Tailings Overview

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Summary

- ✓ What are tailings and what are their properties?
- ✓ What are the types of dams and containment of tailings?
- ✓ What are the key design features?
- ✓ What can go wrong?
- ✓ What is best management practice?

Tailings Properties

Tailing Types: copper, gold, iron ore, bauxite, oil sands, massive sulphide, phosphate, laterite nickel

Geotechnical Properties: settling and consolidation behaviour, permeability, gradation, plasticity,

Geochemistry: ARD potential, neutral leaching

Process Modifications: water (thickening, paste, dewatered); geochemistry (sulphide floatation)

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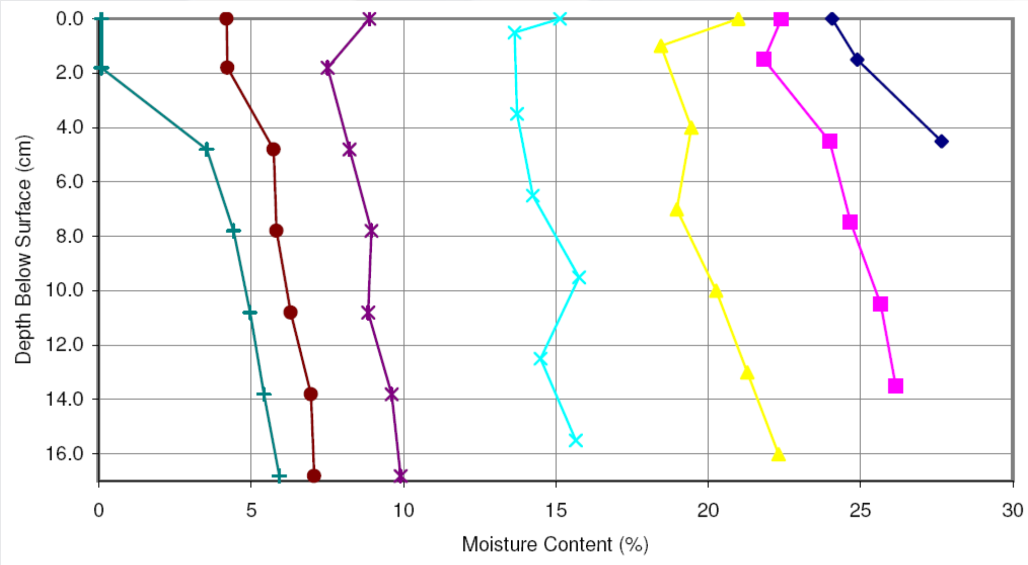
Tailings Evaporation Properties

Evaporation Cell Tests

- Evaporation of ~ 40 mm (4 days in summer) results in de-saturation at surface at ~ 80% solids
- A crust was formed on the surface, due to clays (8%) or precipitates (TDS ~ 300 mg/L)



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6.5 inch slump test and tailings densities

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Dewatering Technologies

Thickened and paste tailings

- Less water in tailings.
- Tailings is saturated and requires a dam for stability in seismic areas.
- Non-segregating tailings reduces permeability
- Questionable cost or technical advantage
- Water recovery potential

Dewatered tailings

- Expensive.
- Requires compaction for seismic stability.

De-sulphidized tailings

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Myra Falls Paste Plant

Paste Plant and Superflow Thickener

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Vacuum filter and filtered tailings

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Paste tailings mixing unit

Consolidation bleed from paste tailings & 5% cone

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Greens Creek Filtered Tailings Disposal Site

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Tailings de-watered at mill using pressure filters

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Placement and spreading of tailings with a dozer

Horizontal Belt Vacuum Filters – Mantos Blancos, Chile

25,000 tpd to single stage cyclones

Cyclone underflow filtered, overflow thickened & stored separately

Filtered material on the belt.
Note the high water content of the feed material.

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Cycloned/Dewatered Tailings Cone

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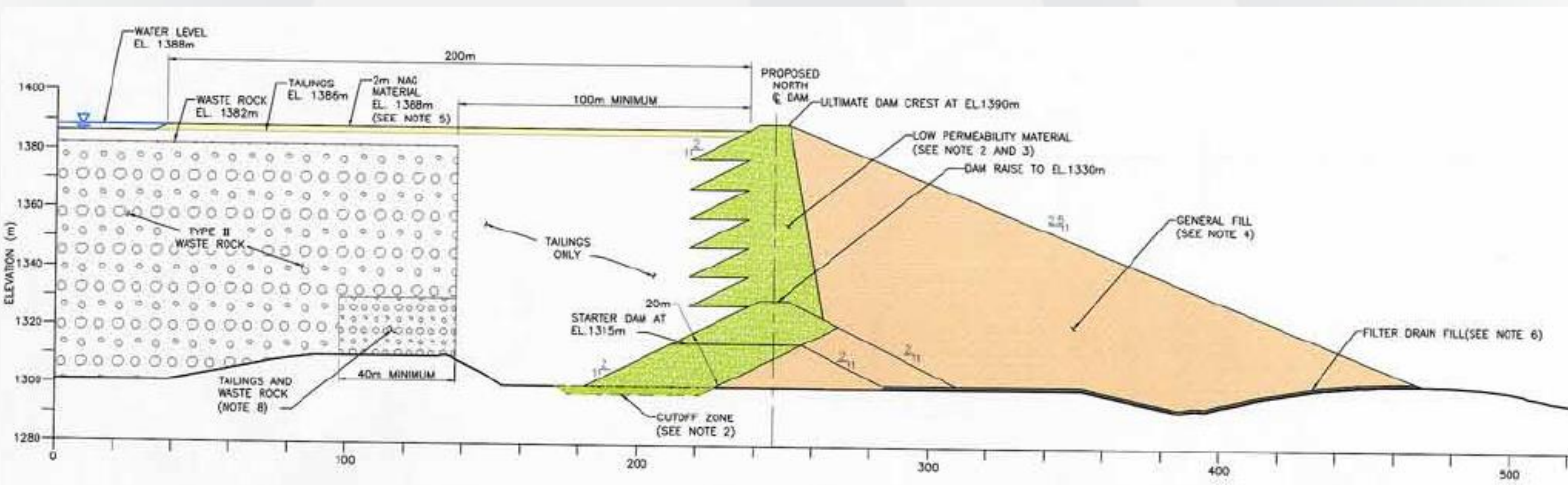
Reduces fills by about 30%

Upstream stability is not an issue – in high seismic areas with high raises you may need to have a “slight” d/s slope.

Core zones, and even liners, can be placed vertically.



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55 Years of Operation and Closure With Cyclone Sand Dams

Figure 1: Secondary cyclone (flow comes in from pipe on the right, overflow exits through pipe on the near side, cycloned sand slurry exits from the far side)

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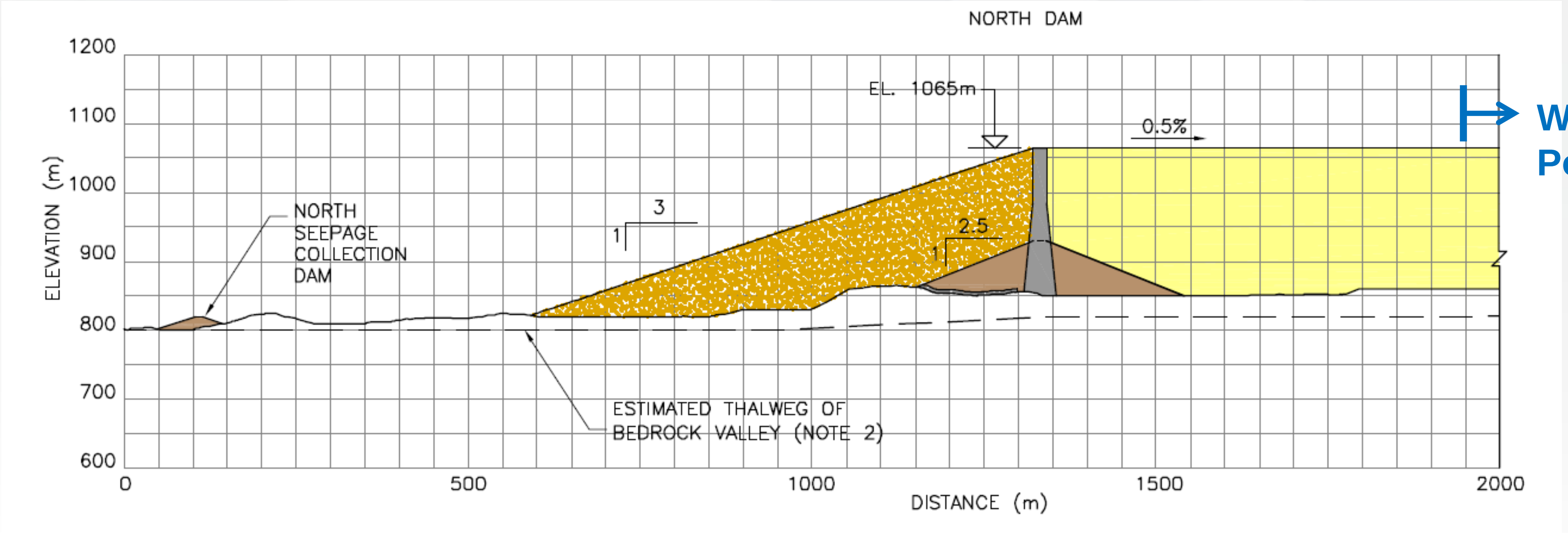
- ✓ Water kept away from dams to improve stability
- ✓ Till core to reduce seepage
- ✓ 3H:1V slopes for seismic stability and to facilitate reclamation

Gibraltar Cyclone Dam



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Upstream Construction : Vale Inco R4, Sudbury, Ontario


Inco R4, Sudbury

Civil

- Mine production - 36,000 tpd
- Height of Dams, 30 m, crest length, 5 km
- Total storage - 200 Mt
- EPCM
- Tailings management
- Slurry cut off
- Electrical/Mechanical Pipeline

Environmental

- Closure plan 14 mines, 2 smelters, 2 refineries
- Revegetation, lowering, relocation
- Biological assessment, fish and wildlife
- Pits and underground

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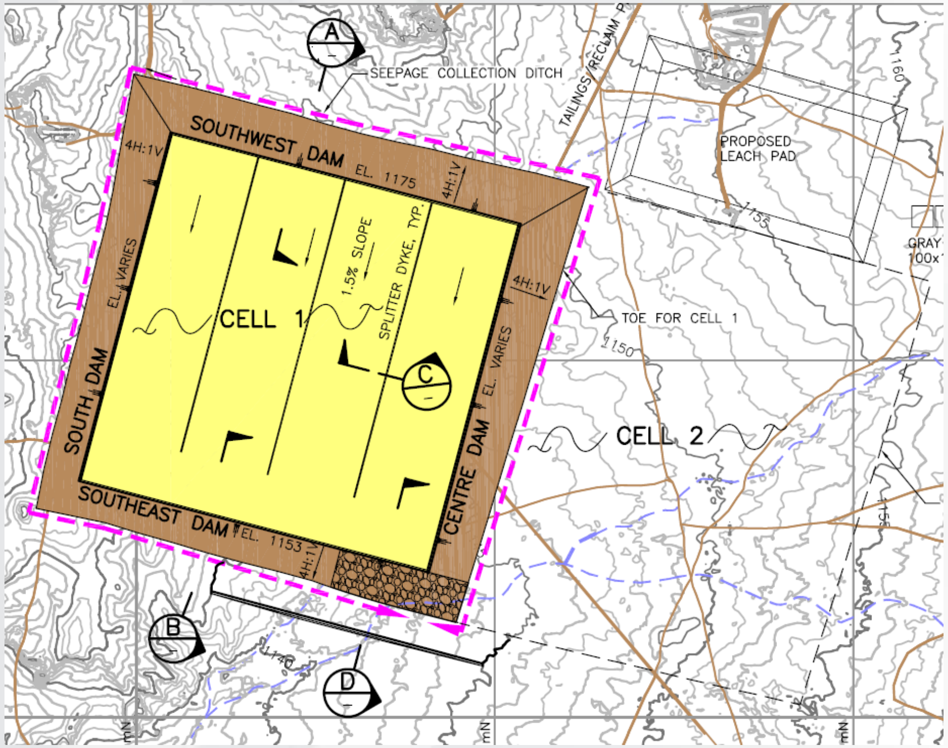
Using the benefit of tailings in arid environments

- Consolidated tailings in desert climates eliminates piping risk and need for filters.
- Water savings can be achieved with cell construction
- Dust control water can be reduced.
- Dry closure landscapes

Escondida and Oyu Tolgoi



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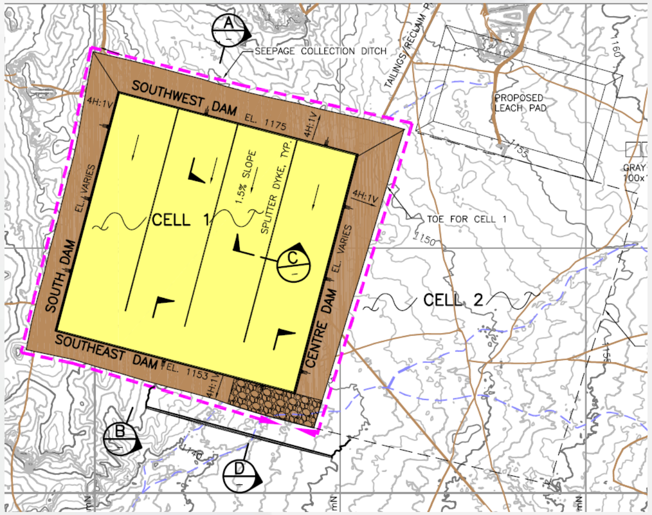
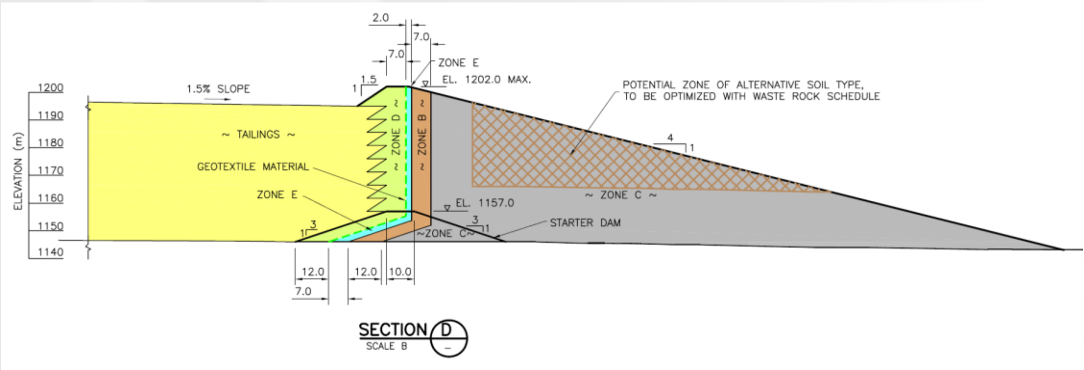
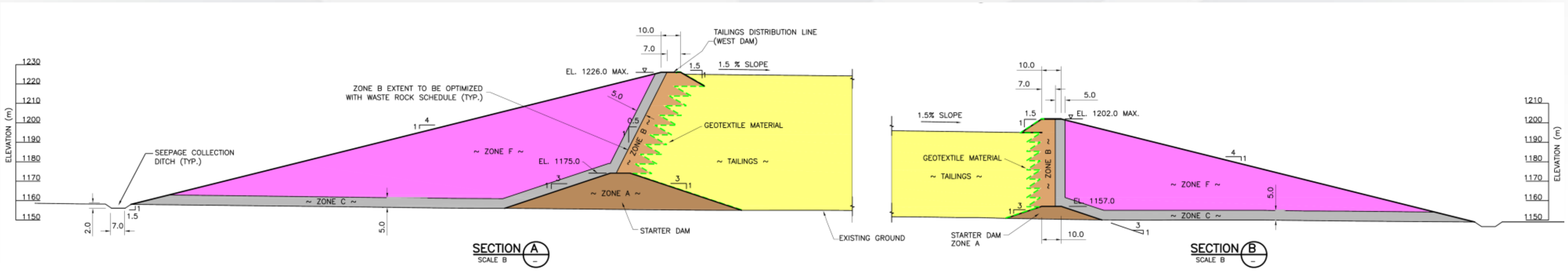
Water control - dry climates







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Technical Components


Depressurization well – artesian flow

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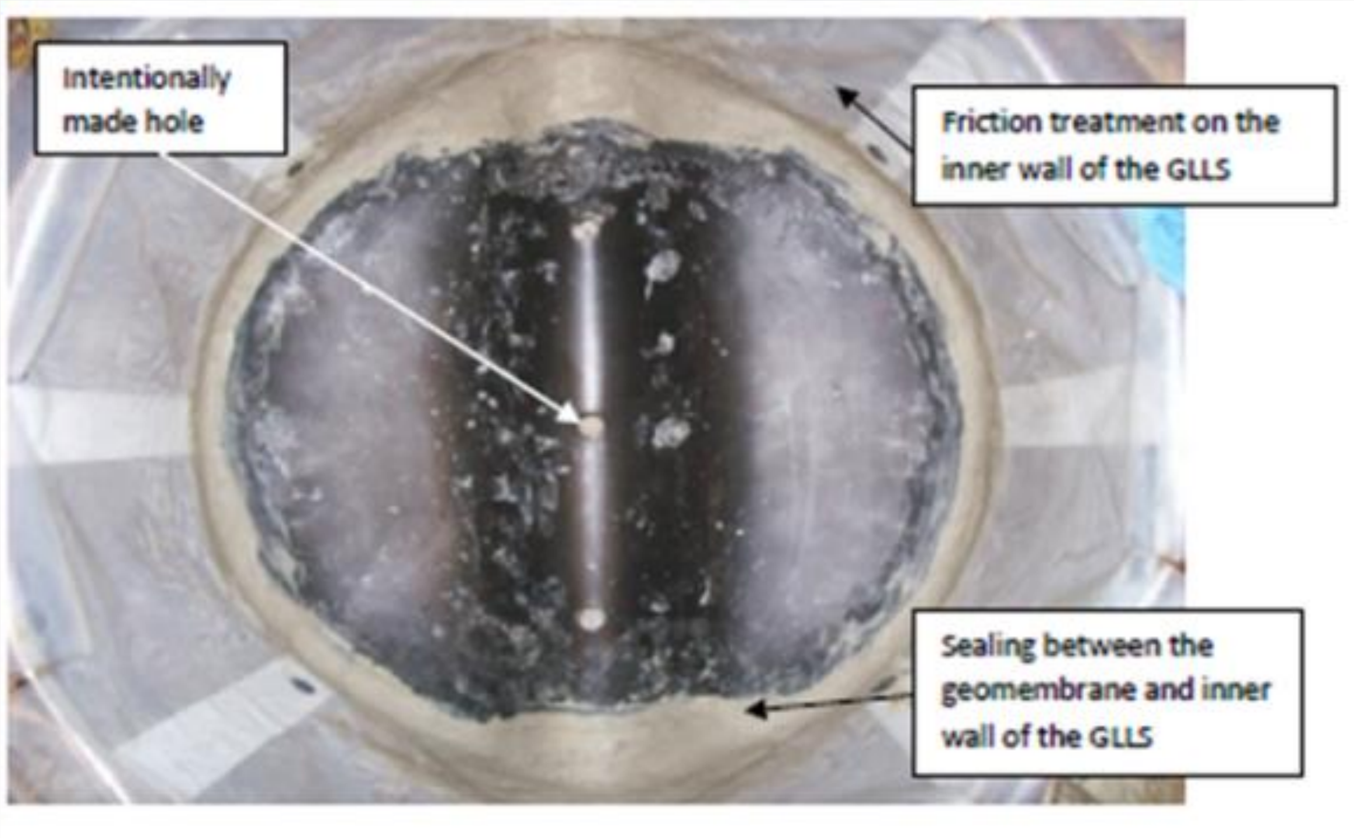
- Shunned for dams due to concerns with longevity.
- Tailings/geomembrane liners dramatically decrease potential seepage.
- Geotextile filter fabrics can be used for tailings dams with “dry” closure as gradients and piping risks do not exist over the long term.



5 Myths of Geomembranes

1. A liner bedding layer is required
2. A liner protection layers is required to prevent ice damage
3. Drains are required over or between liners to reduce the head on the liner to reduce seepage
4. Geomembranes only last, maybe, a few hundred years.
5. QA/QC of liners is of “critical” importance.

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Tailings Reduce Hydraulic Gradients and make a Safer Dam

- Grouting of core zone foundations normally eliminated.
- Width of core zone can be reduced to reflect lower gradients
- Risk of “piping” failure is lower than for a water dam.
- Hydraulic fractures – “self-healed” with tailings

Highland Valley Copper

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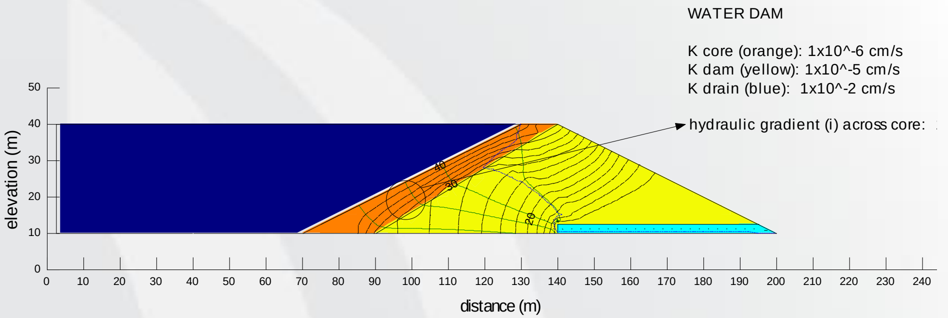
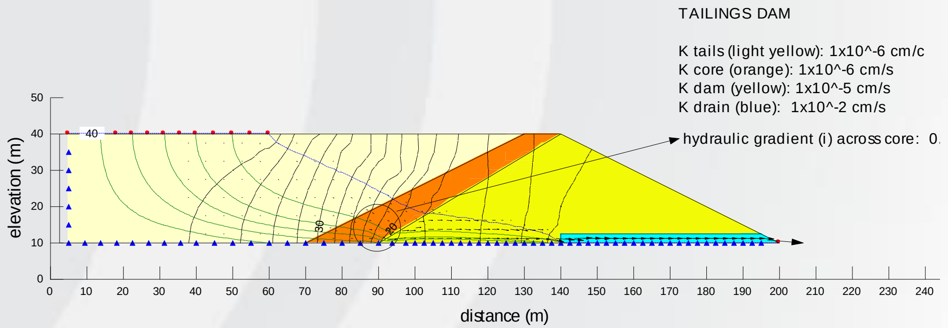
KCB avoids pervious zones on the upstream side of tailing dams

- Upstream pervious shell was designed for water dams for rapid drawdown condition (does not apply to tailing dams)
- Negates gradient reduction through the tailings.
- Increases risk of piping failure.
- Requires greater width of impervious zone to meet gradient requirements across the core of the dam





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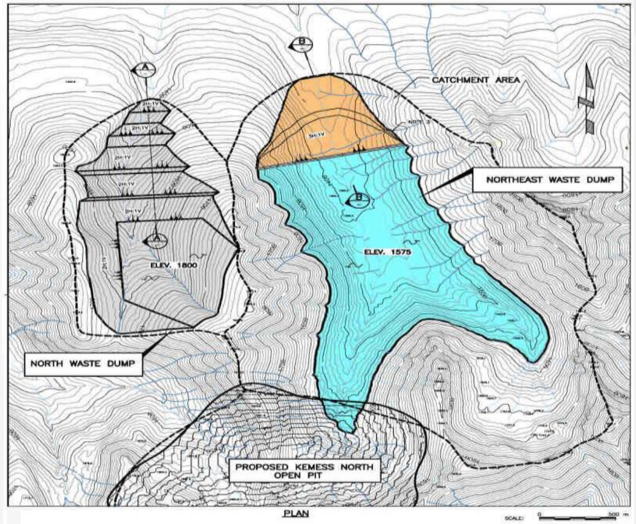
Alternative Assessment - Typical Example



OPEN PIT WITH DAMS

COMPONENT/SUB-COMPONENT	I. D. No.	FAILURE MODE AND CAUSE (WHAT IF?)	EFFECTS	PROJECT STAGE	LIKELIHOOD	CONSEQUENCES: WATER QUALITY	CONSEQUENCES: BIOPHYSICAL	CONSEQUENCES: COMMUNITY/SOCIAL	CONSEQUENCES: COST	CONFIDENCE: LEVEL OF CONFIDENCE	CONFIDENCE: ADJUSTED LIKELIHOOD	COMPENSATING FACTORS AND ADEQUACY OF EXISTING CONTROLS	RISK LEVEL (ADJUSTED FOR LEVEL OF CONFIDENCE)	RISK LEVEL	POINTS
100 SERIES DAM															
FILTERS, DRAINS, FILL, FOUNDATION	OP-100.1	DAM FAILURE	RELEASE OF ALL TAILINGS AND WATER	C/O/CL	D	4	4	3	5	M	D	DESIGN	D, 5	4	5
	OP-100.2	UNKNOWN SOIL CONDITIONS	HIGHER DAM COSTS	C/O	C	1	1	1	4	L	B	GEOTECHNICAL DRILLING PROGRAM-DESIGN FOR FLAT SLOPES	B, 4	3	25
	OP-100.3	LACK OF CONSTRUCTION MATERIALS	HIGHER DAM COSTS	C/O/CL	C	1	1	1	3	L	B	GEOTECHNICAL DRILLING PROGRAM	B, 3	4	5
	OP-100.4	DAM FOUNDATION FAILURE TOWARDS KEMESS CREEK	CANNOT RAISE DAM BECAUSE SLOPE EXTENDS TOWARD THE CREEK	C/O	B	2	2	2	4	L	A		A, 4	2	150
	OP-100.5	EXPANDED FOOTPRINT WITH NO FAILURE	LOSS OF HABITAT IN DAM AREA	C/O/CL	A	1	2	1	2	H	A		A, 2	4	5
200 SERIES IMPOUNDMENT															
DIVERSION CHANNELS-CONDUIT, TAILINGS BEACH, RESERVOIR SLOPE, DECANT, SEEPAGE POND RELOCATION, TAILS STORAGE/ POND LEVEL, DIVERSION CHANNEL ROUTE	OP-200.1	INSUFFICIENT SETTLING TIME	POOR RECLAIM WATER	O	A	1	1	1	3	M	A	STORE WATER FOR ONE YEAR AND USE EXISTING POND/ESTABLISH WELLS IN WASTE ROCK-EAST SIDE PIT	A, 3	3	25
	OP-200.2	TAILINGS GEOCHEMISTRY IS WORSE THAN PREDICTED	LEACHING OF METALS AND DEGRADED SURFACE WATER	O/CL	C	3	3	1	3	M	C	LOW PERMEABILITY COVER AND TREATMENT	C, 3	5	1
	OP-200.3	PIT WALL FAILURE	SHUTDOWN OPERATIONS	O	C	1	1	1	3	M	C	DESIGN AND MONITOR, EFFECT OF FLOODED PIT ON WALL STABILITY ASSESSED	C, 3	5	1
	OP-200.4	SEEPAGE OF CONTAMINATED WATER	DEGRADATION OF GROUNDWATER AROUND THE OPEN PIT, POTENTIAL CONNECTION TO KEMESS CREEK	O/CL	C	2	2	1	3	M	C	MONITORING WELLS, HYDROLOGY STUDIES REQUIRED TO EVALUATE POTENTIAL SEEPAGE	C, 3	5	1
	OP-200.5	KEMESS SOUTH MINE STOP EARLY	REDUCED STORAGE VOLUME AND LIFE OF OPEN PIT STORAGE	O	C	1	1	1	2	M	C		C, 2	>5	0
	OP-200.6	SETTLED DENSITY LESS THAN EXPECTED	PUMP TO DUNCAN SOONER HIGHER COSTS	O	C	1	1	1	3	M	C	SETTLING TESTS, STUDIES	C, 3	5	1
	OP-200.7	HIGHER RATIO OF SULPHIDE TO NEUTRAL TAILINGS DUE TO CYCLONING	ARD POTENTIAL AND LEACHING OF METALS INCREASING CLOSURE COST	O/CL	B	3	3	1	4	L	A	TESTING AND DESIGN	A, 4	2	150
	OP-200.8	INCREASED MINE RESERVES	REQUIRE NEW TAILINGS FACILITY	O	A	4	4	3	4	M	A	BUILD NEW FACILITY	A, 4	2	150
300 SERIES WATER RECLAIM															
PUMP BARGES, PUMP BACK SYSTEMS, PUMPING	OP-300.1	SINKING OF BARGE	POTENTIAL SHUTDOWN	O	C	1	1	1	2	M	C	USE EXISTING SYSTEM FOR BACKUP	C, 2	>5	0
	OP-300.2	SHUTDOWN OF EXISTING SYSTEM	REDUCED WATER FLOW, SHUT DOWN PART OF MILL	O	B	1	1	1	2	M	B	DESIGN AND ENSURE BACKUP WATER SUPPLY	B, 2	5	1
	OP-300.3	DIRTY RECLAIM WATER	HIGH PUMP MAINTENANCE, PUMP GLANDS	O	B	1	1	1	2	M	B	STORE WATER FOR ONE YEAR AND USE EXISTING POND/ESTABLISH WELLS IN WASTE ROCK-EAST SIDE PIT	B, 2	5	1
	OP-300.4	WATER SHORTAGE	DISRUPTION OF PRODUCTION	O	B	1	1	1	2	L	A	PROPER DESIGN AND IMPLEMENTATION-DRAW DOWN DUNCAN AND TSF	A, 2	4	5
400 SERIES TAILINGS DISTRIBUTION															
TAILINGS PIPELINE, CYCLONE STATIONS, DEWATERING PLANT, THICKENERS	OP-400.1	FREEZING OR SANDING OF LINES	TEMPORARY SHUTDOWN	O	B	2	2	2	2	H	B	DESIGN WITH DOWNHILL SLOPE	B, 2	5	1
	OP-400.2	PIPELINE BREAK	TEMPORARY SHUTDOWN & POTENTIAL DISCHARGE	O	C	3	3	2	2	H	C	CONTAINMENT, DETECTION & DESIGN	C, 3	5	1
500 SERIES CLOSURE															
COVERS, CLOSURE SPILLWAY, WATER TREATMENT PLANT, FINAL DAM	OP-500.1	TAILINGS GEOCHEMISTRY IS WORSE THAN PREDICTED	REQUIRE LOW PERMEABILITY COVER, OR FLOODED PIT	CL	B	3	3	2	3	M	B	DESIGN, TESTING AND ENGINEERING	B, 3	4	5
	OP-500.2	REVEGETATION IS UNSUCCESSFUL	REQUIRE ADDITIONAL VEGETATION	CL	C	1	4	1	2	M	C	TEST PLOT PROGRAM	C, 4	4	5
	OP-500.3	TAILINGS IS TOO "SOFT" TO RECLAIM	INCREASES DIFFICULTY OF RECLAMATION	CL	B	1	4	1	2	M	B	PLAN FOR BOTH WET AND DRY CLOSURE	B, 4	3	25
	OP-500.4	EROSION OF SPILLWAY	CREATES CHANNELS AND RELEASES TAILINGS	CL	C	3	3	2	2	L	C	ENSURE SPILLWAY IS IN ROCK, OR APPROPRIATELY ARMOURED	C, 3	5	1
	OP-500.5	DO NOT MEET WATER QUALITY OBJECTIVES	RELEASE POOR WATER QUALITY	CL	B	3	3	1	2	L	A	DESIGN, MONITORING	A, 3	3	25
														SUM	589

	CAPITAL, OPERATING AND CLOSURE COSTS*						TOTAL COST SUMMARY			
FACILITY	Foundations & Dams	Water Management	Tailings Transport & Infrastructure	Environment, Water Treatment & Closure	Waste Rock Incremental Haulage	Engingeering, EIA, Monitoring	TOTAL CAPITAL COST	TOTAL OPERATING COST	CONTINGENCY (20% for Option 1) (30% for Option 2)	TOTAL COST
Option 1										
Duncan Lake (Tailings and Waste Rock)	$ 58,754,955	$ 4,700,000	$ 32,425,000	$ 25,800,000	$ 42,400,000	$ 8,207,198	$ 65,635,200	$106,651,953	$ 25,977,431	$ 198,264,584
TOTALS:	**$ 58,754,955**	**$ 4,700,000**	**$ 32,425,000**	**$ 25,800,000**	**$ 42,400,000**	**$ 8,207,198**	**$ 65,635,200**	**$106,651,953**	**$ 25,977,431**	**$ 198,264,584**
Option 2										
RAISE EXISTING DAM 10m (tailings)	$ 50,630,000	$ 2,050,000	$ 39,230,000	$ 12,500,000	$ -	$ 4,574,600	$ 942,000	$108,042,600	$ 23,245,380	$ 132,229,980
SITE M, (70 m high dam) near airstrip (tailings)	$365,169,623	$ 4,370,000	$ 70,218,000	$ 10,650,000	$ -	$ 26,072,377	$313,603,312	$162,876,688	$ 134,433,600	$ 610,913,600
OPEN PIT FILLING (tailings)	$ 571,000	$ 1,360,000	$ 8,534,000	$ 75,000	$ -	$ 1,032,400	$ 9,208,600	$ 2,363,800	$ 3,104,520	$ 14,676,920
EAST CIRQUE (waste rock)	$ 86,330,000	$ 1,450,000	$ -	$ 4,650,000	$ 10,000,000	$ 5,945,800	$ 93,046,800	$ 15,329,000	$ 29,512,740	$ 137,888,540
NORTH CIRQUE (temporary waste rock storage)	$ 3,206,000	$ 7,300,000	$ -	$ 2,000,000	$112,000,000	$ 1,150,360	$ 4,458,360	$121,198,000	$ 4,096,908	$ 129,753,268
TOTALS:	**$505,906,623**	**$ 16,530,000**	**$117,982,000**	**$ 29,875,000**	**$122,000,000**	**$ 38,775,537**	**$421,259,072**	**$409,810,088**	**$ 194,393,148**	**$ 1,025,462,308**

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Risk Binning Example

Risk Review Chart

CONSEQUENCE	LIKELIHOOD: E - CONCEIVABLE BUT IMPROBABLE	D - UNLIKELY	C - POSSIBLE	B - LIKELY	A - ALWAYS CERTAIN
5 -CATASTROPHIC	RISK LEVEL 5 — E, 5	RISK LEVEL 4 — D, 5 CTP-100.3	RISK LEVEL 3 — C, 5	RISK LEVEL 2 — B, 5	RISK LEVEL 1 — A, 5
4 - MAJOR	RISK LEVEL >5 — E, 4	RISK LEVEL 5 — D, 4	RISK LEVEL 4 — C, 4 CTP-400.3	RISK LEVEL 3 — B, 4 CTP-100.2	RISK LEVEL 2 — A, 4 CTP-100.1, CTP-200.9, CTP-200.11, CTP-200.14, CTP-400.6, CTP-400.7
3 - MODERATE	RISK LEVEL >5 — E, 3	RISK LEVEL >5 — D, 3	RISK LEVEL 5 — C, 3 CTP-100.5, CTP-200.1, CTP-200.2, CTP-200.3, CTP-200.4, CTP-200.5, CTP-200.6, CTP-200.7, CTP-500.1, CTP-500.2	RISK LEVEL 4 — B, 3 CTP-200.8, CTP-500.3, CTP-500.4, CTP-500.5	RISK LEVEL 3 — A, 3 CTP-100.4, CTP-100.6, CTP-200.10, CTP-200.12, CTP-400.2, CTP-400.5, CTP-500.6
2 - MINOR	RISK LEVEL >5 — E, 2	RISK LEVEL >5 — D, 2	RISK LEVEL >5 — C, 2 CTP-300.1, CTP-400.1	RISK LEVEL 5 — B, 2 CTP-300.2, CTP-400.4	RISK LEVEL 4 — A, 2
1 - INSIGNIFICANT	RISK LEVEL >5 — E, 1	RISK LEVEL >5 — D, 1	RISK LEVEL >5 — C, 1	RISK LEVEL >5 — B, 1	RISK LEVEL 5 — A, 1

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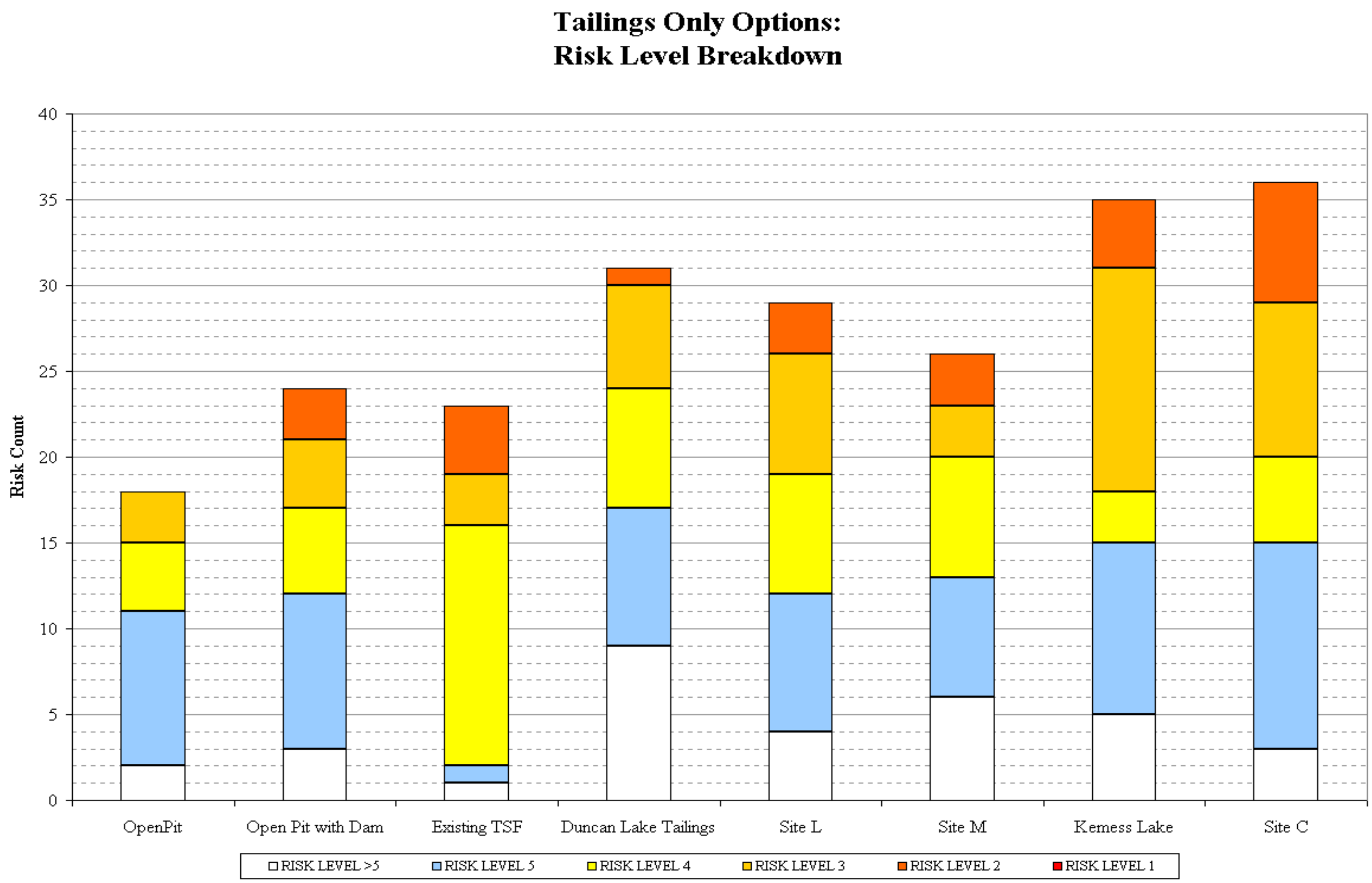
All options have risks – understand and manage the risks



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What is the Cost of Tailings Storage?

Parameter	Lower Grade (e.g. porphyry copper)	Higher Grade (e.g. gold)
Value of ore/t of tailings	$50.00/t	$300/t
Cost of tailings disposal	$ 0.50/t	$ 2.50/t
Dam height	50 m to 300 m	10 m to 50 m
Milling rate	120,000 tpd	7,000 tpd
Incremental cost of tailings to ore	Very High	Moderate

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What are the consequences of tailings incidents?

Type	Effect	Cost
Design/environment /social issues	Permitting delays	~$1 Million
Dam incident e.g spill or release	Short term environmental effect. Fine,	~ 1 Million
Dam failure	Major or catastrophic effect	$10 M to > $1 B Loss of reputation

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Tailing Dam Failure vs Water Dam Failure

Tailing Dams

- Tailings solids can oxidize and/or leach metals.
- Tailings behave as a heavy fluid versus water.
- Dam Break ; slurry and water

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Dam Incidents

Static Liquefaction

(Sullivan Mine, B.C)

Peru – Rockfill on Soft Clay

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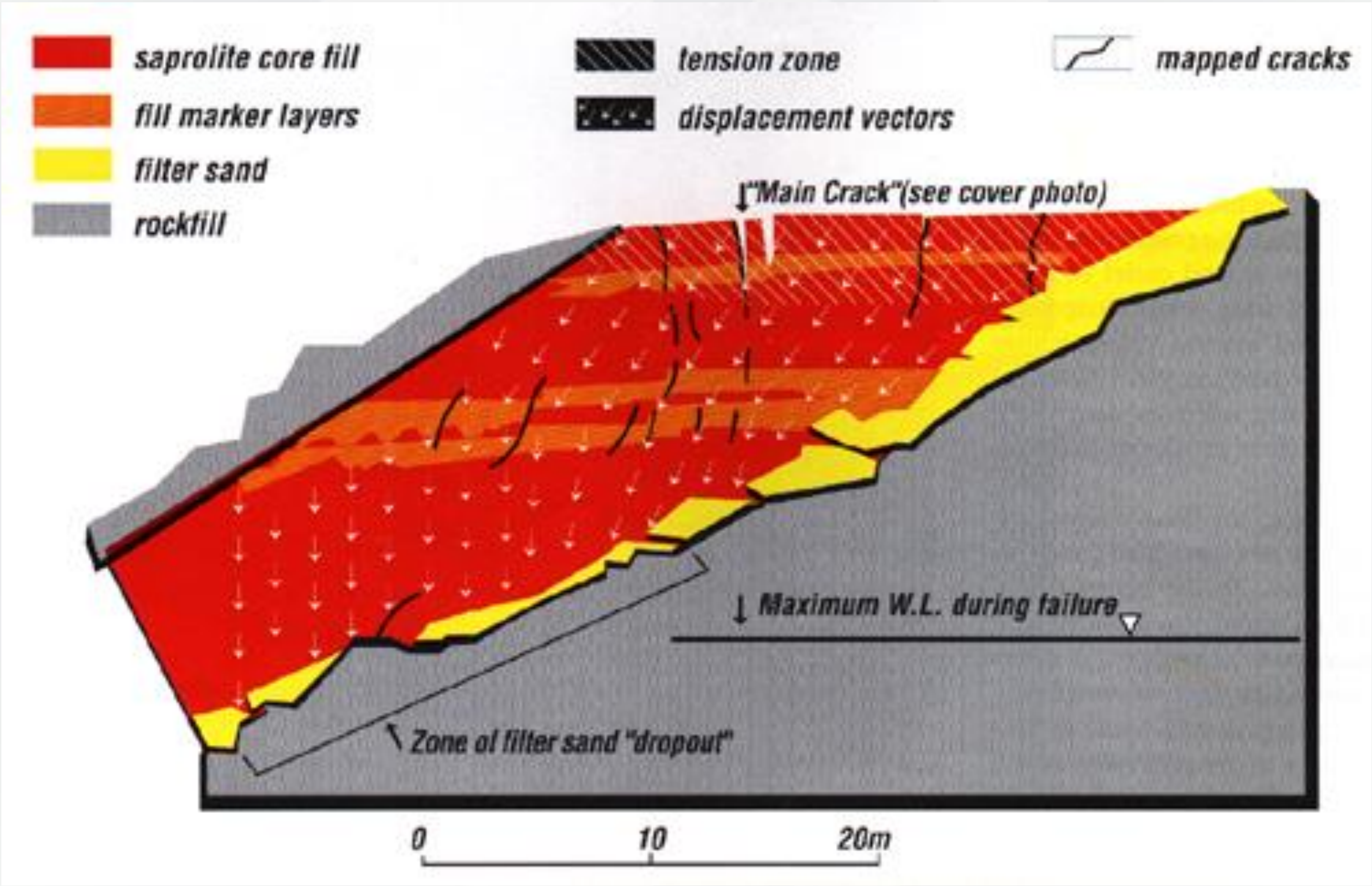
Bedding Plane (Residual) Failure

- Miss "critical" failure mode
- Flood criteria – abused
- Closure design not "robust"
- Optimistic design
- ARD/ML

Hydraulic Gradients



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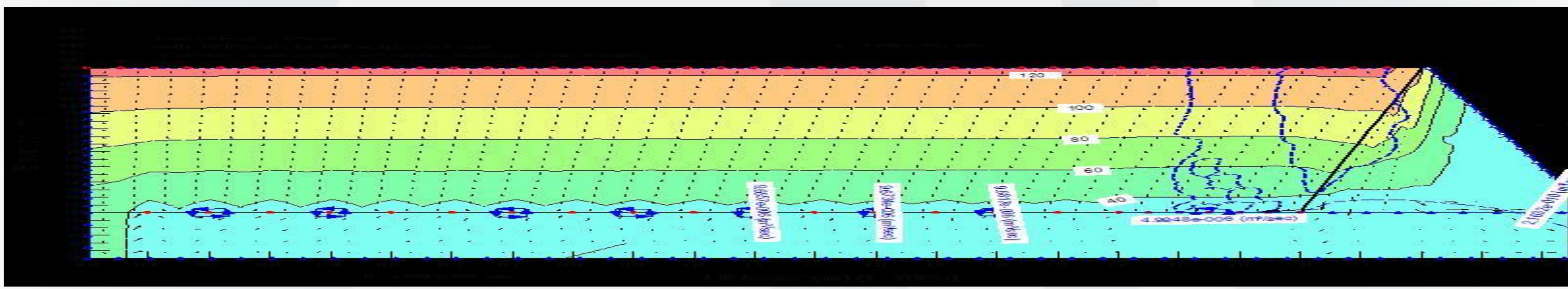
Components that increase risk without commensurate reduction in cost

Underdrain pipes that can be “clogged” by consolidated tailings and are at risk of movement or breakage leading to piping failures.



Reducing Water Management Risk

- Redundant spillways
- “Robust” storage of floods
- Closure “idiot” proofing of flood water release
- Avoid pipe inlets/decants

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Tailings Risk – Assume the unexpected

Build in "robustness"

- Diversions will ice up or infill with sediment
- Spillways will get blocked with debris
- Operators will make mistakes
- QA/QC will vary

Closure

Design for Closure at all Phases

- Physical stability – water & seismic
- Chemistry stability
- Environment stability
- Social stability

Water Quality

- Monitor and if water quality exceeds discharge limits:
  - Pump water to open pit
  - Divert surface clean water
  - Raise dams
  - Treat portion of water

Reclamation

- Testing of plant species
- Habitat enhancement with liquid fertilizers
- Optimization of final geometry to suit reclamation
- Refinement of plan to include 1st Nations input to final land/water use objectives

Dam Safety

- Long term care & maintenance – Monitoring and spillway maintenance
- Financial bonding and responsibility for long term

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Closure Plan-Lake Reclamation

Porphyry Copper Experience – Highland Valley

Trojan

Highmont (wetlands)

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Re-vegetated Surface of Closed Brenda Cyclone Tailings Dam

Closure Plans can be Successful

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Trends in Tailings Management

- Tailings management practices continue to evolve and improve
- ICOLD, ANCOLD, MAC – Guidelines continue to be developed to assist the industry.
- Environmental compliance components are increasing and Regulators are becoming very risk adverse.
- Tailings is not a “low” level science and training at all levels is required.

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QUESTIONS?

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