SECTION B.6

GEOTECHNICAL RISK ASSESSMENT AND MANAGEMENT

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Geotechnical Risk Assessment and Management

5th Annual BC Metal Leaching and ARD Workshop

Simon Fraser University

Notes by

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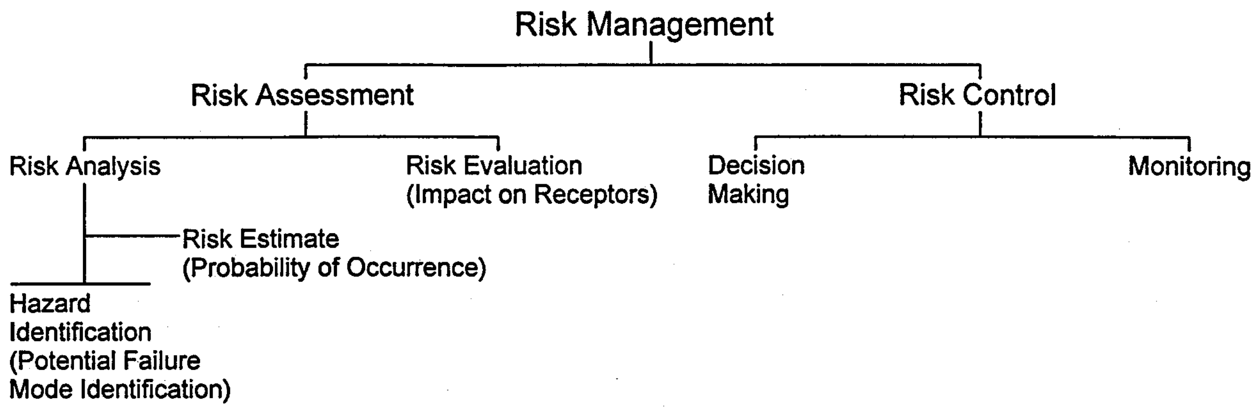
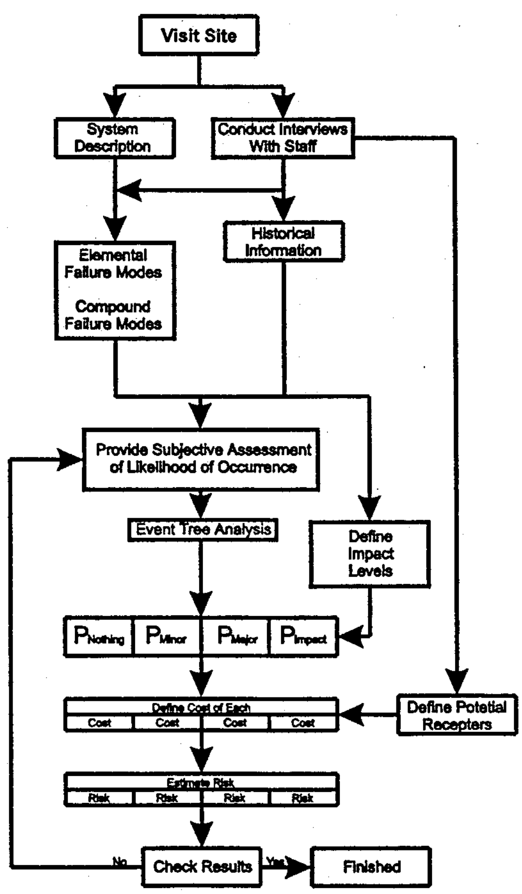
Risk Management Approach

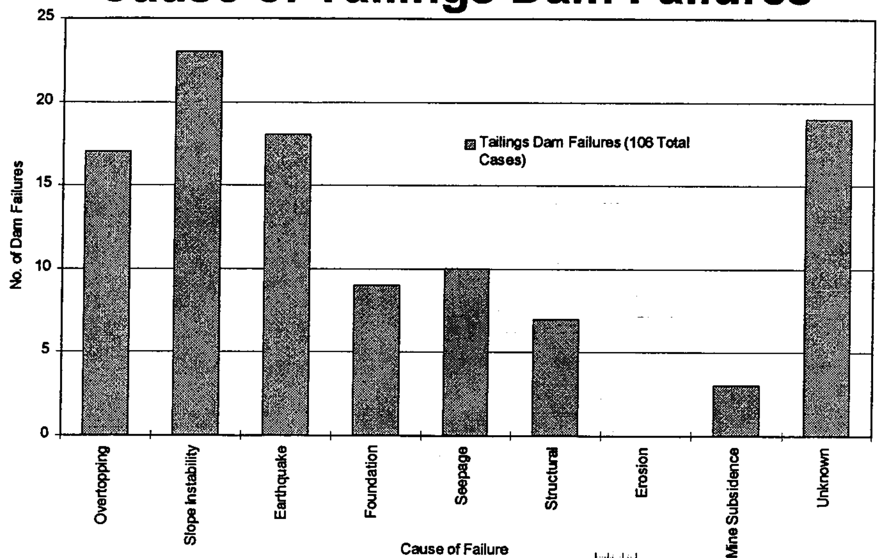


(modified after CSA 1991)



Risk Assessment Process

Cause of Tailings Dam Failures



(from USCOLD, 1994)

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Historical Data

Examples of Elemental Failure Modes for Impoundment Systems

Reservoir (overtopping)
1 Landslide into reservoir generates a wave which overtops the dam
2 Wave action overtops dam
....
Dam (upstream or downstream instability)
....
11 Seismic liquefaction of dams
12 Seismic deformation of dams
13 Seismic liquefaction of tailings leads to erosion
....
20 Dam face erodes due to uncontrolled precipitation or snow melt

Foundation beneath dam
21 Karst collapses beneath dam
22 Collapse due to mine subsidence allows tails to escape into mine or void
23 Sliding on weak soil or liner interface
24 Compression of weak soils leads to cracking of dam
25 Permafrost degrades
....
Structure in Dam Fails
31 Piping around a culvert or decant pipe
32 Reclaim tower fails
....
36 Landslide blocked spillway
37 Ice blocks spillway

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Description of Likelihood of Occurrence

Based on Case History Approach
(Lifetime)

Likelihood of Phenomena (Case History Assessment)	**Potential Frequency Based on Historical Data**	**Example of common events with the same level of likelihood**
Very High Likelihood of Occurrence	Happens Repeatedly (appx. 1 time / yr)	Power loss to plant, Common Cold
High Likelihood of Occurrence	Happens Several Times (appx 1 time / yr to 1 time / 5 yrs)	Sinkhole develop in dam
Moderate Likelihood of Occurrence	Happens Once in a While (appx 1 time / 6yrs to 1 time / 20yrs)	Decant tower knocked over by ice
Low Likelihood of Occurrence	Rarely Happens (less than 1 time / 20yrs)	Traffic Accident hits pipeline
Negligible Likelihood of Occurrence	Barely Imaginable	Maximum Credible earthquake

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Description of Consequence Categories

Very Low Minor non-reportable release of sediment or contaminated water. Easy to control and stop continued losses. No injury and no significant damage to environment. No loss in production.

Low Minor release of sediment or contaminated water. Localized problems, controllable, no significant permanent damage to environment. Loss of production < 1 day.

Moderate Release of fluids and sediment. Can be controlled and repaired but significant effort required. Possible interruption of 2-3 days to repair.

High Significant release of solids and fluids affecting surface water. Damage can be repaired but some long lasting contaminant effect. Some fines for non compliant discharge. possible interruption to productions for up to 2 weeks.

Very High Major uncontrolled release. Major failure of dams, dumps or tailing ponds. Surface water contaminated for long periods. Long shut down, possibly closure. Major fines or clean up costs.

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Generalized Risk Classifications

Consequences	Likelihood of Occurrence: Very High	High	Moderate	Low	Negligible
Very High	Highest Risk VH/VH	VH/H	VH/M	VH/L	Low Risk VH/N
High	H/VH	High Risk H/H	H/M	H/L	H/N
Moderate	High Risk M/VH	M/H	Moderate Risk M/M	M/L	M/N
Low	L/VH	L/H	L/M	Low Risk L/L	L/N
Very Low	Low Risk VL/VH	VL/H	VL/M	VL/L	Negligible Risk VL/N

High Risk — High Risk Classification - More Work is Required to Define Concepts for Feasibility Le

Mod. High Risk — Moderately High Risk - More Work Required for Final Design Unless the Degree of Confidence Surrounding the Likelihood is Low or Medium in Which Case, More Work is Required to Define Concepts for Feasibility Level

Moderate Risk — Moderate Risk - More Work is Required for Final Design

Low Risk — Low Risk - No Significant Additional Work Required

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Risk Categories Used for Mine Project FMEA

Low Risk
Failure modes that were identified as having low risk were considered to have either a low likelihood of occurrence or a low consequence. No additional work was considered necessary for low risk failure modes.

Moderate Risk
Failure modes that were identified as moderate were considered to be reasonably well defined and understood and to require more work at a final design stage. However, any moderate risks where the likelihood of occurrence was regarded to be low or moderate was considered to require more work at this stage to better concepts and the risk category was therefore raised to high to prompt action.

Moderately High Risk
Failure modes that were identified as having a moderately high risk were also considered to be adequately addressed at this feasibility level unless the degree of confidence surrounding the likelihood of occurrence was low or moderate. If the degree of confidence was not high, it was considered that the risk could be higher than identified and the classification should be raised by one category to a High Risk category. This implied that additional work was required to define and strengthen concepts for the feasibility level.

High Risk
Failure modes that were considered to have a high risk classification were considered to require additional work to confirm concepts or confirm model results.

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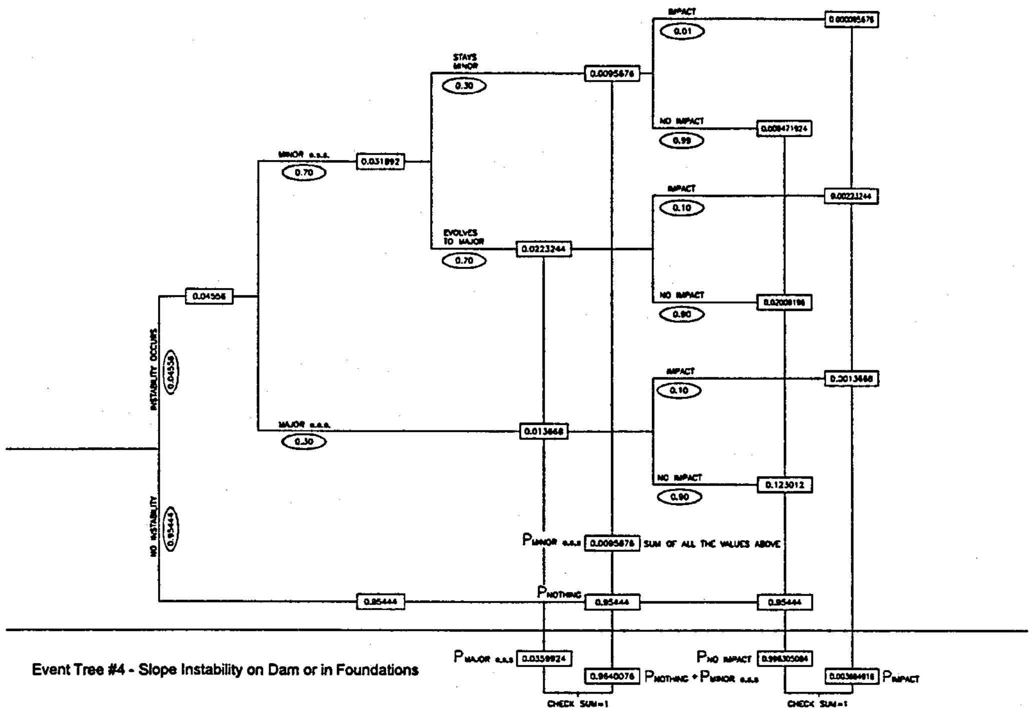
Risk Assessment of Tailngs System
Event Tree for Compound Failure



Event Tree #4 - Slope Instability on Dam or in Foundations

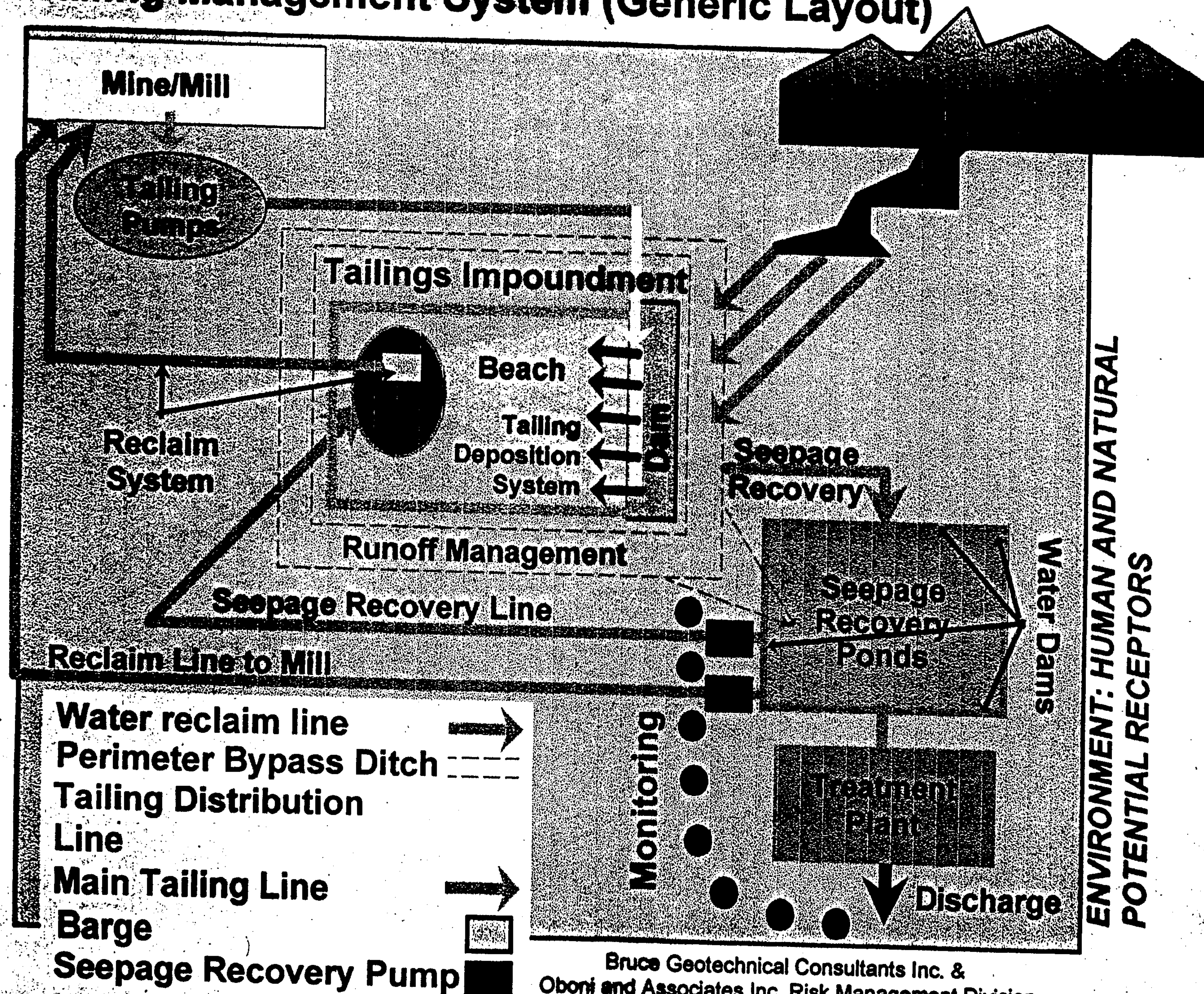
Relationship between Case History Approach and Probability

Likelihood of Phenomena (Case History Assessment)	**Potential Frequency Based on Historical Data**	**Probability of Occurrence Px ($P_{x\ min}$ - $P_{x\ max}$)**	**Example of common events with the same level of likelihood**
Very High Likelihood of Occurrence	Happens Repeatedly (appx. 1 time / yr)	(10^{-1} - 10^{0})	Power loss to plant, Common Cold
High Likelihood of Occurrence	Happens Several Times (appx 1 time / yr to 1 time / 5 yrs)	(10^{-2} - 10^{-1})	Sinkhole develop in dam
Moderate Likelihood of Occurrence	Happens Once in a While (appx 1 time / 6yrs to 1 time / 20yrs)	(10^{-3} - 10^{-2})	Decant tower knocked over by ice
Low Likelihood of Occurrence	Rarely Happens (less than 1 time / 20yrs)	(10^{-4} - 10^{-3})	Traffic Accident hits pipeline
Negligible Likelihood of Occurrence	Barely Imaginable	(10^{-4} -$10^{-5)}$	Maximum Credible earthquake

Subjective probability P_x of an event x
Given the "case history" rating or Likelihood
and the "state of the system" rating.

	State of the system					
Likelihood of Phenomena (Case History Assessment)	Very Good	Good	Moderate	Fair	Poor	Very Poor
Very High Likelihood of Occurrence	10^{-1}	1.5×10^{-1}	2.5×10^{-1}	4.5×10^{-1}	7.0×10^{-1}	10^{0}
High Likelihood of Occurrence	10^{-2}	1.5×10^{-2}	2.5×10^{-2}	4.5×10^{-2}	7.0×10^{-2}	10^{-1}
Moderate Likelihood of Occurrence	10^{-3}	1.5×10^{-3}	2.5×10^{-3}	4.5×10^{-3}	7.0×10^{-3}	10^{-2}
Low Likelihood of Occurrence	10^{-4}	1.5×10^{-4}	2.5×10^{-4}	4.5×10^{-4}	7.0×10^{-4}	10^{-3}
Negligible Likelihood of Occurrence	10^{-5}	1.5×10^{-5}	2.5×10^{-5}	4.5×10^{-5}	7.0×10^{-5}	10^{-4}

Tailing Management System (Generic Layout)



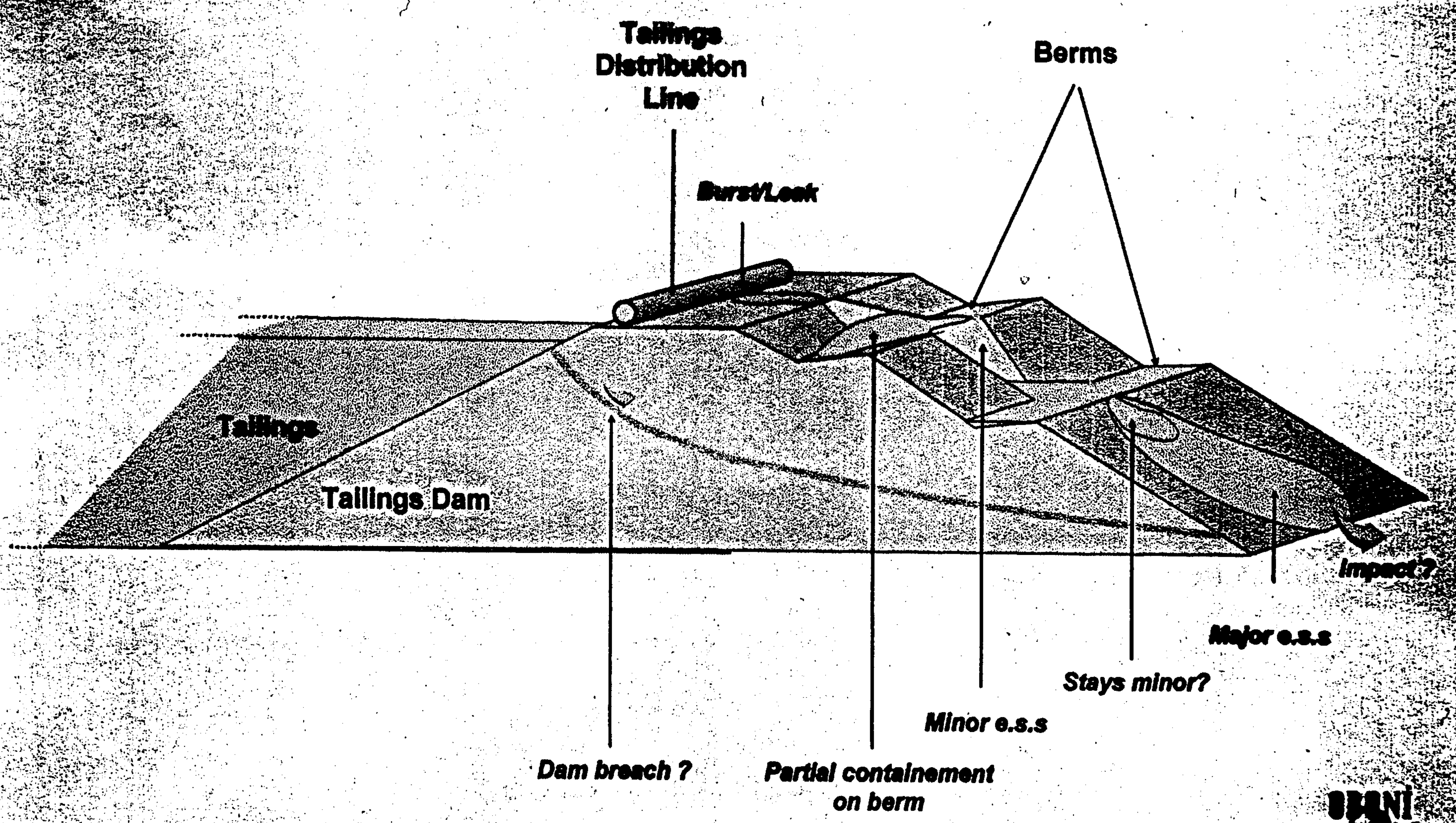
Bruce Geotechnical Consultants Inc. &
Oboni and Associates Inc. Risk Management Division

OBONI

TAILINGS DISTRIBUTION LINE LONG/SHORT DURATION BURST/LEAK AT THE CREST OF THE TAILINGS DAM

FIGURE 2

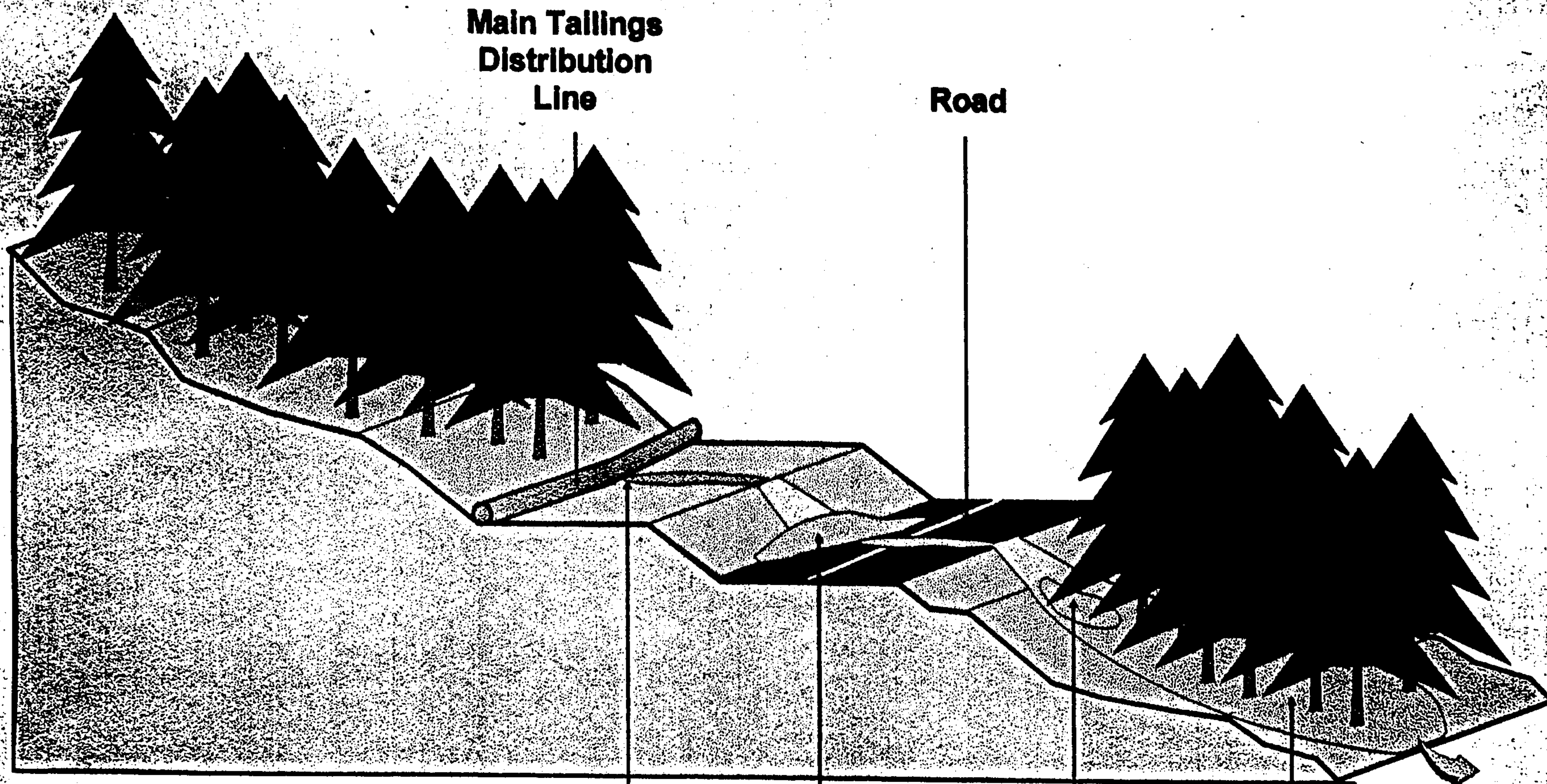
not to scale



MAIN TAILINGS DISTRIBUTION LINE LONG/SHORT DURATION BURST/LEAK

FIGURE 3

not to scale



Summary of Probabilities of Occurrence and Annual Probabilities of Occurrence, Annual Risk Units and Ranges For Various Mines

Years of mine lif 23

Compound Failure Scenarios	Consequence Category	Lifetime Prob of occurrence	Annual Prob of Occurrence	Cost Category (Refer to table 7.2)	Annual Risk Units Cost Category. x Ann. Prob	Range	Comments
Ponding on Berms	P Nothing						
	P Minor ess						
Event tree 1	P Major ess						
	P Impact						
Distribution Line Breaks on Dam	P Nothing	0.98902	0.04300	100	4	3-16	
	P Minor ess	0.01022	0.00044	50,000	22	2-113	
Event Tree 2	P Major ess	0.00076	0.00003	500,000	17	2-83	
	P Impact	0.00036	0.00002	1,000,000	16	9-230	
Overtopping	P Nothing	0.99966	0.04346	100	4	3-17	
	P Minor ess	0.00013	0.00001	50,000	0	0-1	
Event Tree 3	P Major ess	0.00021	0.00001	500,000	5	1-103	
	P Impact	0.00021	0.00001	1,000,000	9	9-206	
Slope Instability	P Nothing	0.95444	0.04150	100	4	3-17	
	P Minor ess	0.00957	0.00042	50,000	21	0-21	
Event Tree 4	P Major ess	0.03599	0.00156	500,000	782	4-782	
	P Impact	0.00369	0.00016	1,000,000	160	32-374	
Main Tailing Line	P Nothing	0.98906	0.04300	100	4	2-16	
	P Minor ess	0.01016	0.00044	50,000	22	2-137	
Event Tree 5	P Major ess	0.00076	0.00003	200,000	7	2-285	
	P Impact	0.00006	0.00000	1,000,000	2	2-167	
Polishing Pond Failure	P no Impact	0.99991	0.04347	100	4	3-17	
Event tree 6	P minor impact	0.00002	0.00000	100,000	0	0-3	
	P major impact	0.00007	0.00000	1,000,000	3	0-49	
Mill Spill	P no impact	0.99901	0.04344	100	4	3-17	
	P minor impact	0.00026	0.00001	10,000	0	0-426	
Event Tree 7	P major impact	0.00074	0.00003	50,000	2	2-563	
Probability of a Breach occurring as a result of Messs	P Breach	0.004440	0.0001930	10,000,000	1930	53-6017	

Note the column giving the Range shows the range of values calculated for all active mines as of April 1997.

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