McGill

Harnessing Uncertainty for Orebody Modelling and Strategic Mine Planning

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Sustainable Mineral Resource Development and Optimization under Uncertainty

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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
- Conclusions - Uncertainty is great!

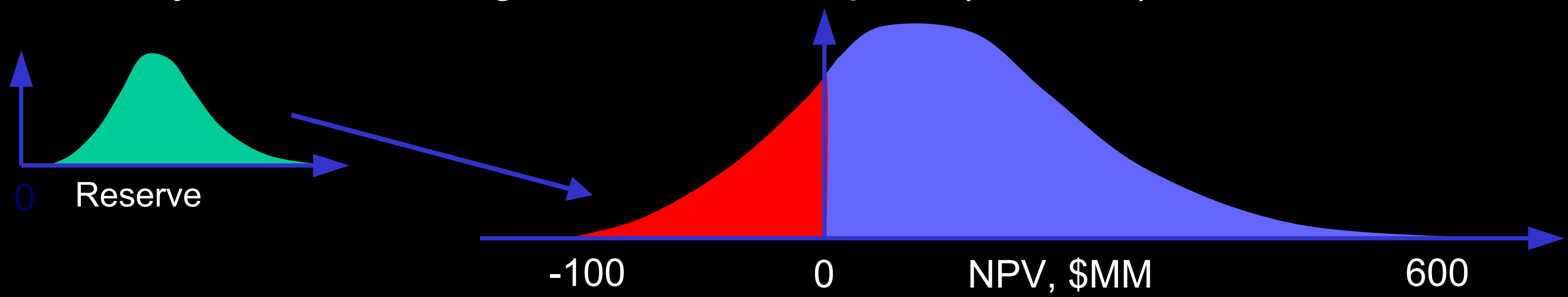
Uncertainty Matters:

The Economic Side of Uncertainty

Changing the way we do things

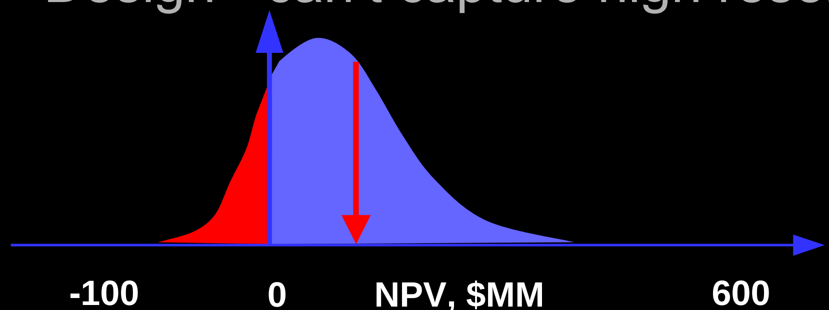
Uncertainty Matters:
Return on Investment is Uncertain, therefore Risky

- Possibility of not making a return on capital (NPV<0)

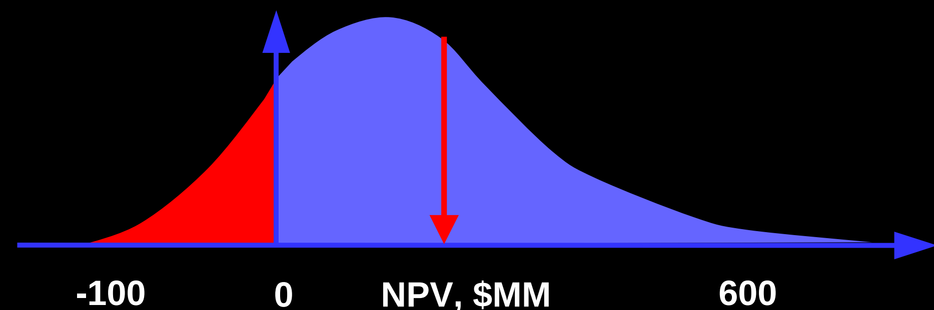


- Alternative development plans may have different risk profiles and expected values. Example:

Design - can’t capture high reserves



Design … can capture…



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

Uncertainty is not a "Bad Thing"

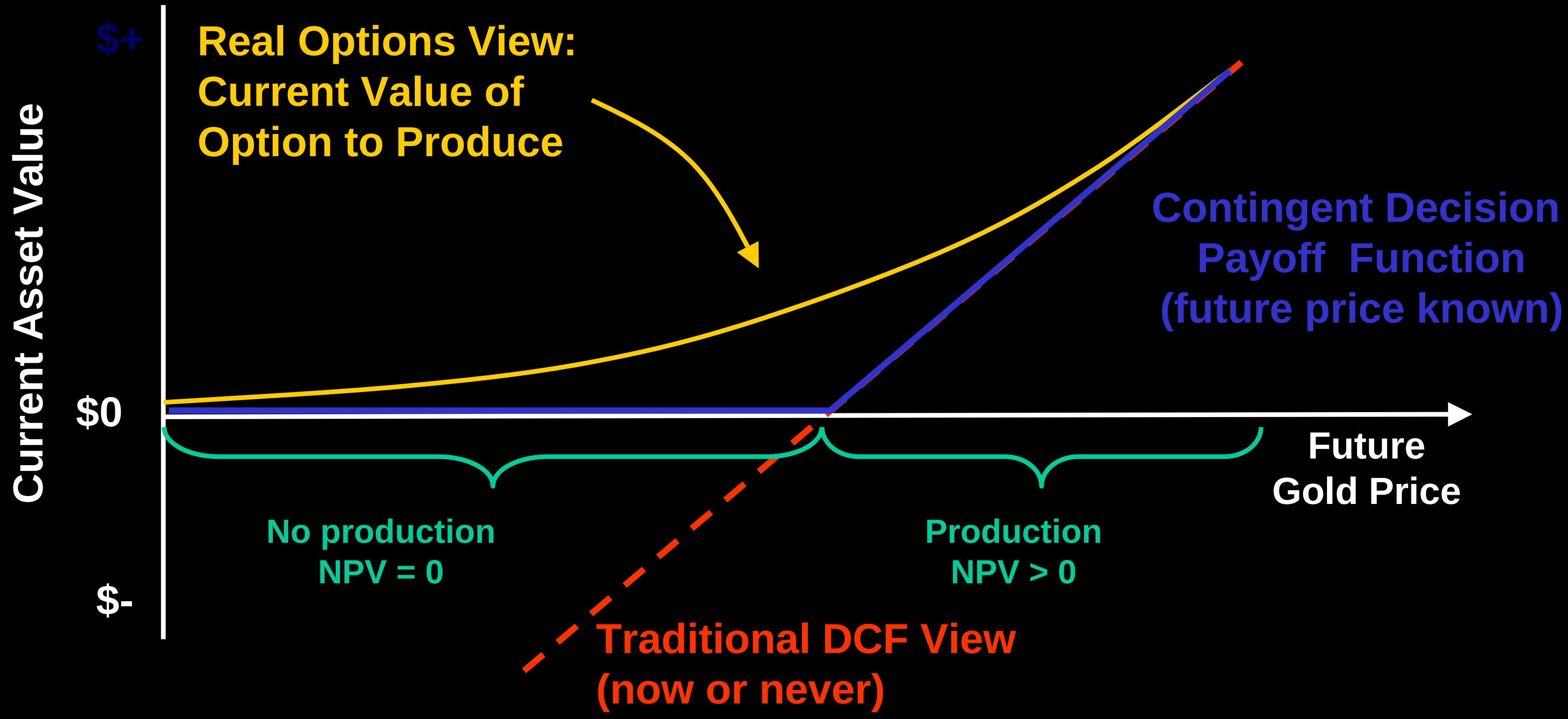
Many managers believe that uncertainty is a problem and should be avoided…..

… 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.

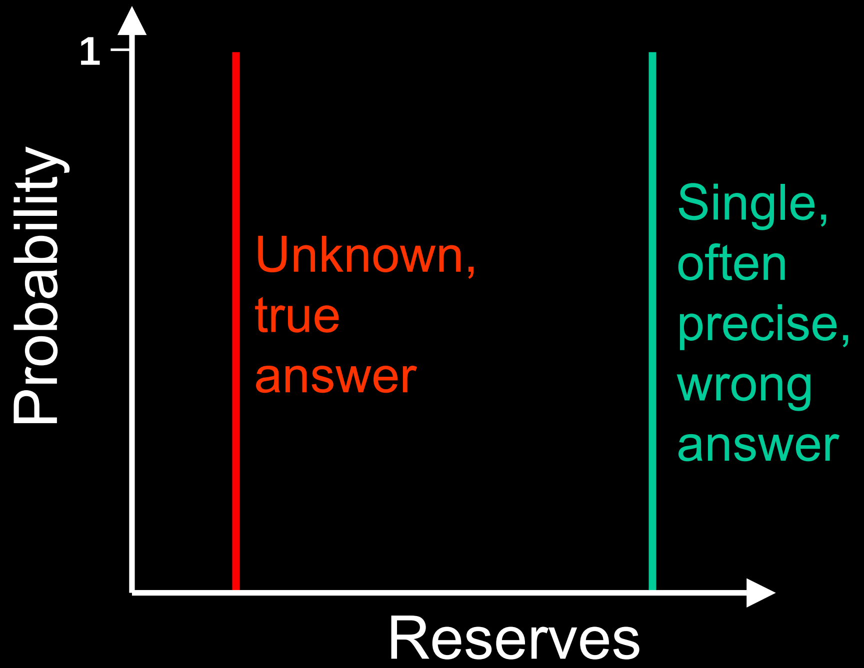
Once your way of thinking explicitly includes uncertainty, the whole decision-making framework changes.

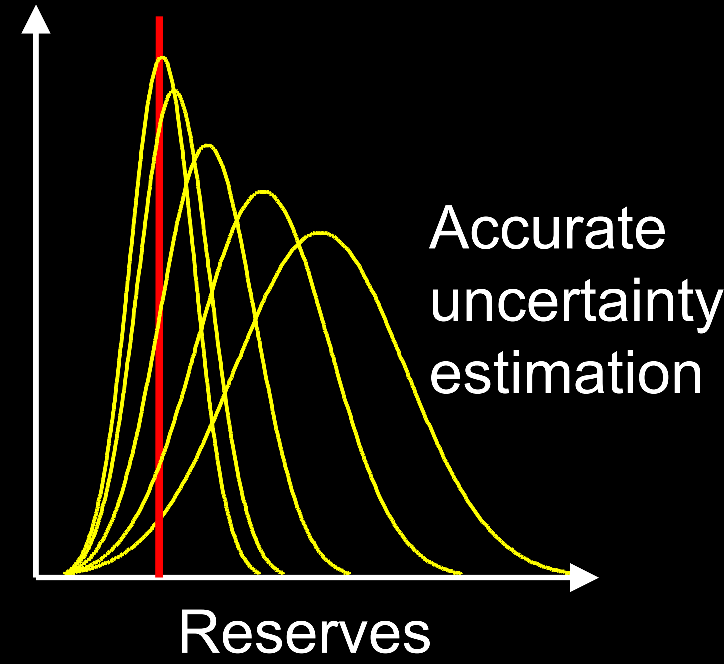
Martha Amram and Nalin Kulatilaka
in "Real Options"

Real Options vs DCF View of Value



Accurate Uncertainty Assessment Needed

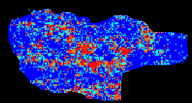




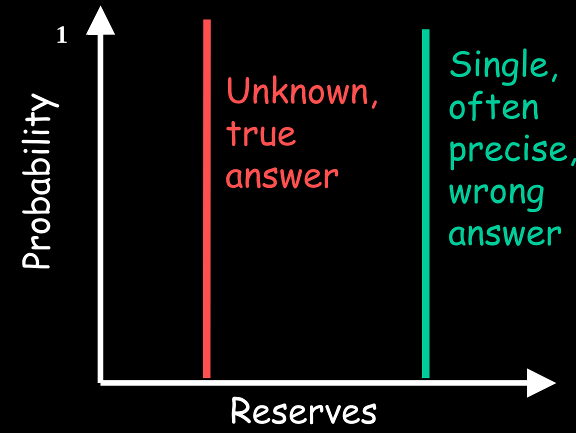
“The goal of technical evaluation should be to strive for an accurate assessment of uncertainty, not a single precise answer”

Mining Project Valuation

Single estimated model



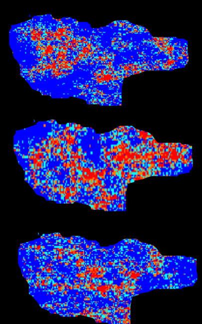
Traditional view



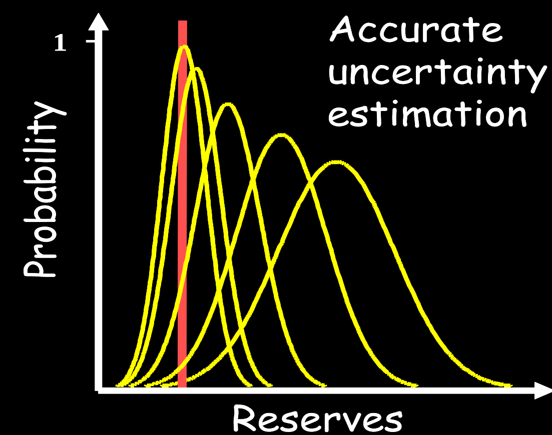
Orebody Model → **Mining Process or Transfer Function**
Mine Design
Production Scheduling →

Financial and Production Forecasts

Multiple probable models



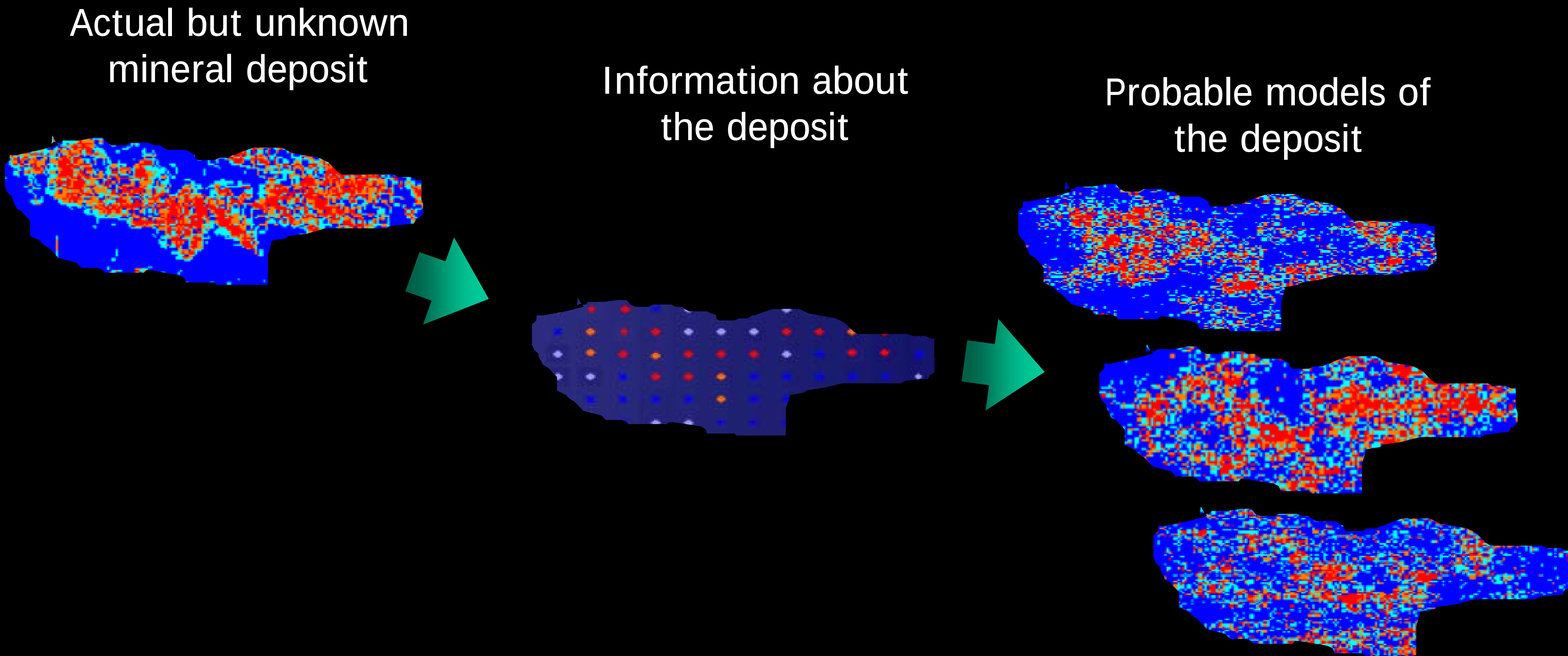
Risk oriented view



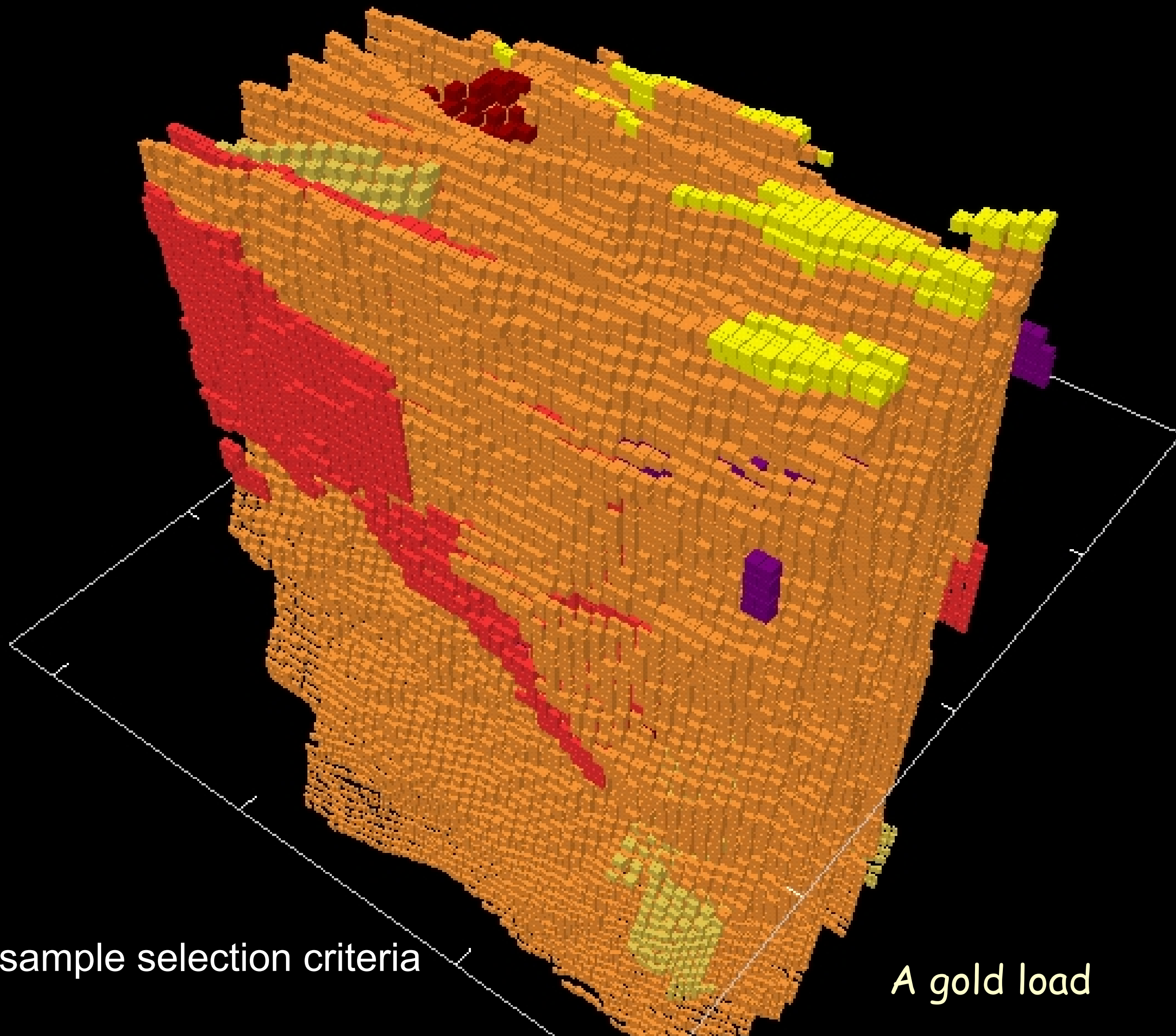
Quantitative Models of Geological Uncertainty:

Stochastic or geostatistical conditional simulations

Describing the Uncertainty about a Mineral Deposit



Describing the Uncertainty about a Gold Deposit

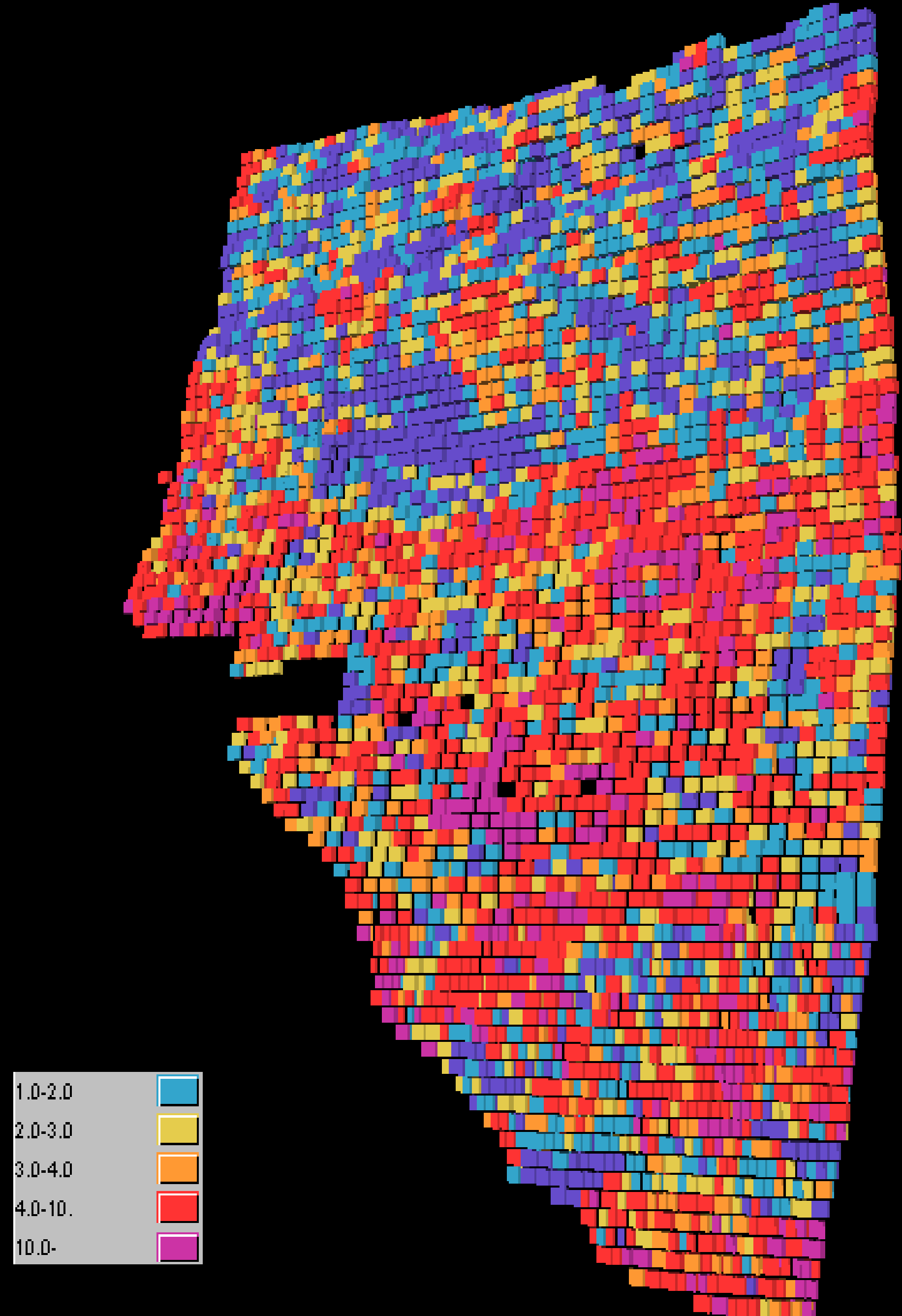


A gold load

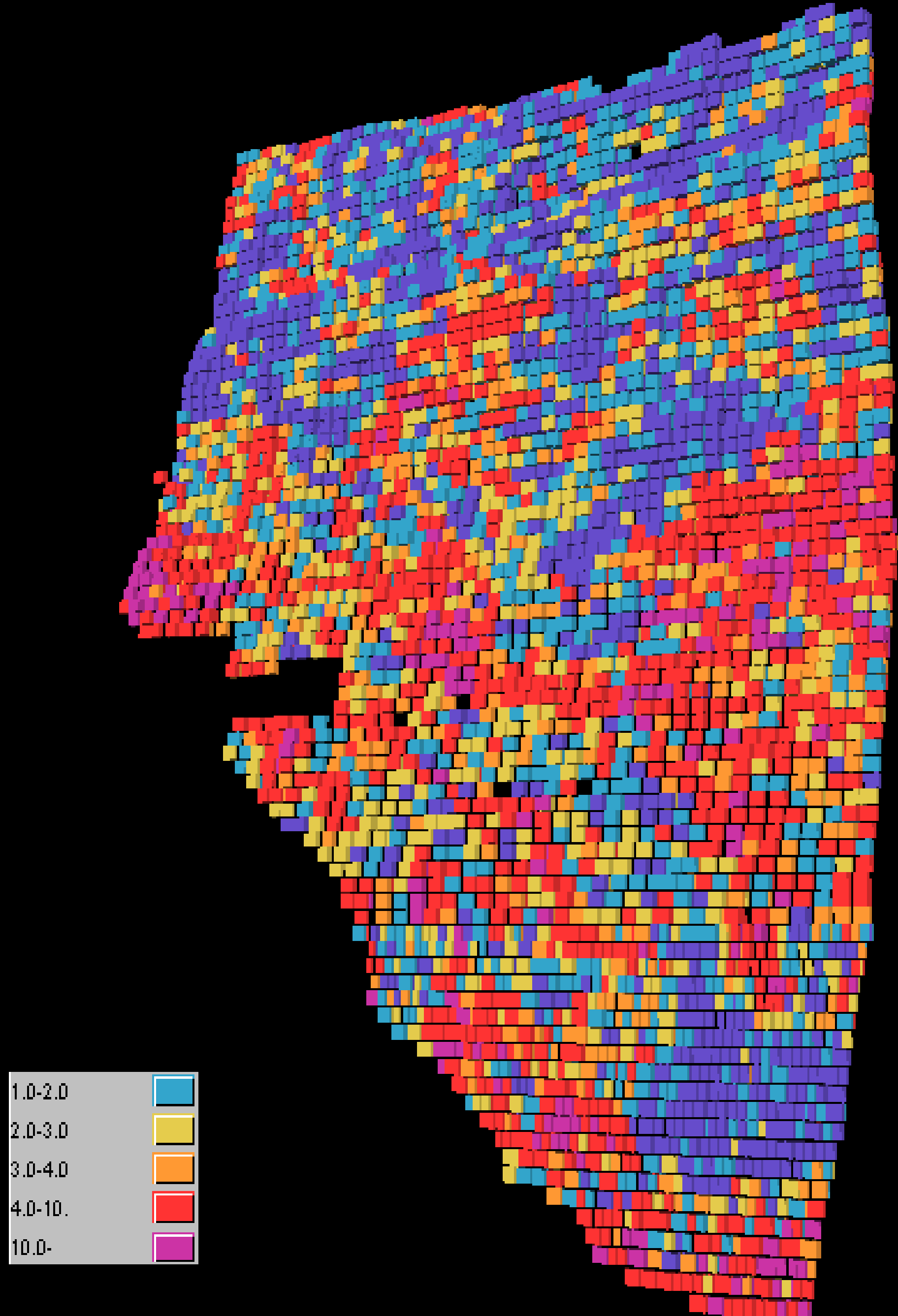
Model characteristics:

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

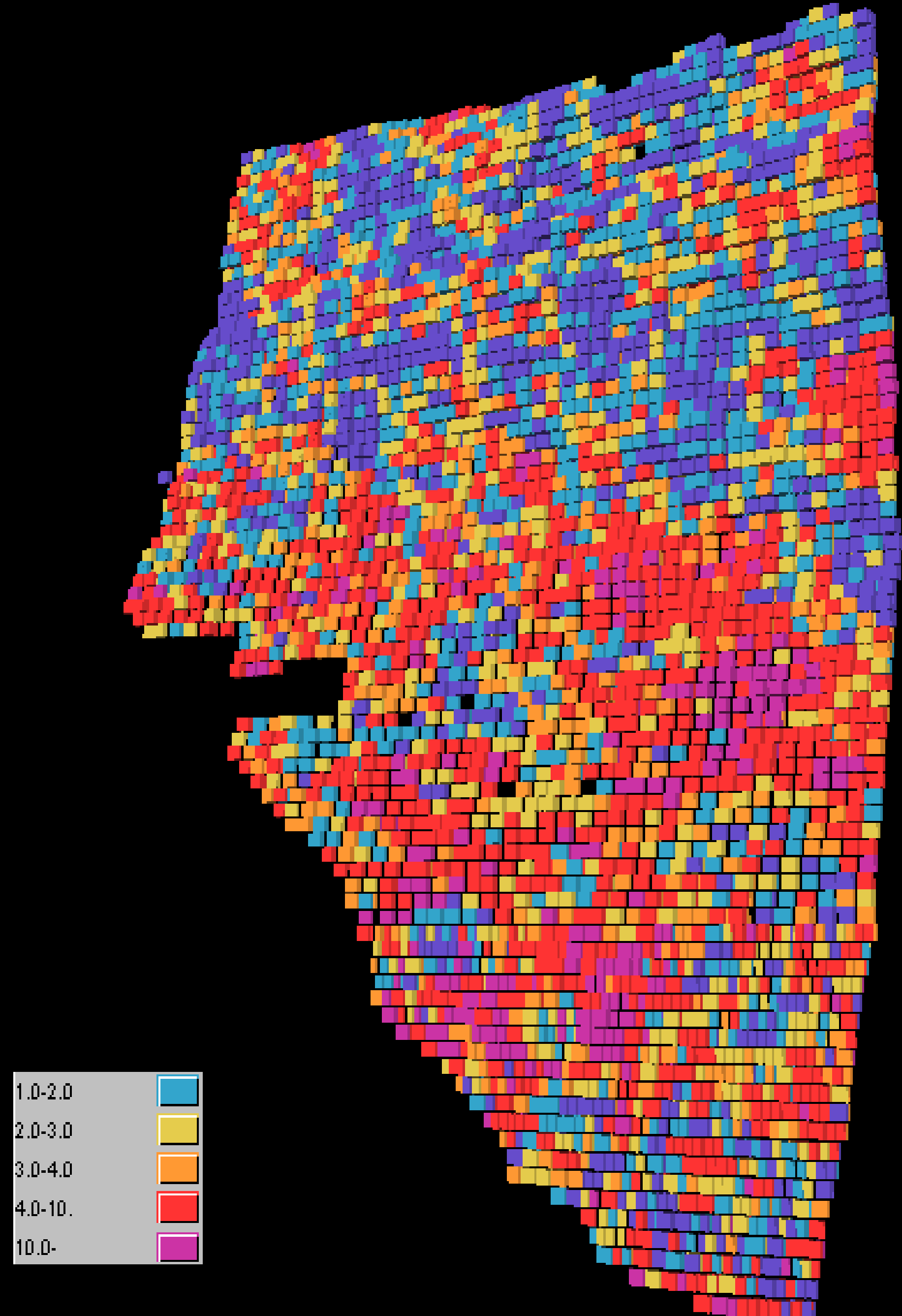
Lode 1502
Simulation #1



Lode 1502
Simulation #2



Lode 1502
Simulation #3



Moving Forward in Optimization:

Limits of Traditional Mine Design

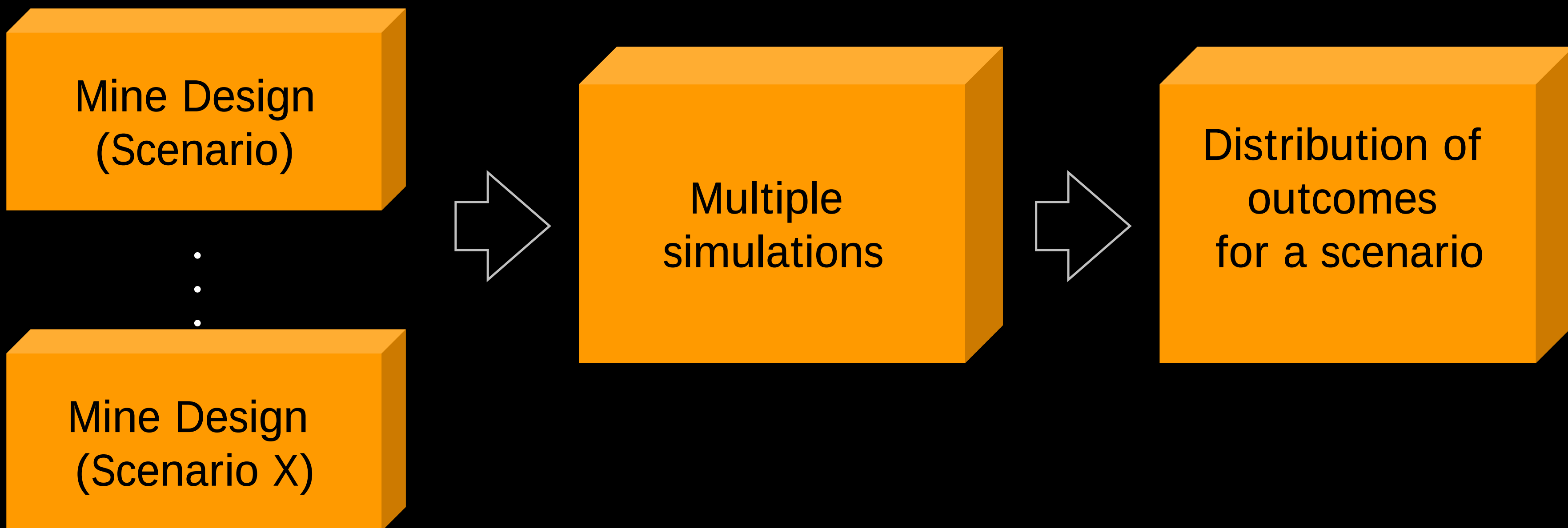
Using Models of Uncertainty

Risk Analysis in a Mine Design

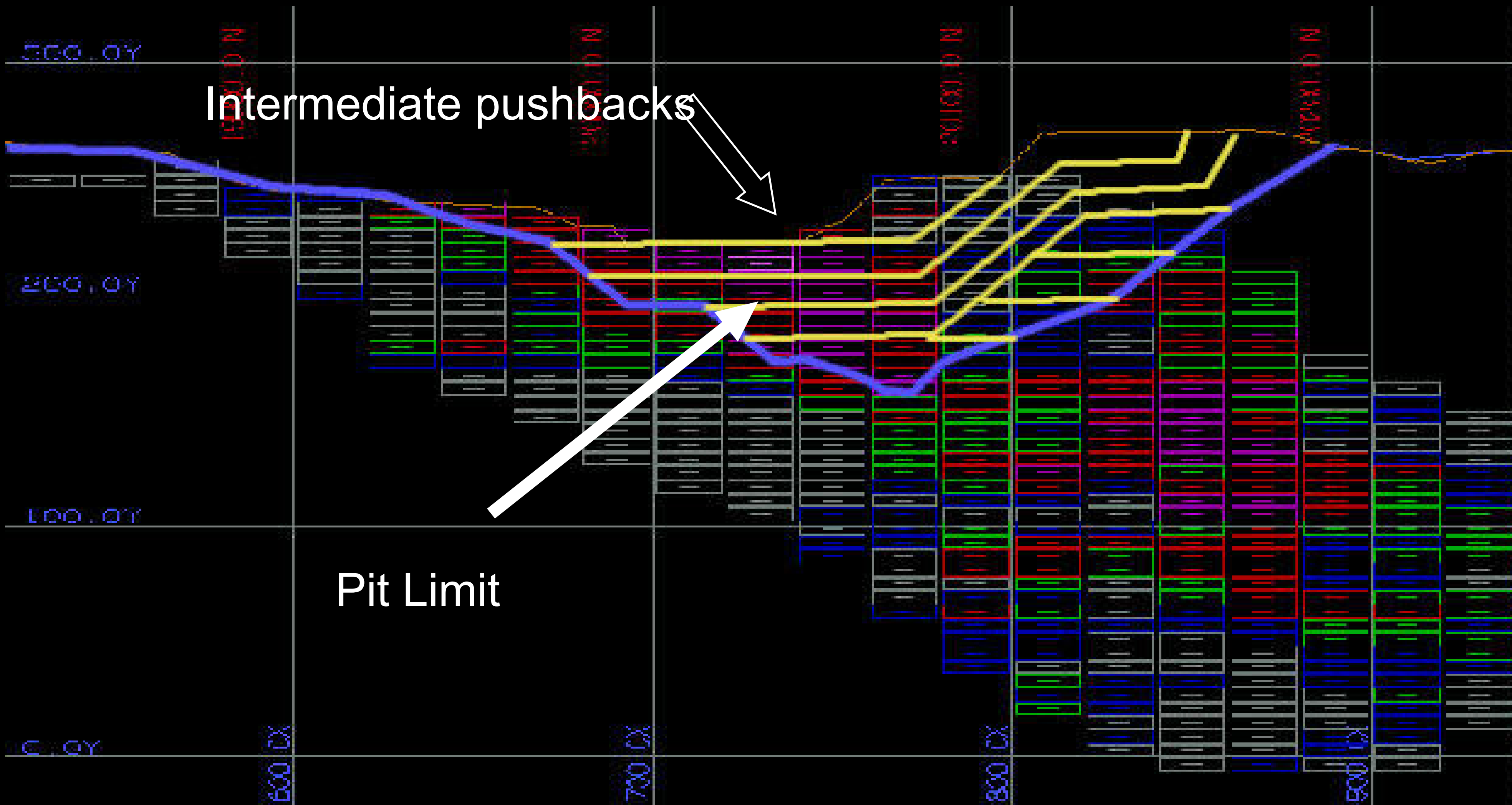
Objective

Quantify the impact of grade uncertainty to tonnage, grades, metal and net present value - net present vnalue vs risk exposure

Methodology

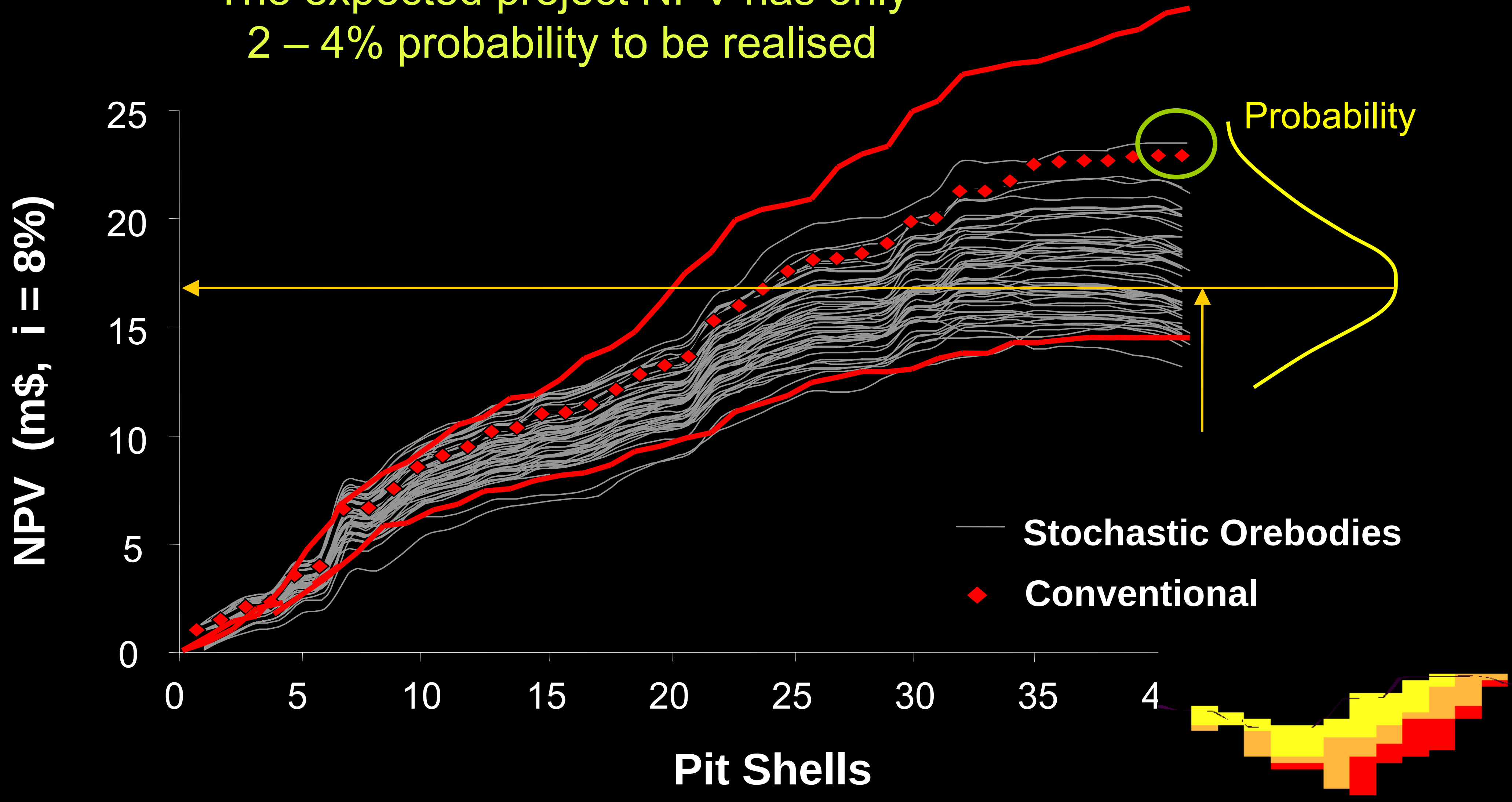


Open Pit Mine Design and Production Scheduling



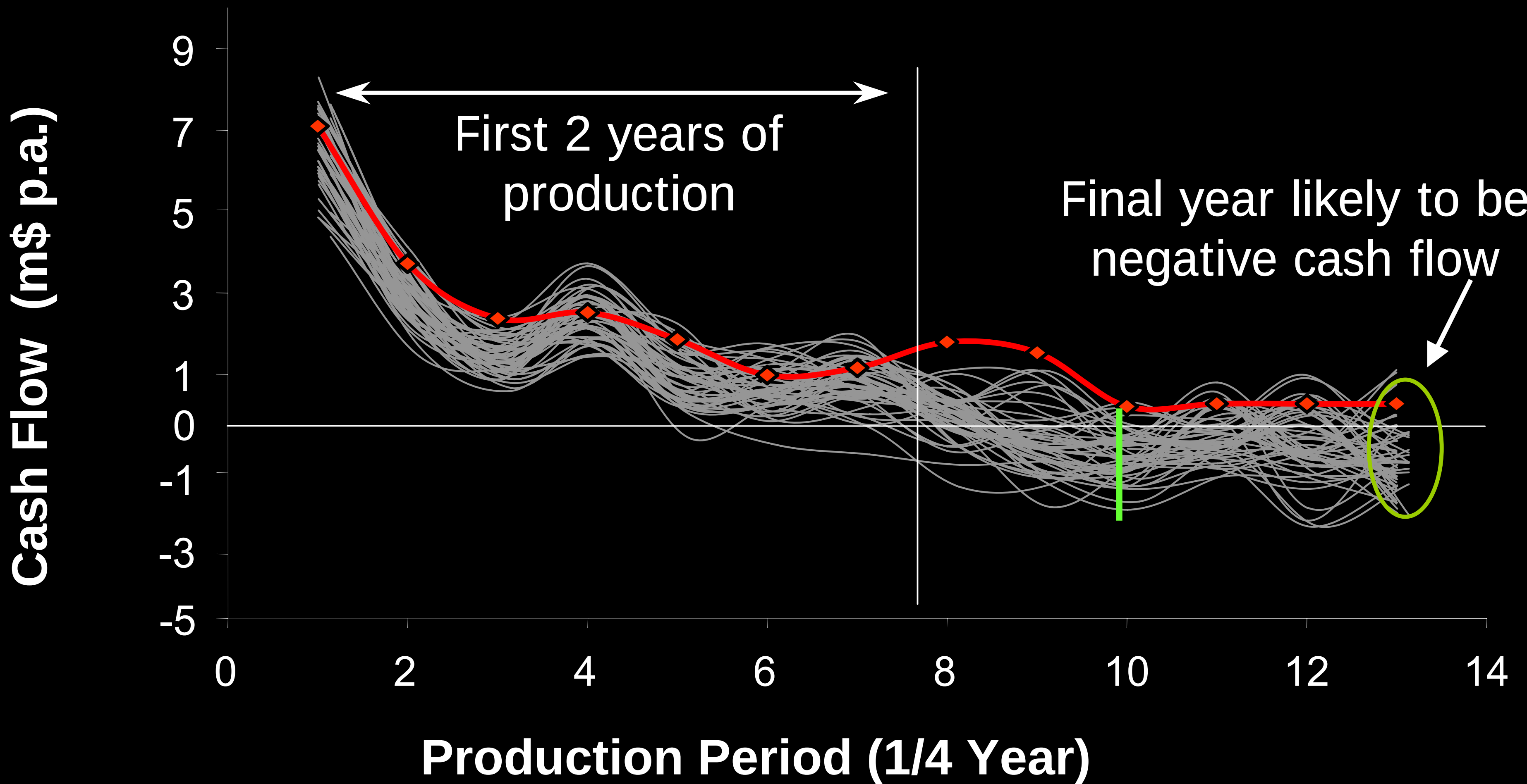
Limits of Traditional Modelling

The expected project NPV has only
2 – 4% probability to be realised

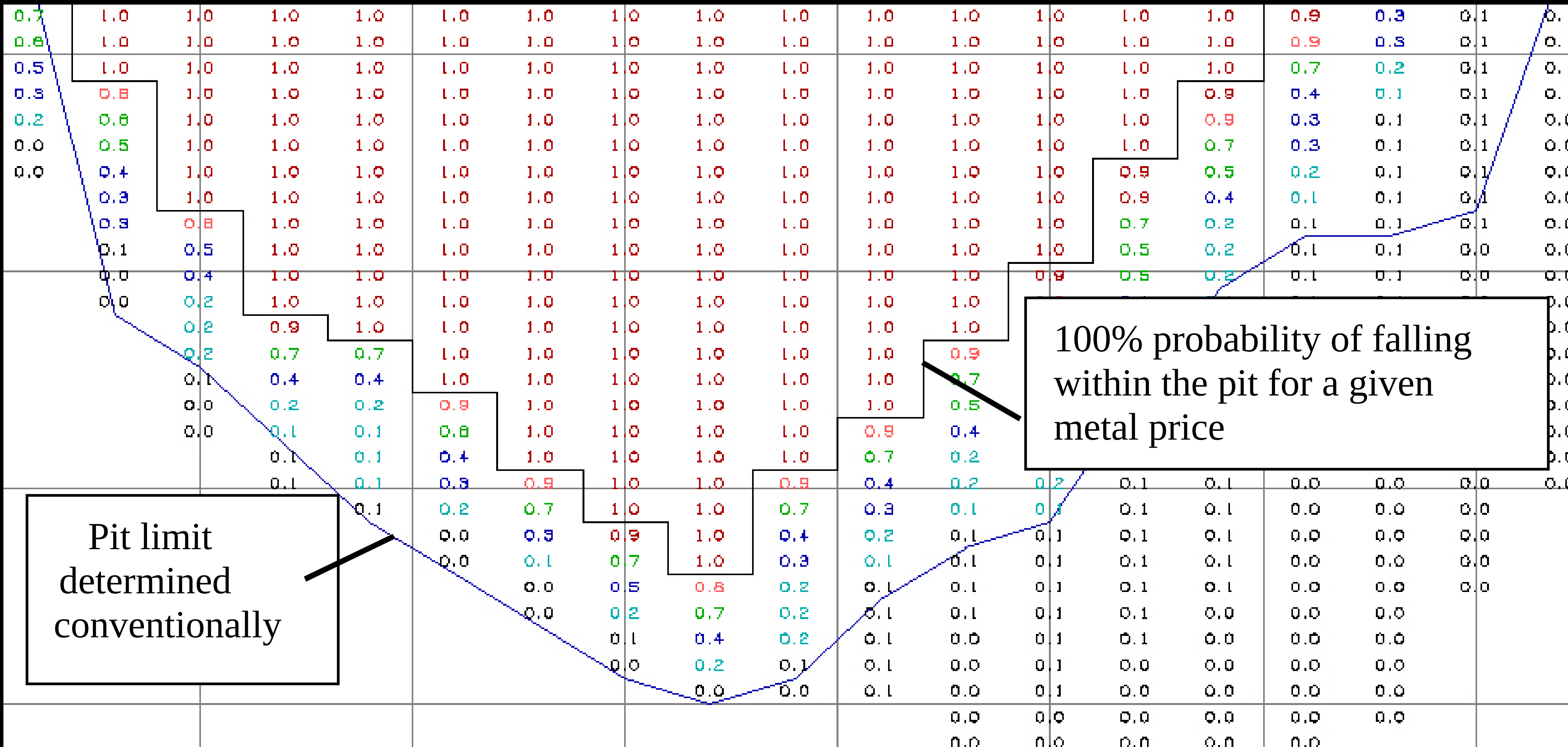


Limits of Traditional Modelling

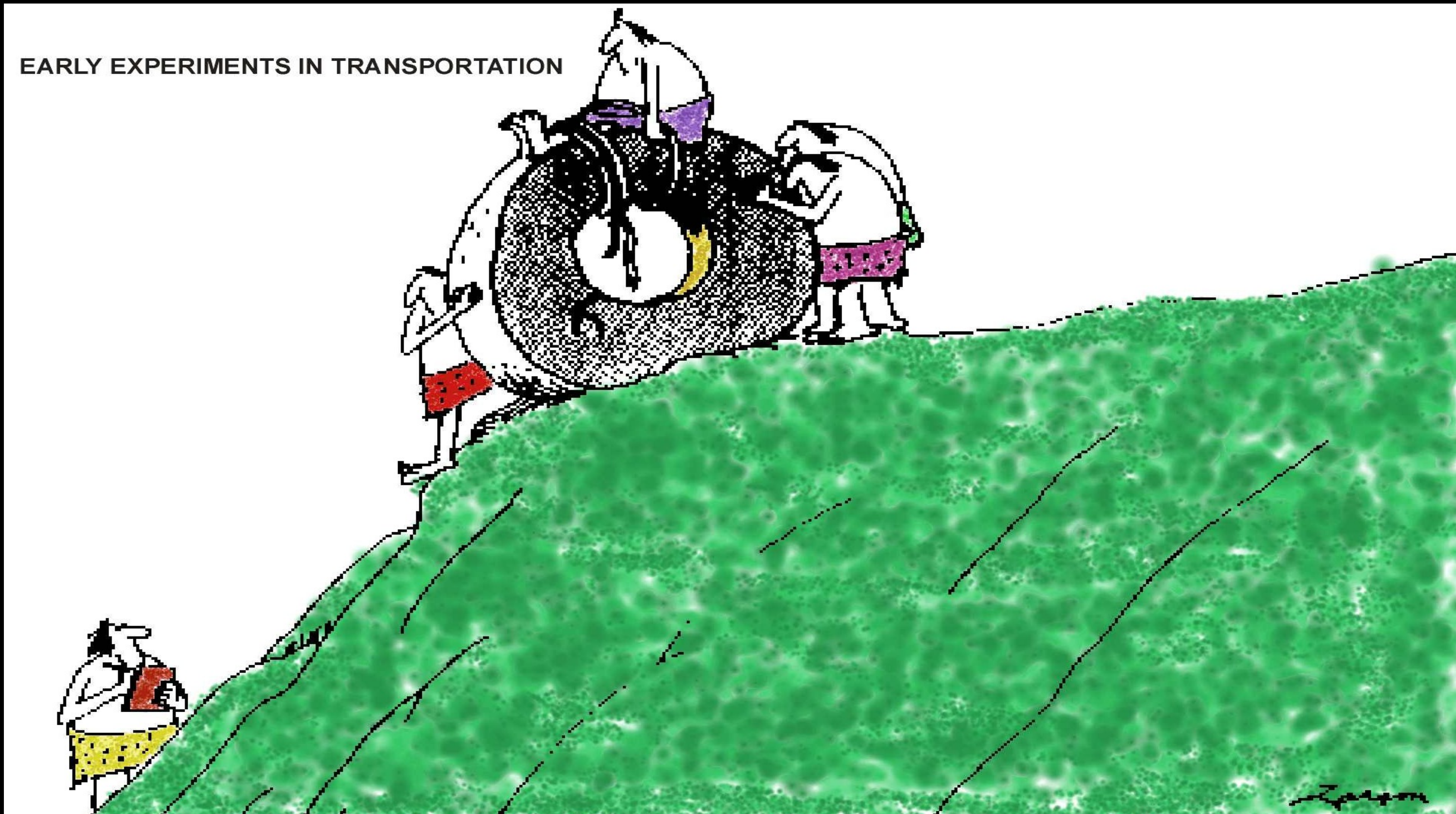
Discounted Cash Flow



Probabilities on Pit Limits



This is Not ...

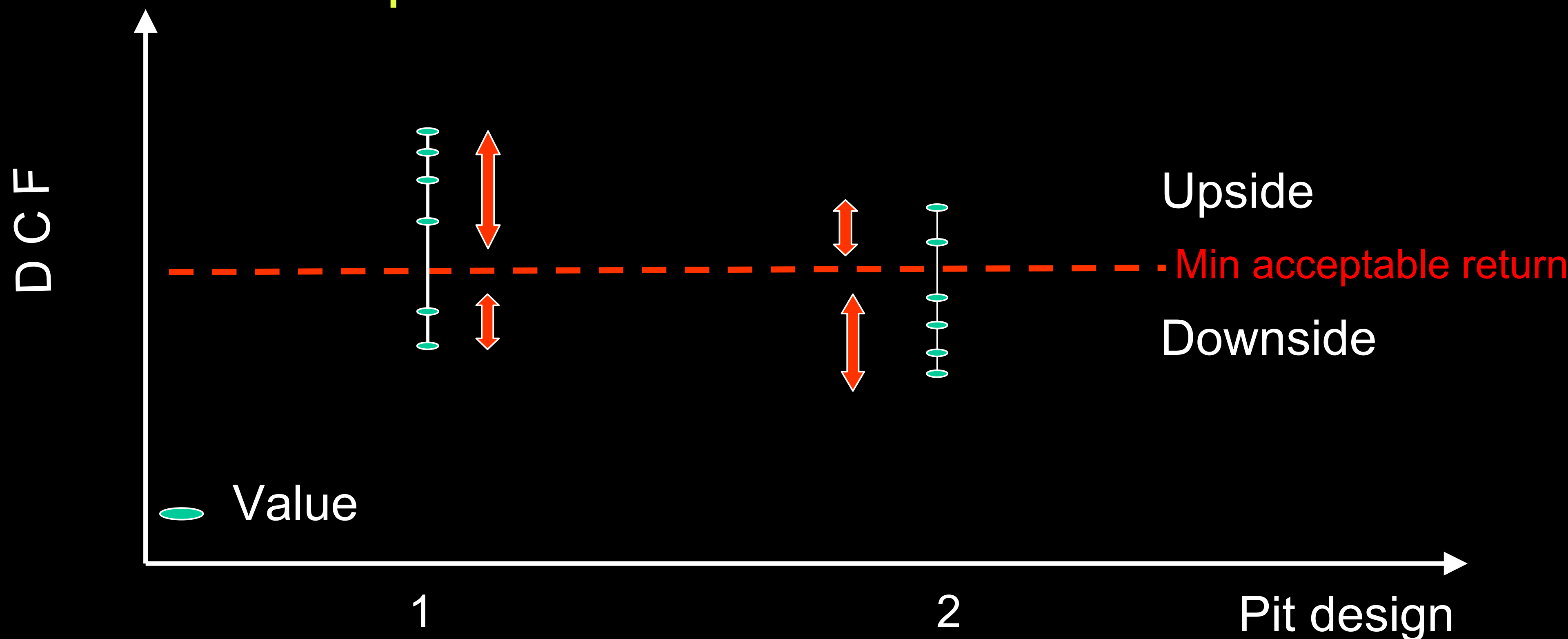


Moving Forward ….. Step 1

Exploring existing technologies

Past Work – Open Pit Mine Design

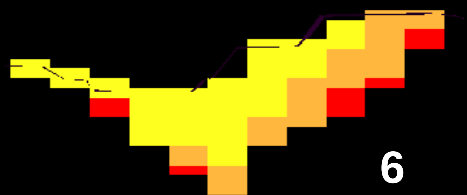
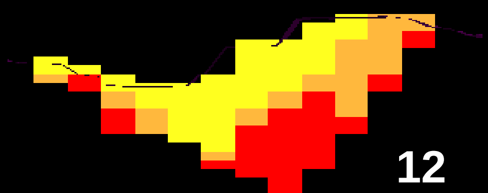
Upside Potential / Downside Risk



$$\text{Upside or } Downside = \sum \left([Value - MAR] * probability \right)$$

Past Work – Open Pit Mine Design

Upside Potential / Downside Risk

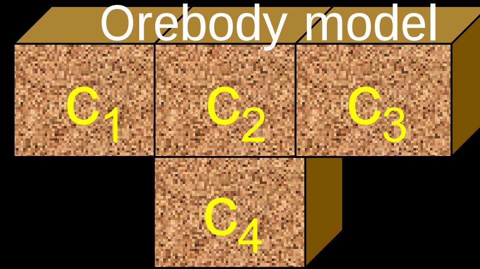
Pit Design	Upside Potential (m$)			Downside Potential (m$)		
	CB-1	CB-2	CB-3	CB-1	CB-2	CB-3
 2	2.3	2.41	1.8	0.0	-0.079	-0.20
 4	1.3	2.1	1.6	-0.78	-0.15	-0.51
 6	2.4	2.43	1.9	0.0	-0.022	-0.28
 12	2.9	2.40	1.2	0.0	-0.16	-0.96

Moving Forward ….. Step 2

Re-writing optimizers

Models of Uncertainty in Optimization

Integer Programming



An objective function

Maximise $(c_1 x_1^{\,1} + c_2 x_2^{\,1} + \ldots.)\ \ldots$

c = constant

$X_1^{\,1}$ = binary variable

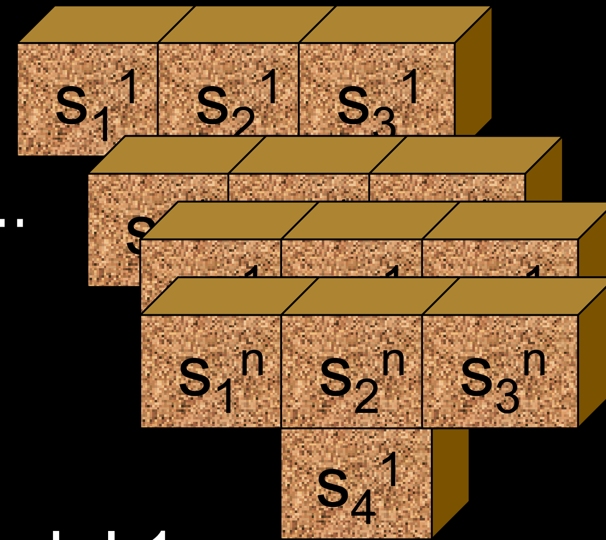
Subject to

$c_1 x_1^{\,1} + c_2 x_2^{\,1} + \ldots. \geq b_1$ → Period 1

$\vdots$

$c_1 x_1^{\,p} + c_2 x_2^{\,p} + \ldots. \geq b_p$ → 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

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

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

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

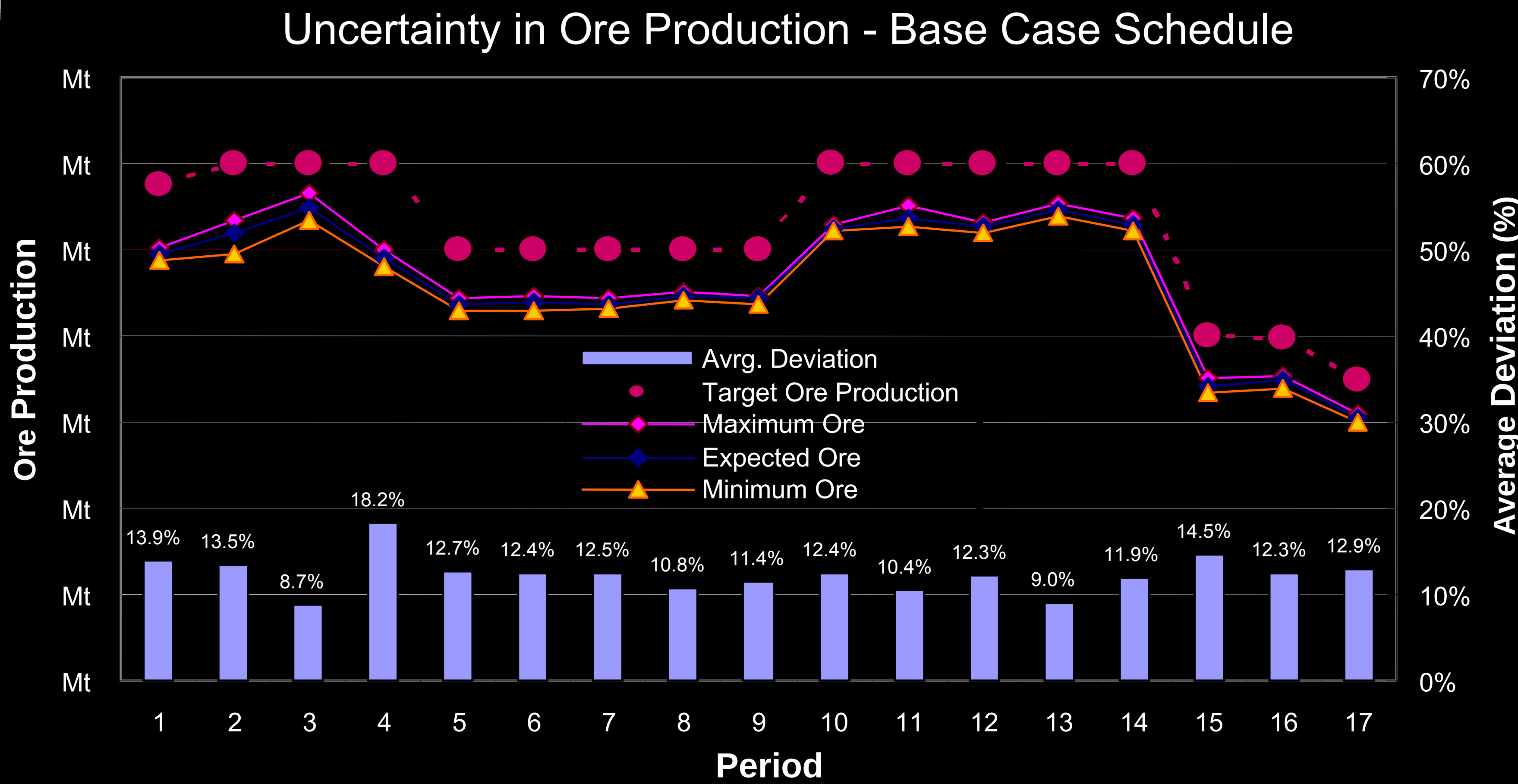
→ Period p

“Uncertainty Will

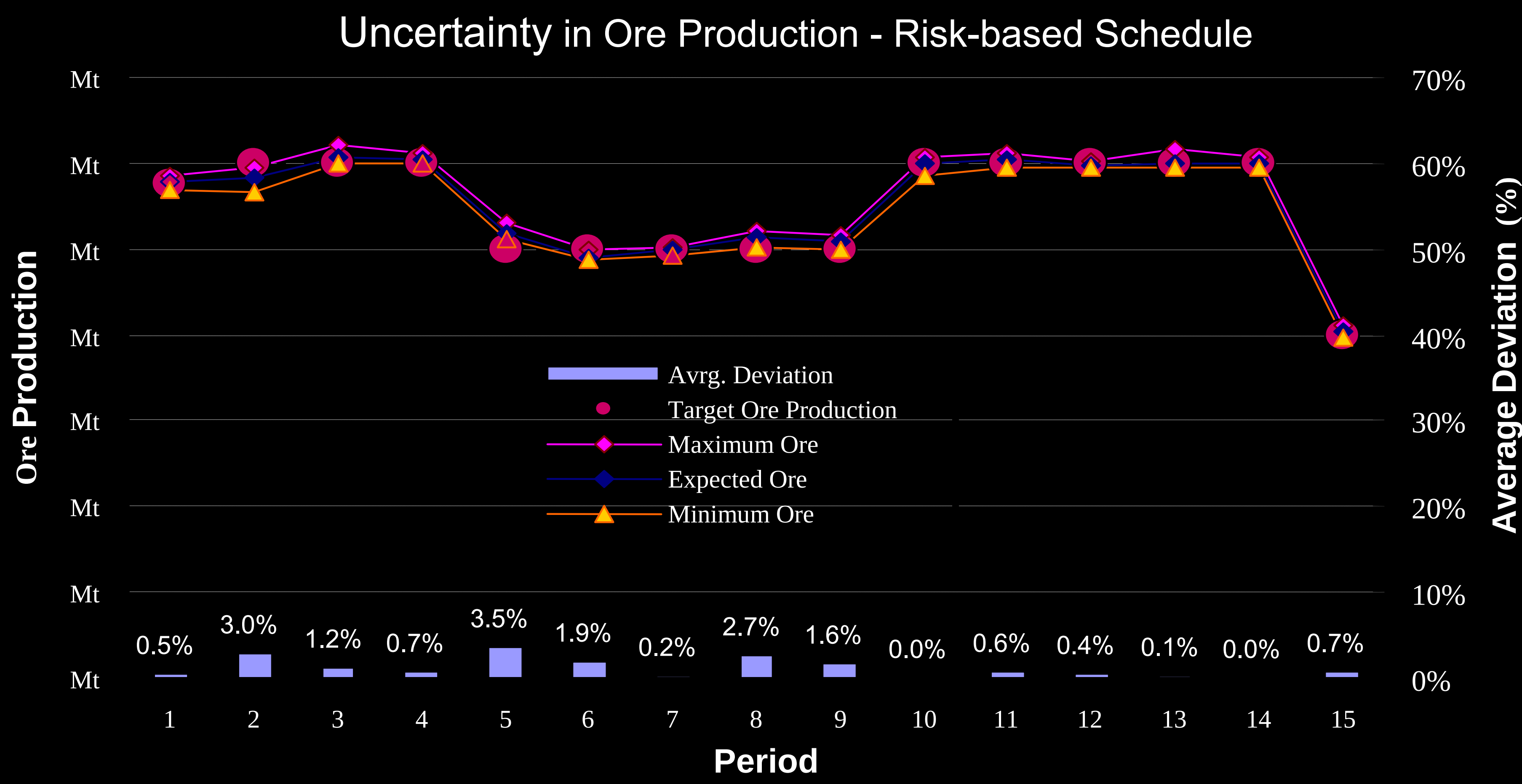
Create Opportunities and Value”

Higher NPV for less risk

Base Case: Geological Risk Assessment of Ore Production

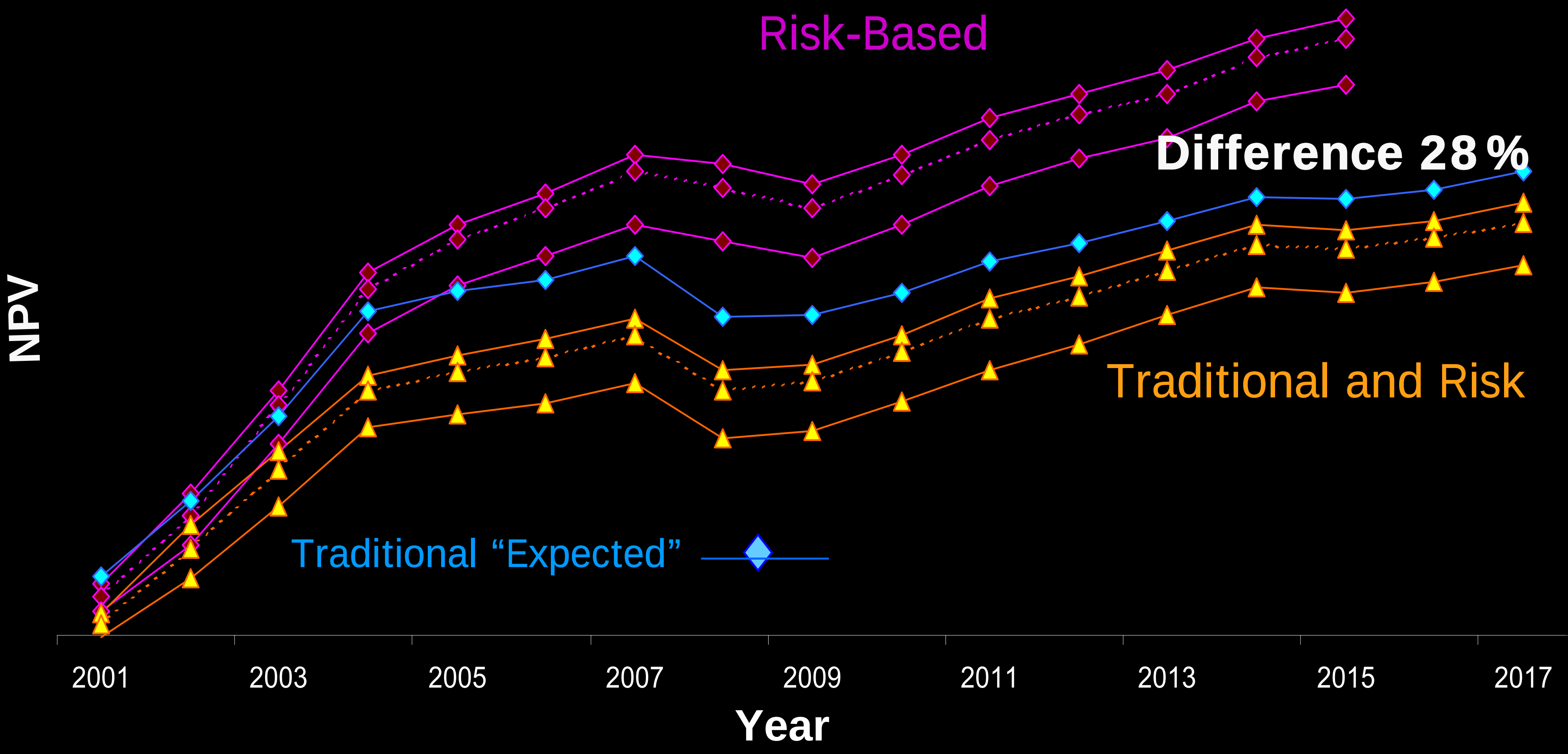


Risk-based: Assessment in Ore Production



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

Multistage combinatorial optimization



Uncertainty is Good:

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

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

Part 2

Stockpile input

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

Part 3

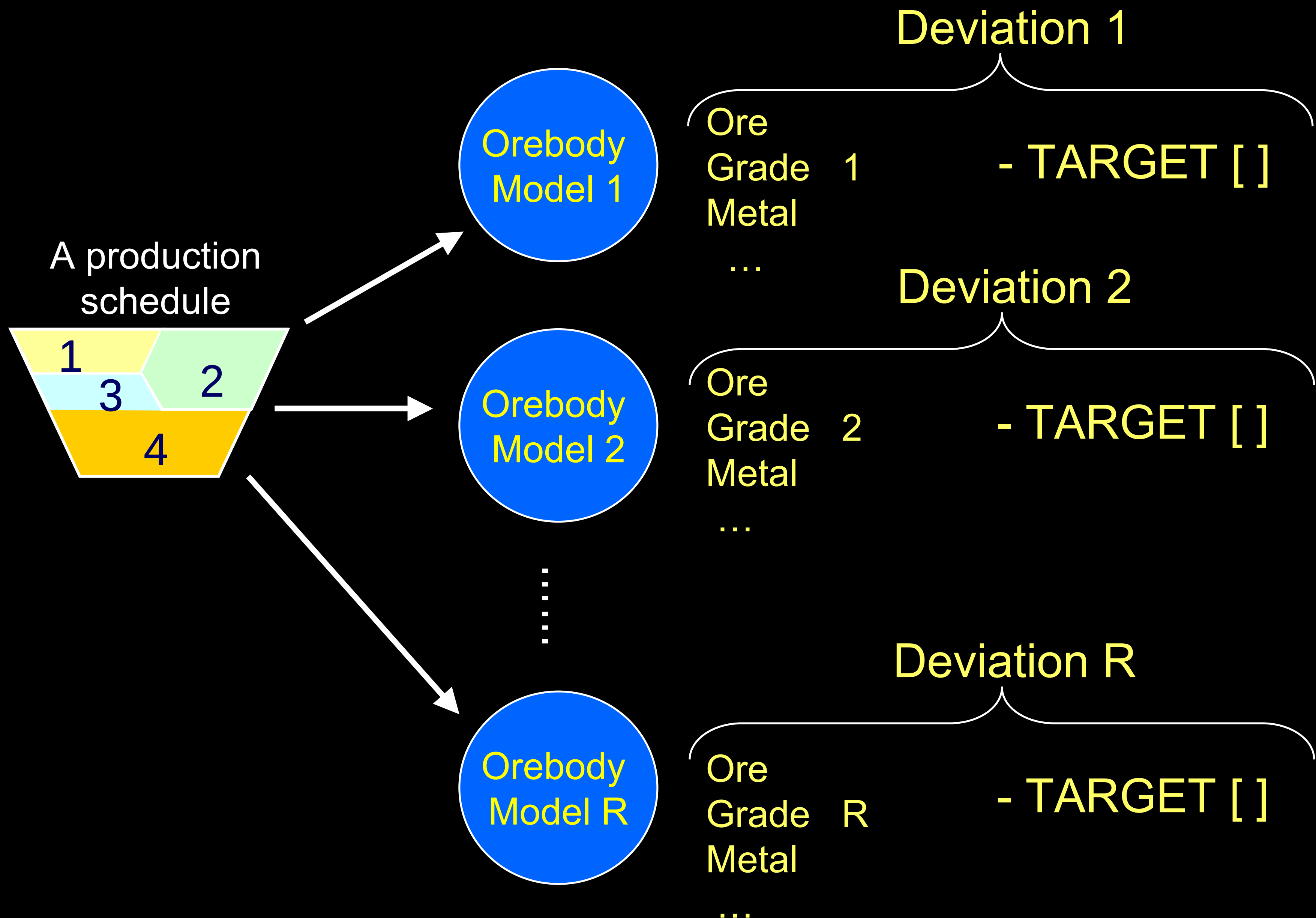
Stockpile output

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

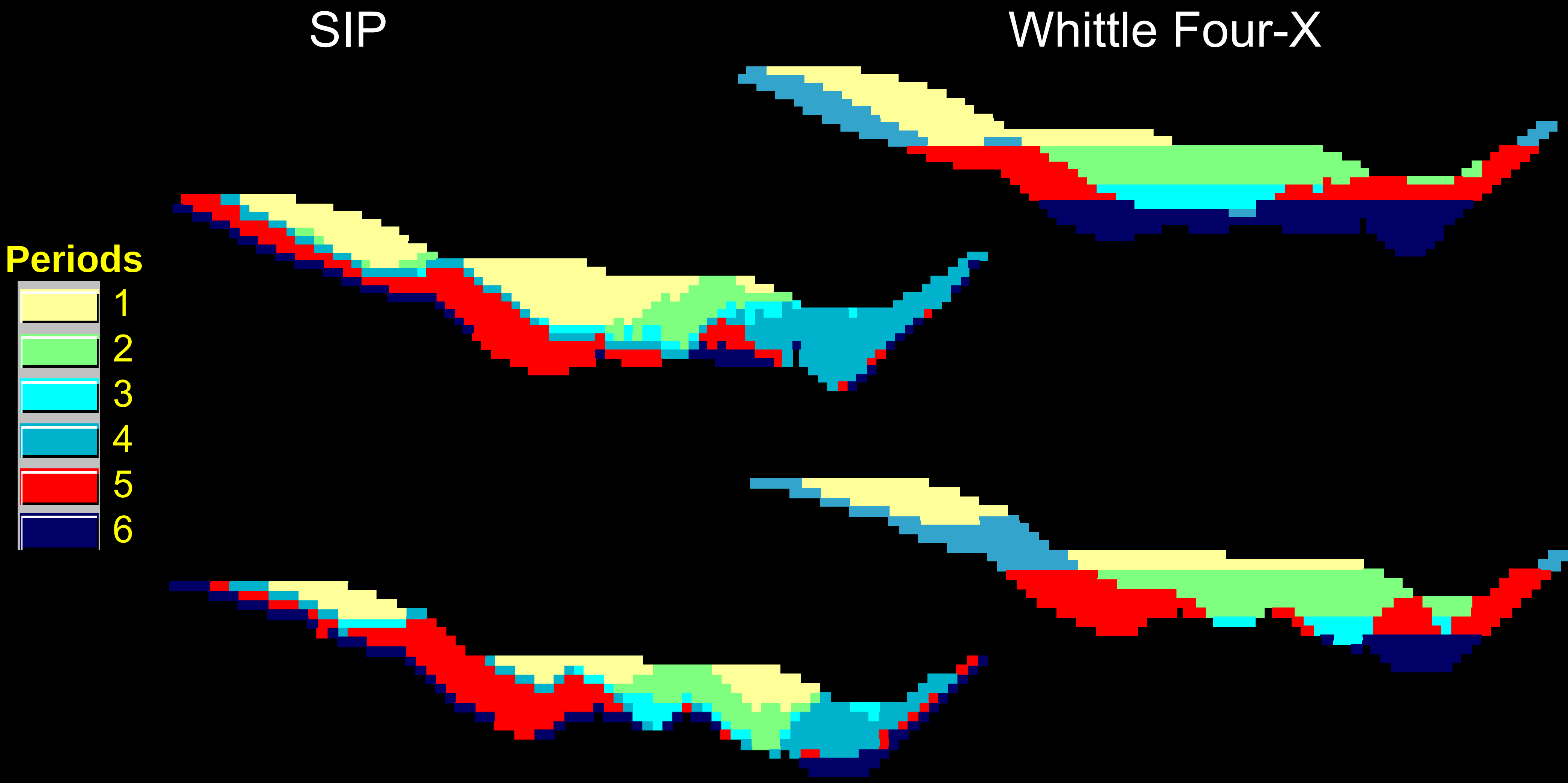
Part 4

Risk management

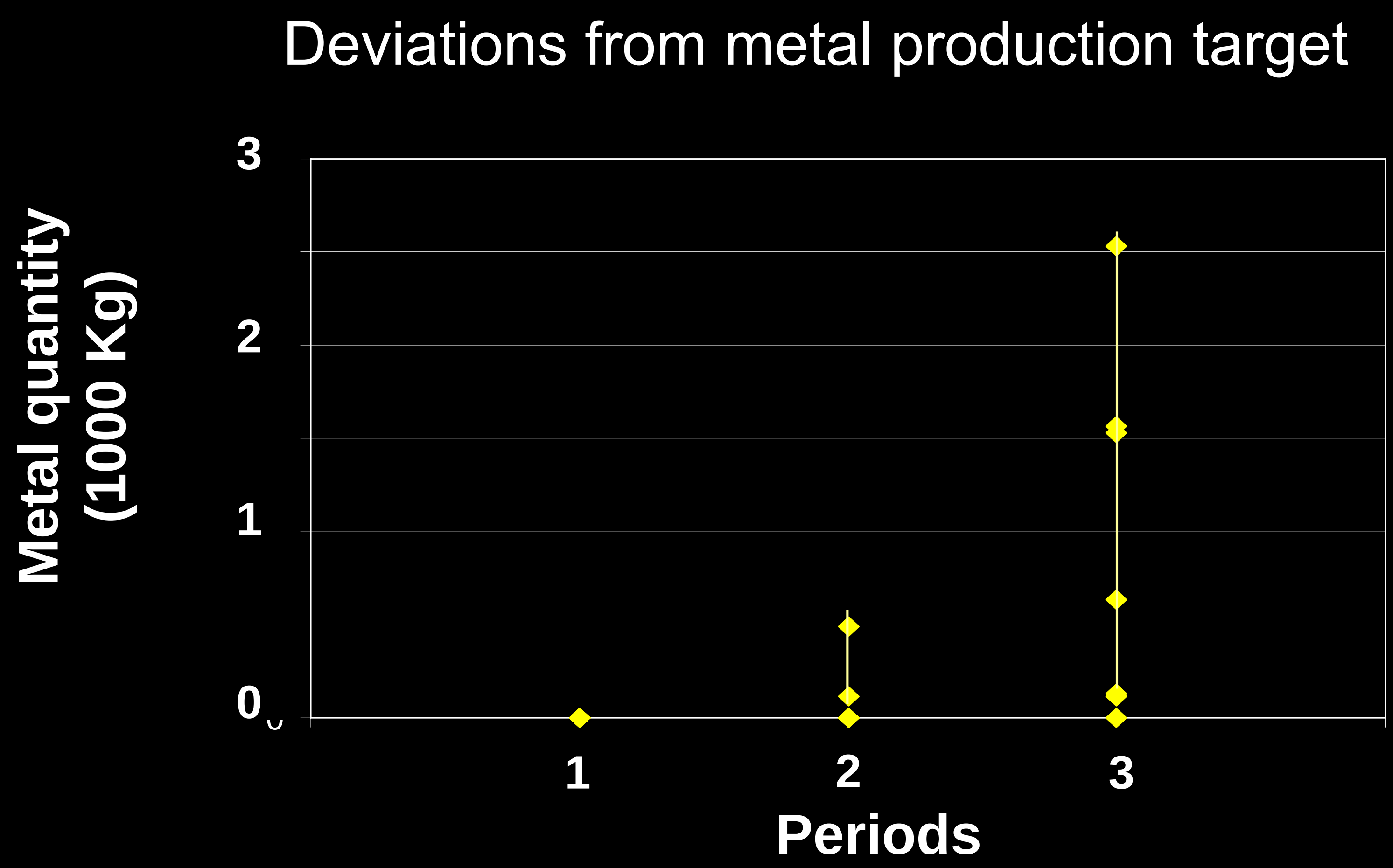
Stochastic Integer Programming - SIP



Cross-Sectional Views of the Schedules



Managing Risk Between Periods



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

RDF – risk discounting factor

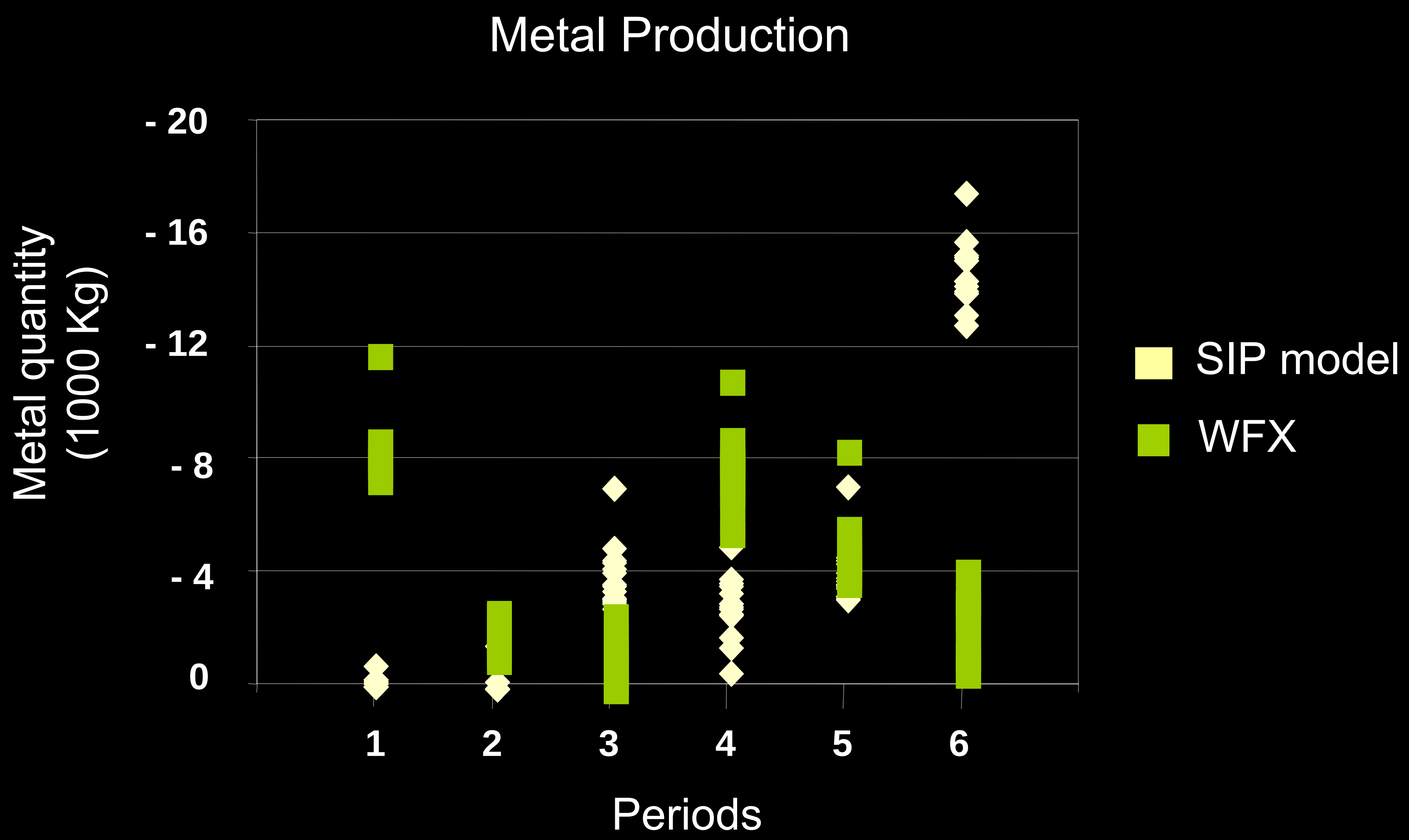
r – orebody risk discount rate

Case Study on a Large Gold Mine

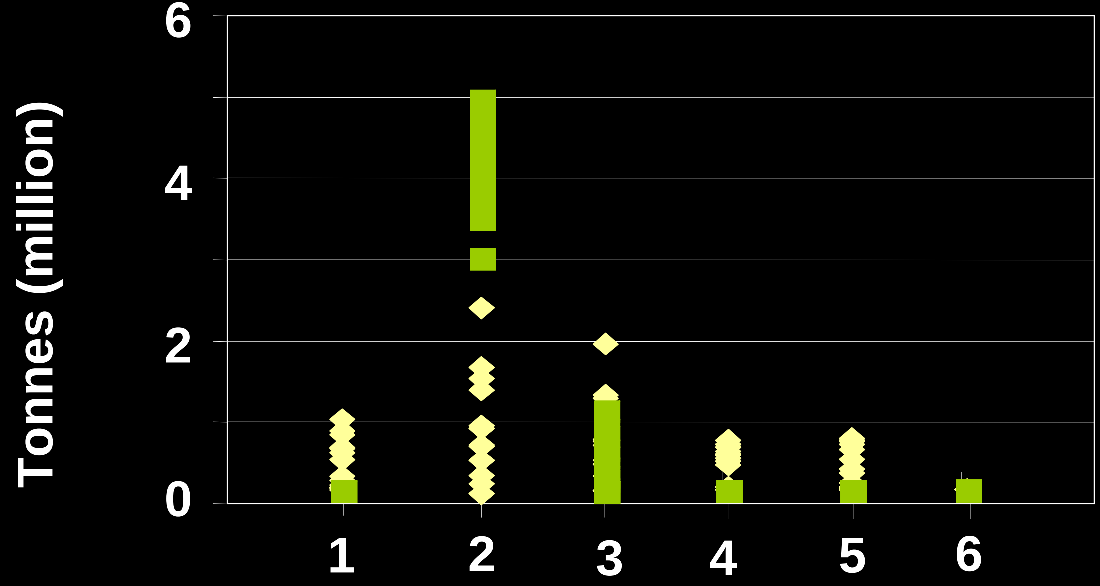
The SIP specific information

Orebody risk discounting rate	**20 %**
Cost of shortage in ore production	**10,000 /t**
Cost of excess ore production	**1,000 /t**
Cost of shortage in metal production	**20 /gr**
Cost of excess metal production	**20 /gr**
Number of simulated orebody models	**15**

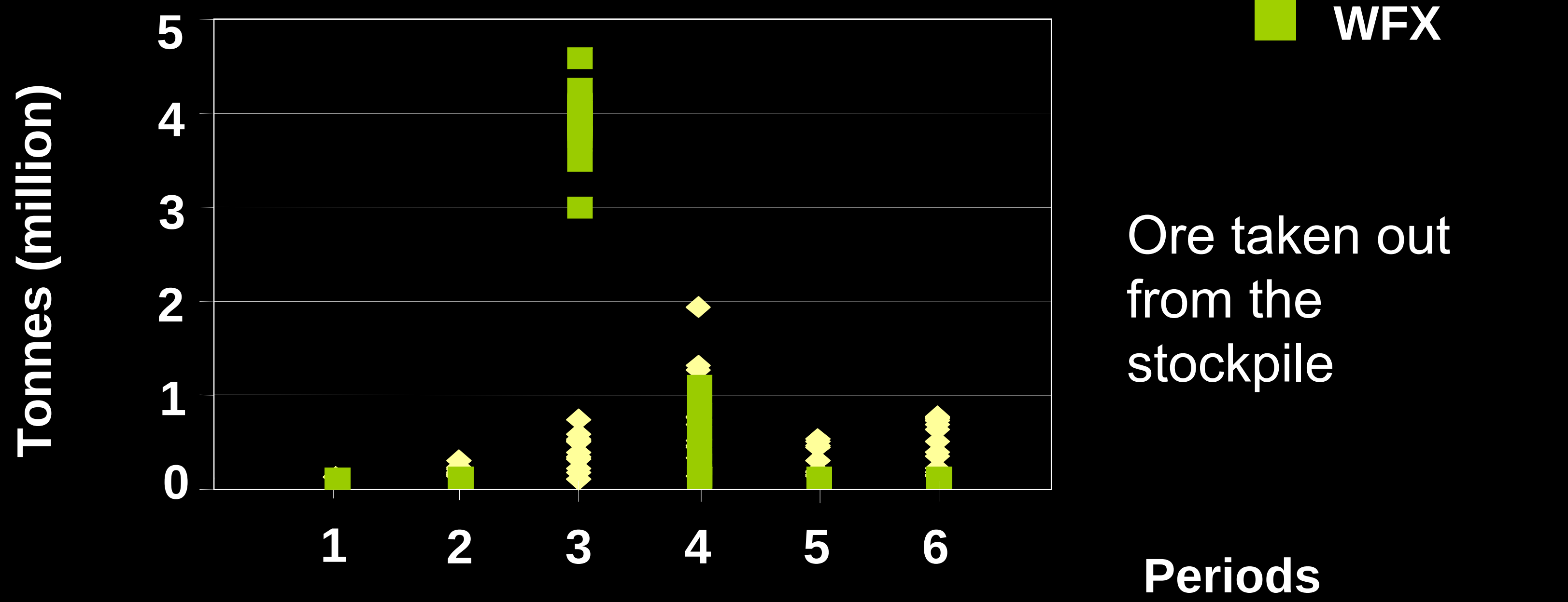
Deviations from Production Targets



Stockpile's Profile



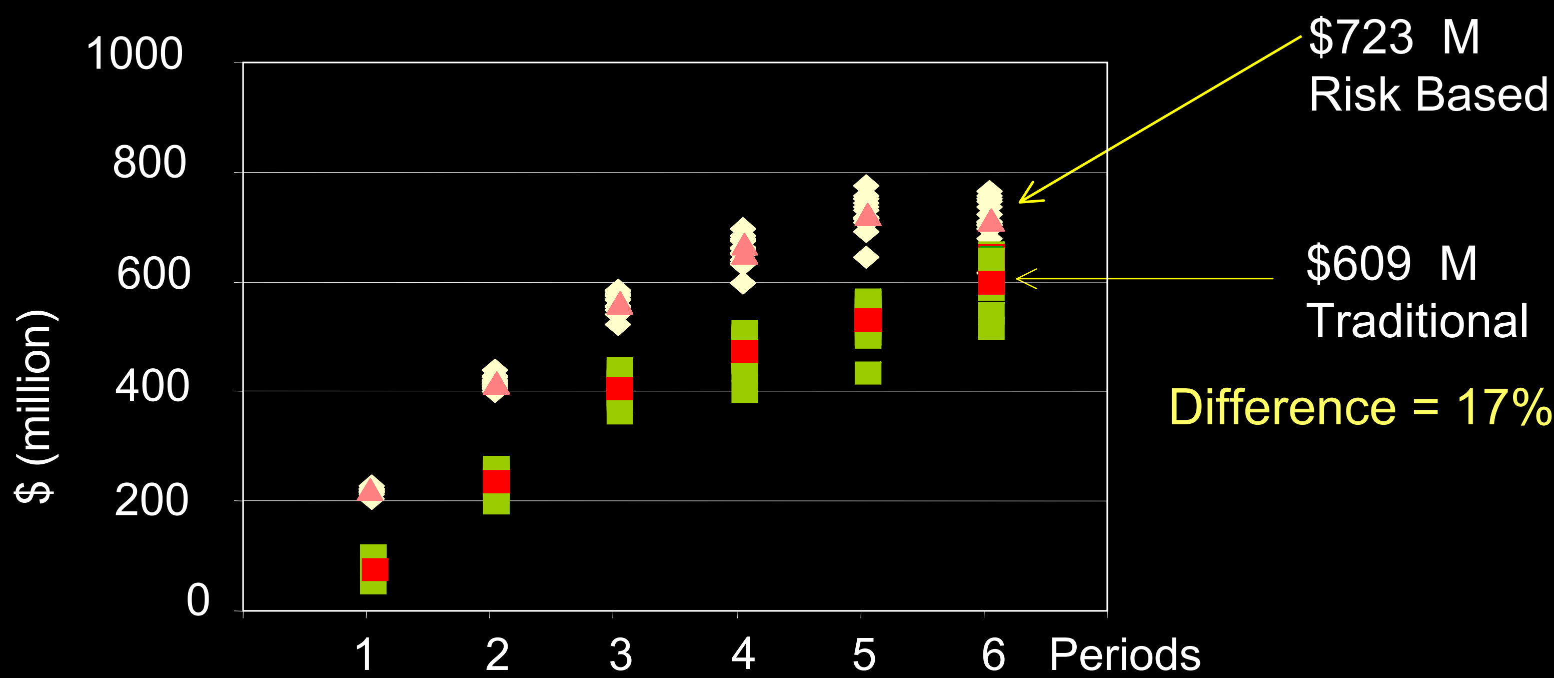
Available ore at the end of each period



Ore taken out from the stockpile

Uncertainty is Good: Traditional vs Risk-Based

Stochastic Integer Programming



Cumulative NPV values

SIP model **WFX**

Average NPV values

SIP model **WFX**

Geological Risk Discounting= 20%

Some conclusions

- "…. uncertainty is (not) a problem and should be avoided ?"
- "… you can take advantage of uncertainty…."
- "….uncertainty will create opportunities and value."
- " …once your way of thinking explicitly includes uncertainty, the whole decision-making framework changes."
- We need:

  Stochastic mine planning and NEW mathematical models

And

- It is all about good people:

  Education and training in a long term sense

Please join us!