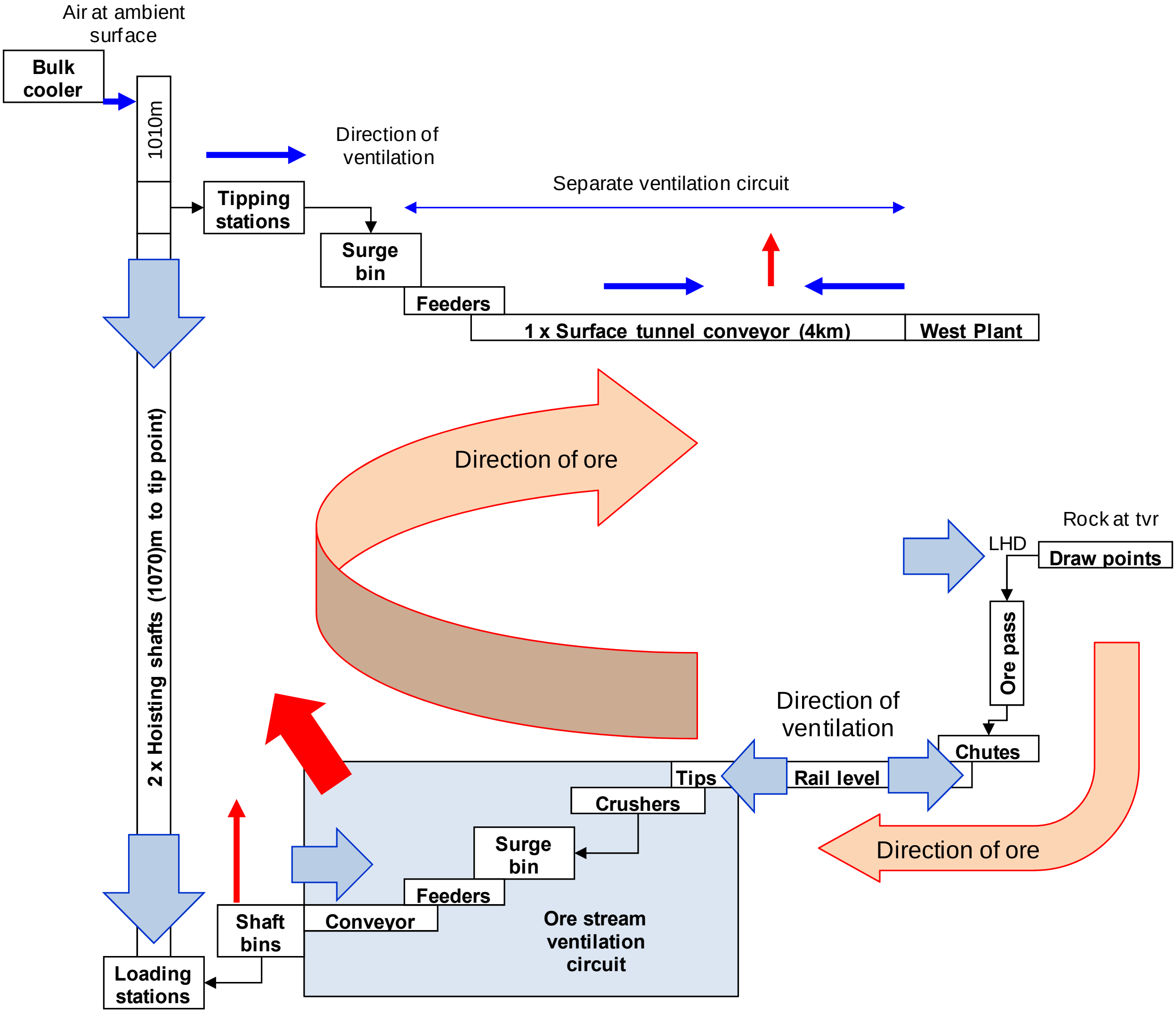


Figure C.2 Schematic Basic Ore Transport Flow Chart

Table C.5 Geometry and Mass of Transport Components

Assuming bulk density = 1,800 kg/m^3

		Bucket	Rail Car	Skip
Volume	m3/s	6	14	25
Mass	t	10.8	25.3	45.2
Radius (sphere)	m	1.13	1.50	1.81
Velocity	m/s	2.2	3.3	18

Table C.6 Estimates of Rock Residence Times [Mid Production Shift]

Location	**Comment**	**Length m**	**Velocity m/s**	**Duration mins**
Draw point	Average time in pile before load			9.0
LHD tram	150m at 8km/hr - in bucket	150	2.2	1.1
In ore pass	Based on first in first out			140.0
Load on rail level	12 minutes average (24 total)			12.0
Tram rail level	1500m @ 18km/h	1500	5.0	5.0
Tip through crusher				1.0
Surge bin & feeders				5.0
Convey to shaft bins				2.0
In shaft bin & load				10.0
Hoist in shaft	1070m at 18m/s	1070	18.0	1.0
			Total underground time	186
Tip to surge bin				4
Surge bin/feeders				10
Tunnel conveyor	4000m at 6m/s	4000	6	11
			Time in conveyor tunnel	25
			Total draw point to end conveyor	211

The objective of this analysis is to obtain an impression of the order of magnitudes involved and therefore by how much and where broken rock is likely to transfer heat to the ventilation system.

Assuming active draw points will be loaded [26 buckets] every 1.2 days on average, an analysis of a draw point loading cycle is shown in Table C.7.

Table C.7 Drawpoint Loading Cycles

LHD trip time drawpoint to orepass		
Load bucket	min	0.25
Tram loaded to OP	min	1.14
Tip bucket	min	0.25
Return empty	min	1.14
Time per bucket	min	2.77
Say nominal	min	3.00

Drawpoint loading cycle analysis		
Load per bucket	t	10.8
Buckets per cycle		26
Tonnes per cycle	t	282
Volume per cycle	m3	156
Time per cycle	min	78
Wait to next cycle	hours	29

With respect to heat transfer from broken rock, the following assumptions are made for the situation in the middle of a production shift;

1. During production rock will report to draw points with a mean particle size of 300mm and at a uniform temperature of tvr = 77^{O}C. There will be a reduction in pile temperature between loading cycles subject to ventilation rates in the draw point during the about 29 hour gap.

2. Rock will then be picked up by a loader after lying in the draw point pile for an average 9 minutes [3 bucket cycles] while the draw point is being worked.

3. When transported in the loader bucket [say 6m^3 or c11 tonnes] the bucket load will cool as a function of it's temperature, mass and size. That is, all mixed ore entering the loader bucket is at a uniform temperature from the draw point [<77.2°C] and will enter the ore pass at some lower mean temperature.

4. It is assumed that the loader bucket can be represented by a sphere of the same mass and that the steel bucket itself will have little effect on heat transfer i.e. steel has a high thermal conductivity [45W/m °C] compared to that of rock. The thermal capacity of the loader bucket is ignored as is it's cooling during the return trip to the draw point i.e. the temperature of the loader bucket is assumed to be the same as the ore in it.

5. When tipped into the ore pass there will be a significant increase in heat transfer through the falling rock. Then, when at rest in the pass, heat transfer will be very limited as the ore pass will be in host rock with little or no air passing through it. For the purposes of this analysis it is therefore assumed that the temperature of broken rock does not change in the ore pass. This will be about right if passes are kept full with rock entering at a similar mean temperature and the residence time is short.

6. Increased heat transfer will then occur as rock passes through loading chutes into rail cars followed by heat transfer through the car sides [steel] as it is transported to the shaft crusher stations. In a similar manner to loader buckets It is also assumed that rail cars can be modelled as a sphere of similar mass, say 14m^3 or c25 tonnes capacity each.

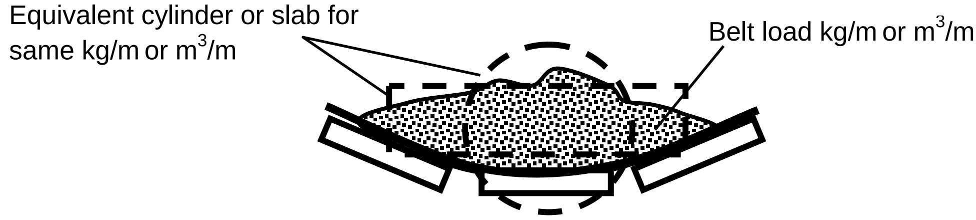
7. Heat transfer will then increase again through the crusher in to surge bins feeding shaft skip loading pockets. This will have to be taken into account when designing crusher station ventilation systems for management of dust.

8. Heat transfer in shaft skips is again treated as a sphere of say 25m^3 or c45 tonnes capacity each. A cylindrical shape may also be considered.

9. Once tipped to the conveyor horizon ore will discharge directly onto the belt to surface. Cooling in this facility will be dependent on size, shape and residence time as the host rock will be significantly cooler than at production depth.

10. In the surface conveyor tunnel ore will be transported as an open pile on a single belt. This geometry can be modelled using a cylinder or slab of infinite length with the same mass or volume density per unit length of belt. For example, if the belt is carrying 1,273kg/s for a production rate of 110,000tpd and the belt speed is 4m/s the average load will be 318kg/m or 0.15m^3/m, refer Figure C.3.

Figure C.3 Surface Conveyor Load



Overall, it is relatively straightforward to determine realistic design values for rock residence times and the geometry to be considered in all stages or transport. It is not as straightforward to estimate the rate of heat transfer at various points in the system.

C.4 Broken Rock Heat Transfer Model

The heat transfer model is based on the following rationale;

1. The rate of heat transfer from broken rock to surrounding ventilation depends on thermal properties of the rock, it's size, shape, heat transfer coefficients and difference in temperature between the rock and surrounding air. There will also be a difference if the rock is considered as an isolated particle or as a broken pile.

2. For dry rock, the heat transfer coefficient combines heat transfer by convection and radiation with values obtained from basic shapes [sphere or cylinder], velocity and temperature differentials. For wet rock, it is also necessary to include the effect of evaporation that will increase the rate of cooling. Evaporation rates are then dependent on psychrometric properties of surrounding air [vapour pressure e kPa] and not just air dry bulb temperature. In this project it is the design intent toad some 50l/s of chilled water to the ore stream for the purposes of dust suppression.

3. Not only does the rate of heat transfer reduce as the rock temperature reduces but there will also be a temperature gradient from the centre of a rock particle or rock pile in a similar manner to the cooling of strata adjacent to mine airways i.e. the rock does not cool down uniformly. The consequence of these effects is that the rate of heat transfer for the same difference in rock to air temperature will be significantly higher from fresh rock at the draw point than in cooled rocks further down the transport system. This results in a rate of change of rock temperature being described by an exponential equation of the form $tr = A\ e^{-\lambda t}$. where λ represents the rate of change of temperature and A is a constant describing rock properties and geometry, Figure C.4.

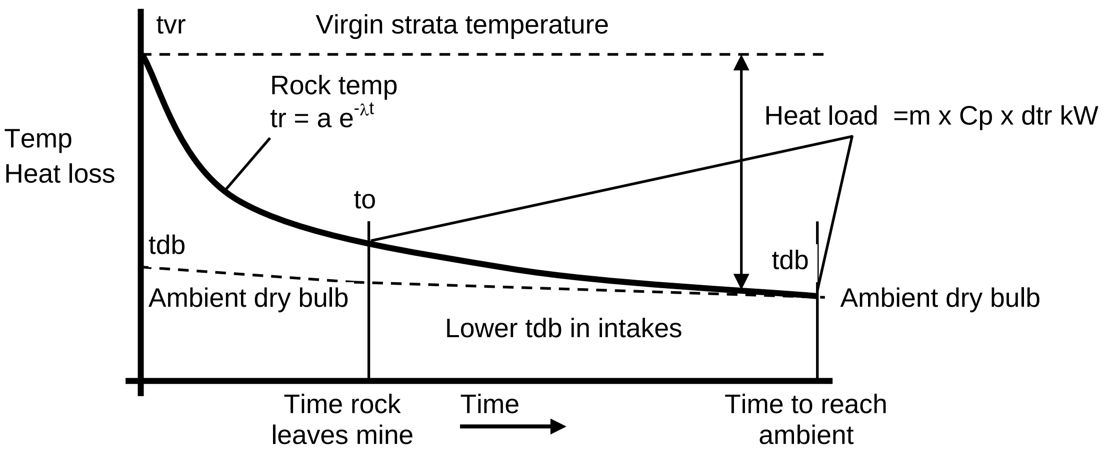


Figure C.4 Rate of Cooling of Broken Rock

4. A further complication is that the ambient dry bulb and evaporation rates will change in the system with ventilation being counter flow to the direction of rock transport and drying of the rock.

The issue is to determine the likely shape of the temperature decay curve in various sections of the rock transport system and hence estimate mean rock temperatures together with resultant heat loads.

C.4.1 Unsteady State Heat Transfer

Calculation of unsteady state heat transfer through and from three dimensional shapes is by any measure a complex task. However, using methods described for basic shapes such as a sphere and making some general assumptions about likely heat transfer coefficients, it is possible to obtain an order of magnitude analysis. This analysis does not include heat generation resulting from oxidation of sulphide ore that should be limited given the short residence time of rock in the system but this issue should be reviewed for the broken pile itself.

Considering a solid sphere of radius rm in Figure C.5, the calculations are as follows;

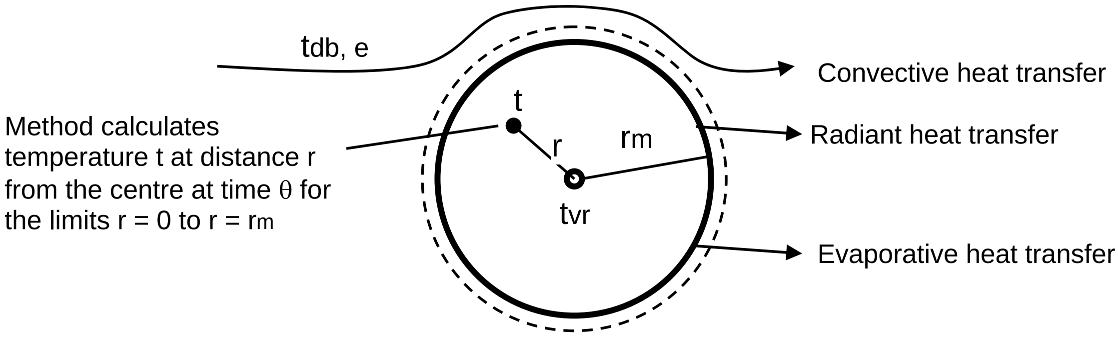
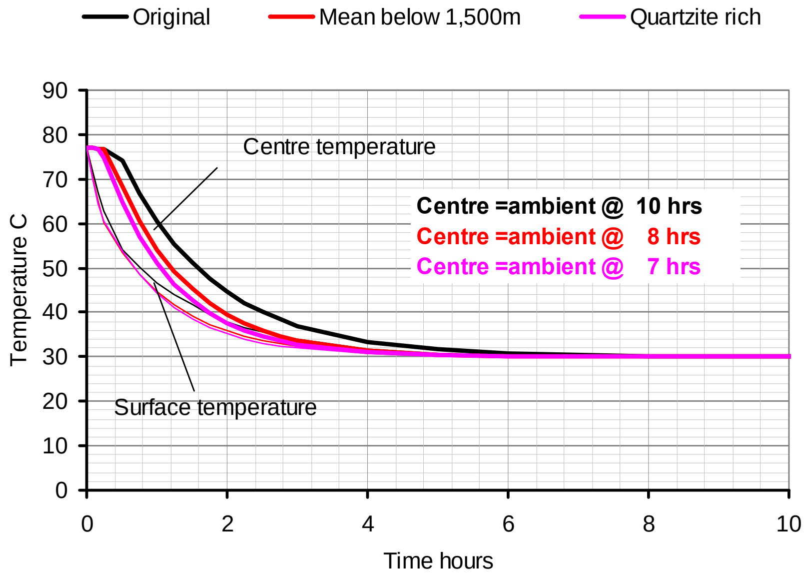


Figure C.5 Unsteady State Cooling of a Sphere

a. The sphere is surrounded by moving air at a temperature tdb and vapour pressure e kPa.
b. At time θ = 0 seconds the whole sphere is at a temperature tvr which is >> tdb > twb
c. Heat is lost from the surface of the sphere by convection and radiation with a total heat transfer coefficient ht W/m^2 ^{O}C. Evaporation also results in heat transfer while the rock is wet or partially wet.
d. The effective rate of cooling W/m^2 ^{O}C due to evaporation is obtained from an assumed constant atmospheric vapour pressure. This is an identified approximation.
e. The sphere cools by transferring heat to the surroundings until at some point the entire sphere is at tdb, or close to it, subject to evaporation rates.
f. From time θ = 0 to the time that the entire sphere is at tdb the temperature at any point in the sphere can be calculated. Therefore the rate of cooling and time taken to cool can be calculated together with the log mean or arithmetic average temperature and total heat loss to the surrounding atmosphere.
g. The rate at which the sphere is emitting heat can also be calculated from the predicted surface temperature using Q = ht. A [ts – tdb] where A is the surface area of the sphere and ts is the surface temperature.
h. The total heat energy at time θ = 0 is = m.Cp.tvr and at any other time is m Cp.t" where t" is the mean temperature of the sphere. The heat lost is therefore m.Cp.[tvr – t"]. In this case m is the mass of the sphere.
i. Knowing the mass of the sphere [single particle or loader bucket], the results provide an estimate of heat load per tonne with time.

The analysis for a 300mm diameter spherical rock starting at tvr = 77^{O}C in air at tdb =30^{O}C and a surface heat transfer coefficient of ht = 35W/m^{2} ^{O}C [15 convection, 15 evaporative and 5 radiant] is shown in Figure C.6. That is, the behaviour of a single partially wet sphere surrounded by air in isolation from other rocks.



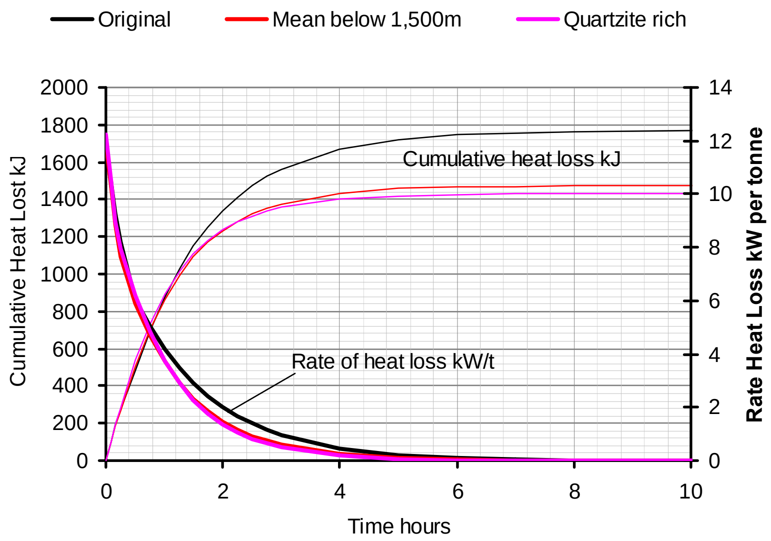
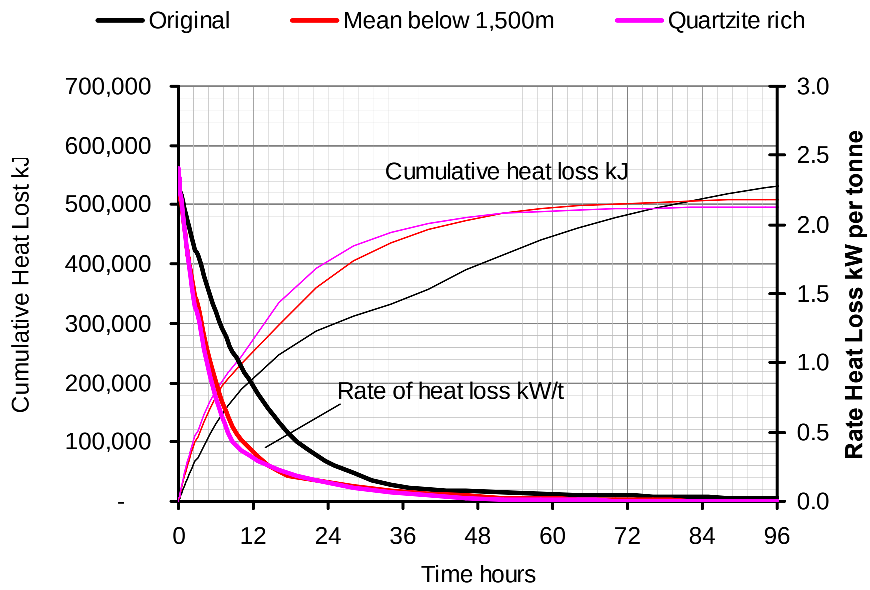


Figure C.6 Analysis for an Isolated Sphere Radius 0.15m – Wet Single Rock

Using a sphere of 1.13m diameter to represent a loader bucket, the results indicate a much slower rate of cooling, refer Figure C.7. A similar behaviour would occur in rail cars and shaft skips. However, the most significant uncertainty is the effective conductivity of broken rock in relation to the thermal conductivity of the solid rock particles. For the analysis provided here it is also assumed that the thermal conductivity of the broken rock is that same as that for the solid particles. Values of 2W/mK for broken rock of 3.9W/mK have been employed [this remains a significant unknown value].

The analysis for a sphere representing a loader bucket indicates a very much longer period of cooling and certainly much longer than the residence time in the circuit [in round numbers, 3 hours underground and 0.5 hours on the surface conveyor].



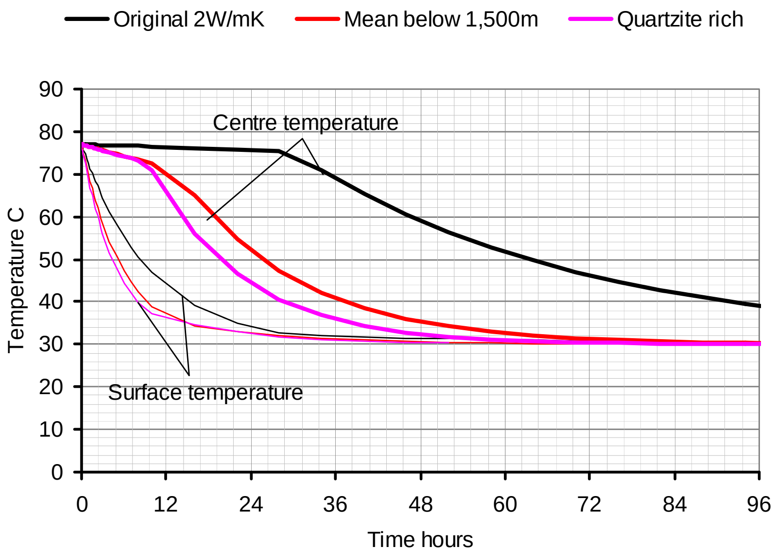


Figure C.7 Analysis for an Isolated Sphere Radius 1.13m – Wet Loader Bucket

C.5 Process Simulation

Using the estimated residence time of rock in the transport system and thermal model described above, the temperature of rock is modelled for each step in the transport system. This represents residence time in the circuit without 140 minutes in ore passes where it assumed that heat transfer will be negligible.

Although the rate of cooling is dependent on particle size and movement of air through and around piles, this analysis indicates a similar rate of cooling.

In the conveyor tunnel ventilation circuit air is initially travelling in the same direction as the bel pile [CV201] then in the opposite direction [CV202] which will affect surface heat transfer coefficients.

The overall distribution of estimated heat loads for 60 MW potentials [refer Table C.3] is shown in Table C.8. The value for loading horizons has been increased to 20% to account for various uncertainties in the model.

Table C.8 Nominal Distribution of Heat Loads

Area	Average 1,500m %	Average 1,500m MW
Total available	100	60
Loading horizon	20.0	12.0
Rail level and shaft	30.0	18.0
Total underground	50	30.0
Skip discharge/bin and feeders	3.0	1.8
Conveyor tunnel to surface (1)	7.0	4.2
Total emission	57.0	36.0

With respect to cooling of draw point piles between loading cycles, the predicted rock temperature with depth and time into the pile is shown in Table C.9. This analysis used the basic plane surface of an infinite solid to take into account the rock pile only being exposed on one surface and residing in a hot host rock.

Table C.9 Temperature in Draw point Rock Pile With Time

		Distance into pile m							
Hours	Days	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00
3	0.125	71.3	75.0	75.0	75.0	75.0	75.0	75.0	75.0
6	0.25	65.1	74.4	75.0	75.0	75.0	75.0	75.0	75.0
12	0.5	57.6	71.3	74.6	75.0	75.0	75.0	75.0	75.0
18	0.75	53.4	67.9	73.5	74.8	75.0	75.0	75.0	75.0
24	1	50.7	65.1	72.0	74.4	74.9	75.0	75.0	75.0
48	2	45.1	57.6	66.3	71.3	73.6	74.6	74.9	75.0
72	3	42.5	53.4	62.0	67.9	71.5	73.5	74.4	74.8
96	4	40.8	50.7	58.9	65.1	69.4	72.0	73.6	74.4
168	7	38.2	46.1	53.1	59.1	63.9	67.6	70.3	72.1
336	14	35.9	41.6	47.0	52.0	56.4	60.4	63.7	66.5
504	21	34.8	39.5	44.0	48.3	52.3	56.0	59.3	62.2
672	28	34.2	38.2	42.2	46.1	49.7	53.1	56.2	59.1

As expected there is limited penetration of the cooling zone during the c 1.1 day period between loading. A higher rate of cooling would be expected if air movement occurs through the pile but rocks would return to higher temperatures after removal of two or three loader buckets.

The consequence of this analysis is that rocks in draw points will remain a significant source of heat when not being loaded with very high temperatures occurring if ventilation is redistributed during non loading periods.

C.6 Summary

Recognising the number of broad assumptions made for this orders of magnitude analysis, the results suggest the following;

1. Initial rates of cooling will be about 6 kW per tonne [dry] and 12kW per tonne [wet] in draw points. If the top 300m layer of rock is considered then the initial rate of heat transfer will be of the order 75kW per draw point. The balance of heat transfer is through evaporation which will vary with draw point moisture content resulting from dust suppression.

2. Using the model for isolated particles rather than larger masses of broken rock, the distribution shown in Table C.8 provides indicative values for the purposes of sizing refrigeration capacity. Most importantly c50% of the potential heat load will apply to the underground mine. The individual area loads can be applied uniformly as a linear heat source for climate simulation.

3. Even though the overall heat load to the underground workings can be shown to be significantly lower than the maximum potential it is still significant. For this reason main transfer points and crushing stations [rail level, crushers and shaft tips] should be ventilated with dedicated circuits reporting to return airways. In particular, and also for control of fire, air should not be allowed to return from the shaft tip points and conveyor tunnel into the intake shaft ventilation stream.

4. Dust control will require rock piles to contain 2 to 5% water by mass and will presumably be introduced at draw points and transfer points by sprays. High evaporation rates from hot rocks [some 22g/s per tonne] will require significant water flow rates in dust suppression systems. This suggests that dust suppression water should be chilled to assist reduction of rock surface temperatures and hence evaporation rates. The current plan is to provide for up to 100l/s chilled service water.

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ADDENDUM D CONVEYOR DRIFT TO WEST PLANT DEVELOPMENT VENTILATION

The purpose of this addendum is to provide a conceptual ventilation strategy for the development of the conveyor drift and initial works on the mid shaft skip discharge horizon.

The rationale for the development phase ventilation circuit is as follows;

1. The drift will be developed from surface to the skip discharge horizon using conventional drill and blast techniques at about 5m [c 440t] per day.

2. Being separate from the mine, the face will fire at will with rapid re entry being important until such time that the intake shafts are holed.

3. Assuming that the face will be cleared to a stockpile as it becomes more remote from surface, then provision needs to be made for face equipment plus one loader [250kW] plus two trucks [say 2 of 25t 250kW for 440/25 = 18 trips to surface per day]. Using a conventional force system, this would require about [1 x 250 + 2 x 250] x 0.06 = 45m^3/s at the duct discharge for an open area velocity of about 1.3m/s. In any event, a high ventilation rate will be required for acceptable re entry times unless a force overlap ventilation system were to be employed.

4. Re entry times for explosives with medium to low fume characteristics and with **50m^3/s at the face** would range up to c65minutes with a forcing system. This value is of course very much subject to standards of duct installation and maintenance.

5. The range of twin or single duct sizes required to deliver 50m^3/s at 4.0km are shown in Figure D.1 and, assuming an exhaust raise were to be installed, for 50m^3/s at 3.0km [CV201 to CV22 transfer] in Figure D.2. These duties can be met with 250kW civil tunnelling type fans, possibly with some modification to the actual drift profile, Figure D.3.

   It is important to note the relatively small change in duct diameter for various duct lengths i.e. for 50m^3/s at the face the duct will remain large even if reduced to 2.0 or 3.0 km in length.

   The main issue arising here is that it is possible to develop the entire conveyor drift from surface to the shaft holing points using drill and blast techniques and readily available infrastructure. However, once holed, the intensity of mining activity in the skip discharge area will be limited by the ventilation rate available unless additional air is to be drawn from one of the shafts i.e. force fans relocated to bulk heads using the drift as an exhaust.

   The problem would then be possible contamination of the skip horizon development if the shaft[s] [No.11, No.12 and No.13] is/are still being sunk. However, if the shafts are using a reversible ventilation system [exhaust when blasting] then this could be acceptable.

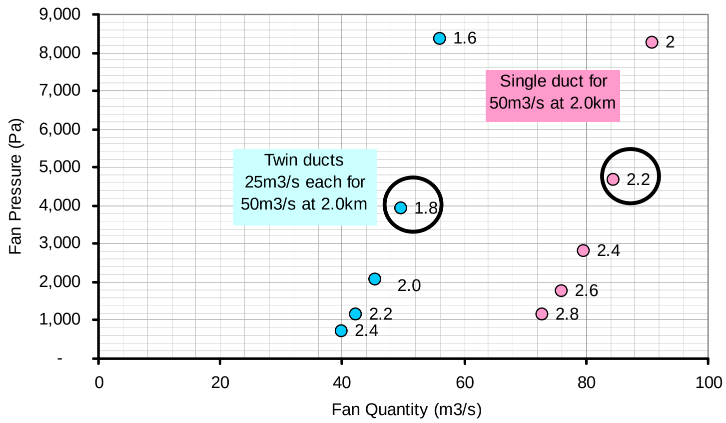


Figure D.0.1 Duct Sizes for 50m³/s at Face at 4.0km

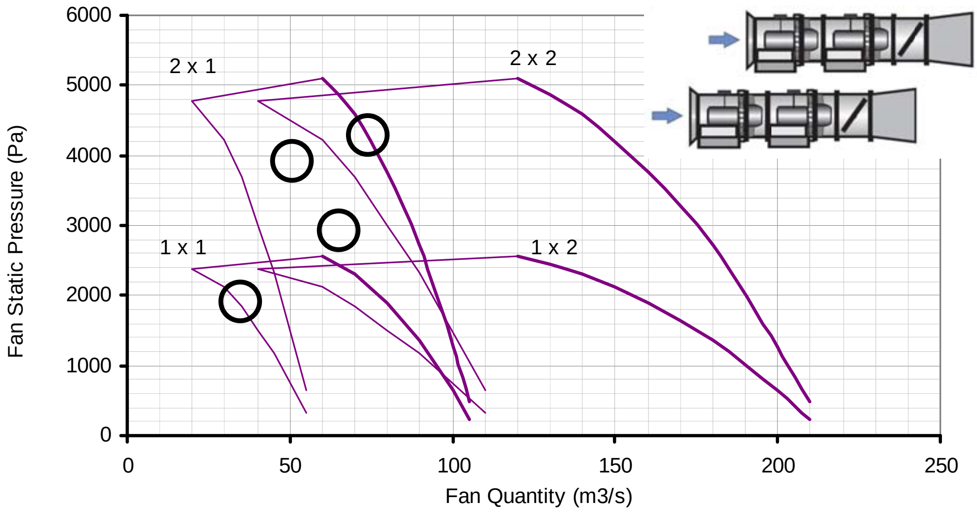


Figure D.2 Conceptual Fan Curves [250kW civil tunnelling units]

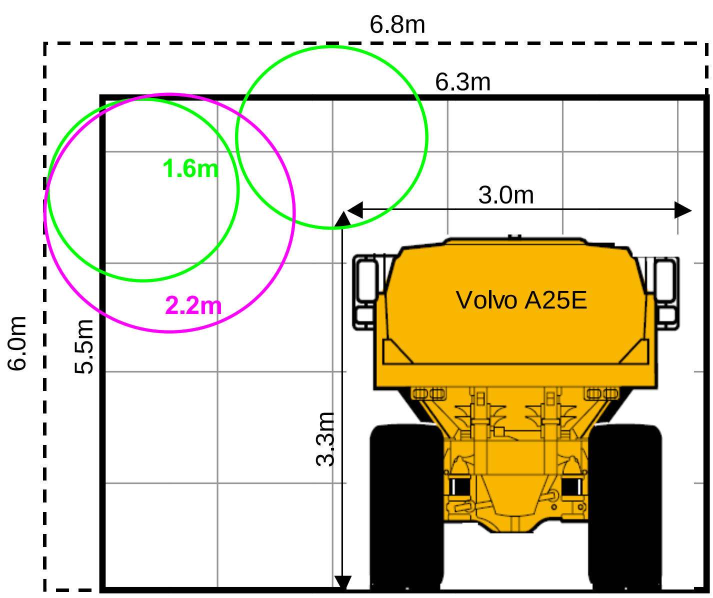


Figure D.3 Duct Sizes and Truck Profiles

ADDENDUM E GEOTHERMAL PROPERTY MEASUREMENTS

NEW GEOTHERMAL PROPERTY MEASUREMENTS

The following geothermal properties were originally used in earlier work.

	Quartzite/Diabase	Apache Leap Tuff
• Thermal conductivity	3.90 W/m°C	1.95 W/m°C
• Specific heat capacity	0.95 kJ/kg°C	1.14 kJ/kg°C
• Density	2.80 t/m^3	2.10 t/m^3
• Diffusivity	1.5x10^{-6} m^2/s	0.8x10^{-6} m^2/s

The exact source of this original data is unknown but it is believed to have come from earlier McIntosh work. In the course of this present work, the Ventilation Advisory Board recommended that these parameters be examined further and a program of measurements was carried out. The new measurements of the rock thermal properties [conductivity, specific heat, density] for samples from below 1500 m were completed in Nov/Dec 2008. The work was carried out by Dr M Jones from the Bernard Price Institute of the University of the Witwatersrand in South Africa. The grouped 'raw' measured data are given below [scatter of the data is considered to be consistent with the variations in the rock samples].

The following summarizes this new data.

	Mixed-mean below 1500m
• Thermal conductivity	4.83 W/m°C
• Specific heat capacity	0.80 kJ/kg°C
• Density	2.72 t/m^3
• Diffusivity	2.2x10^{-6} m^2/s

	Quartzite rich areas
• Thermal conductivity	6.55 W/m°C
• Specific heat capacity	0.80 kJ/kg°C
• Density	2.69 t/m^3
• Diffusivity	3.0x10^{-6} m^2/s

Note that only samples below 1500 m depth were considered and there was no check on the Apache Leap Tuff properties [which are not as important in this present analysis]. With this exception, the new values have been used in the analyses documented in this report.

Grouped 'raw' measured data

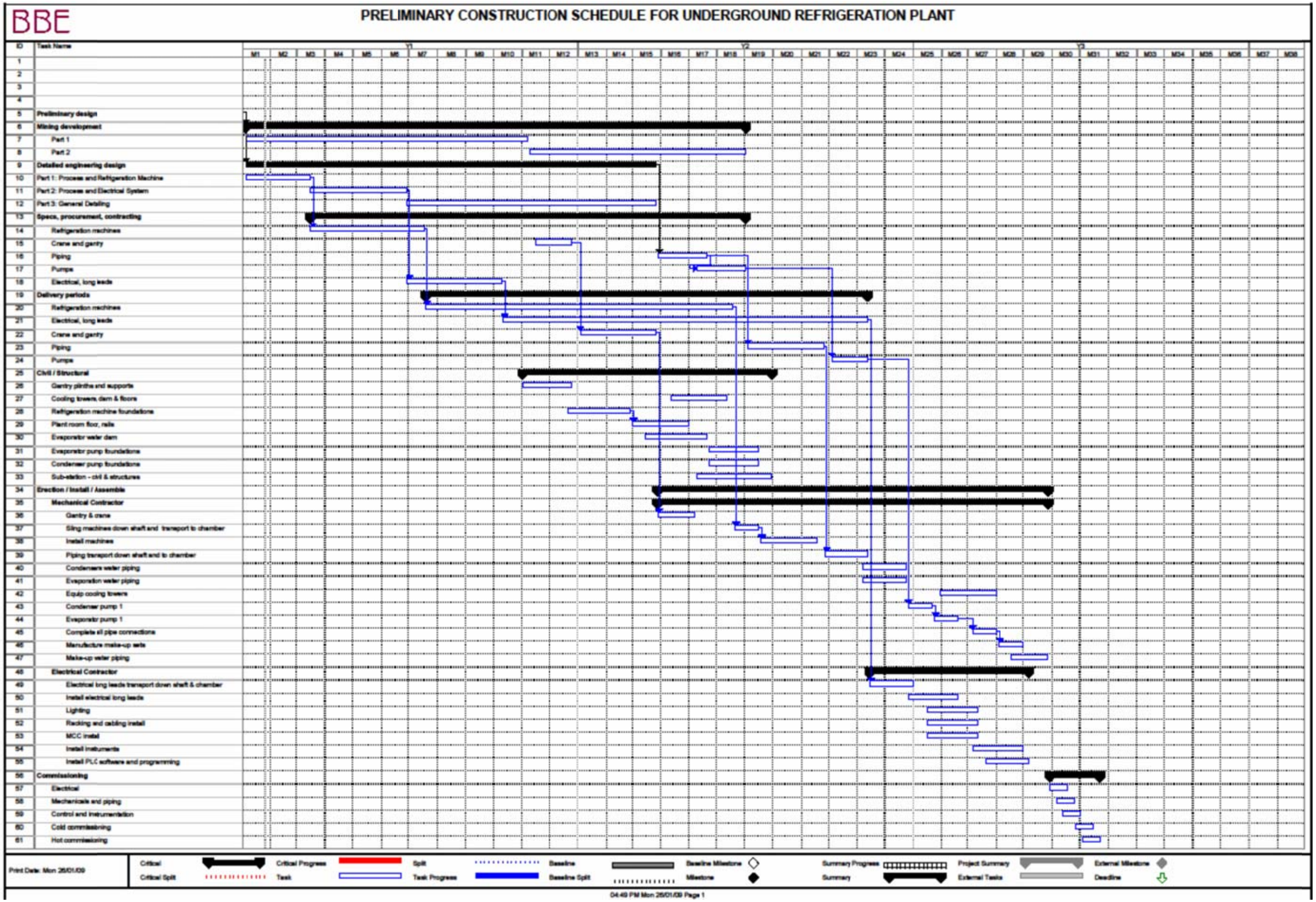
Model designation	Data	Total	% Rock 92.3
Diab PHY	Average of Heat Capacity	766	
	Average of Density (dry)	2753	4.5
	Average of Thermal Diffusivity	2.51	
	Average of Porosity	2.43	
	Average of Average Conductivity	5.33	
Diab POT	Average of Heat Capacity	813	
	Average of Density (dry)	2786	18.7
	Average of Thermal Diffusivity	1.84	
	Average of Porosity	0.67	
	Average of Average Conductivity	4.18	
Diab POT_PHY	Average of Heat Capacity	810	
	Average of Density (dry)	2626	17.5
	Average of Thermal Diffusivity	1.57	
	Average of Porosity	4.80	
	Average of Average Conductivity	3.39	
Kqs	Average of Heat Capacity	801	6.5
	Average of Density (dry)	2667	
	Average of Thermal Diffusivity	2.70	
	Average of Porosity	1.20	
	Average of Average Conductivity	5.76	
Kvs	Average of Heat Capacity	805	13.1
	Average of Density (dry)	2748	
	Average of Thermal Diffusivity	2.37	
	Average of Porosity	2.00	
	Average of Average Conductivity	5.28	
Pzls	Average of Heat Capacity	763	11.4
	Average of Density (dry)	2800	
	Average of Thermal Diffusivity	2.34	
	Average of Porosity	4.40	
	Average of Average Conductivity	5.09	
QEP	Average of Heat Capacity	814	10.5
	Average of Density (dry)	2657	
	Average of Thermal Diffusivity	2.33	
	Average of Porosity	2.07	
	Average of Average Conductivity	5.08	
Qzite	Average of Heat Capacity	804	10.1
	Average of Density (dry)	2692	
	Average of Thermal Diffusivity	3.03	
	Average of Porosity	0.50	
	Average of Average Conductivity	6.55	
Total	Average of Heat Capacity	800	801
Total	Average of Density (dry)	2723	2717
Total	Average of Thermal Diffusivity	2.33	2.20
Total	Average of Porosity	1.94	2.37
Total	Average of Average Conductivity	5.08	4.83

ADDENDUM F NOTE ON UG REFRIGERATION PLANT CONSTRUCTION SCHEDULE

NOTE ON CONSTRUCTION SCHEDULE
FOR UNDERGROUND REFRIGERATION PLANT

The preliminary high-level construction schedule for the underground plant is given below. The following notes apply:

1. Section 13 of the main report text allows about 30 months for completion of underground plant from start of refrigeration plant related excavations.
2. This nominal high-level construction schedule matches this requirement but it will only be possible with the following features:
   a. Total mining excavation period is taken as 18 months. This is nominal and requires detailed planning of the sequencing of the different excavation areas such as: main plant chamber, cooling towers, pump chambers, dams, workshop, sub-station and inter-connecting excavations.
   b. Civil works must commence before the mining excavations are all fully complete - overlap of this in the nominal schedule is 8 months. Following the sequencing in pt 2a, the sequencing of the civil works in each of the different excavations will also require detailed and interconnected planning.
   c. Mechanical installation contractor must commence before the civil works are all fully complete - overlap of this in the nominal schedule is 4 months. Following the sequencing in pt 2b, the sequencing of the mechanical installation works in each of the different chambers will also require detailed and interconnected planning.
   d. Electrical installation contractor must commence before the mechanical installation works are all fully complete - overlap of this in the nominal schedule is 5 months. Following the sequencing in pt 2c, the sequencing of the electrical installation works in each of the different chambers will also require detailed and interconnected planning.
3. The situation will clearly not allow the classical project management credo of completing the one discipline before the other commences.
4. The assumed main critical delivery periods are taken as:
   a. Underground refrigeration machines 11 months
   b. Long-lead electrical items such as transformers, switchgear, etc 13 months
5. This schedule will be difficult to achieve but it will be possible if the mining and civil works can be achieved expeditiously.


PRELIMINARY CONSTRUCTION SCHEDULE FOR UNDERGROUND REFRIGERATION PLANT
ID
Task Name
Y1
Y2
Y3
M1 M2 M3 M4 M5 M6 M7 M8 M9 M10 M11 M12 M13 M14 M15 M16 M17 M18 M19 M20 M21 M22 M23 M24 M25 M26 M27 M28 M29 M30 M31 M32 M33 M34 M35 M36 M37 M38
5 Preliminary design
6 Mining development
7 Part 1
8 Part 2
9 Detailed engineering design
10 Part 1: Process and Refrigeration Machine
11 Part 2: Process and Electrical System
12 Part 3: General Detailing
13 Specs, procurement, contracting
14 Refrigeration machines
15 Crane and gantry
16 Piping
17 Pumps
18 Electrical, long leads
19 Delivery periods
20 Refrigeration machines
21 Electrical, long leads
22 Crane and gantry
23 Piping
24 Pumps
25 Civil / Structural
26 Gantry plinths and supports
27 Cooling towers, dam & floors
28 Refrigeration machine foundations
29 Plant room floor, rails
30 Evaporator water dam
31 Evaporator pump foundations
32 Condenser pump foundations
33 Sub-station - civil & structures
34 Erection / Install / Assemble
35 Mechanical Contractor
36 Gantry & crane
37 Sling machines down shaft and transport to chamber
38 Install machines
39 Piping transport down shaft and to chamber
40 Condensers water piping
41 Evaporation water piping
42 Equip cooling towers
43 Condenser pump 1
44 Evaporator pump 1
45 Complete all pipe connections
46 Manufacture make-up sets
47 Make-up water piping
48 Electrical Contractor
49 Electrical long leads transport down shaft & chamber
50 Install electrical long leads
51 Lighting
52 Racking and cabling install
53 MCC install
54 Install instruments
55 Install PLC software and programming
56 Commissioning
57 Electrical
58 Mechanicals and piping
59 Control and instrumentation
60 Cold commissioning
61 Hot commissioning
Print Date: Mon 26/01/09
Critical
Critical Split
Critical Progress
Task
Split
Task Progress
Baseline
Baseline Split
Baseline Milestone
Milestone
Summary Progress
Summary
Project Summary
External Tasks
External Milestone
Deadline
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ADDENDUM G TRADE OFF STUDY FOR DIFFERENT REFRIGERATION STUDIES

TRADE-OFF STUDIES ON REFRIGERATION SYSTEM

20th September 2010

CONTENTS

1. Introduction
2. Base-case design
3. What-if more surface plant and less underground plant
4. What-if more underground plant and less surface plant
5. What-if chilled water to underground instead of underground refrigeration plant
6. What-if ice to underground instead of underground refrigeration plant
7. Conclusions

Table 1
Table 2
Table 3
Table 4

Figure 1 Alternative chilled-water-to-underground systems
Figure 2 Typical turbine-generator station
Figure 3 Typical hydro-displacement station

1. INTRODUCTION

The base-case design is defined by a total refrigeration plant of 97 MW of which 67% is surface refrigeration plant and 33% is underground refrigeration plant [this ignores the needs of the surface conveyor to the West Plant and that of chilling the service water].

This trade-off study examines what-if more surface plant and less underground plant and vice versa.

The trade-off study then assumes that the surface bulk air cooling remains the same as the base-case, but that the underground plant is replaced by sending chilled water or ice underground. With regards the chilled water systems, there are a number of different ways of achieving this which include open-circuit systems with energy recovery and closed-circuit systems of varying configuration. Each of these is examined below in terms of an order-of-magnitude trade-off study.

2. BASE-CASE DESIGN

The base-case design is defined by:

- Surface refrigeration plant 65 MW for surface bulk air cooling of 2180 kg/s to 12°Cwb
- Underground refrigeration plant 32 MW for a suite of secondary air coolers
- Total refrigeration plant is 97 MW

This trade-off study ignores the needs of the surface conveyor to the West Plant and that of chilling the service water.

3. WHAT-IF MORE SURFACE PLANT AND LESS UNDERGROUND PLANT

In this scenario, the surface bulk air cooling effect will be increased by making the downcast ventilation colder - this component will be maximised if the total mixed downcast of 2180 kg/s is cooled to 5°Cwb.

The following is not considered practical, even for trade-off examination and hence have not been considered:

- Air temperatures colder than 5°Cwb which would require non-standard and more complex refrigeration machinery.
- Introducing special 'fridge' shafts dedicated entirely to downcasting ultra-cold air.

In the base-case design, the total mixed downcast temperature is 12°Cwb and the additional bulk air cooler duty introduced by reducing this temperature to 5°Cwb will be a further 36.69 MW. In this scenario, the total surface bulk air cooler duty will now be 99.69 MW and, with the losses, the total surface refrigeration machine rating will be 102.85 MW.

The main disadvantage of the approach of using more surface bulk air cooling is that the heat flow from the rock into the colder intake will be increased. Also, and more importantly, any ventilation leakage will also relate to a greater 'leakage' or loss of cooling effect. In other words, the 'positional efficiency' of the surface based air coolers is not optimal. Thus, although a further 36.69 MW of refrigeration effect is introduced on surface, this does not all achieve effective cooling underground.

The modelling indicates that, if the surface air cooler duty is maximised as above, then the remaining cooling to be provided by the underground system will relate to an air cooler[s] duty of 6.13 MW and, with the 'losses', the underground refrigeration plant duty will be 7.54 MW.

This is to be compared to the base-case design in which the underground refrigeration system had an effective air cooler duty of 26 MW and, with the 'losses', the underground refrigeration machine duty would be 32 MW. Thus, the scenario of maximising the use of surface bulk air cooling very significantly reduces the underground plant and related needs.

In this scenario, where the surface bulk air cooling is maximised, the total [surface and underground] required refrigeration machine capacity will be 110.39 MW. This is to be compared to the base-case design in which the total refrigeration machine capacity was 97.00 MW.

The main advantage of this approach is that the requirements of the underground refrigeration system are minimised – but these needs are not negated altogether. The related excavation requirements will be much smaller, indeed, with a total underground plant requirement of 7.54 MW, it may be appropriate to have a number of smaller plants scattered located to suit the hot zones [provided return ventilation for heat rejection is available] rather than the centralized system in the base-case.

The above process parameters are summarised in Table 1.

The capital cost comparison relates to more refrigeration machine capacity in total but less underground plant and more surface plant – note surface plant is less expensive per MW. Perhaps the most relevant issue is that there is significantly less underground excavation required. These selected basic capital cost issues are summarised in Table 1.

Note that this, and all other costing in this trade-off study, is not a full-budgeting-estimating type evaluation but, rather, selected costs of the main parameters that change relative to each other were examined.

The running cost comparison relates to less underground machine operation but more surface refrigeration machine operation. Because of the cooler heat rejection facilities, the surface plant is more energy efficient [better CoP] and uses less power per refrigeration MW. These selected basic power cost issues are summarised in Table 1.

General comparative points

In terms of the basic tangible comparative issues, Table 1 indicates that the base-case is to be favoured [marginally]. However, it must not be concluded that the base-case is optimal. Indeed, the relatively small overall differences indicate that the optimum will probably have less underground plant [and more surface plant] than that stated in the base-case.

In terms of the less tangible issues, the following is noted:

- With more surface air cooling, the issue of ventilation leakage becomes more critical.
- There will be an increased NVP [natural vent pressure] effect with the colder downcast that will assist the main fan operation and reduce main fan power consumption.
- The maintenance aspects are obviously easier for the scenario of greater surface machinery and less underground machinery.
- With more surface air cooling and less underground cooling, there will be fewer underground cooling towers and the scrubbing effect of the gases and dust in these towers will be less.
- The ventilation and cooling of the conveyor-to-surface system, which will utilise controlled leakage out of the downcast system, would benefit from the downcast being colder.
- In order to create 5°Cwb mixed condition in the shafts, the air off the coolers will need to be about 3°Cwb [because some warm ambient air must mix from the brow]. This means that unless some special arrangements are made [such as bratticing] there will be cold zones in the shaft just below the brow. In this approach, the air will arrive at the station zone at 16/22°Cwb/db which is a very comfortable condition. For the base-case, this temperature would be 21/29°Cwb/db [which is of course fully acceptable].
- Perhaps the most relevant issue is that there will be less underground excavation required at a critical time in the mine development – this will probably relate to significant scheduling opportunities.

Thus, there would appear to be motivation to increase the mix of refrigeration that is introduced from surface bulk air cooling. However, when examining the profile of the phase-in of the ventilation and refrigeration needs, there is a limitation on primary ventilation capacity at the time that the underground cooling is needed. It is this constraint that originally set the sizing of the underground plant at 32 MW and it is this constraint that needs to be reviewed in the light that it may be preferable to ultimately have greater surface bulk air cooling [and less underground air cooling].

Process issues		Base case	More sBAC
Surface bulk air cooler duty	kW	63 000	99 689
Refrigeration plant surface	kW	65 000	102 854
Secondary ug air coolers	kW	26 000	8 944
Secondary ug cooling with loss effect	kW	29 000	9 976
Refrigeration plant underground	kW	32 001	11 008
Total air cooling duty	kW	92 000	109 665
Total refrigeration plant	kW	97 000	113 862
Capital cost issues			
Refrigeration plant surface	kW	ref	37 854
Refrigeration plant underground	kW	20 993	ref
Underground plant related excavation	m³	15 000	ref
Refrigeration plant surface	$	ref	28 390 441
Refrigeration plant underground*	$	27 290 516	ref
Running cost issues			
Refrigeration plant surface duty	kW	ref	37 854
Refrigeration plant underground duty	kW	20 993	ref
Refrigeration plant surface power	kW	ref	7 571
Refrigeration plant underground power	kW	6 998	ref
Refrigeration plant surface power	$	ref	68 137 059
Refrigeration plant underground power	$	62 978 114	ref
	$	**90 268 630**	**96 527 500**

* Includes excavation costs which will be about 20% to 25% of total plant cost.

TABLE 1. Comparison for scenario with maximum surface bulk air cooling

4. WHAT-IF MORE UNDERGROUND PLANT AND LESS SURFACE PLANT

The requirement for the ventilation air to arrive at the station zone underground at an acceptable temperature [27.5°Cwb is used here] sets the minimum surface bulk air cooler duty that is sensible for this trade-off study. Accounting for auto-compression and heat flow from the shaft barrel, this will require that the air leaves surface at 19.9°Cwb. Under these conditions, the required surface air cooler duty will be 8.26 MW and, with the losses, the plant duty will be 8.52 MW.

In this scenario, the downcast ventilation will arrive at the station underground at 27.5°Cwb – the design reject condition - and there will be very little inherent cooling capacity left in the ventilation flow. Thus, the underground refrigeration system will essentially have to deal with the underground heat load and the models indicate that the required underground refrigeration machine duty will be 68.88 MW. This is to be compared to the base-case design in which the underground refrigeration machine duty would be 32 MW.

In this scenario, where the surface bulk air cooling is minimised, the total [surface and underground] required refrigeration machine capacity will be 77.40 MW. This is to be compared to the base-case design in which the total refrigeration machine capacity was to be 97 MW.

The above process parameters are summarised in Table 2.

The capital cost comparison relates to less refrigeration machine capacity in total but more underground plant and less surface plant – note surface plant is less expensive per MW. Perhaps the most relevant issue is that there is a significant increase in required underground excavations. These selected basic capital cost issues are summarised in Table 2.

The running cost comparison relates to more underground machine operation but less surface refrigeration machine operation. Because of the cooler heat rejection facilities, the surface plant is more energy efficient [better CoP] and uses less power per refrigeration MW. These selected basic power cost issues are summarised in Table 2.

General comparative points

In terms of the basic tangible comparative issues, Table 2 indicates that the base-case is to be favoured compared to more underground plant. In terms of the less tangible issues, the following is noted:

- The maintenance aspects with more underground machinery are obviously more arduous than the base-case design.
- Under the scenario of minimal surface air cooling, the cooling of the conveyor-to-surface system will require more additional and an independent refrigeration capacity.
- Perhaps the most relevant issue is that there will be more underground excavation required at a critical time in the mine development and, there is no doubt that, the pre-production mine development will be negatively influenced.

Process issues		Base case	More ugBAC
Surface bulk air cooler duty	kW	63 000	8 260
Refrigeration plant surface	kW	65 000	8 522
Secondary ug air coolers	kW	26 000	55 965
Secondary ug cooling with loss effect	kW	53 697	57 132
Refrigeration plant underground	kW	32 001	68 881
Total air cooling duty	kW	92 000	70 683
Total refrigeration plant	kW	97 000	77 403
Capital cost issues			
Refrigeration plant surface	kW	56 477	ref
Refrigeration plant underground	kW	ref	36 880
Underground plant related excavation	m³	ref	17 288
Refrigeration plant surface	$	42 358 086	ref
Refrigeration plant underground*	$	ref	47 944 446
Running cost issues			
Refrigeration plant surface duty	kW	56 477	ref
Refrigeration plant underground duty	kW	ref	36 880
Refrigeration plant surface power	kW	11 295	ref
Refrigeration plant underground power	kW	ref	12 293
Refrigeration plant surface power	$	101 659 406	ref
Refrigeration plant underground power	$	ref	110 641 030
	$	**144 017 491**	**158 585 476**

* Includes excavation costs which will be about 20% to 25% of total plant cost.

TABLE 2. Comparison for scenario with minimum surface bulk air cooling

5. WHAT-IF CHILLED WATER TO UNDERGROUND INSTEAD OF UNDERGROUND REFRIGERATION PLANT

This evaluation assumes the surface bulk air cooling remains the same as the base-case but that the underground plant is replaced by sending chilled water underground.

There are a number of different ways of achieving this which include:

- Open-circuit
    - Energy recovery
        - Turbines
        - Hydro-displacement
- Closed-circuit
    - High pressure in shaft with water-to-water heat exchanger[s] underground and secondary low pressure water system to suite of air coolers

The possibility of high pressure water in the shaft and through-out mine distributing chilled water to high pressure air cooling coils is considered highly unlikely on a cost and safety basis. This possibility has not been addressed here.

Thus this trade-off study now examines the four alternatives as follows:

- Base-case - underground plant serving the underground air cooler needs
- Open-circuit system from surface through turbine-generator station serving underground air cooler needs
- Open-circuit system from surface through hydro-displacement station serving underground air cooler needs
- Closed-circuit system from surface with high pressure shaft piping with water-to-water heat exchanger[s] underground and secondary low pressure water system to serve underground air cooler needs

These alternative systems are sketched in Figure 1. Typical turbine-generator station is shown in Figure 2 and a hydro-displacement station is shown in Figure 3. Although not widely used in mines, it is considered that the water-to-water heat exchanger would take the form of a system of Vahterus type plate-and-shell heat exchangers.

The order-of-magnitude process design calculations were carried-out for each system so that exactly the same underground air cooling effect is provided in each case. The key process parameters are summarised in Table 3. For example, note the differences in flow down the shaft, chilled water flow rate circulated underground and the power needs.

Following the process design work and the sizing of each of the equipment components as well as the system losses, consideration was given to the main capital and running cost components. The selected cost components evaluated were: cost of power, surface and underground plant, piping, turbine generators, hydro-displacement stations and water-to-water heat exchangers. This selected cost comparison is given in Table 3.

In terms of the basic tangible comparative issues and the selected cost components, Table 3 indicates that the base-case with underground located refrigeration plant is to be favoured. Of the three chilled-water-to-underground systems examined, the hydro-displacement system is the best, and in power costs alone it will be more attractive than the underground plant scenario. The turbine-generator system and the water-to-water heat exchanger system have similar total cost penalty, but the water-to-water heat exchanger system will be attractive from the power cost perspective [also better than the underground plant scenario].

Indeed, the high estimated capital cost of the water-to-water heat exchanger equipment penalises this system and should improved more cost-effective designs be available in the future, this may deserve further consideration.

The above does not provide sufficient argument for replacing the underground plant with chilled-water-from-surface systems. The only argument that may possibly motivate this alternative approach would relate to scheduling issues and the timing of the underground excavations for the plant [this will be discussed elsewhere].

WATER TO UNDERGROUND COMPARISON

		Underground plant	Water via turbine	Water via hydro-lift	Water-water heat xchange
Underground plant duty	kW	32 000	0	0	0
Underground plant power	kW	10 667	0	0	0
Water flow rate in shaft	kg/s	0	500	483	648
No. of 300mm shaft columns down		0	4.0	4.0	5.0
Chilled water flow rate underground	kg/s	500	500	483	648
Underground distribution pumping	kW	507	507	490	648
Net-pump turbine power	kW	0	3 859	0	0
Hydro-lift pumping	kW	0	0	896	0
Surface plant duty	kW	0	40 823	39 435	52 633
Surface plant power	kW	0	7 851	7 584	10 122
Total power	kW	11 173	12 216	8 970	10 770
Cost of power	$	19 833 937	29 219 993	zero ref	16 200 800
Cost of underground plant	$	41 600 000	zero ref	zero ref	zero ref
Cost of surface plant	$	zero ref	30 617 438	29 576 445	39 474 792
Cost of turbine-generator and pump station	$	zero ref	22 663 521	zero ref	zero ref
Cost of hydro-displacement station capital	$	zero ref	zero ref	33 000 000	zero ref
Cost of hydro-displacement replacement valv	$	zero ref	zero ref	12 000 000	zero ref
Cost of water-water heat exchanger	$	zero ref	zero ref	zero ref	36 500 000
Cost of shaft piping system and accessories	$	zero ref	12 800 000	12 800 000	16 000 000
Total cost component	$	61 433 937	95 300 951	87 376 445	91 974 792
Total cost component	$	zero ref	33 867 014	25 942 508	30 540 855

TABLE 3. Comparison of various chilled water-to-underground systems

6. WHAT-IF ICE TO UNDERGROUND INSTEAD OF UNDERGROUND REFRIGERATION PLANT

This evaluation assumes the surface bulk air cooling remains the same as the base-case but that the underground plant is replaced by sending ice underground.

This system is shown schematically in Figure 1. The surface ice making system would comprise a suite of hard ice makers in which the ice is made in a sub-zero condition and harvested by defrosting. The ice pieces will be conveyed to the shaft head[s] in belt conveyor system[s] and discharged by gravity into vertical plastic pipes which will deliver the ice to underground ice-melt dams. The ice fed into the vertical pipes would typically be 94% ice-mass fraction and that arriving underground would be 87 % ice mass fraction. From the underground melting dams, a secondary chilled water flow would be circulated to the suite of air coolers and back to the melting dam for re-cooling. Return water flow to match the down flow of ice would be pump-returned to surface for re-freezing.

The main process parameters and selected costs are shown in Table 4 where it can be observed that both the capital and power costs of the ice system do not compare favourably with the base-case proposal with underground refrigeration plant. It is concluded that the ice concept will not be optimal for this application.

ICE TO UNDERGROUND COMPARISON

		Underground plant	Ice to underground
Underground plant duty	kW	32 000	0
Underground plant power	kW	10 667	0
Ice mass fraction to shaft pipe surface	%	na	95
Ice mass fraction to melt dam	%	na	87
Ice 'slurry' in shaft pipe	kg/s	na	110
Surface ice feeder plant duty	kW	na	9 211
Ice maker plant duty	kW	na	37 400
Surface ice feeder plant power	kW	na	1 880
Ice maker plant power	kW	na	11 688
No. of 400mm ice shaft columns down		na	2
No. of 300mm pipe shaft columns up		na	1
Chilled water flow rate underground	kg/s	500	417
Underground distribution pumping	kW	507	423
Total power	kW	11 174	13 990
Cost of power	$	zero ref	25 350 398
Cost of underground plant	$	41 600 000	zero ref
Cost of ice feed plant and ice maker	$	zero ref	58 608 550
Cost of shaft piping system and accessories	$	zero ref	4 800 000
Total cost component	$	41 600 000	88 758 948
Total cost component	$	zero ref	47 158 948

TABLE 4. Comparison with ice-to-underground system

7. CONCLUSIONS

The trade-off study of the scenario where the surface bulk air cooling effect is maximised, and hence the underground plant requirements reduced, indicates that the base-case is to be favoured [marginally]. However, this does not mean that the base-case is optimal. The relatively small overall differences indicate that the optimum will probably have less underground plant [and more surface plant] than stated in the base-case. The most relevant issue is that there will be less underground excavation required at a critical time in the development and this may give significant scheduling opportunities. Thus, there may be motivation to increase the mix of refrigeration that is introduced from surface bulk air cooling. However, the profile of the phase-in of the cooling needs, indicates that there is a limitation on primary ventilation capacity at the time when the underground cooling is needed. It is this constraint that originally set the sizing of the underground plant at 32 MW and it is this constraint that needs to be reviewed in the light that it may be preferable to ultimately have greater surface bulk air cooling [and less underground air cooling].

The trade-off study of the scenario where the surface bulk air cooling effect is minimised indicates the requirement of less refrigeration machine capacity in total, but more underground plant and less surface plant – note surface plant is less expensive per MW. Perhaps the most relevant issue is that there would be a significant increase in required underground excavations. Again this trade-off study favours the base-case.

The trade-off study examining chilled water from surface or ice from surface indicates that the base-case with underground located refrigeration plant is to be favoured. Of the three chilled-water-to-underground systems examined, the hydro-displacement system is the best and, on power costs alone, it will be actually more attractive than the underground plant scenario. The turbine-generator system and the water-to-water heat exchanger system have similar total cost penalty, but the water-to-water heat exchanger system will be attractive from the power cost perspective [also better than the underground plant scenario].

Regarding the possibility of using an ice-to-underground system, the trade-off study indicated that both the capital and power costs of the ice system do not compare favourably with the base-case proposal and, it is concluded that the ice concept will not be optimal for this application.

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20 September 2010

Figure 2. Typical turbine-generator station

Figure 3. Typical hydro-displacement station

ADDENDUM H RESPIRABLE DUST AND SILICA

The purpose of this addendum is to provide recommendations with respect to respirable dust and silica standards for the Resolution project.

With respect to dust concentration standards;

1. Recent analysis of rock samples from exploration boreholes indicate a range of quartz content, nominally 20 to 50% for diabase and 40 to 80% for other rocks including sandstone and conglomerates.

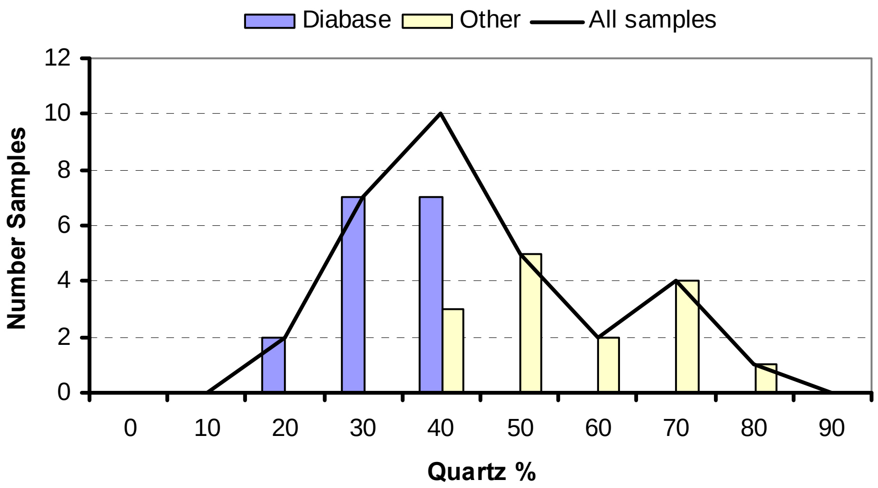

Figure H.1 Range of Quartz Contents of 31 Rock Samples

It is understood that the bulk of mining activity will be undertaken in diabase indicating an average host rock quartz content of 37%.

2. Depending on how crystal grain boundaries fail during drilling, blasting, transport and crushing, it is possible that the respirable dust fraction will have a free crystalline silica content some 30 to 45% of that in the host rock, say 10 to 15%. This will of course have to be verified by sampling.

3. World wide standards for respirable dust and free crystalline silica vary, are subject to continuous review but invariably reducing. This is particularly the case now that silica is recognised as a human carcinogen.

4. Historically, typical values for 8 hour TWA exposure concentrations for respirable dust were 3mg/m^3 [coal] to 5mg/m^3 [metal] and 0.2 to 0.3 mg/m^3 for free crystalline silica.

   A NIOSH review of the health effects of silica in 2002 recommends a TWA limit of 0.05mg/m^3 [10 hour day 40 hour week]. This document also recognises the difficulties of measuring lower concentrations and, with consideration to carcinogenic effects, is effectively suggesting an "as low as reasonably achievable" approach.

   The RTZ occupational exposure limits [8 hour day 40 hour week] are 5mg/m^3 for general respirable dust [not coal] and 0.1mg/m^3 for respirable crystalline silica. These are also consistent with recent Australian ASCC/NOHSC recommended limits.

5. Adverse physiological effects from inhalation of inert respirable dust and free crystalline silica are dependent on cumulative lifetime exposures. It is not therefore appropriate to change exposure limits for altered shift lengths providing that the average duration of exposure is similar to or less than that of 40 hours in a seven day period.

6. At this point in time it is recommended that the mine adopt current RTZ standards of 5.0mg/m^3 respirable dust and 0.1mg/m^3 for free crystalline silica, both pro rata on a 40 hour week TWA basis.

7. Using these values it is therefore possible to calculate the effective respirable dust limit for various crystalline silica contents. For example, if respirable dust contains 15% SiO_2 and the free crystalline silica limit is 0.3 mg/m^3 then the total respirable dust limit would be 0.3 / 0.15 = 2.0mg/m^3. For the proposed free crystalline silica limit of 0.1 mg/m^3 the total respirable dust limit becomes 0.1 / 0.15 = 0.67mg/m^3.

   The obvious issue arising from this situation is that the combined effect of high crystalline silica contents and reduced limits, makes it increasingly difficult to comply with 8 hour or 40 hour TWA exposure limits during normal mining work.

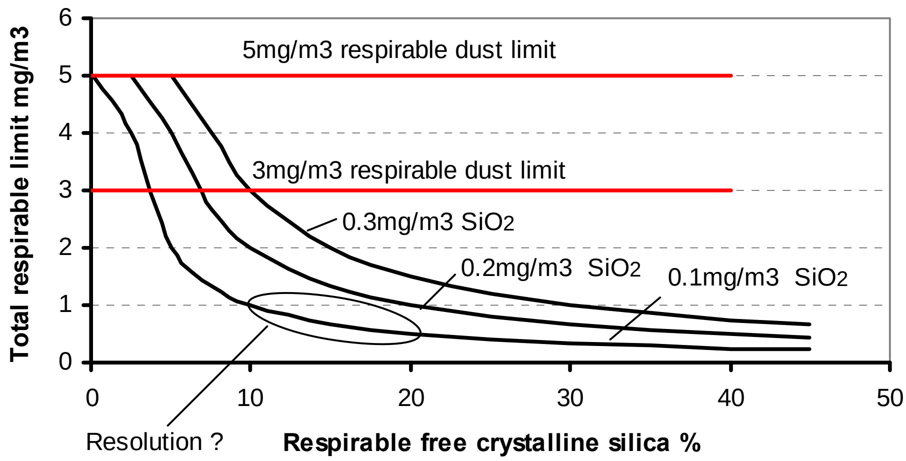

Figure H.2 Effect of Free Crystalline Silica Limit on Respirable Dust Limit

8. With consideration to the highly mechanised nature of the proposed mining method most workers will not be in dusty environments for significant periods of the week. It is recommended that the 0.1mg/m^3 free crystalline silica limit is used as a 40 hour TWA over seven days with a short term exposure limit of 0.3mg/m^3. In practice this means that periodic compliance samples will be suitable for the majority of the workforce but a more rigorous exposure monitoring regime will be required for some occupations, for example crusher operators or conveyor belt inspections.

9. It is noted that in some documents, free silica in the form of cristobalite and tridymite are considered more hazardous [NTO, 2003]. These occur in igneous rocks and may be found in the Resolution ore body. The NIOSH document also distinguishes between free crystalline silica, quartz, cristobalite and tridymite implying that the health hazard is dependent on how silica forms present in the respirable dust fraction.

10. In any event, due to the assumed carcinogenic effects of silica [in whatever form] worldwide limits for respirable dust will most likely continue to fall and a limit of 0.05mg/m^3 may well be imposed on the project by the time it comes into full production. This is similar to the situation with diesel particulate matter where an “as low as technically achievable” position is being taken i.e. when the industry demonstrates it can comply the limits are reduced further.

11. Overall, this analysis indicates that;

    a. Control of respirable dust will be a significant issue for which normal controls are essential, in particular dust suppression, maintenance of an appropriate moisture content in ore and dedicated exhaust circuits.
    b. It should be assumed, for design purposes, that a respirable free crystalline silica limit of 0.05mg/m^3 will be imposed at some point in time, regardless of justification from epidemiological studies.
    c. Consideration should be given to how the exposures of various underground occupations will be monitored and controlled.

References

Control of Substances Hazardous to Health Regulations 2002 [as amended 2005]
Proposal for a Workplace Exposure Limit for Respirable Crystalline Silica
http://www.hse.gov.uk/consult/condocs/cd203.pdf

NIOSH HAZARD REVIEW Health Effects of Occupational Exposure to Respirable Crystalline Silica
April 2002

NTP, 2003 Silica, Crystalline [Respirable Size]
US National Toxicology Program

SIMTARS. Adjustment of occupational exposure limits for unusual work schedules.
Occupational Hygiene, Environment & Chemistry Centre

Sample	From	Quartz %	Lith 1	Lith 2	Lith 3	Lith 4	Description
Test 1	1576.04	45.21	47% Crystal lithic tuff	32% Sandstone	21% Crystal tuff		Phyllic altered crystal tuff, crystal-lithic tuff and sandstone.
Test 2	1601.54	53.52	100% Sandstone				Phyllic-advanced argillic sandstone.
Test 3	1632.46	56.41	91% Sandstone	9% quartz-eye porphyry			Phyllic altered sandstone and quartz-eye porphyry.
Test 4	1679.20	70.52	100% Sandstone				Phyllic-advanced argillic altered sandstone.
Test 5	1707.80	78.36	100% Sandstone				Phyllic altered sandstone.
Test 6	1736.94	65.62	57% Quartzite-siltstone breccia	37% Sandstone	6% Fault Zone (indeterminant lithology)		Advanced argillic-phyllic altered sandstone, advanced argillic altered quartzite-siltstone breccia.
Test 7	1777.60	43.83	74% Diabase	26% quartz-eye porphyry			Advanced argillic altered diabase and diabase breccia cut by phyllic altered quartz-eye porphyry.
Test 8	1821.31	40.09	66% Diabase	30% quartz-eye porphyry	4% feldspar porphyry		Phyllic altered diabase cut by phyllic altered quartz-eye porphyry and feldspar porphyry.
Test 9	1859.51	33.51	91% Diabase	9% heterolithic breccia			Argillic-phyllic altered diabase cut by phyllic altered heterolithic breccia.
Test 10	1908.07	36.67	79% Diabase	21% quartz-eye porphyry			Phyllic-argillic altered diabase cut by phyllic altered quartz-eye porphyry.
Test 11	1943.89	41.93	58% Diabase	40% quartz-eye porphyry	2% feldspar porphyry		Phyllic altered diabase cut by phyllic altered quartz-eye porphyry and feldspar porphyry.
Test 12	1985.45	30.45	100% Diabase				Potassic altered diabase with strong phyllic and weaker advanced argillic overprint.
Test 13	2032.00	28.98	67% Diabase	33% quartz-eye porphyry			Potassic-phyllic altered diabase cut by potassic altered quartz-eye porphyry.
Test 14	2057.92	78.88	100% Quartzite				Potassic altered quartzite with moderate phyllic overprint and trace argillic alteration.
Test 15	2106.90	24.87	100% Diabase				Potassic altered diabase with moderate phyllic overprint and trace argillic alteration.
Test 16	2154.90	35.68	100% Diabase				Potassic altered diabase with moderate phyllic overprint and trace argillic alteration.
Test 17	2201.00	40.51	100% Diabase				Potassic altered diabase with weak to moderate phyllic overprint.
Test 18	2237.00	41.68	63% Diabase	37% quartz-eye porphyry			Potassic altered diabase with weak to moderate phyllic overprint, cut by potassic altered quartz-eye porphyry.
Test 19	2269.33	45.10	85% Diabase	15% quartz-eye porphyry			Potassic-phyllic altered diabase cut by phyllic altered quartz-eye porphyry.
Test 20	2302.97	67.71	100% quartz-eye porphyry				Potassic-phyllic altered quartz-eye porphyry.
Test 21	1534.98	40.82	61.3% Kvs Conglomerate	38.7% Kvs Sandstone			Phyllic & advanced argillic altered conglomerate with primary cp; potassic altered sandstone with primary cp.
Test 22	1566.00	45.13	93.0% Kvs Conglomerate	7.0% Fault zone (indeterminant lithology)			Argillic, phyllic & advanced-argillic altered conglomerate with moderate hypogene enrichement to bn; argillic altered fault zone with moderate hypogene enrichment to bn.
Test 23	1607.03	55.89	28.73% Kvs Sandstone	28.46% Fault zone (indeterminant lithology)	26.46% Kvs Conglomerate	16.35% Kvs Crystal tuff	Phyllic altered sandstone with hypogene enrichment to cc-bn; advanced-argillic altered fault zone with hypogene enrichment to cc; advanced argillic conglomerate with hypogene enrichment to bn; phyllically altered crystal tuff with hypogene enrichment to bn-cc.
Test 24	1648.66	75.87	95.0% Kvs brecciated tuff	5.0% Kvs volcanisediment			Phyllic & advanced-argillic brecciated tuff with mainly hypogene enrichment to cc-bn, and phyllic altered volcaniclastics with mainly primary cp.
Test 25	1678.72	33.60	100% Pc Diabase				Phyllic altered diabase & potassic altered diabase breccia with hypogene enriched cp-py to bn-cc.
Test 26	1699.58	57.05	100% Pc Dripping Springs Quartzite				Strong advanced-argillic overprinting phyllic altered quartzite with hypogene enrichment of cp-py to cc-bn.
Test 27	1725.12	38.46	100% Pc Diabase				Phyllic, potassic & advanced argillic altered diabase with primary cp & hypogene enrichment to bn-cc.
Test 28	1785.02	36.84	67.0% Pc Diabase	33.0% Heterolithic breccia			Potassic-phyllic altered diabase with mainly primary cp mineralization.
Test 29	1827.35	83.04	81.67% Pc Dripping Springs Quartzite	18.33% Pc Dripping Springs quartzite conglomerate			Phyllic, advanced argillic & potassic altered quartzite (& quartzite breccia) with trace primary cp remaining following hypogene replacement of cc-bn.
Test 30	1886.13	46.87	61.44% Pc Diabase	24.92% Ti Felsic igneous, undifferentiated	13.64% Pc Diabase breccia		Potassic-phyllic altered diabase, phyllic-potassic altered felsic igneous, undifferentiated & diabase breccia, with primary cp.
Test 31	1934.29	57.48	54.47% Ti Felsic igneous, undifferentiated	40.79% Pc Diabase	4.74% Ti QEP		Phyllic-potassic altered felsic igneous, undifferentiated; potassic-phyllic-argillic altered diabase; potassic-phyllic altered QEP; with primary cp.

ADDENDUM I WHAT-IF DESIGN TEMPERATURE IS REDUCED TO 25°Cwb

Addendum B discusses the heat stress management plan limits and the selection of the temperature design criteria used in the main report.

The recommended design reject temperatures are 27.5°Cwb in development faces when persons are outside air conditioned cabins and 30°Cwb in production crosscuts when equipment is operated remotely. That is, designing for level 1 conditions in development faces and level 2 conditions in production cross cuts [see Table B.1, Addendum B]. About 30% of the total ventilation [below Skip Discharge level] will relate to the 30°Cwb limit and 70% to the 27.5°Cwb limit.

Addendum B also noted that temperatures used for the design of mine cooling systems are set so that, on average, specified work place return air temperatures [reject temperatures] are met. For example, if the reject temperature is set at 27.5°Cwb then return air temperatures may range from 26 to 29°Cwb due to the dynamic nature of the mining process superimposed on diurnal variations in surface air temperatures.

In terms of a sensitivity study, the question has been asked: what-if the design temperature was reduced to 25°Cwb - this is the purpose of this addendum.

The reduced design temperature will result in the following compounding effects on heat load:

- General intake temperatures will need to be reduced and this in turn will increase the heat flow from the surrounding rock and broken rock and increase the actual mine heat load.
- Reject ventilation will leave the work spaces at a lower heat energy level and this reduction in enthalpy will need to be provided by refrigeration.

Heat load from the mobile and static equipment will generally not be temperature dependent and will remain generally unchanged.

By extrapolating from the base-case heat load analysis and VUMA runs, it is estimated that the refrigeration requirements will increase by about 50 MW as referenced underground.

The additional refrigeration will be applied by increasing both the surface and underground refrigeration proposed capacities. The selection of the best split between surface and underground additions needs to take account of the following type of considerations:

- Applying more-and-more cooling on surface by creating ultra-cold downcast air from the surface air coolers will eventually have only diminishing returns because:
  - It becomes exponentially more expensive in terms of OPEX and CAPEX to produce ultra-cold air and ultimately the equipment becomes non-standard.
  - Surface air cooling is not 'positionally' efficient. For example, in the base-case design, 12% of cold air from surface is used on or above the Skip Discharge level and does even not reach the main underground mine.
  - Heat flow into the shaft barrels will increase with colder downcast air.
  - Ventilation leakage relates to a greater loss of cooling resources with colder downcast air.
- Applying more-and-more refrigeration plant underground will:
  - Be limited by underground heat rejection capacity into the return ventilation.
  - Lead to exponentially increasing costs in terms of OPEX and CAPEX as condensing temperatures and pressures increase.
  - Require more underground development work that could affect the entire mine establishment schedule.

[For simplicity, there have been no considerations in this sensitivity study of increasing the base-case primary ventilation rate along with the required increased shaft sizes and increased underground intake/return infrastructure. Although, this will be a possible option to consider in detailed design should the lower temperatures become the specified design criteria.]

The base-case underground plant design capacity is 40 MW which will make use of 1200 kg/s of return ventilation from the large ROWA tunnels for heat rejection. Although, in theory, there will be 2760 kg/s of return ventilation underground, it will not be possible to concentrate all of this capacity for heat rejection. Indeed the maximum additional return ventilation that could be used practically is considered to be about 700 kg/s. In order to avoid an additional cooling tower site in a different location, this additional flow could probably be taken from the ROWA tunnels provided there is a modification in the planned overall ventilation distribution. This [the 700 kg/s] means that a reasonable limit to increasing the underground plant capacity will be an additional rating of about 24 MW. This would relate to three more [3 x 8 MW] refrigeration machine modules and will give an increase of 60% over the base-case underground refrigeration plant duty.

The remaining additional cooling will have to be provided from surface in the form of colder downcast air. To provide the additional cooling effect underground, the surface downcast air temperature will need to be 3.2°Cwb less [than base-case value of 10.5°Cwb] and this will require an additional 23% of surface bulk air cooling duty.

CAPEX implications

BBE/Quoin prepared cost estimates for the surface and underground refrigeration systems and, in terms of the items in the BBE scope, the increase in costs for the surface and underground refrigeration systems will be of the order of $ 50 million [including provision for conveyor drift cooling]. But this excludes many other significant factors such as:

- Additional underground excavations for refrigeration plants, substations, air coolers, etc.
- Increased power supply infrastructure to underground, substations, switchgear, etc
- Increased make-up water supply infrastructure to underground
- Overland piping from central surface plant to the surface bulk air coolers [this was part of RSV scope]
- Increased power supply infrastructure to surface works, substations, switchgear, etc
- Increased make-up water supply infrastructure to underground

These factors could increase the $ 50 million indicated above by another 40% to 50%.

OPEX implications

The main additional OPEX costs will include maintenance, consumables, make-up water and, most importantly, power. It is estimated that the additional make-up water consumption will be of the order of 23 l/s. It is estimated that the additional electrical power use will be of the order of 16 MW.

ADDENDUM J DRAWINGS

SURFACE REFRIGERATION SYSTEM

070-2-30-8-1-0-00-019	Overall system layout
070-2-30-8-1-0-00-020	PFD for refrigeration plant, condenser cooling towers, ice store and service water
070-2-30-8-1-0–00-021	PFD for surface bulk air coolers
070-2-30-8-1-0-40-023A	GA of bulk air coolers [No.11 and No.12 Shafts]
070-2-30-8-1-0-40-023B	GA of bulk air cooler [No.13 Shaft]
070-2-30-8-1-0-40-024	GA of condenser cooling towers
070-2-30-8-1-0-40-026	GA of bulk air cooler drift into shaft
070-2-30-8-1-0-40-027	GA of service water pre-cooling tower and dams
070-2-30-8-1-0-90-028	Electrical single line diagram
070-2-30-8-1-0-40-029	Plant layout for refrigeration machines
070-2-30-8-1-0-40-030	Site plan for shaft sinking phase
070-2-30-8-1-0-40-033	GA of drift for bulk air cooler for shaft sinking phase
070-2-30-8-1-0-40-034	GA of bulk air cooler for sinking phase
070-2-30-8-1-0-40-035	PFD for cooling and ventilation system No.14 Shaft sink
070-2-30-8-1-0-00-036	Overall system site layout [No.9, 10, 14, 11, 12 and 13 Shafts
070-2-30-8-1-0-40-037	GA of bulk air cooler [No.14 Shaft sink]

UNDERGROUND REFRIGERATION SYSTEM

070-2-30-8-1-0-00-040	PFD for refrigeration plant, condenser cooling towers and dams
070-2-30-8-1-0-00-041	Site layout of cooling system
070-2-30-8-1-0-40-042	GA of refrigeration machines
070-2-30-8-1-0-40-043	GA of underground cooling towers
070-2-30-8-1-0-40-045	GA of evaporator pump chamber
070-2-30-8-1-0-40-046	GA of condenser pump chamber
070-2-30-8-1-0-90-047	Electrical single line diagram
070-2-30-8-1-0-40-050A	GA of 0.5 MW underground air cooling coils
070-2-30-8-1-0-40-050B	GA of typical multi-coil 1.0 MW bulk air cooler
070-2-30-8-1-0-40-050C	GA of typical multi-coil 1.5 MW bulk air cooler
070-2-30-8-1-0-40-050D	GA of typical multi-coil 3.0 MW bulk air cooler
070-2-30-8-1-0-00-051	PFD conveyor cooling and service water system

MAIN FAN STATIONS

070-2-30-8-1-0-40-060	GA of individual fan installation
070-2-30-8-1-0-00-062	General shaft and exhaust manifold layout
070-2-30-8-1-0-40-064	GA of conveyor drift exhaust fan
070-2-30-8-1-0-40-070	GA of temporary auxiliary fan
070-2-30-8-1-0-40-071	A of typical intake booster fan station