“VENTILATION SYSTEM OPTIMIZATION FOR DEEPENING OF HIGHLY MECHANIZED UNDERGROUND HARD ROCK MINES”

Daniel Naupari
Mine & Flows

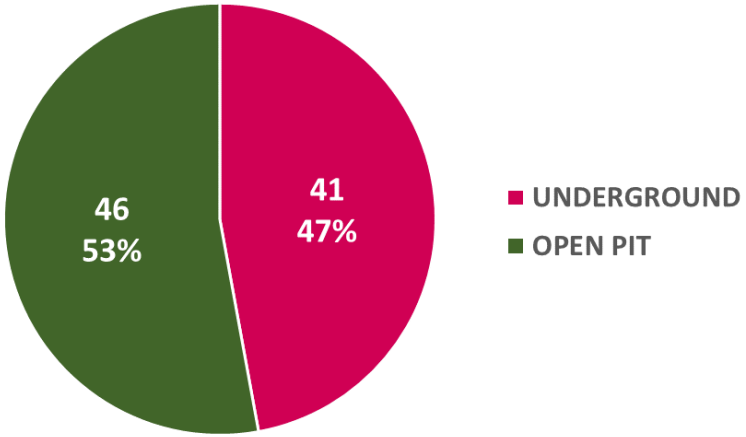
September 26th, 2023

PRESENTATION OUTLINE

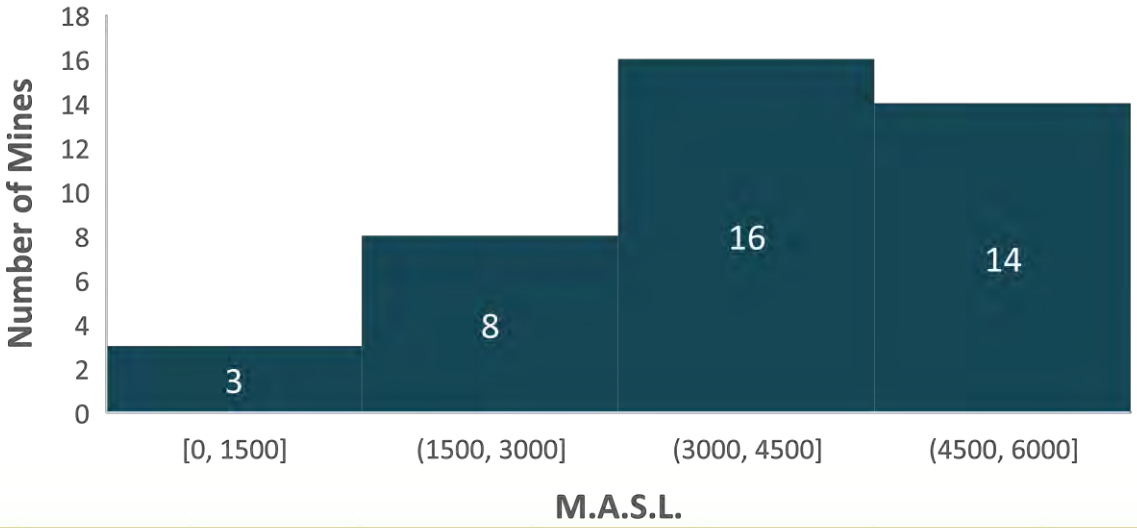
1. Mining in Peru and the Andes
2. Modern Mine Ventilation System Design
3. Prefeasibility Base Model
4. Case Study Conditions
5. Feasibility Study: Opportunities for Improvement
6. Results and LOM Simulation
7. Conclusions
8. Future Work

Mining in Peru

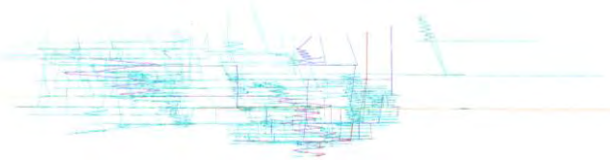
MINING METHOD



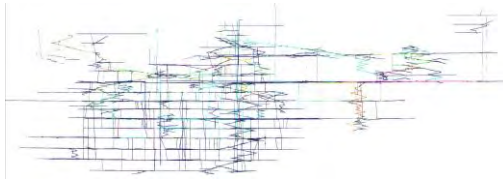
DISTRIBUTION OF UNDERGROUND MINES BY ELEVATION



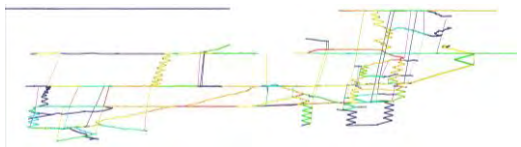
Mining in the Andes



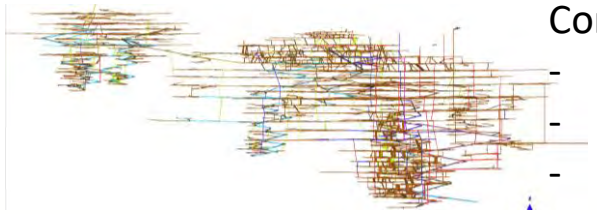
Raura (Huánuco-Lima)
- 4700 MASL
- 0.73 kg/m3
- Depth: 733 m



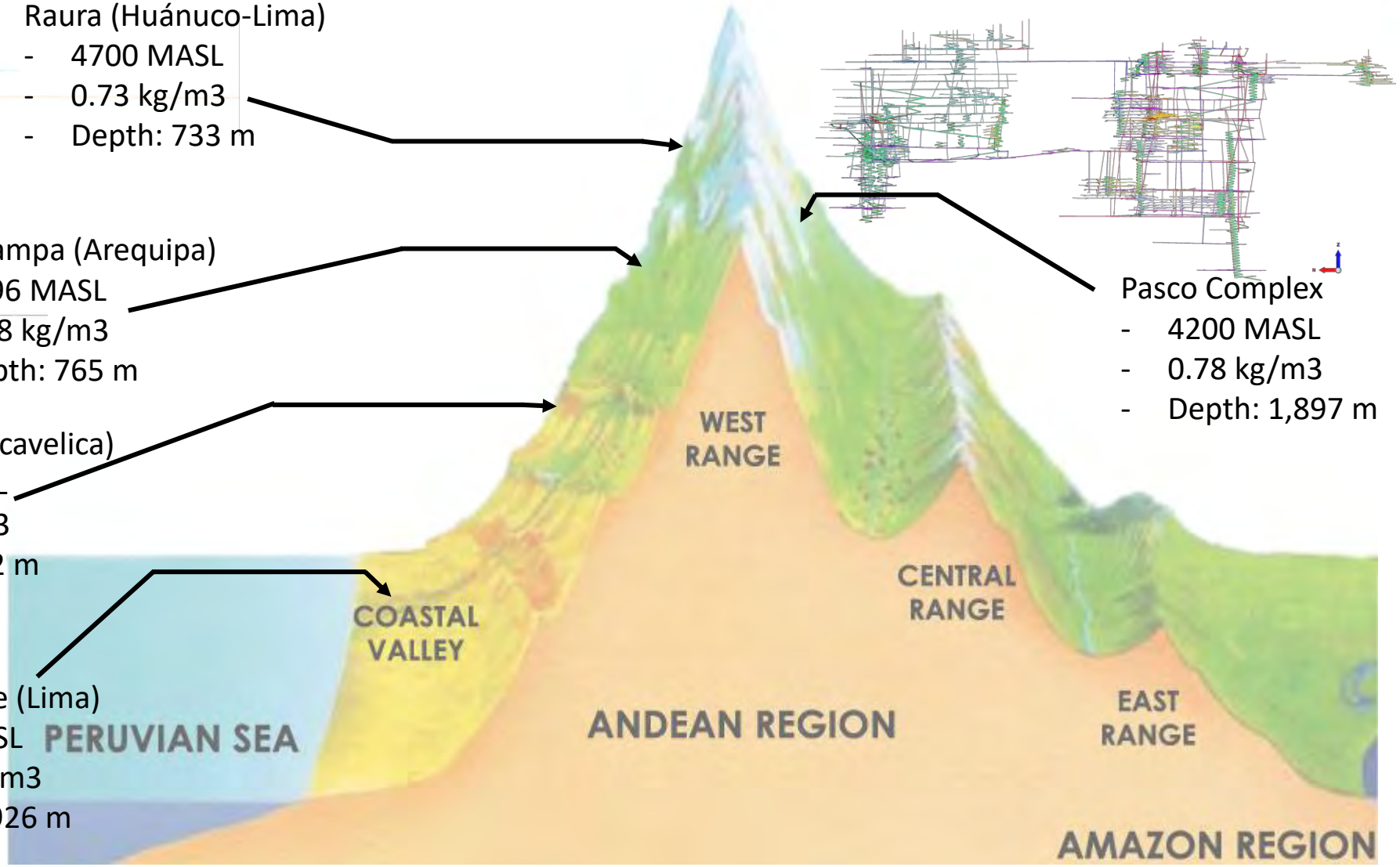
Orcopampa (Arequipa)
- 3796 MASL
- 0.78 kg/m3
- Depth: 765 m



Cobriza (Huancavelica)
- 2500 MASL
- 0.91 kg/m3
- Depth: 672 m



Condestable (Lima)
- 250 MASL
- 1.12 kg/m3
- Depth: 926 m



Pasco Complex
- 4200 MASL
- 0.78 kg/m3
- Depth: 1,897 m

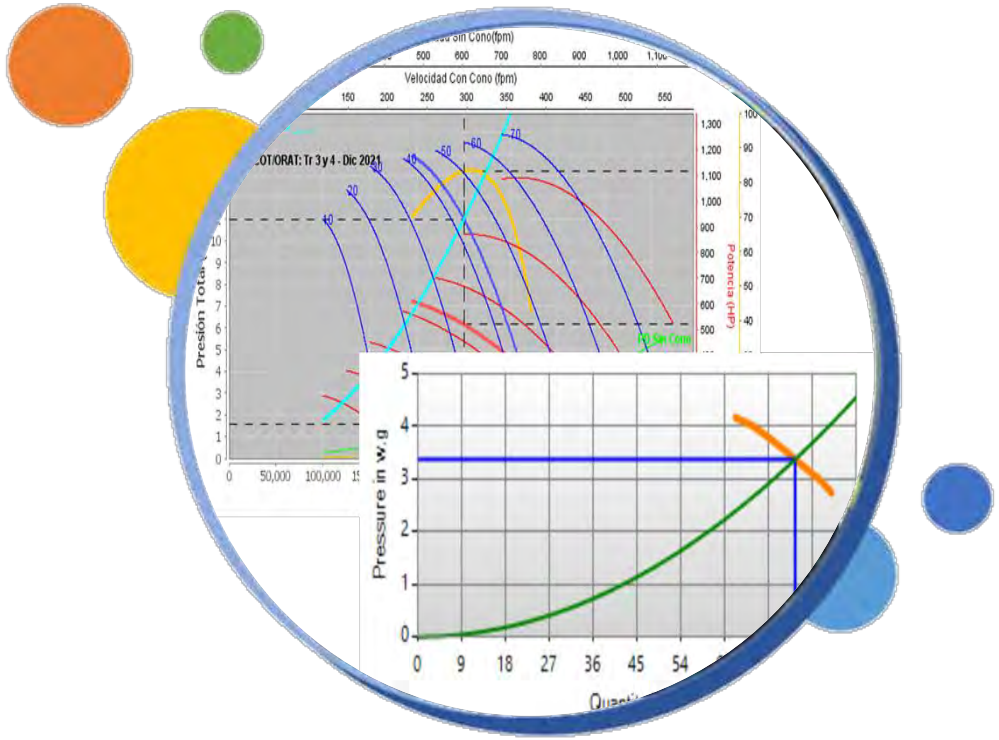
Modern Mine Ventilation System Design

- *Sequenced Modelling*

- Construction

BUILD-UP THE MODEL

- Create the airways based on the mine maps
- Adjust the dimensions for each excavation
- Define the openings and the close ends



Modern Mine Ventilation System Design

- *Sequenced Modelling*

- Construction
- Calibration
- Simulation

CALIBRATION

- Adjust environmental conditions
- Add & Set up fans to operational parameters
- Adjust resistances and friction factors

Modern Mine Ventilation System Design

Modern Mine Ventilation System Design

- *Sequenced Modelling*

- Construction
- Calibration
- Simulation

SIMULATION STAGE FOR LONG-TERM PLANNING

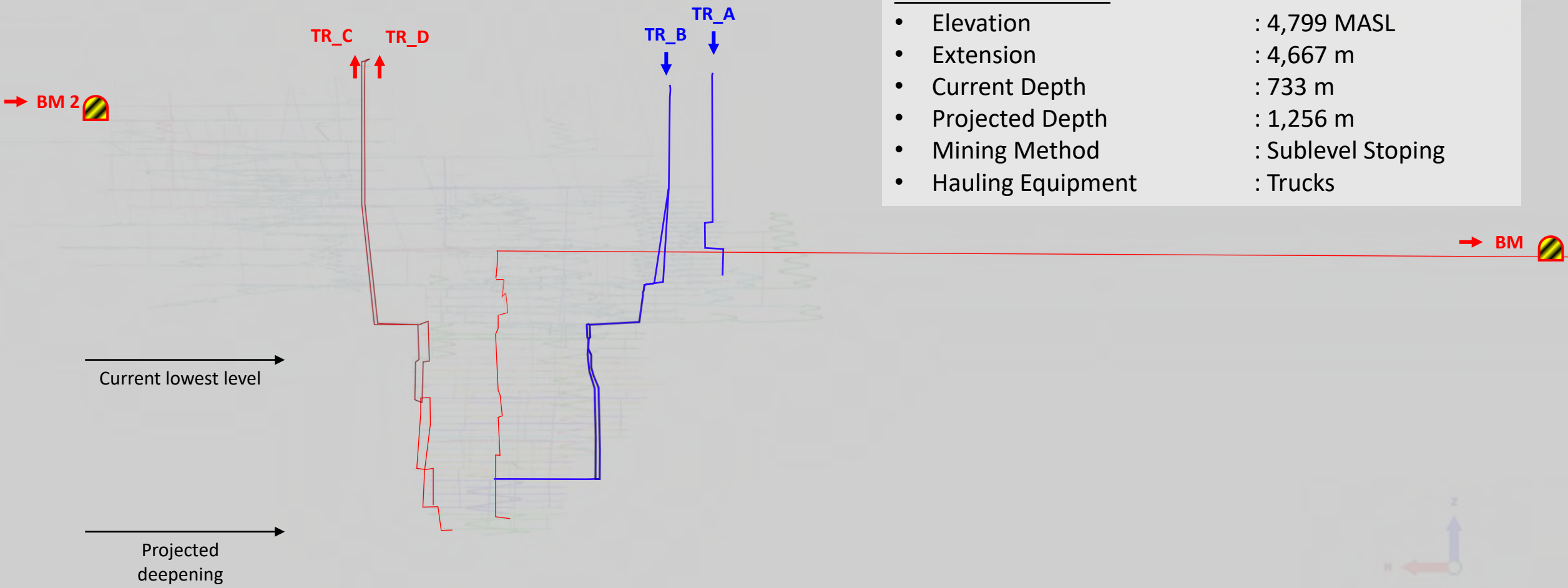
- Model able to simulate feasible scenarios
- Ventilation design aligned with production forecast
- Accurate simulation of power consumption

Prefeasibility Study

Base Case

Mine & Flows
Ventilación de Minas y Túneles

Prefeasibility



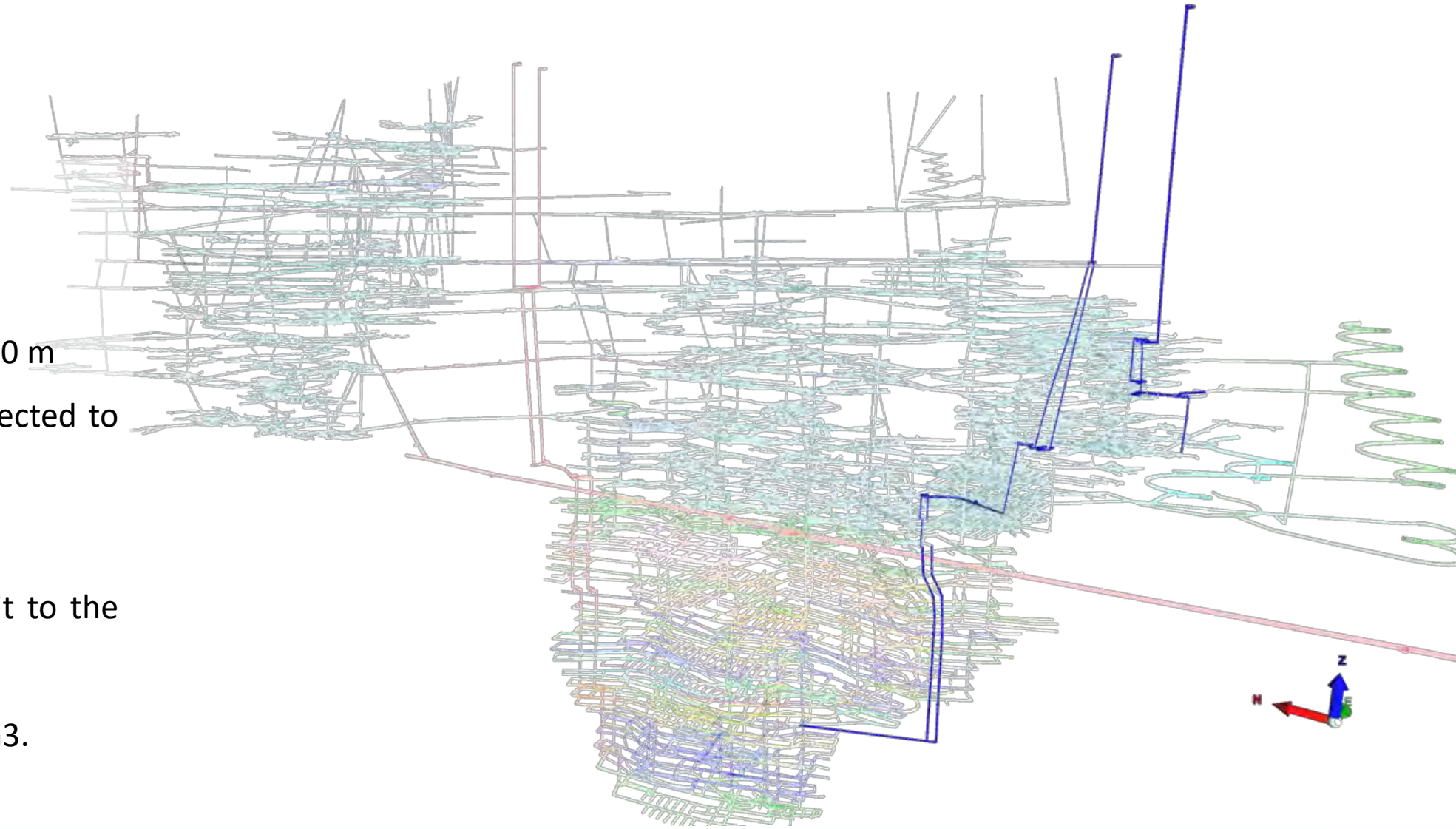
MINE CONDITIONS:

- Elevation : 4,799 MASL
- Extension : 4,667 m
- Current Depth : 733 m
- Projected Depth : 1,256 m
- Mining Method : Sublevel Stoping
- Hauling Equipment : Trucks

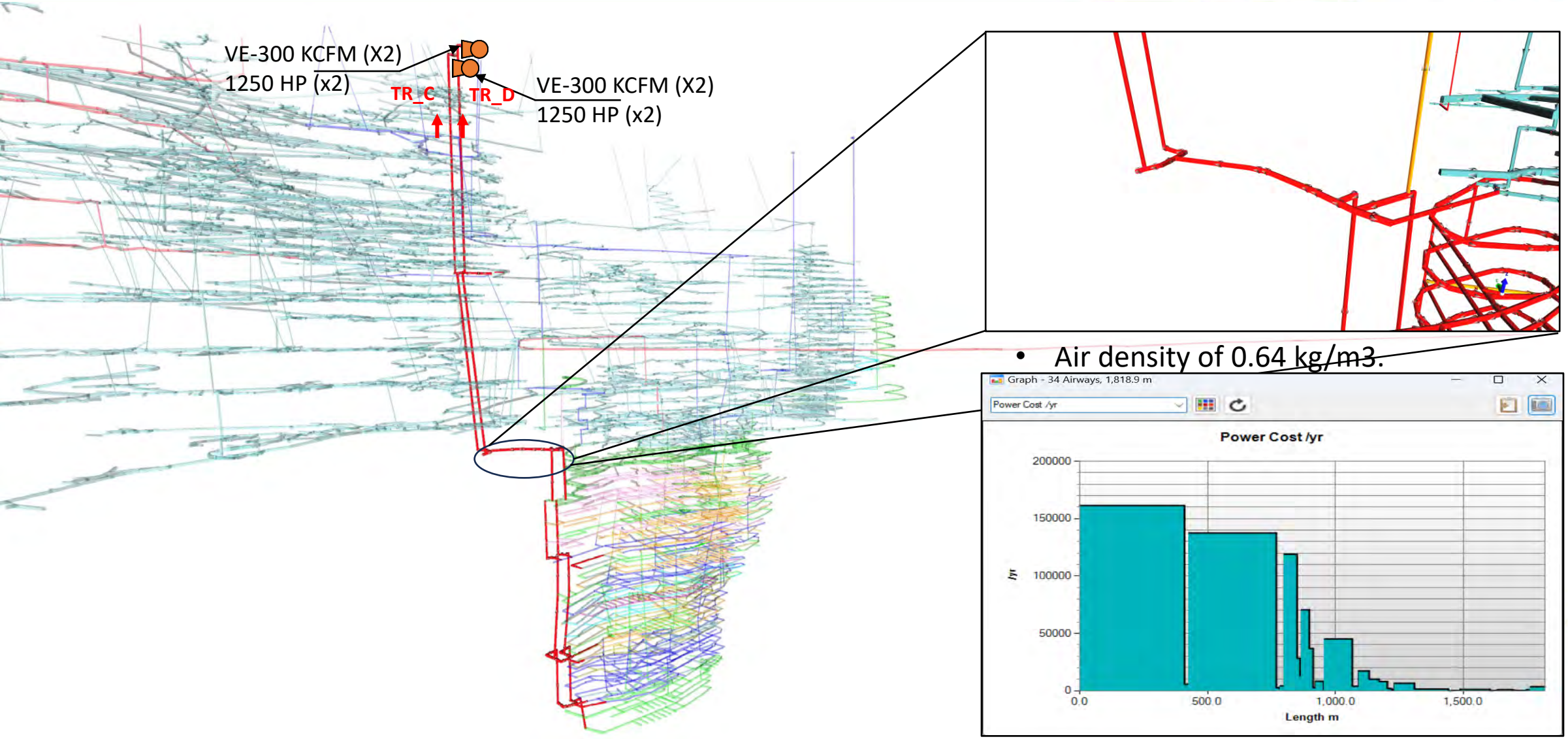
Prefeasibility

INTAKE CIRCUIT:

- Zoned (South).
- Vertical distance of 1,340 m
- Two parallel circuits directed to the same zone.
- Defined main levels.
- Effective fresh-air circuit to the bottom level.
- Air density of 0.64 kg/m3.

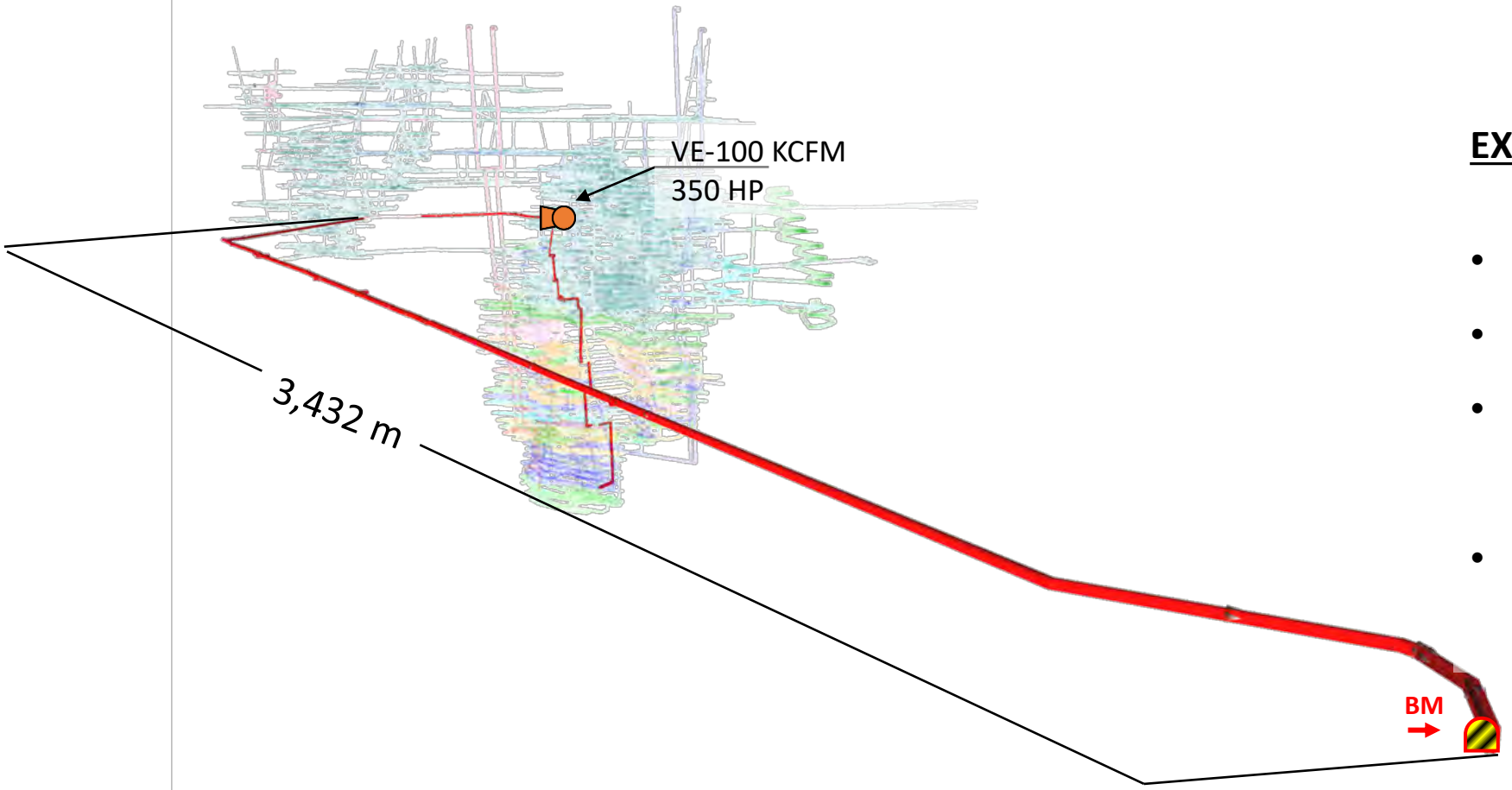


Prefeasibility



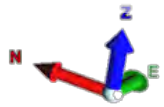
- Air density of 0.64 kg/m3.

Prefeasibility

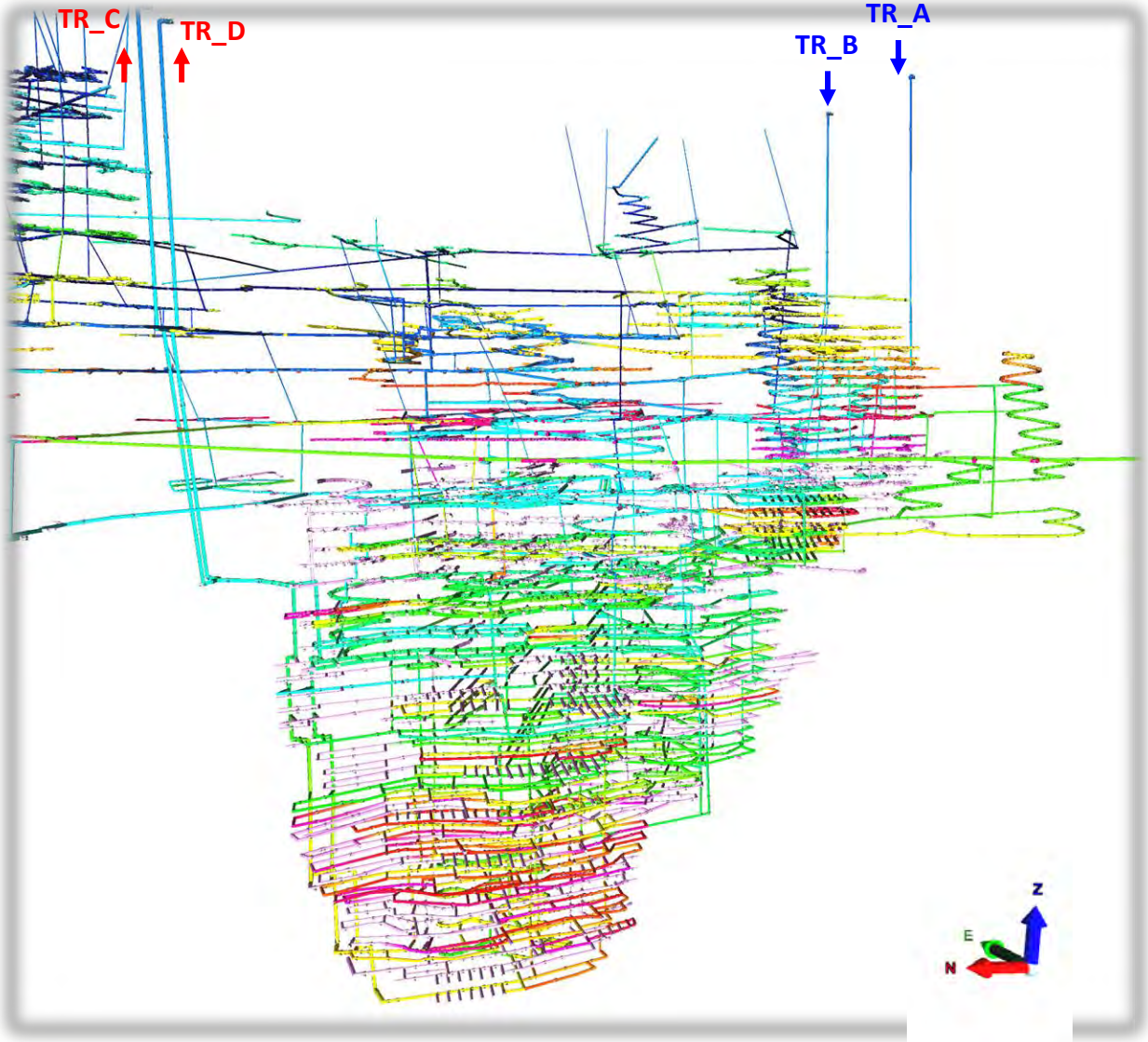


EXHAUST CIRCUIT:

- Zoned (North).
- Horizontal distance of 3,432 m.
- Exhaust through mid-upper zone towards portal (BM).
- Air density of 0.64 kg/m3.

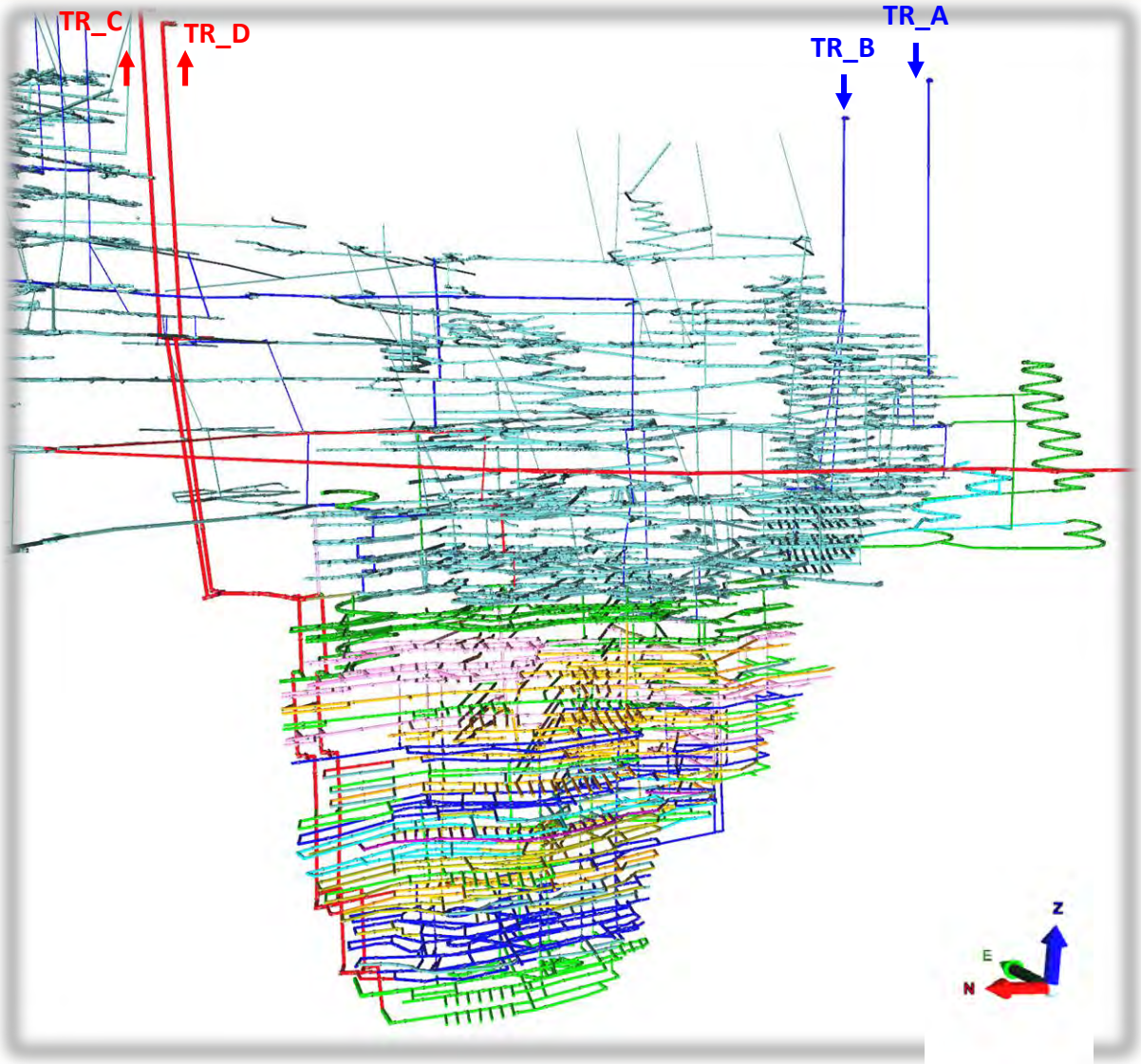


Prefeasibility Base Model



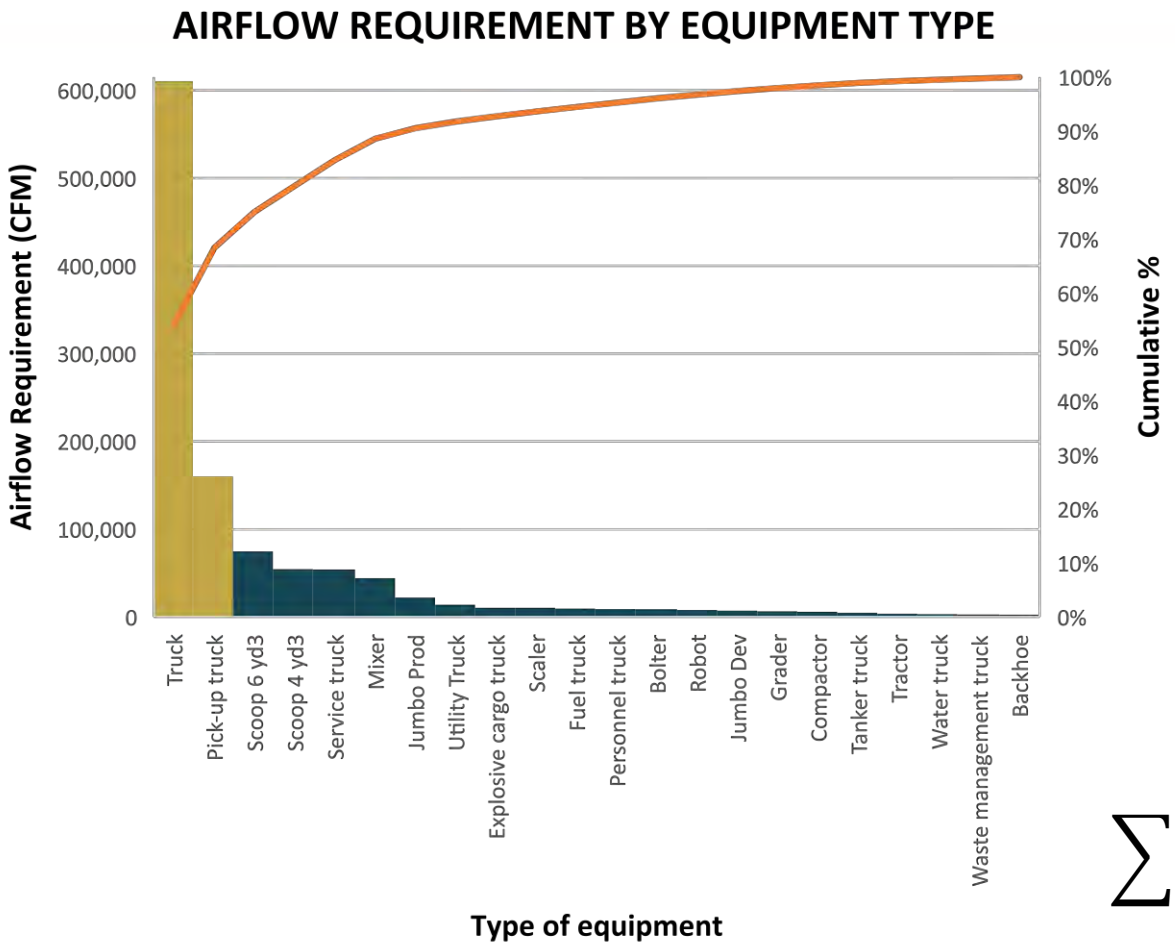
Environment	
Air Density Compressible Flow	0.64 kg/m^3
Air Density Incompressible Flow	0.64 kg/m^3
Surface Temperature Adjust	Si
Current Year	2021.515
Rock Specific Heat	790.0 J/kgC
Rock Thermal Conductivity	2.00 W/mC
Rock Density	2.700 kg/m^3
Rock Thermal Diffusivity	0.938 m^2/s 10-6
Airway Age	5.000 years
Surface Datum of MineGrid	4,866.4 m
Rock Wetness Fraction	0.15
Geothermal Gradient	2.5 C/100m
Surface Datum Pressure Barometric	56.221 kPa
Surface Atmospheric Lapse Rate	6.4 C/1000m
Surface Datum Relative Humidity	39.7 R
Surface Datum Elevation Above Sea Level	4,700.0 m
Surface Datum Rock Temperature	20.0 C
Surface Datum Temperature Wet Bulb	20.0 C
Surface Datum Temperature Dry Bulb	30.0 C

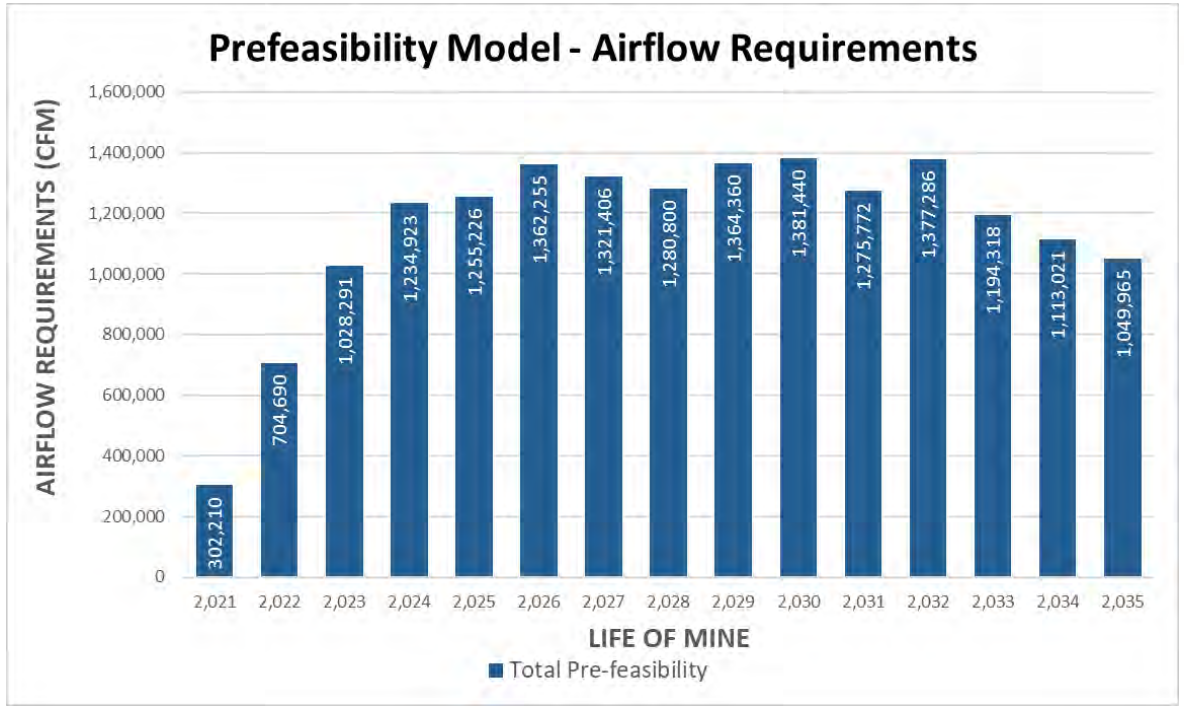
Prefeasibility Base Model



Friction Factors (kg/m^3)	
Custom	
Auto	
*Raises	**0.013**
*Airways	**0.01**
*Ramps	**0.014**
*RaiseBored Airway	**0.005**
Smooth Blasted	**0.0085**
Average Blasted	**0.012**
Rough Blasted	**0.015**
Very Rough Blasted	**0.02**
Concrete Lined Airway	**0.0033**
Concrete Shaft Sets	**0.0417**
Timbered Airway	**0.0333**
Flexible Duct	**0.0029**

Prefeasibility Base Model



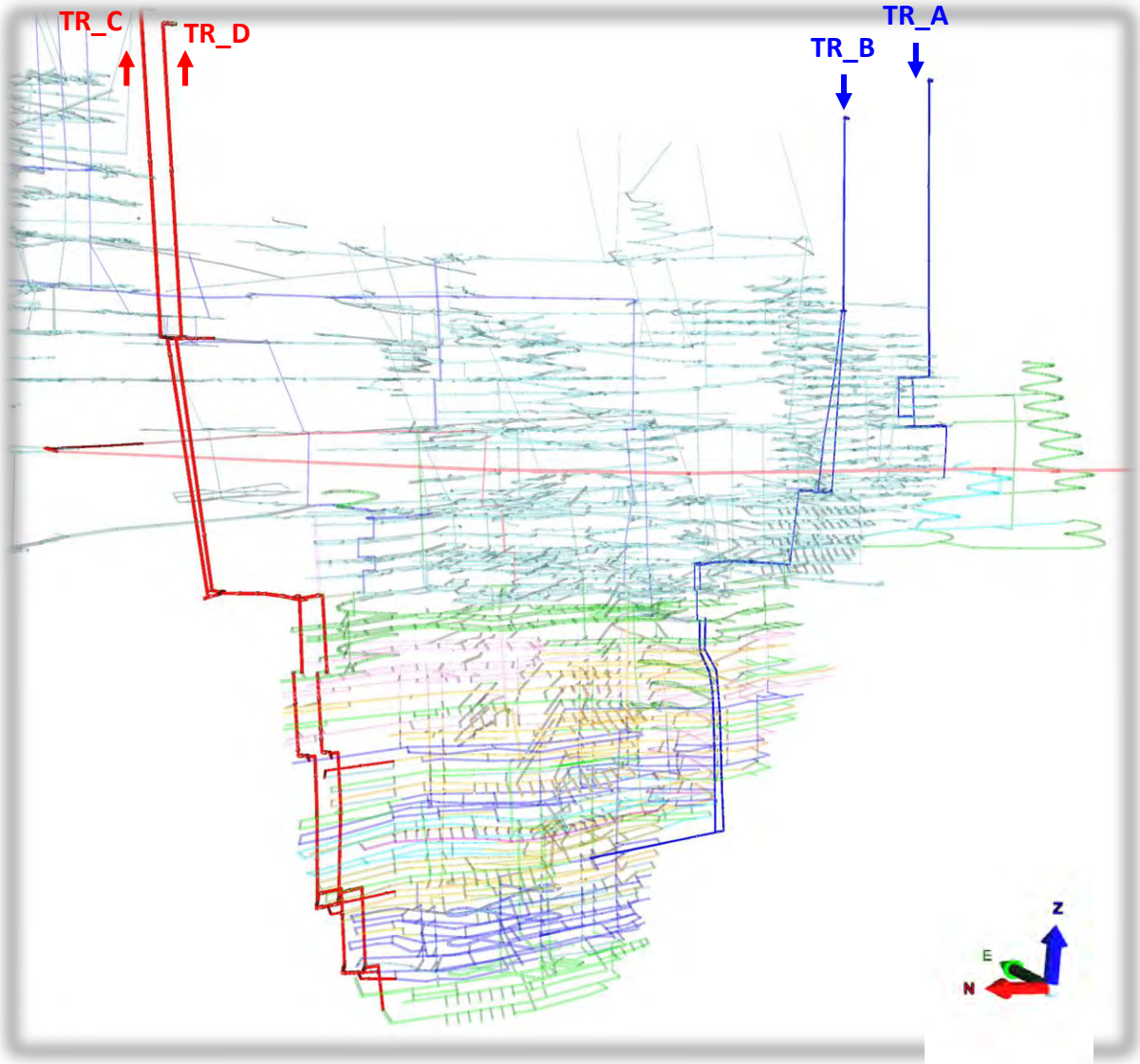


$$\sum [(Diesel\ Equipment + Workers + Temperature\ Control + Wood\ Consumption) + \boldsymbol{Leaks}\ (\mathbf{15}\%)]$$

D.S.N°024-2016 and modifications from D.S.N°023-2017:

§ ART. 252 (d) *"The airflow requirements in the mine must be the sum of the airflow required by workers, the airflow to maintain appropriate temperature conditions in the working area and the airflow for the operation of diesel equipment. If there is no diesel equipment in the mine, it must be considered instead the airflow required to ensure gas dilution from the blasting, in accordance with the guidelines from Annex 38".*

Prefeasibility Base Model

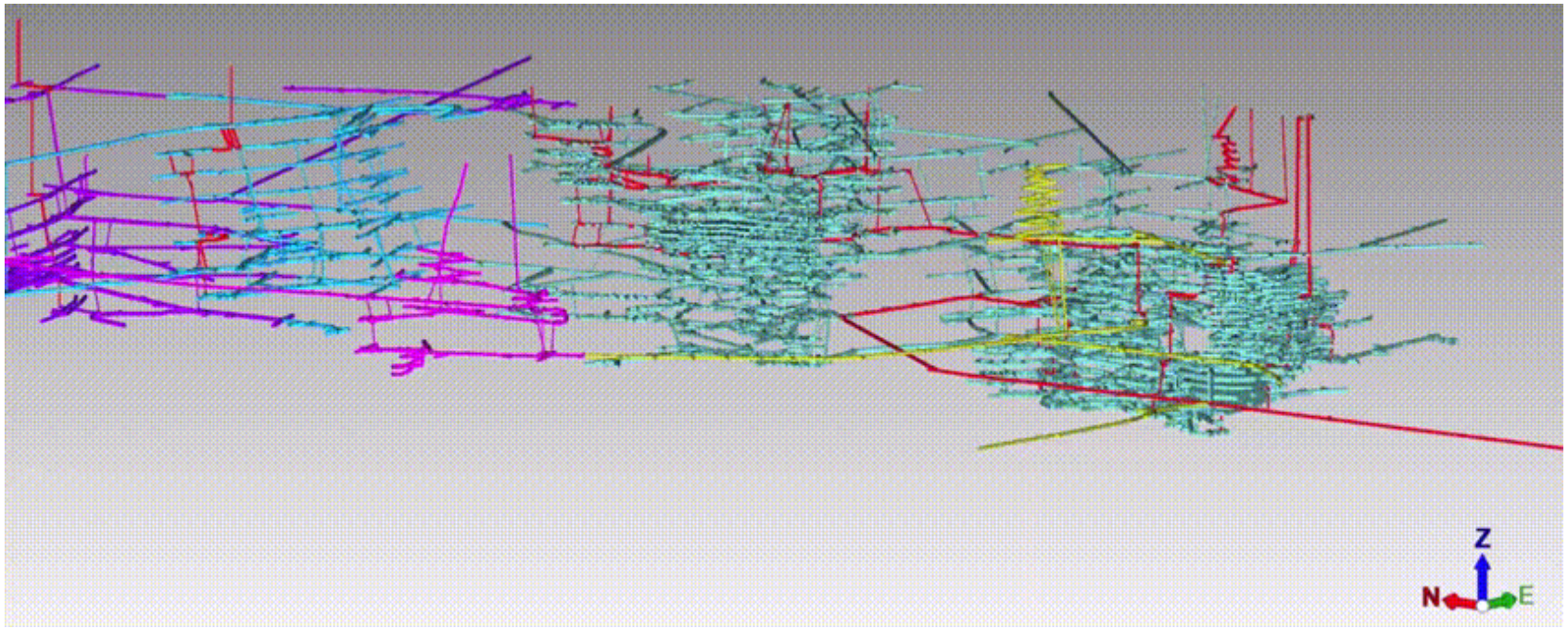


Prefeasibility Study - CAPEX	
Component / Activity	**Escalated value**
Ventilation Infrastructure	
Ventilation Circuit - TRONCAL TR 03	$ 6,097,892
Ventilation Circuit - TRONCAL TR 04	$ 6,258,108
Secondary Ventilation System	$ 2,866,347
Power Distribution System	
Electric Substation + Distribution No. 01 (TR 03 + TR 04)	$ 7,852,259
Electric Substation + Distribution No. 02 (Secondary System)	$ 225,374
CAPEX PFS	**$ 23,299,979**

Prefeasibility Study - OPEX	
Component / Activity	**Escalated value**
Power consumption	$ 22,320,716
NPV OPEX	**$ 11,201,248**

IRR: annual 12 %

Case Study Conditions



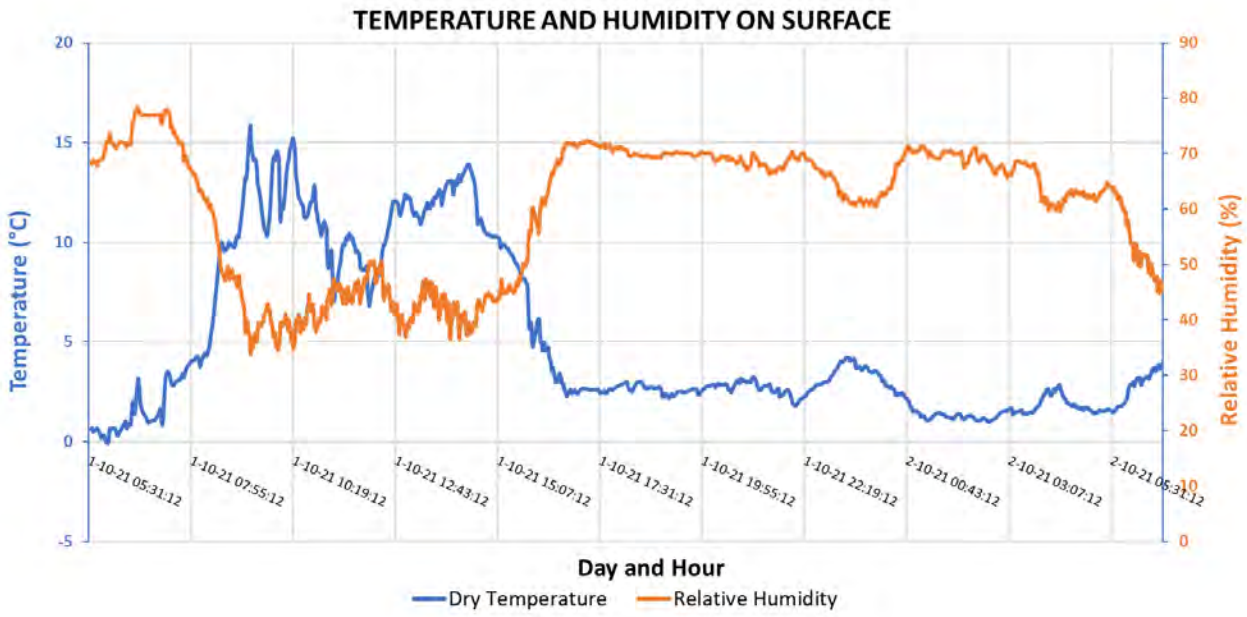
- Main Portal Elevation at 4,800 MASL
- Air Density: 0.73 kg/m3
- Barometric Pressure: ~58,270 Pa
- Dry Temperature: 2.36 - 11.20 °C
- Relative Humidity: 43 - 67 %
- Power Cost: 0.072 US$/Kw-hr

Feasibility Study

In-Depth Analysis

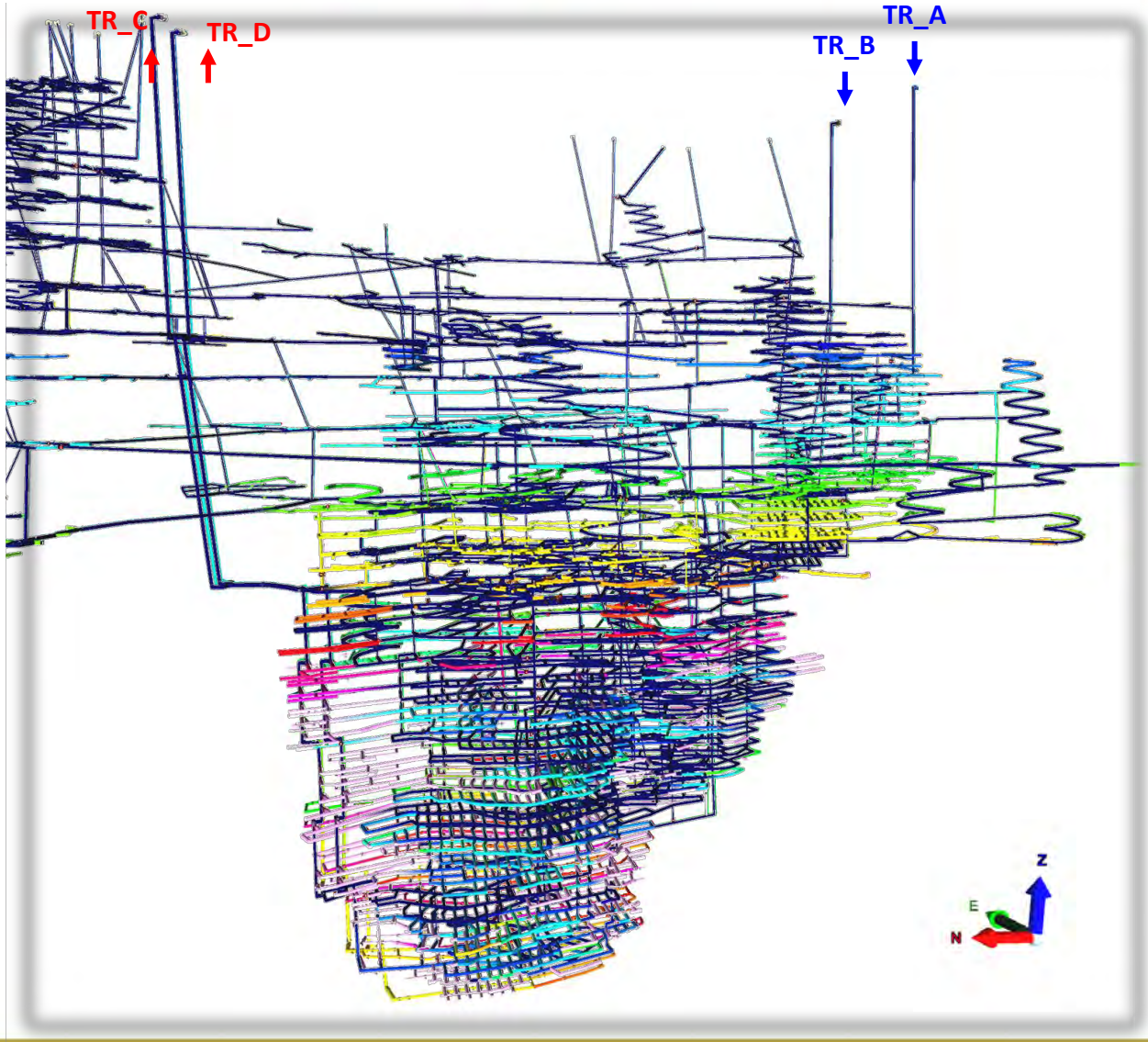
Mine & Flows
Ventilación de Minas y Túneles

Ventsim Model Calibration



AVERAGE VALUES

	Dry Temperature (°C)	Relative Humidity (%)	Barometric Pressure (Pa)
AVG Day	11.20	42.85	58,282.91
AVG Night	2.60	39.7	58,260.32
Prefeasibility	30.0	39.7	56,221.00



Ventsim Model Calibration

Environment	PFS	FS
Air Density Compressible Flow	0.64 kg/m^3	0.73 kg/m^3
Air Density Incompressible Flow	0.64 kg/m^3	0.64 kg/m^3
Surface Temperature Adjust	Si	Si
Current Year	2021.515	2021.515
Rock Specific Heat	790.0 J/kgC	790.0 J/kgC
Rock Thermal Conductivity	2.00 W/mC	2.00 W/mC
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Airway Age	5.000 years	5.000 years
Surface Datum of MineGrid	4,866.4 m	4,866.4 m
Rock Wetness Fraction	0.15	0.15
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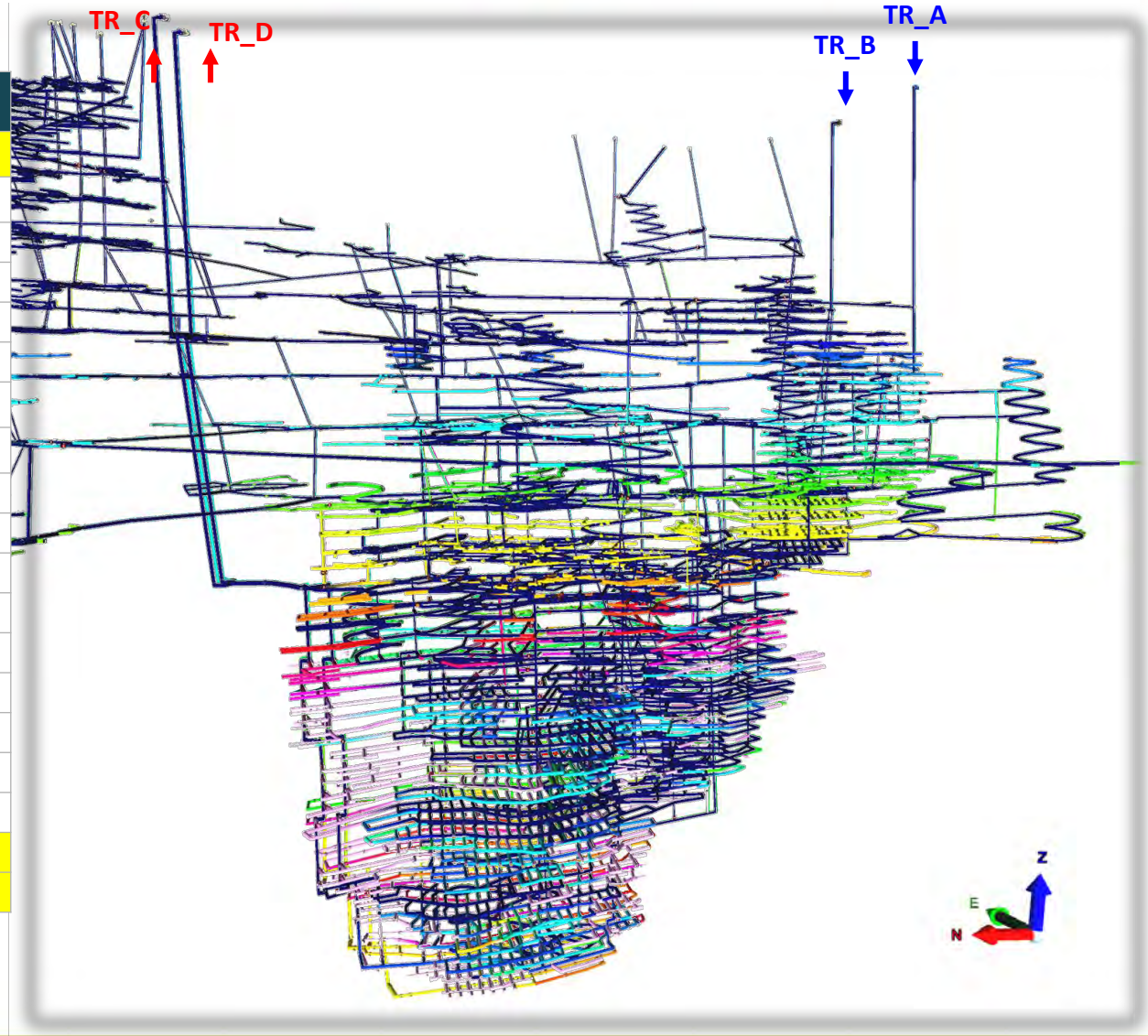
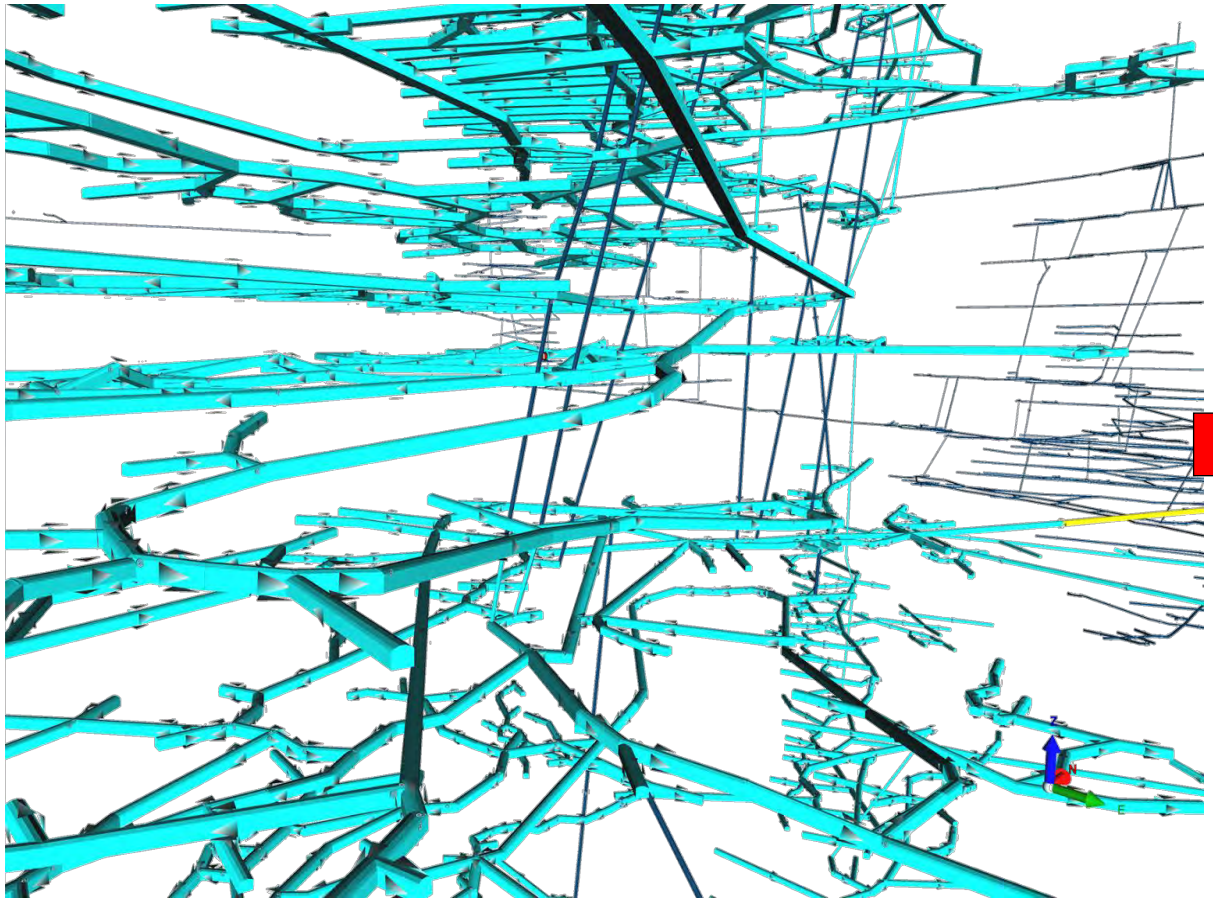
Surface Datum Elevation Above Sea Level	4,700.0 m	4,700.0 m
Surface Datum Rock Temperature	20.0 C	20.0 C
Surface Datum Temperature Wet Bulb	20.0 C	-0.3 C
Surface Datum Temperature Dry Bulb	30.0 C	2.6 C

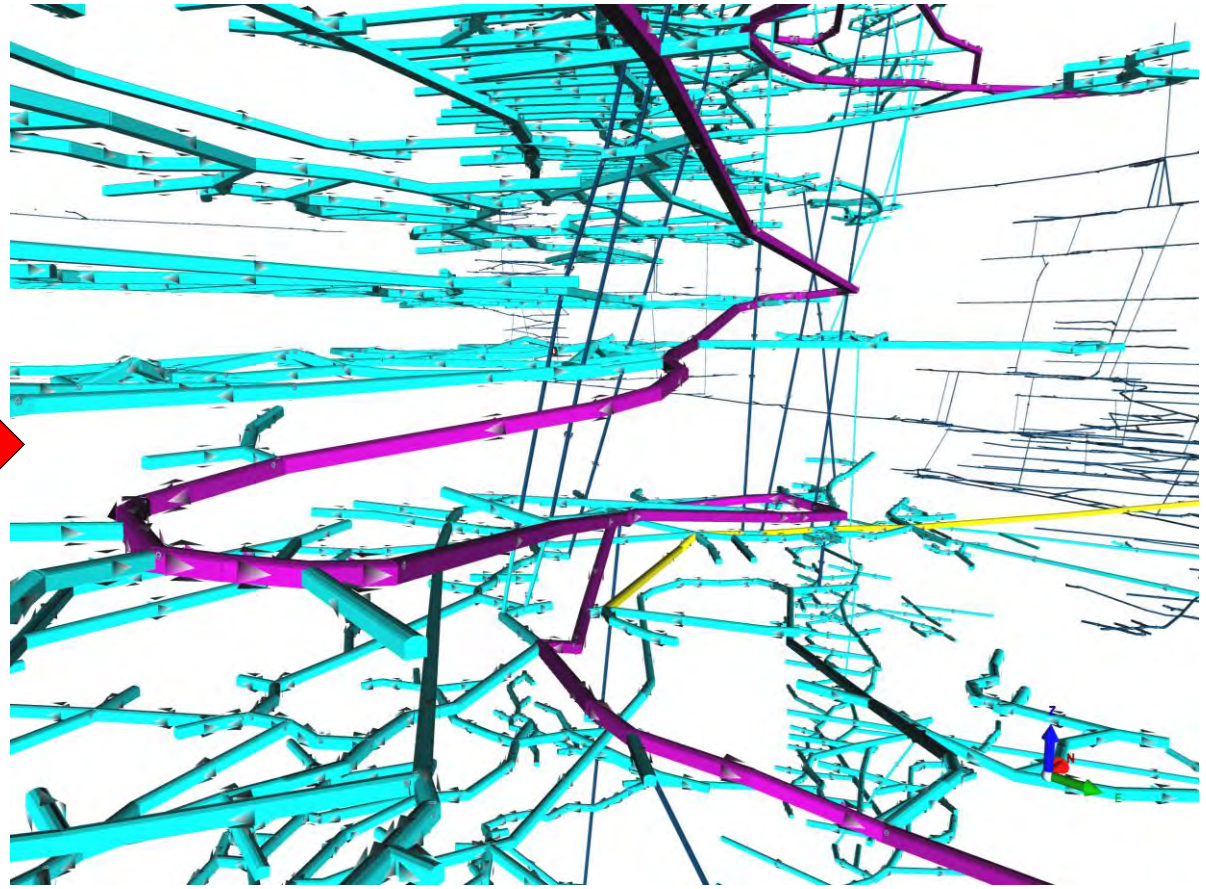


Ventsim Model Calibration

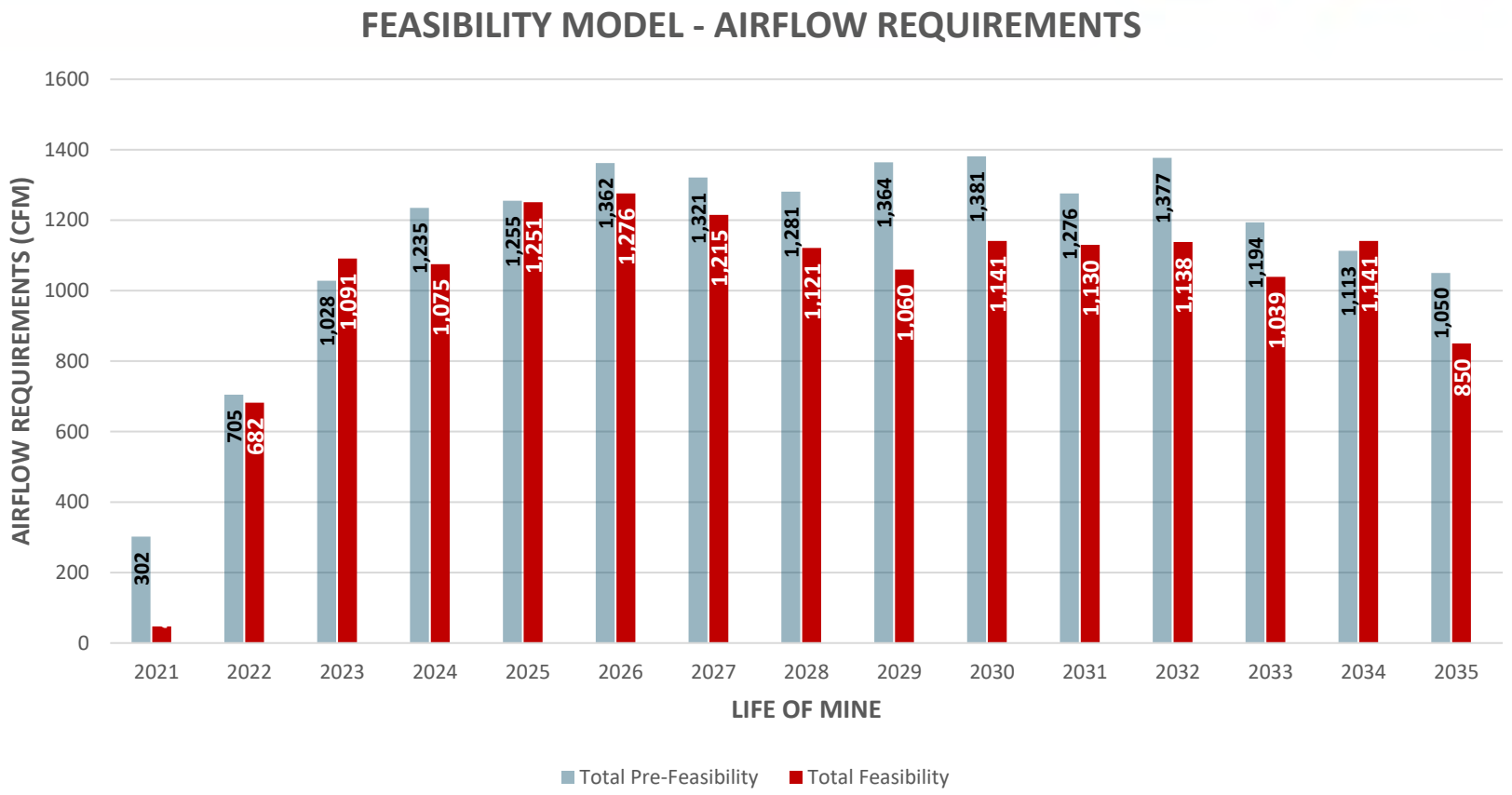
FORMER FRICTION FACTORS CONFIGURATION



FINAL FRICTION FACTORS CONFIGURATION



Ventsim Model Calibration



	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Total Pre-Feasibility (KCFM)	302	705	1,028	1,235	1,255	1,362	1,321	1,281	1,364	1,381	1,276	1,377	1,194	1,113	1,050
Total Feasibility (KCFM)	47	682	1,091	1,075	1,251	1,276	1,215	1,121	1,060	1,141	1,130	1,138	1,039	1,141	850

Re-evaluation of the ventilation infrastructure

TR C – TR D

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Ventilación de Minas y Túneles

Opportunities for Improvement

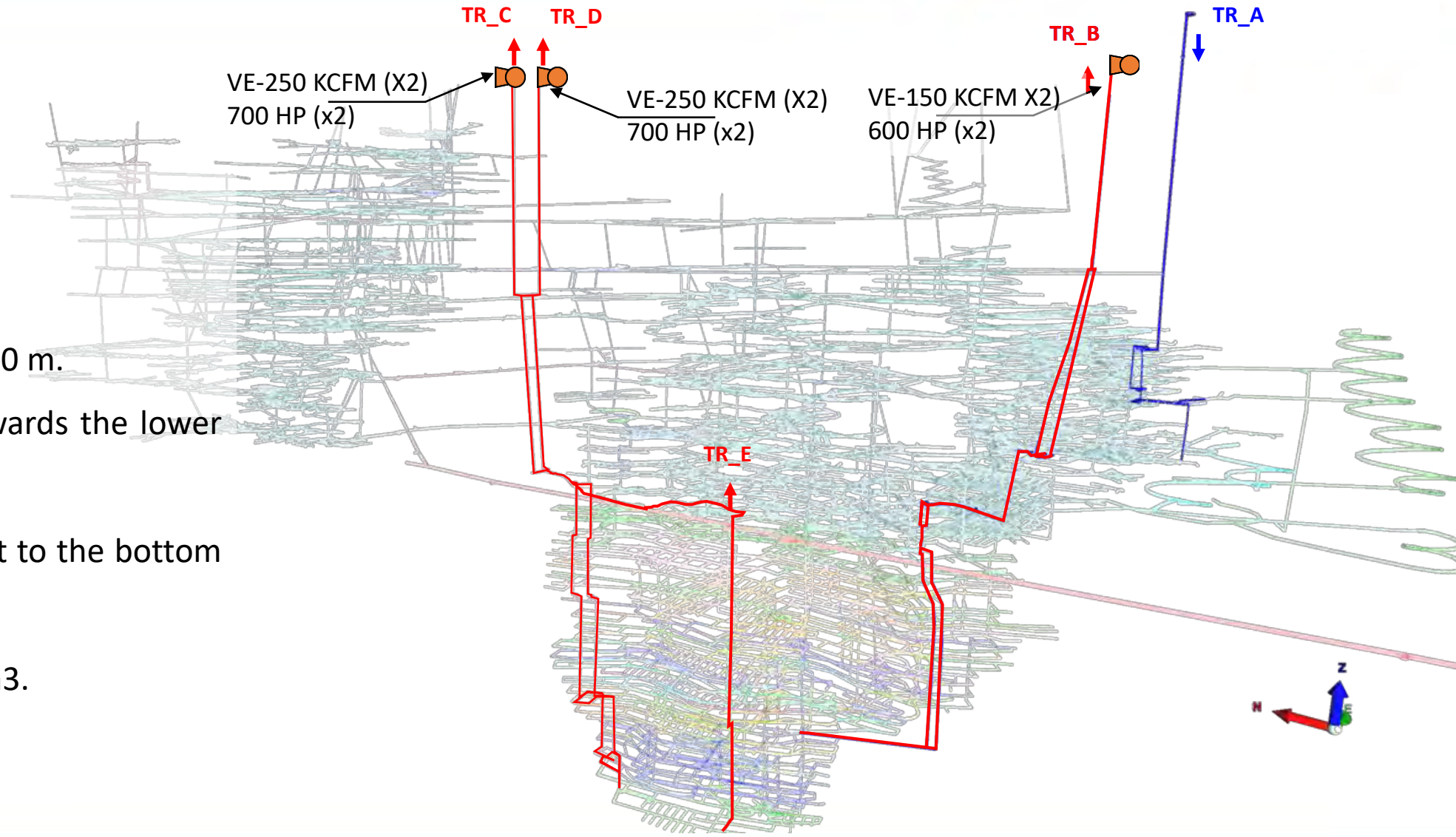
- **REUSE**
  - Use of existing infrastructure for the new design of the ventilation circuits.
- **RECONFIGURATION**
  - Reconfiguration of TR_C and TR_D circuits.
  - Decrease of operating costs based on the optimization of power consumption.
- **GAP**
  - Analysis of variations between original conditions and new design.
  - Opportunity to define new evacuation routes toward the portal.

Opportunities for Improvement

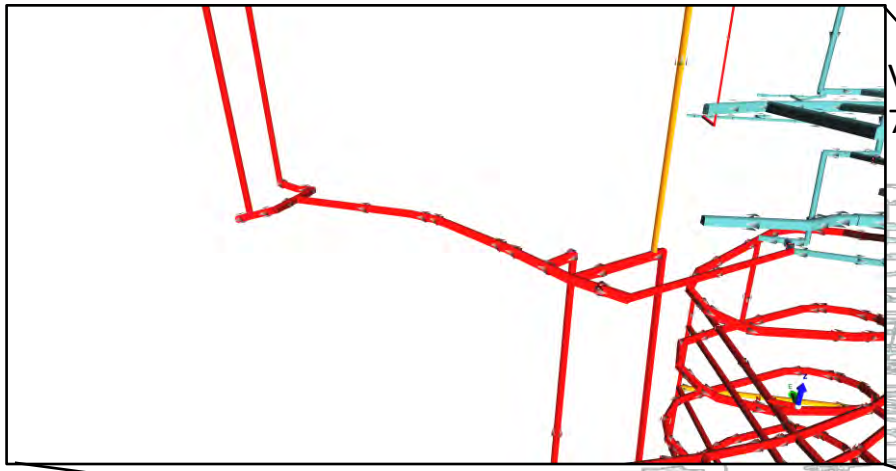
REDISTRIBUTION:

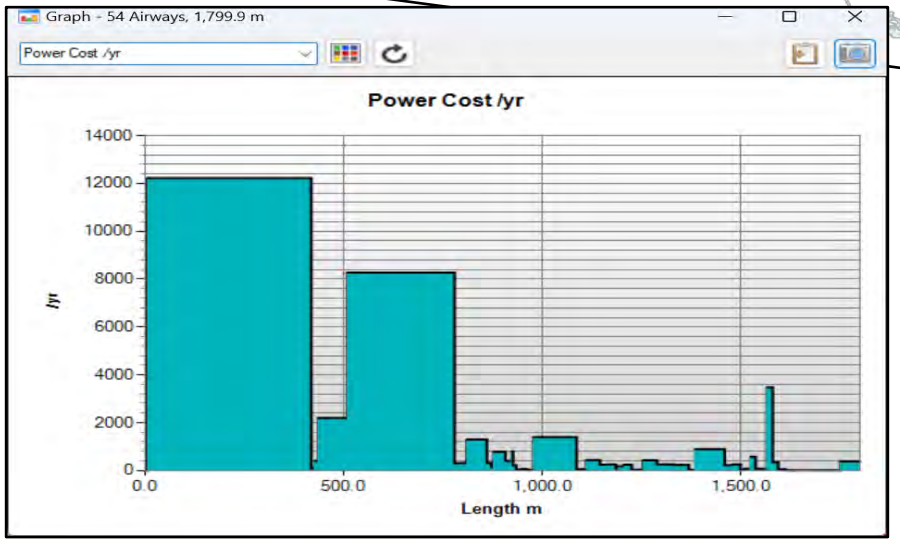
- Zoned (Lower levels).
- Vertical distance of 1,340 m.
- Single intake circuit towards the lower levels.
- Effective fresh-air circuit to the bottom level.
- Air density of 0.73 kg/m3.

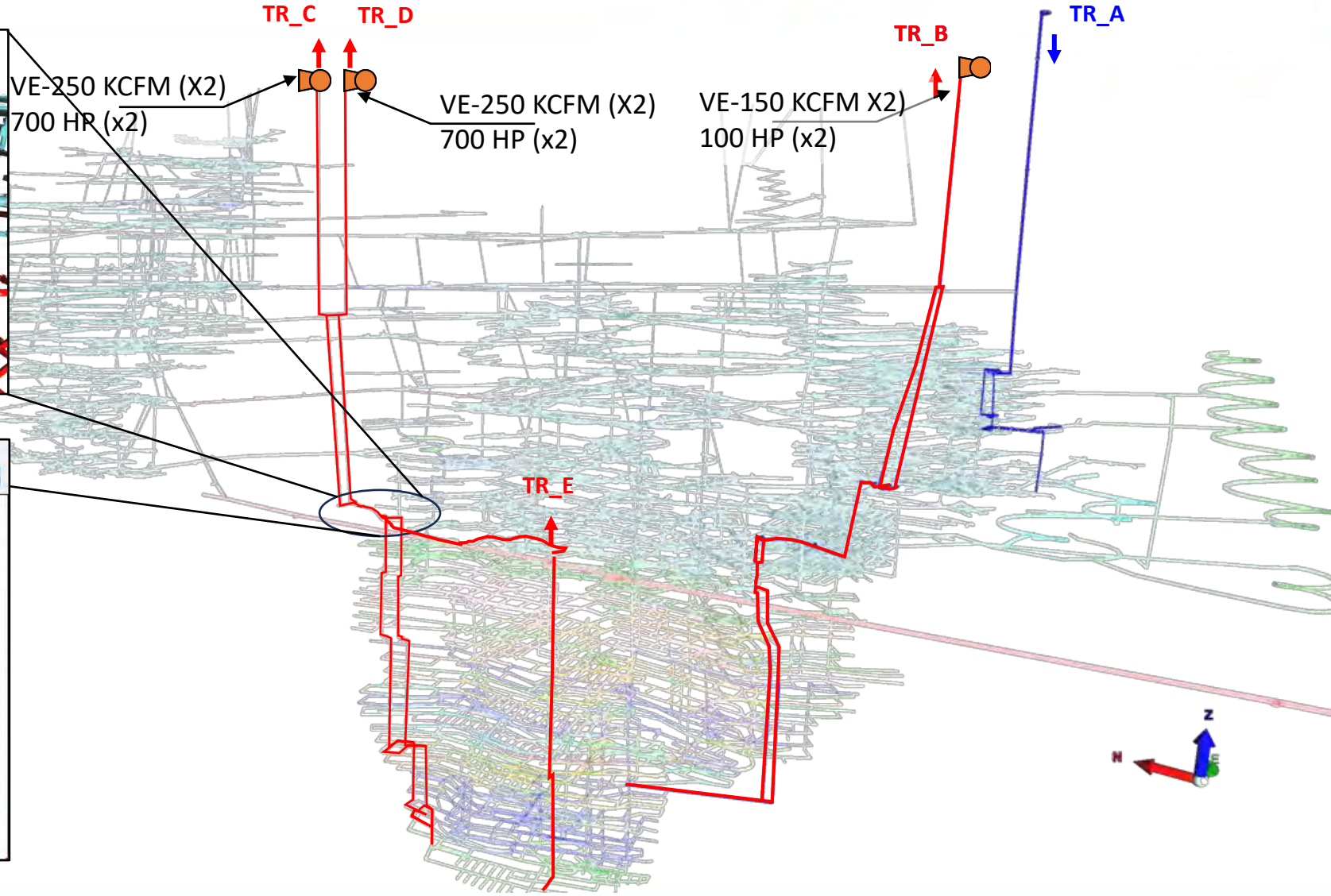
$$P \ \& \ Q^3$$



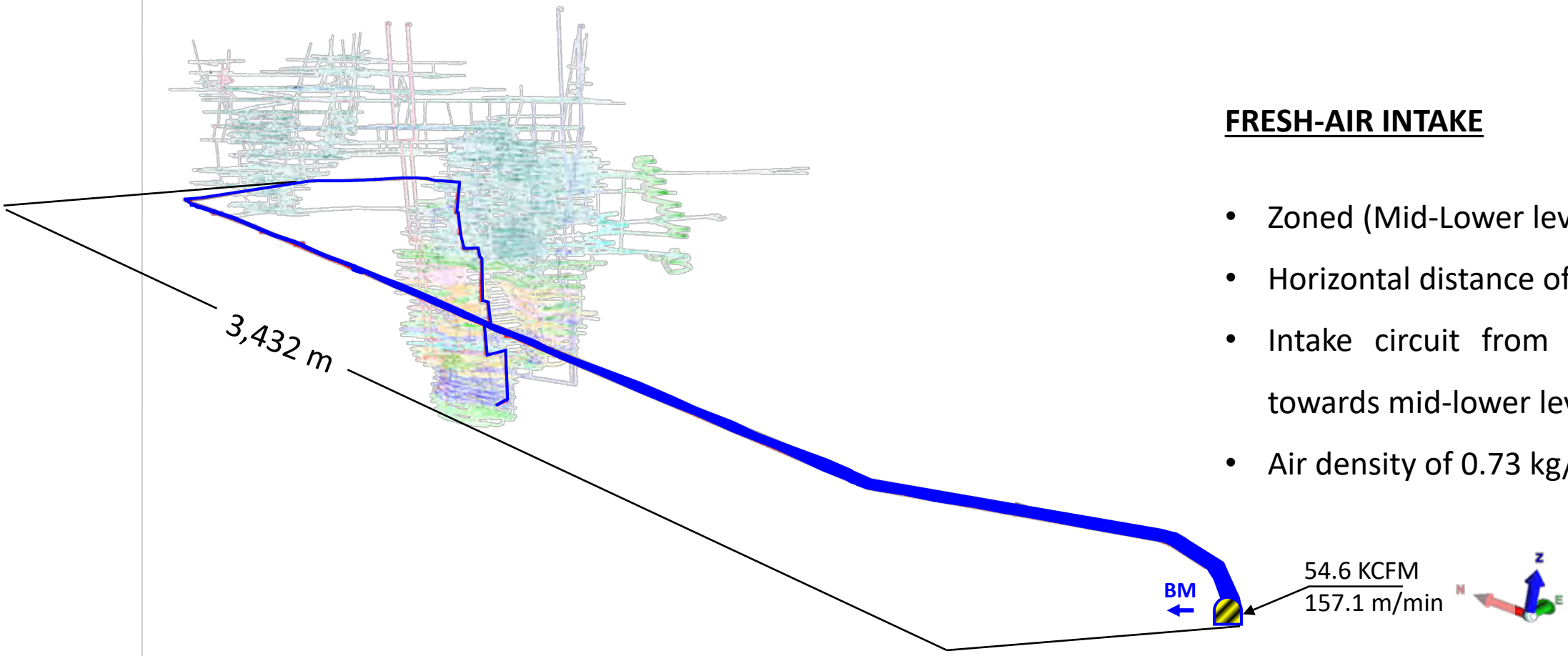
Opportunities for Improvement







Opportunities for Improvement



FRESH-AIR INTAKE

- Zoned (Mid-Lower levels).
- Horizontal distance of 3,432 m.
- Intake circuit from portal (BM) towards mid-lower levels.
- Air density of 0.73 kg/m3.

Main Fans' Operating Points

TR B – TR C – TR D

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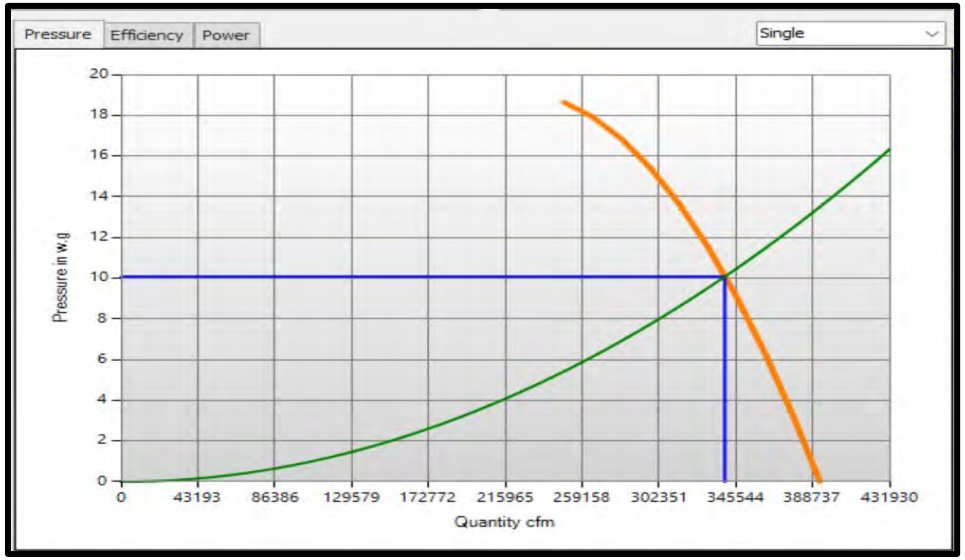
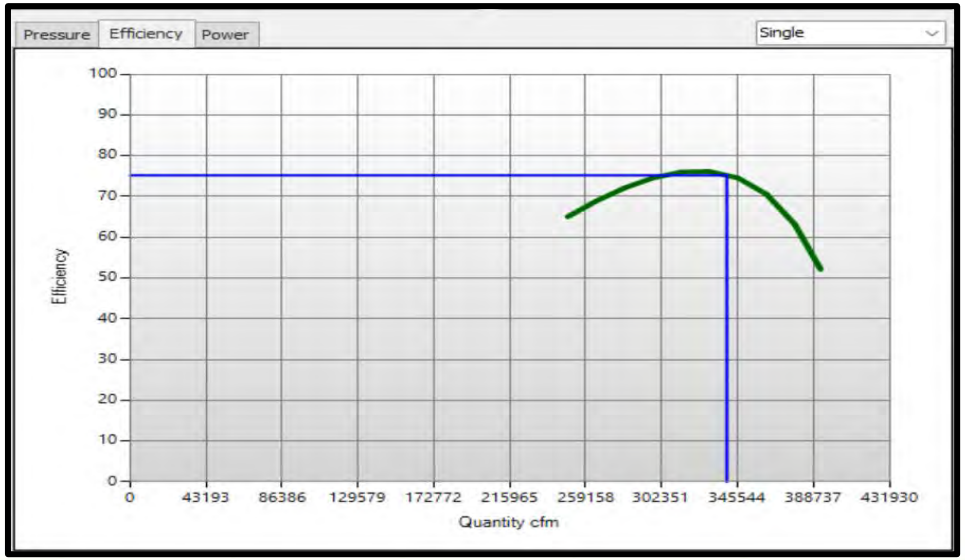
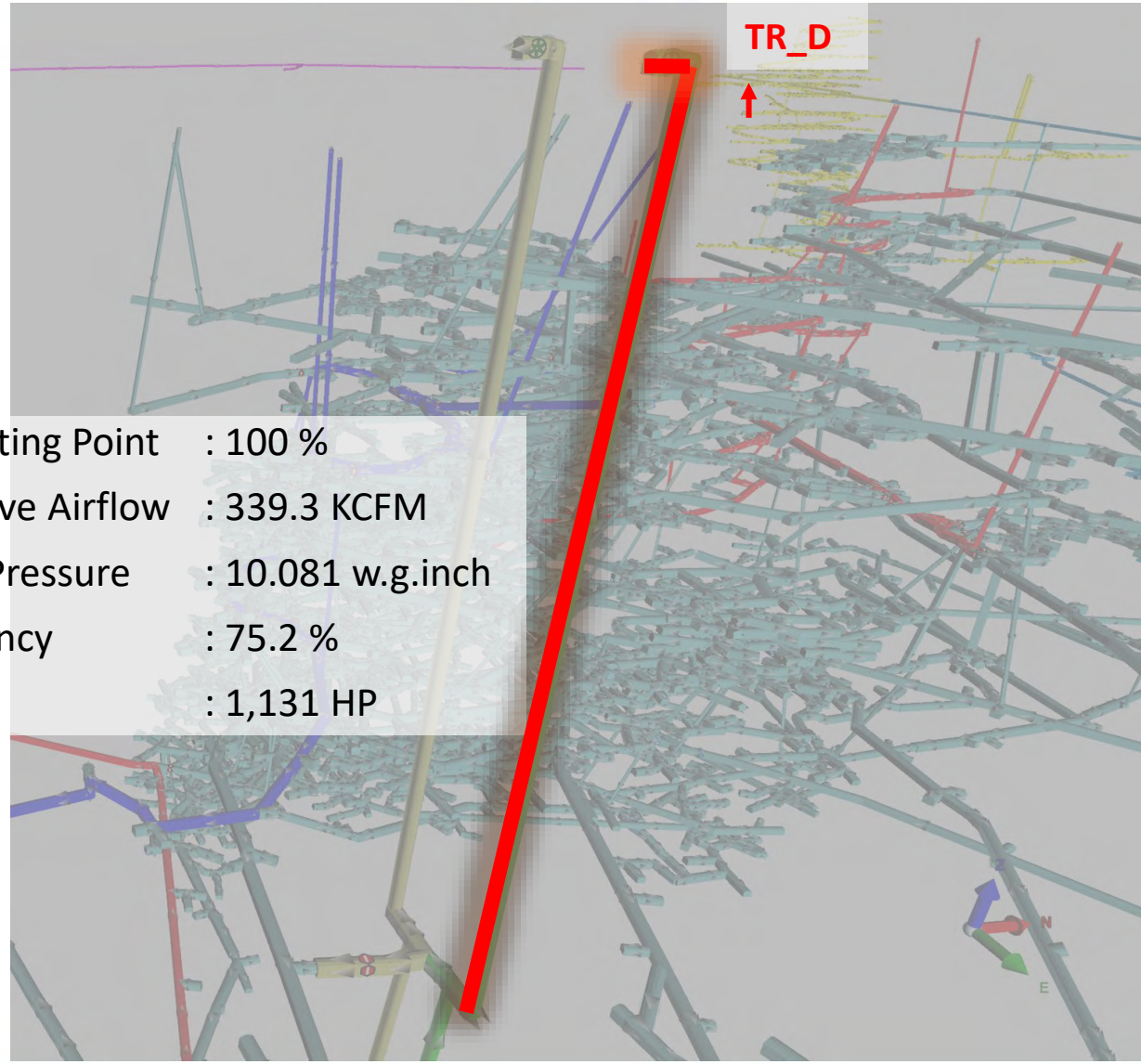
Fan curve – Prefeasibility (2032)

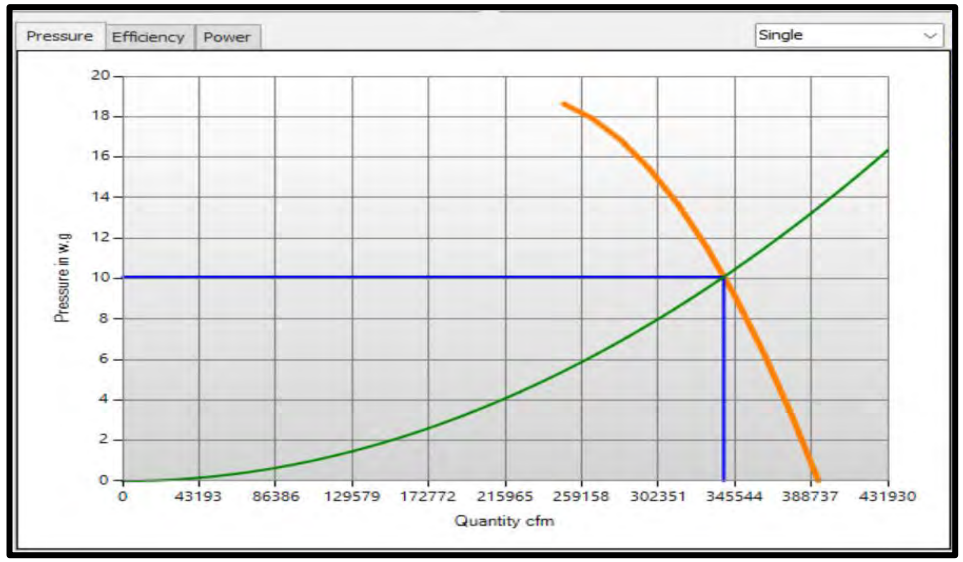


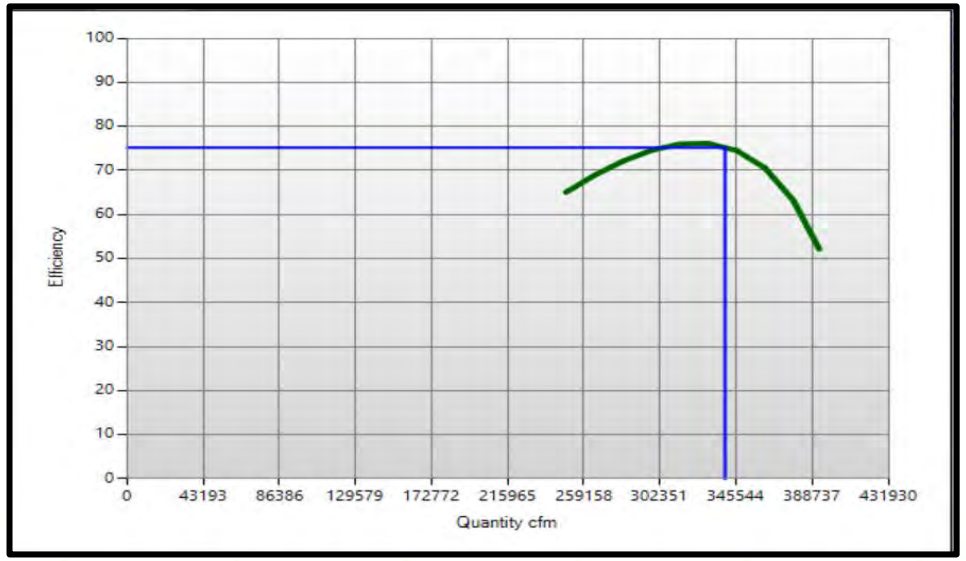


- Operating Point : 100 %
- Effective Airflow : 339.3 KCFM
- Total Pressure : 10.081 w.g.inch
- Efficiency : 75.2 %
- Power : 1,131 HP

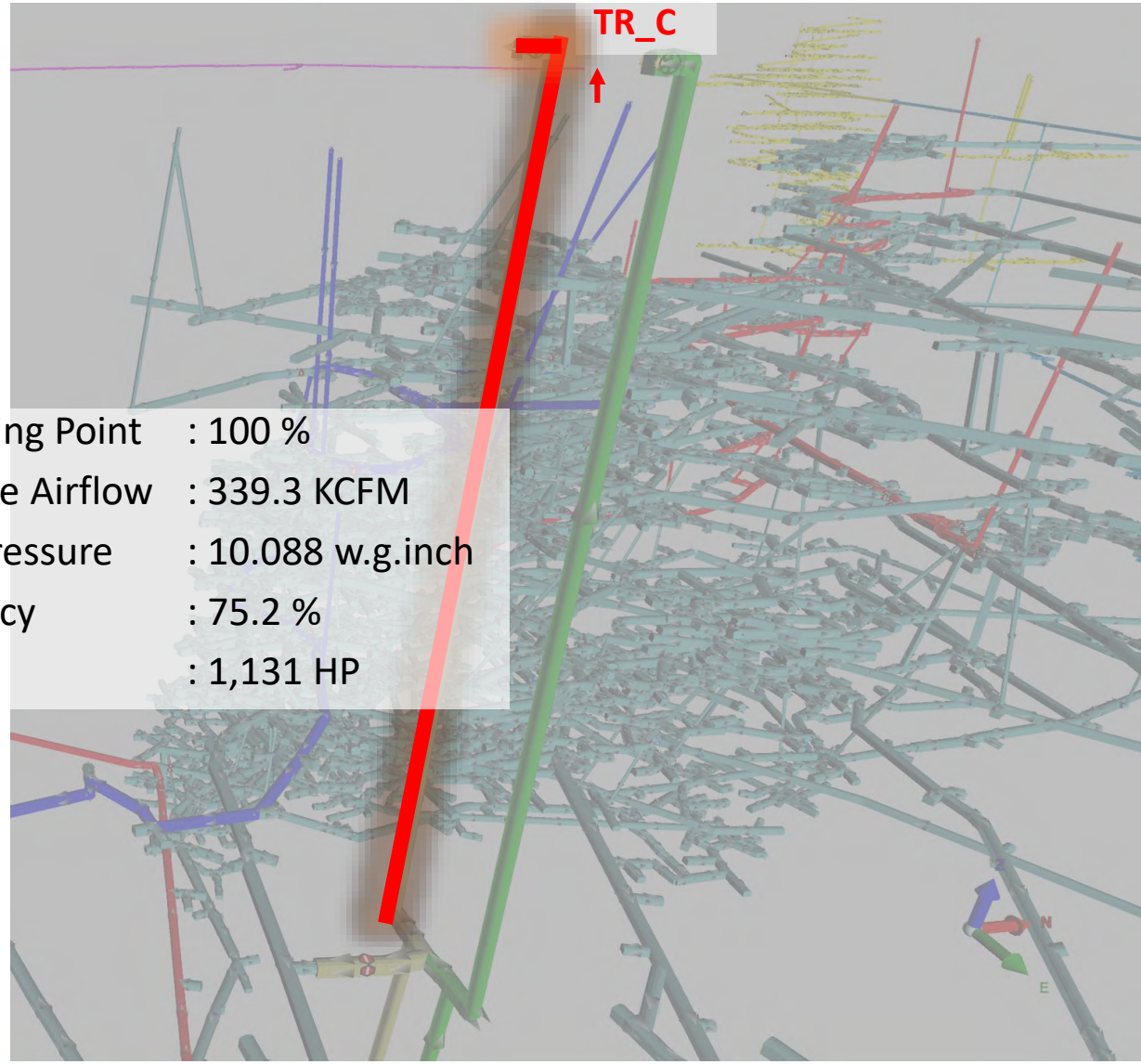


Fan curve – Prefeasibility (2032)

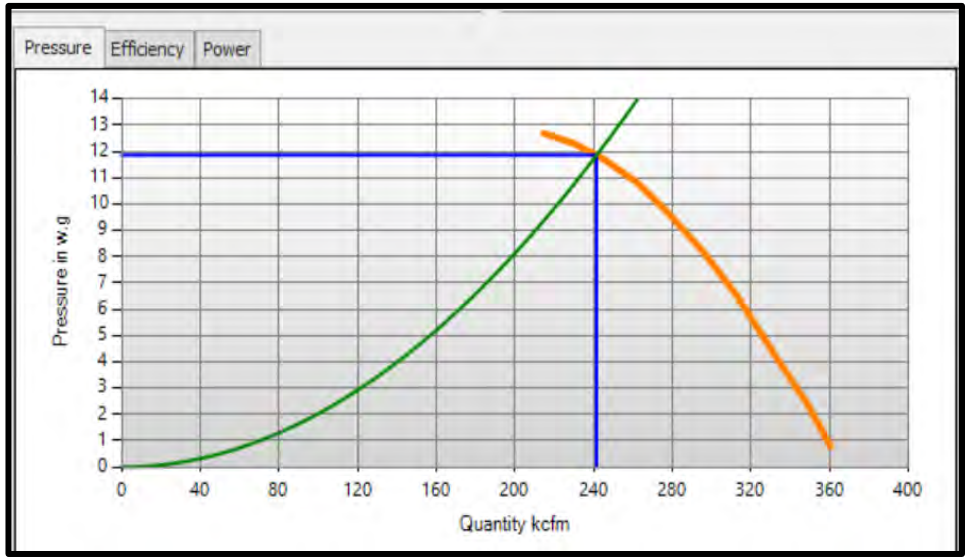


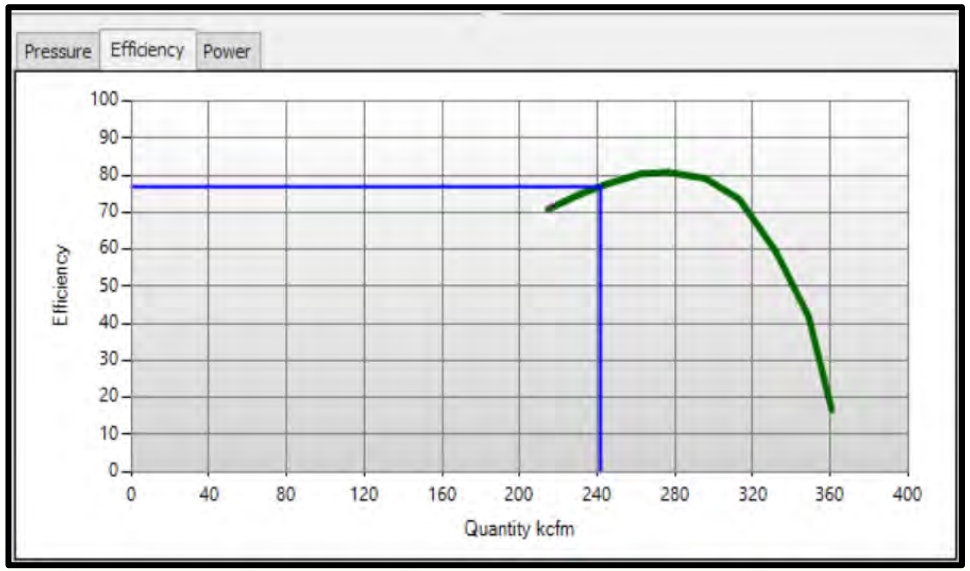


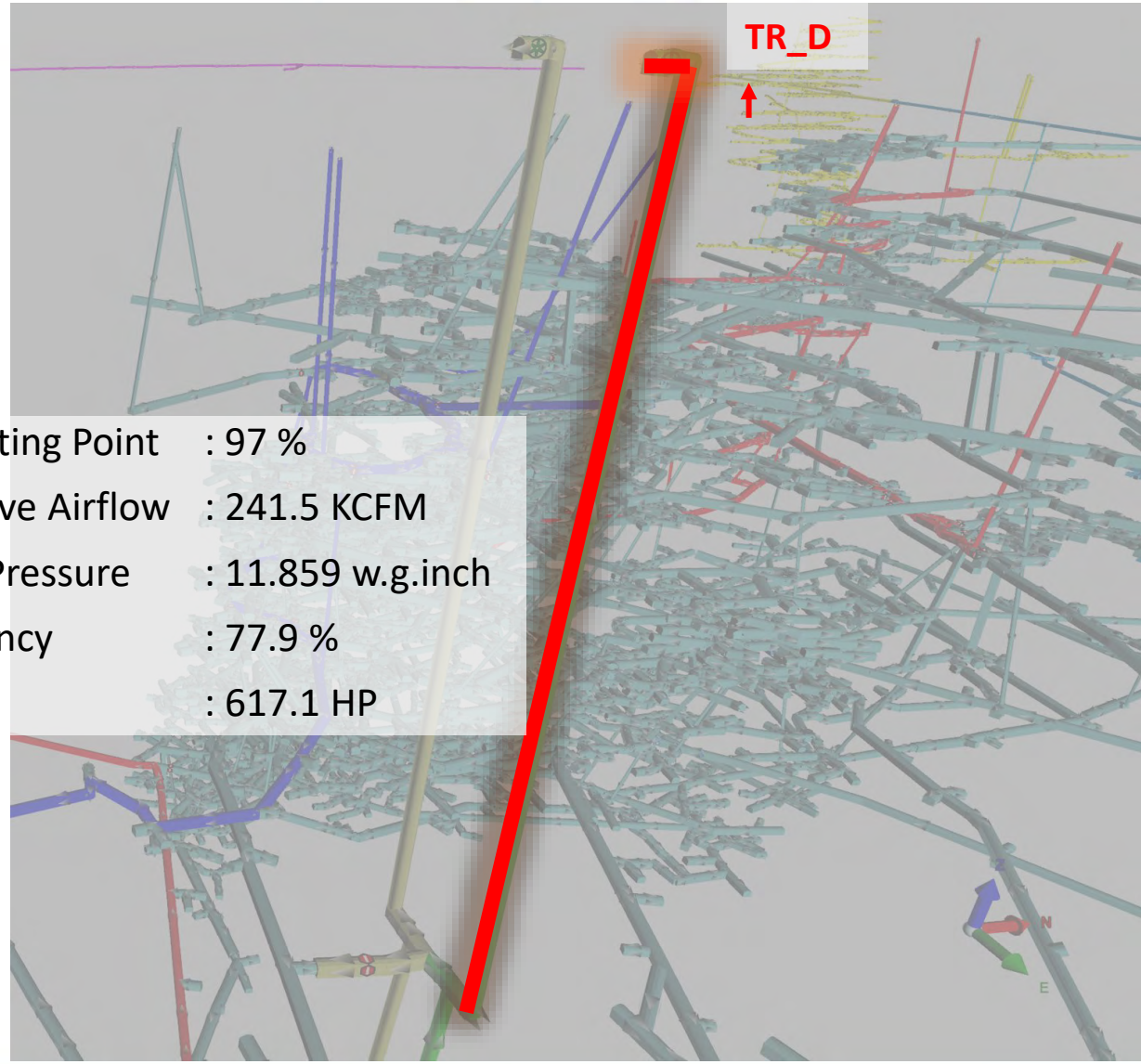
- Operating Point : 100 %
- Effective Airflow : 339.3 KCFM
- Total Pressure : 10.088 w.g.inch
- Efficiency : 75.2 %
- Power : 1,131 HP



Fan curve – Feasibility (2032)

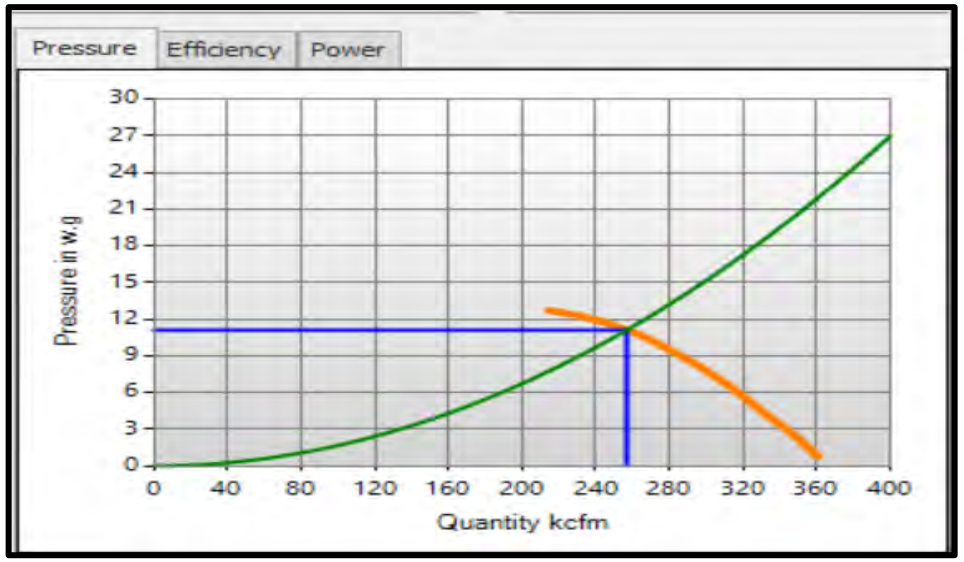


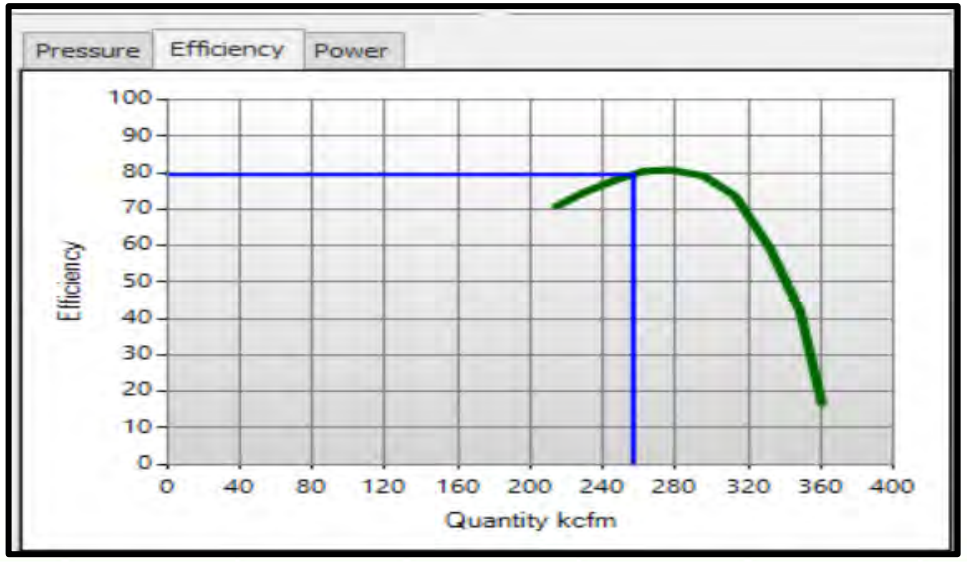




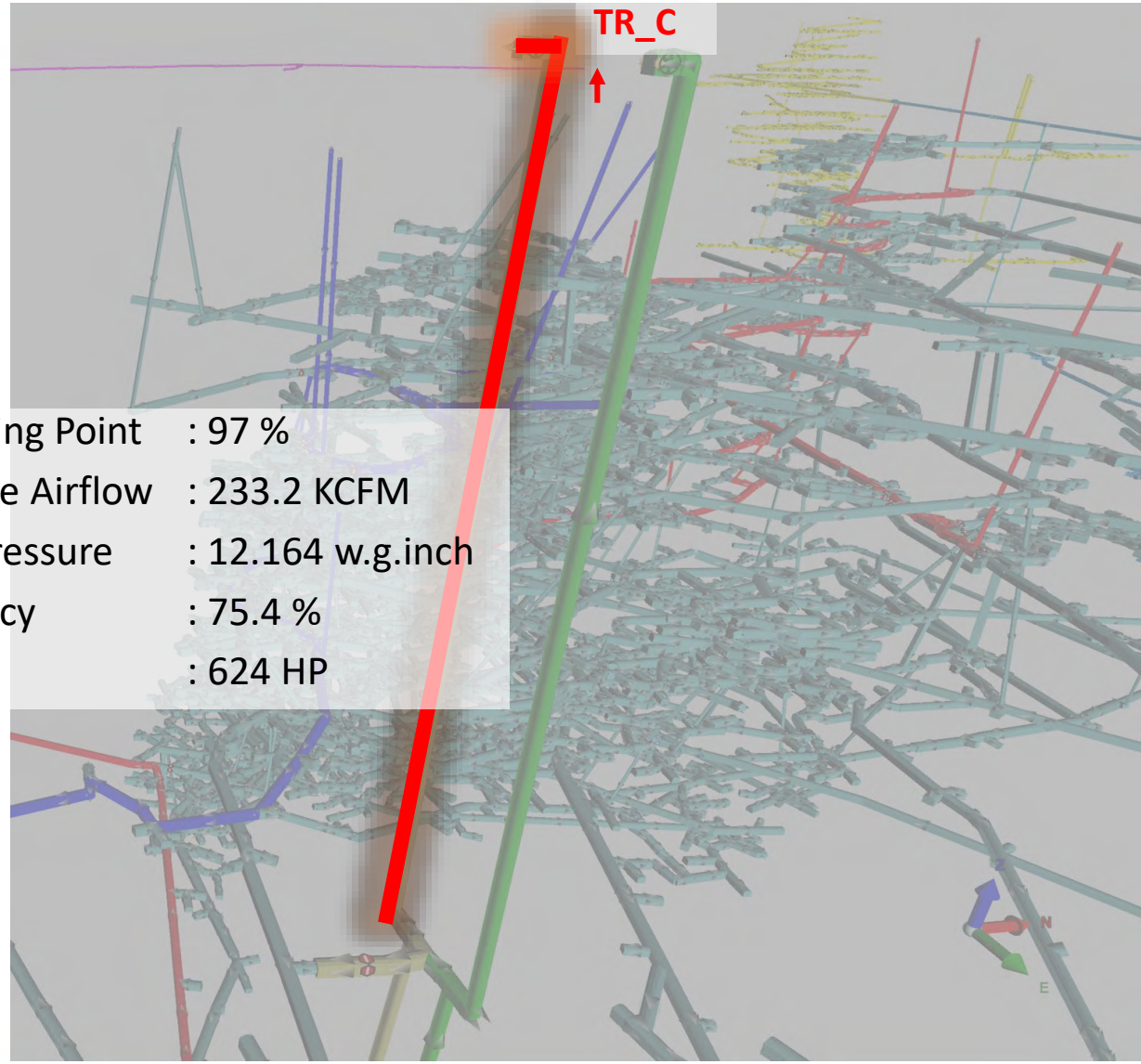
- Operating Point : 97 %
- Effective Airflow : 241.5 KCFM
- Total Pressure : 11.859 w.g.inch
- Efficiency : 77.9 %
- Power : 617.1 HP

Fan curve – Feasibility (2026)

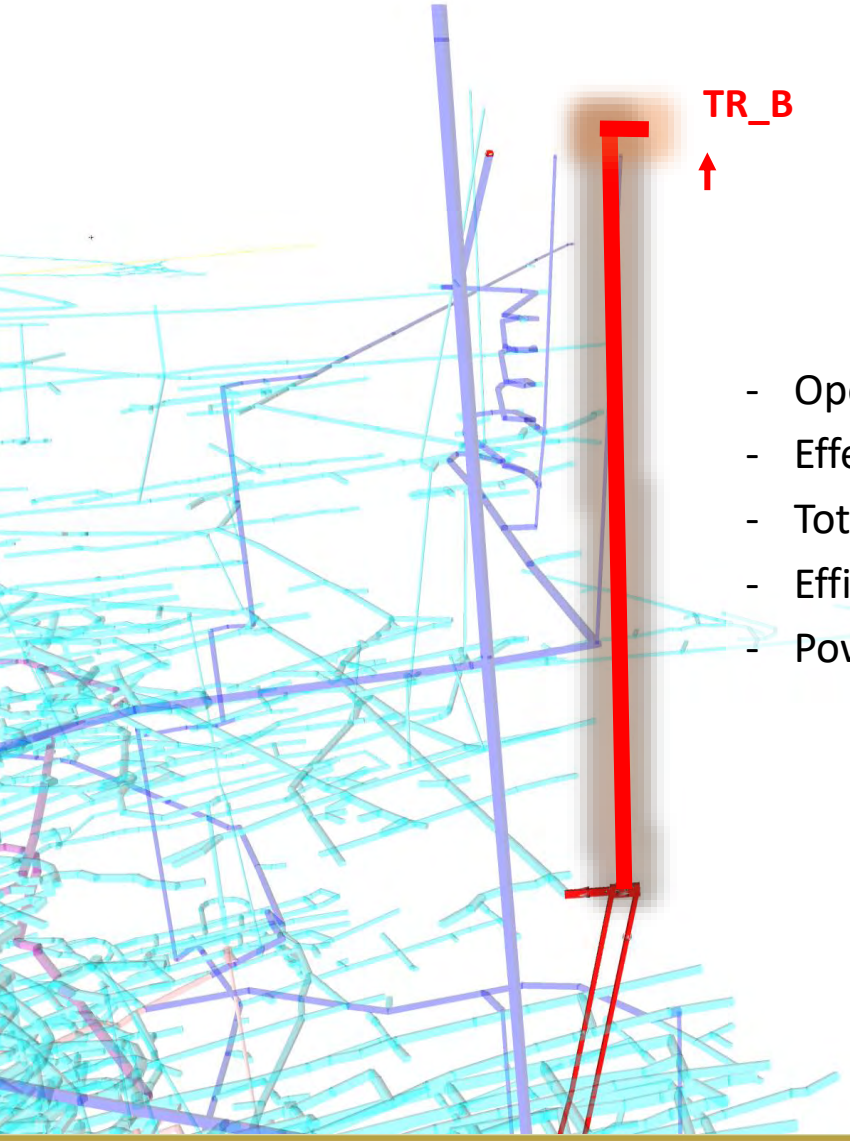




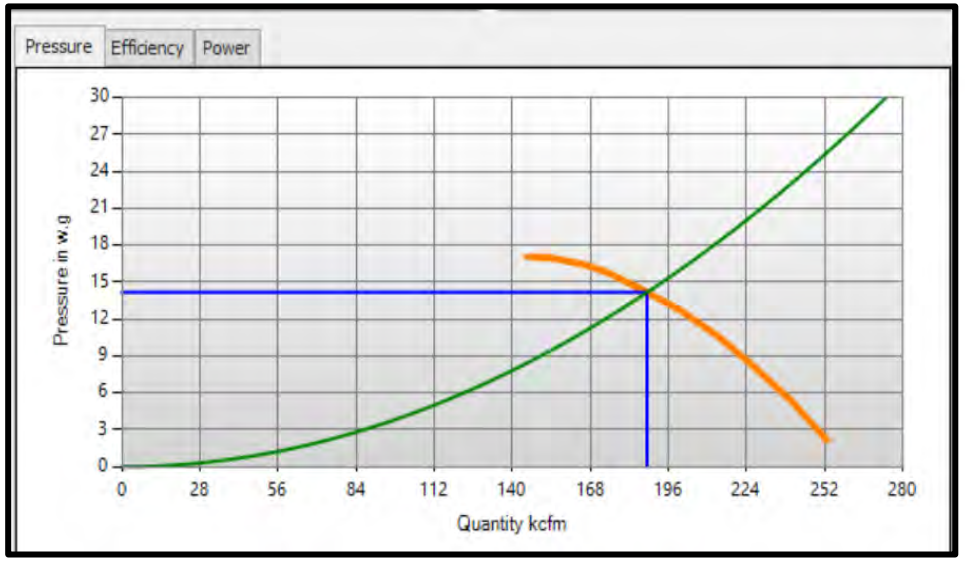
- Operating Point : 97 %
- Effective Airflow : 233.2 KCFM
- Total Pressure : 12.164 w.g.inch
- Efficiency : 75.4 %
- Power : 624 HP

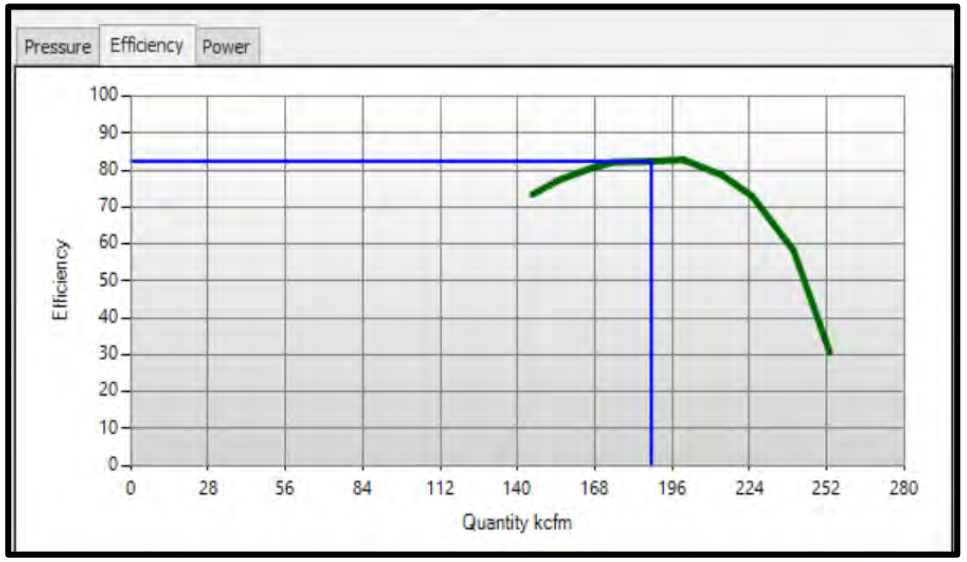


Fan curve – Feasibility (2026)



- Operating Point : 97 %
- Effective Airflow : 188.4 KCFM
- Total Pressure : 14.183 w.g.inch
- Efficiency : 82.5 %
- Power : 536.6 HP





Results

Prefeasibility Study - CAPEX	
Component / Activity	**Escalated value**
Ventilation Infrastructure	
Ventilation Circuit - TRONCAL TR 03	$ 6,097,892
Ventilation Circuit - TRONCAL TR 04	$ 6,258,108
Secondary ventilation System	$ 2,866,347
Power Distribution System	
Electric Substation + Distribution No. 01 (TR 03 + TR 04)	$ 7,852,259
Electric Substation + Distribution No. 02 (Secondary System)	$ 225,374
CAPEX PFS	**$ 23,299,979**

Feasibility Study - CAPEX	
Component/ Activity	**Escaleted Value**
Ventilation Infrastructure	
Ventilation Circuit-TRONCAL TR 02	$ 1,699,152
Ventilation Circuit-TRONCAL TR 03	$ 1,791,015
Ventilation Circuit-TRONCAL TR 04	$ 1,783,941
Power Distribution System	
Electric Substation + Distribution N° 01 (TR 03 + TR 04)	$ 7,852,259
CAPEX FS	**$ 13,126,367**

Prefeasibility Study - OPEX	
Component / Activity	**Escalated value**
Power Consumption	$ 22,320,716
NPV OPEX	**$ 11,201,248**

Feasibility Study - OPEX	
Component / Activity	**Escalated value**
Power Consumption	$ 12,928,244
NPV OPEX	**$ 6,554,564**

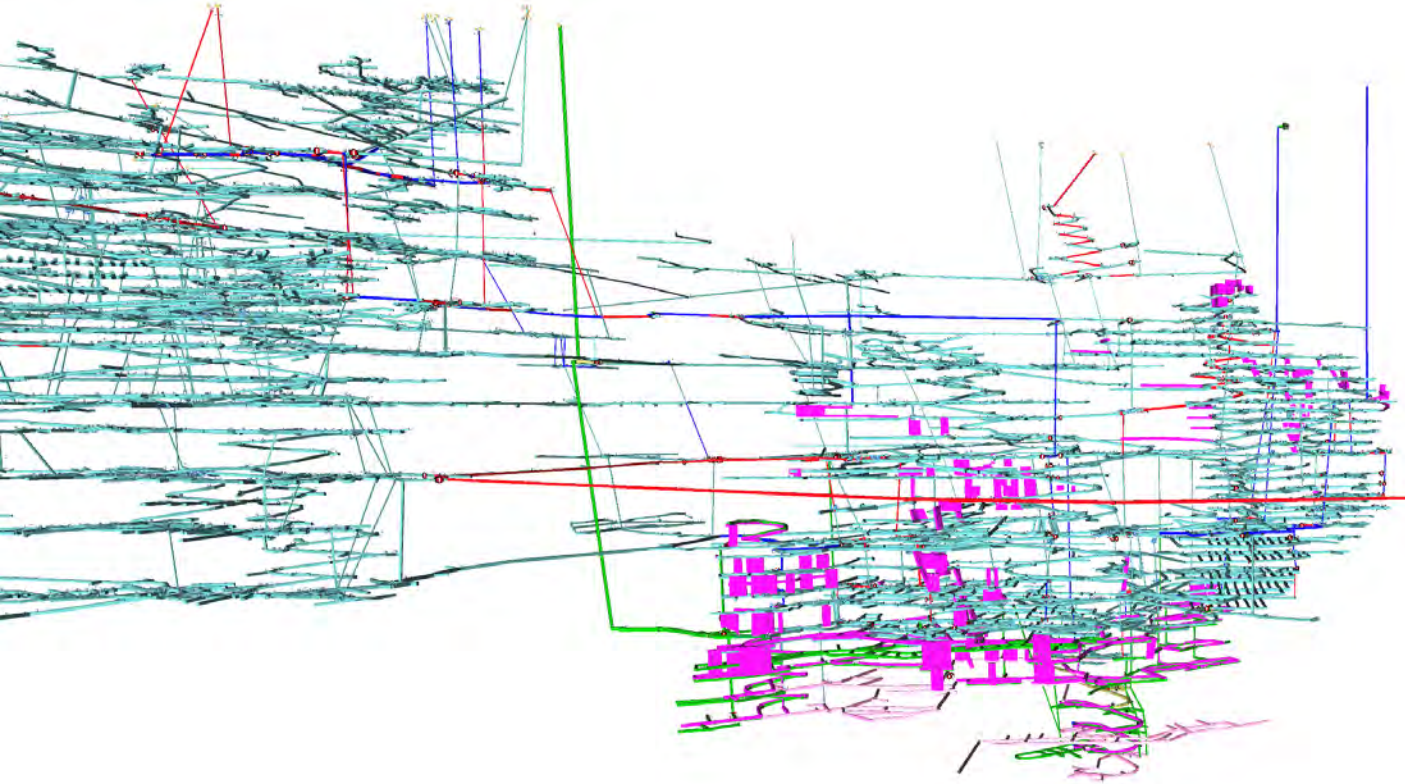
TIR: 12 % annual

CAPEX Savings : $ 10,173,612
OPEX Savings : $ 4,646,683
TOTAL Savings : $ 14,820,295

SIMULATION STAGE

Base Model + Calibration +
Operational Plans

Results – Simulation Stage



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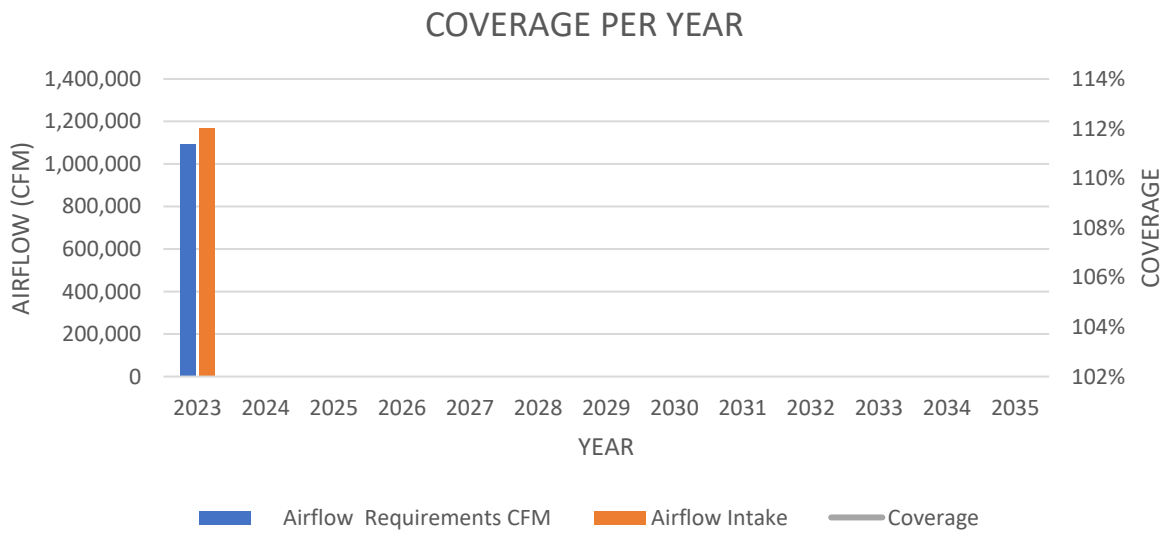
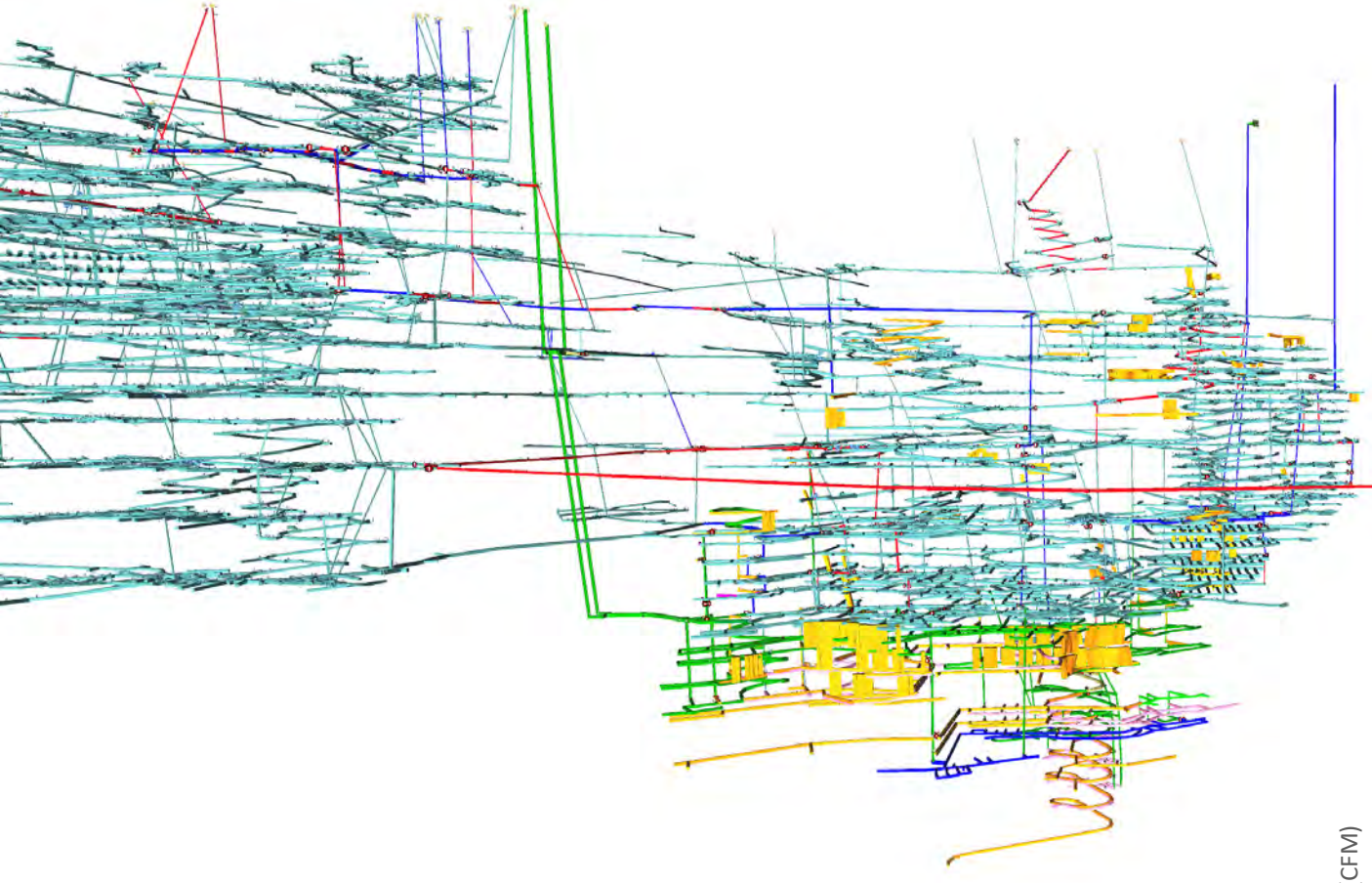


Results – Simulation Stage



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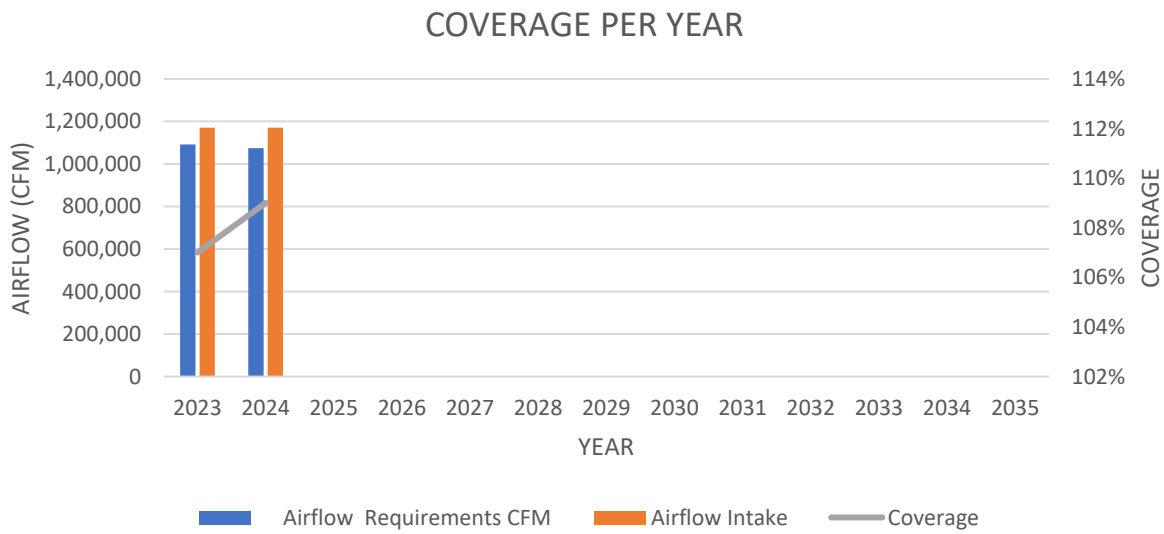

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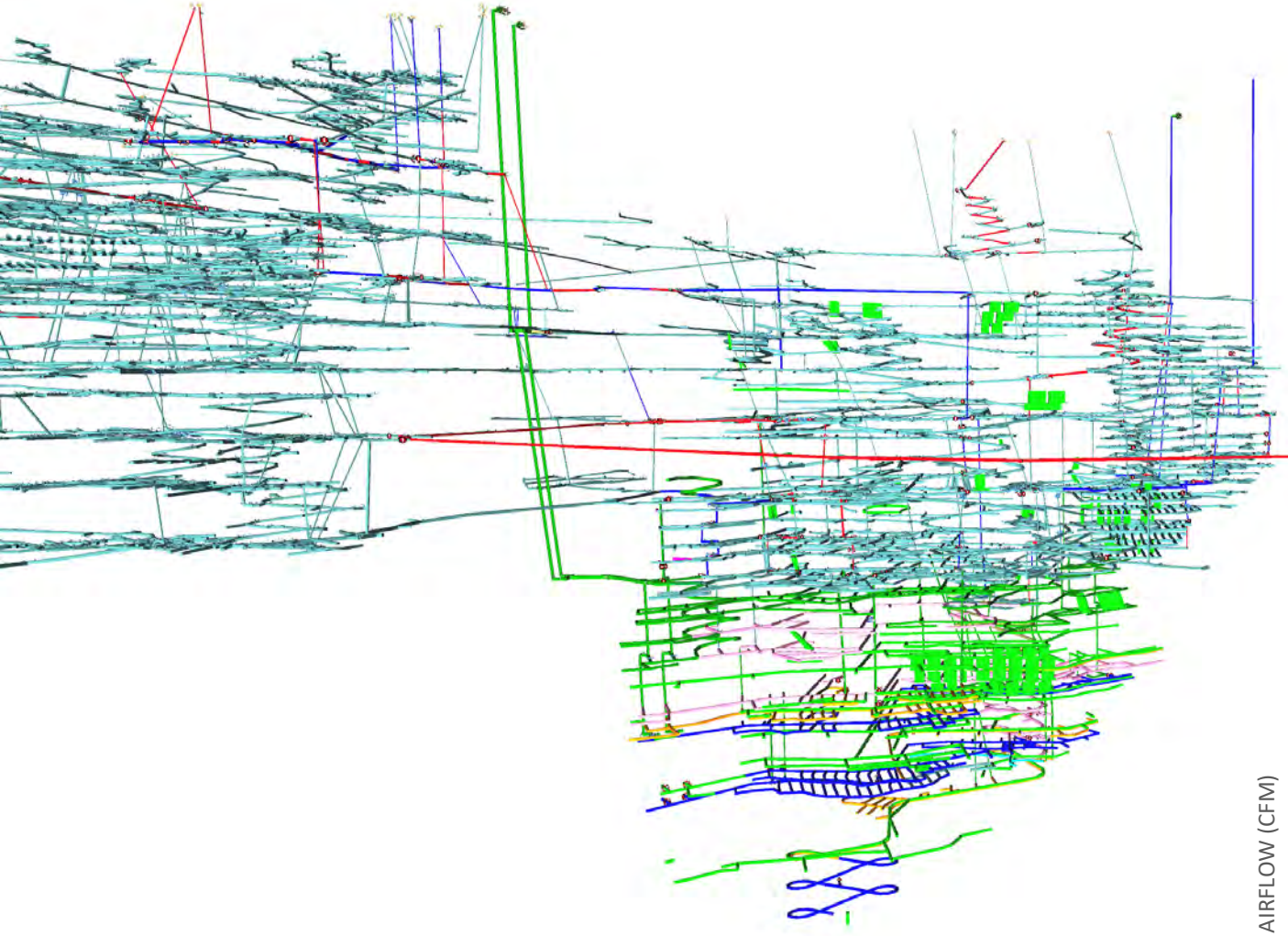

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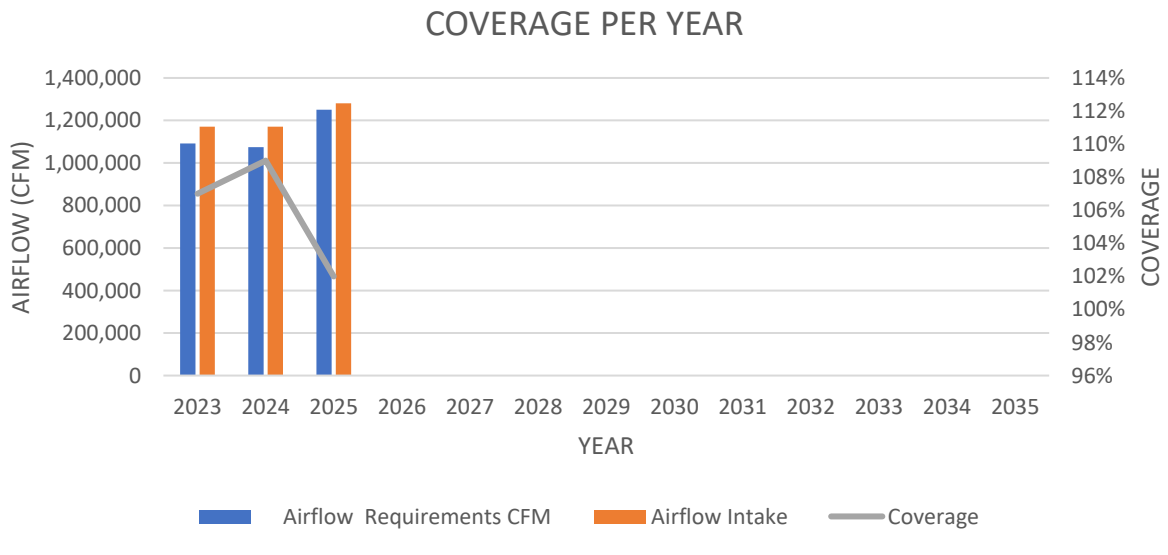

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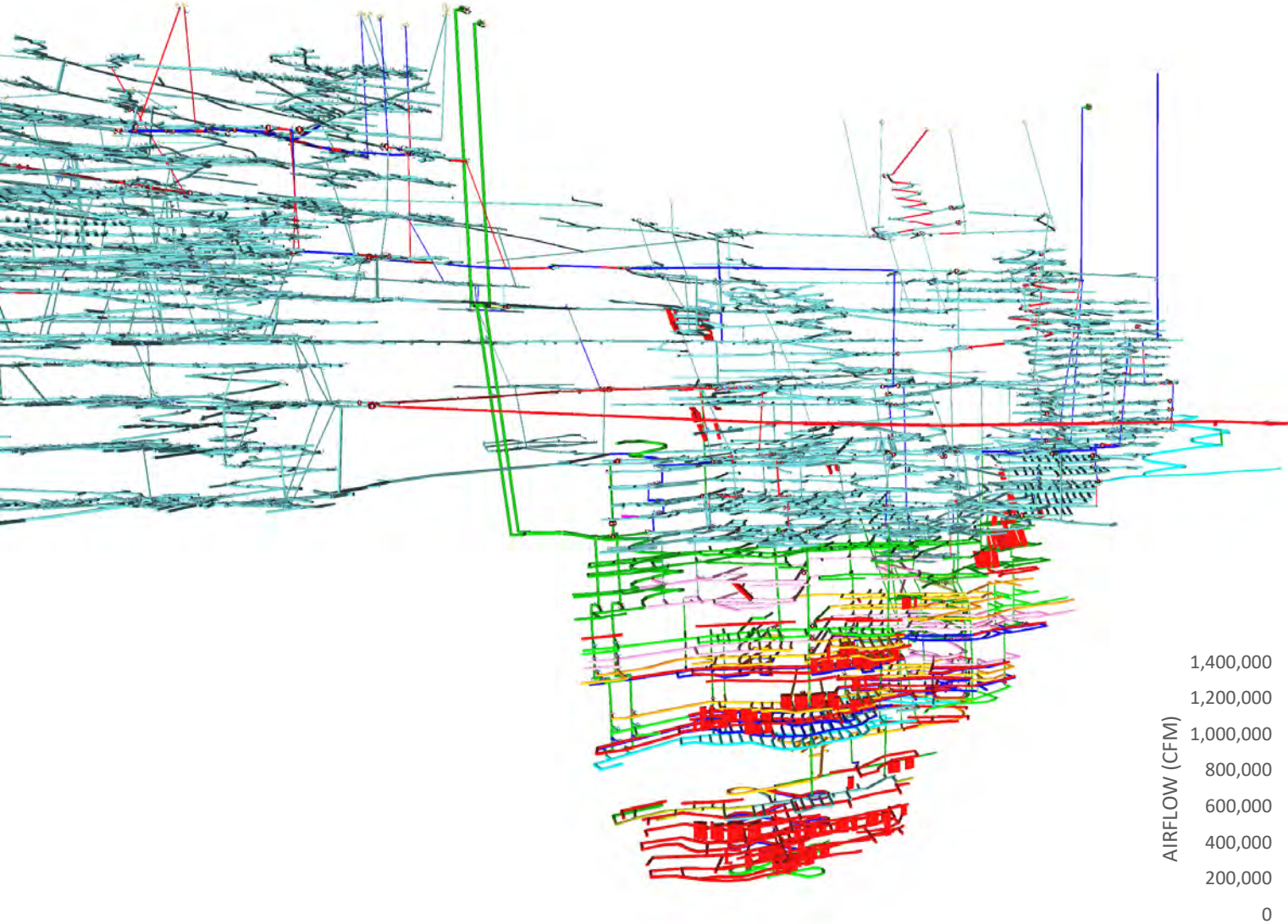

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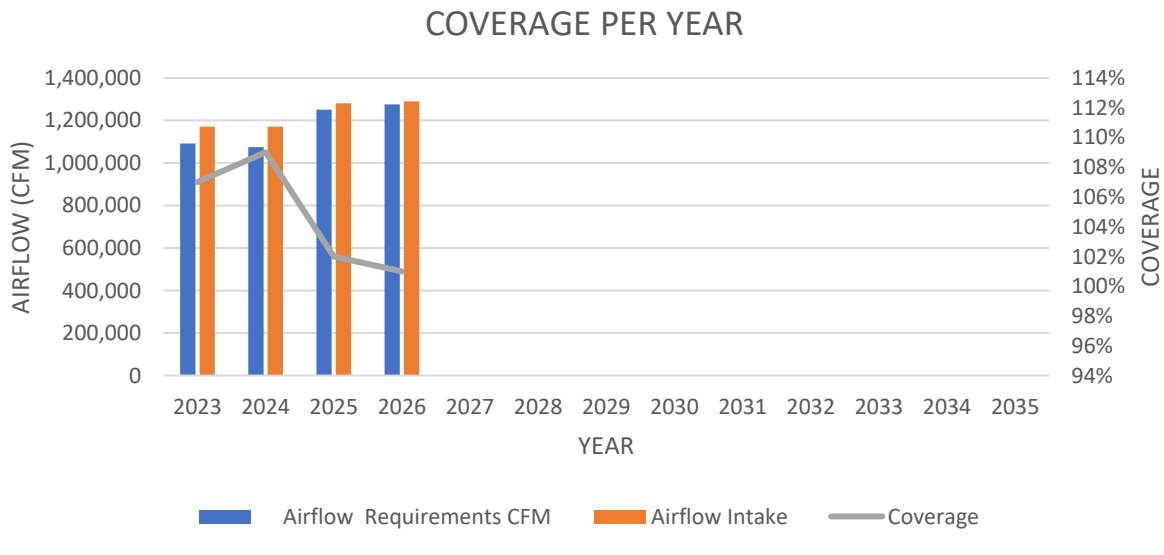

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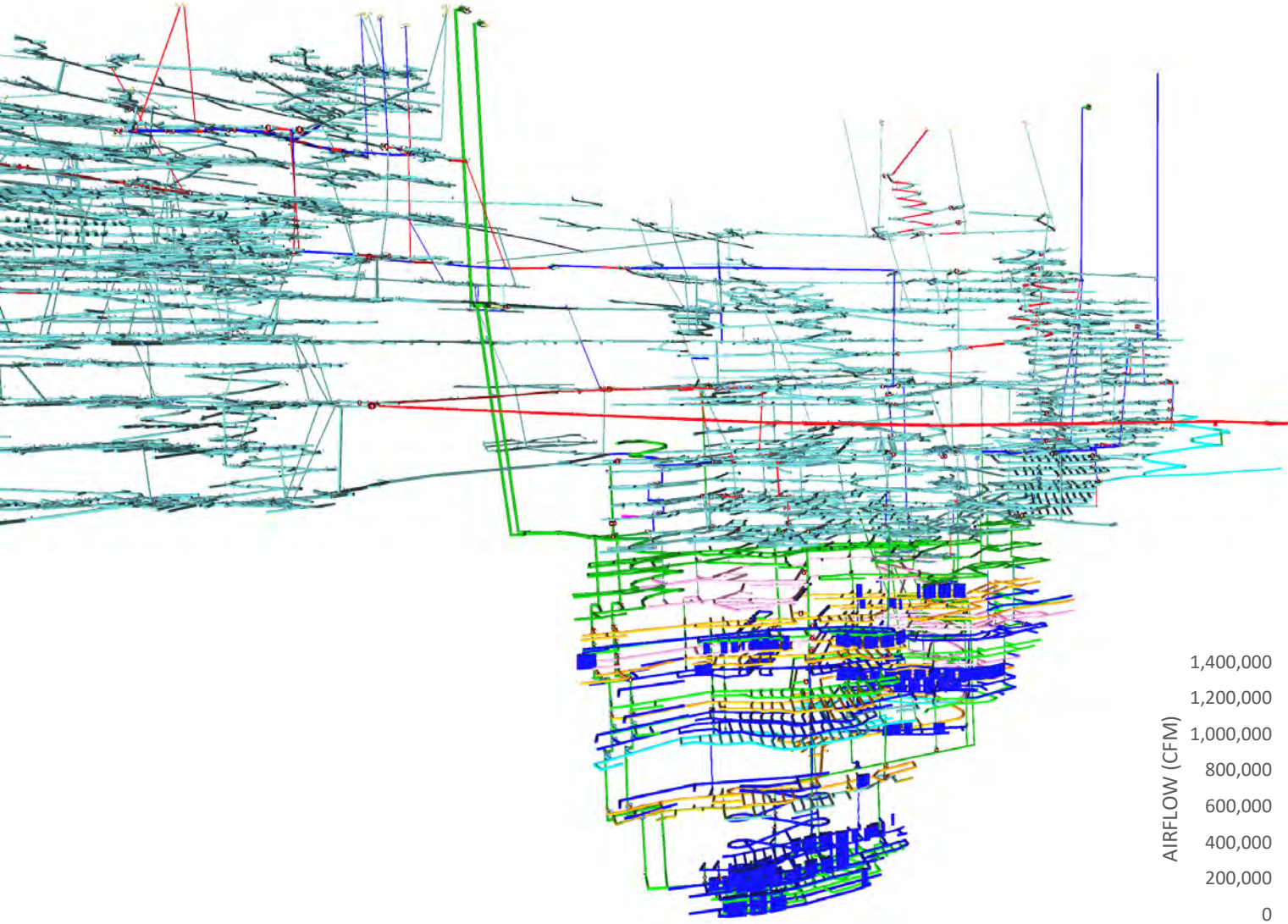

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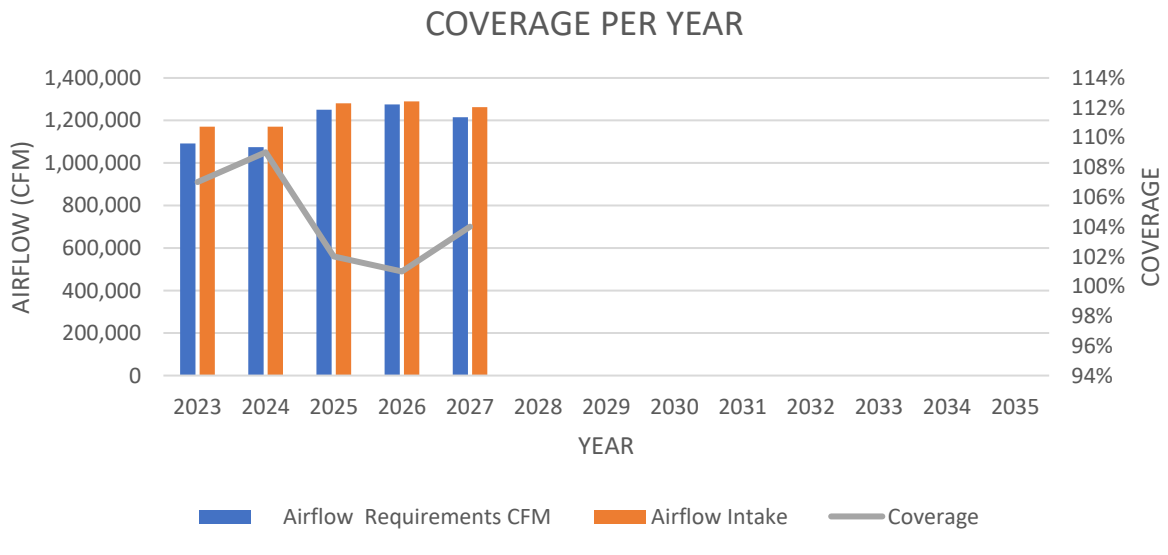

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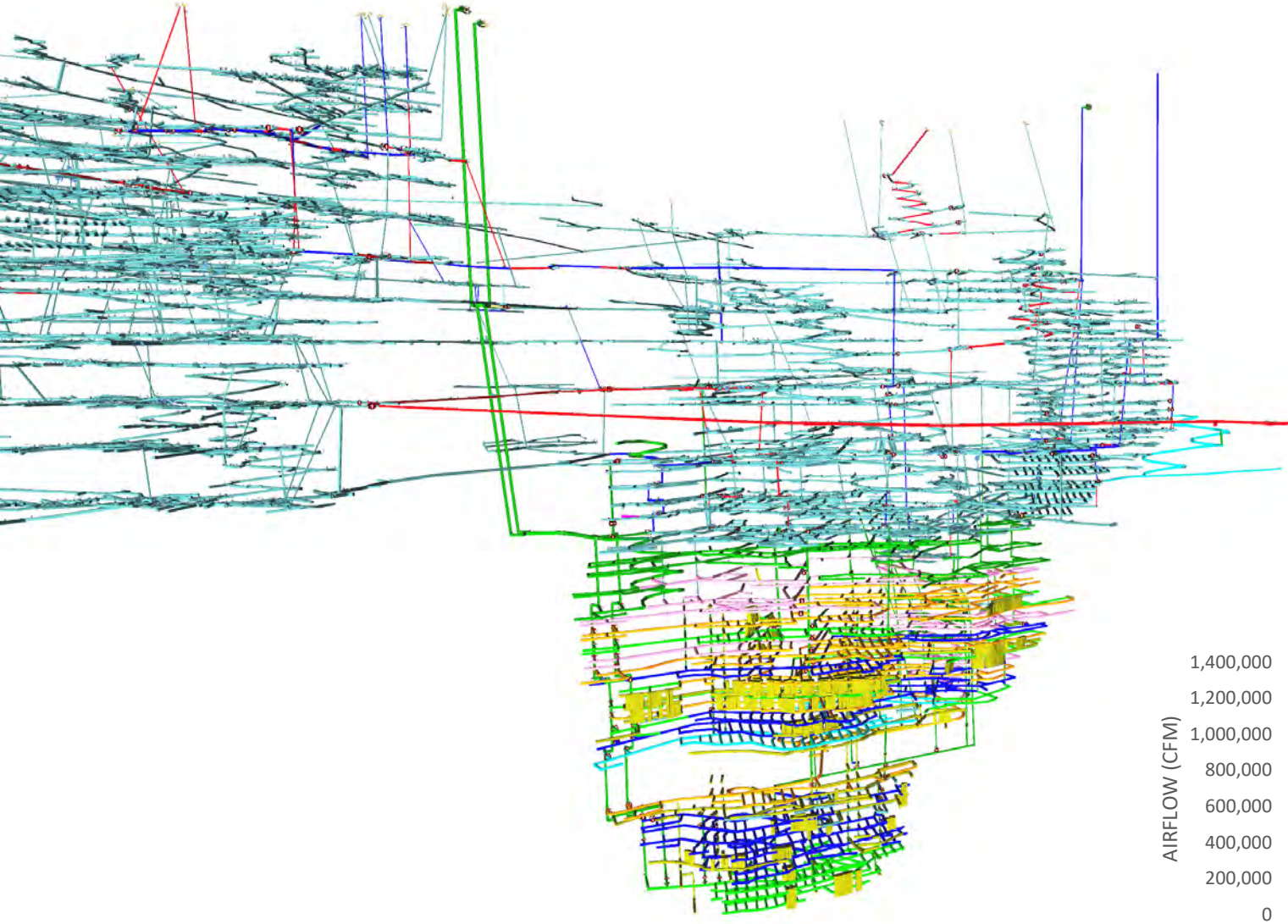

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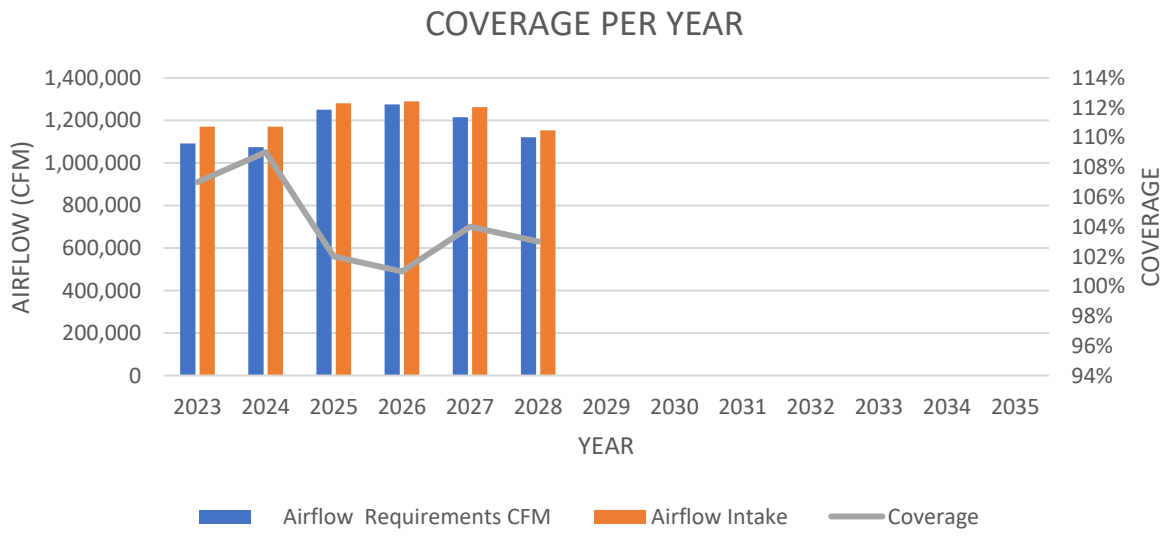

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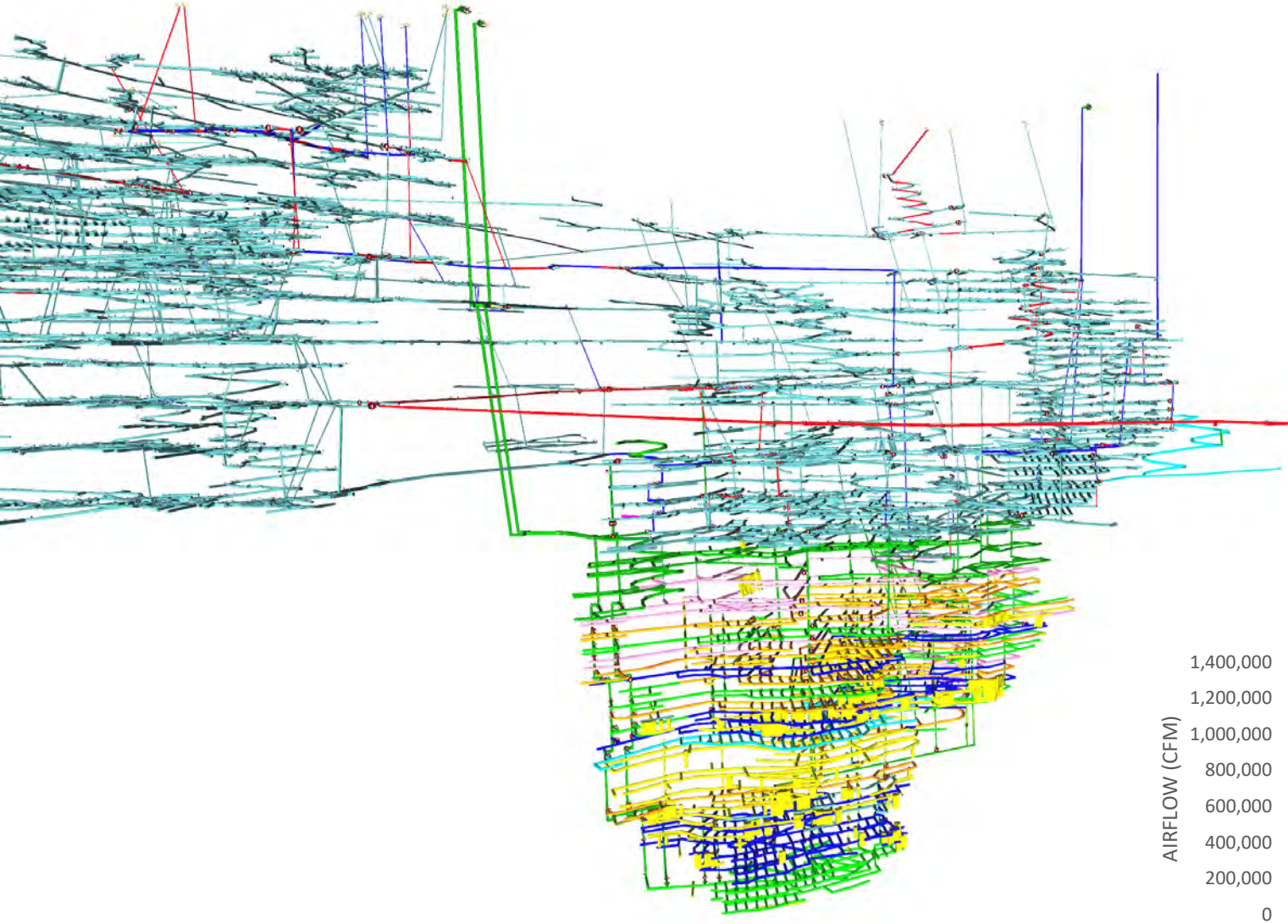

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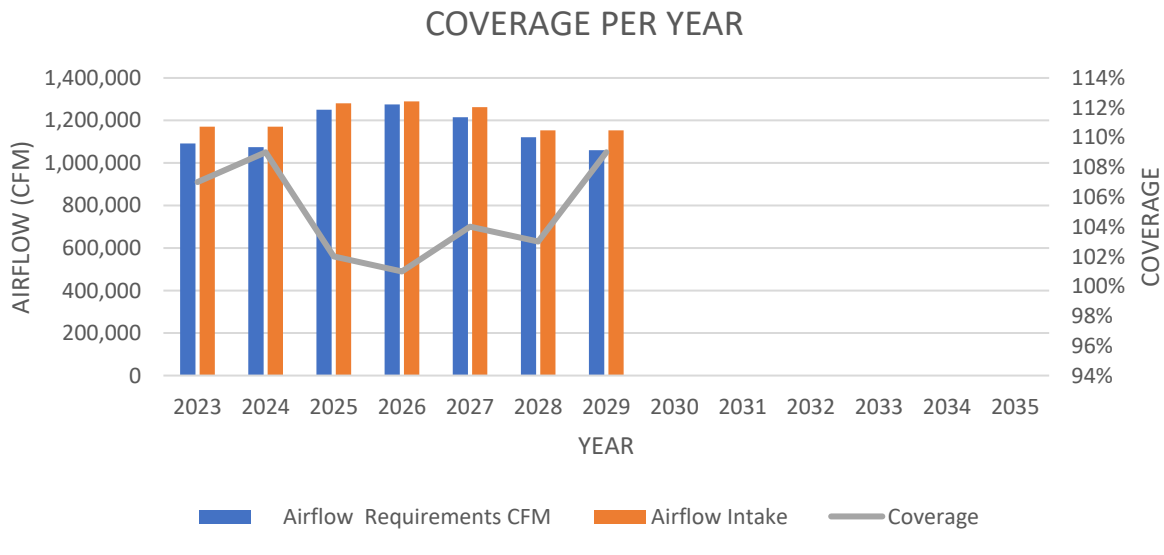

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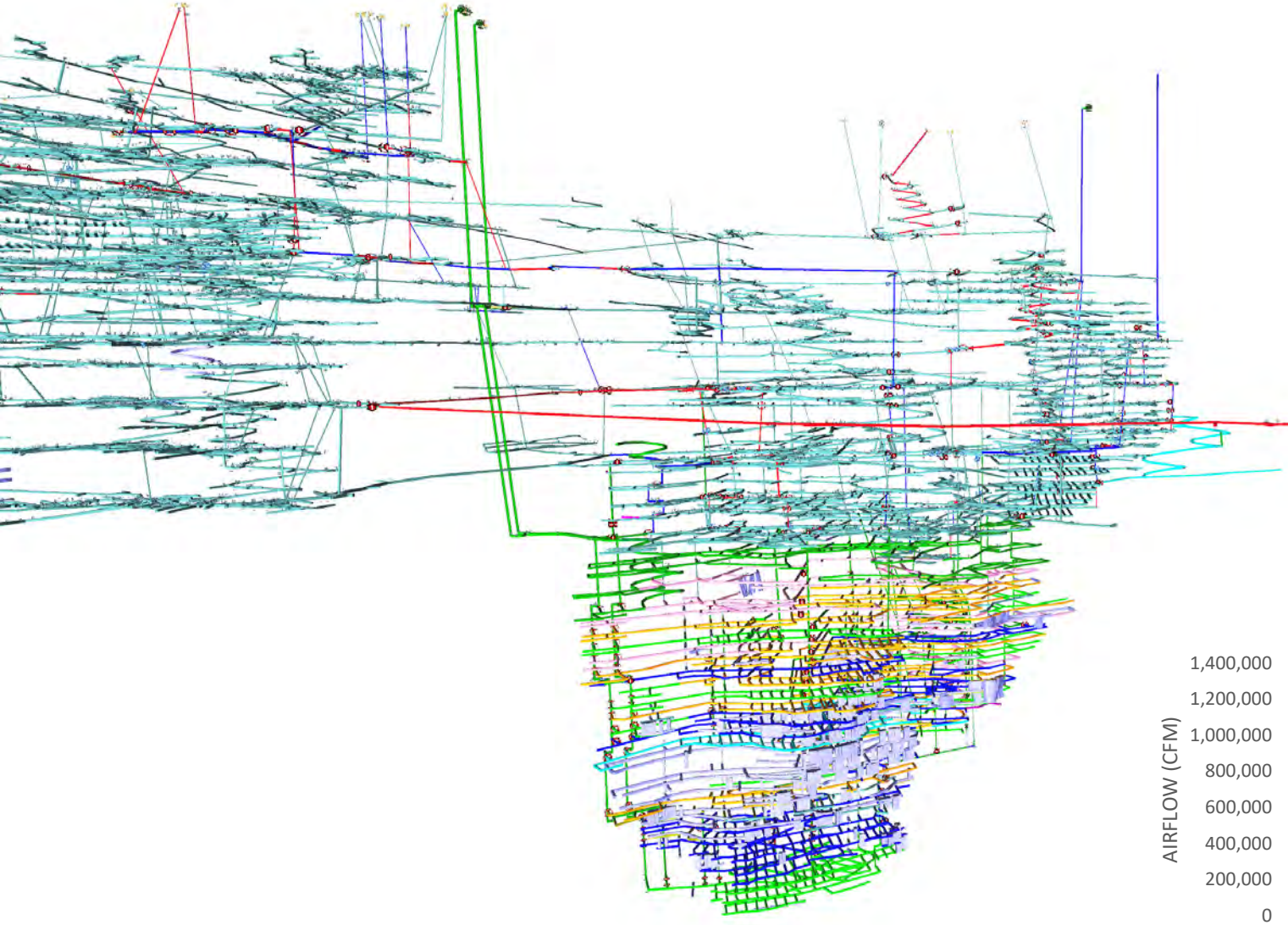

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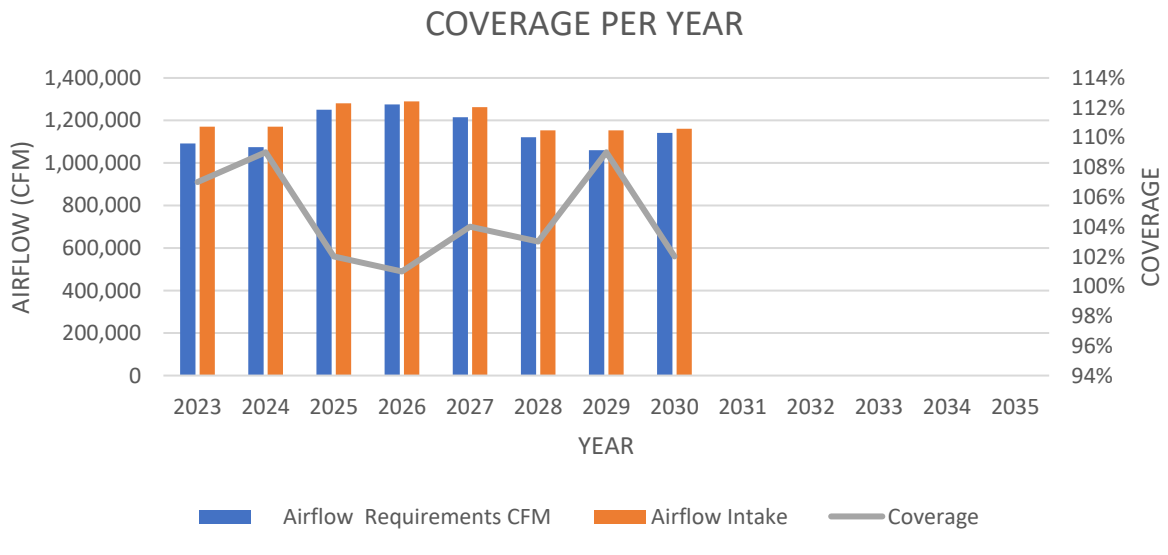

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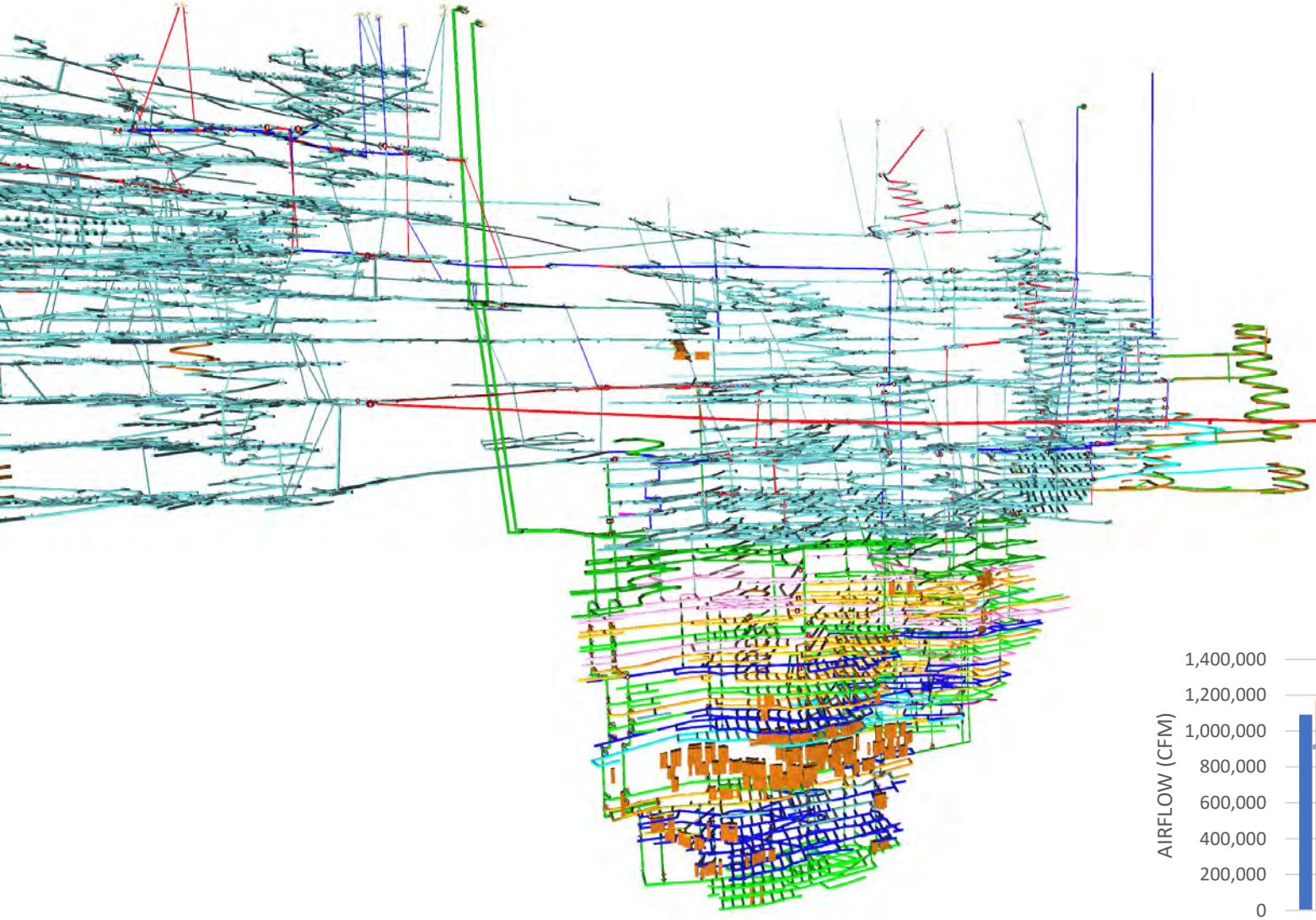

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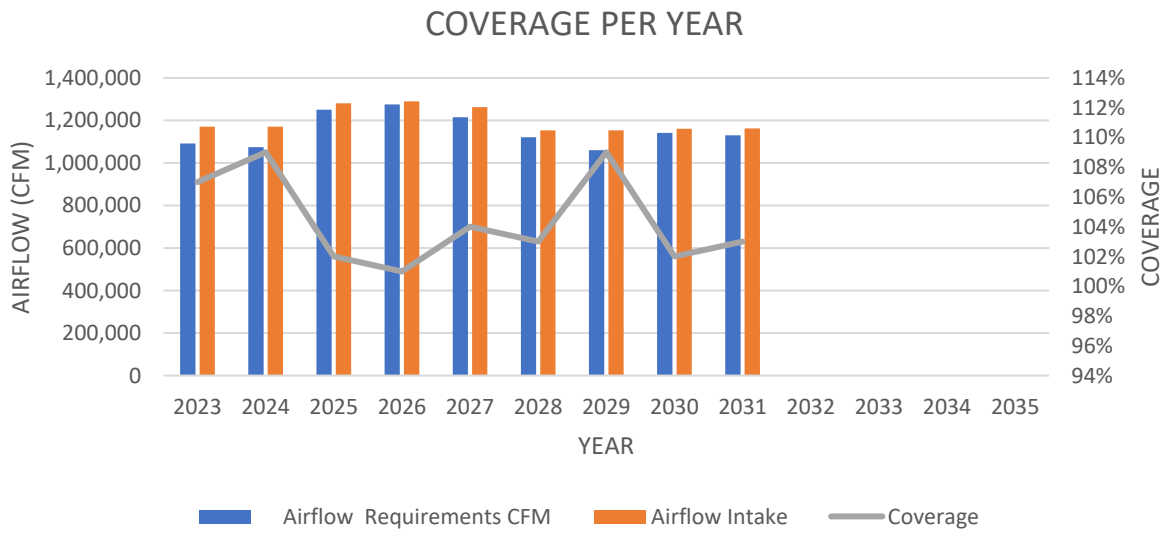

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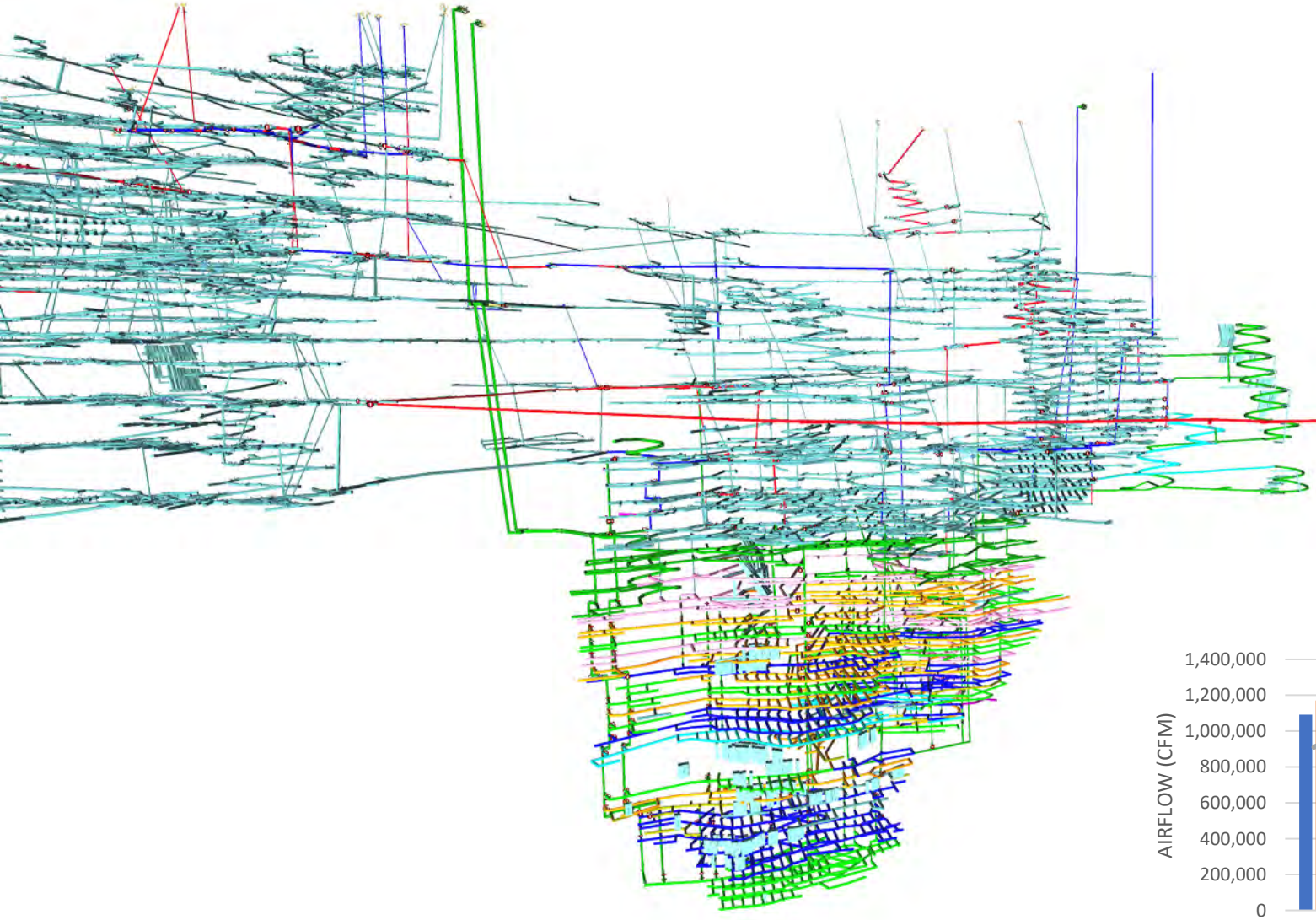

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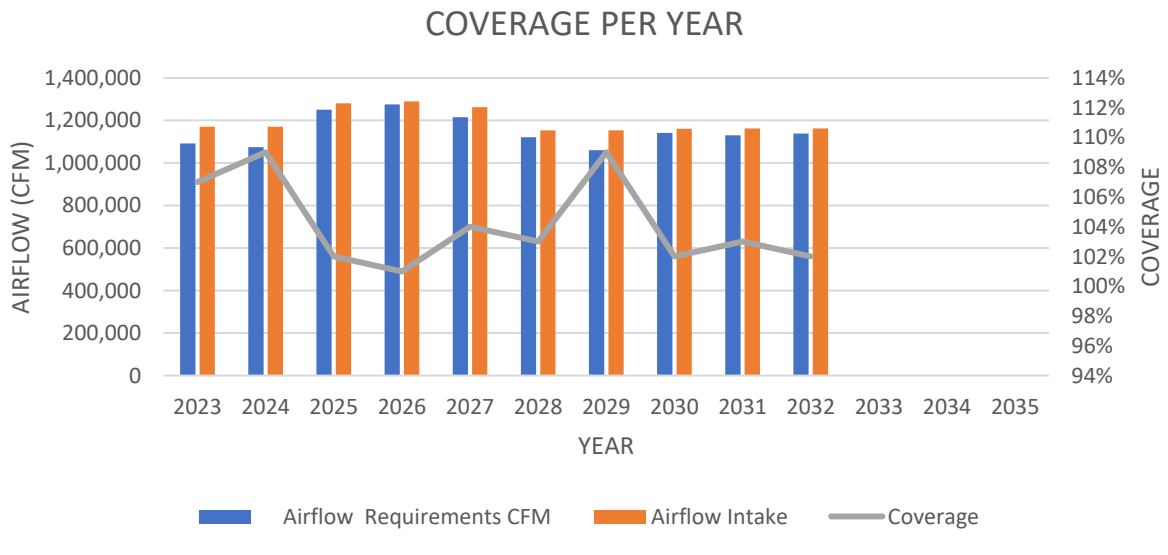

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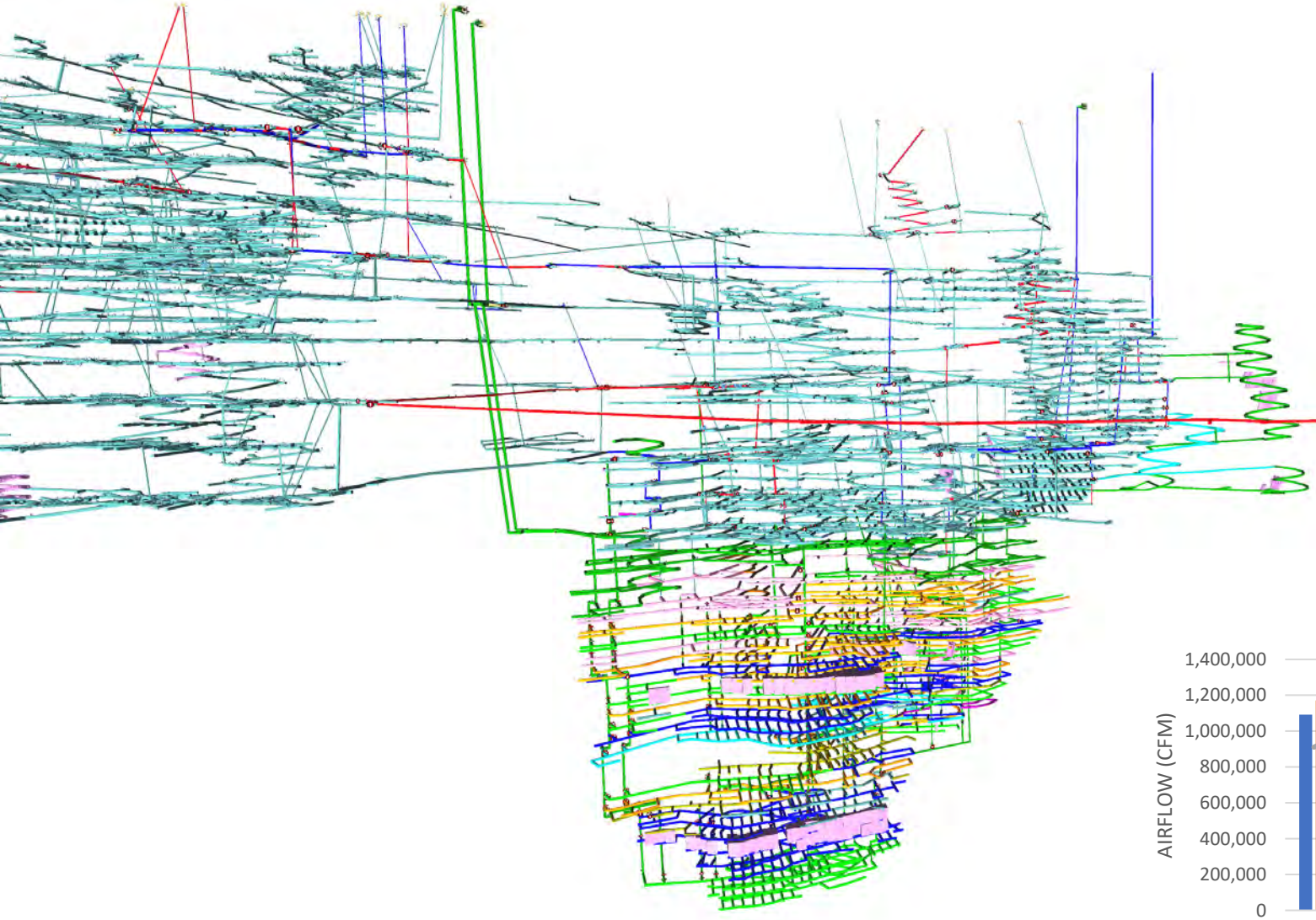

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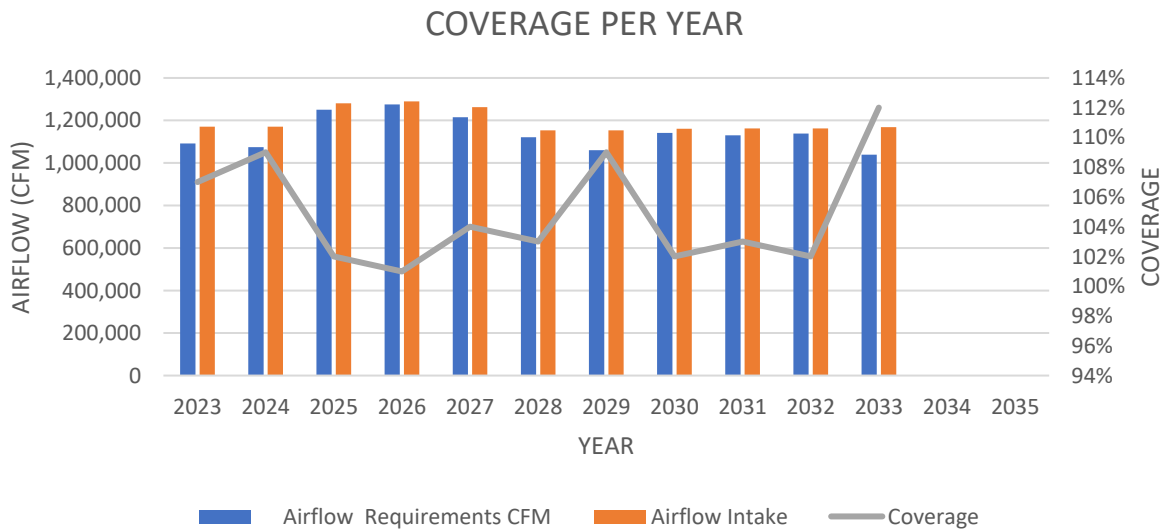

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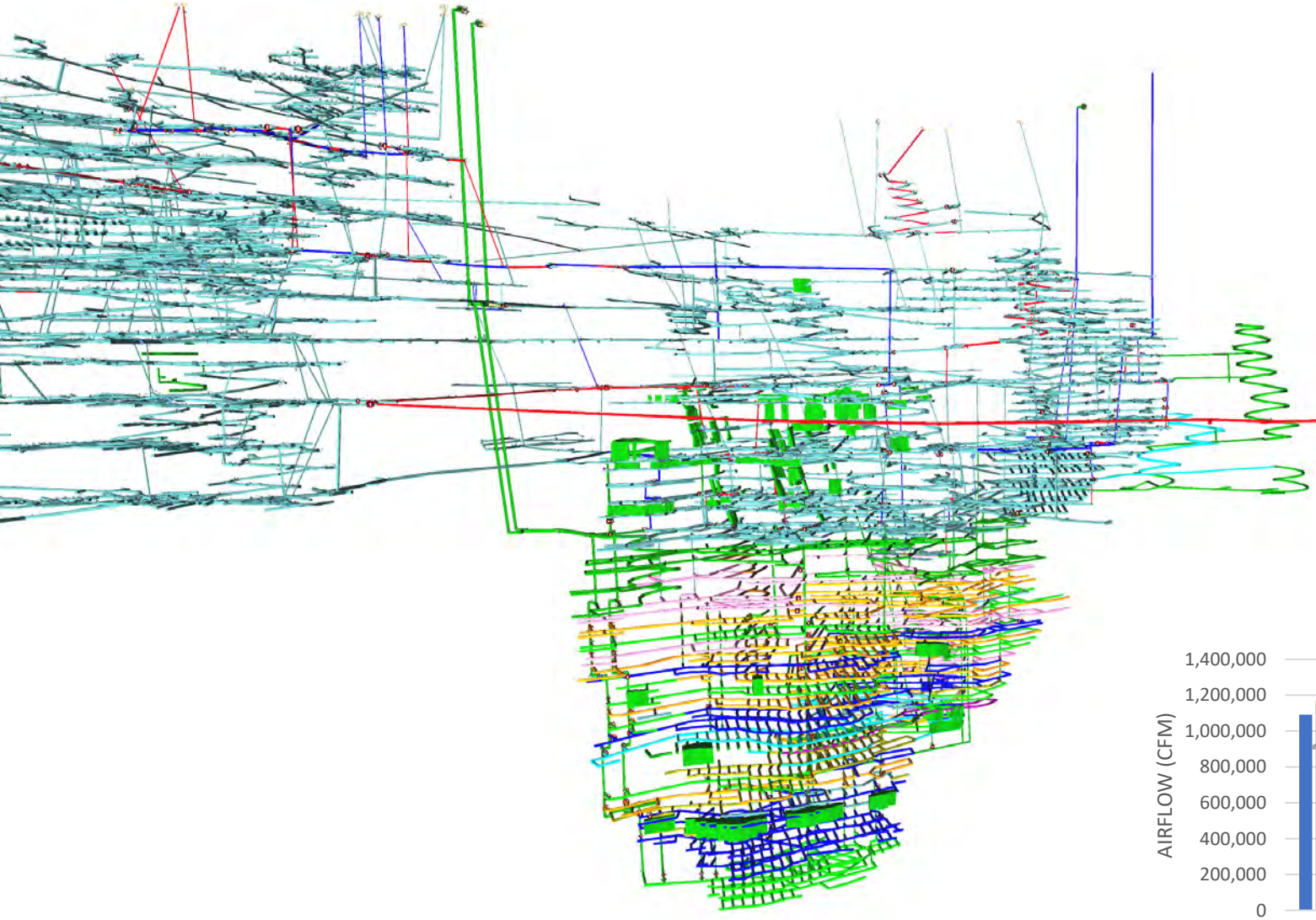

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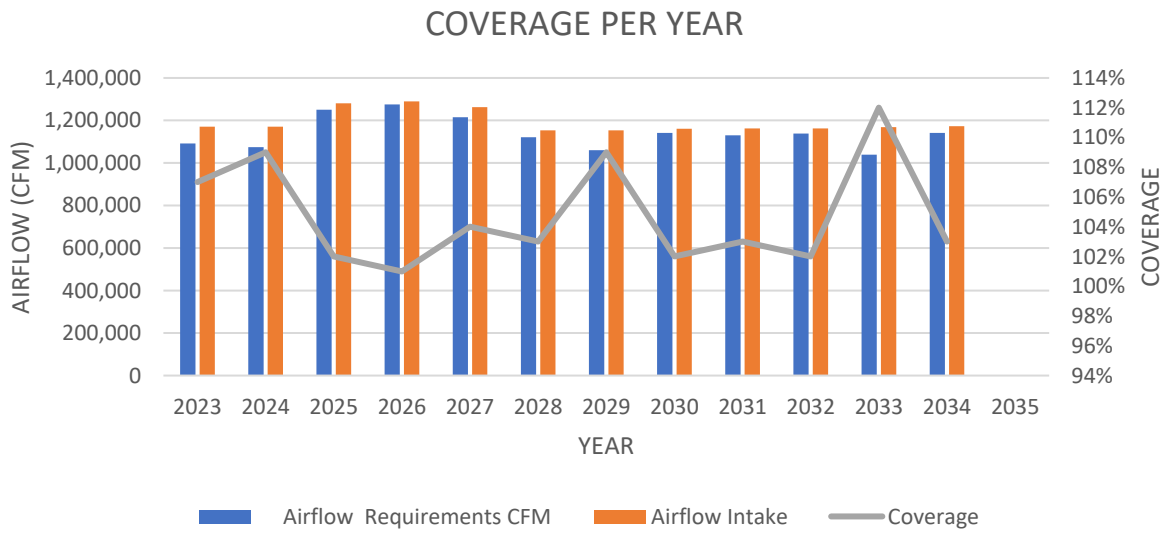
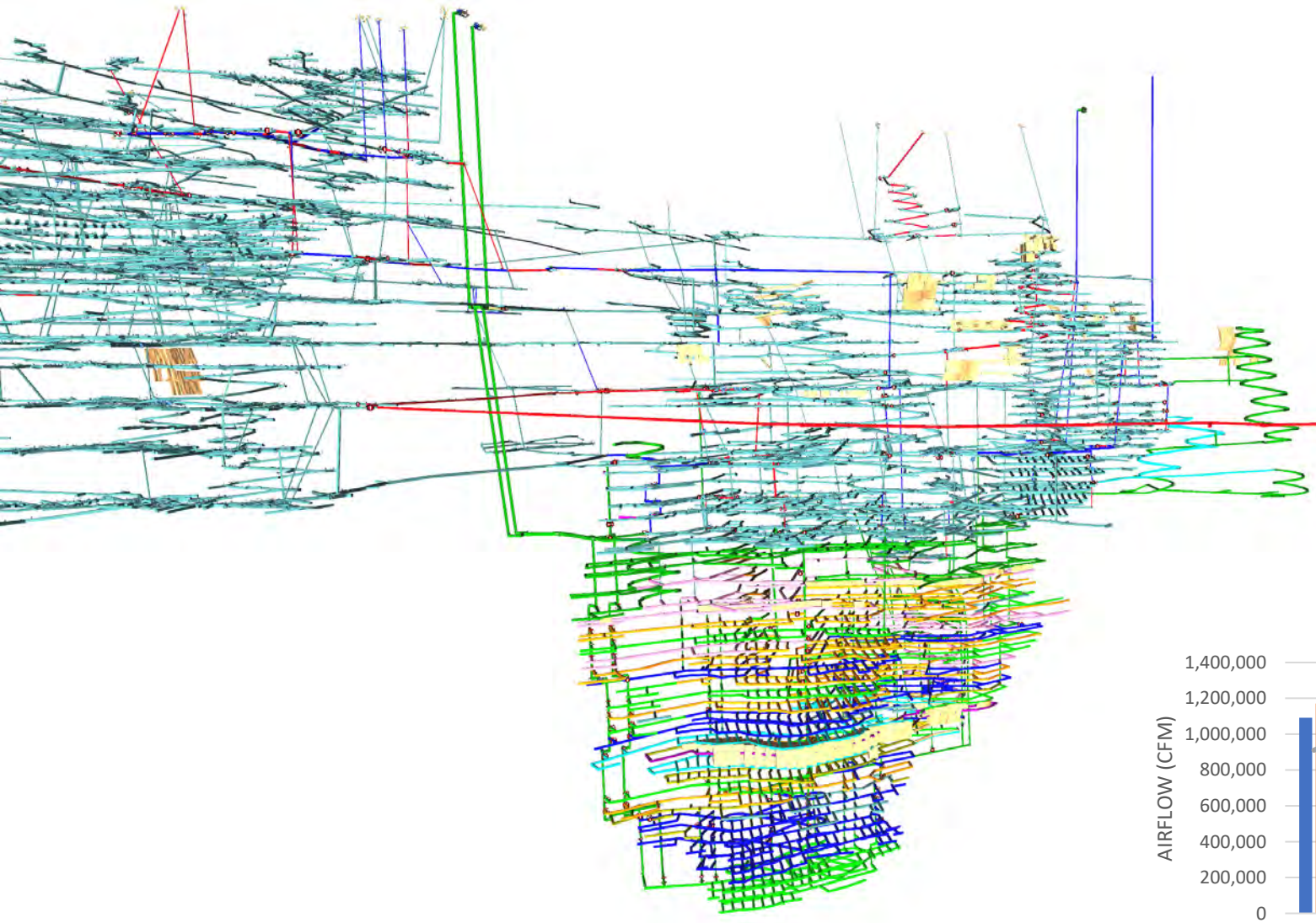


Results – Simulation Stage



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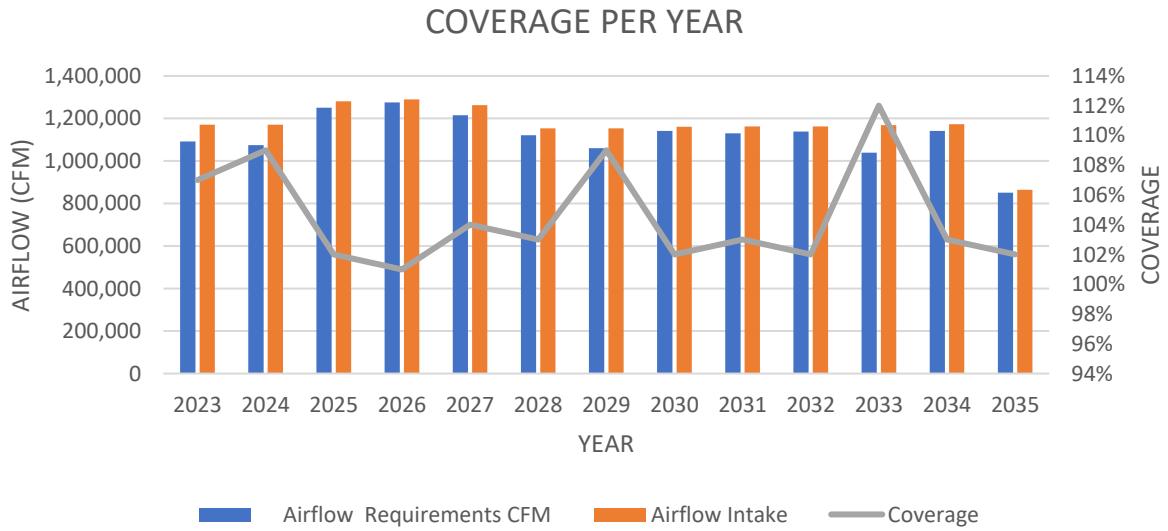

Conclusions

- The process of model construction and parameters calibration is fundamental to obtain a reliable model, adjusted to reality and accurate enough to be able to plan and simulate multiple scenarios, and find opportunities of improvement. Ventsim is a software that makes this process simple, practical and highly illustrative.

- After the assessment of multiple scenarios, the results converged in a trade-off analysis between the ventilation infrastructure (CAPEX) and the fan selection (power consumption – OPEX), resulting in an important reduction of overall costs with respect to the initial estimations at the Prefeasibility Stage, with savings up to $10.1 million in CAPEX and $4.6 million in the net present value of the OPEX.

- Having the possibility to schedule the expansion of the mine ventilation system by years was a key part of the analysis in the estimation of the maximum airflow requirement over LOM, directly impacting in the decision of the economic diameter, and adjusting the fan operating point to what will be required, reducing a considerable amount of power consumption in benefit of the mine economics.

Future Work

The operator has been evaluating the need for a fire, heat and contaminants simulation process for the short-, medium- and long-term. However, given the uncertainty of certain operational parameters unrelated to the ventilation process, it may require some time before the decision is made and the next ventilation assessment takes place.

Questions?

contacto@mineflows.com

Ventilation, safety and productivity for your operation.