SECTION B.3

APPLYING RISK ASSESSMENT TO ARD

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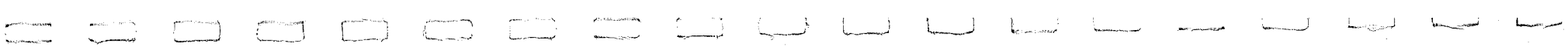
Placer Dome



APPLYING RISK ASSESSMENT TO ARD

A Work in Progress

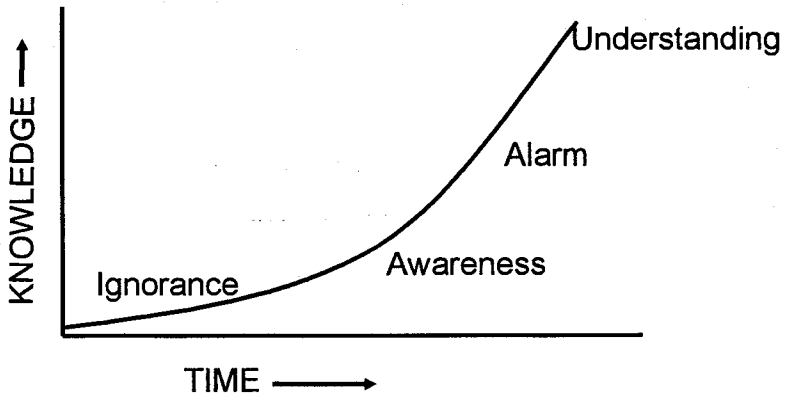
by

K. Ferguson & G. Johnson

OBJECTIVES

- ✓To show how risk assessment has been applied to ARD
- ✓To identify possible opportunities for further applications
- ✓To get us all thinking about "risk" rather than "hazard"

THE PATH TO ARD "ENLIGHTENMENT"

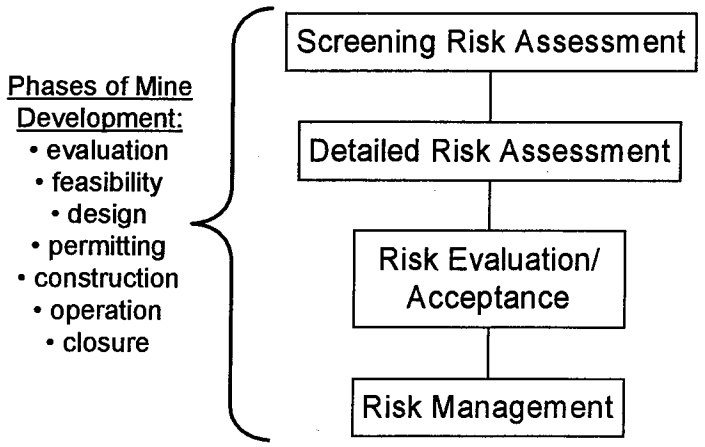


THE RISK TRIPLET

- ✓What can happen?
  - What can go wrong?
- ✓How likely is it?
  - What is the frequency/probability?
- ✓What are the consequences?
  - What is the damage?

✓RISK $\neq$ HAZARD

PHASES OF RISK ASSESSMENT/ MANAGEMENT



SOME SPECIFIC APPLICATIONS OF RISK ASSESSMENT TO ARD

- ✓Project evaluations
- ✓Regulatory/public approvals
- ✓Engineering reliability analysis
- ✓Ecological and human health risk assessment
- ✓Closure cost analysis

SOME RISK ASSESSMENT TOOLS

- ✓Screening matrix (fatal flaw analysis)
- ✓What if?
- ✓Failure Mode and Effect Analysis
- ✓Hazops
- ✓Quantitative (sensitivity & probabilistic)

PROPERTY EVALUATIONS - SCREENING MATRIX

- ✓ Applicable to property acquisitions (fatal flaw analysis)
- ✓ Relatively little data available
- ✓ Need to identify order of magnitude costs and environmental risks
- ✓ Simple approach will usually be the most effective but may indicate need for more advanced techniques

ISSUES TO CONSIDER IN ASSESSING THE PROBABILITY OF ARD

- ✓ ABA - %S and NP
- ✓ Proportion and tonnage in ABA categories
- ✓ Total quantity of material
- ✓ Kinetic factors including particle size, reactivity and slaking potential
- ✓ Potential management options

ISSUES TO CONSIDER IN ASSESSING CONSEQUENCES OF ARD

- ✓ Strength of ARD
- ✓ Metals of concern - toxicity ranking
- ✓ Volume of ARD
- ✓ Dilution and buffering capacity
- ✓ Value and proximity of aquatic resources
- ✓ Potential for human effects (drinking water)
- ✓ Regulatory standards

THE LIKELIHOOD MATRIX

Likelihood	Examples of Data
1. Will Occur	• ABA indicates strong ARD and high snow/rain climate
2. Likely	• ABA indicates moderate ARD; high metal leaching potential
3. Might	• ABA indicates moderate ARD with long lag or semi-arid climate
4. Unlikely	• ABA indicated moderate ARD but kinetic indicates unreactive sulphides
5. Will not Occur	• ABA indicates unlikely ARD and/or desert climate and/or underwater disposal

CONSEQUENCE MATRIX

Consequences	Cost	Examples
1. Severe	>$20 M	• Metals and acid reach large river with significant fish
2. Significant	$10 – $20 M	• Contaminated aquifer and potential effects on wells
3. Moderate	$5 – $10 M	• Copper in short section of river above aquatic stnd.
4. Minimal	$1 –$5 M	• Small surface seeps to nearby creek exceed criteria
5. No Impact	<$1M	• Small visually discoloured seeps but no sign. impact

THE PDI ARD SCREENING MATRIX

Likelihood \ Consequence	1	2	3	4	5
1	1	2	4	7	11
2	3	5	8	12	16
3	6	9	13	17	20
4	10	14	18	21	23
5	15	19	22	24	25

RISK EVALUATION MATRIX

Risk Range	Outcome
1-10	Issue must be resolved prior to proceeding with project.
11-19	Action/contingency plan required to address issue. Proceed with project.
20-25	No immediate action required. Proceed with project. Verify assumptions with monitoring.

ENGINEERING RELIABILITY ASSESSMENT -FMEA

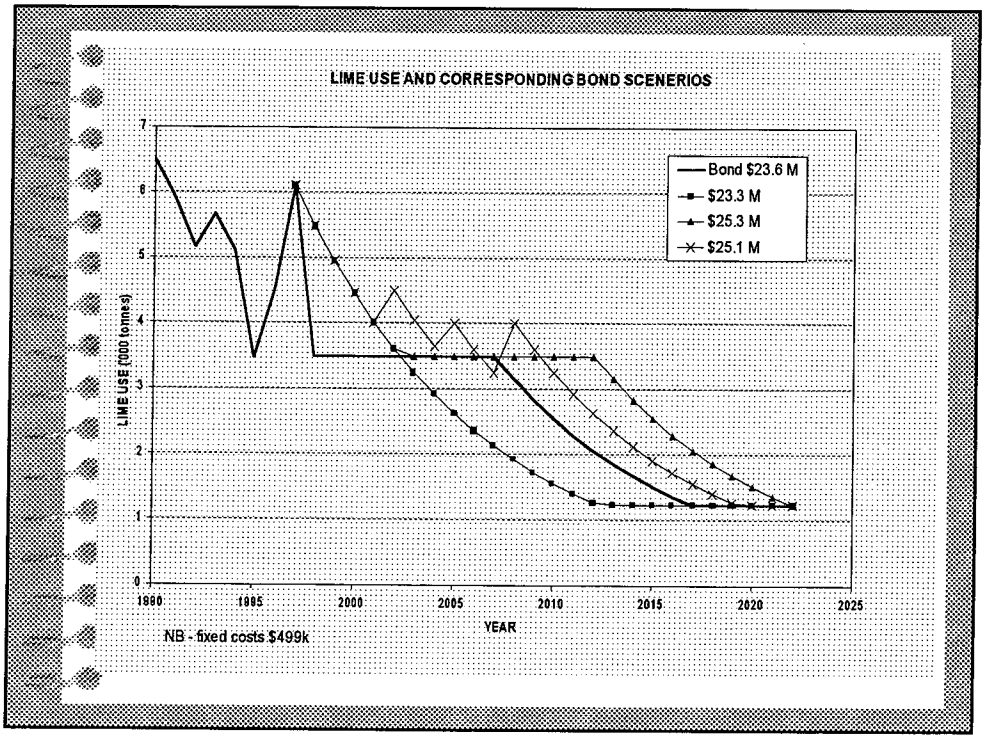
- ✓ Applicable to detailed design and operations
- ✓ Objective to improve reliability of ARD control
- ✓ Examine design, operation and maintenance from a "failure" point of view
- ✓ Risk triplet of:
  - What can go wrong?
  - What is the probability of it going wrong?
  - What are the consequences of it going wrong?
- ✓ Recommendations:
  - What can be done to reduce the probability or the consequences of failure?

FMEA APPLIED TO ENGINEERING RELIABILITY ASSESSMENT

Component/ Phase	Failure Modes	Consequence (I,II,III,IV, V)	Comments	Failure Likelihood (I,II,III,IV,V)	Comments	Compensating Factors (Secondary Containment Monitoring and contingency plans)	Overall Risk
Ditch Inputs							
1.Southern Toll						Partial - north end only	
	1.1 Excessive Precipitation	IIto II	quality not bad and would be diluted	IIto II	relatively low flow in section of ditch	appears reasonable design	3.0
	1.2 Ice Blockage	II	water quality not bad	IIto III	potential blockage at ST pond	ongoing maintenance	4.5
	1.3 Seepage Loss	I	expect low volume of seepage	IIto III	possible loss to Getty Creek	periodic monitoring of Getty Creek diversion	3.5
	1.4 Sloughing Blockage	II	water quality not bad	IIto III	some sloughage at one location	continue to remove material	4.5
	1.5 Earthquake	II	water quality not bad	IIto II	low earthquake zone - possible slumping of D Dk		4.5
	1.6 Diversion ditch break	IIto II	quality not bad and would be diluted	IIto III	ditch reasonable condition w/ east lower section		4.0
	1.7 Erosion	IIto II	quality not too bad and likely slow release	IIto II	relatively little silt from area	continue to remove materials	3.0

CLOSURE COST ANALYSIS - QUANTITATIVE (SENSITIVITY) MODEL

- ✓ Construct water and contaminant balance to predict short term concentrations and flows from waste rock dumps
- ✓ Calibrate to recent historical concentrations and loadings
- ✓ Calculate lime requirements
- ✓ Make medium to long-term lime use assumptions
- ✓ Add fixed and variable costs



ECOLOGICAL RISK ASSESSMENT - QUANTITATIVE (PROBABILISTIC) MODEL

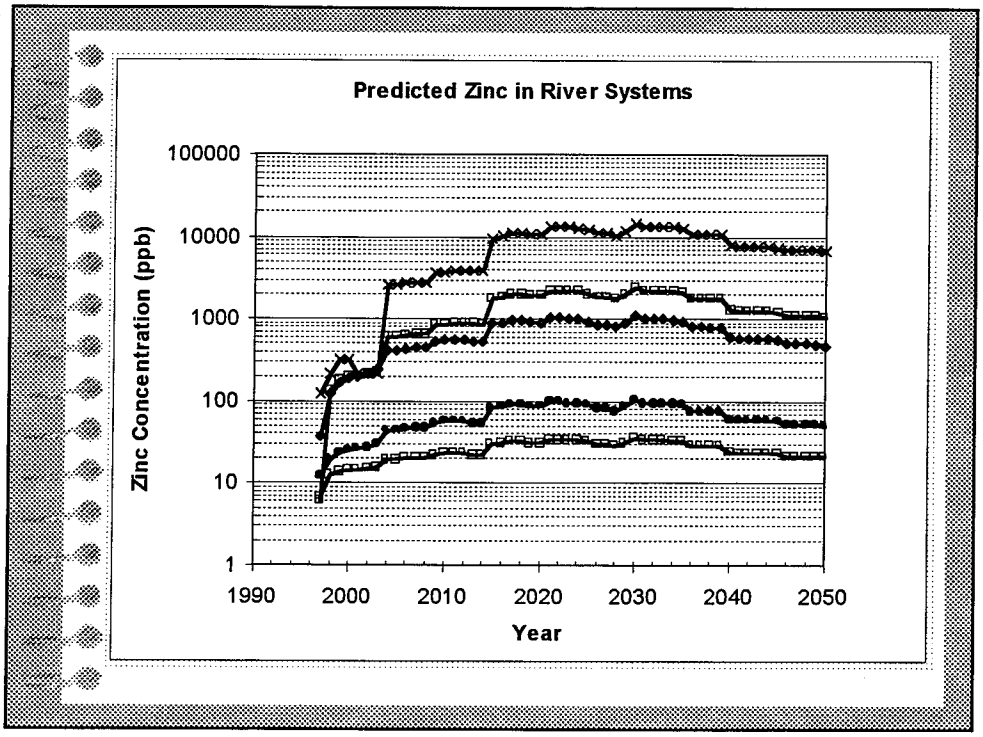
- ✓ Applicable to detailed design and operations
- ✓ Proposal to significantly expand open pit operation with two different dumping options
- ✓ significant proportion of rock potentially acid generating
- ✓ test pads confirmed ARD potential
- ✓ very high neutralization potential
- ✓ high dilution and neutralization potential in receiving streams

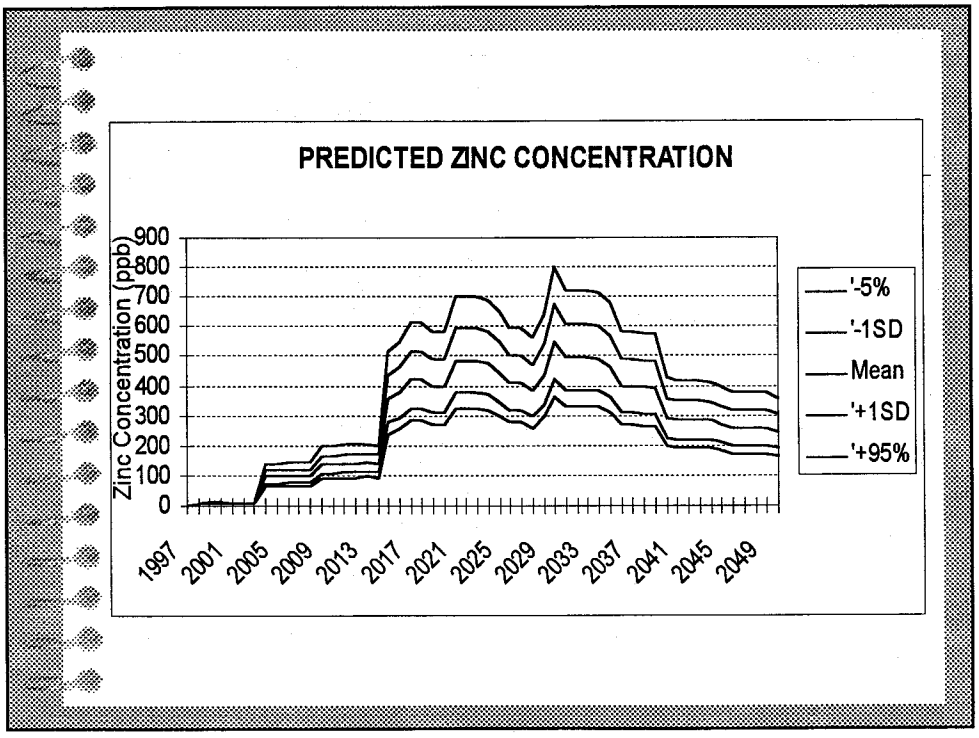
WASTE ROCK MODEL

- ✓ Divides rock into acid forming, neutral and neutralizing by lithologies
- ✓ Rough schedule of production
- ✓ Considers construction/dumping schedule
- ✓ Considers exposure time
- ✓ Critical parameters are surface areas of dump versus time, amount of potentially acid generating material, diffusivity, sulphide oxidation rates and metal/sulphate relationships

WATER BALANCE MODEL

- ✓ Waste rock model provides source terms
- ✓ Simple dilution model to predict downstream concentrations based on source and background loadings
- ✓ Based on measured and calculated flows (eg. based on catchment areas)
- ✓ Based on actual concentrations and derived/assumed values
- ✓ Verified using measured concentrations for 1997
- ✓ Modelled annual average concentrations

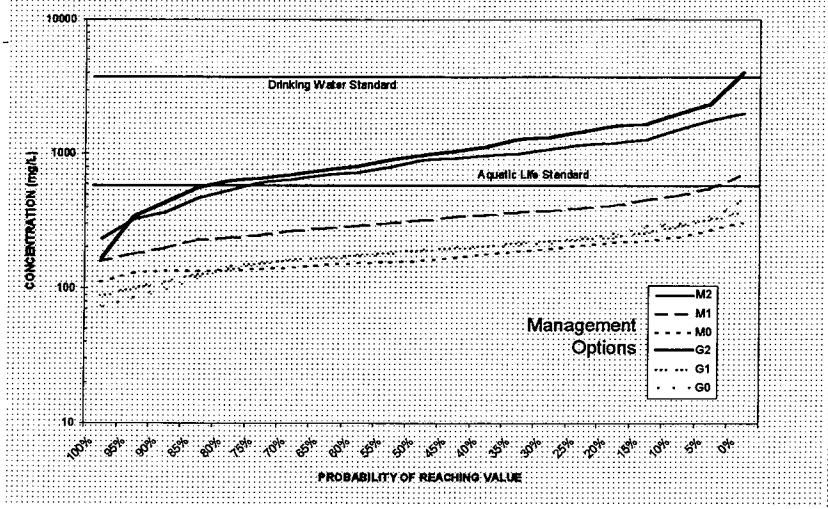




MANAGEMENT OPTIONS

Option/ Measure	M2	M1	M0	G2	G1	G0
Material Management	Yes	Yes	Yes	Yes	Yes	Yes
Compaction & Covers	No	Yes	Yes	No	Yes	Yes
Level of Diligence	Mod.	High	V. High	Mod.	High	V. High

PROBABILITIES OF MAXIMUM ZINC CONCENTRATIONS- YEAR 2021



SUMMARY OF RESULTS

- ✓ Relatively little difference between waste dump construction options
- ✓ Management plans are required to meet standards:
  - material management involving identification, segregation and special placement especially for outer faces of dumps
  - covers for outer face
  - compaction of problematic layers
  - a relatively high level of diligence
- ✓ With these measures there is a high probability of a "walk away" closure

CONCLUSIONS

- ✓ Risk assessment can be applied to many different types of ARD problems
- ✓ Begun to develop more sophisticated applications
- ✓ Just begun to tap the capabilities
- ✓ Need more information to "calibrate" approaches
- ✓ Risk assessment really does help us towards ARD "enlightenment"