# Stochastic Long-Term Production Scheduling of the LabMag Iron Ore Deposit

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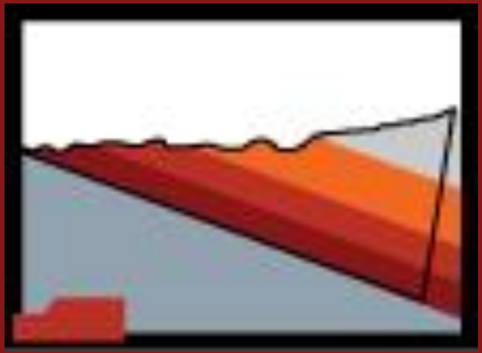


# Introduction

1. Mine profitability : long term production schedule

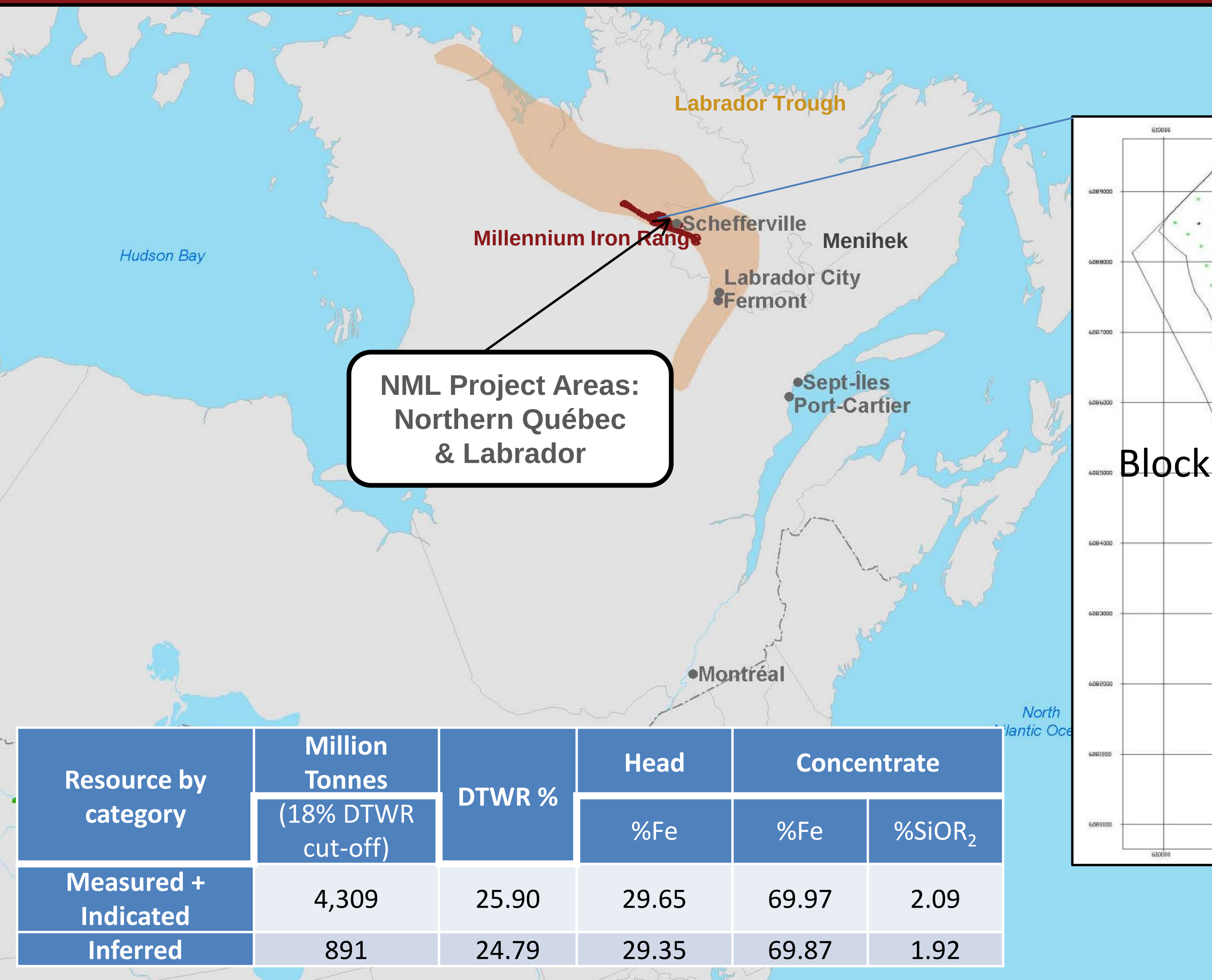
2. Inherent risk in any schedule : tonnages and grades not fully known

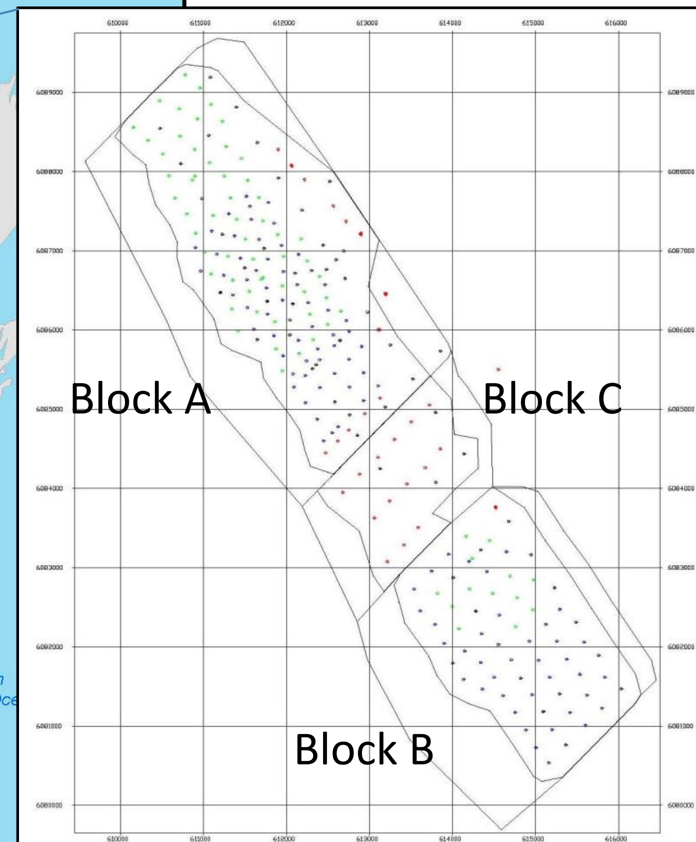
3. Conventional scheduling based on single orebody estimates
    - No risk management
    - Unable to manage multiple goals at once
    - Sub-optimal

This study:

1. Method for simulating the deposit stochastically
2. Evaluate risk in previous schedule
3. Derived a schedule that optimizes profitability
    - Simultaneously managing geological and thus financial risk

# LabMag: Location and Drilling




| Resource by category | Million Tonnes (18% DTWR cut-off) | DTWR % | Head %Fe | Concentrate %Fe | Concentrate $\%SiOR_2$ |
|---|---|---|---|---|---|
| Measured + Indicated | 4,309 | 25.90 | 29.65 | 69.97 | 2.09 |
| Inferred | 891 | 24.79 | 29.35 | 69.87 | 1.92 |



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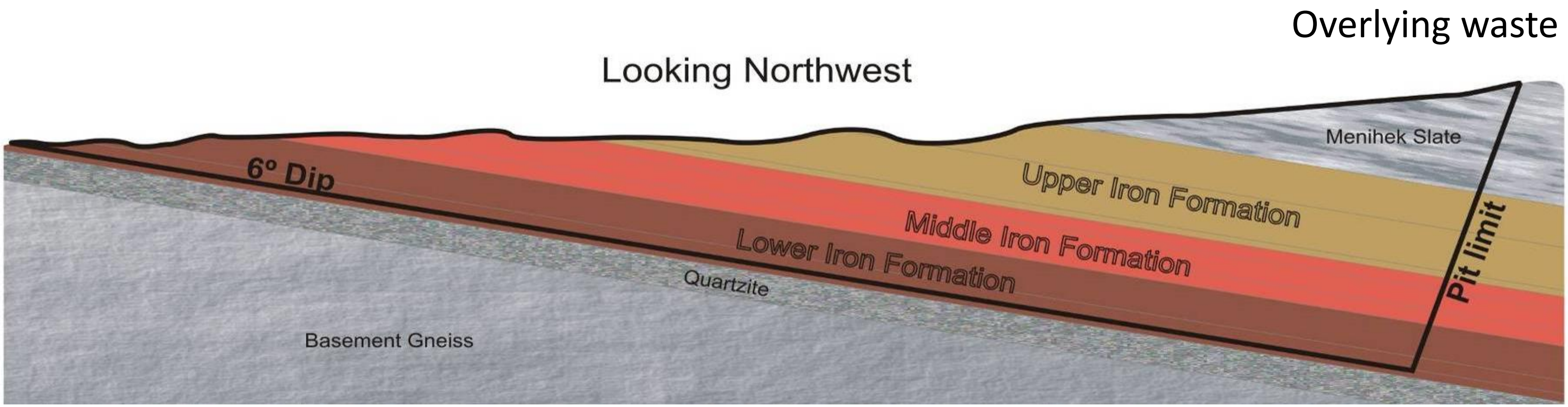
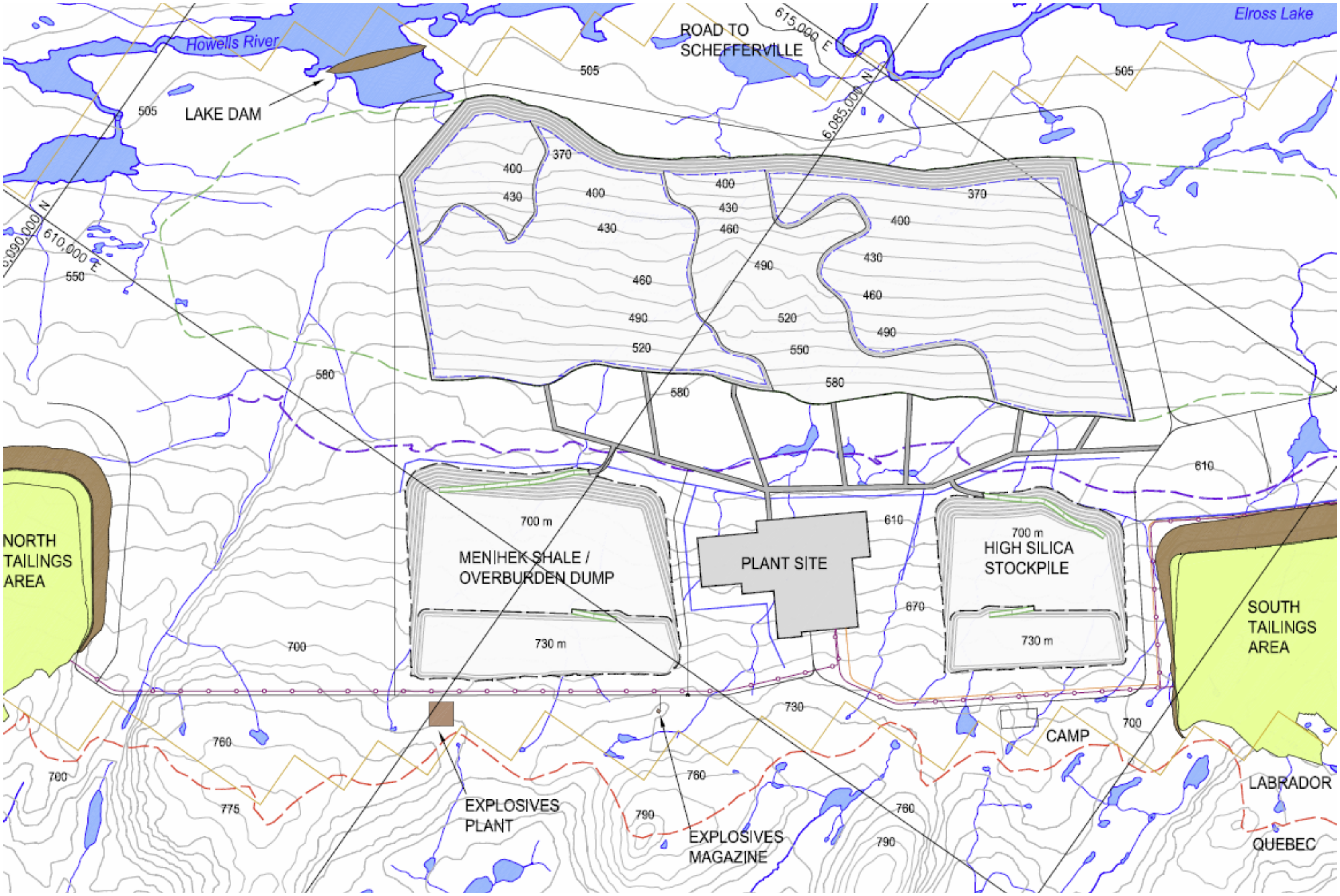
# LabMag: A Sedimentary Deposit

**Millennium Iron Range Taconite: Typical Cross-Section**




- Magnetic taconite ore similar to that of Minnesota's Mesabi Iron Range
- Sedimentary ore body averaging 60 meters thick with 7 distinct stratigraphic layers
- Shallow, near surface, slightly dipping ore body with very low stripping ratio
- Minor overburden and internal waste
- Open pit mineable

# LabMag: Sample Site Layout



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# Davis Tube Test

- A method for measuring the quantity of magnetic iron recoverable from an ore
- Traditional chemical analysis shows total iron content, whether magnetic or non-magnetic
- Typical processing techniques for magnetite (Taconite) use magnetic separation
- Davis Tube Test gives an approximation of the expected recovery by weight
- Clean concentrate of magnetic material can then be analyzed for iron grade as well as the primary impurity, silica

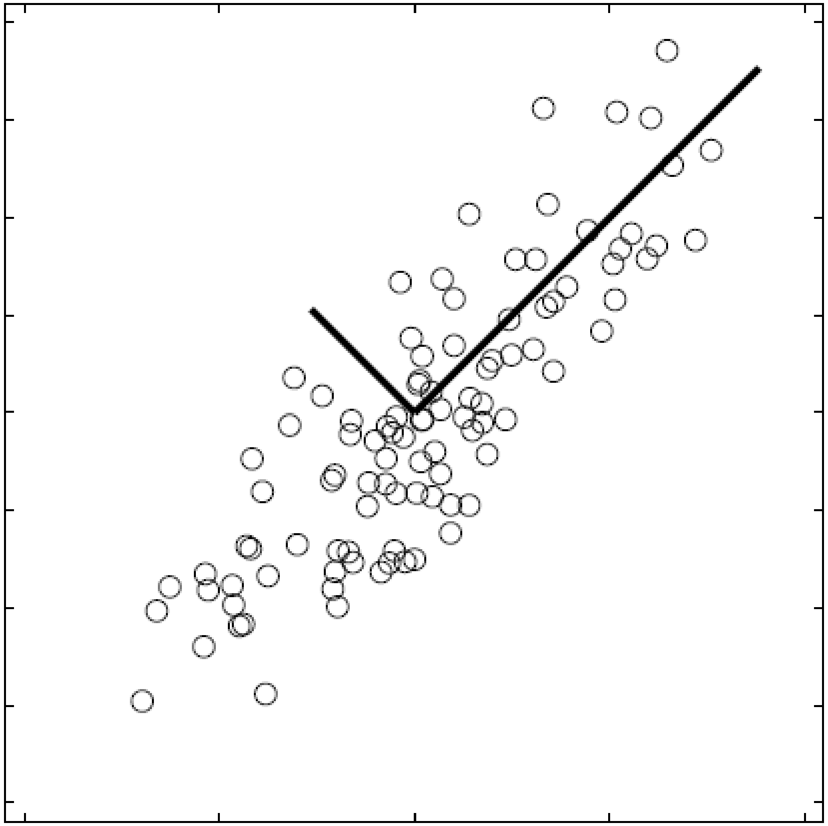
- FeH is the iron grade of the material fed into the Davis Tube process
- DTWR is the Davis Tube Weight Recovery
- FeC is the iron grade in the Davis Tube Concentrate
- SiC is the silica grade in the Davis Tube Concentrate

# Two-Stage Stochastic Simulation

1. Simulate 7 lithological layers
    - Conventional modeling has perfectly flat surfaces that are not realistic and do not account for the uncertainty in the horizons
    - Relationship between thicknesses of each layer to be preserved
2. Simulate 4 properties
    - Each lithology is a separate domain
    - Correlation between qualities must be preserved

*****Needed: a technique to maintain variable correlations**

# Min/Max Autocorrelation Factors (MAF)



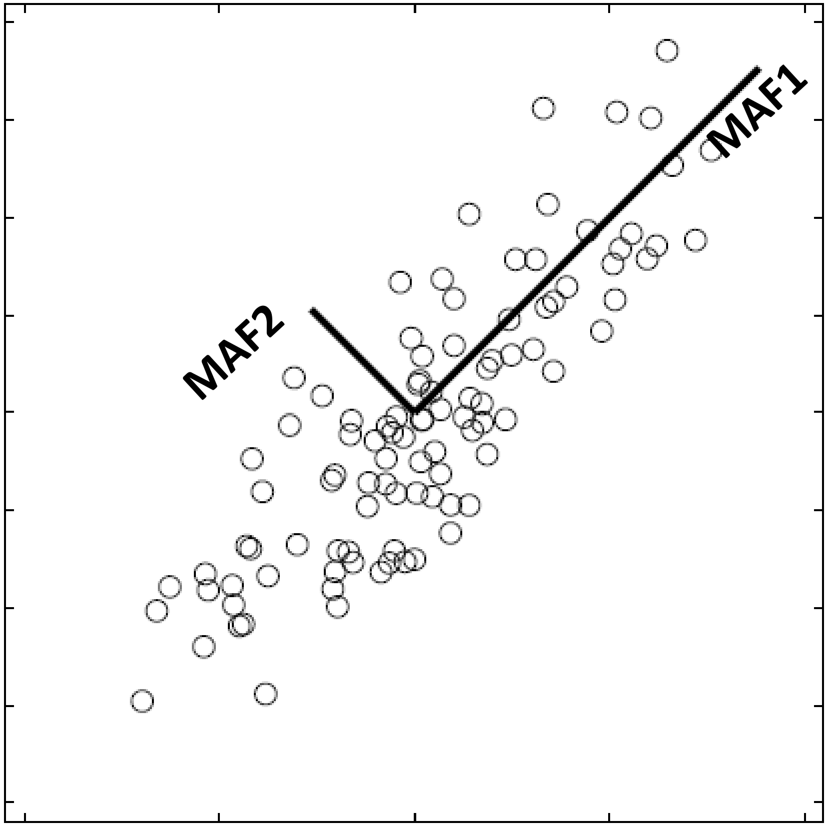
We can use SGS to simulate 1 variable, say DTWR
We can then use SGS to simulate FeH
…then FeC…then SiC.

But this would not preserve the existing correlation between the variabels.

Ie. FeH, DTWR, FeC, SiC are correlated variables
In particular, there is a strong correlation between FeH - DTWR and between FeC - SiC

MAF takes multiple correlated variables and transforms them into uncorrelated "factors"

# Min/Max Autocorrelation Factors (MAF)




MAF transforms these 4 variables into 4 factors (MAF1, MAF2, MAF3, MAF4) that have no correlation

Each factor is a linear combination of the original variables

The process is based on a two-stage Principal Component Analysis (PCA)

PCA projects the data in such a way as to capture big (principal) variability in the data and ignore small variability

MAF factors can be simulated independently with SGS, and then back-transformed to the original variables to preserve all correlations



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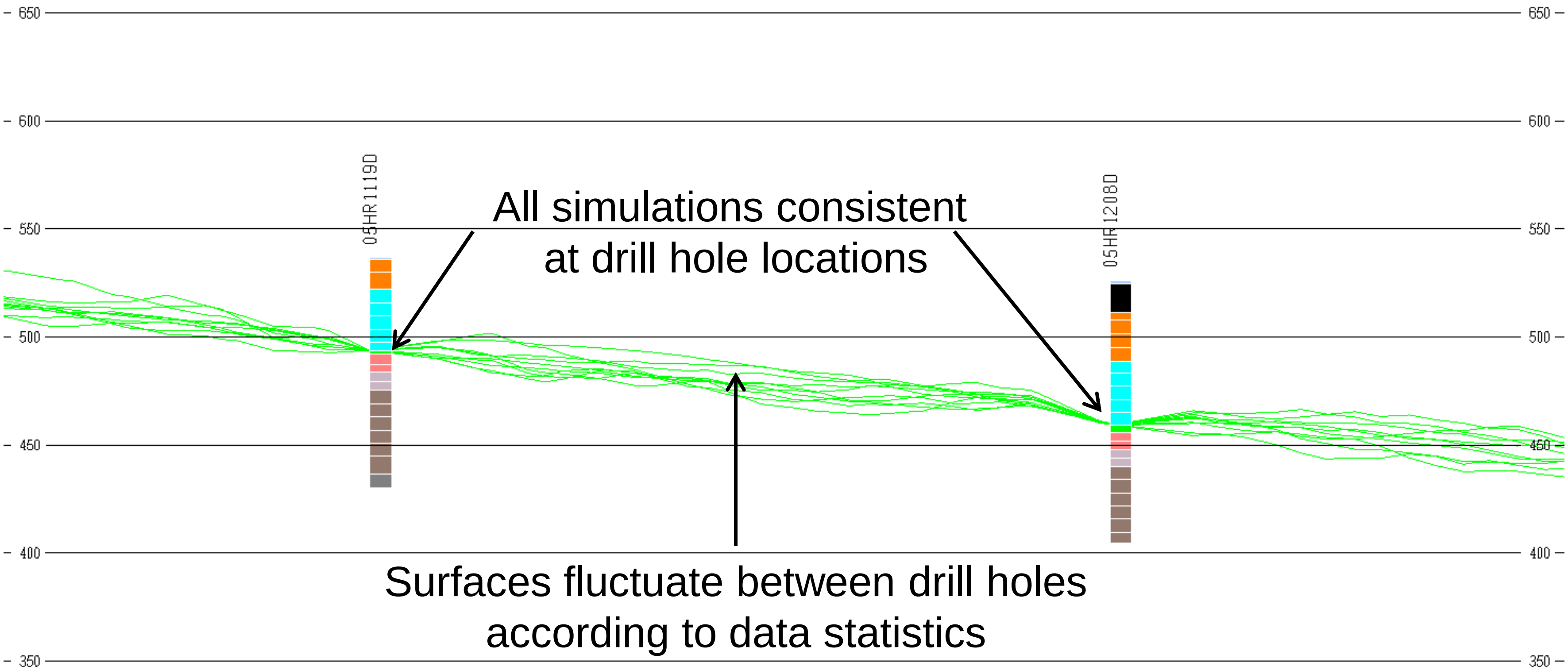
# Simulation Method

1. Use MAF to decorrelate variables of interest to uncorrelated factors
2. Use method like SGS to simulate the uncorrelated factors
3. Back transform the factors to original data space
4. Verify simulations:
   - Check if consistent with the data at the data locations
   - Check statistics such as histograms, variograms are reproduced
   - Check correlations between variables are preserved
   - Visual inspection

# Lithology Simulation

Example: 10 simulations for GC layer



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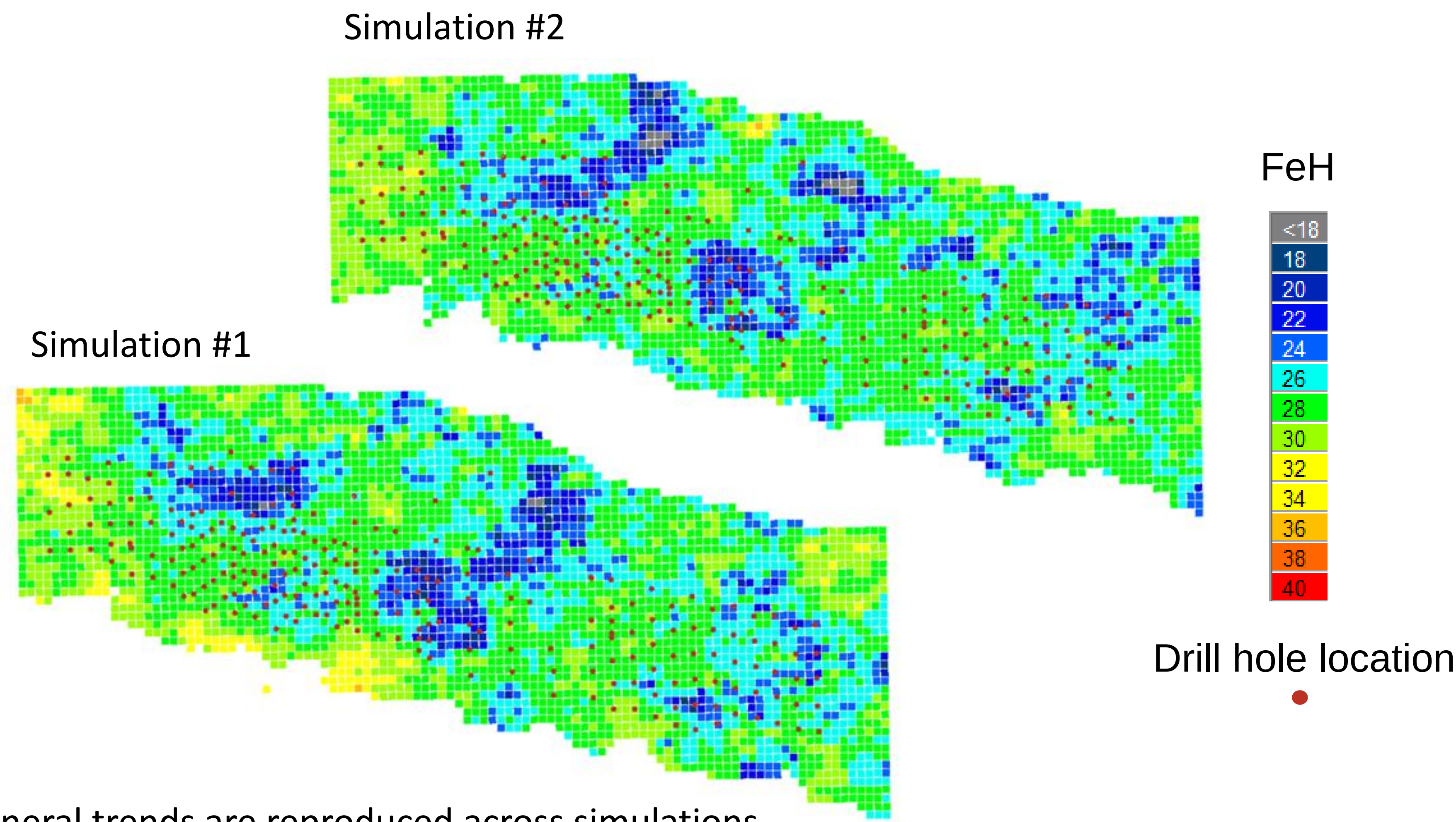
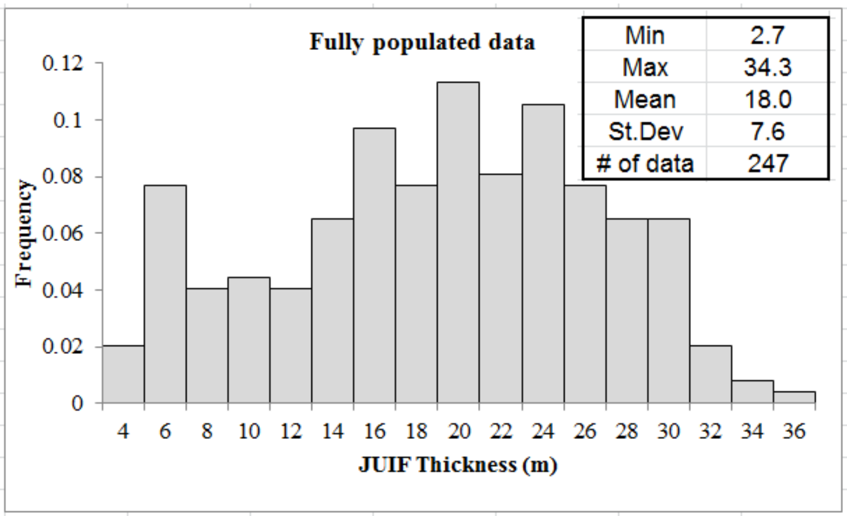
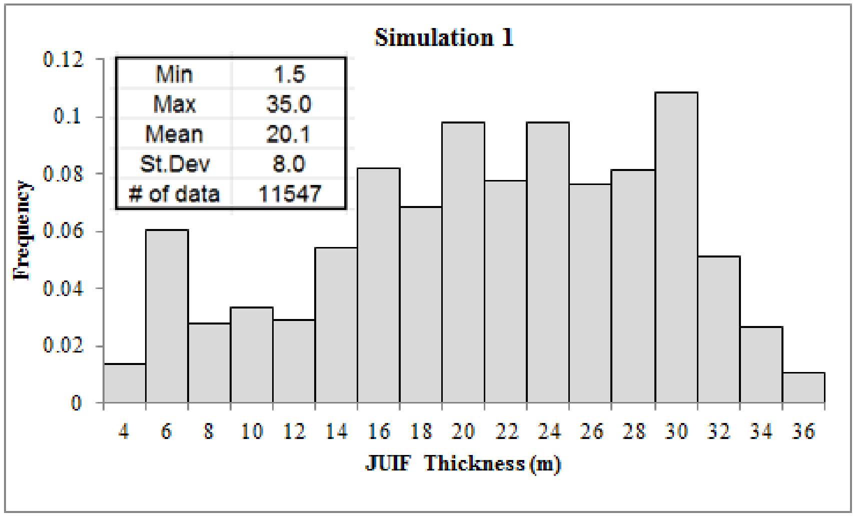
# Grade Simulations



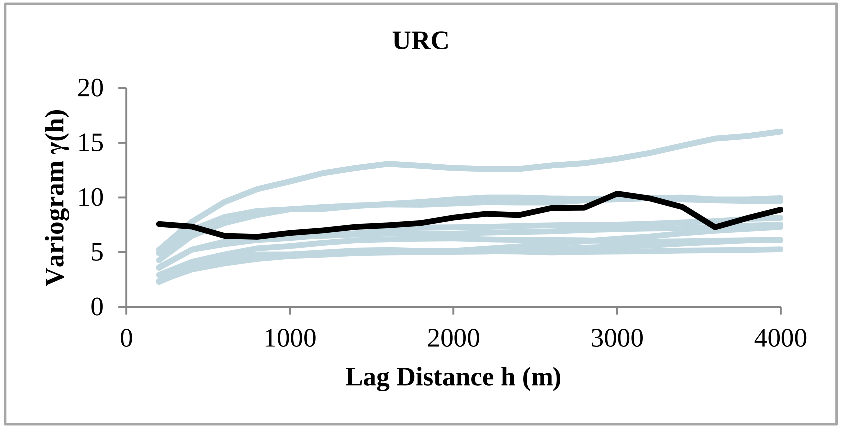

General trends are reproduced across simulations
Local variations exist between drill holes

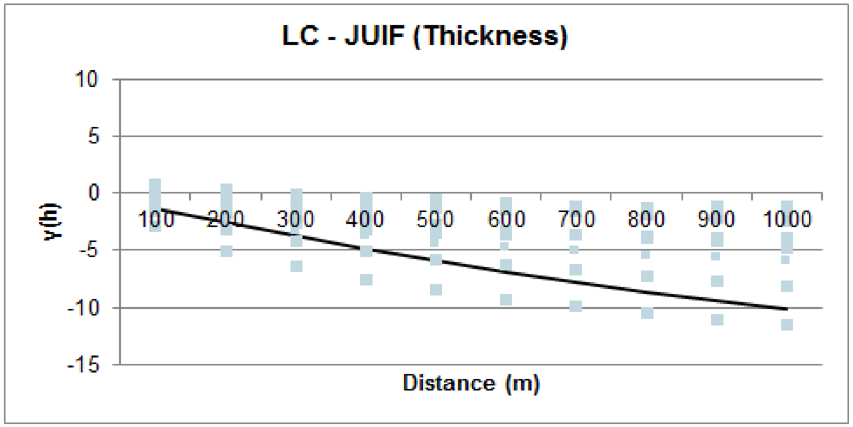
# Simulation Validation




Histograms



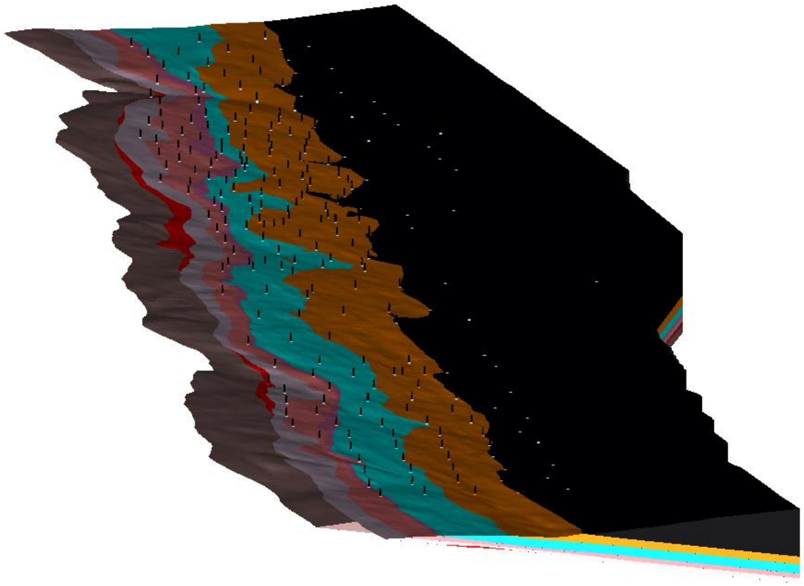




Variogram

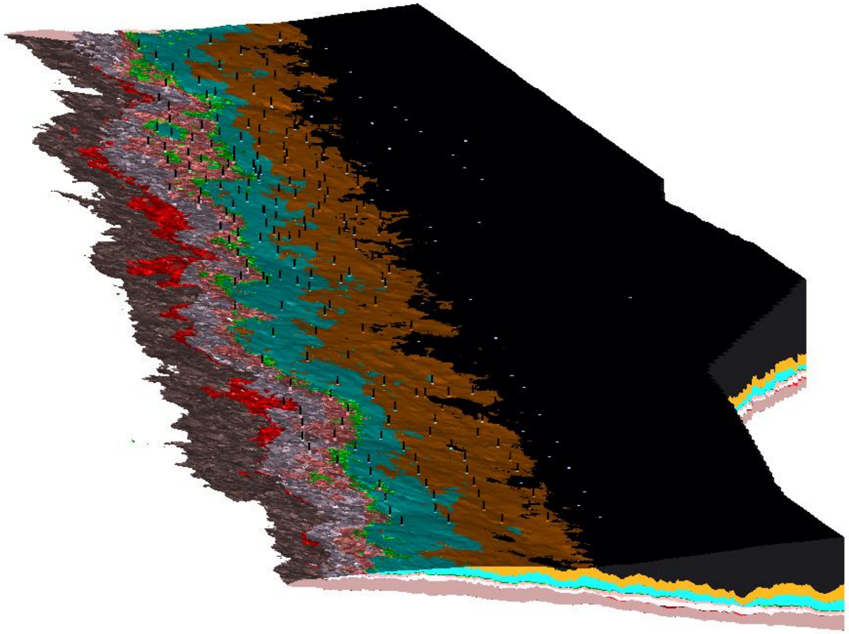
Cross-Variogram

# Full-field simulation

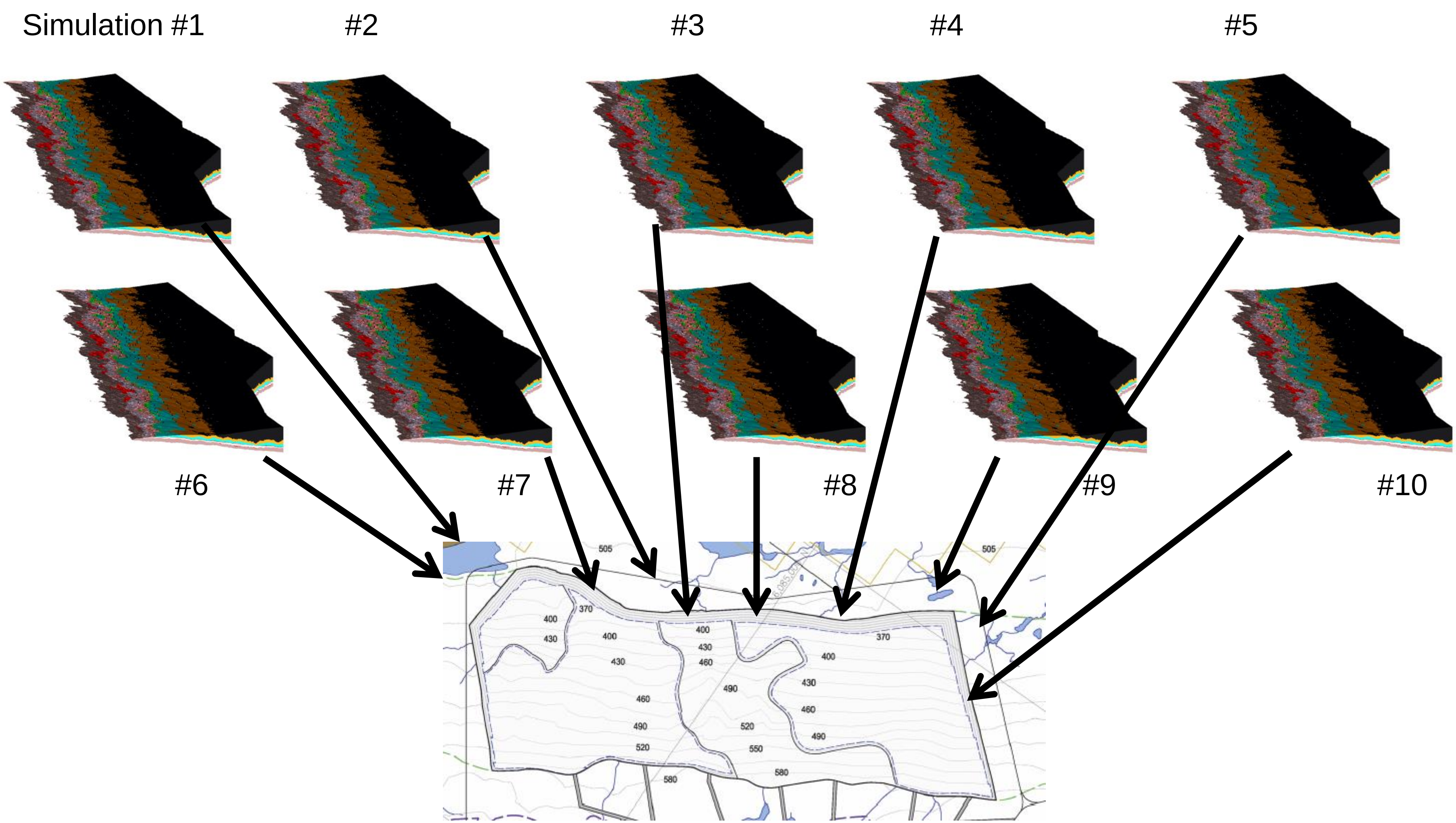
Determinstic (kriged) model



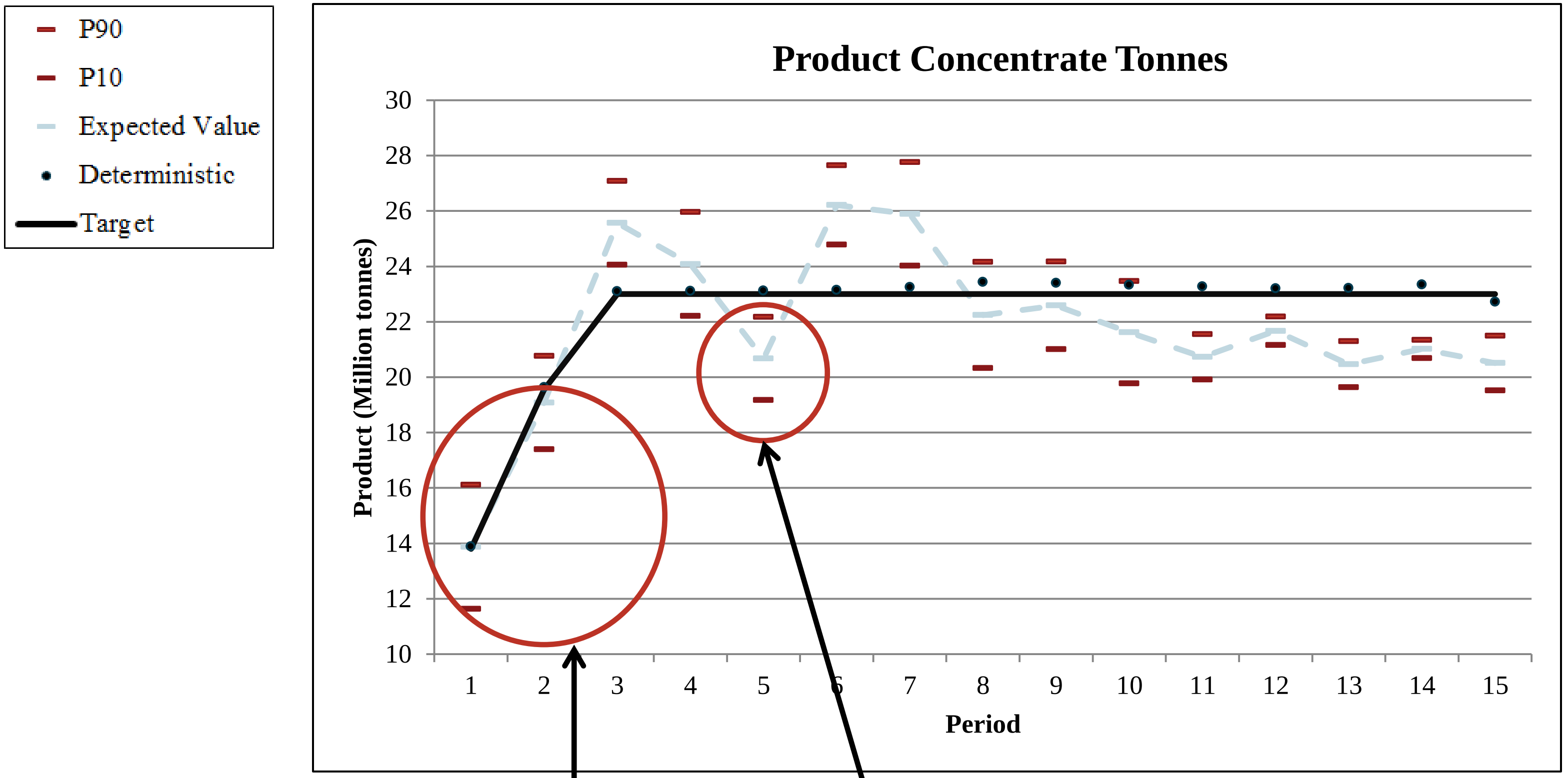
Simulated model



# Mining Schedule: Quantify Uncertainty



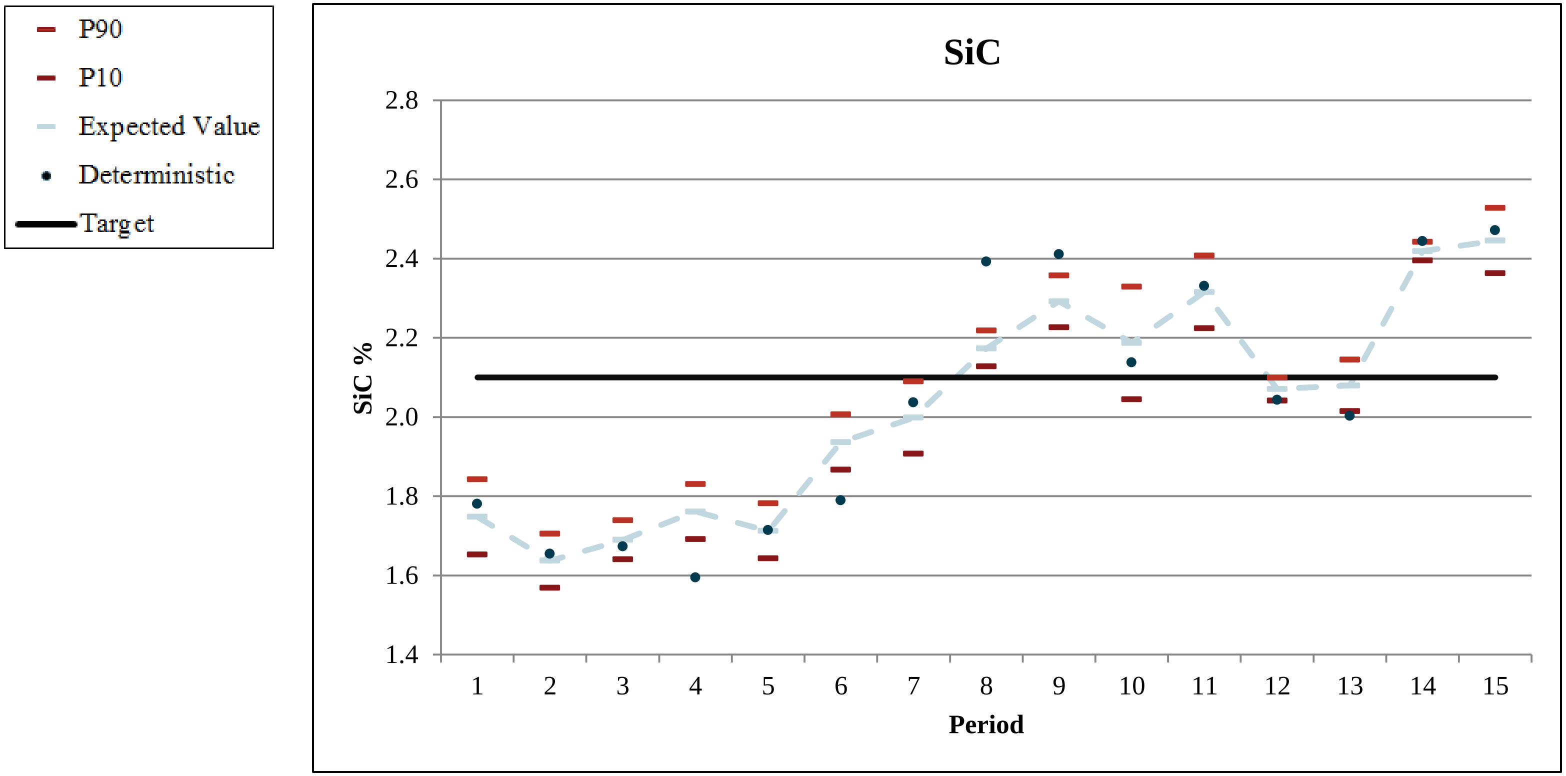
# Results




Y1 & Y2 possible short-falls

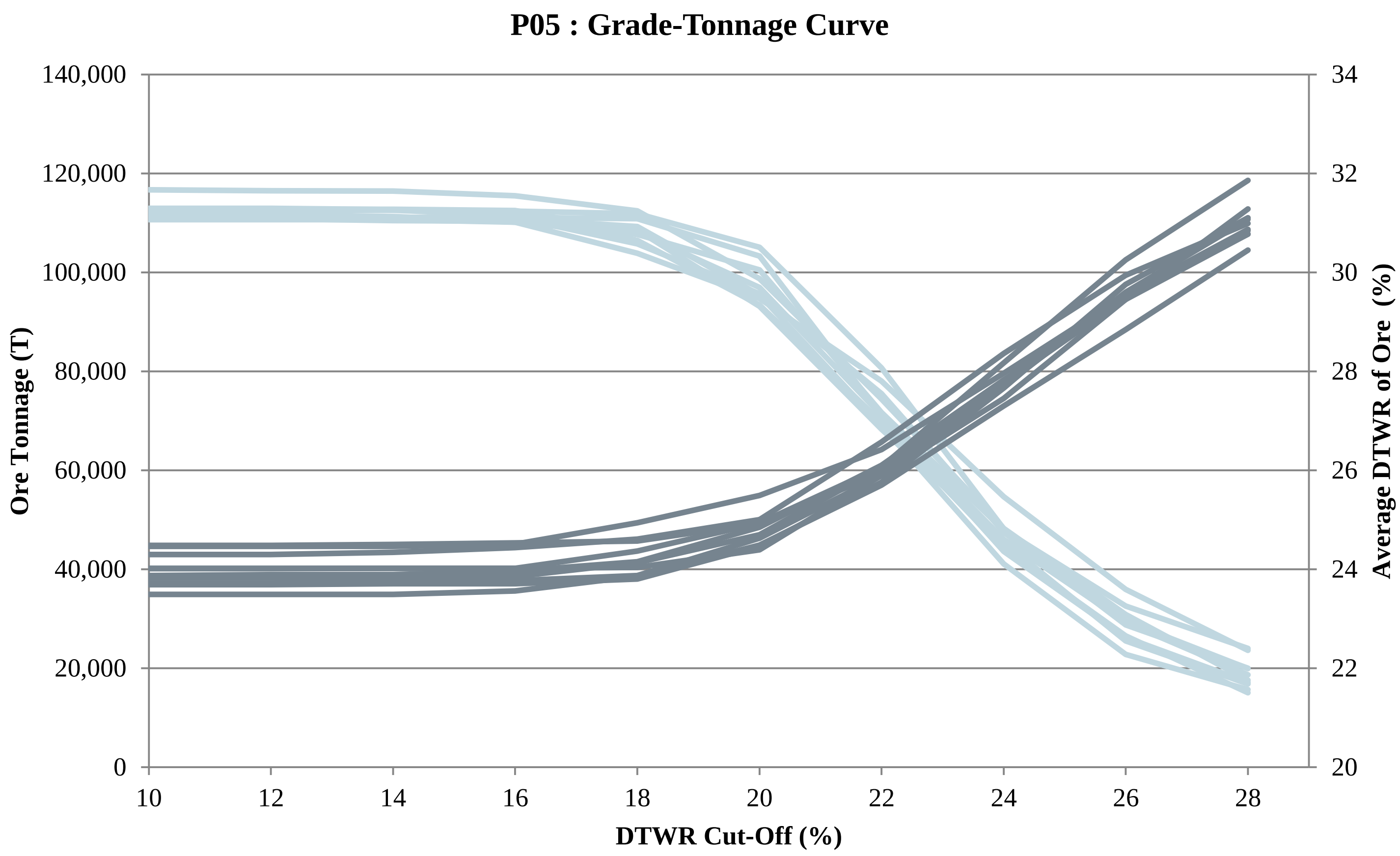
Y5 likely short-fall

# Results



P90
P10
Expected Value
Deterministic
Target
SiC
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
SiC %
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Period

# Results



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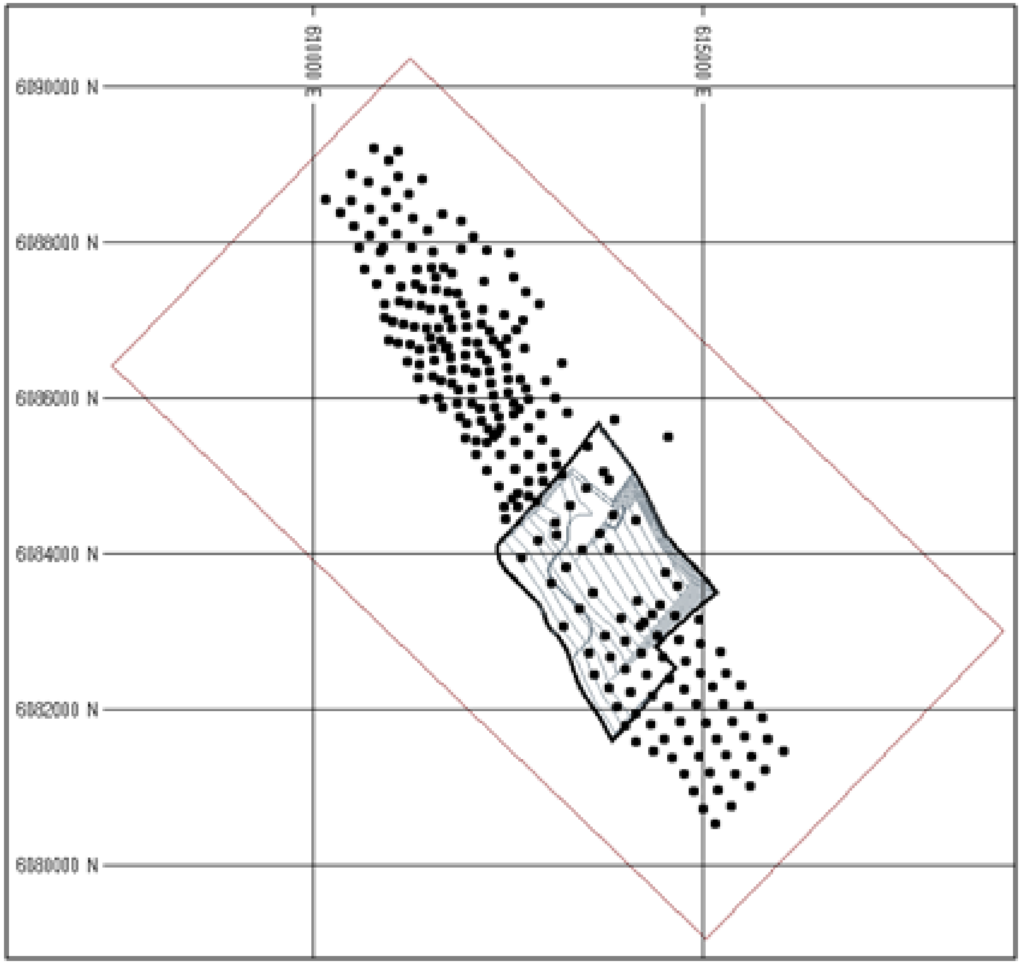
# First 10 Years: Most Uncertain



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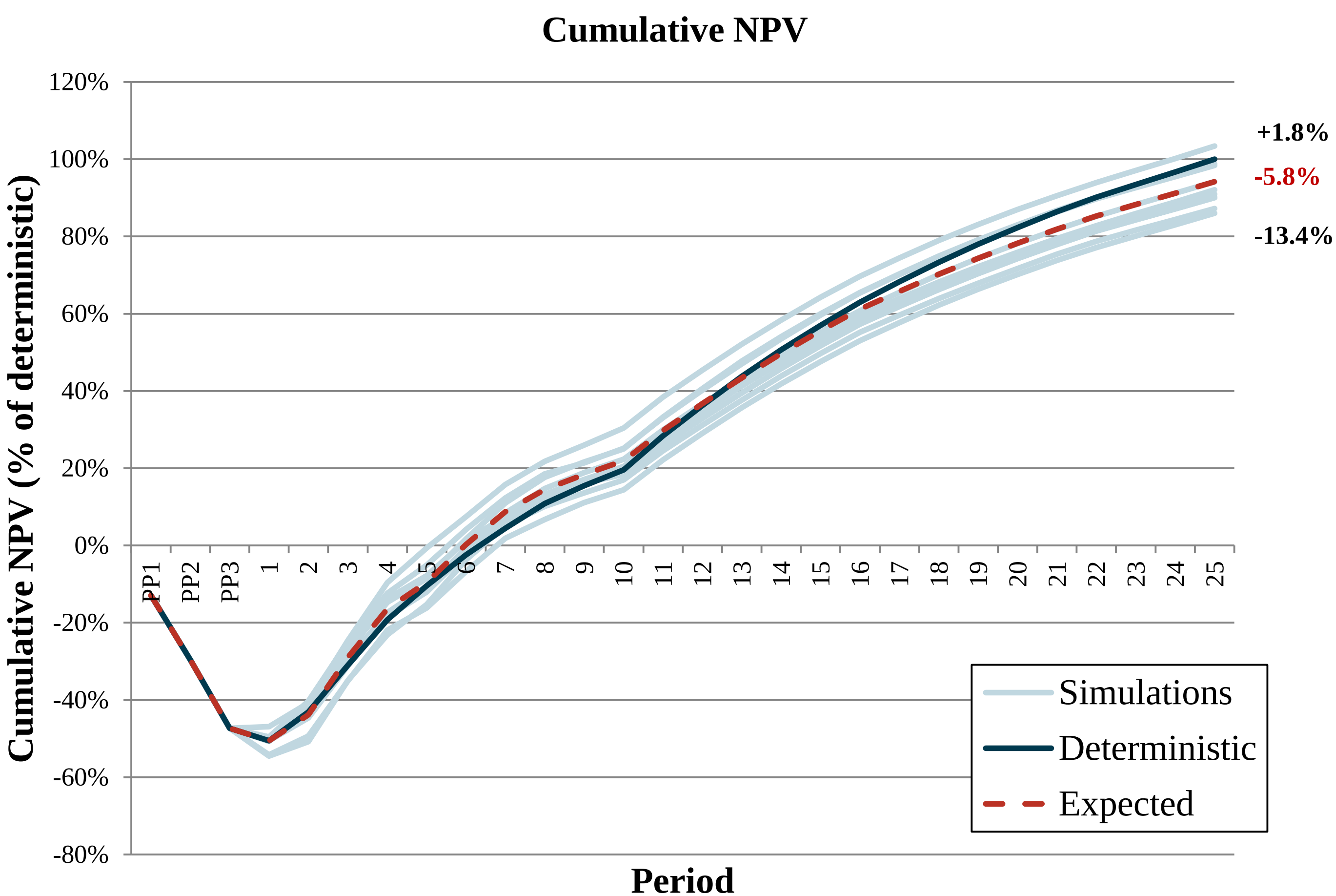
# Financial Risk in the Manually Derived Schedule




Expected:
5.8% lower NPV

Upside (P10):
1.8% NPV

Downside (P90):
13.4%

Expected Value is calculated by evaluating each simulation in the schedule, one at a time, and then averaging the resulting NPVs. Note that this *differs* from evaluating the one average model in the schedule.

# Solution: Stochastic Optimization

Better mine plan: account for uncertainty

Combinatorial problem:

- Consider all technically feasible mining sequences
- Choose one with highest expected NPV across <u>all</u> simulations

Uncertainty can not be removed, but it can be managed

Earlier years can mine for tonnages/grades with greater certainty

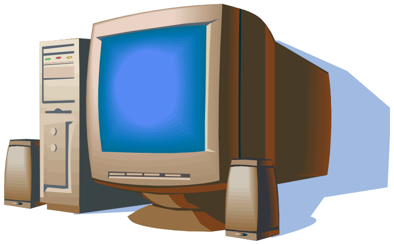
Uncertainty can be pushed to later years when more information will be available due to mining

# Stochastic Integer Programming (SIP)

- SIP is a type of mathematical programming and modelling
- SIP generates an optimal result for some function
  (while considering multiple equally probable scenarios)
- The optimal result is bounded by constraints
  Examples:
  - Slope constraints
  - Quantity of material the plant can handle
  - Desired product grades

# Objective Function

Maximize some function, defined here as:



The Net Present Value (NPV) of the schedule
i.e. Revenue – Operating Costs, discounted by period

The variables are binary, one for each combination of:
Block
Period
Destination

The optimization determines the value for each variable, and thus when and where to send each block.

Note that this means variable cut-offs!

# Penalties

1. Deviations from production targets
   - Concentrate tonnes
   - Primary impurity (silica) levels

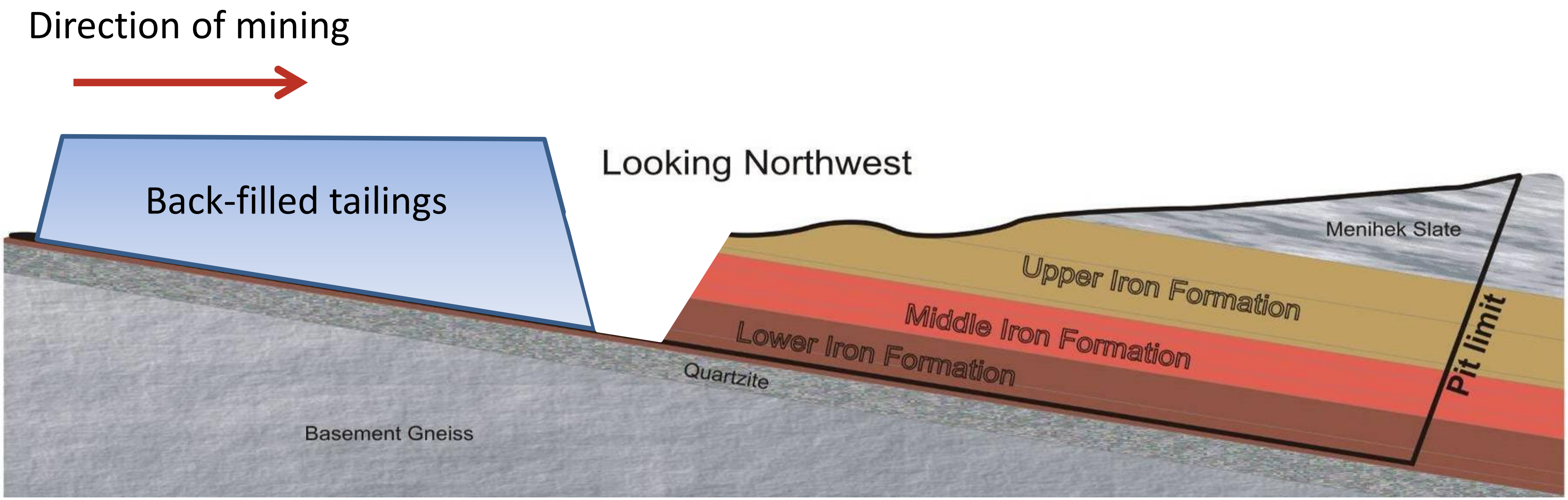
2. Higher operating costs due to truck haulage

3. Deviations from “smooth” mining

# Constraints

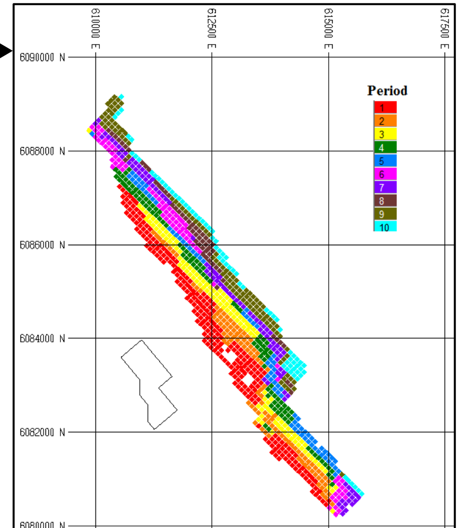
1. Slope and sequencing constraints
2. Processing capacity constraints
3. Grade constraints
4. Equipment smoothing constraints
5. Equipment access and mobility constraints

# In-Pit Tailings Disposal

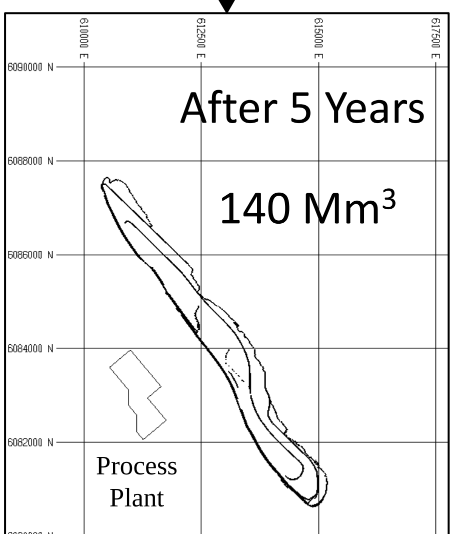


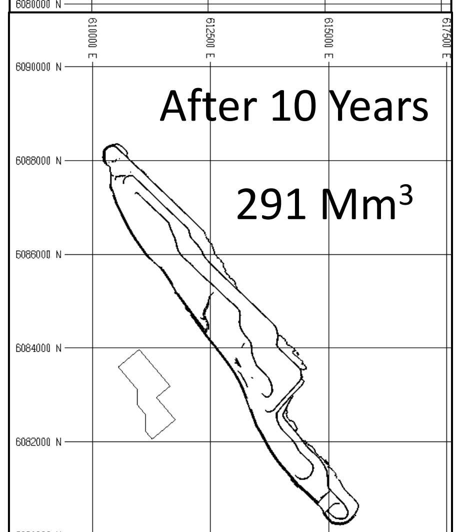
# 10 Year Optimization and Pit Designs

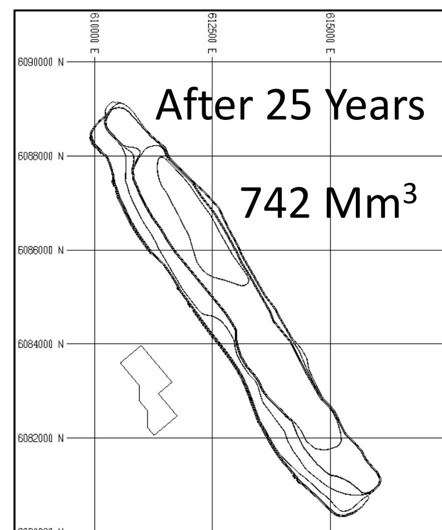
10 Year Optimization
Based on Block Model
Each colour is a different period




Manual Pit Designs
Based on Optimization

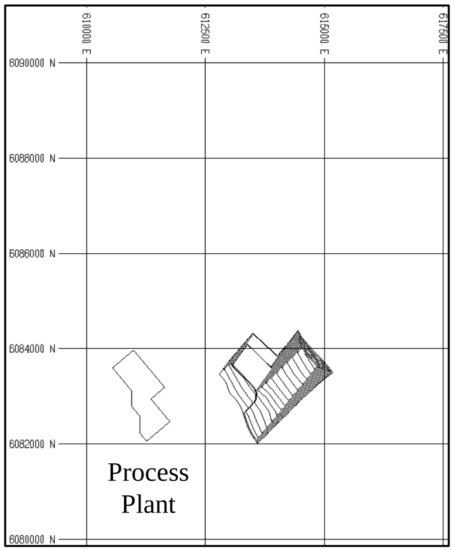


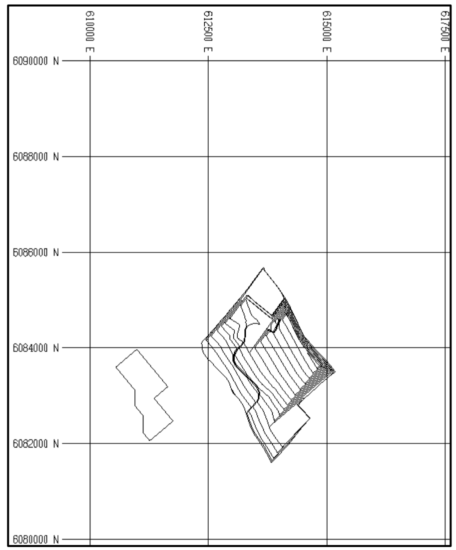



# Manually Derived Schedule

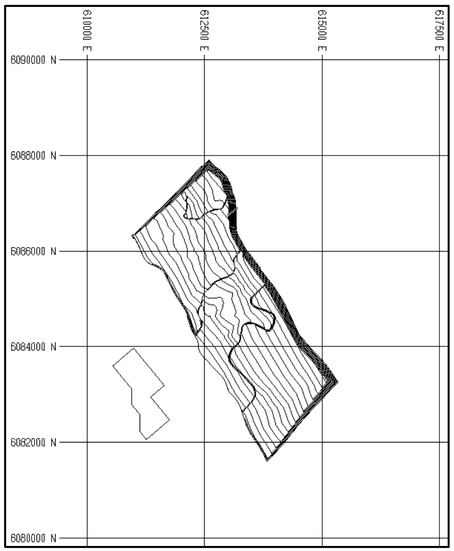
## After 5 Years



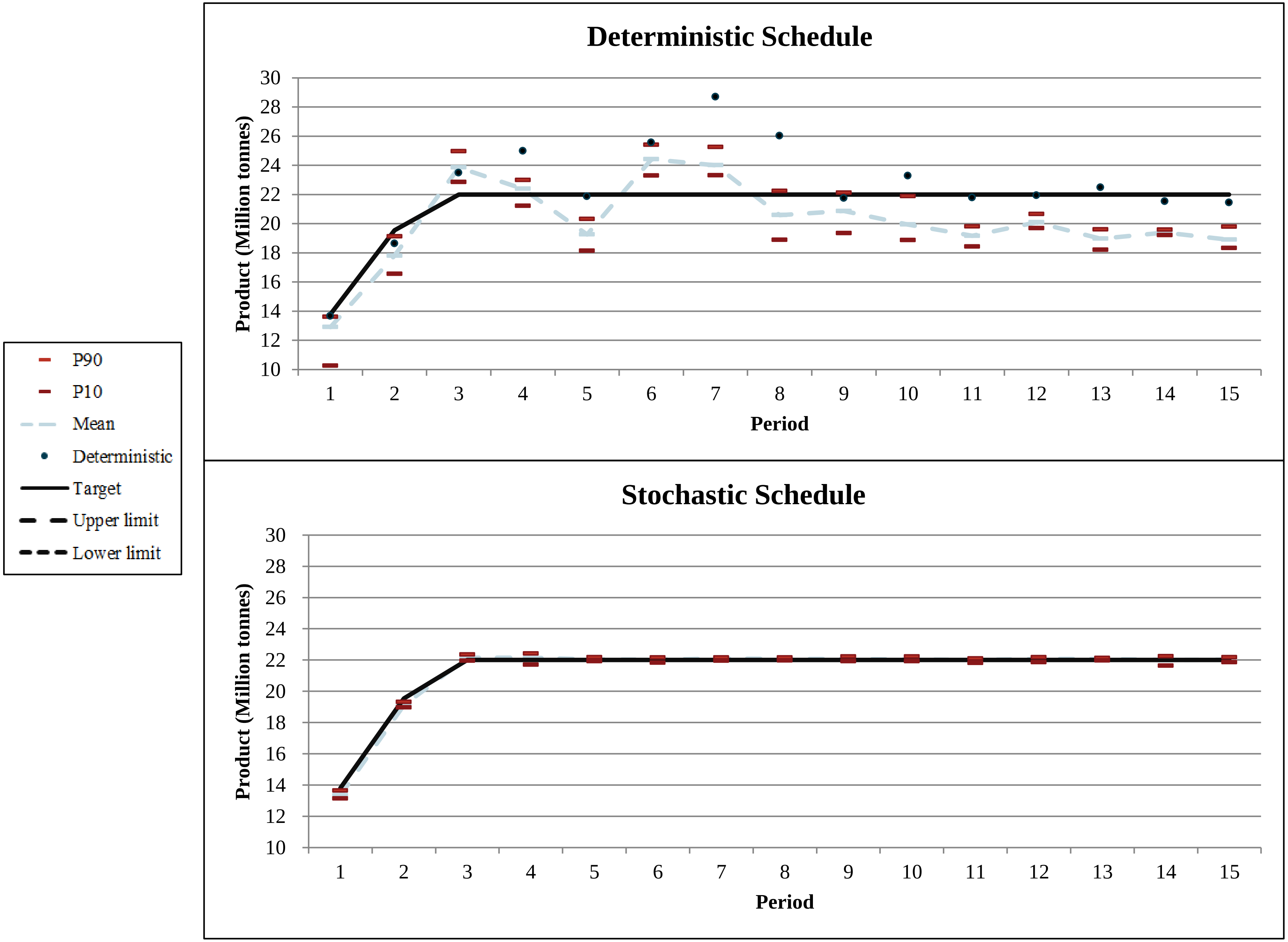

## After 10 Years




## After 25 Years



# Product Tonnes



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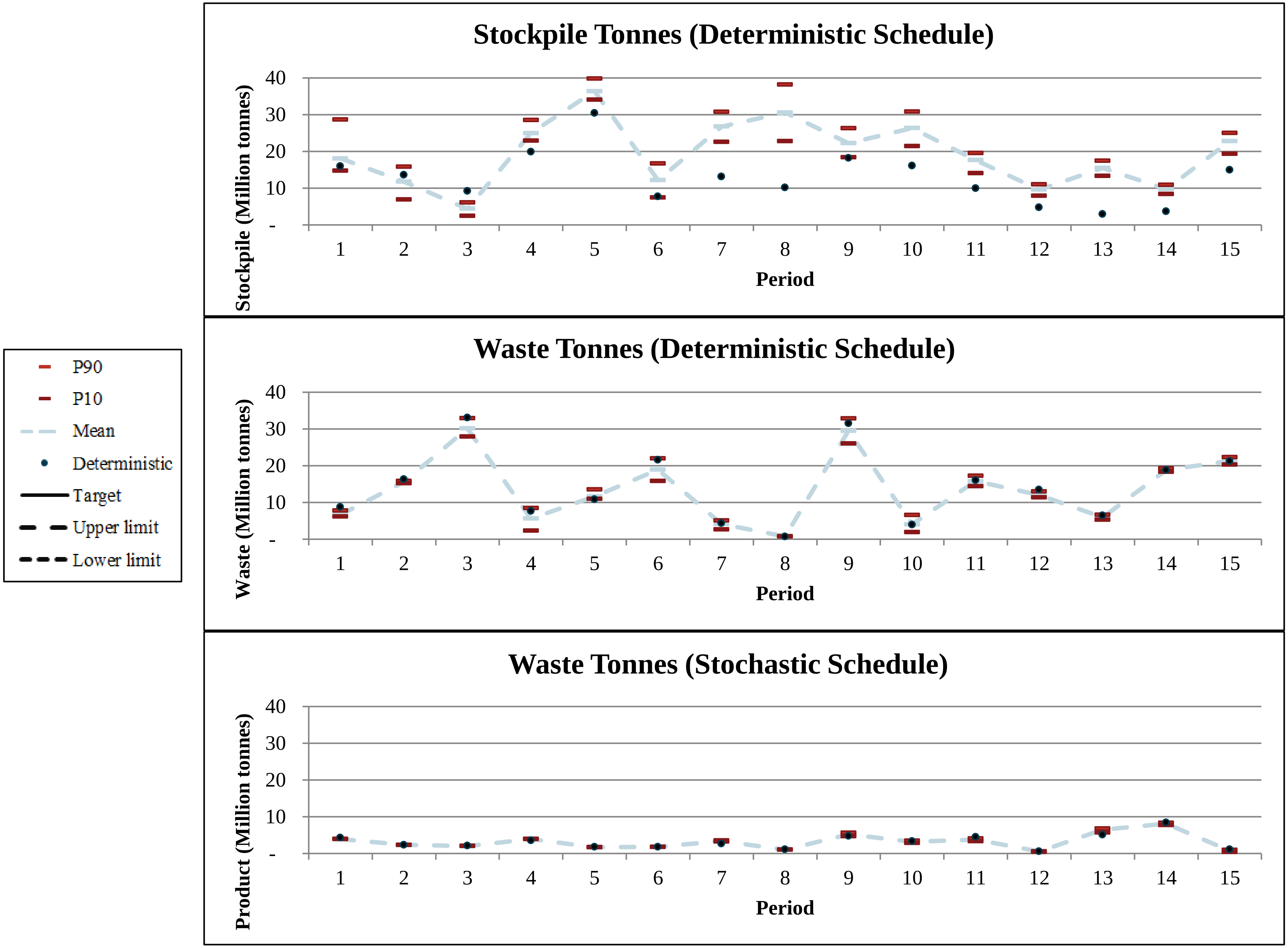
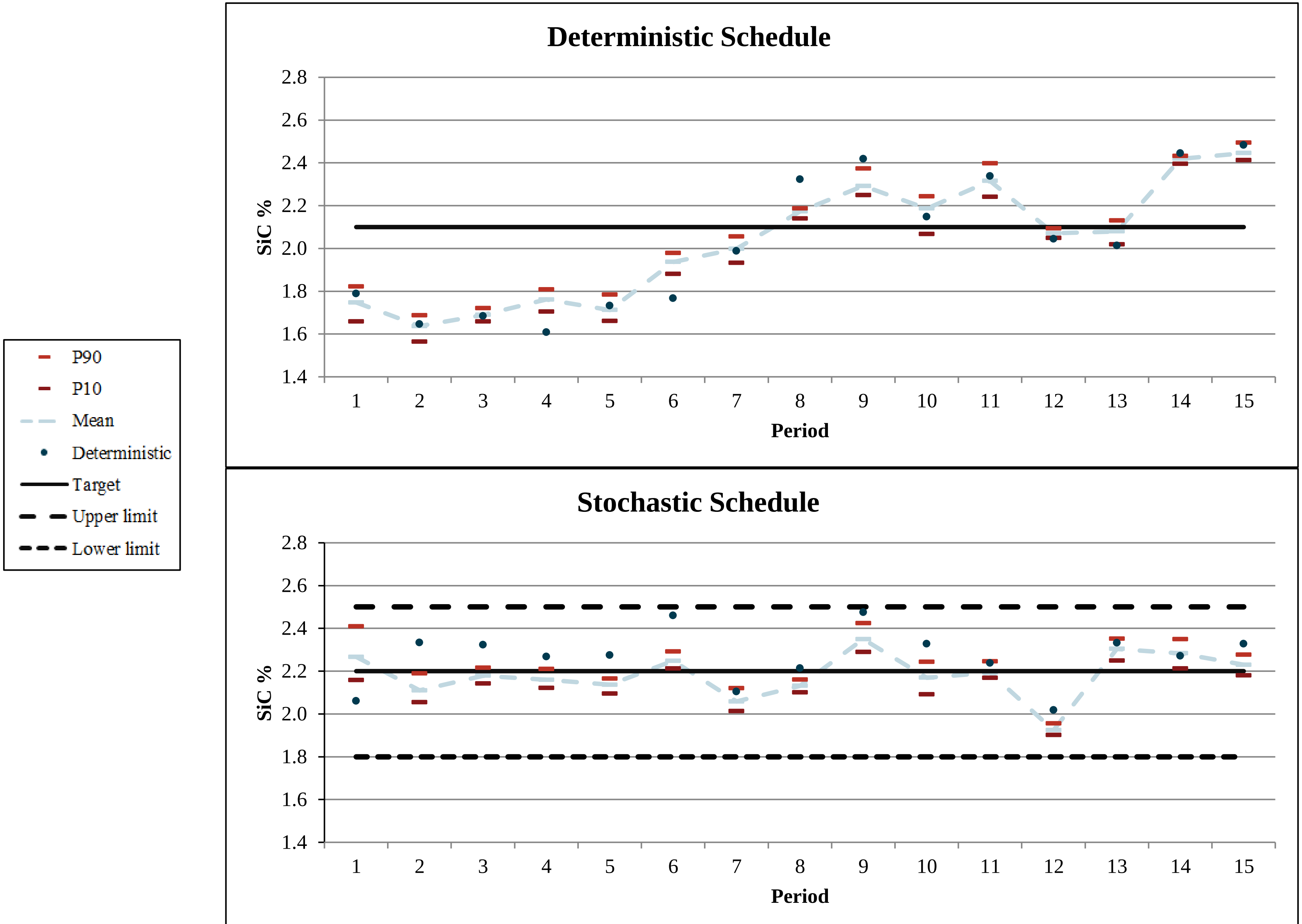
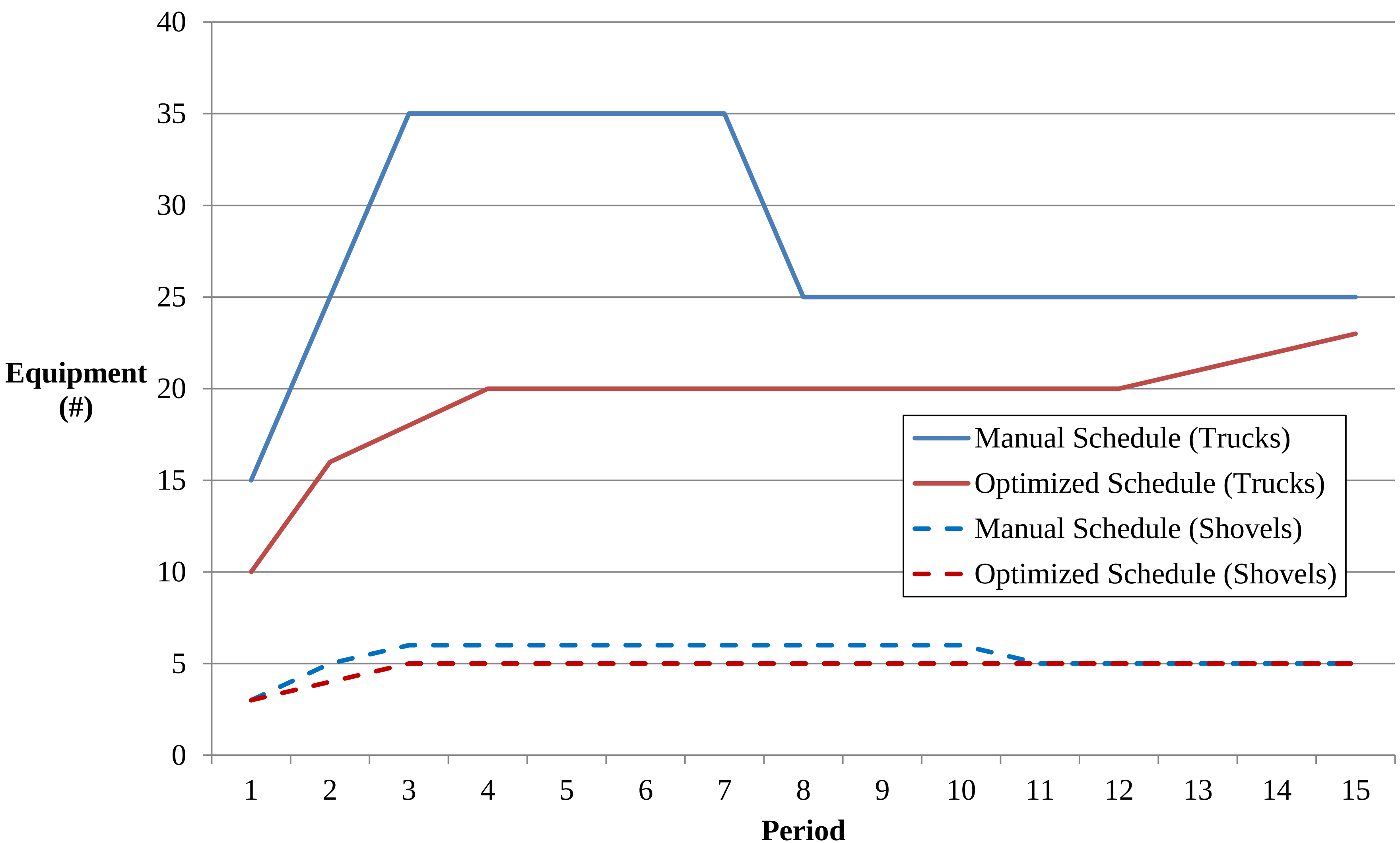
# Unprocessed Tonnes



# Silica in Concentrate (SiC)



# Major Equipment Fleet



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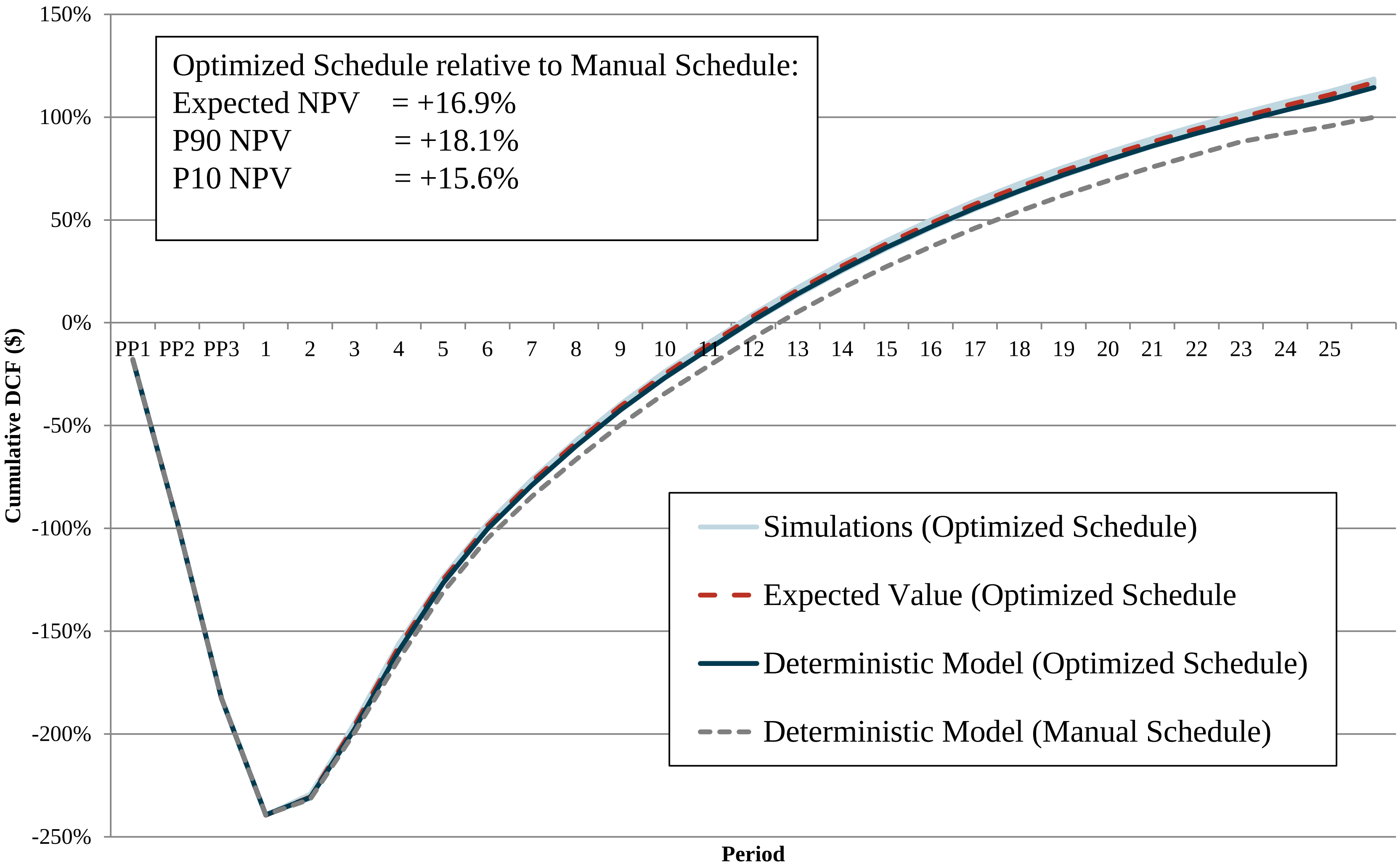
# Cumulative DCF



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# Questions?

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**OTCQX : NWLNF**

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