COSMO – *Stochastic Mine Planning Laboratory*
Department of Mining and Materials Engineering

Stochastic Mine Planning Concepts, Applications and Contributions:

From past developments to production scheduling with 'future data'

Roussos Dimitrakopoulos

Overview

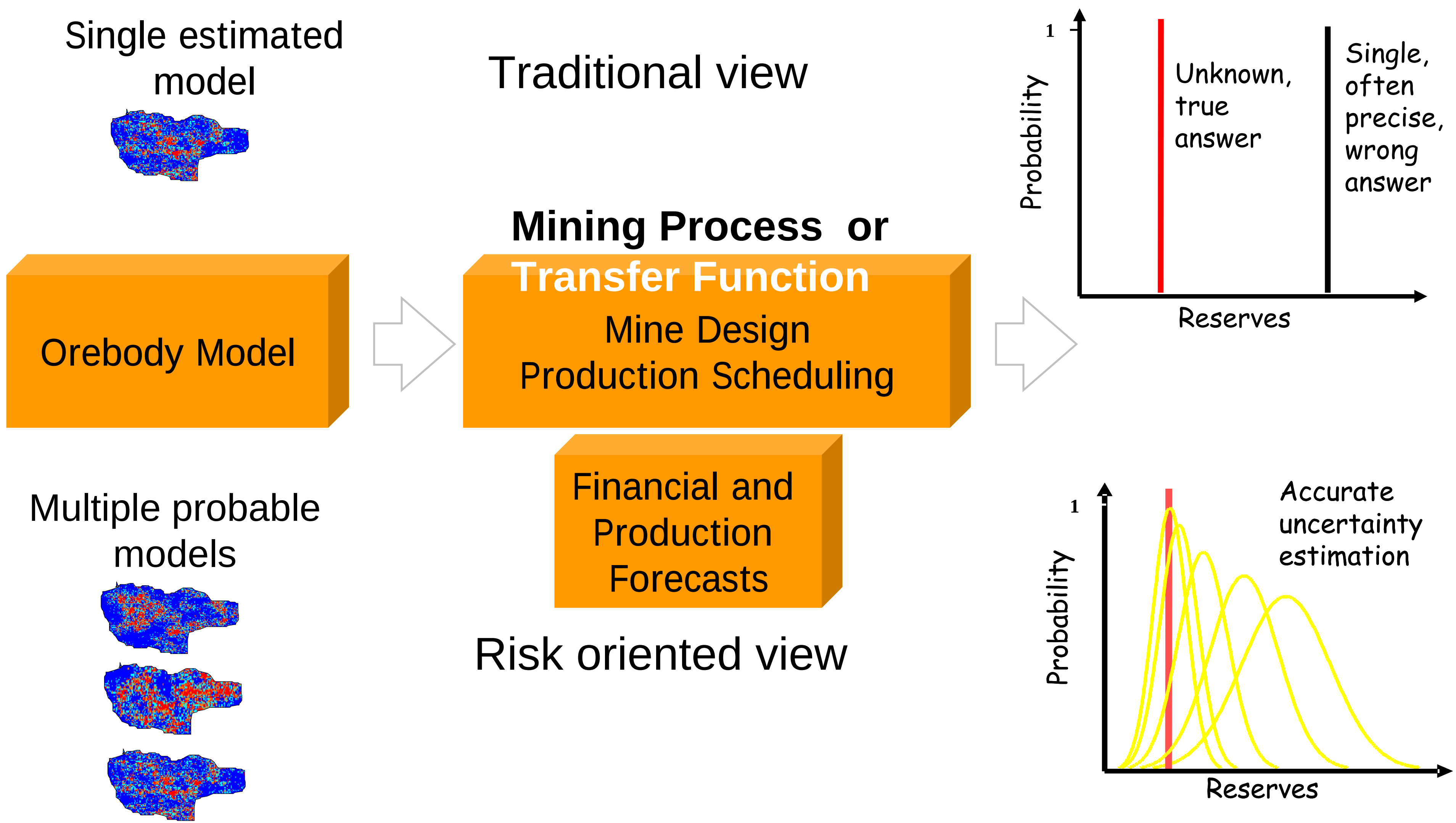
- The economic side of uncertainty
- Models of geological uncertainly
- Limits of traditional mine design optimization
- Shifting the paradigm: Stochastic mine planning
- Using uncertainty to improve project performance
- Uncertainty is great!

Risk in Mining: A World Bank Survey

- 60% of mines had an average rate of production LESS THAN 70% of planned rate
- In the first year after start up, 70% of mills or concentrators had an average rate of production LESS THAN 70% of design capacity
- Key contributor to mining risk felt in all downstream phases:

  Geology and reserves

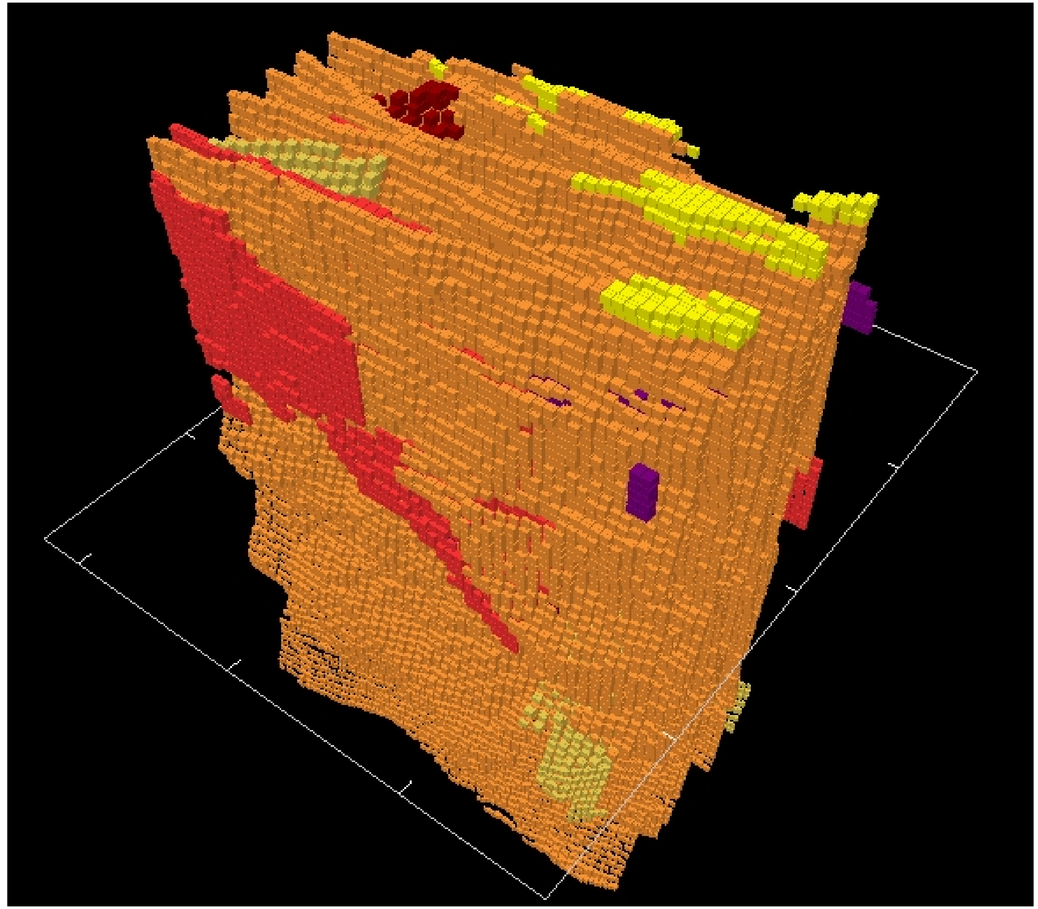
Mining Project Valuation



Quantitative Models of Geological Uncertainty:

Stochastic or geostatistical
conditional simulations

Describing the Uncertainty about a Gold Deposit



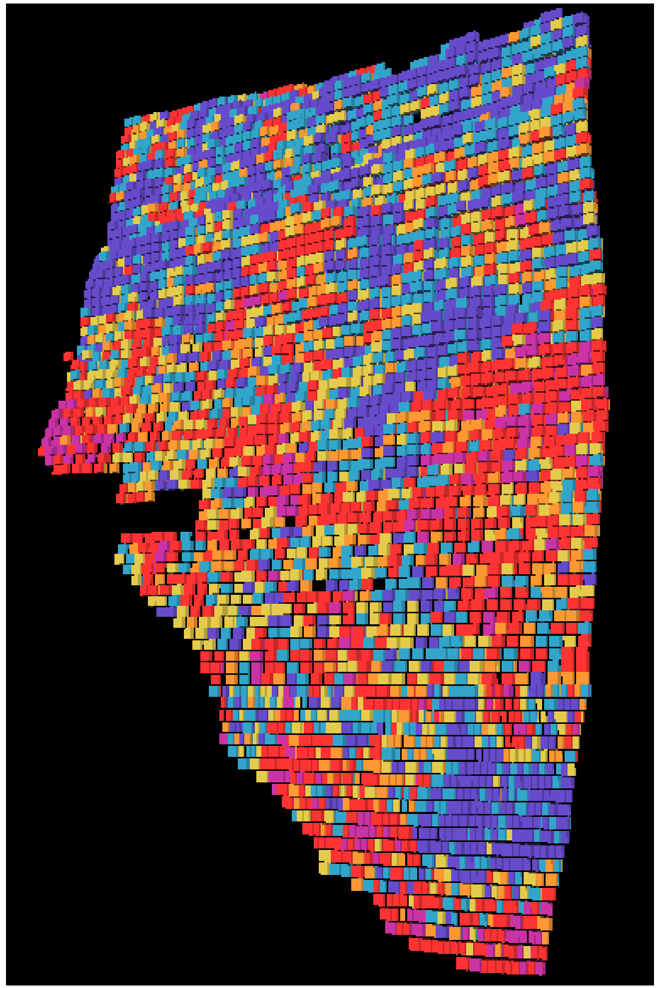
Model characteristics:

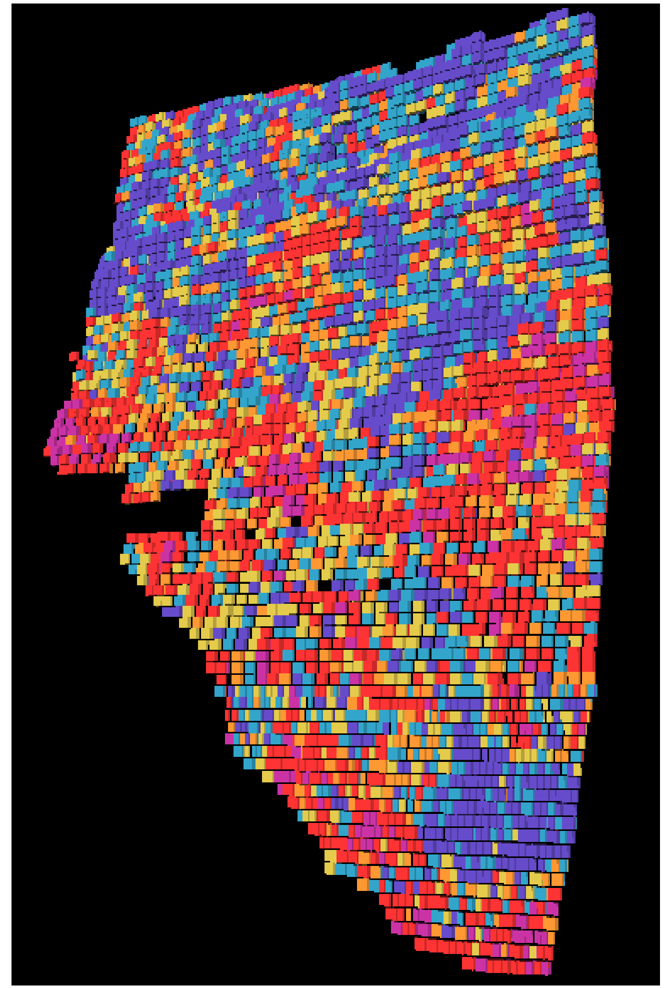
- o Large number of blocks
- o Multiple domains
- o Resource classes with specific sample selection criteria

A gold load

Describing the Uncertainty about a Gold Deposit

Lode 1502
Simulation #1





Uncertainty is not a "Bad Thing"

Many managers believe that uncertainty is a problem and should be avoided…..

… you can take advantage of uncertainty. Your strategic investments will be sheltered from its adverse effects while remaining exposed to its upside potential. Uncertainty will create opportunities and value.

Once your way of thinking explicitly includes uncertainty, the whole decision-making framework changes.

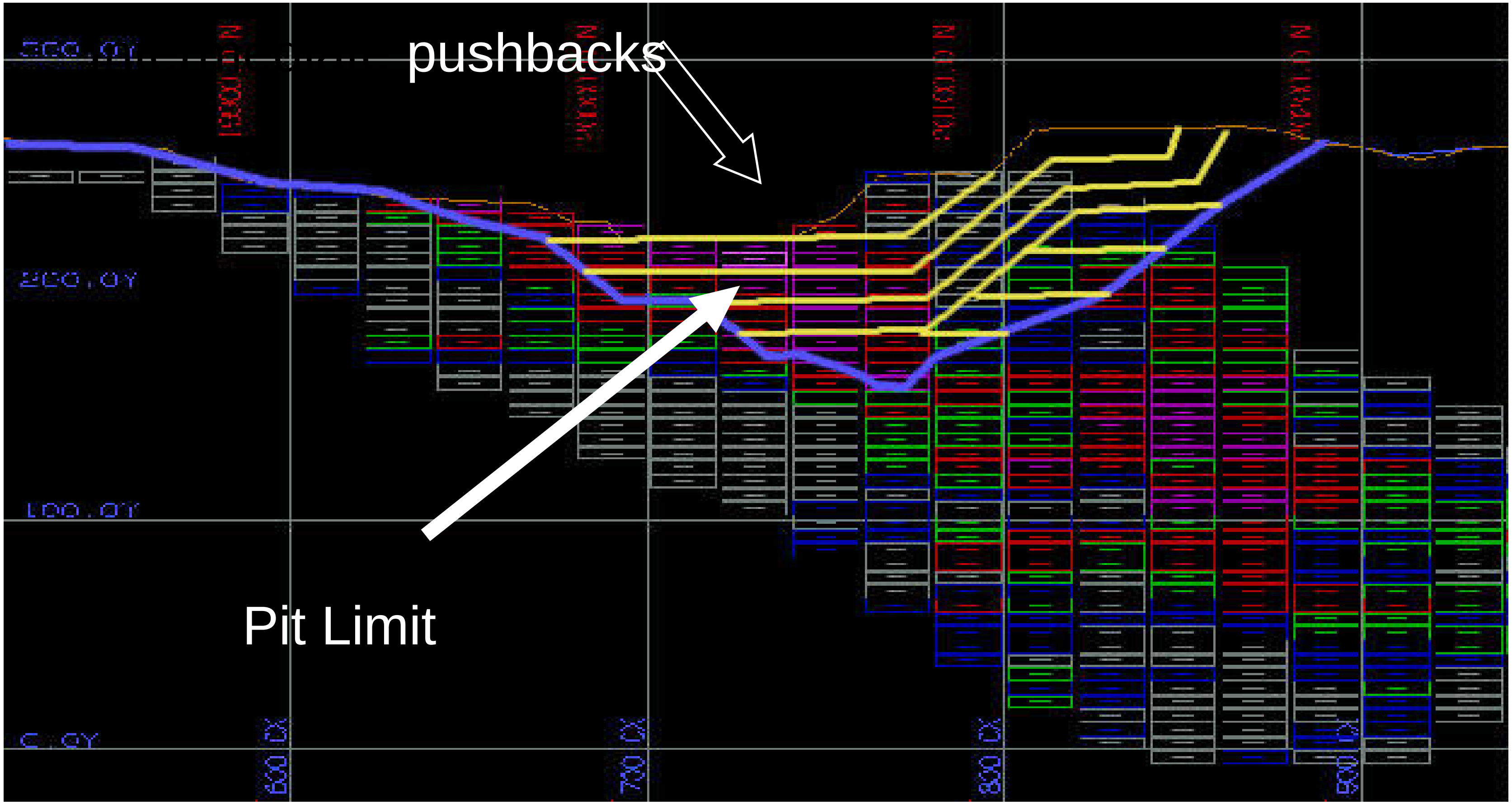
Martha Amram and Nalin Kulatilaka
in "Real Options"

Moving Forward in Optimization

Limits of traditional mine design

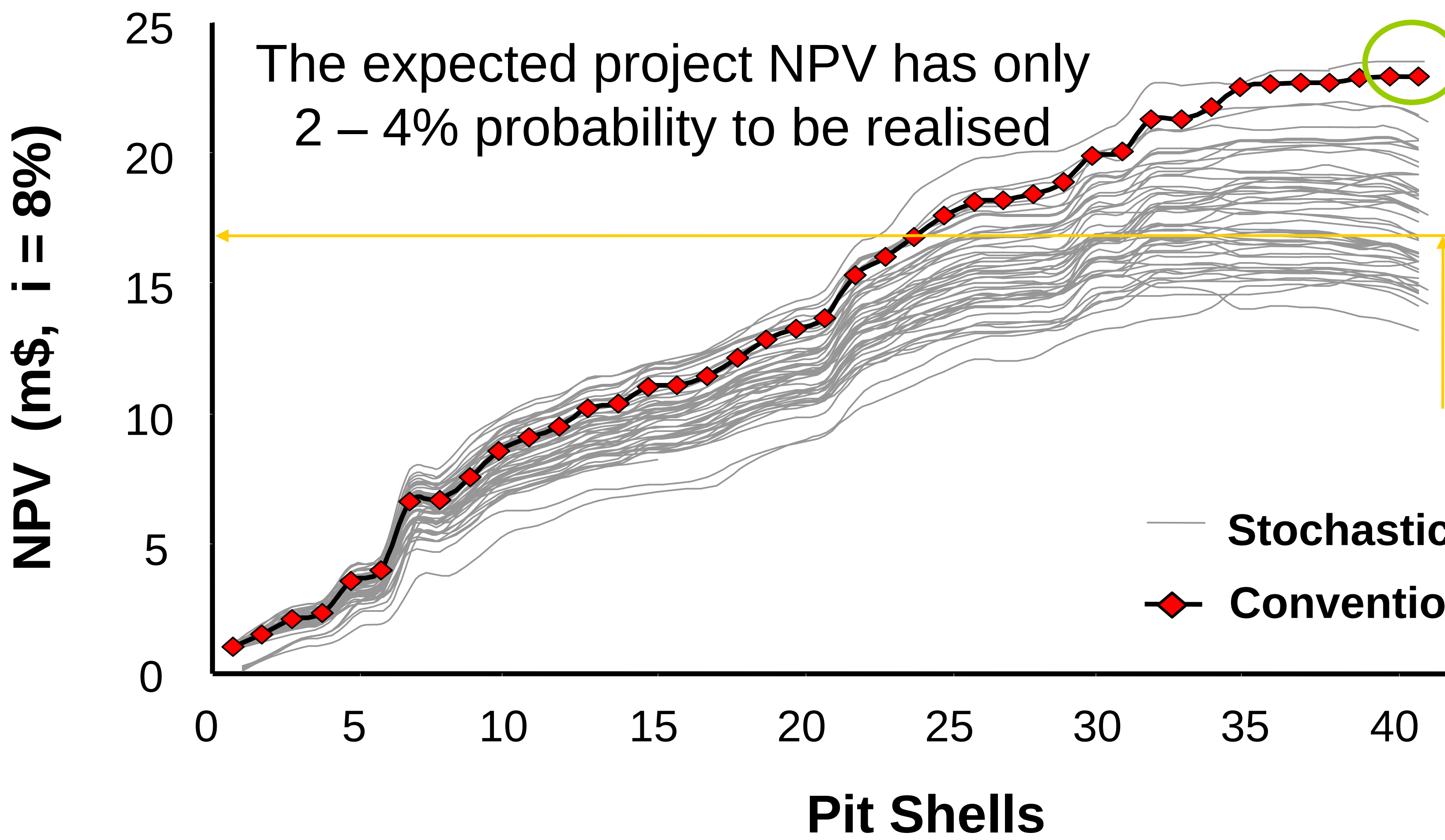
Using models of uncertainty

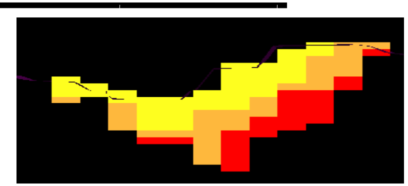
Open Pit Mine Design and Production Scheduling



Risk Analysis in a Mine Design

Limits of Traditional Modelling

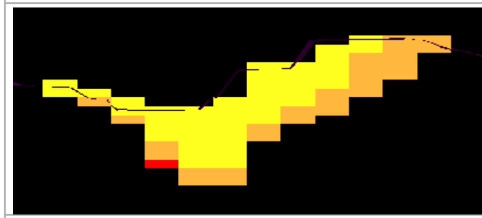
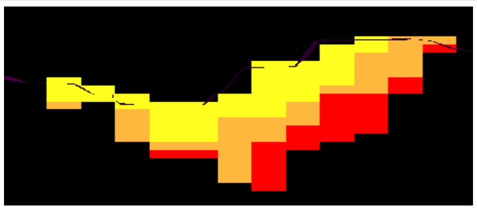
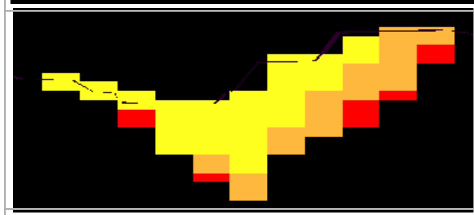
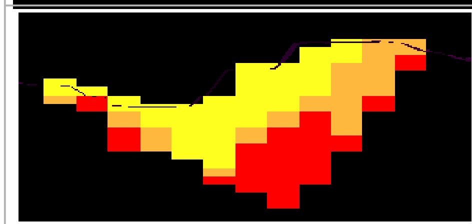




Moving Forward ….. Step 1

Exploring existing technologies

Past Work – Open Pit Mine Design

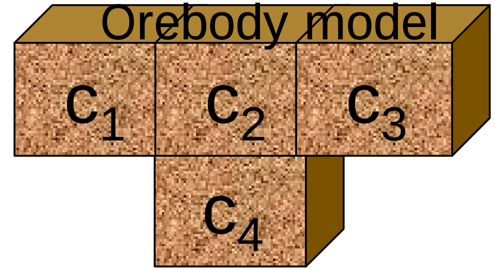
Pit Design	Upside Potential (m$)			Downside Potential (m$)		
	CB-1	CB-2	CB-3	CB-1	CB-2	CB-3
	2.3	2.41	1.8	0.0	-0.079	-0.20
	1.3	2.1	1.6	-0.78	-0.15	-0.51
	2.4	2.43	1.9	0.0	-0.022	-0.28
	2.9	2.40	1.2	0.0	-0.16	-0.96

Moving Forward ….. Step 2

Re-writing optimizers

Models of Uncertainty in Optimization

Integer Programming



An objective function

Maximise $(c_1x_1^1+c_2x_2^1+\ldots.)\ \ldots$

c = constant

X_1^1 = binary variable

Subject to

$c_1x_1^1+c_2x_2^1+\ldots. \geq b_1$ → Period 1

⋮

$c_1x_1^p+c_2x_2^p+\ldots. \geq b_p$ → Period p

Stochastic Integer Programming

The objective function now .....

Maximise $(s_{11}x_1^1+s_{21}x_2^1+\ldots\; s_{12}x_1^1+s_{22}x_2^1+\ldots)$.

Subject to

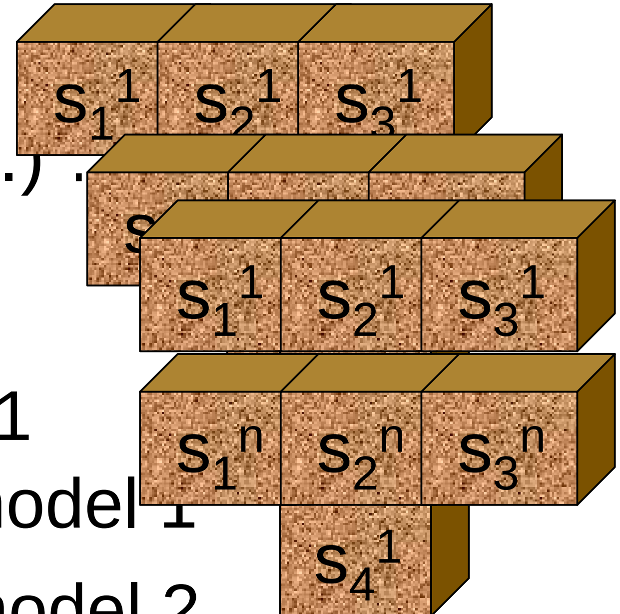
$$s_{11}x_1^1+s_{21}x_2^1+\ldots \geq b_1$$

→ Period 1

Simulated model 1

Simulated model 2

Simulated model r



$$s_{11}x_1^p+s_{21}x_2^p+\ldots \geq b_1$$

$$s_{12}x_1^p+s_{22}x_2^p+\ldots \geq b_1$$

$$s_{1r}x_1^p+s_{2r}x_2^p+\ldots \geq b_1$$

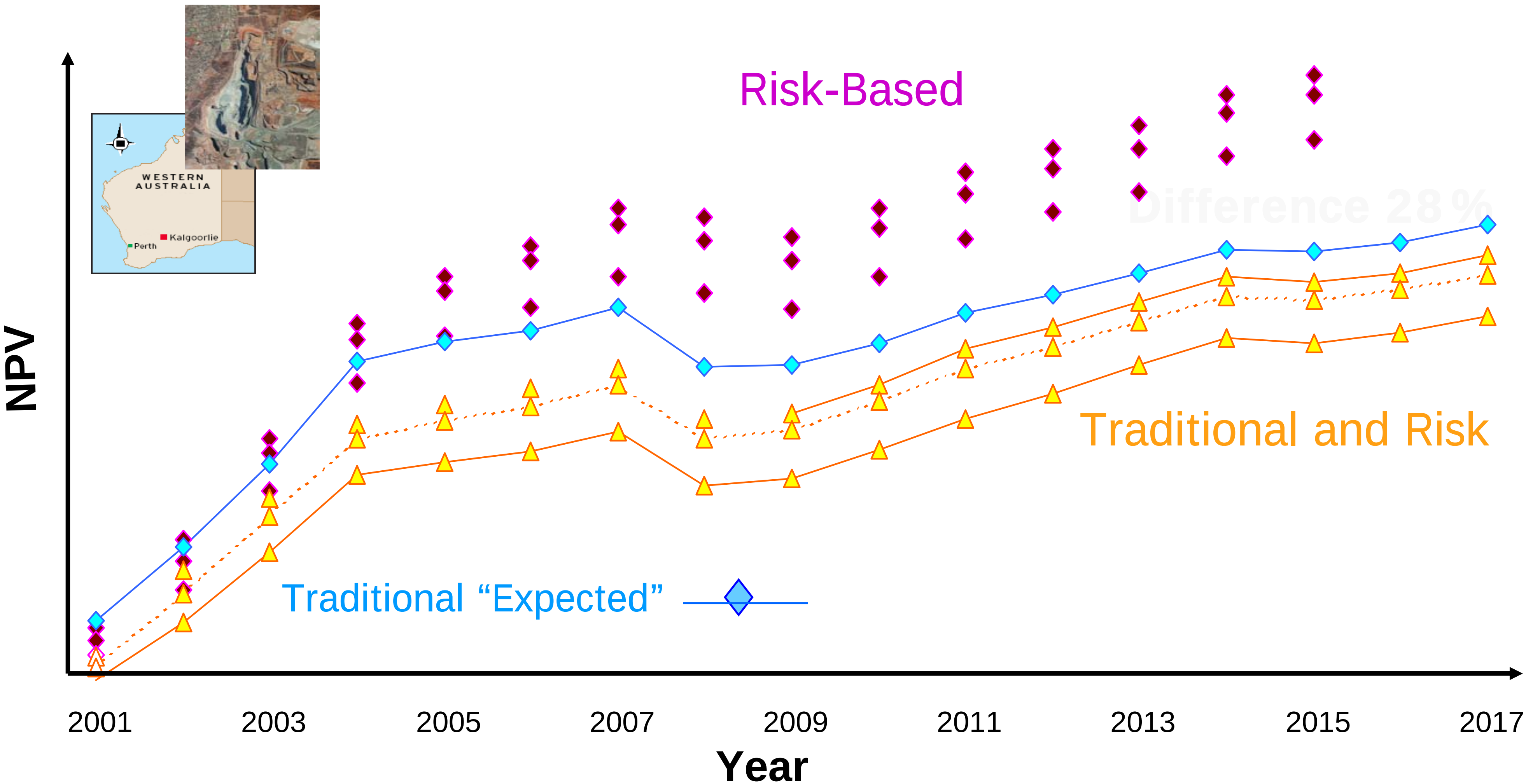
→ Period p

Higher NPV for Less Risk

"Uncertainty will

create opportunities and value"

Uncertainty is Good: “Base case” vs “Risk-based”



Discounting Geological Risk

The discounting goes along

with production sequencing

SIP - Production Scheduling Model

Objective function

$$\text{Max} \sum_{t=1}^{P} \left[\sum_{i=1}^{N} E\{(NPV)_i^t\}\ b_i^t \right.$$

Part 1
Mill & dump

$$\left. - \sum_{s=1}^{M} (c_u^{ty} d_{su}^{ty} + c_l^{ty} d_{sl}^{ty}) \right]$$

Part 2
Risk management

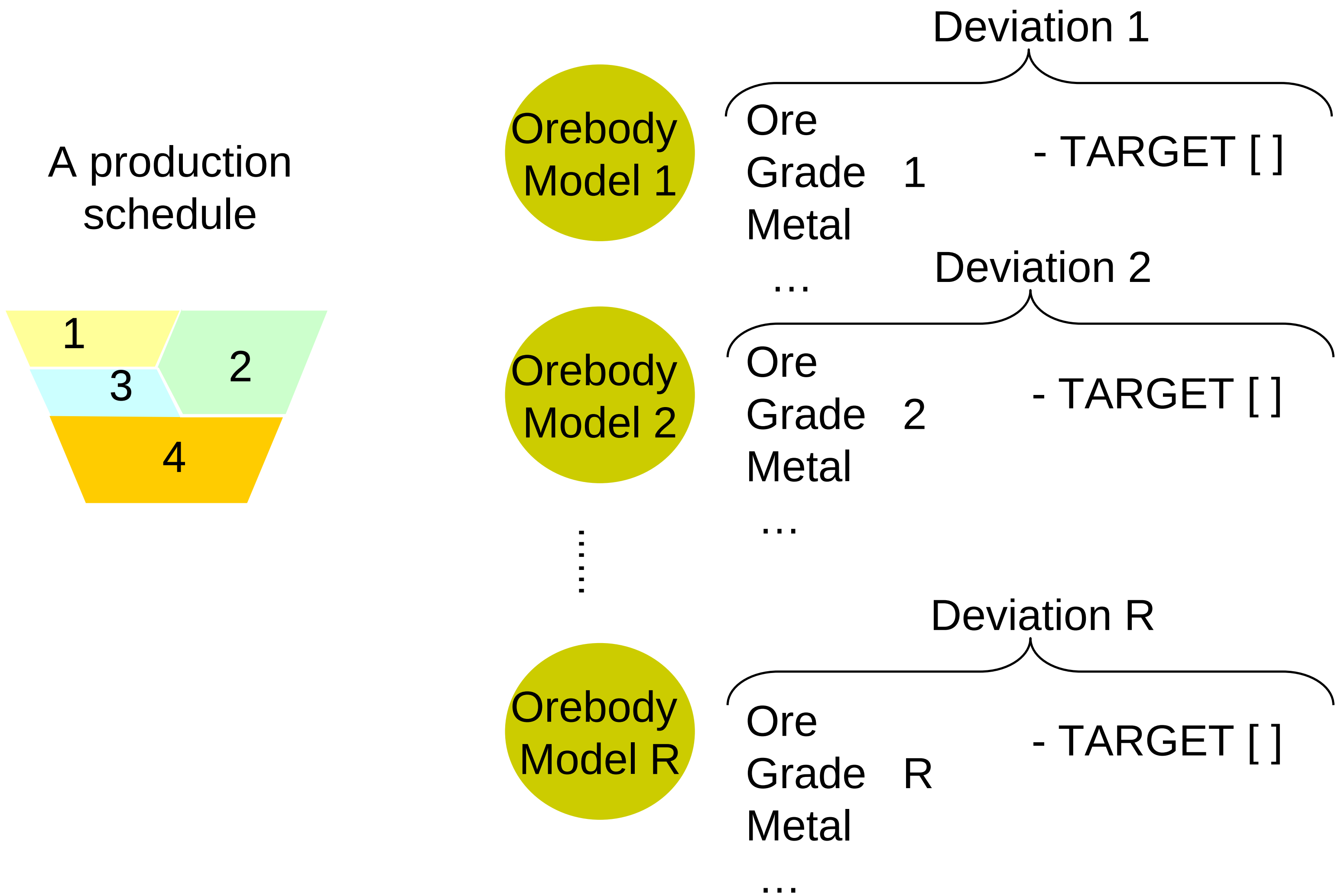
$$- \sum_{i=1}^{U} E\{(NPV)_i^t + MC_i^t\} * s_i^t$$

Part 3
Stockpile input

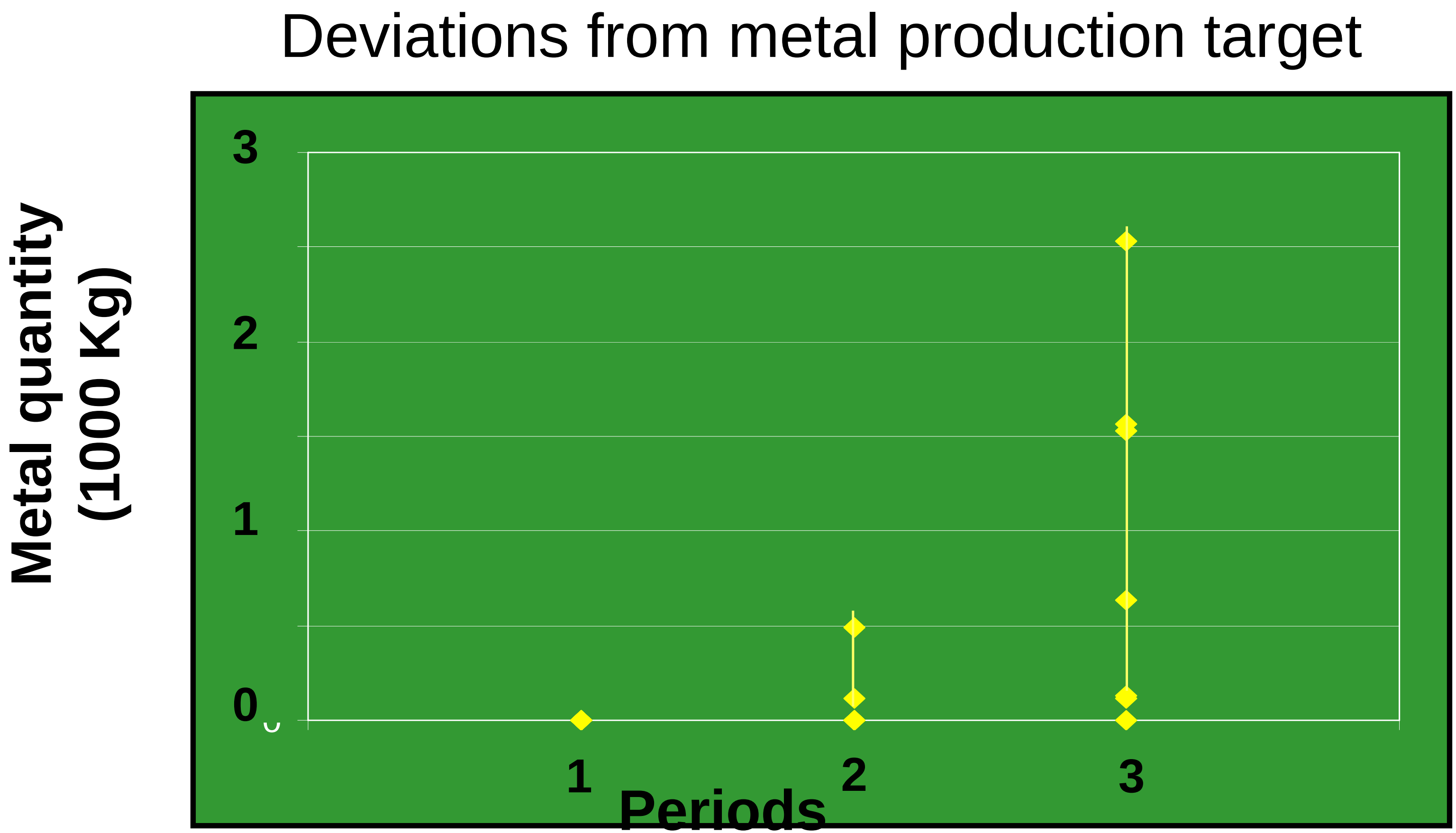
$$+ \sum_{s=1}^{M} (SV)_s^t\ (P)\ q_s^t$$

Part 4
Stockpile output

Stochastic Integer Programming - SIP



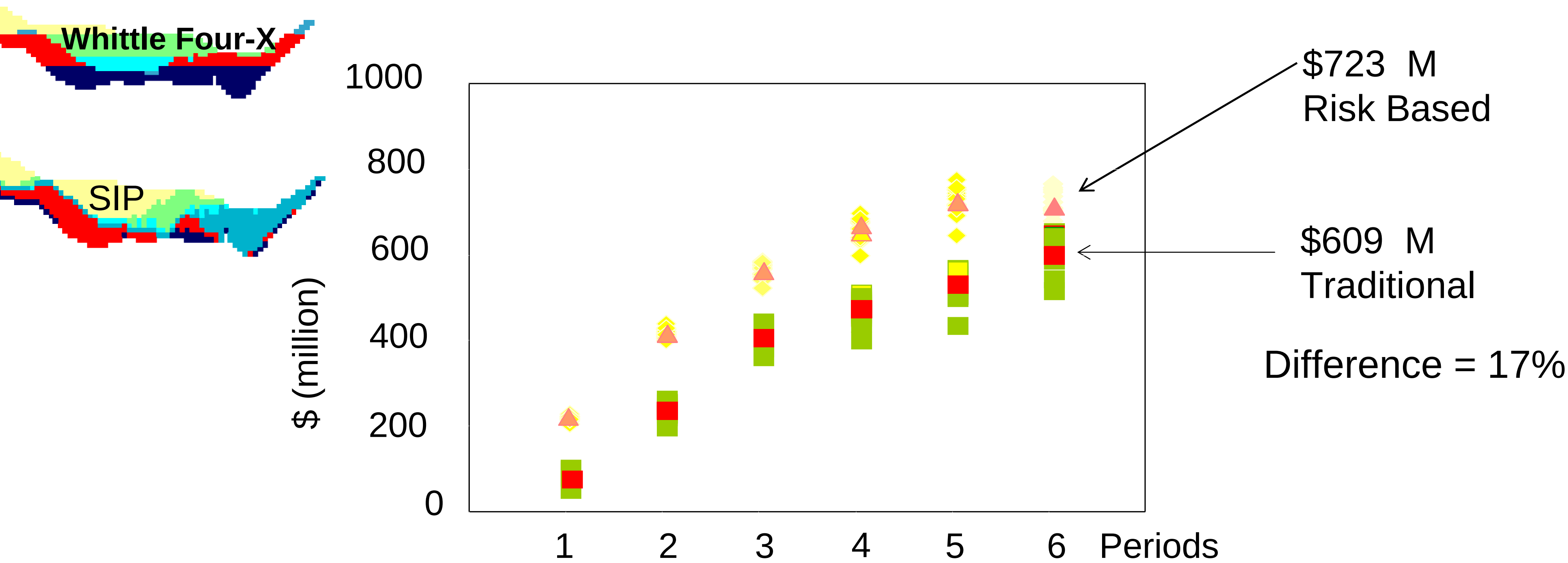
Managing Risk Between Periods



$C^t = C^{t-1} * RDF_{t-1}$ $RDF_t = 1/(1+r)^t$

RDF – risk discounting factor r – orebody risk discount rate

Uncertainty is Good: Traditional vs Risk-Based



Cumulative NPV values

SIP model WFX

Average NPV values

SIP model WFX

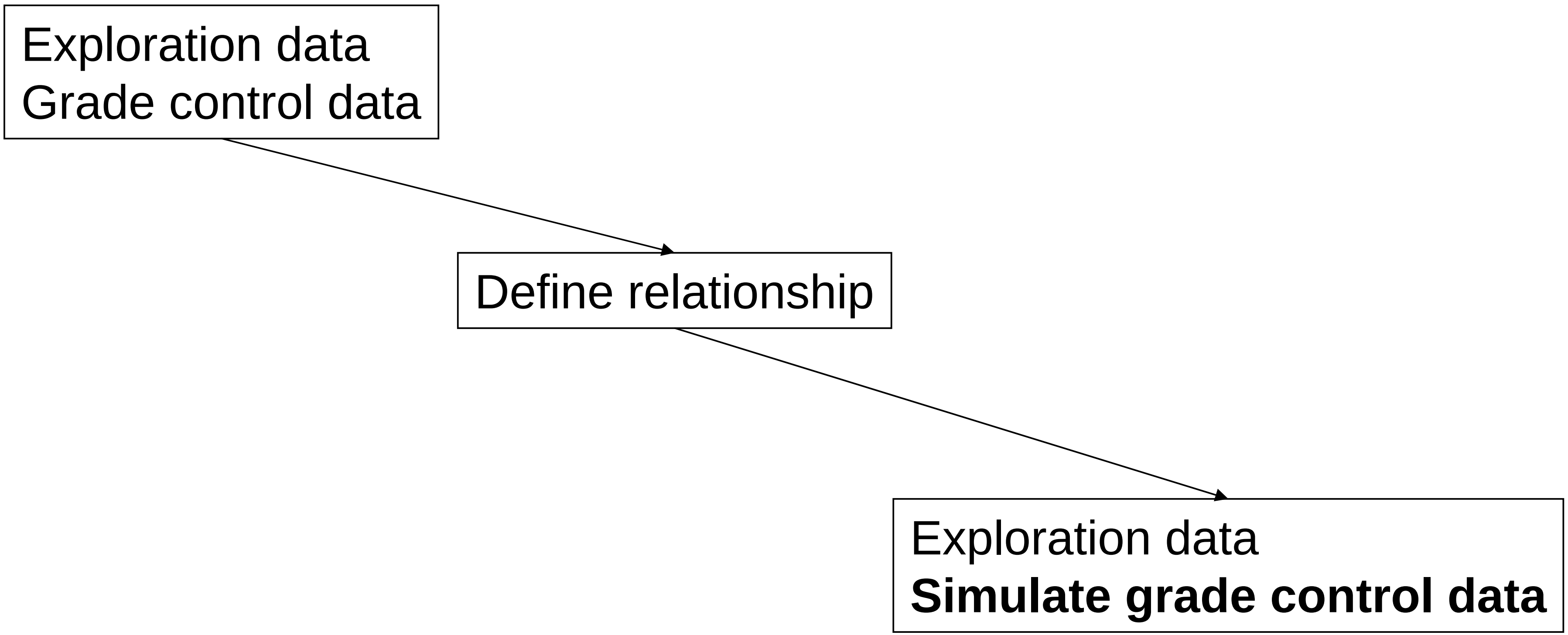
Geological Risk Discounting= 20%

Future Drilling Data

Production sequencing with simulated grade control drilling

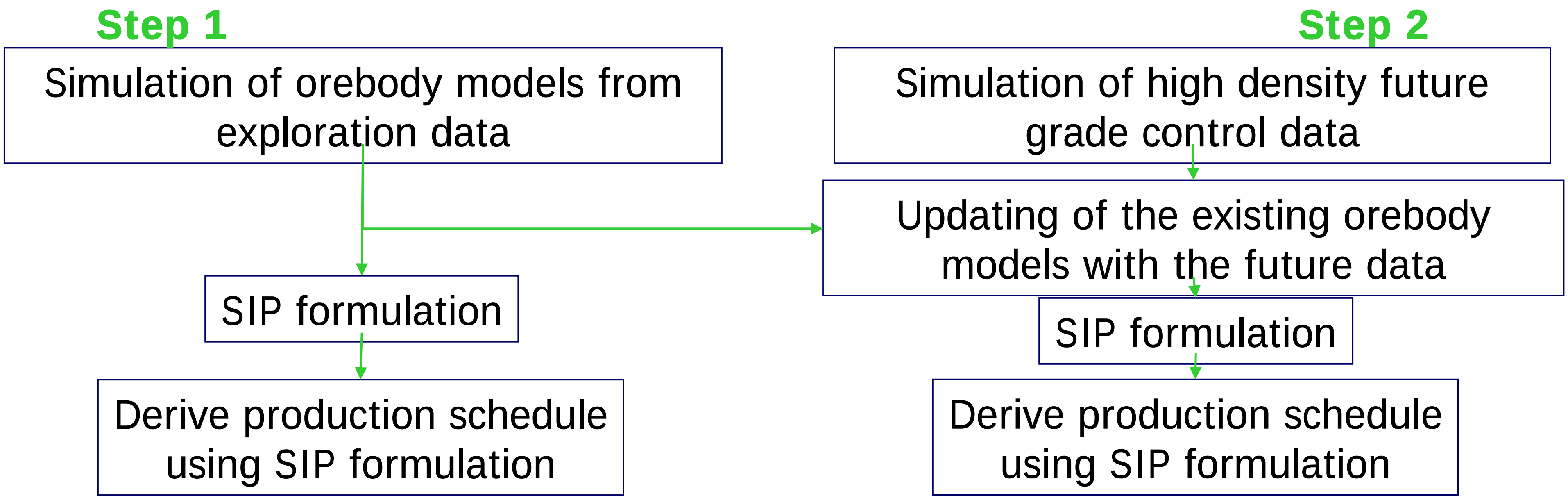
‘Future’ Grade Control Data

Bench/Section of pit already mined out



Bench/Section of pit NOT yet mined out

Scheduling and Simulated Future Data



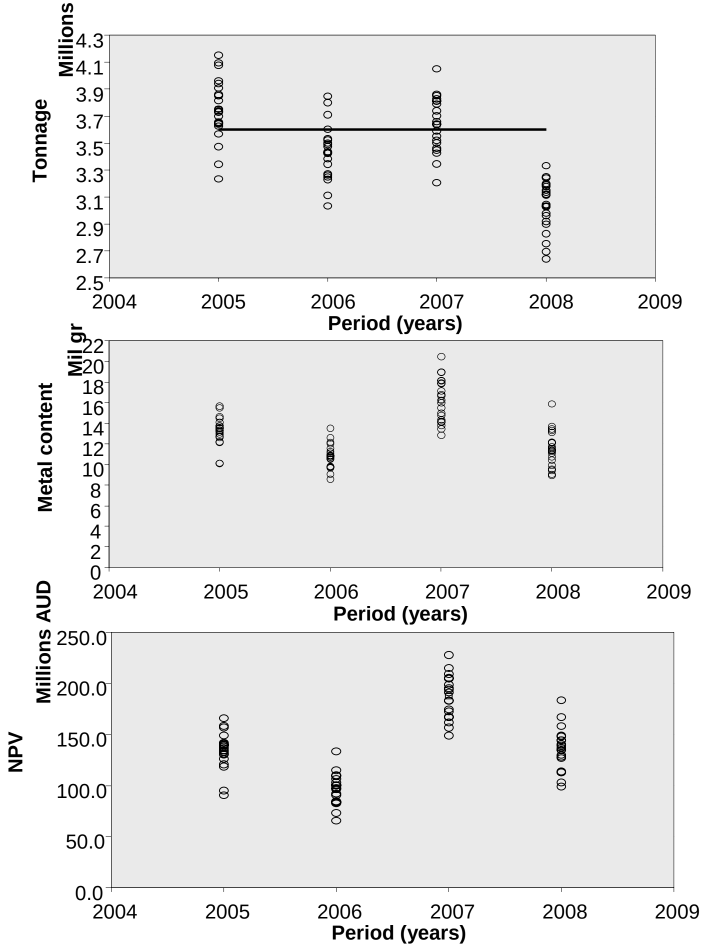
Step 3

Schedules:

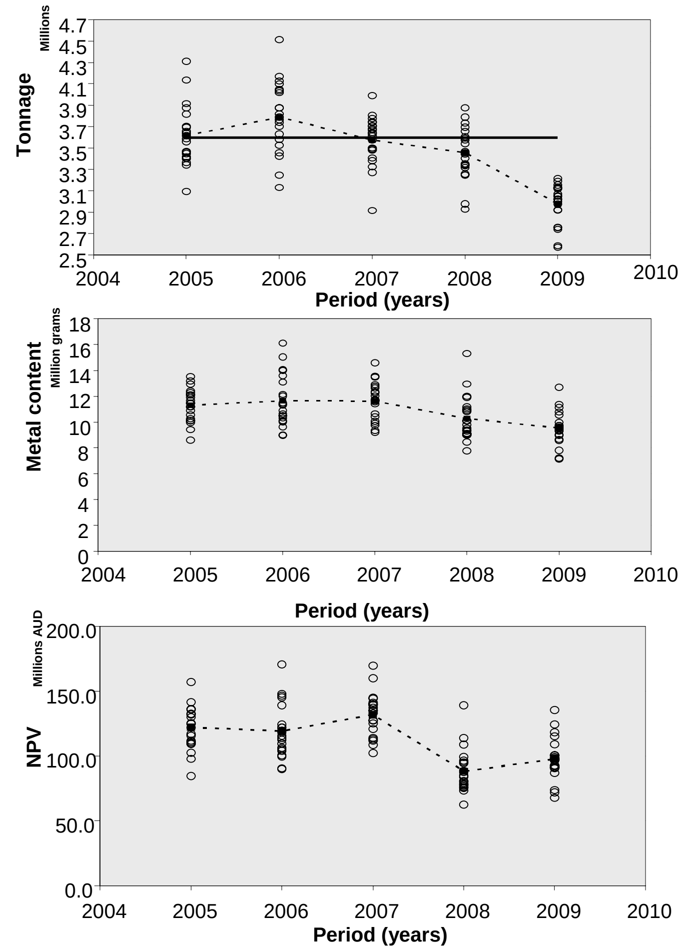
- SIP schedule derived from simulations based on exploration data
- SIP schedule derived from simulations based on simulated grade control information (updated models)
- Risk analysis of mine's schedule with the updated models

Scheduling and Simulated Future Data

SIP and Simulated Orebody



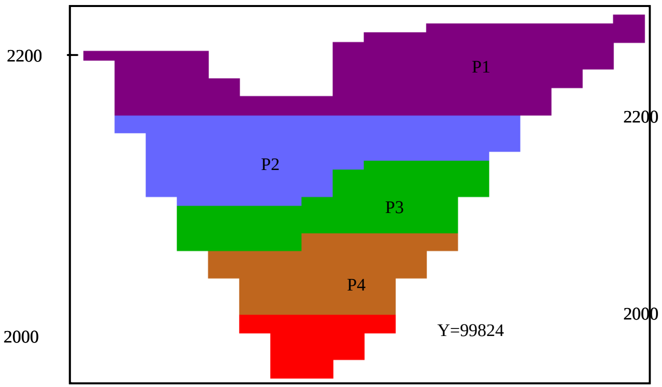
SIP and Simulated Future Data



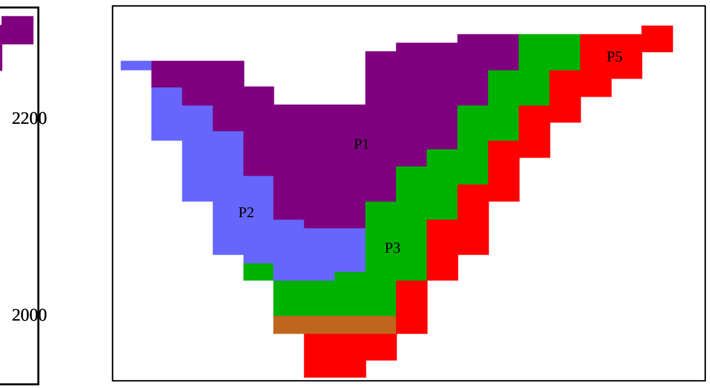
Mill target (ore production) Average of the simulations Simulations

Scheduling and Simulated Future Data

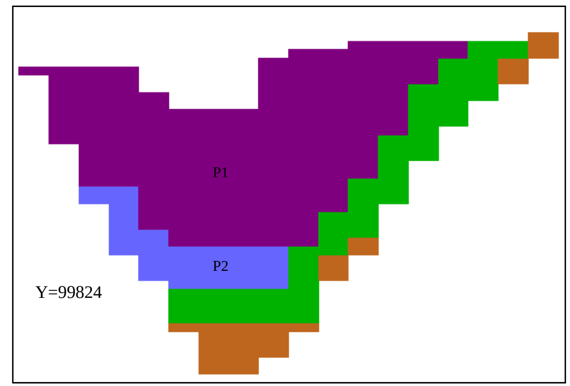
Mine’s Schedule

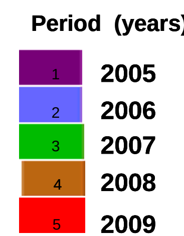


SIP & Simulated Orebody



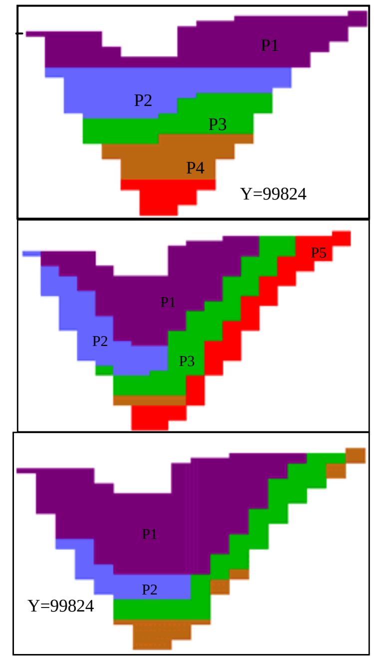
SIP & Future data





Scheduling and Simulated Future Data

	Simulations (exploration data)	Updated simulations (future data)	Mine's schedule (future data)
Ore Tonnes (Mt)	14	18	10
Metal Tonnes (Mt)	52	55	38
NPV ($ Mil.)	552	560	330



Uncertainty is Great

And we will eventually find out