20+ Years of AMC Hill of Value®
Mine Strategy Optimization

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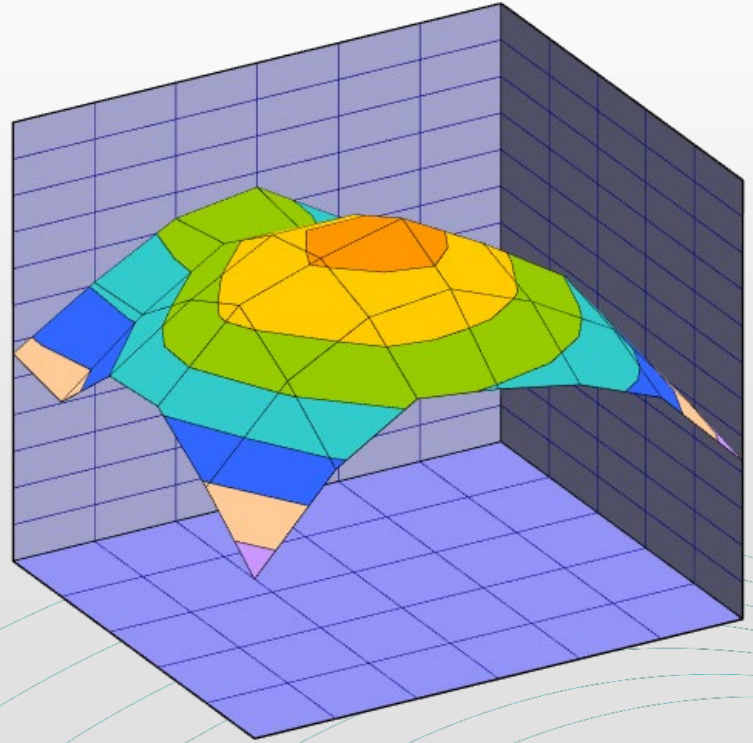
20+ years' AMC Hill of Value® Wisdom

- The AMC Hill of Value® concept
- Simple examples with a single aim
  - 2D/3D examples: 1 or 2 decision parameters, 1 value measure
  - Multi-dimensional examples: multiple decision parameters
- Multiple aims, potentially conflicting
- Dealing with uncertainty:
  - Trade-offs between upside rewards and downside risks
  - Identifying robust strategies
- Debunking with the primary misconception:
  More ounces mean more value—NO! They don't!

The AMC Hill of Value® Strategy Optimization Process



Getting to the best combination of cut-off grades, production rates, and other decision parameters, while accounting for the uncertainty of external uncontrollable scenarios, such as product prices, to achieve the corporate goals

Where is the industry's focus?

- There is a lot of emphasis in the mining industry on improvements in productivity, efficiency, unit costs etc.

  This is "Doing Things Right".

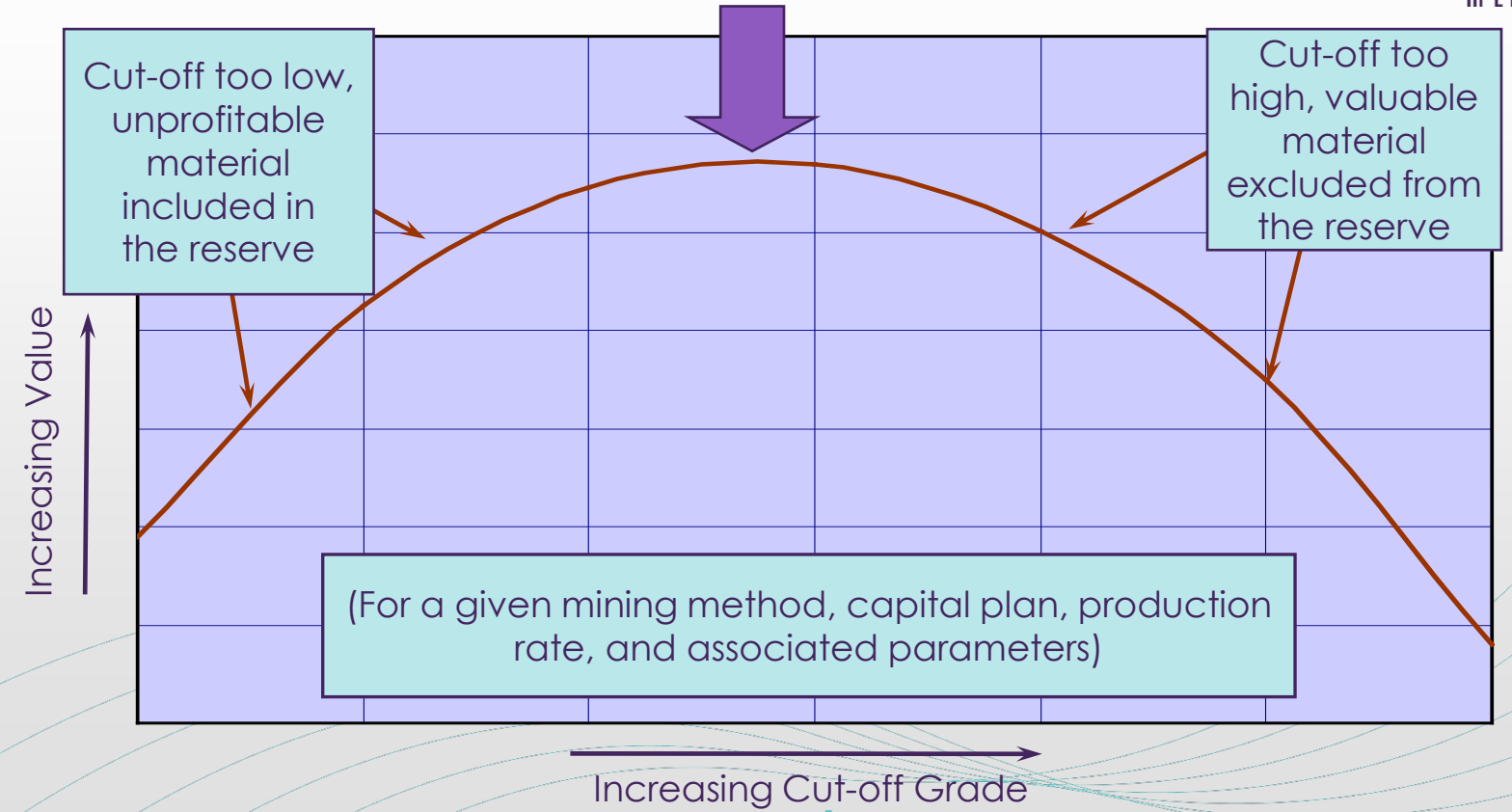
- This is good, but we often miss the more fundamental issue:

  Are we "Doing the Right Things"?

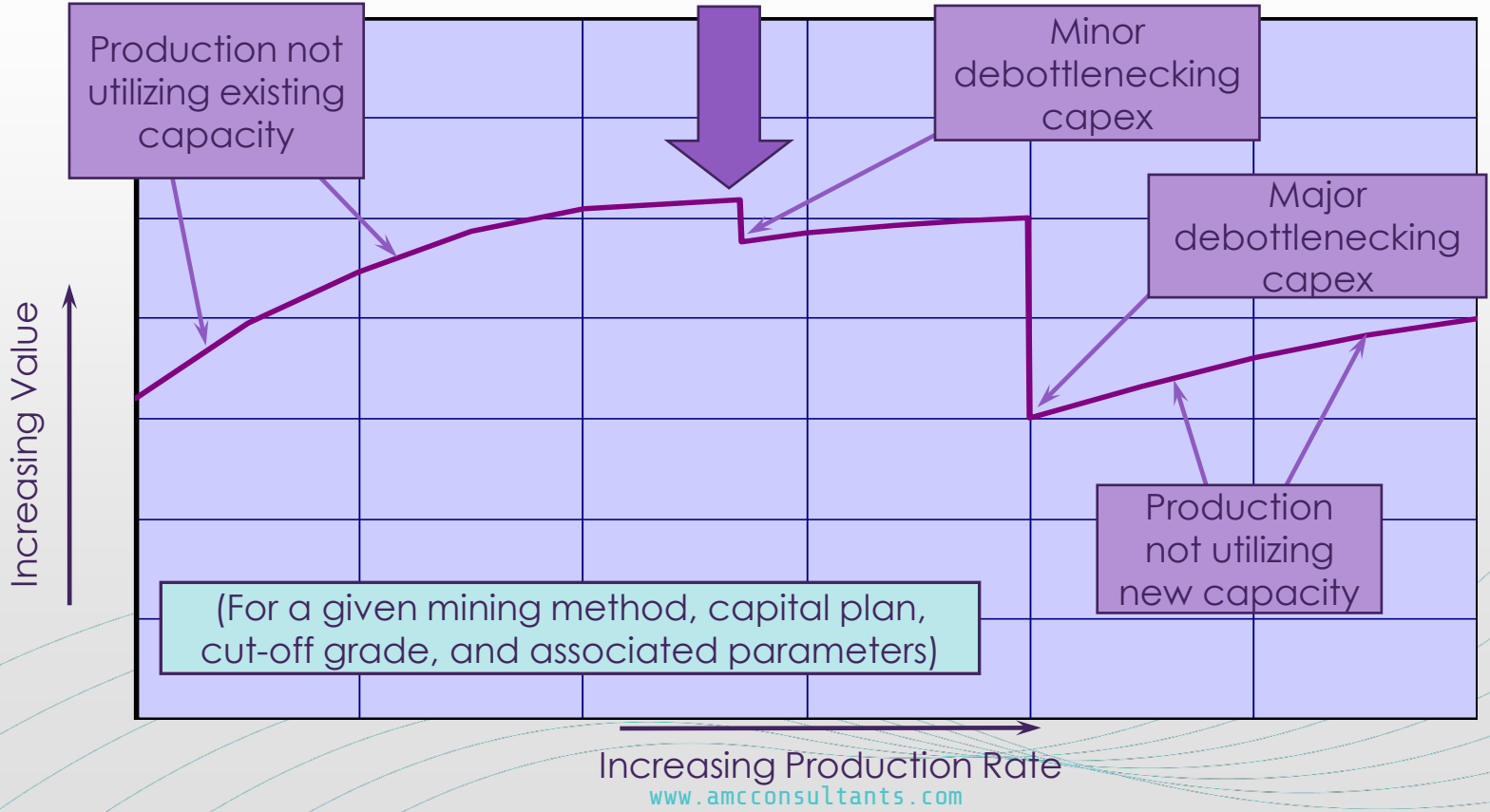
- Ultimately, we should aim to be *"Doing the Right Things Right".*

- But logically the first concern must be **"Doing the Right Things".**

There is an optimum cut-off grade . . .

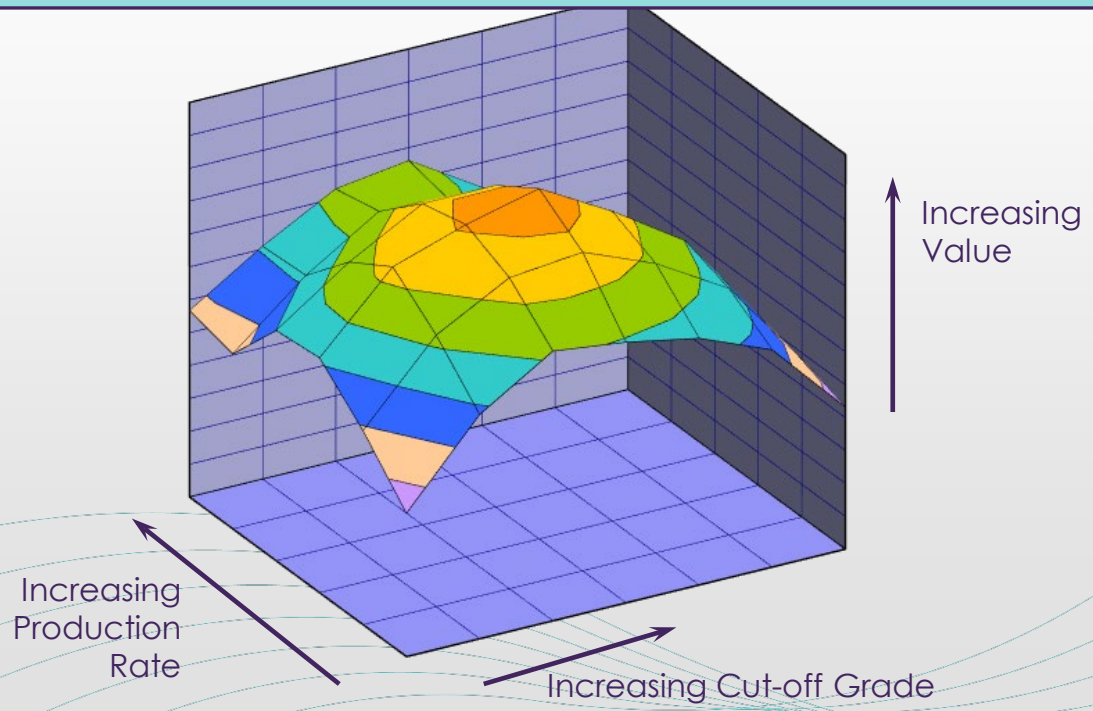


. . . and an optimum production rate

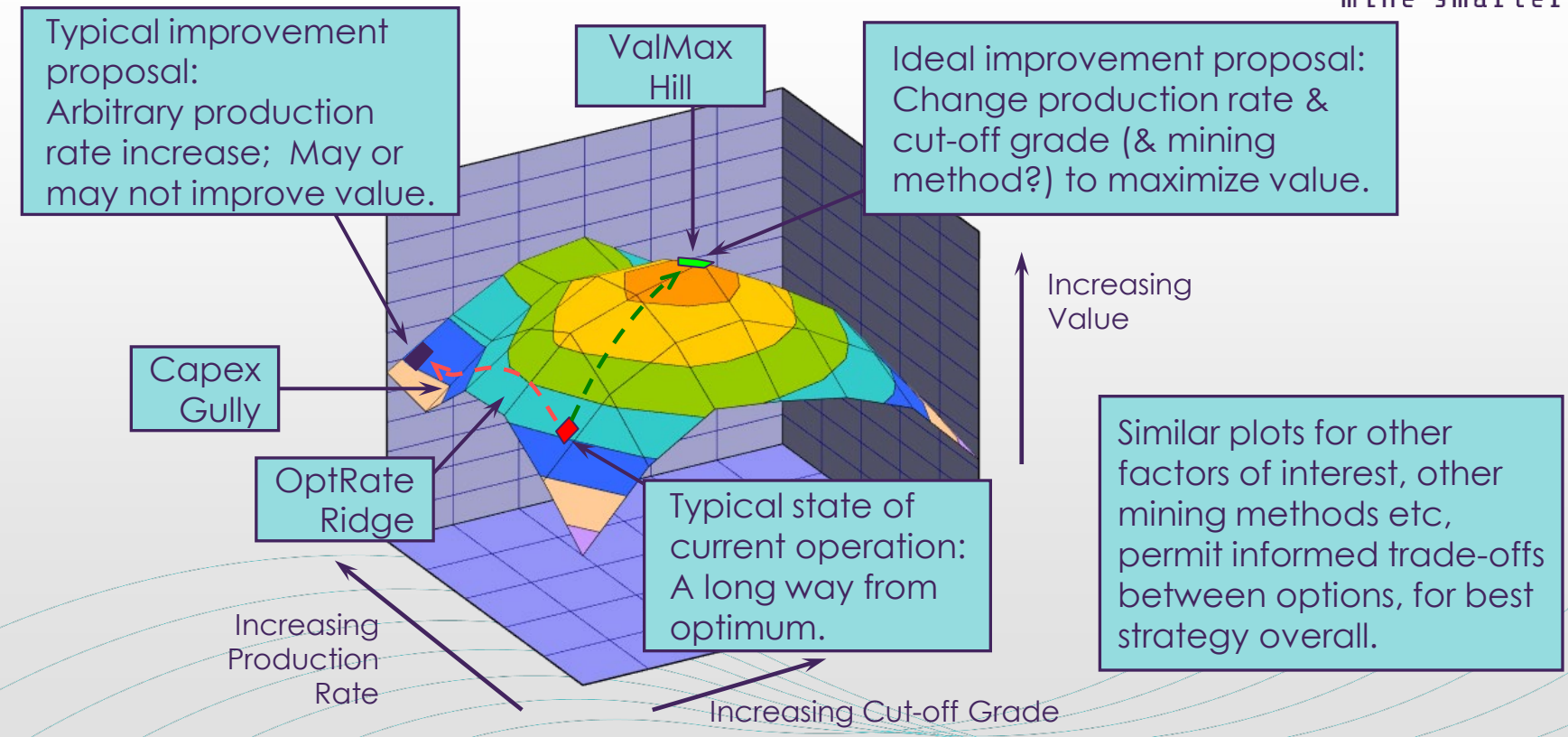


What is the optimum combination?

For a given mining method, capital plan, and associated parameters, value will be a function of both production rate and cut-off grade



Finding and Climbing the AMC Hill of Value®



Must we get the strategy precisely right?

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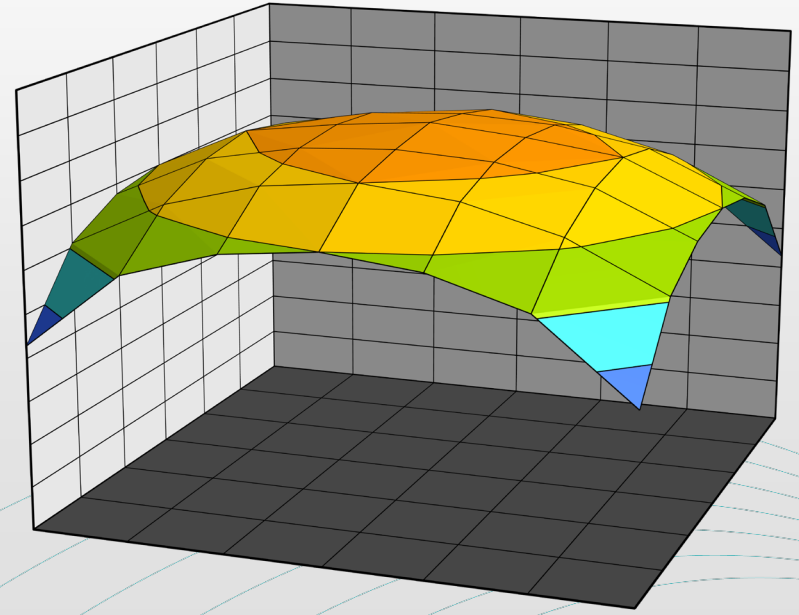
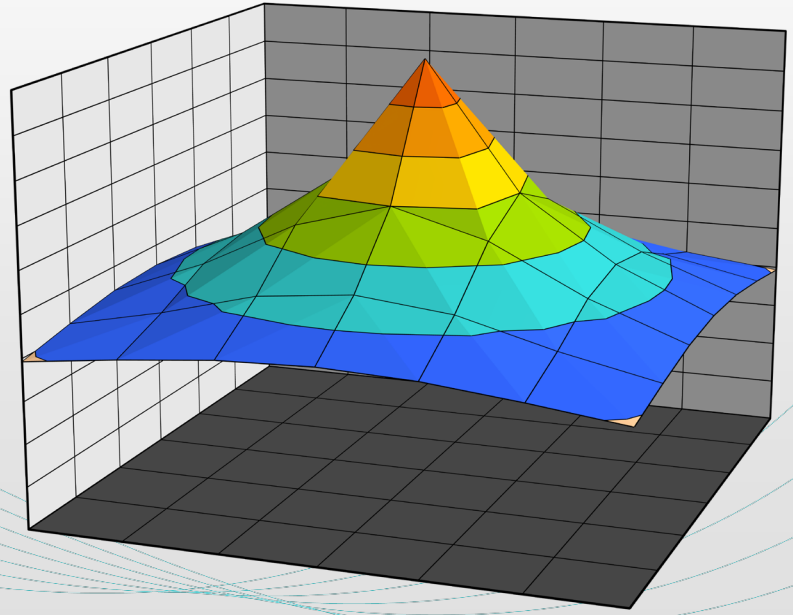
AMC Hill of Value® with "flat" top

Precise strategy specification **not** critical

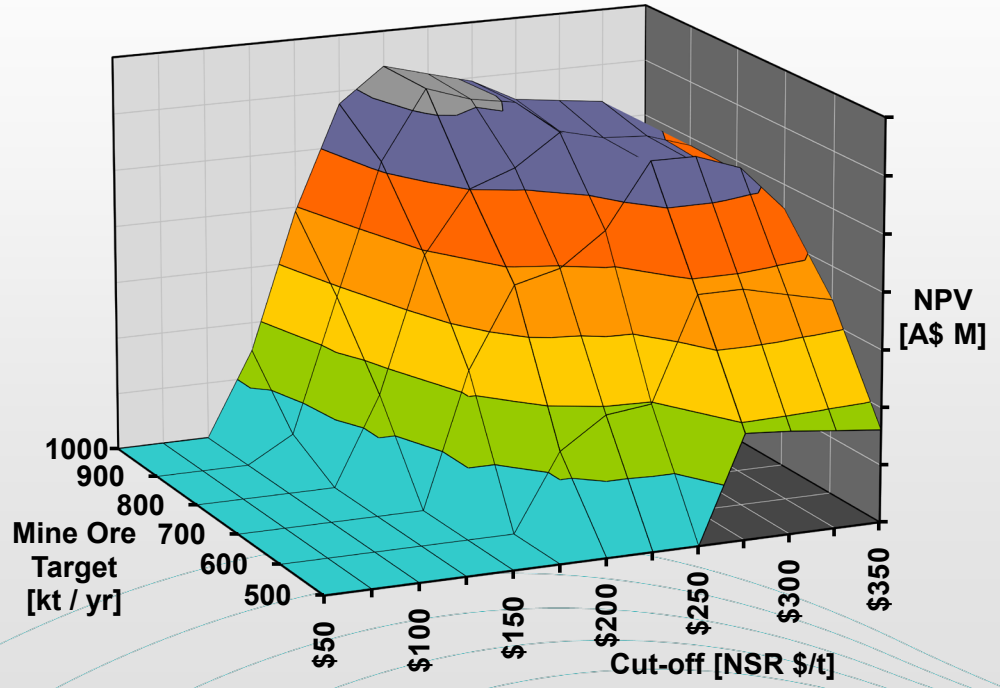


AMC Hill of Value® with "pointed" top

Precise strategy specification **critical**



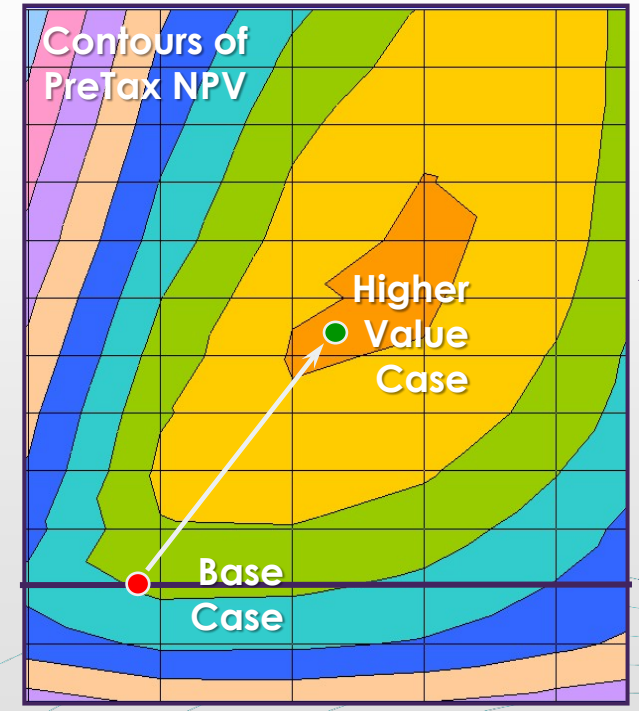
Hills are rarely (never?) like steeples



But will often be steeper on one side of the maximum value than the other.

Desire to get more metal in the reserve by reducing cut-off may lead to dangerous value-destructive decisions!

Simple Open Pit Case Study: NPV vs ROM Cut-off & Mining Rate



- Open pit mining plans are often "self-debottlenecking".
  - Planned mining rates deliver planned ore tonnes at planned cut-offs.
  - The ROM cut-off is optimized *at those rates* "automatically".
- Faster mining gives higher ROM cut-off.
  - Higher head grade more than covers higher mining costs and adds value – up to a point.
- Access development rates underground are analogous

The impact of Lane-style balancing cut-offs

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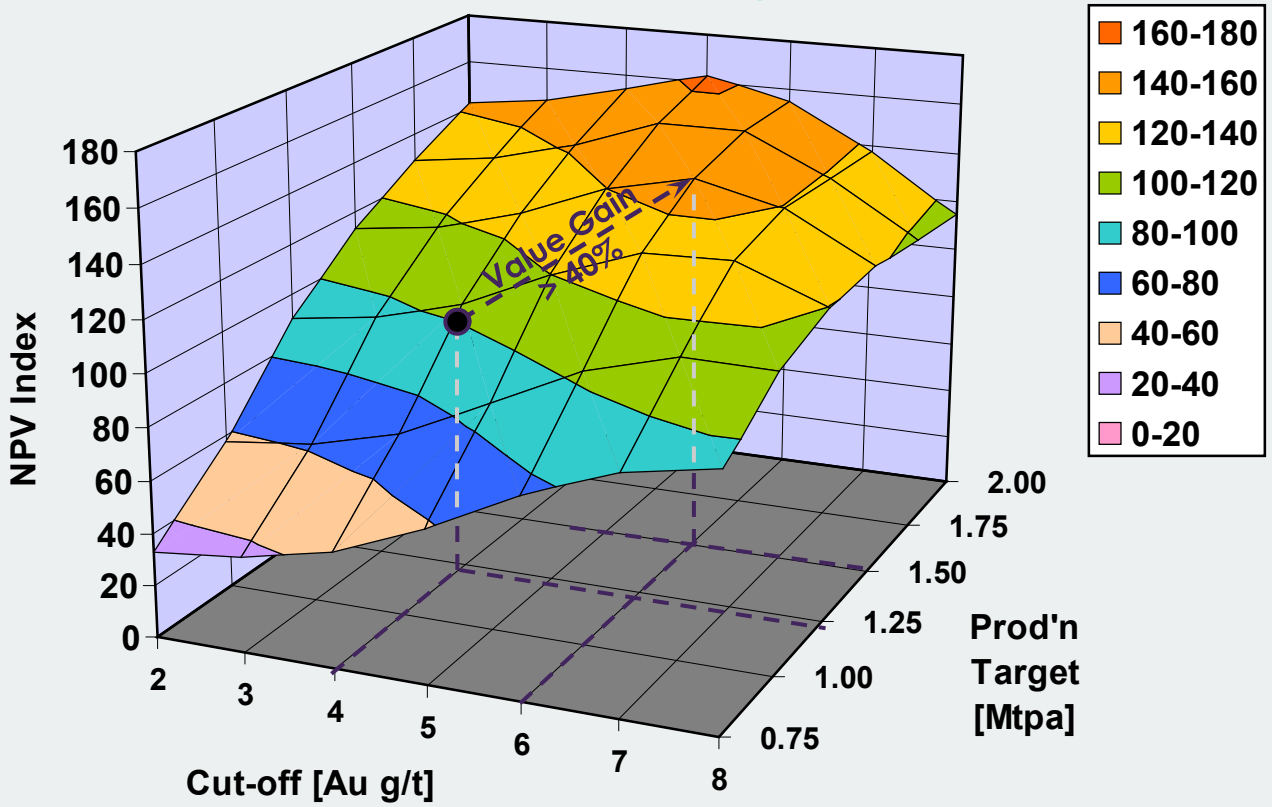
- Ken Lane (1964, 1988) identified the concept of "balancing" cut-offs: the cut-offs that result in two stages of the overall production process simultaneously operating at their capacities:

  e.g., when mining rock from the pit at maximum rate, the cut-off that "fills the mill" with the best available grade of ore.

- We can typically only specify independently two of three operating decisions:
  - Maximum mining rate
    - Of total material moved in an open pit
    - Of access development exposing mineralized footprint underground
  - Maximum ore handling and treatment rate (in both "mine" and "mill")
  - Cut-off grade
    - Typically for mill feed in an open pit with stockpiling of lower-grade ore
    - Typically between ore or waste left in-situ underground
- The grade distribution then forces the required value of the third parameter.
- The balancing cut-off is often the value-maximizing cut-off, and is independent of product prices and costs.

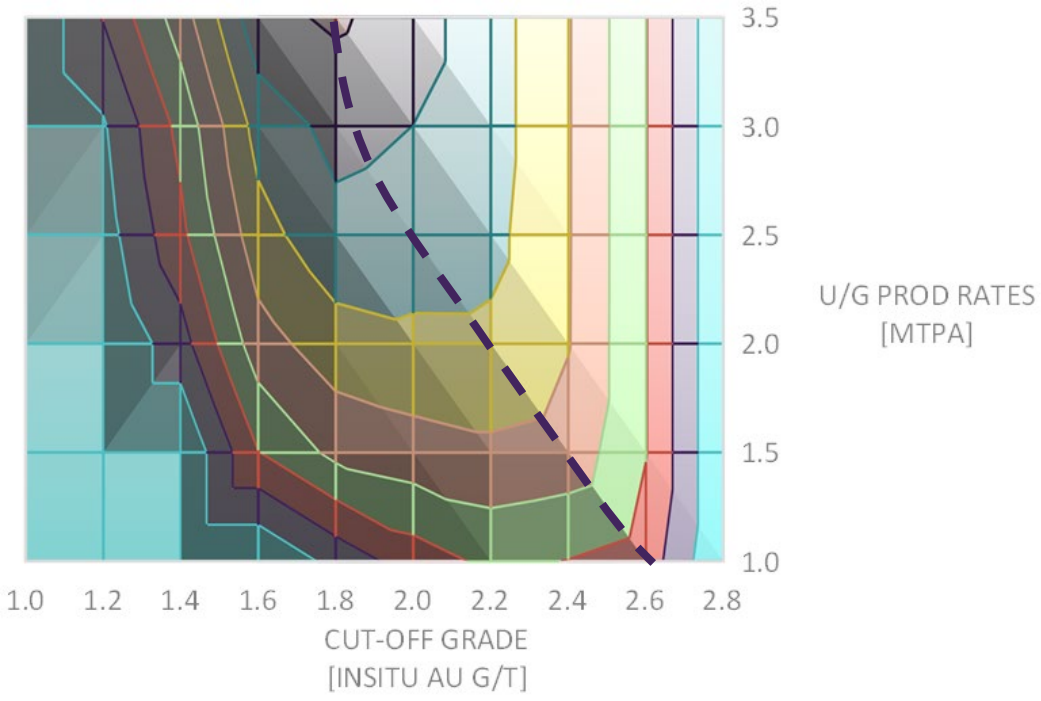
Case Study: U/g Gold:
NPV vs COG & Production Rate Optimization



Typical AMC Hill of Value® findings

NPV vs Cut-off & Production Rate

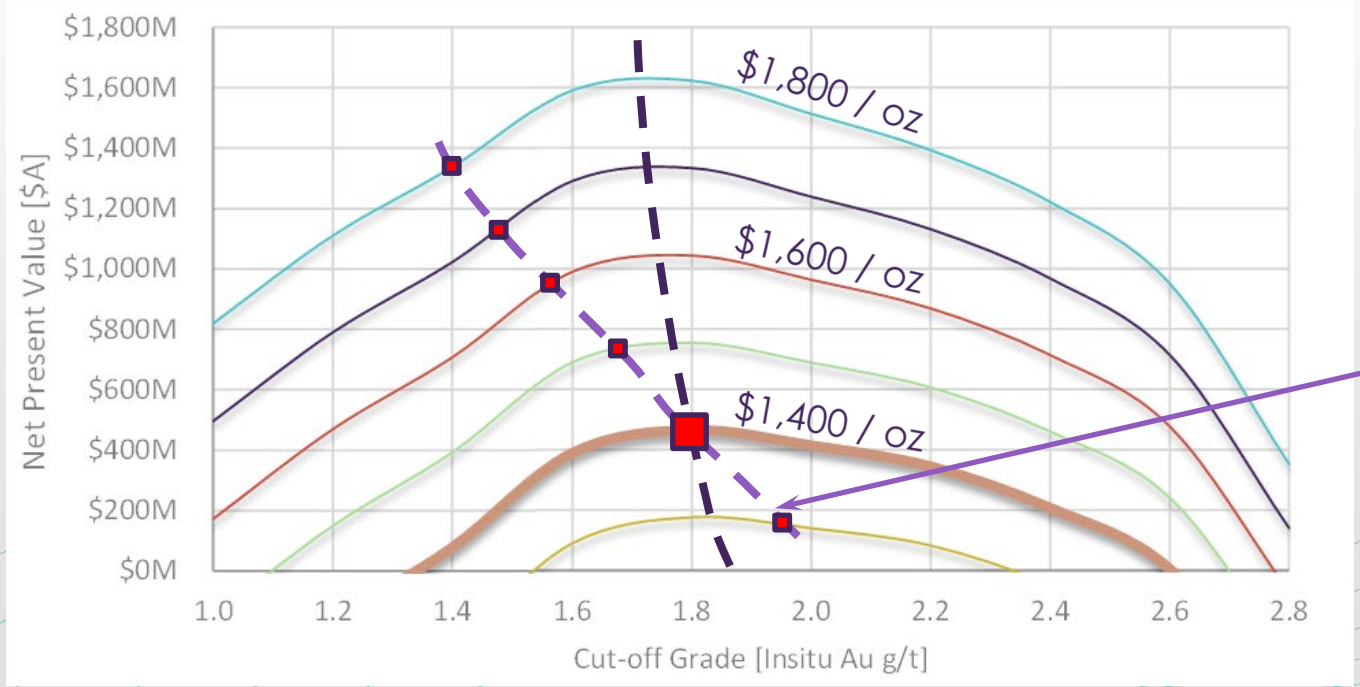
Optimum cut-off reducing with increasing production rate is common.



Typical AMC Hill of Value® findings

NPV vs Cut-off & Au Price

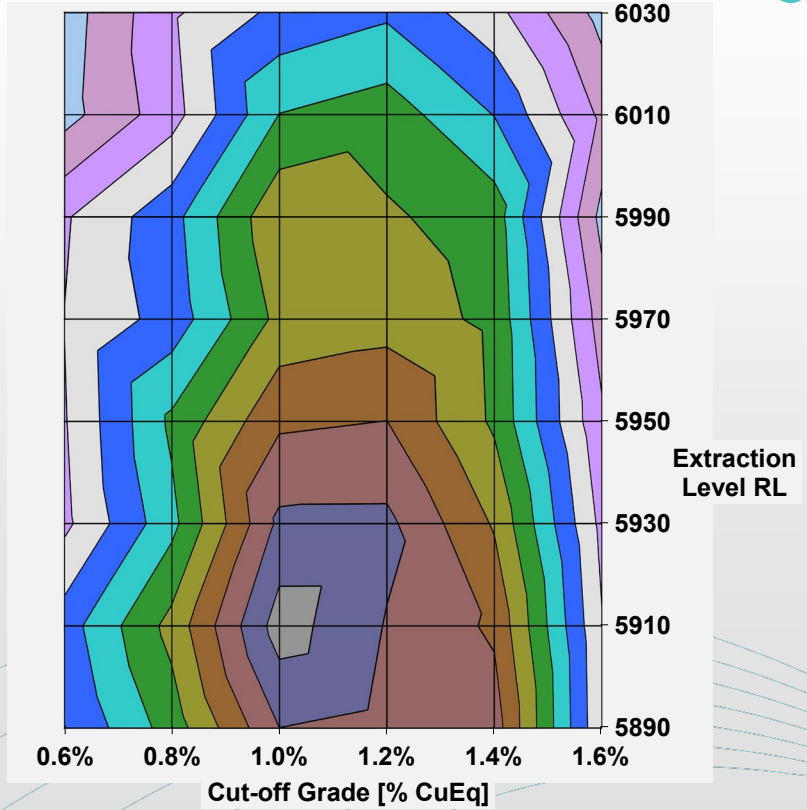
Minimal change in **optimum** cut-off with changing metal price is common



compared to break-even style changes.

Optimum cut-off at base case price adjusted in inverse proportion to price change. Curve plotted through those cut-offs on AMC Hill of Value® for each price. (NOTE: These are NOT the break-even cut-offs at each price.)

Block caving extraction level size and elevation



- Porphyry copper block caving operation
- Orebody narrowing with depth
- NPV vs extraction level boundary cut-off and elevation.
- Trading off resource recovery or loss against capital cost of extraction horizon and initial draw of waste from outer draw points

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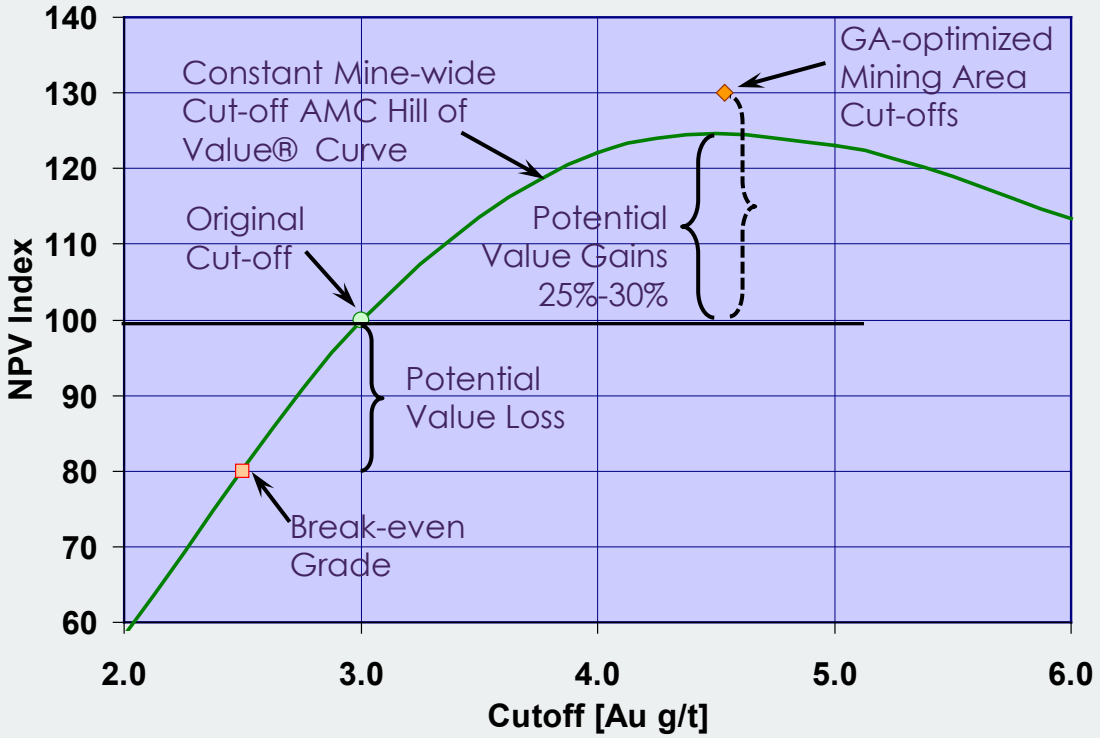
Case Study: U/g Gold: COG Optimization – Mine-wide & by Area



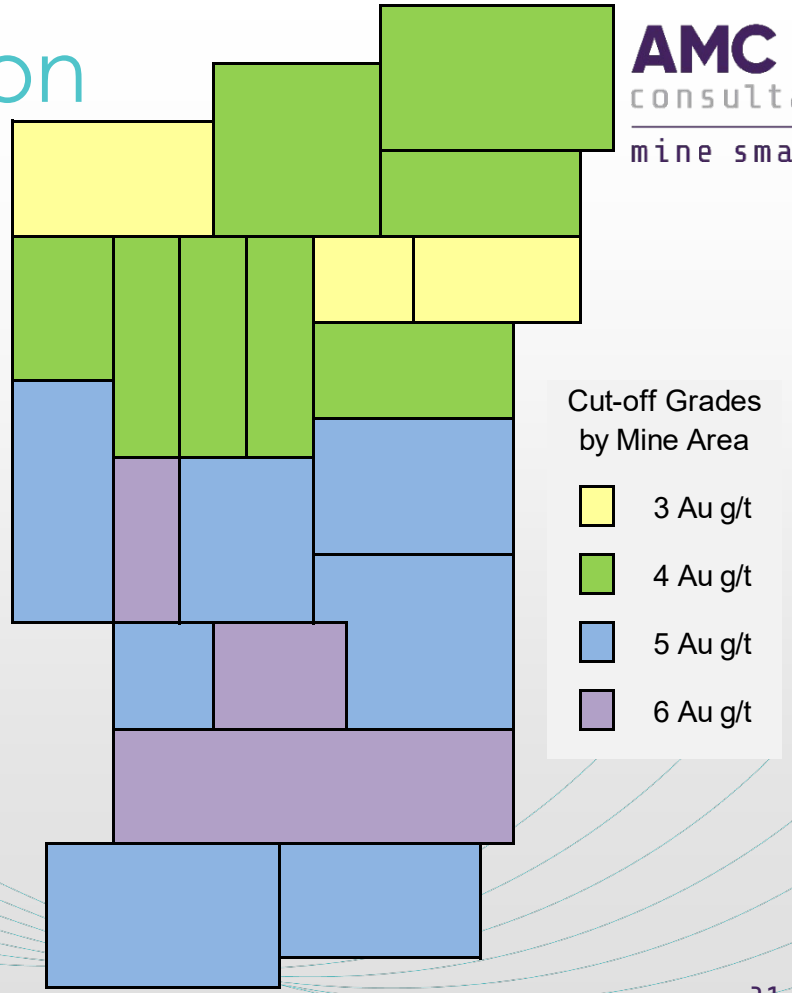
Longitudinal projection of mine areas

Optimized mine area cut-offs

Impacted by:

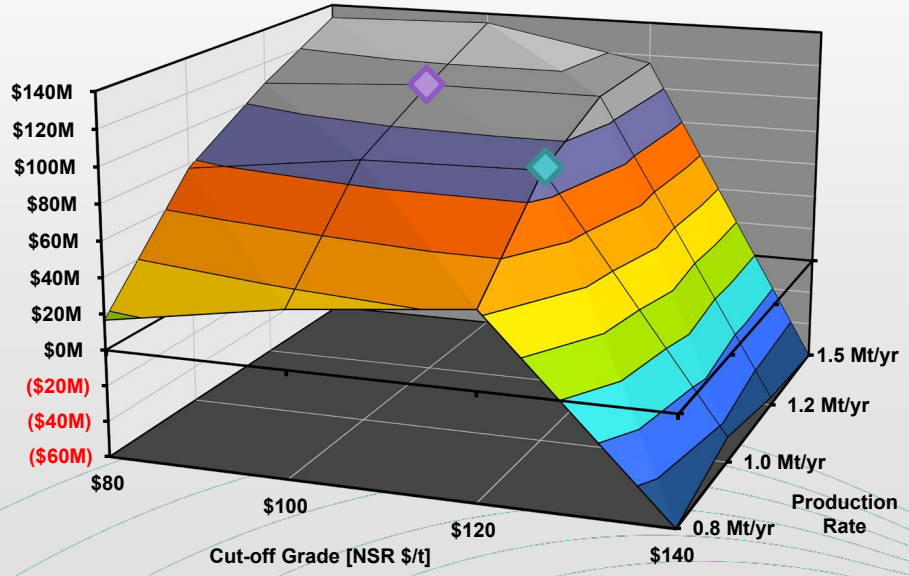
- Ore tonnes constraints for individual areas and total mine
- Trucking tonne.kilometre constraints
- Complex predecessor – successor scheduling relationships between adjacent areas
- Reserves data at 1 g/t cut-off increments only

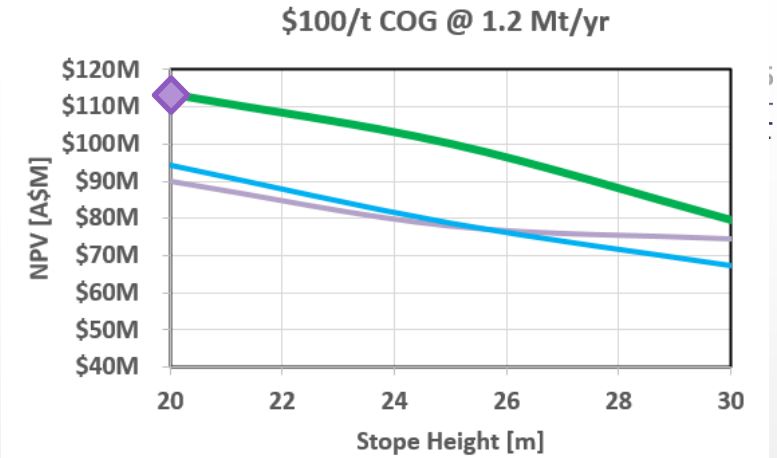
Optimum mine area cut-offs do not simply increase with depth.

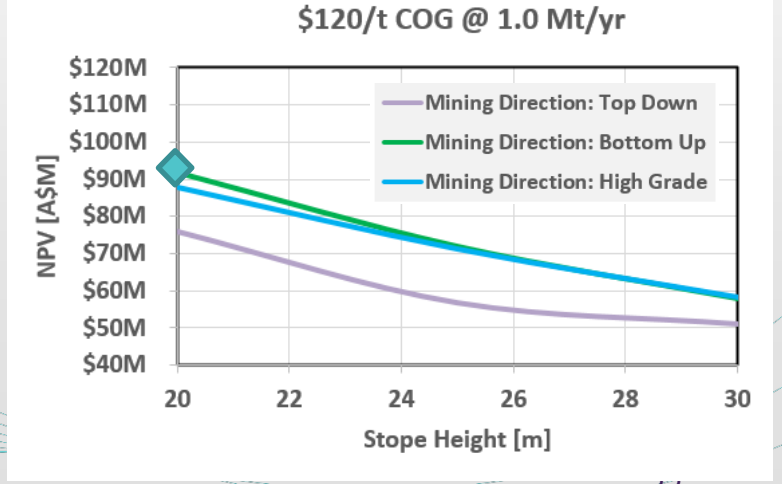


Optimizing multiple decisions

Cut-off, production rate, sublevel interval, mining direction

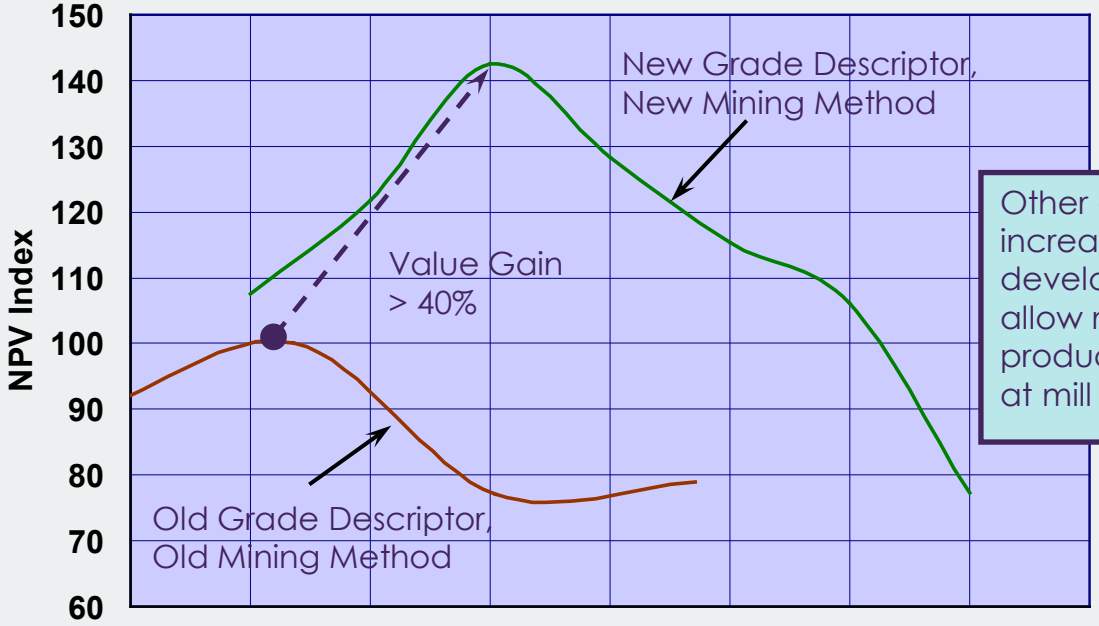






Case Study: U/g Polymetallic Base Metals: Grade Descriptor, Mining Method & Cut-off

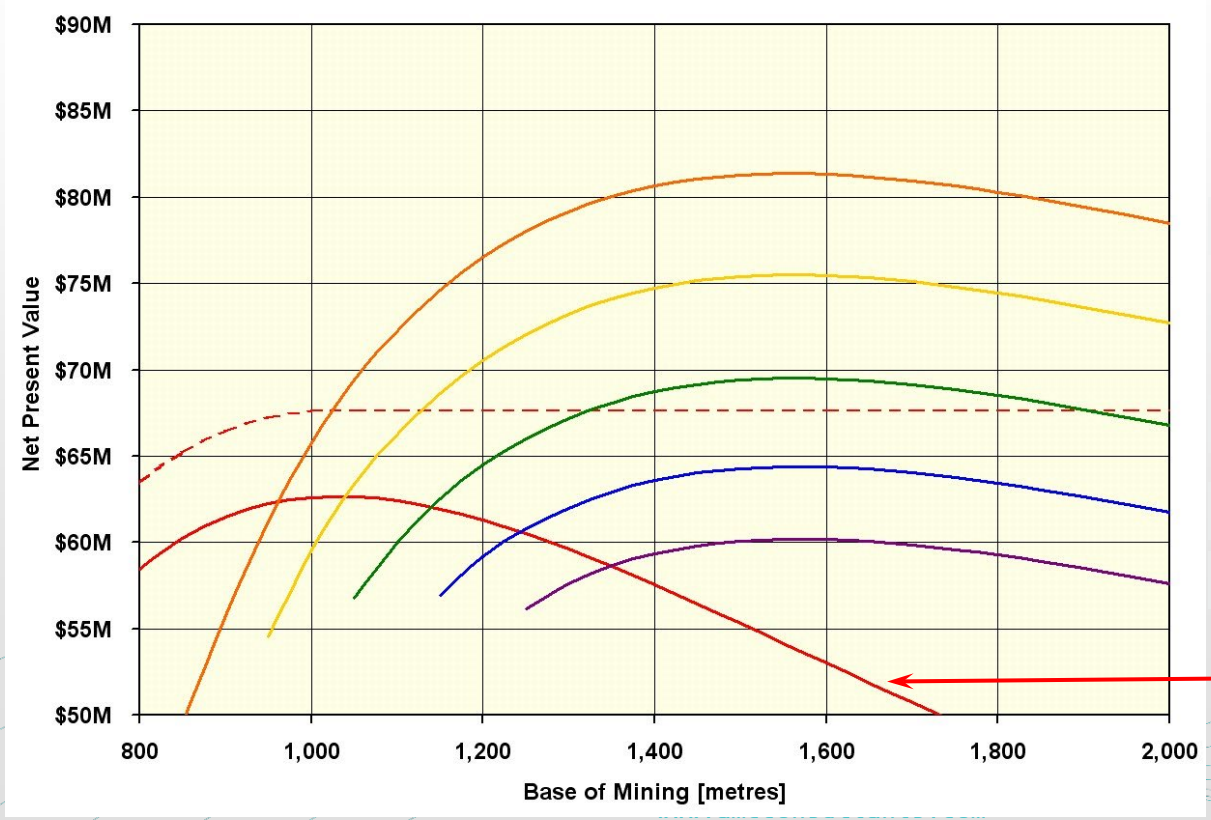
Changing grade descriptor changed understanding of spatial distribution of value, leading to a changed mining method.



Other gains from increasing stocks of developed ore to allow mine to produce consistently at mill capacity.

(old grade descriptor values scaled to be numerically similar to new grade descriptor values)

Optimum time of transitioning from trucking to surface to shaft hoisting (1)



Shaft Hoisting starts when production front is at depth of:

800 m

900 m

1,000 m

1,100 m

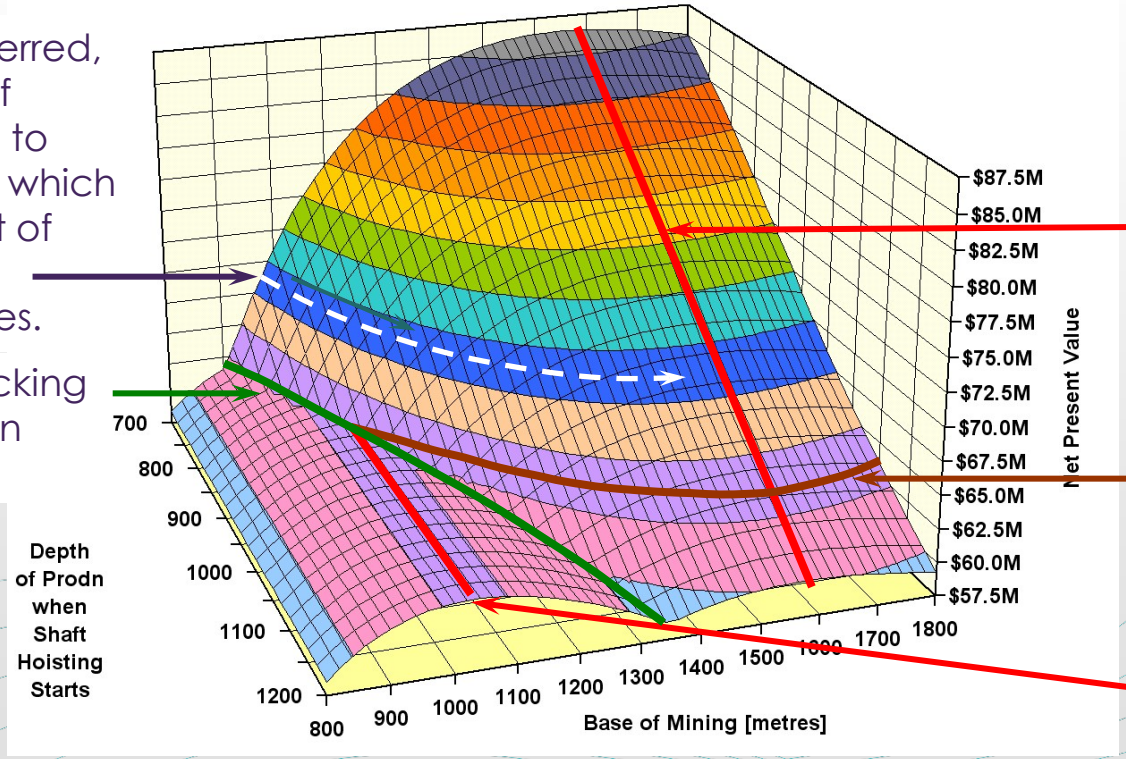
1,200 m

Trucking Only

Optimum time of transitioning from trucking to surface to shaft hoisting (2)

As the shaft is deferred, the extra depth of resource required to justify it increases, which increases the cost of exploration and potential difficulties.

Shaft – trucking break-even depth



Economic depth trucking to shaft: Benefit reduces the longer the shaft is deferred.

Limit of shaft adding value

Economic depth trucking to surface

Inter-relationships may be complex

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For the zinc mine and concentrator on the following slide:

- Recovery was a non-linear but increasing function of metal feed rate, not ore grade.
- Higher ore grades at higher cut-offs gave softer ore, which milled at a higher rate than lower-grade harder ores.
- At any cut-off, the Zn feed rate constraint itself is more likely to be the bottleneck with a lower target than with a higher.
- At any cut-off, mining rate constraints are more likely to be the bottleneck with a higher metal feed target than with a lower.
- The metal feed rate was an operating control decision to be optimized. (Just two options illustrated, but many available.)
- Higher feed rates requiring debottlenecking capex traded off against increased revenue from higher annual metal sales.

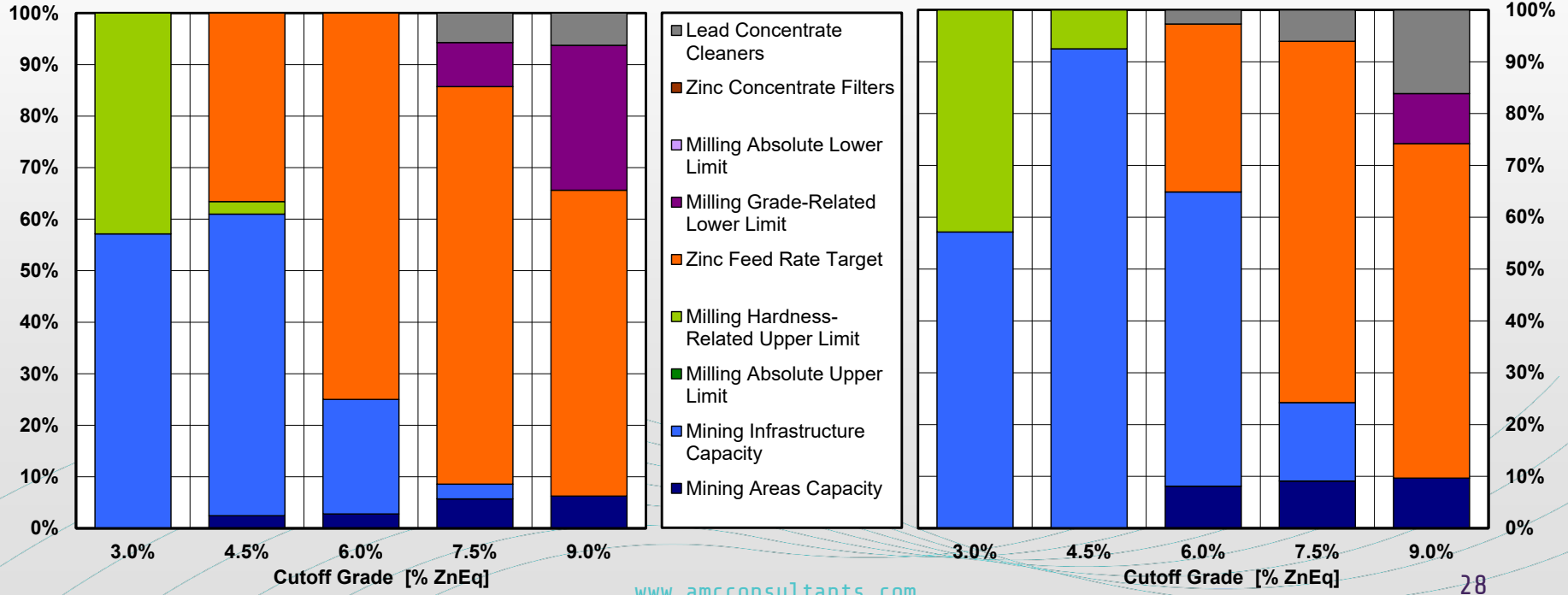
Proportions of time various constraints are active for different operating strategies

Lower Zn metal feed rate:

Zn feed rate is the main bottleneck.

Higher Zn metal feed rate:

The mine is the main bottleneck.



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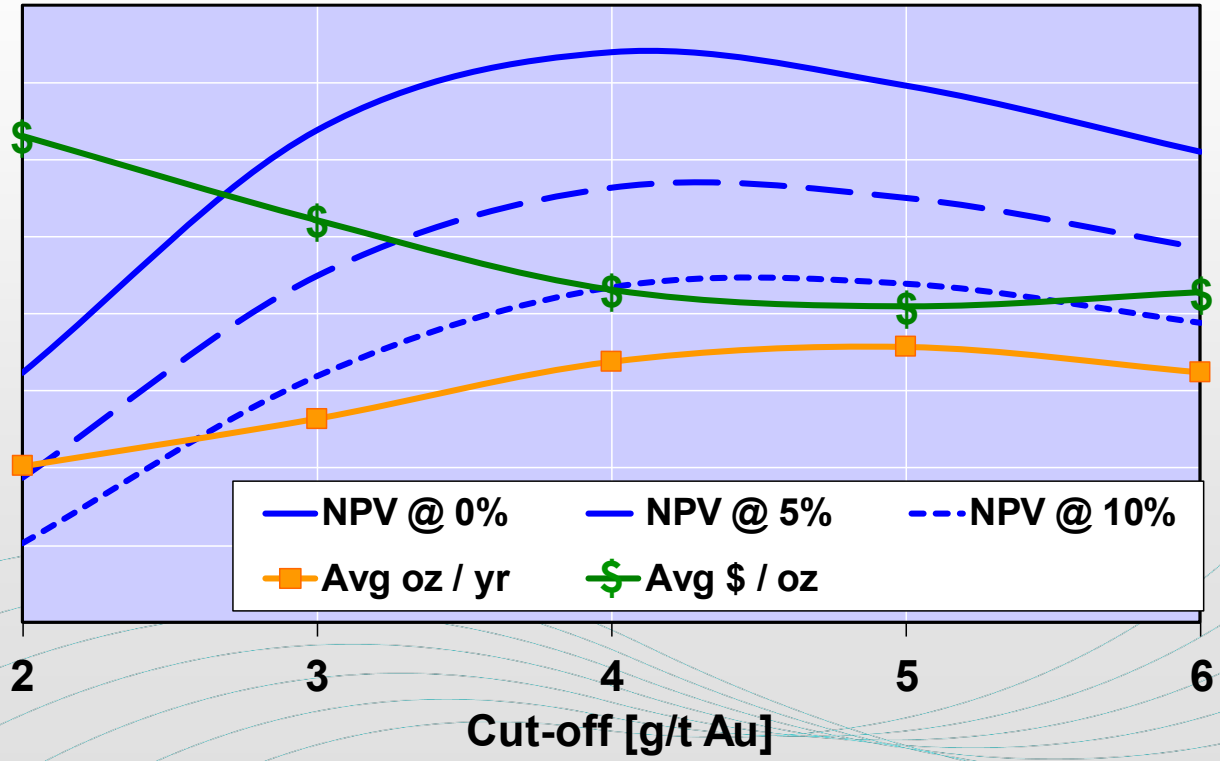
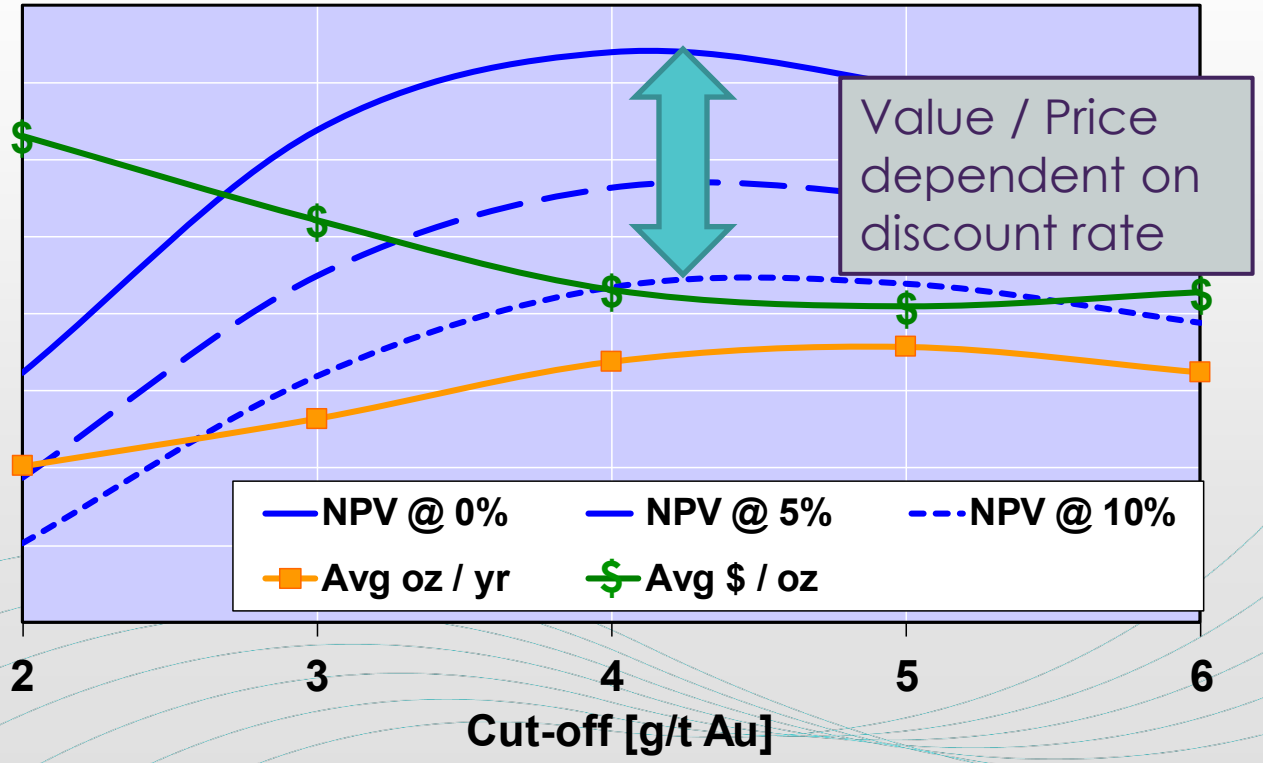
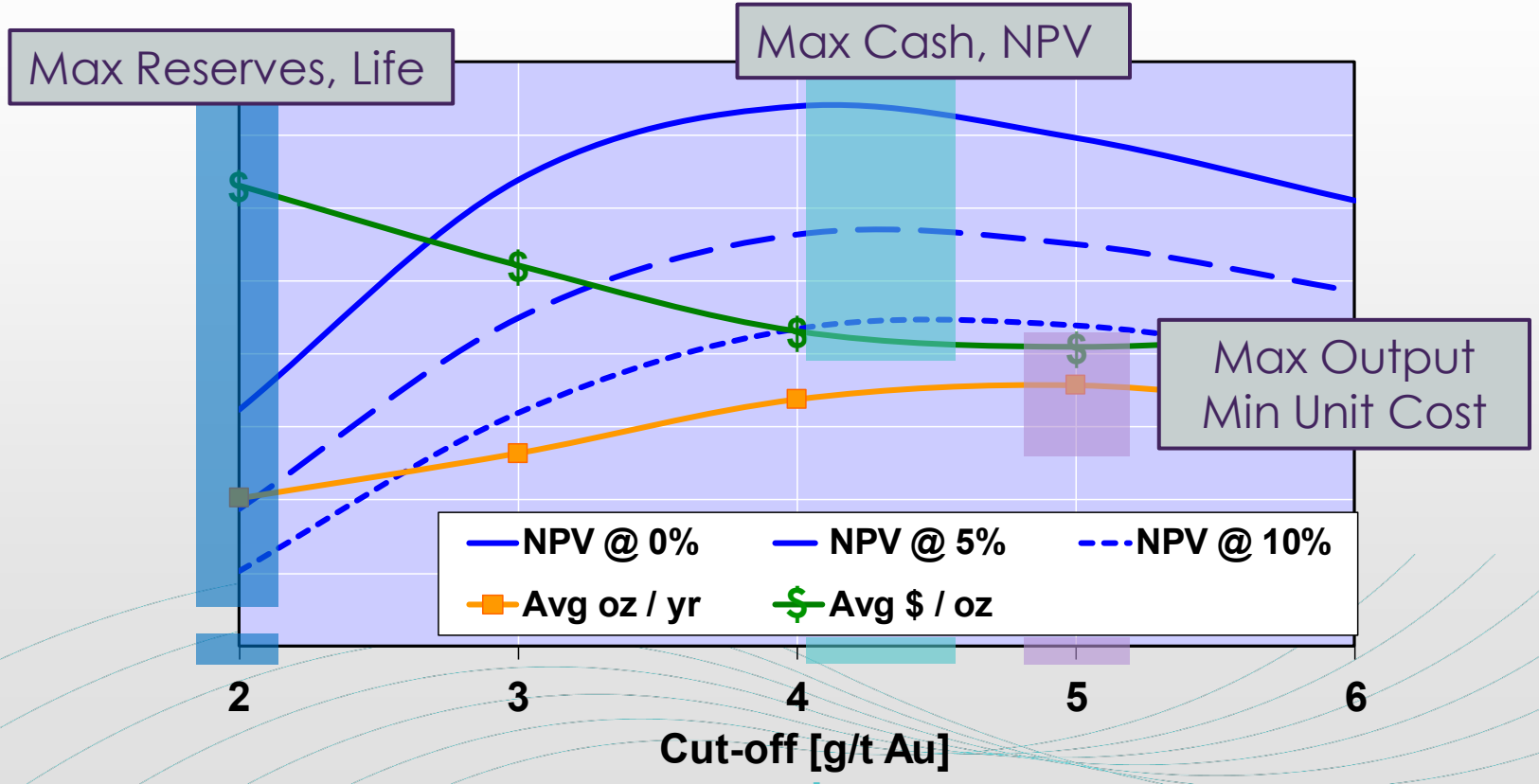
Underground Case Study Results: Various Value Measures vs Cut-off Grade



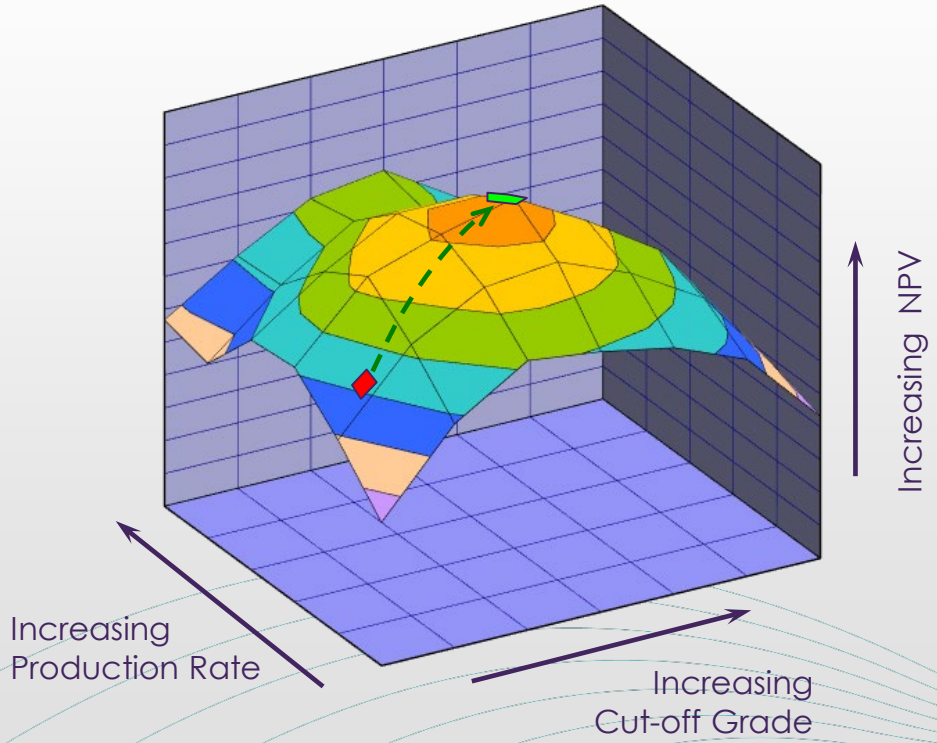
Discount rate may affect sale price, but may have little or no effect on optimum strategies



Different strategies deliver different goals: Different goals require different strategies!

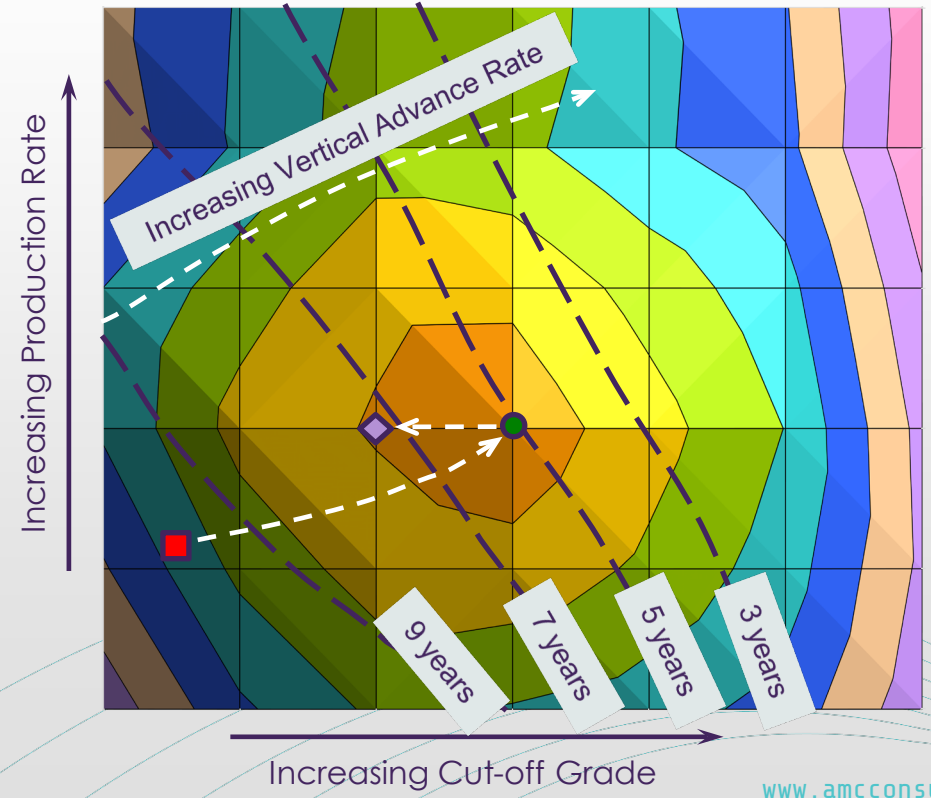


An apparently simple AMC Hill of Value®



- The illustrative AMC Hill of Value® for an underground mine, optimizing cut-off grade and production rate to maximize NPV, is an apparently simple decision.
- But there's more . . .

Finding the best strategy with multiple and potentially conflicting aims



- Focussing on one goal makes decision-making simple.
- But maximizing NPV reduces mine life from ~10 years to 5, which is socially unacceptable.
- Mine life can be increased to a socially-acceptable 7+ years, with minimal reduction in NPV.
- Increasing cut-off and production rate reduces mine life and also increases the vertical advance rate, increasing the technical risk of achieving targets.

Case Study: Porphyry Copper Open Pit: Pit Size, Mining Rate, Plant Capacity, Staging

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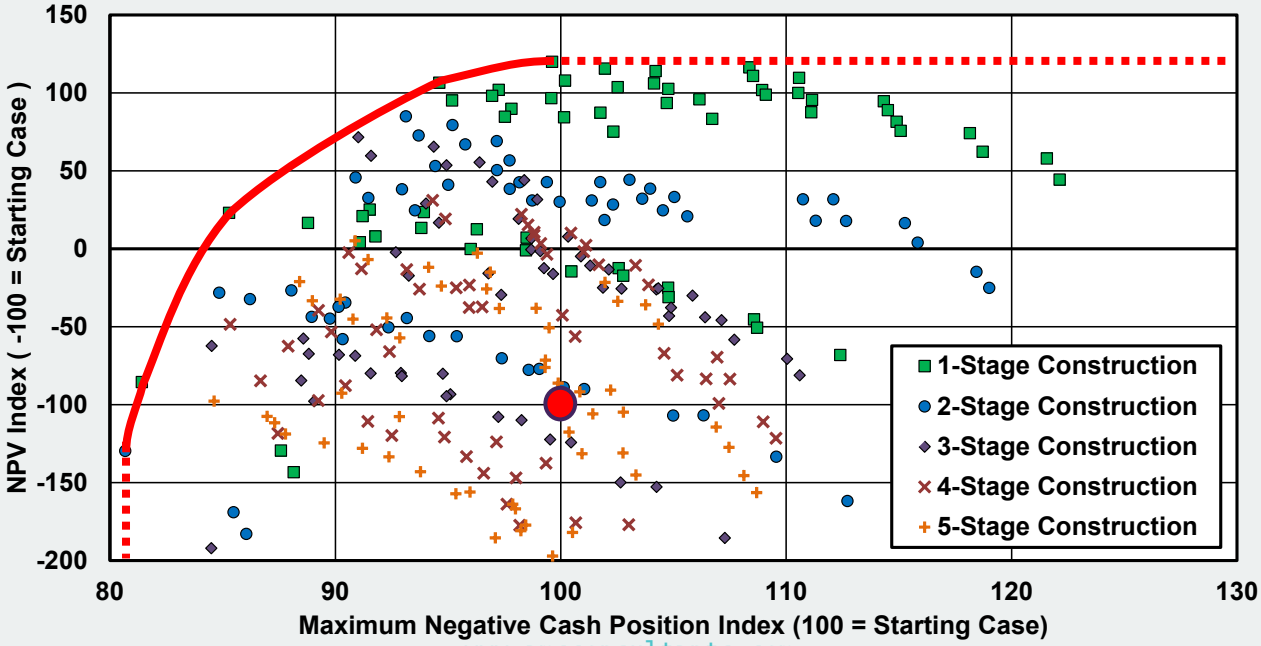
Trading off NPV and cash outlay (Negative NPV starting point)

Data points in each set for combinations of maximum mining rate and maximum capacities of two alternative treatment processes that may operate alone or concurrently.



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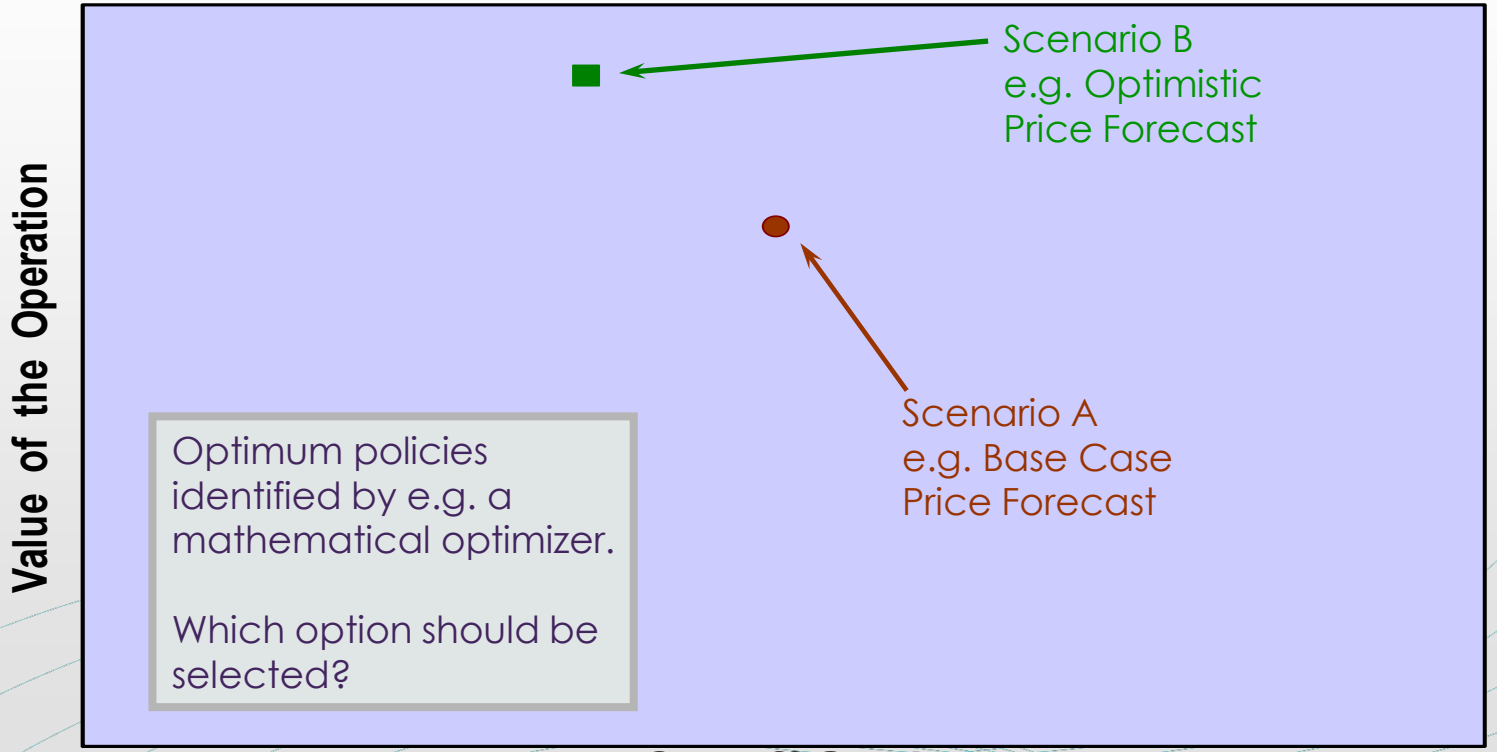
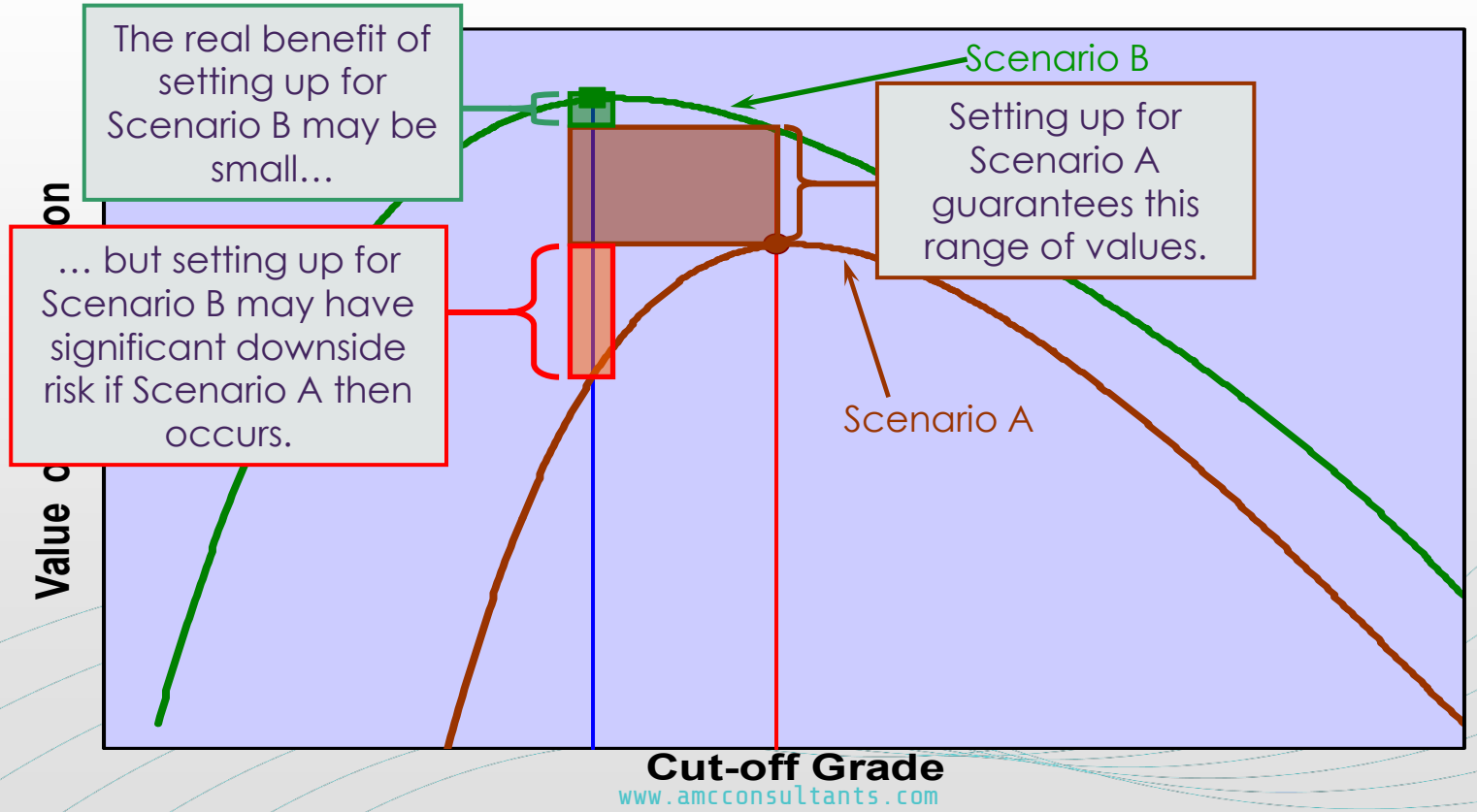
When should strategy optimization studies be done?

- As an integral and essential part of the prefeasibility study, to find the best plan to take forward into the detailed feasibility study.
- At an operating mine, every few years, to review and update the long-term mine plan, especially if:
  - Forecast economic conditions have changed significantly.
  - Knowledge of the resource has changed significantly.
  - The previous plan is becoming obsolete.
- Should be reviewed as part of the annual planning cycle, but is a separate project outside the annual cycle, to set the big-picture plans for the next cycle.

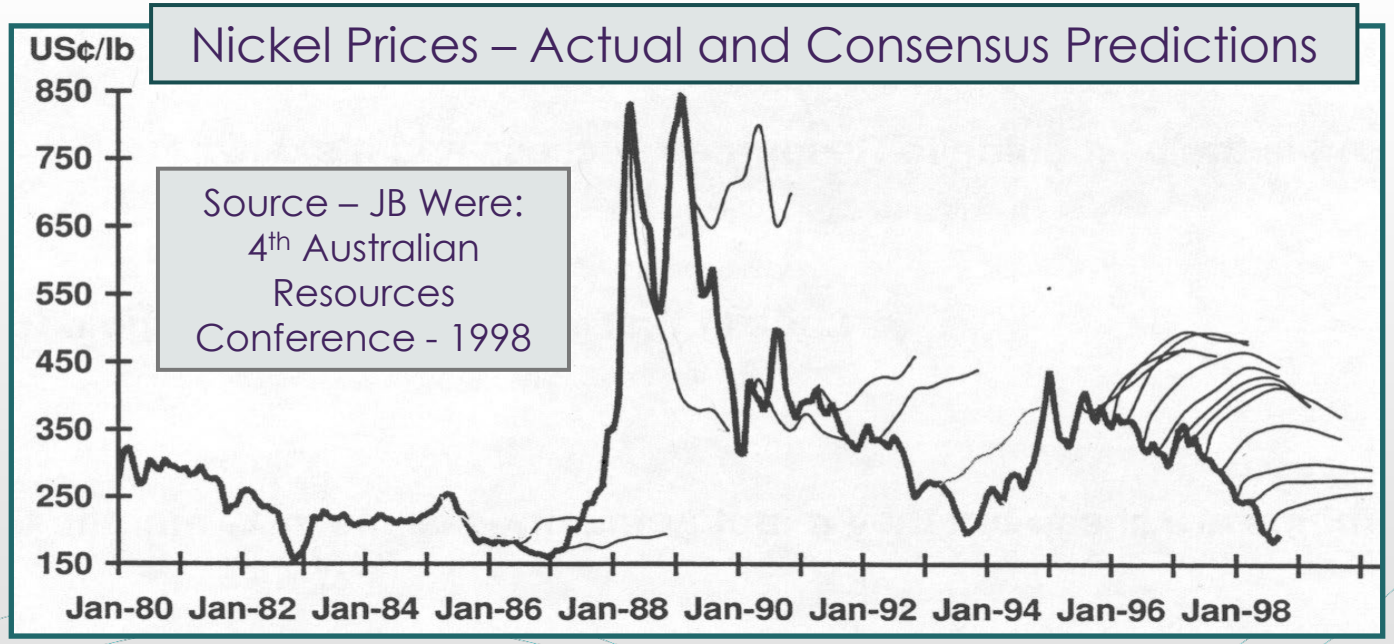
Knowing just the optimum strategy for any scenario may be misleadingly incomplete.



Knowing the full curves for various scenarios can be a powerful risk management tool !

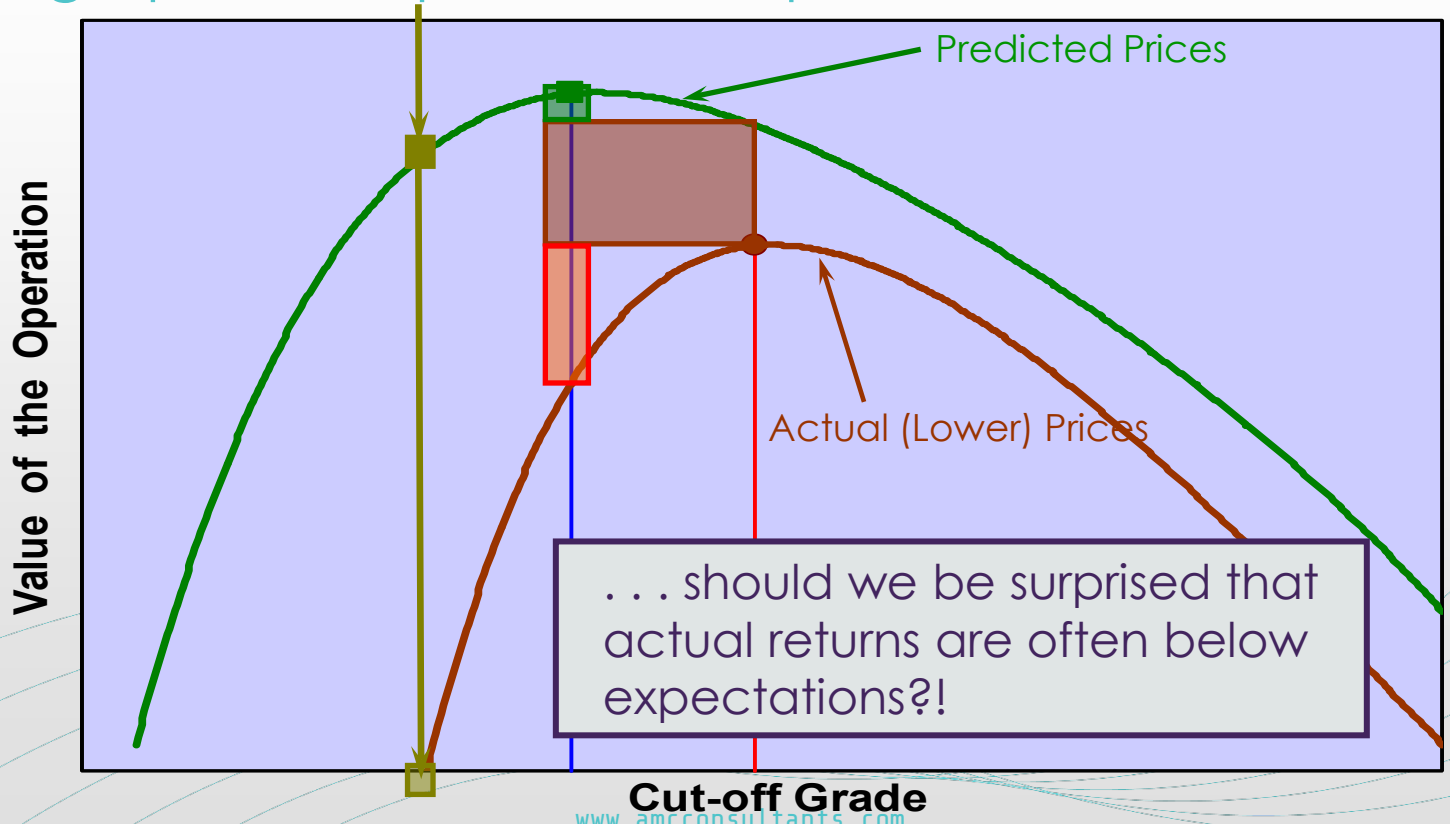


History indicates major strategies are often founded on wrong assumptions!



- What price scenario should we plan for, if the "best" predictions are consistently wrong?!

If we typically set cut-offs below optimum, using optimistic price assumptions . . .

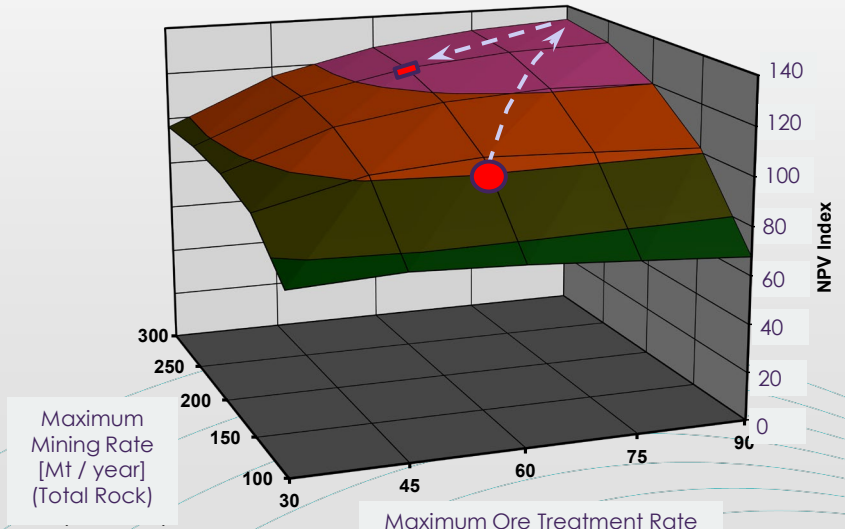


Case Study: Open Cut Gold: Treatment and Mining Rates, Impact of Au Price on Strategy

Base Case Au Price

37% NPV increase by maximizing mining and treatment rates.

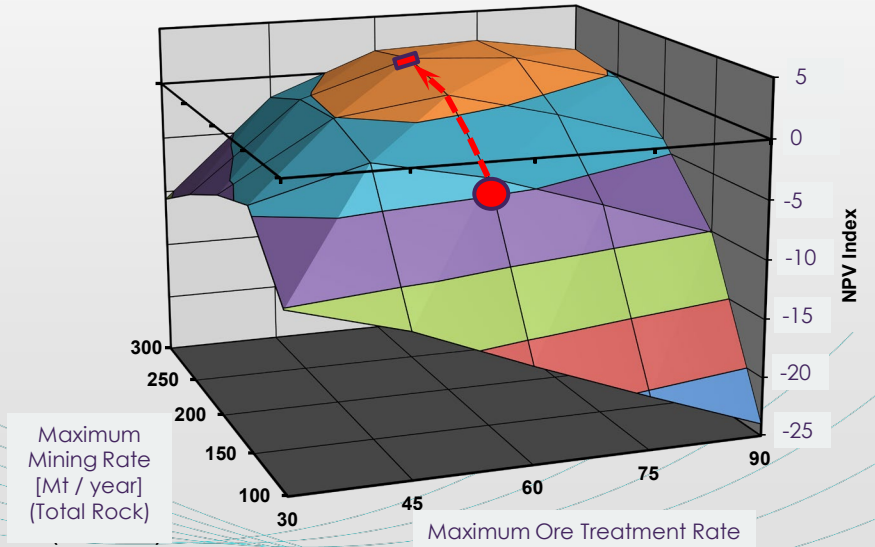
Small loss of potential value from adopting "safe" strategy.



Au Price $^{2}/_{3}$ of Base Case

Base Case Strategy: Negative NPV.

"Safe" Strategy: Best (and positive) NPV at faster mining rate but same treatment rate as base case.

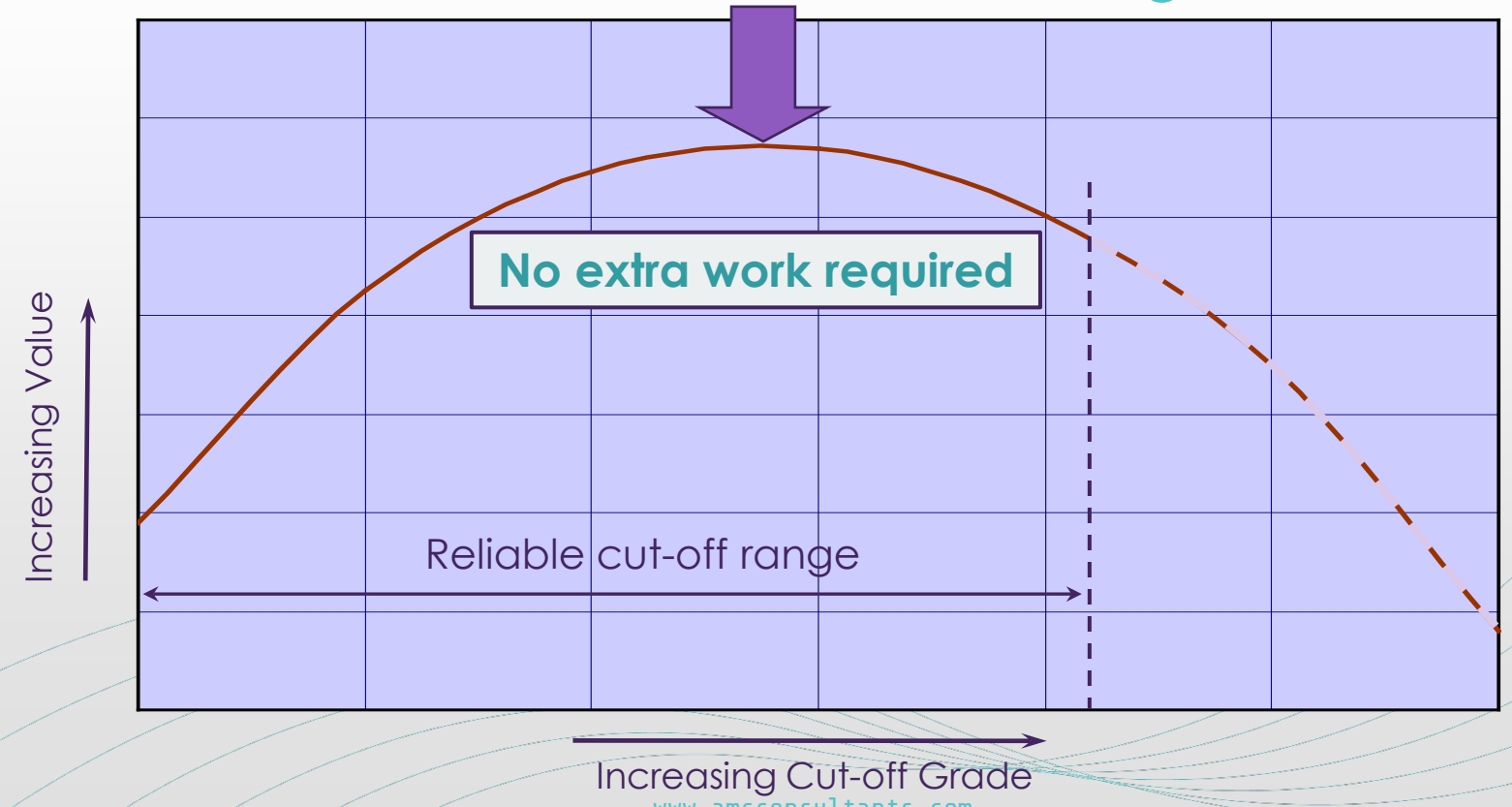


What if the current model is not valid for the full range of desired cut-offs?

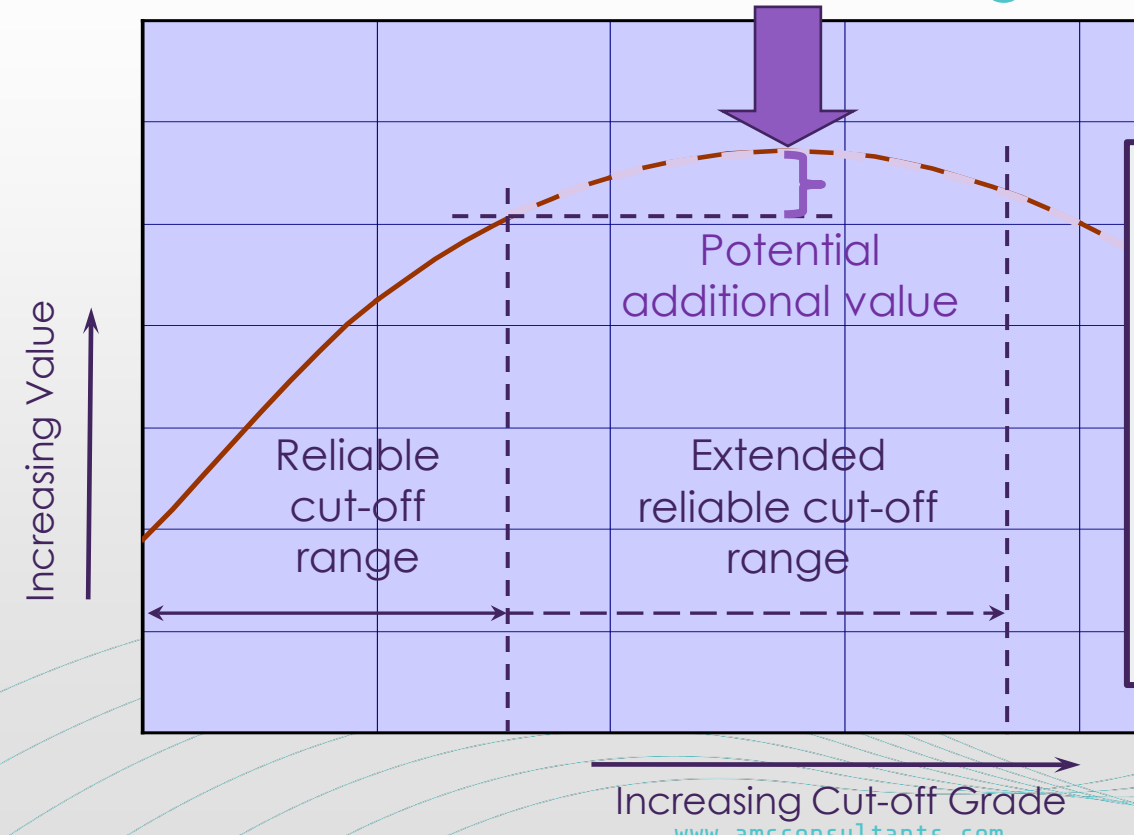
- Often not able to be reworked within the timeframe of the planning study.

- Doesn't have to be a problem:
  Use the current model and identify **from the study** whether additional geological work is actually required.

The optimum cut-off may turn out to be within the model's reliable cut-off range



Or the optimum cut-off may be outside the model's reliable cut-off range



Does the potential value added exceed the additional cost of improving the reliable cut-off range?

- Yes: then do so.
- No: optimum cut-off = maximum reliable cut-off

Dealing with other uncertainties (1)

- Exploration results:
  - Existence, tonnes and grades etc of exploration targets
  - Conversion rate of Inferred Resources
- Geotechnical conditions
  - Pit wall stability, stope hangingwall overbreak
  - Hence pit wall angles, sublevel intervals, ground support costs, dilution
  - Constraints on sequencing
- Geometallurgical issues
  - Recovery, product quality, product mix

etc., etc.

Dealing with other uncertainties (2)

- Typical approach: We don't have reliable information so you can't model it.
- Illogical! The least certain input is metal price!
  - We wouldn't evaluate a project ignoring metal price because it's uncertain!
  - We use our best estimates and flex around them.
- Better approach: for all uncertain parameters:
  - Use our best estimates of values and relationships and flex them across the likely range.

Dealing with other uncertainties (3)

- Does the value change as we flex uncertainties?
  - Probably!
  - Does that change our decisions?
    - Depends on the decision: Selling price? Develop or not?
- Do the optimum operating strategies change as we flex uncertainties?
  - Maybe, maybe not!
  - If so, can we resolve the uncertainties before we have to commit to a plan of action?
    - If not, what's the robust strategy that balances upside rewards and downside risks (as illustrated for price above)?

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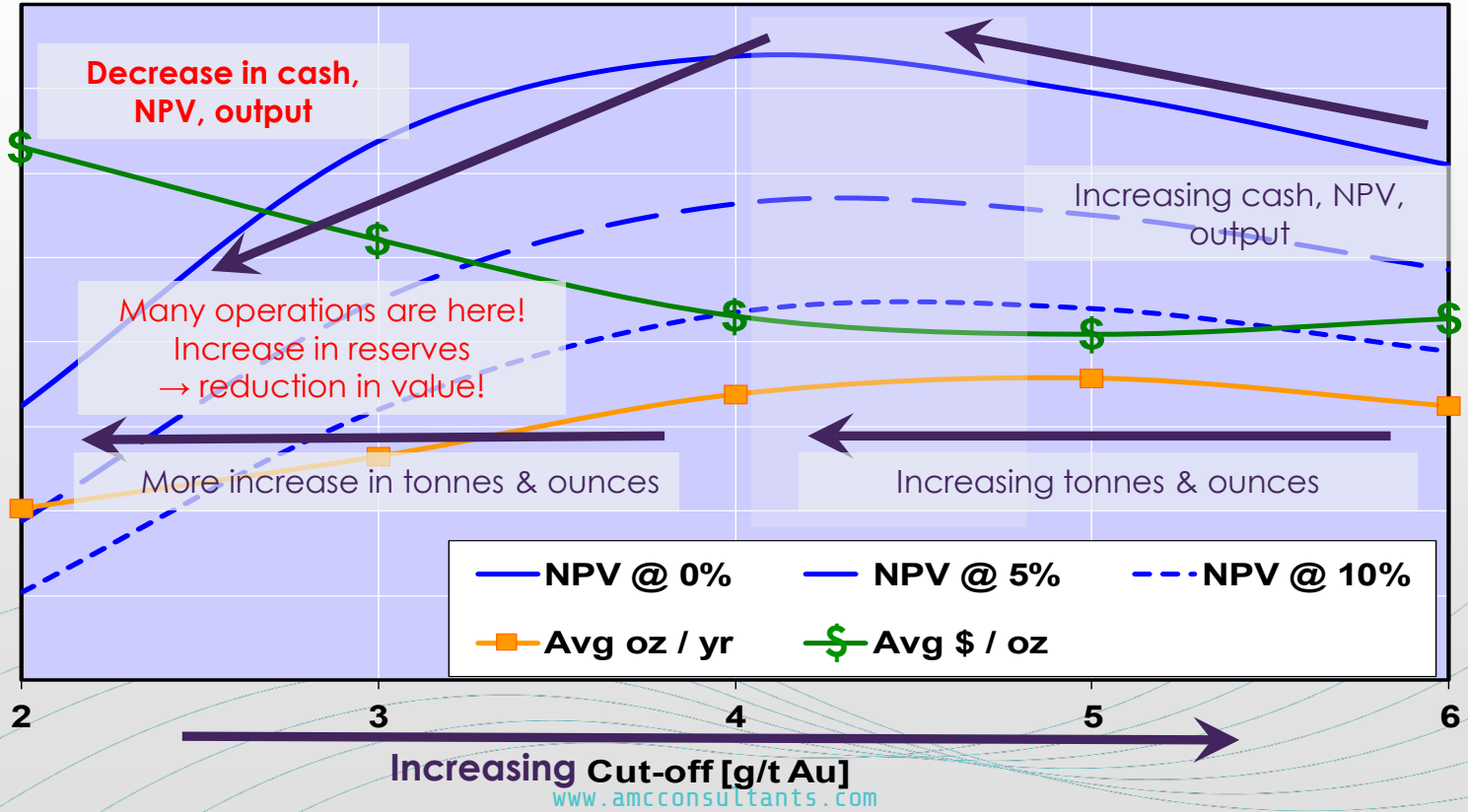
- Debunking with the primary misconception:
  More ounces mean more value—NO! They don't!

Misconception:
Increase in reserves is correlated with value



Conventional wisdom is not always wise!

Typical high-level metrics are at best uncorrelated, at worst, negatively correlated, with value!

- Increasing reserves from new discoveries usually adds value.
- Increasing reserves by reducing the cut-off in existing resources almost always destroys value!
- Cost reductions that cut "fat" will typically improve value but, like price increases, will not necessarily lead to different optimum cut-offs and other operating strategies.
- Cost reductions that cut or defer capabilities and capacities typically reduce revenue by more than the costs saved, destroying, not adding, value.
- Apparent excess capacity when everything is working well is not "fat". It is typically essential for maintaining value-adding capabilities when natural variability turns easy times into hard.

Looking ahead . . .

Where to in the future for AMC Hill of Value® ?

- We are limited only by our imagination and computer power.
- If it can be described, it can be modelled and evaluated (whether we have all the information or not).
- All mines have many similarities, but every operation has unique characteristics that are often (perceived to be?) critical but cannot necessarily be black-boxed.
  - Even if unique characteristics aren't critical, it's often necessary to demonstrate that by rigorous inclusion of them in the evaluation anyway.
  - There is therefore an element of "R&D" in every project.

Where to in the future for AMC Hill of Value® ?

Expanding the range of decisions, analysis, and outputs

- Proof of concept work already done on many of these
- Just waiting for projects where they're part of the scope of work.

Where to in the future for AMC Hill of Value® ?

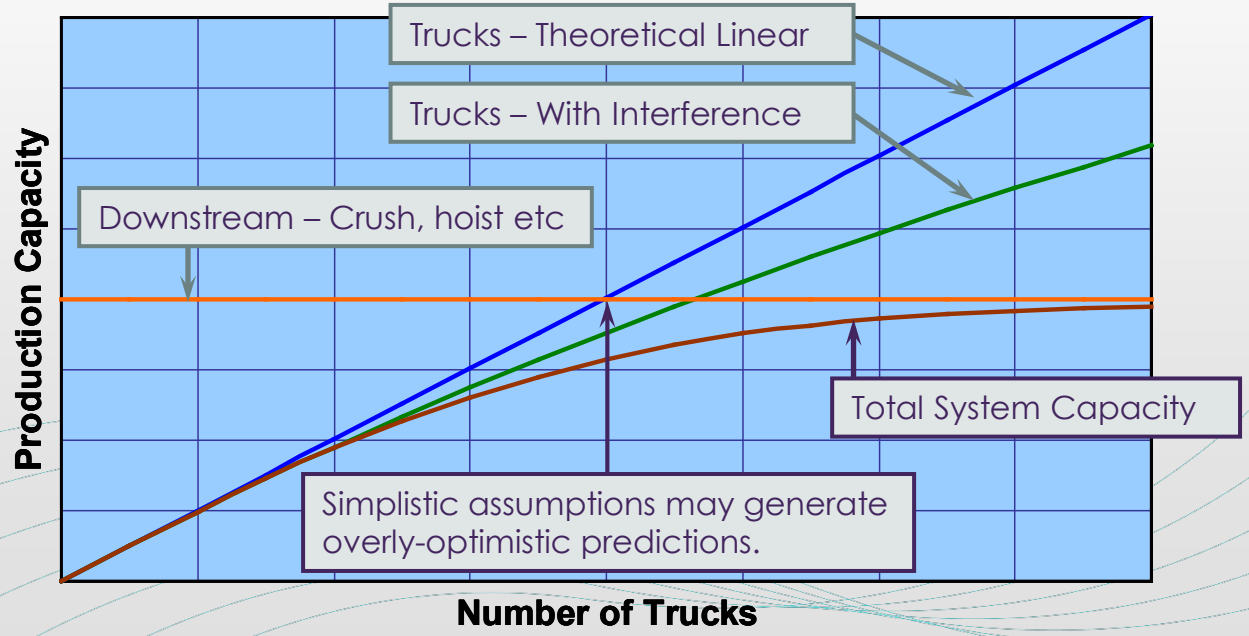
- Pit – underground transition
  - Transition elevation straightforward, but what if, e.g.:
    - Advancing pit operations progressively constrain areas that can be worked underground
    - Underground operations can access material within the ultimate pit earlier, potentially changing the shape of the ultimate pit?
  - Proof of concept done
- Probabilistic analysis
  - Of input assumptions, schedule critical paths etc.
  - We already test ranges of prices etc and show how "lateral" moves of AMC Hill of Value® may indicate changing strategies with price.
  - AMC Hill of Value® for various percentiles of value metrics are analogous.

Where to in the future for AMC Hill of Value® ?

- Geological uncertainty via conditionally simulated (CS) geological block models (esp. in underground operations).
  - Users of CS will typically have a process for generating CS realizations and hence defining stope boundaries.
  - Given these stopes, there will be probabilistic tonnage and grade relationships for reserves at various cut-offs.
  - AMC Hill of Value® of various percentiles of value metrics resulting from the quantification of underlying geological uncertainty, as well as "simple" uncertainly around prices, unit costs, etc, become possible.
  - What are the risk – reward trade-offs associated with geological uncertainty?

Where to in the future for AMC Hill of Value® ?

- Constraints defined by stochastic behaviour of production systems
  - Simulations to more-accurately represent interactions of constraints and surge capacity between sequential processes in the operations.



Where to in the future for AMC Hill of Value® ?

- Portfolio decisions
  - Ranking minimum base case and incremental expansion options by capital efficiency (simplistically NPV/capex) to maximize the value of capex across all the company's operations rather than simply maximizing NPV at one.

AMC consultants
mine smarter

AMC's AMC Hill of Value® Process

A robust and comprehensive assessment of multiple input and scenario combinations to uncover **all** the available options, allowing you to make an informed decision to achieve your **preferred strategic position**.

Strategic opportunities analysis

Options overlaid with scenarios

Relationship between inputs

Given and changeable inputs

05 Preferred Position Selection

After reviewing all the data and analysis, you can make an informed decision and select your preferred strategic position with confidence.

04 Strategic Opportunities Analysis

Through the robust and comprehensive assessment of multiple combinations, the Hill of Value™ process identifies **all** strategic opportunities available to help you understand the trade-offs, enabling you to make an informed decision.

03 Common Scenario Overlay

The model is enriched through the lens of probability and sensitivity by overlaying common scenarios that might happen over the course of the mine life cycle e.g. commodity changes, competitor movements, changes in exchange rates, etc.

02 Multiple Option Generation

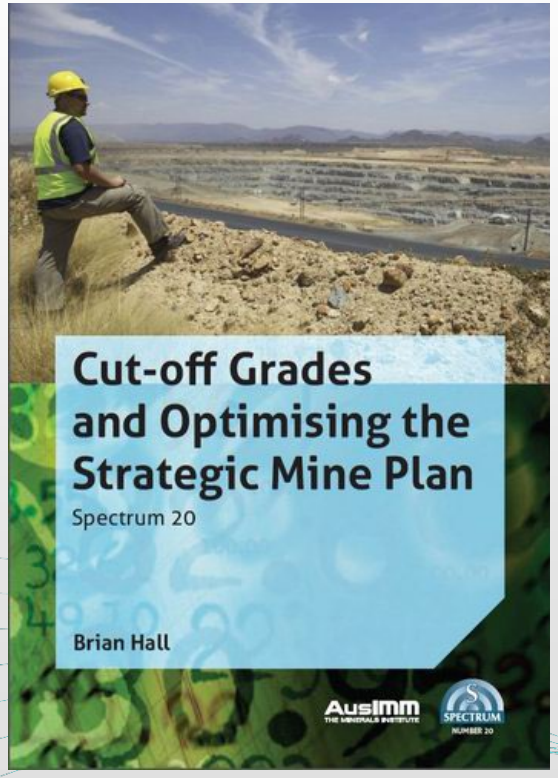
Using the relationships between the given and changeable inputs, we build a robust model that can optimize any value measured, show trade-offs between conflicting goals, and define the connection between upside rewards and downside risks.

01 Data Inputs

Start with given inputs (elements we must work with): e.g. mineral resources, ground conditions, location, and environmental factors. Consider changeable inputs (elements we can influence): e.g. mining method, processing method, production rates, and cut-off grades.

Hill of Value™

For more details:
https://www.ausimm.com/publications/spectrum-series/cut-off-grades-and-optimising-the-strategic-mine-plan/




The End
(of the Beginning)