

# Quantifying Water related Financial Risk for the Mining Industry

Atacama Floods, Chile



PNG drought halts mining at Porgera



Tia Maria, Peru  
Water Pollution → Social Conflict

Samarco, Brasil, Tailings Dam Failure

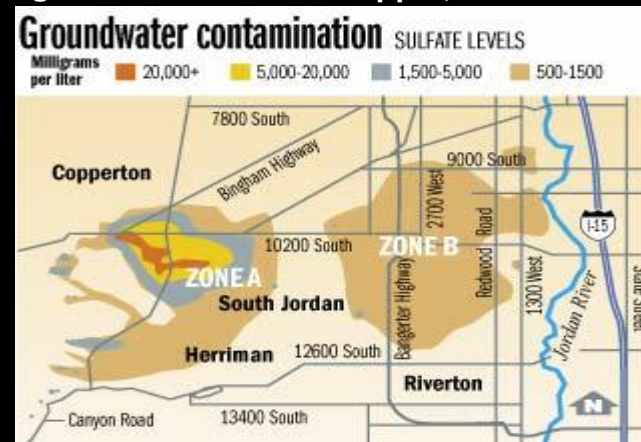
Minera Escondida Copper, Chile  
Water Scarcity - Desalination



Tuslequah Chief Copper-Lead Mine, BC  
Cumulative Effects - Acid Mine Drainage



Kennecott Copper, Utah



## Operator/Investor

CAPEX, OPEX, Production Losses,  
Profit Margins  
Asset Stranding, Operating License,  
Reputation, Regulatory Pressure

## Society

Environmental Degradation, Loss of  
Access to Water, Poverty Trap,  
Property and Life Casualty Losses

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**Columbia University with support from NBIM** with contributions from Gavin Mudd, Stephen Northey, & Tim Werner



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# Research Objective

How to quantify financial risks from environmental factors for **long term investors?**

## Specific Case: Copper/Gold Mining & Water Risks

### Water Management Risks in Mining:

- Scarcity - Aridity, Drought
- Water Quality/Pollution, Waste Spills
- Increasing Water Sourcing & Treatment Costs
- Flooding
- Social Conflict & Asset Stranding
- Regulations & their Effectiveness
- Failure of Risk Mitigation Actions



# Research Questions

1. How do increasing water management costs for mining impact project risk and long run industry cost curve?
2. What are the financial risk exposure pathways for mining related to water & climate? How can data and estimates on these be developed?
3. What are the mine's risk mitigation strategies, their costs and residual risks?
4. Given limited data, high uncertainty, and the potential for catastrophic events, how best can financial risk at the asset and portfolio level be assessed?
5. How well do regulatory and financial disclosure processes address these risks?



# Problem Framing

- Mines are heavily engineered and regulated with life > 10 years
- Environmental/water factors have led to significant social conflict, non-performing assets and production cost risks
- Mining companies disclose their efforts to address these challenges and provide environmental and financial reports
- Analysts and regulators use these reports to assess performance and value the mines
- Is there data to assess whether the risks are properly assessed and disclosed?
- How does one assess the **residual financial risk (beyond the market valuation)** recognizing the complexity in the physical, social/legal, environmental inter-dependence over the long life of a mine? Or for a portfolio of mines?



What are the material financial risks related to water, how do they emerge, and how can one value them? Are they priced right?

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# Short vs Long Term Investor Perspectives

## Short Term Investors:

- Will the company (and its assets) beat market expectations when it announces its results?
- Is the spot commodity price going up (or down) this quarter?
- Will the company have positive exploration results in the near-term?
- Will the company produce more (less) payable metal than the market expects?
- Are costs going to be lower (or higher) than anticipated?
- Will the company's assets get permitted in the near-term?

## Long Term Investors:

- Are the company's assets fundamentally more/less valuable than market perception?
- What should the fundamental commodity price be (supply and demand)?
- Is it likely that company's assets will have reserves higher than estimated?
- Will the company be able to economically extract all of its defined resources?
- What level of costs are sustainable in the long-run?
- Will the company's assets get permitted?
- Are there potential increases in costs due to unforeseen factors that could lead to a stranded or non-productive asset?



## What kind of risks are captured by Market Research & Valuation?

- **Typically Discounted Cash Flow is Used**
  - Emphasizes **Short** or **Near term** Cash Flows
  - Valuations are updated as companies disclose costs, yields and reserves, and analysts update metal prices
  - Production Costs change relatively slowly
    - **Water Management cost changes are included**
  - Risk discounts are applied to address uncertainties
    - Cost and production uncertainties are high in early stages of mine development
    - **Remediation costs occur late in mine development and are highly discounted in Present Value, but = liabilities.**
    - **Not clear how “shocks” are priced accounting for potential mitigation efforts by the company?**
    - **Correlated risks across mines limited to metal prices**



**Residual Financial Risk**  
due to systematic bias  
in estimation and  
disclosure of either the  
value at risk or the  
uncertainty associated  
with the risk



# Financial Implications of Environmental Factors

VALUE

## REVENUE

**Examples:** Production stoppage, permanent mine closure, modified expansion plans

## COSTS

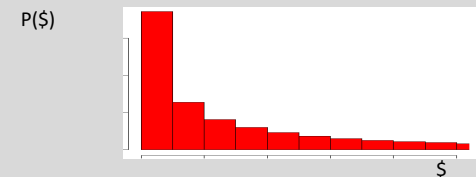
**Examples:** Legal costs, monitoring, community relations, ongoing remediation, permitting

## CAPEX

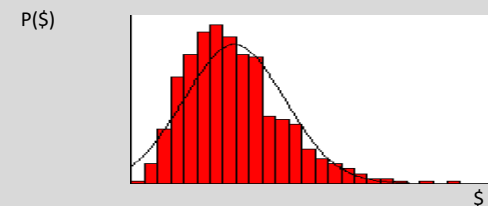
**Examples:** Clean-up costs, settlements, reconstruction

## UNCERTAINTY

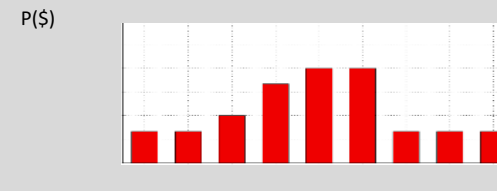
### PROBABILITY OF FOREGONE REVENUE



### PROBABILITY OF INCREASED COSTS



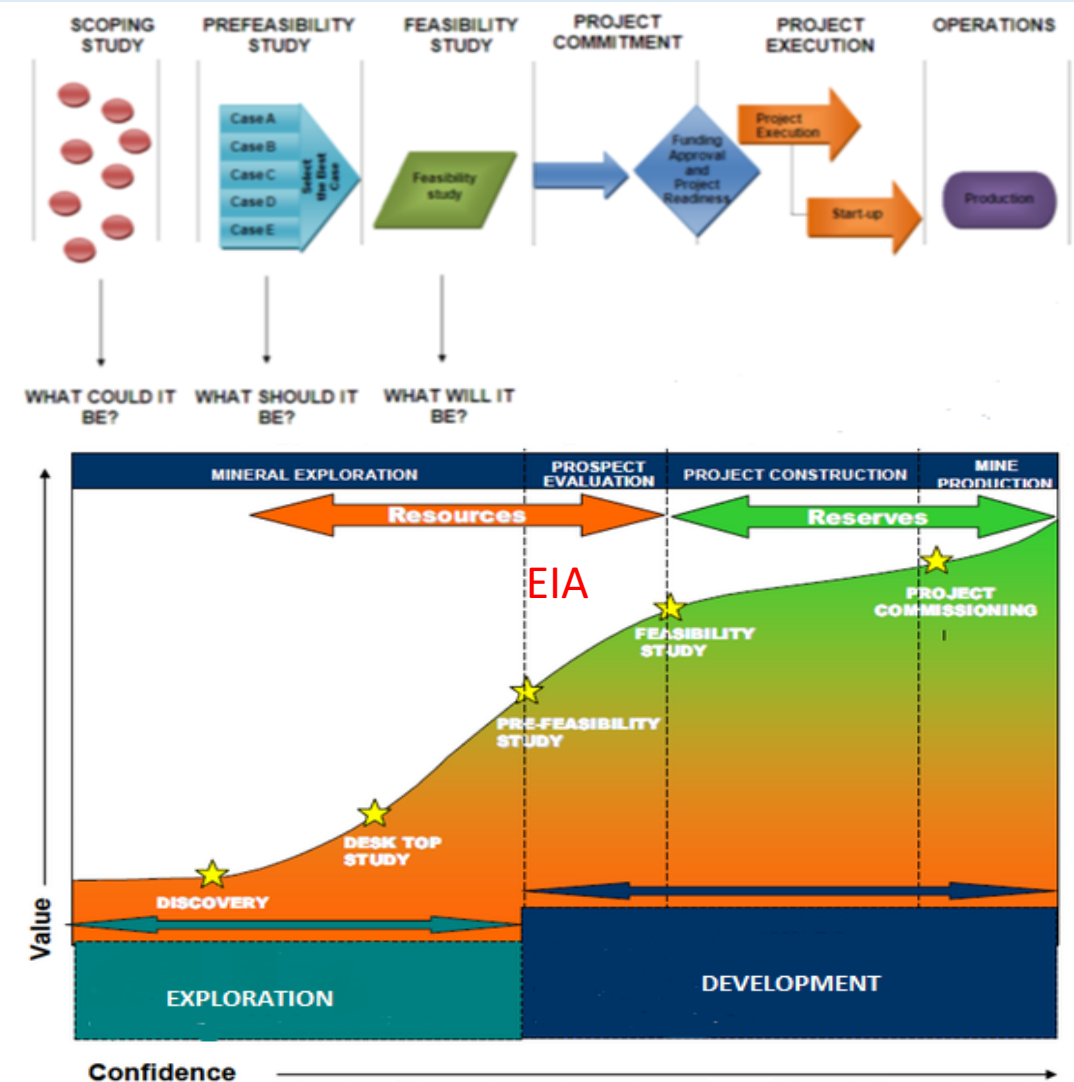
### PROBABILITY OF INCREASED CAPEX



Decisions are made in response to “risk events” → may change assumed mine trajectory

# Value Creation / De-risking Over Time

- Mine Plans include environmental impact assessments and mitigation over decades. They are updated over time.
- **Value is created as the mine is “de-risked”** as analyses and data improve (therefore theoretically **more accurate**)
- Mines become less risky as future outcomes are better understood
- **Biggest water risks → non-performing or stranded assets**
  - Loss of license to operate
  - Social conflict
  - Irreversible Pollution
  - Catastrophic Infrastructure failure
  - Competition over water

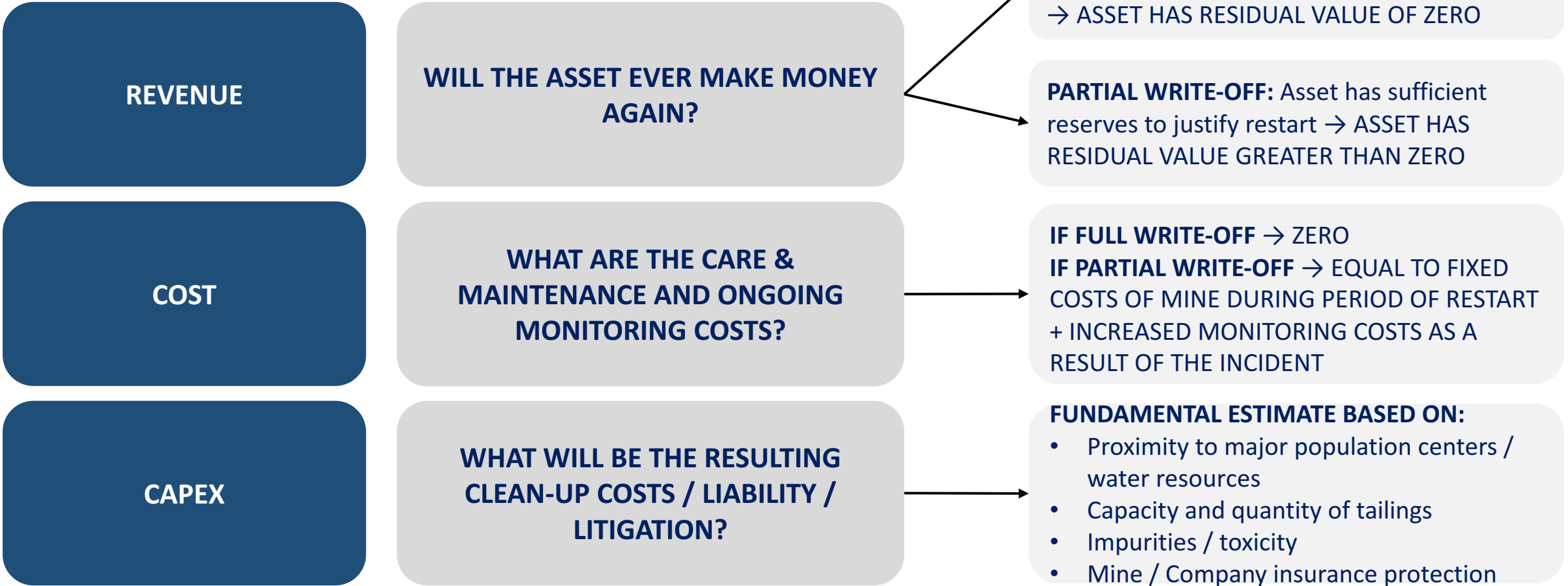


Are there critical triggers and exposure pathways for water risks ?



# Understanding Profitability Impact of Environmental Factors

## EXAMPLE: TAILINGS SPILL



# Issues with Reliance on Company Provided Information

- Investors rely heavily on mining company analyses as a basis for their investment decisions
- Regulators have tried to standardize these analyses under JORC and 43-101 to protect investors and preserve the credibility of these studies / public data and their respective classifications
- Research has shown that analyses are historically inaccurate. However, in the absence of other publicly available information investors have no alternative as a basis for their analyses
- Thus, investors have to come up with subjective determinations of risk associated with company estimates (discounts to NAV)

## M&A Discounts to NAV by Project

Date	Target (Acquiror)	Corporate / Asset	Adj. Acq. Price (US\$ mm)	P/NAV <sup>1</sup> (x)	1-Day Premium (%)	Spot Cu <sup>3</sup> (US\$/lb)	LT Cu <sup>3</sup> (US\$/lb)
13-Mar-17	Rosh Pinah & Perkoa (Trevali)	Asset	\$400	na	-	\$2.63	\$2.91
15-Nov-16	Tenke (BHR)	Asset	\$1,136	0.89x	-	\$2.47	\$2.86
29-Sep-16	Mina Justa (Minsur)	Asset	\$85	na	-	\$2.18	\$2.81
5-Jul-16	Thompson Creek (Centerra)	Corporate	\$934	0.79x	32%	\$2.20	\$2.80
30-Jun-16	Batu Hijau (PT AMI)	Asset	\$1,300	1.09x	-	\$2.19	\$2.80
9-May-16	Tenke (China Moly)	Asset	\$2,650	0.88x	-	\$2.15	\$2.84
25-Apr-16	Reservoir (Hevsun)	Corporate	\$615	0.56x	35%	\$2.27	\$2.84
10-Mar-16	Kevitsa (Boliden)	Asset	\$712	0.97x	-	\$2.23	\$2.86
15-Feb-16	Morenci (Sumitomo)	Asset	\$1,000	1.26x	-	\$2.07	\$2.86
15-Jan-16	Grasberg (Indonesian Gov.)	Asset	\$1,700	1.95x	-	\$1.96	\$2.90
24-Aug-15	Norte (Audley Capital)	Asset	\$300	0.57x	-	\$2.22	\$2.99
30-Jul-15	Zaldivar (Antofagasta)	Asset	\$1,005	1.38x	-	\$2.38	\$3.02
26-May-15	Kamoa (Zijin)	Asset	\$412	0.50x	-	\$2.78	\$2.97
25-May-15	Sirius (Independence)	Corporate	\$1,133	1.03x	35%	\$2.81	\$2.97
28-Mar-15	PanAust (GRAM)	Corporate	\$1,039	0.94x	50%	\$2.79	\$3.01
3-Nov-14	Duluth Metals (Antofagasta)	Corporate	\$95	0.50x	120%	\$3.08	\$3.05
6-Oct-14	Candelaria (Lundin)	Asset	\$1,800	1.02x	-	\$3.04	\$3.09
3-Oct-14	Illobo (Magris)	Asset	\$530	1.10x	-	\$3.02	\$3.09
8-Sep-14	Curis (Taseko)	Corporate	\$93	0.36x	17%	\$3.19	\$3.05
28-Aug-14	Kipoi (Tiger)	Asset	\$111	0.34x	-	\$3.19	\$3.05
28-Aug-14	Blackthorn (Intrepid)	Corporate	\$30	0.81x	4%	\$3.19	\$3.05
13-Jul-14	Jabal Sayid (Ma'aden/Barrick)	Asset	\$210	0.62x	-	\$3.24	\$3.01
17-Jun-14	Lumina (First Quantum)	Corporate	\$412	0.48x	28%	\$3.04	\$3.01
13-Apr-14	Las Bambas (MMG)	Asset	\$5,850	1.01x	-	\$3.03	\$2.95
9-Feb-14	Augusta (Hudbay)	Corporate	\$594	0.75x	11%	\$3.27	\$2.99
Average <sup>2</sup> :				0.83x			
Producer Average <sup>2</sup> :				0.99x			
Developer Average:				0.66x			

<sup>1</sup> Based on analyst consensus estimates of NAV.

<sup>2</sup> Average excludes Grasberg and Kipoi as outliers.

<sup>3</sup> Spot copper prices and consensus LT copper price estimates as of date of initial offer.

Source: Bloomberg Financial Markets and CIBC database.

Changing environment/climate and socio-economic conditions may invalidate mine company assumptions and disclosure



# Issues with Reliance on Company Provided Information

- There are empirical examples of bonds being inadequate to cover reclamation costs
- Examples include:
  - Summitville Mine in Colorado, cyanide spill required \$192 million Superfund cleanup while financial assurances posted by operating company were \$4.5 million.
  - 2005 GAO Report: Financial assurances not adequate to cover cleanup costs of majority of investigated abandoned mines on Bureau of Land Management property.
- **Later in this presentation**, we discuss in detail how bias is prevalent in reclamation cost estimates which can have a profound impact on stakeholders (including local communities, regulators and investors)

Remediation Costs vs. Posted Reclamation Bonds

State	Number of notice-level hardrock operations	Percentage of notice-level hardrock operations without financial assurances	Number of plan-level hardrock operations	Percentage of plan-level hardrock operations without financial assurances
Alaska	134	1-4	106	0
Arizona	130	50-74	55	25-49
California	205	5-14	98	15-24
Colorado	102	0	30	0
Idaho	32	5-14	23	5-14
Montana	150	1-4	30	0
Nevada	450	0	324	1-4
New Mexico	24	15-24	11	15-24
Oregon	165	1-4	10	0
Utah	167	50-74	49	15-24
Washington	127	Do not know	12	0
Wyoming	18	0	38	0

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# Key Issues Focused on

**FINANCIAL RISK  
MODELING**

Model long term risk evolution and mitigation,  
over quantifiable risk exposure pathways ←  
information biases & uncertainties

Robust real options model  
theory and application

**CLIMATE EXTREMES**

As a trigger for water scarcity & flooding →  
infrastructure impacts and social conflict

Mispricing of at site risk  
Correlated Portfolio risk

**LOW PROBABILITY /  
HIGH IMPACT EVENTS**

Infrastructure Failure with water system  
impacts

Tailings Dam State  
Identification & Failure  
Impact Analysis

**CUMULATIVE WATER  
POLLUTION EFFECTS**

Regulatory effectiveness and outcomes

Reputational Risk,  
Watershed Impacts

**WATER USE & COSTS**

Bounds on potential water use and wastewater  
treatment costs

Long run cost risk for at  
site water use

**SOCIAL CONFLICT**

Covariates of water related social conflict

Asset Stranding  
potential

**BIAS IN REPORTING**

Mispricing of Risk due to systematic errors in  
company reports

Reclamation Cost  
Disclosure Analysis

**REGULATIONS**

Comparative Analysis Across Countries

Potential Effectiveness,  
Delays

# Water Use and Costs

**Concern:** Increasing scarcity, competition and conflict

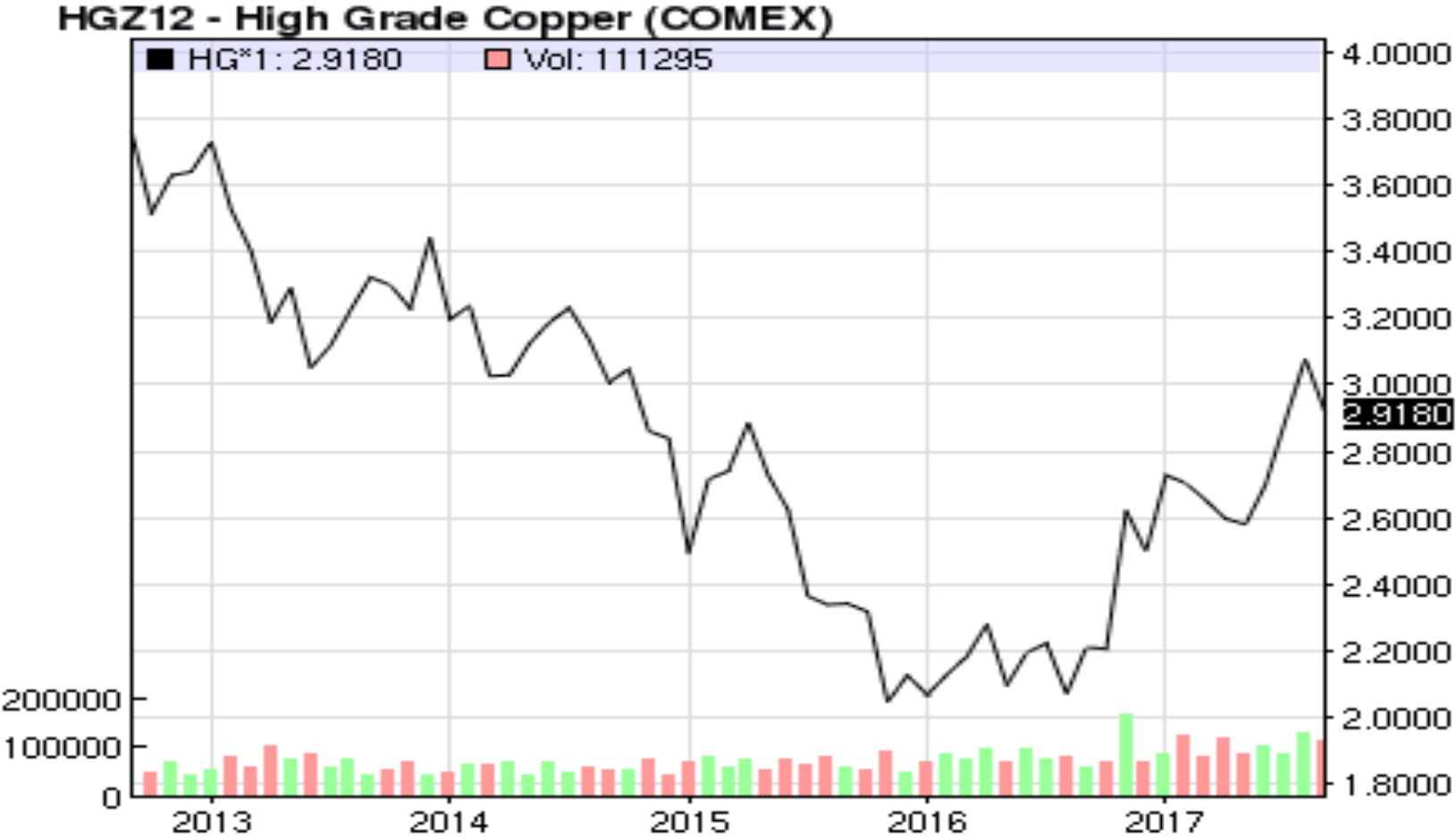
→ increasing long run CAPEX and OPEX for water management

→ reduced IRR → asset stranding, especially as metal prices drop

## **Findings:**

- Significant variations in water use and wastewater/ton produced
  - Declining ore grades = more process water use
- Trends towards re-use and desalination in arid regions, and produced water use in humid regions
- CAPEX and OPEX typically vary from 5 to 10% of total production costs, and efficiency/technology improvements suggest long run cost curves will hold
- Long run Cu/Au gold demand curves trend up faster than projected increase in water costs as a fraction of production costs
- Long run → industry cost curve rises → new demand-supply equilibrium
- WRI Aqueduct Scarcity Risk Index does not predict NAV or Credit Rating

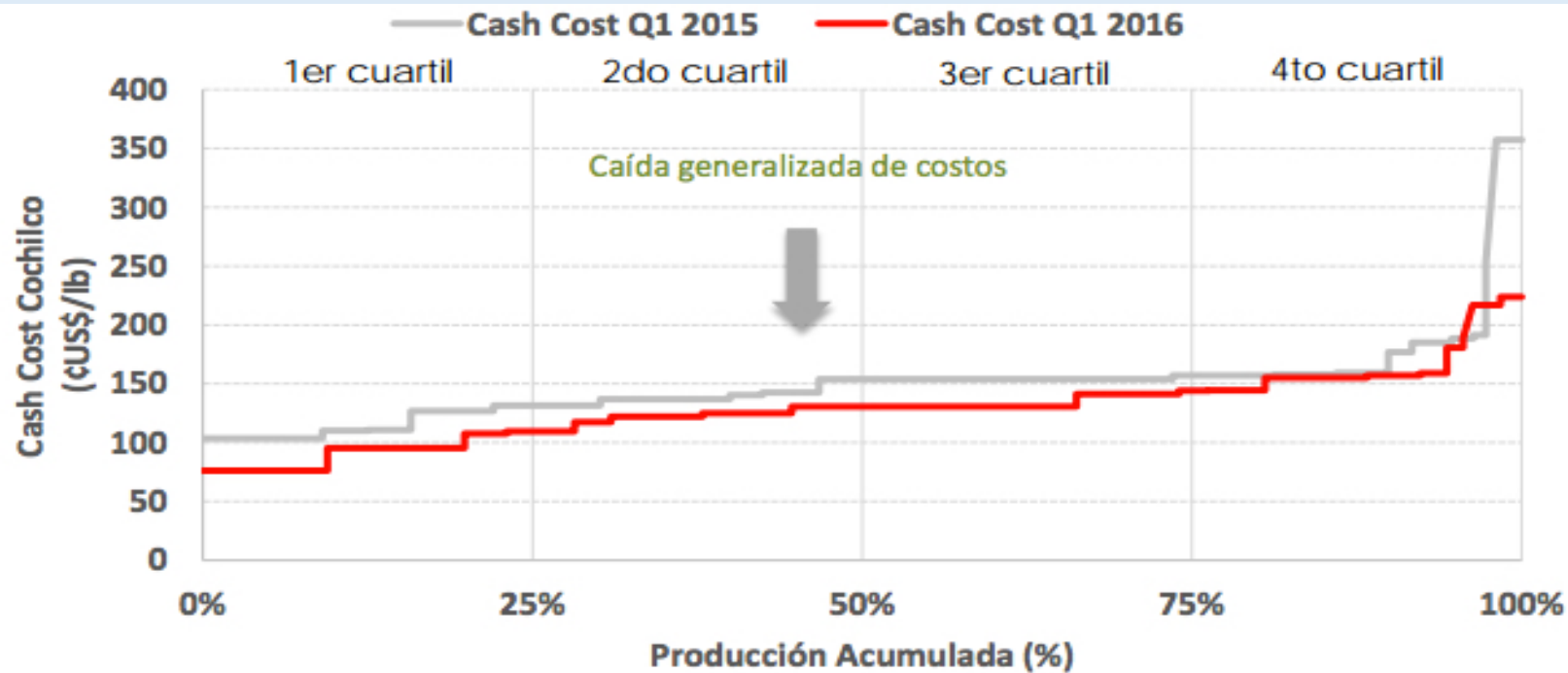
# Copper Price (NASDAQ)



Note the over 100% variation in copper prices over 5 years and year over year variations of +/- 50%



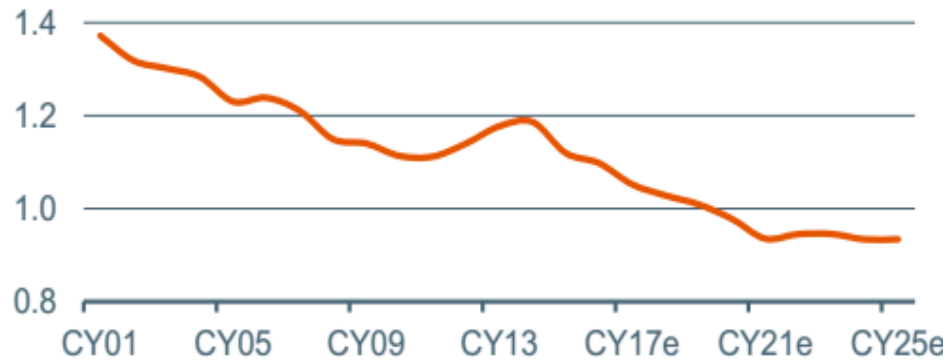
# Water Use and Costs



- According to the [study by the Chilean Copper Commission](#), mine level **cash costs at Chile's 19 largest mines fell to an average of \$1.285 per pound** during the first three months of the year, **down 13.3%** or nearly 20c a pound from the same quarter of last year.
- ...improved mine management, lower costs for electricity, services and shipping and lower treatment and refining charged by smelters. The trend of falling grades, coupled with increasing water costs in Chile makes the cost cutting even more remarkable.

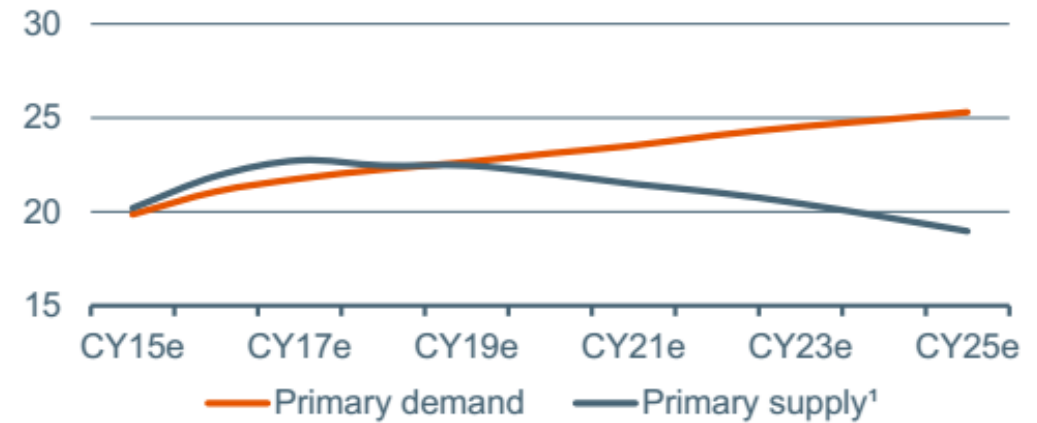
### Industry grades continue to decline

Weighted average copper grade<sup>1</sup>, %



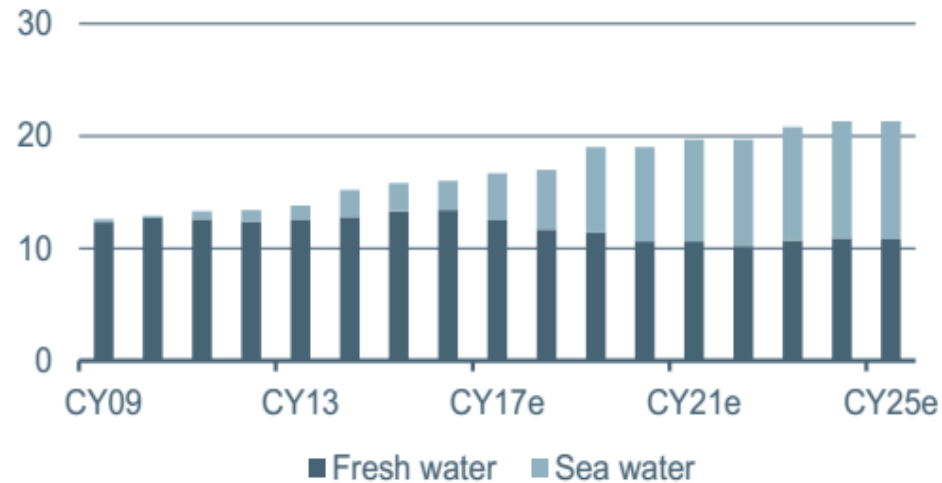
### Deficit expected to emerge at the end of the decade

Copper, Mt



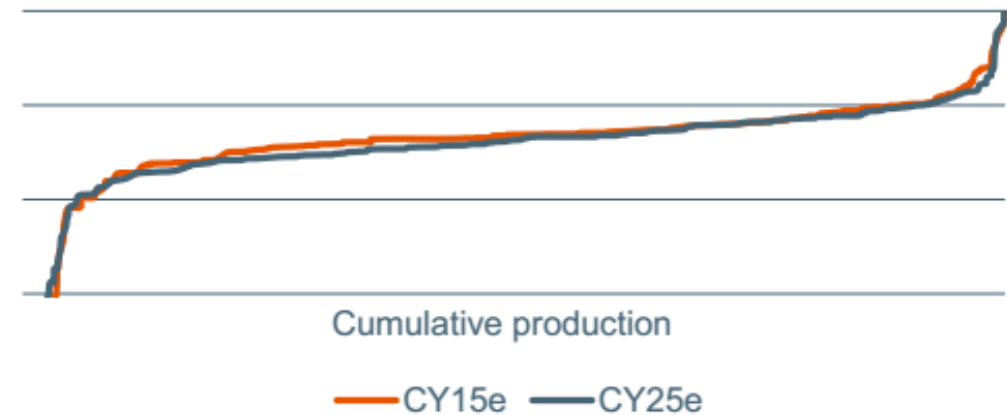
### Water use in copper mining in Chile

m<sup>3</sup>/second



### Industry-wide challenges expected to maintain shape of the cost curve in the long run

C1 cash cost, copper US\$/lb



## Real Options Model:

Simulation-Optimization Modeling framework for risk and asset/portfolio valuation

**Simulation** = performance/outcomes in the face of stochastic shocks over time that lead to decisions on changes in system design or operation and hence costs and revenues

**Optimization** = at any given time where such a decision is needed, assuming the company is a rational economic actor, identify the economically optimal decision to the end of the operating horizon

Thus, the nonlinear dependence between shocks, decisions and outcomes is explicit

Shocks = financial or environmental

## Robust:

Recognizes that data on shocks and the outcomes of the shocks may be quite limited and or biased.

How does one derive appropriate bounds for the probabilities of shock events in this setting?

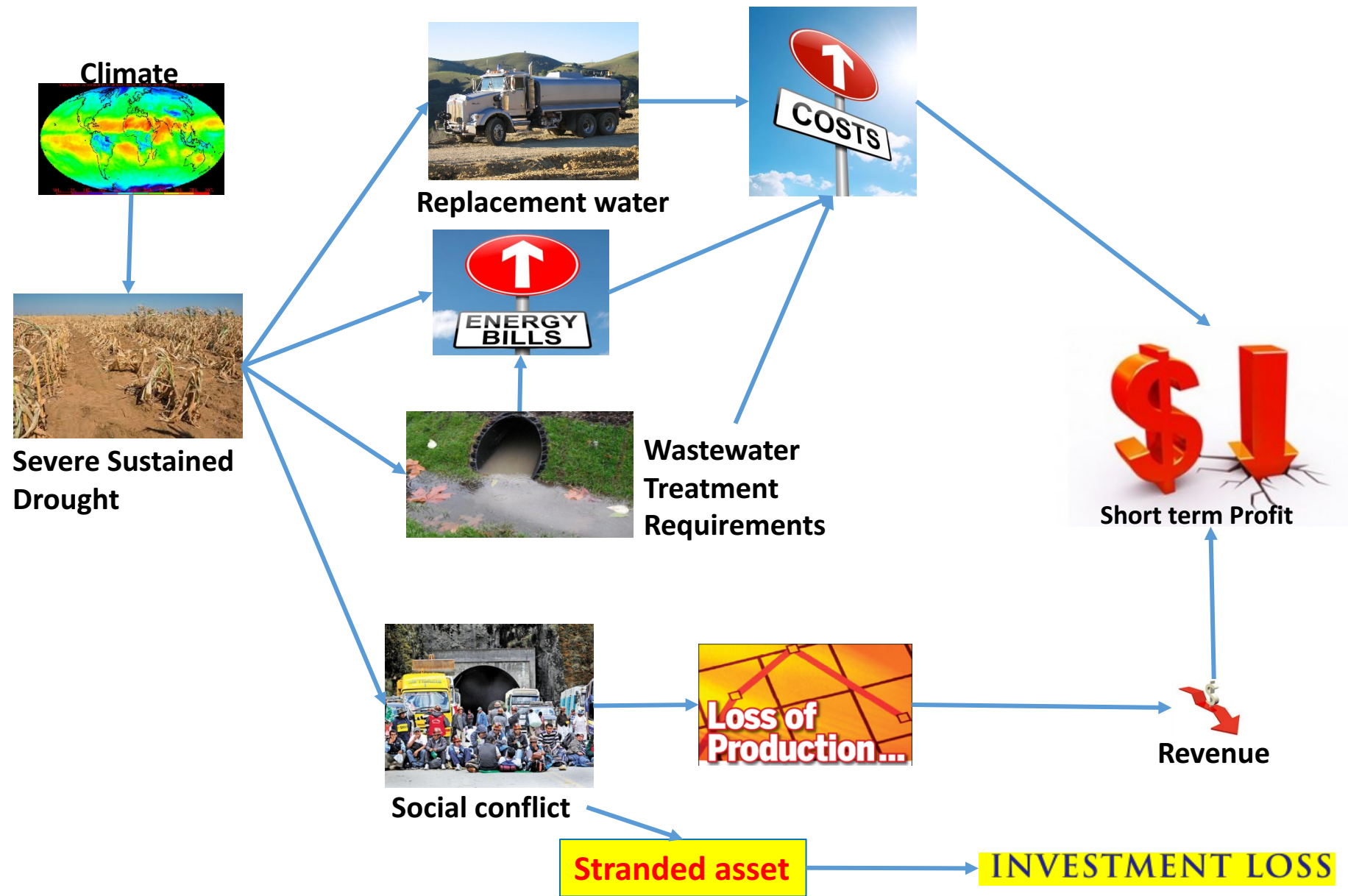
How does one simulate shocks using these robust probability bounds?

Theory Developed. Database and App Developed and available.

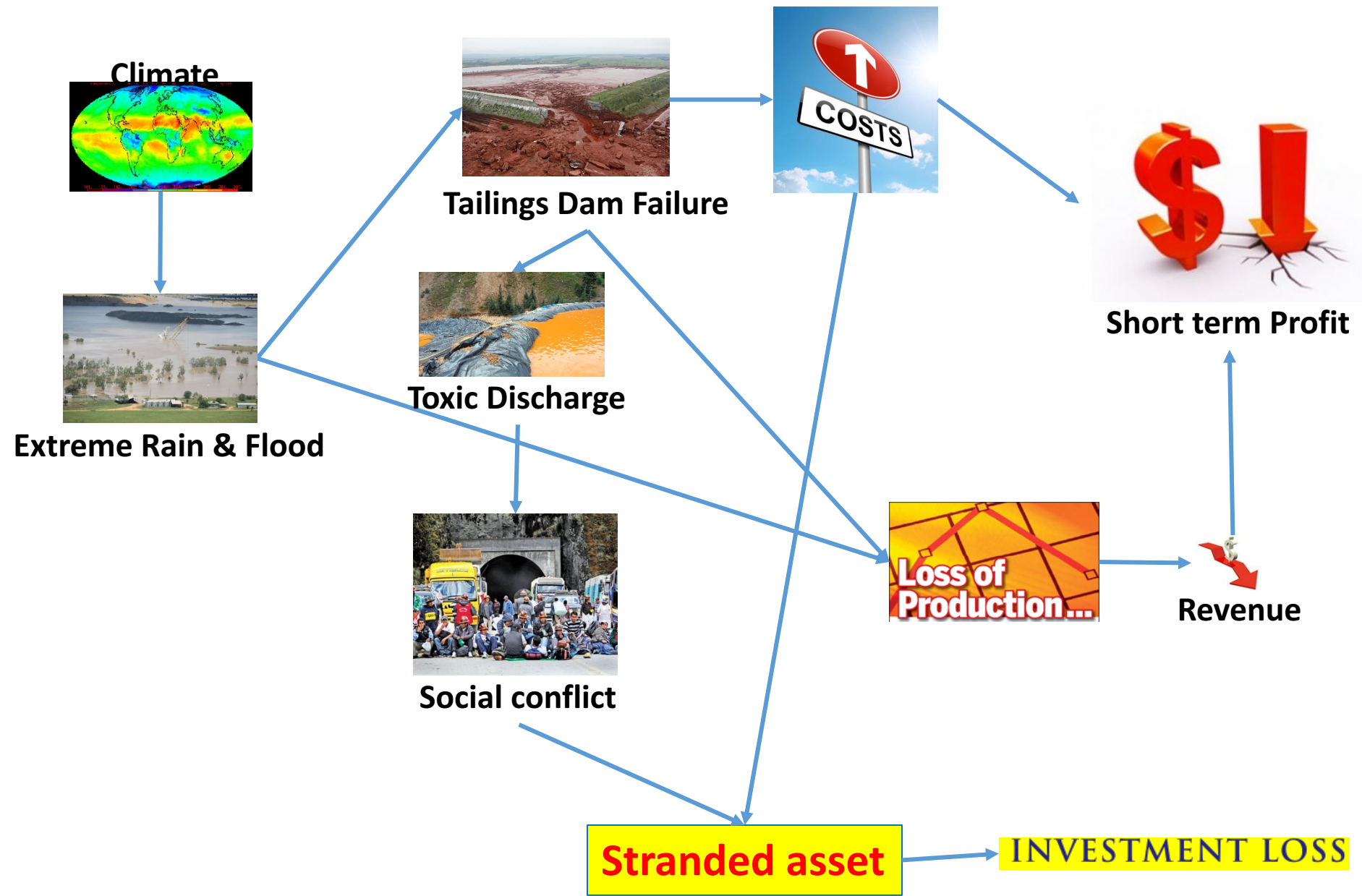
Applied to Assess whether a Mine/Company is over/under Valued considering risks



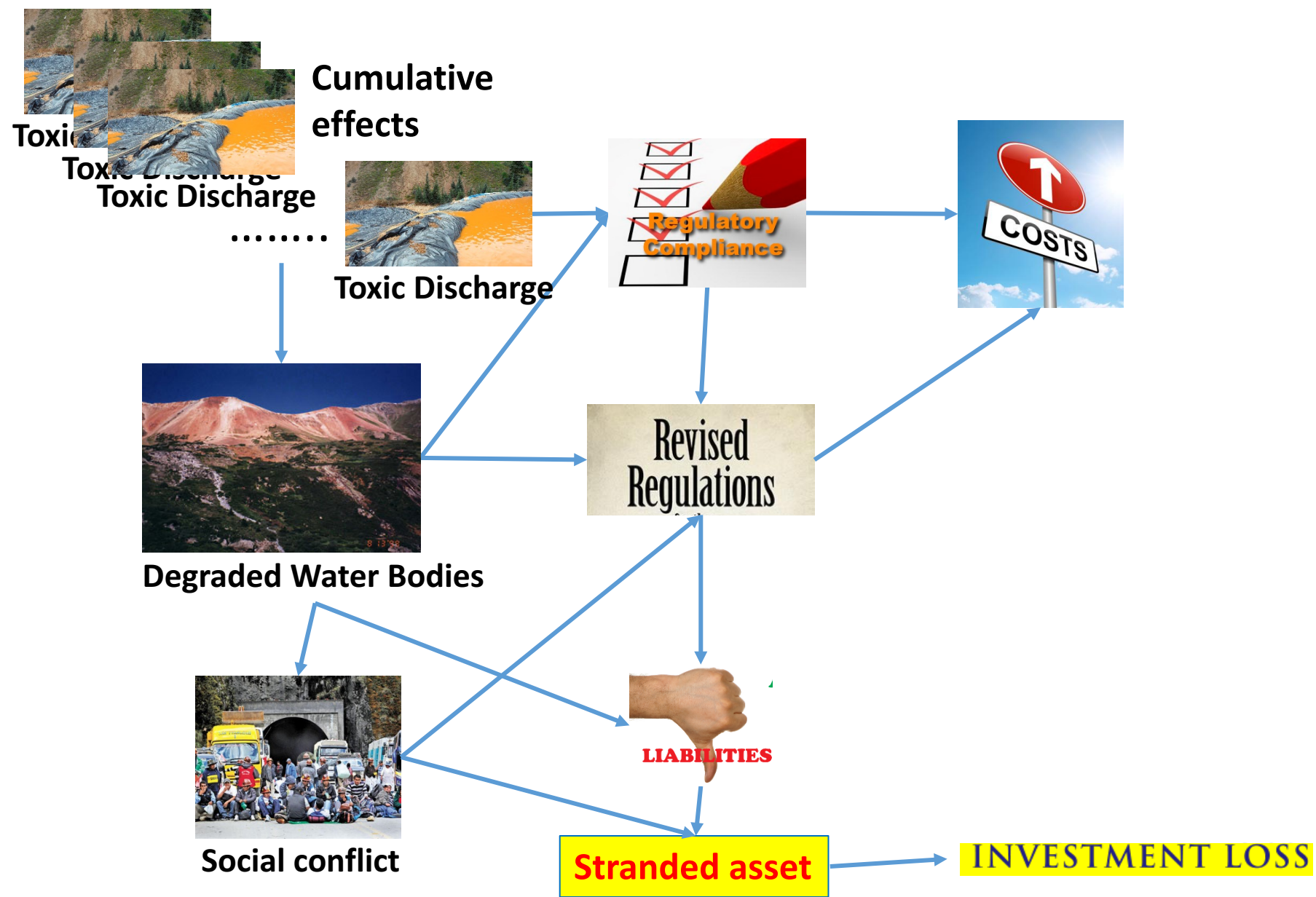
# 1. Financial exposure pathways for a mine ← water related risks?

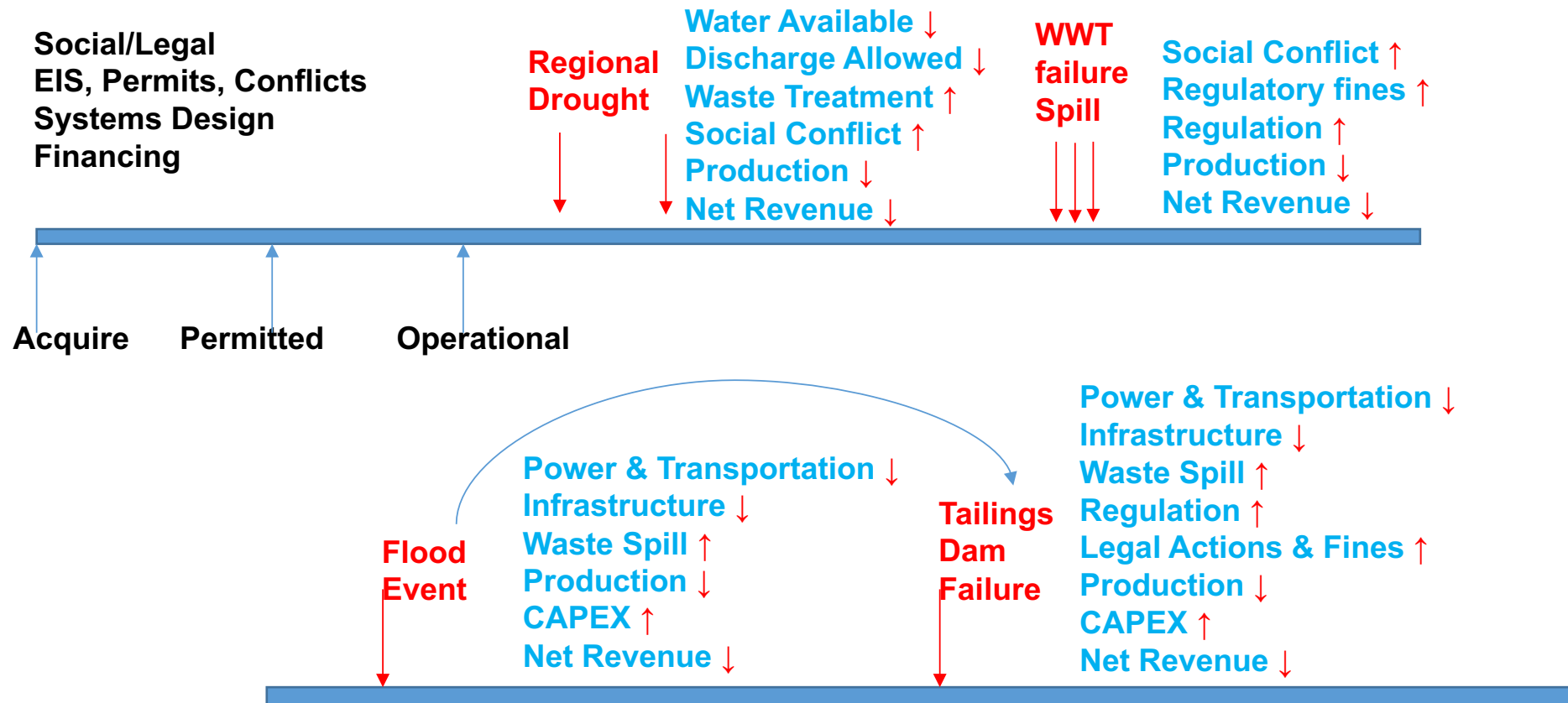


## 2. Financial exposure pathways for a mine ← water related risks?



### 3. Financial exposure pathways for a mine ← water related risks?





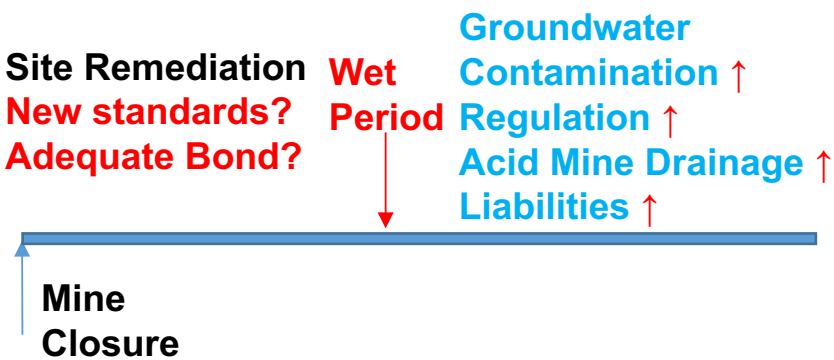
Consider climate extremes, Tailings failures, Social conflict emergence as stochastic shocks whose probability of occurrence changes over time based on covariates → risks that change over time

Mining companies design/insure some of the risks

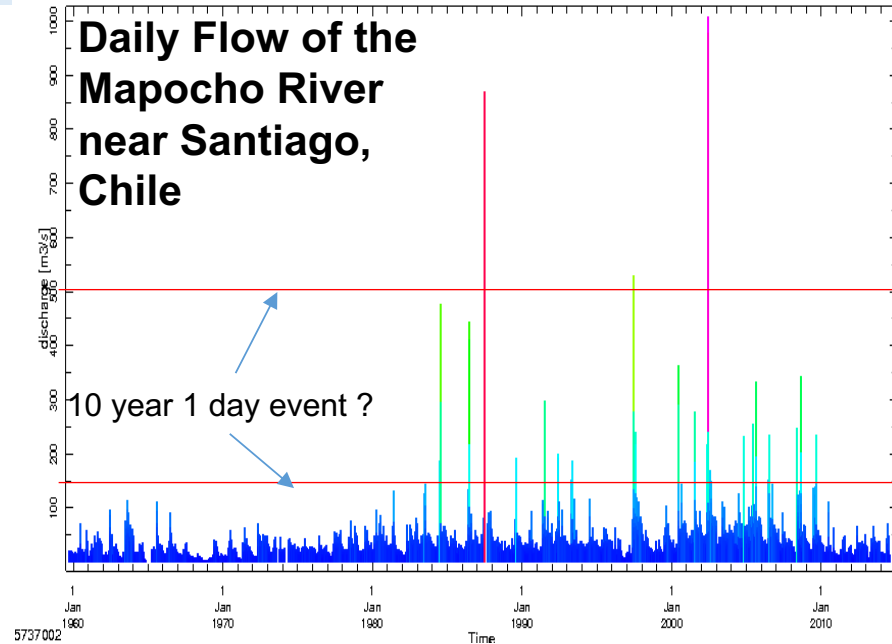
**Outcomes** = function of planning + event effects

**Discounted present value reflects the risk?**

**Simulate all possible occurrences, and best decision forward at each time**







April 17, 2016: “Codelco, the world's top copper producer, said the rains forced the Chilean state-owned miner to suspend production at its century-old underground El Teniente mine, likely leading to the loss of 5,000 tonnes of copper production.”

Mine infrastructure is designed for a certain level of flood or drought risk. Insurance may cover the residual risk with a payout limit.

**Assumption: data used to compute the probabilities is representative of the future.**

Unfortunately, climate risk exhibits regime like behavior →

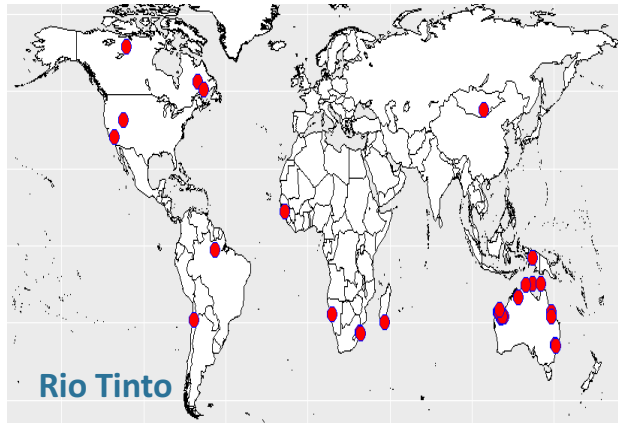
**Design risk estimate may be out of phase with operation period risk**

Climate risk exposure is also **spatially correlated** over a business cycle = **Elevated Portfolio Risk**

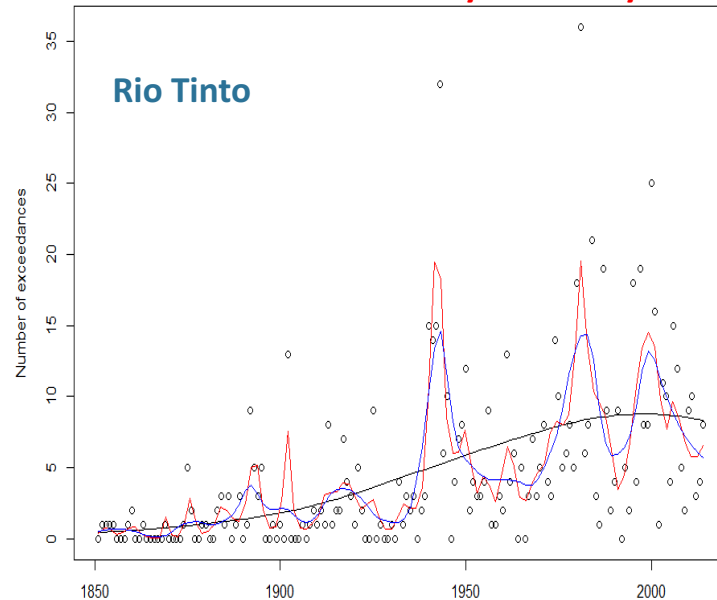
Database and exposure estimation/ranking App Developed and available.

Applied to rank companies in terms of VAR or cVAR exposure, and for Real options Model

# Portfolio Exposure Examples: Rio Tinto (40 assets) and BHP Billiton (38 assets)

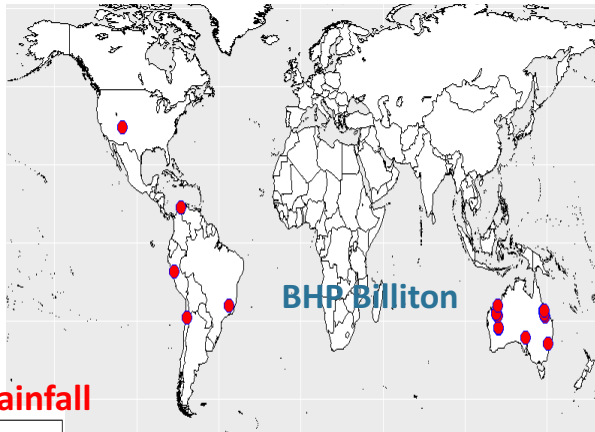


Annual exceedances of 10 year 30 day rainfall

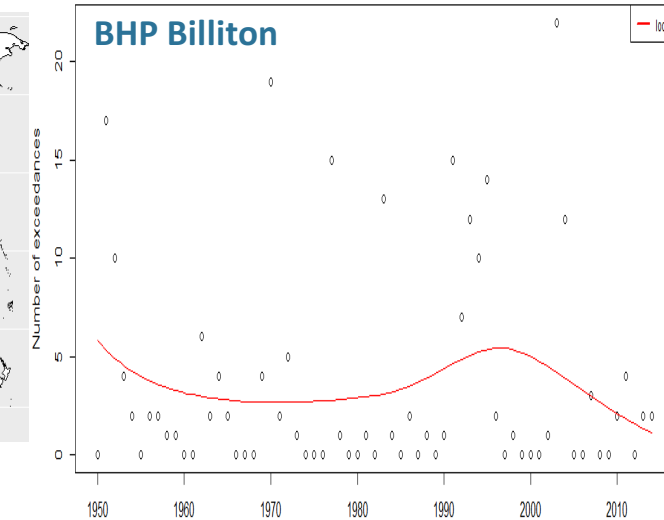


**Extreme Rainfall:** 40 mine Rio Tinto portfolio.

- High clustering: 36 exceedances in one year out of 142
- There is a pronounced trend and decadal variability



Annual exceedances of 10 year drought



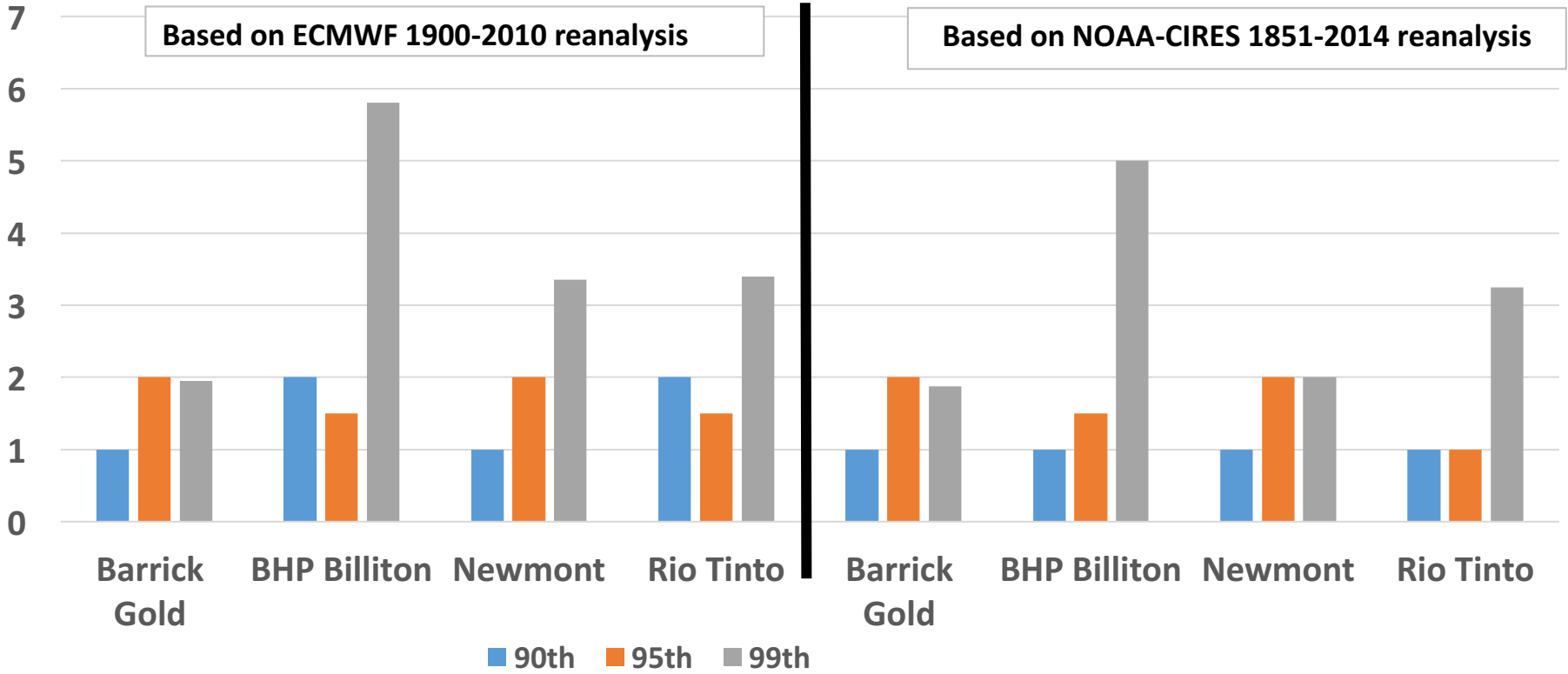
**Drought:** 38 mine BHP Billiton portfolio.

- High clustering : 24 exceedances in one year out of 60

# Portfolio Exposure Examples: Four Companies and Two Climate Datasets

Fat tail risk due to spatial clustering:

Ratio of **actual** number of events in excess of **100 year 1 day extreme** rainfall for Portfolio relative to what is **expected by chance**, for 3 thresholds of the portfolio cdf



# Climate Extremes – Result Example – Comparison Across Companies for Drought Exposure

## Drought Risk Rankings by VAR and CVAR normalized to portfolio size

**Table 2.** Ranking of 15 Companies Based on  $R_{0.95}(0.1)$  and  $CVS'_{0.95}(0.1)$  Measures for a 12 Months Drought Event, Obtained Using the Dai PDSI Data Set and Mine Valuation Obtained From Broker Reports From TD Securities<sup>a</sup>

Company	$R_{0.95}(0.1)$	Rank $R_{0.95}(0.1)$	$CVR_{0.95}(0.1)$	Rank $CVR_{0.95}(0.1)$
Agnico Eagle	0.44	9	0.32	11
All 15	0.17	16	0.20	15
B2Gold	0.33	13	0.34	9
Barrick Gold	0.31	14	0.25	13
Capstone Mining	0.82	1	0.59	1
Eldorado	0.54	4	0.42	7
First Quantum Mineral	0.44	8	0.48	4
Franco Nevada	0.28	15	0.20	16
Goldcorp	0.47	6	0.37	8
Hudbay	0.51	5	0.33	10
Iamgold	0.45	7	0.50	3
Kinross	0.34	11	0.26	12
Lundin Mining	0.35	10	0.43	6
New Gold	0.56	3	0.45	5
Newmont	0.34	12	0.25	14
Teck Resources	0.64	2	0.53	2

<sup>a</sup>A lower rank means a higher exposure.

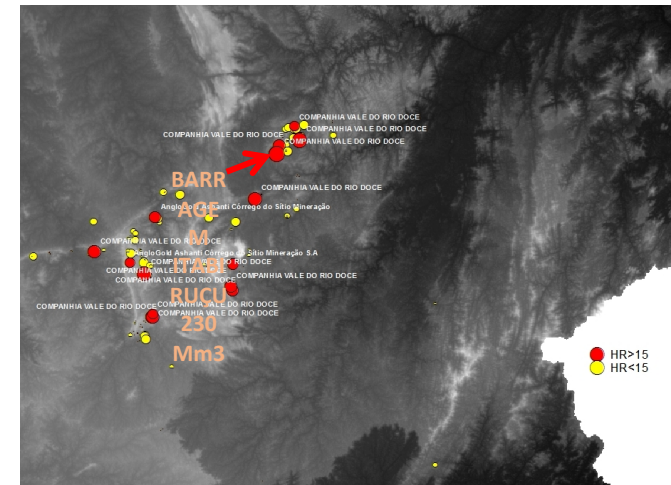
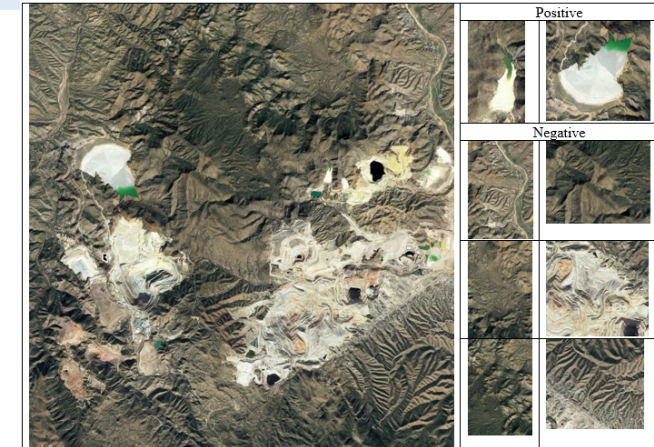


**Concern:** Tailings dams store highly toxic wastes. Their failure can lead to catastrophic, multi-billion \$ liabilities and potential loss of license to operate, asset stranding.

- No global database of dams. Yet, failure rate 3-5x of river dams
- Sequentially constructed of earthen fill. More prone to failure
- Dominant failure modes: Overtopping due to high rain, Geotechnical Failure. Mismanagement

## Approach & Findings:

- Machine Learning approach developed for automatic identification of tailing dams from satellite imagery
- Regression and indexing based approach for probabilistic impact analysis and ranking of dam failure impact (ecological, population) based on runoff from failure.
- Prediction probabilities from the model cover actual Samarco impact
- However, hazard ratings for many other Brazilian tailing dams in the region are much higher than those estimated for Samarco



**Concerns:** If mining companies systematically under-report reclamation costs, then long term investors may face significant residual financial and reputational liabilities.

- Companies may engage in strategic behavior to avoid covering actual reclamation needs since they were not budgeted or disclosed.
- Do biases in this aspect reflect systematic biases in other disclosure?

**Findings:**

- A longitudinal data on reclamation cost, reserves, production and other economic factors was derived from quarterly reports.
- Regression model shows that controlling for changes in production, reserves, inflation and other factors, the % of remaining life of mine emerges as a significant predictor of reported reclamation costs → early estimates are significantly biased lower.
- Comparisons were also made with the EPA's recently released model which only uses a single disclosure of costs by a company, and focuses on a mean value.
- Difficult to compile data on actual reclamation costs vs earlier estimates, but we recommend reclamation bonds reflect 90% probability coverage based on uncertainty estimates

Database and Regression Model Developed and available.

Applied to estimate/predict degree of systematic under-reporting of Reclamation costs

**Concerns:** Water is perceived as a primary determinant of social conflicts related to mining in Latin America, and has led to asset and investment stranding

- Is there quantitative evidence that the probability of conflict relates to a water issue?

**Findings:**

- Data was compiled for reported water related violent and non-violent mining conflicts in Peru and Mexico and a broad set of demographic, water and climate covariates.
- Bayesian and robust regression models find that
  - Past conflict is the strongest predictor
  - Others are Mining Scale, Redistribution of Tax revenues, Corruption Perception
  - Drought (rainfall reduction) rather than absolute water availability, and water fines (related to pollution) are the main water predictors identified
- Cumulative effects of mining and the associated emergence and persistence of conflict may thus be key factors determining asset level risk in a watershed

**Concerns:** Even if site level regulation of mine effluents is effective, collective impacts from mining and other pollutant sources can compromise the water sources, leading to social conflict and loss of license to operate.

- Is there evidence to quantify these effects and attribute them to specific sources?
- Do current regulatory processes effectively address these risks?

**Findings:**

- Significant legacy water pollution effects of mining are identified in all countries
- Data sets to pursue space-time trend identification and attribution are sparse
- Mining companies face considerable risks as increasing water scarcity and competition exacerbate the impacts of polluted waters
- Environmental Impact Assessments and associated bonds are likely highly inadequate to address these challenges
- Risk quantification for the industry and for a mine is consequently difficult.
- An approach to regulation that builds in watershed outcomes and attribution is needed.



## Key Findings and Recommendations

1. Source water (desalination, re-use, efficiency) costs may add up to 10% to copper/gold production costs, and may translate into long term marginal cost curves for production.
2. Uncertainties related to **physical risk factors** : climate; tailings dam failure; and cumulative water pollution effects may lead to significant unpriced residual financial risks. Space and time climate risk clustering needs to be accounted for in portfolio risk.
3. A **robust, real options modeling** framework is useful for deriving risk adjusted E[NPV] by integrating these risk and cost factors, considering their uncertainties, and mine level decisions for mitigating these risks.
4. **Financial Disclosures** need to directly provide information on residual risks and their financial implications, rather than detailed water related metrics. Biases in closure cost disclosures were identified. Analytics to evaluate/verify financial disclosures are needed.

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# Impacts: Reiterating Research Objective

Identify risks that manifest themselves over the long term for mining companies that companies and investors may not effectively consider

- Identify key risk exposure pathways and mitigation strategies
- Develop probabilistic measures of risk factors & their valuation where possible from available data
- Assess potential mispricing or under/over statement of the risks
- Translate risks to financial risk measures (VAR, CVAR) where possible
- Integrate risks, mitigation strategies into a robust real options modeling framework for risk based valuation (with bounds)
- Assess & compare risk adjusted portfolios





# Recommendations: What does this mean for Companies & Investors?

<b>BIAS IN REPORTING / MISALIGNMENT OF INCENTIVES</b>	<b>Company-formulated estimates of reclamation costs are biased and tended to increase nearer to the end of the mine life</b>	<b>Consider potential bias in investment and decision processes</b>
<b>LOW PROBABILITY / HIGH IMPACT EVENTS</b>	<b>The risks associated with tailings dam failures can be to identify companies / assets most at risk.</b>	<b>Consider potential asset and portfolio level risk and uncertainty</b>
<b>LONG DURATION TEMPORAL TRENDS &amp; CUMULATIVE IMPACTS</b>	<b>Certain companies are more exposed to climate extremes than others, based on the locations of their assets.</b>	
	<b>Even when a mine conforms to environmental regulations, significant contamination of water (even far away from site) can occur over time.</b>	<b>Consider long-term implications on license to operate and clean-up costs</b>
	<b>Quality and availability of water impacts social conflict. Parameters were identified that can help predict the likelihood of future conflicts.</b>	<b>Consider potential impact on asset level production, capex, costs and timelines</b>



# Recommendations: What does this mean for Companies & Investors?

## DATA / DISCLOSURE (COMPANY ACCOUNTABILITY)

- Long-term stakeholders need to be aware of risks that can slowly manifest themselves over time, such as cumulative pollution effects. Through better disclosure, investors will be able to identify and encourage companies to mitigate these risks before the problem escalates to a level that is unsolvable.
- Working with mining companies can help identify available data to help inform better analyses.

## METHODOLOGY (INVESTOR / STAKEHOLDER ANALYSIS)

- Discounted cash flows should not be the only methodology relied upon for decision making. Our robust real options approach is superior for risk based valuation with limited data.
- Stakeholders can use a data driven approach to identify the likelihood of social conflict. The key parameters inducing conflict can be identified, which can help shape decision processes by investors, regulators and company management.

## KEY CONCLUSIONS

- Investors, local communities, employees and regulators need to be cognizant that mine study work is prone to bias – different stakeholders need to find ways to hold mine management accountable for providing biased and consistently inaccurate information.
- Low-probability high-impact events can have a catastrophic impact on local communities and on company and portfolio valuations / returns. Long term stakeholders need to be cognizant of these risks in their decision processes and encourage better alignment between themselves and management.
- Certain companies are more exposed to climate extremes and social conflict than others, based on the locations of their assets among other factors.

# Research Extensions: What other relevant projects are we working on at Columbia?

How prevalent is bias in other areas of mining company study work?

How can we apply our findings from this analysis on mining to other industries?

Can we identify “red flags” that cause problems for stakeholders early on before they materialize?

Can we create a generalized model for water valuation to integrate into ordinary company decision making processes?

How can we validate / increase accountability of mining company management for their disclosure / estimates?

How can we improve regulatory models to reduce cumulative effects and reduce social risk?

Focus on timelines, production, capex, opex and producing a method to standardize mining project “discounts to NAV”

Applying our conclusions / methodologies regarding real options & climate extremes to other industries

Using Bayes and other statistical methods to expand upon conclusions from the work with NBIM

Working with Major Mining Company to develop a risk-based water valuation for mining, taking into consideration environmental and social aspects

Attempting to put forth metrics to objectively measure performance both over time and retrospectively, and identify additional data that can be disclosed by mining companies to help inform further analyses

Developing Pilot Process for integrated monitoring, attribution and statistical control for Peru

# Data sets compiled and available

- Mine level water use in Cu and Au, Water development & water/wastewater treatment costs for mines
- Global gridded climate data =100+ years
- Tailing dam attributes, satellite imagery, dam failure attributes
- Social conflict and related covariates for Peru & Mexico
- Mining production, ambient water quality time series for Peru, USA
- Remediation cost estimate reports over time for mines
- Financial reporting and valuation data for mines from market research
- “Water Risk” indices from Aqueduct
- Water related mining regulations for comparative analysis across countries