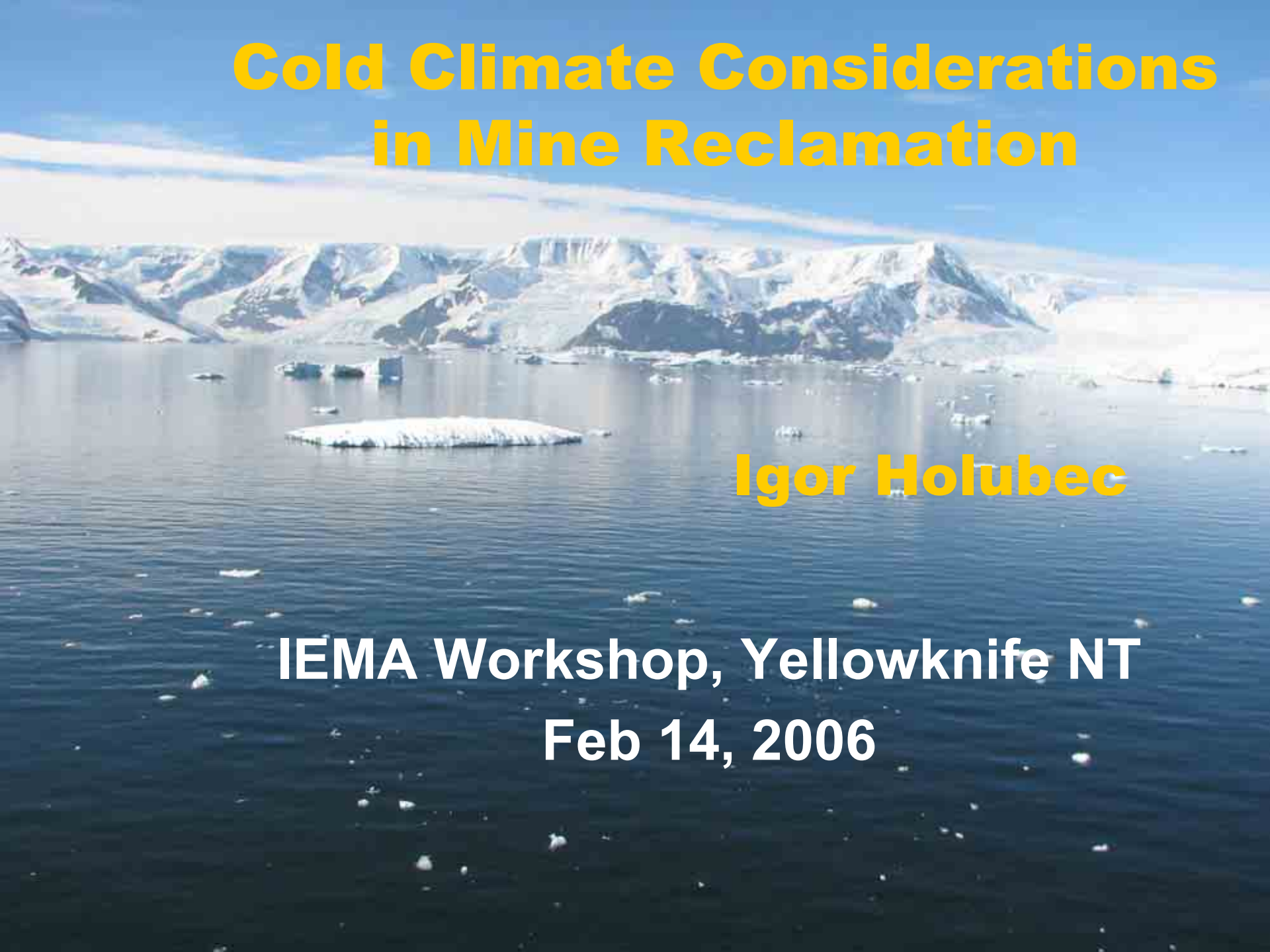


Cold Climate Considerations in Mine Reclamation

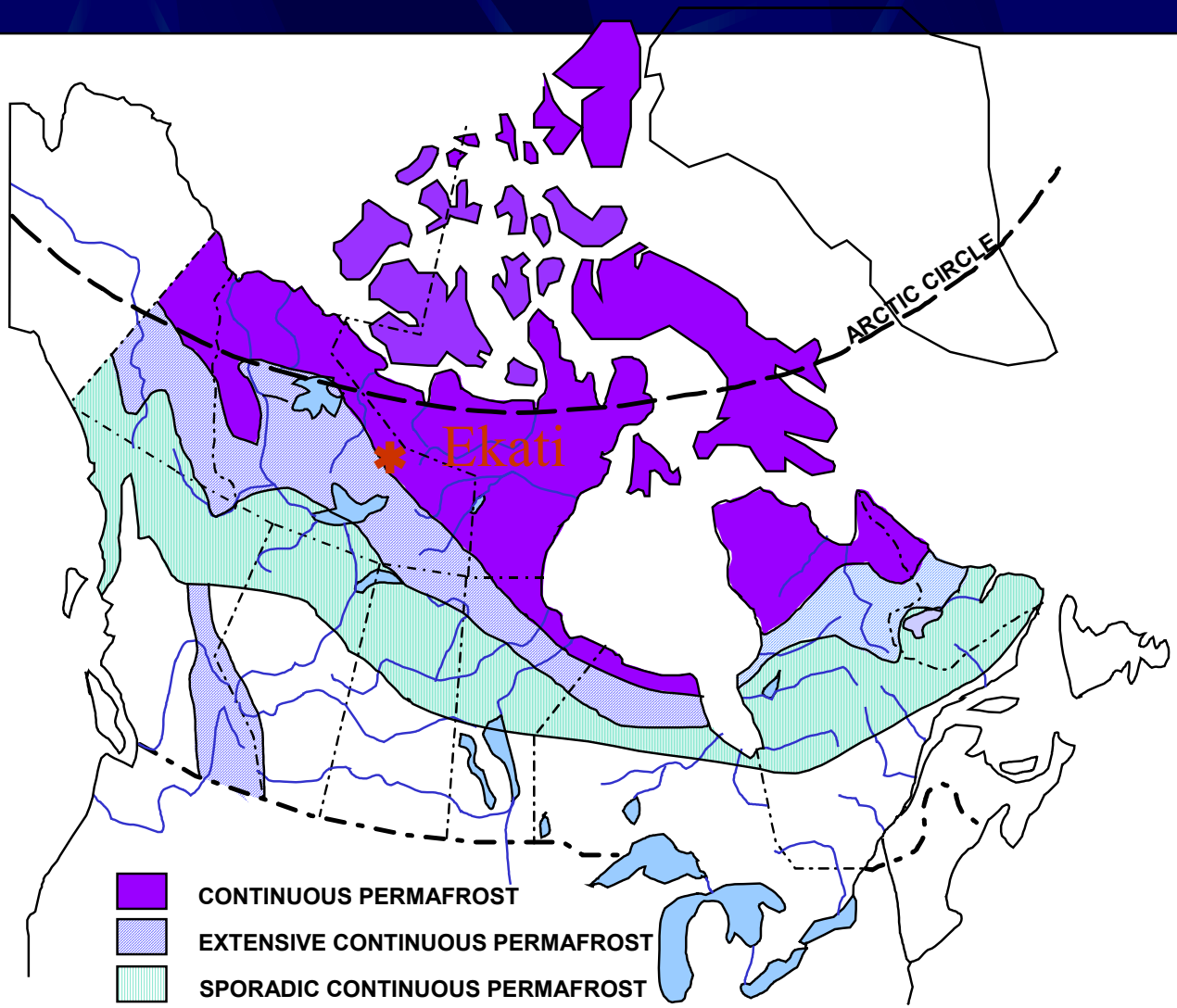
Igor Holubec

IEMA Workshop, Yellowknife NT

Feb 14, 2006

Considerations in Cold Climate

- Permafrost
- Climate Warming
- Difficult Access
- Long-term
- Ekati
  - Climate warming
  - Dams & tailings
  - Waste Rock
  - Access



PERMAFROST ACROSS CANADA

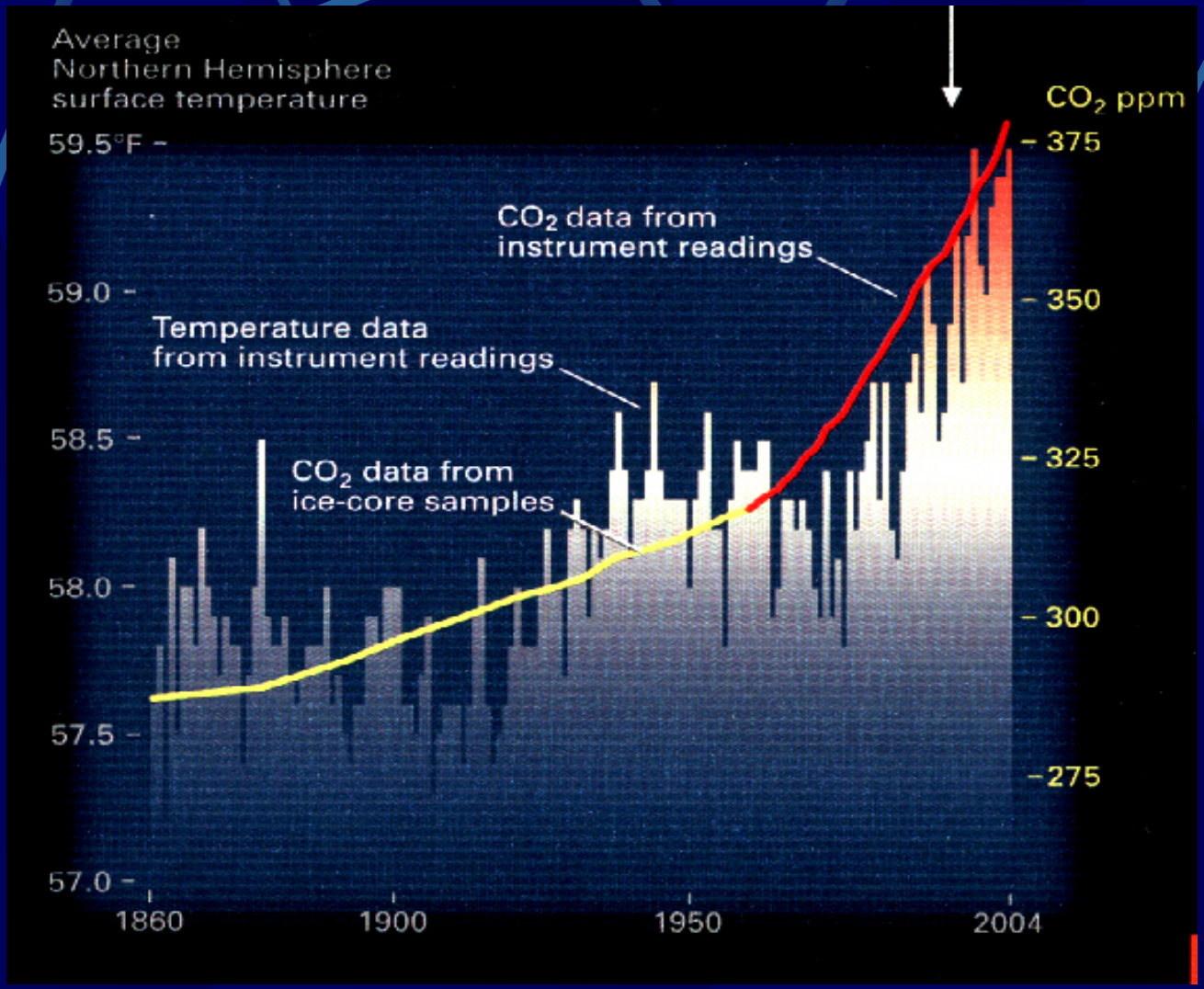
Permafrost

- Ground temperature below 0°C
- Ground/rock normally have ice
- Higher strength & practically impermeable
- Design considerable more difficult

Ice in Permafrost

Igor Holubec

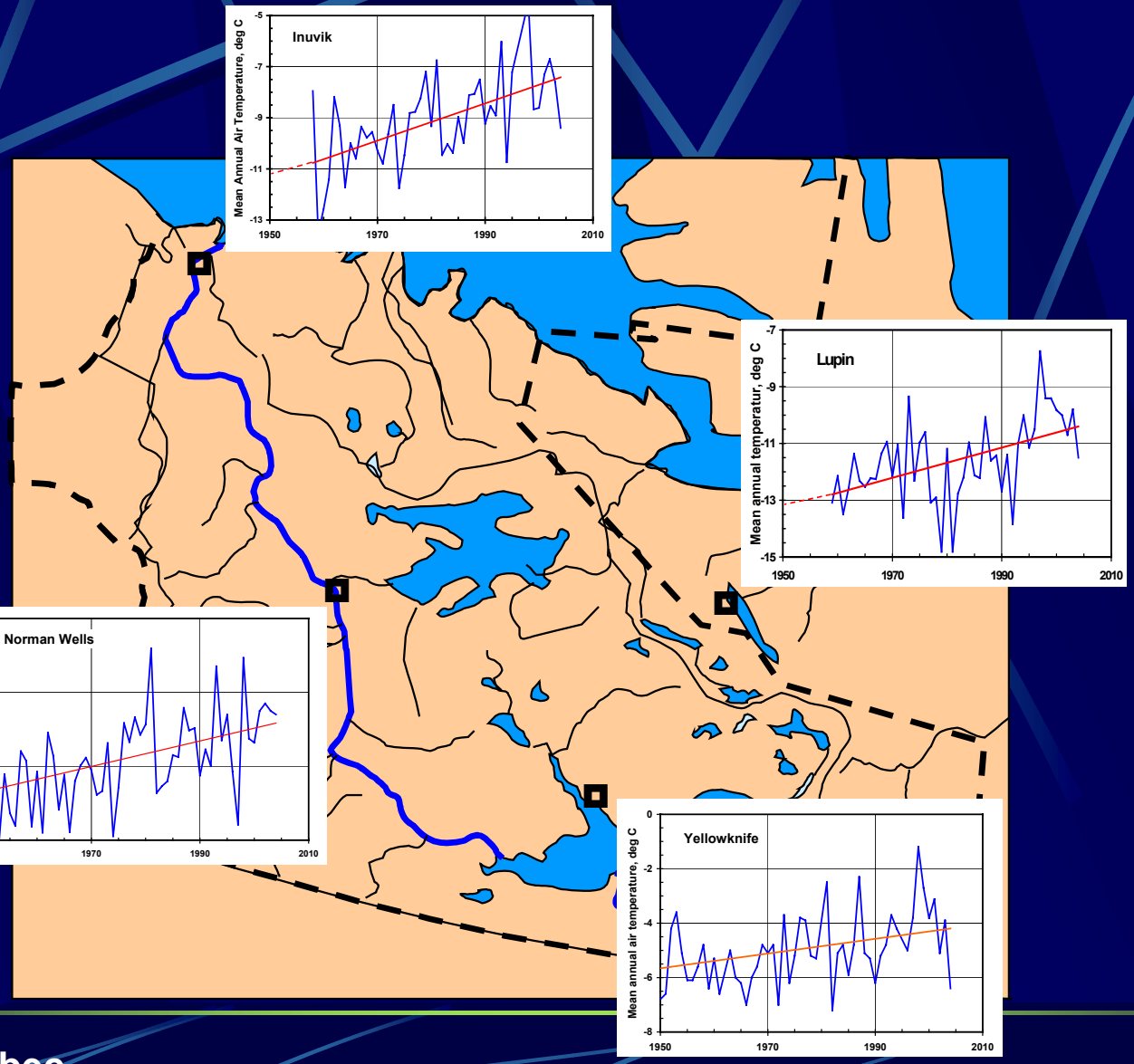
Global Warming



Global Warming

- Alps glaciers receded by 75%
- All oceans are warming
- Antarctica – Air = 7 to 11°C/100 years
- Both air and ground in NT is warming
- Warming in NT not uniform

MAAT Rise in NT



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MAAT Rise in NT

Locations	MAAT In 2005[a]	MAGT In 2005[b]	Avg. air temperature warming rate	Years to reach 0ºC
	ºC	ºC	ºC/100 yrs	MAGT
Yellowknife	-4.3	0.1	3.7	0
Normal Wells	-4.8	-0.4	4.1	10
Inuvik	-7.3	-2.9	7.6	38
Lupin	-9.6	5.2	8.2	63

Permafrost thaw may:

- create earth slope instabilities
- release suspended solids into rivers and lakes
- differential settlement may cause to fail roads, dams and plants/buildings
- lead to seepage below dams, tailings and landfill storage areas
- Eliminate permafrost encapsulation reclamation option

Access to Arctic

Igor Holubec

Long-term?

- Regulatory guidance is missing
- Defining Long-term, examples:
  - Newmont Australia specifies physical stability for 200 to 500 year time frame
  - US Forest Service goal is 1000 years
  - Canadian Nuclear Safety Commission requires a period of 10,000 years

Review Comments from NWT Guidelines (Chouinard 2005)

- *"I hope you look after the land good and keep it clean …. Because we are going to be depending on it for future generations". (KIA Elder).*
- *"Climate warming will thaw the permafrost in relatively shot time frame in NWT and while access to most of the NWT mines is costly, it may become prohibitively costly when winter and ice roads are not available due to climate warming".*
- *"Be careful not to be too definitive on climate change, there are many uncertainties associated with the predictions*

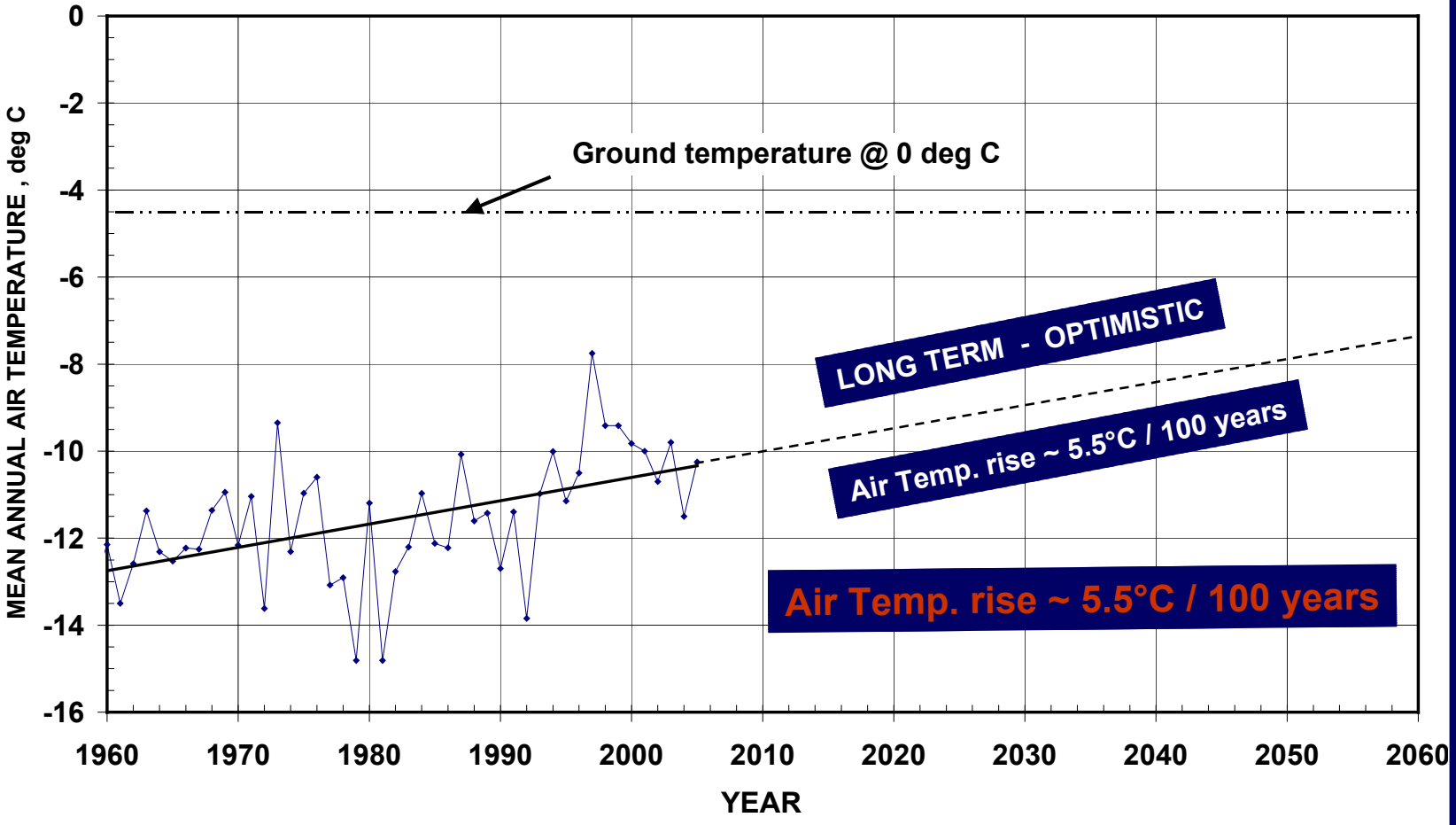
PRECAUTIONARY PRINCIPLE
(UN Principle 1992)

- *In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.*
- Upheld by Supreme Court of Canada

Ekati Conditions

- Climate warming
- Dams & tailings
- Waste Rock
- Access

Lupin, Climate Warming



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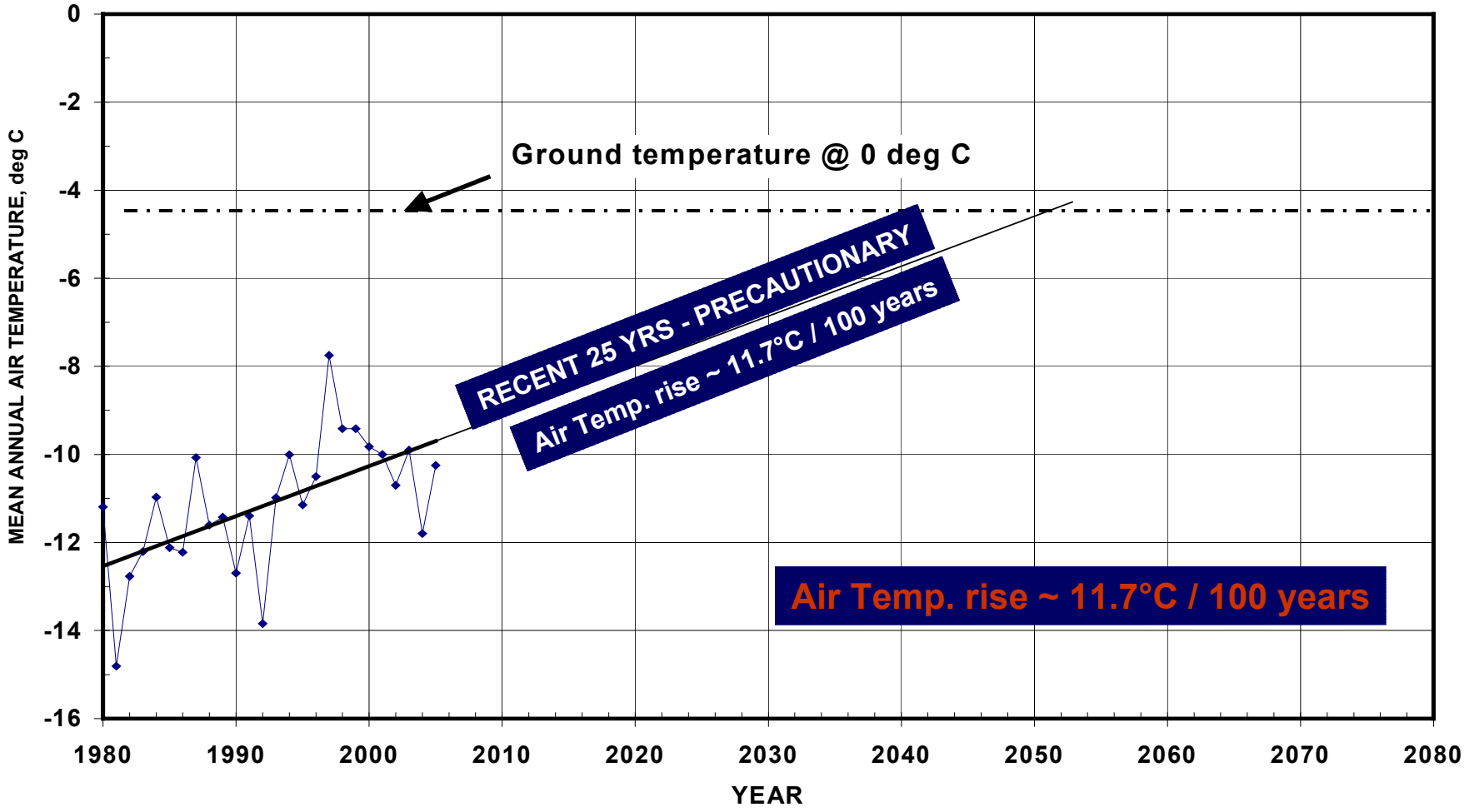
Lupin, Climate Warming



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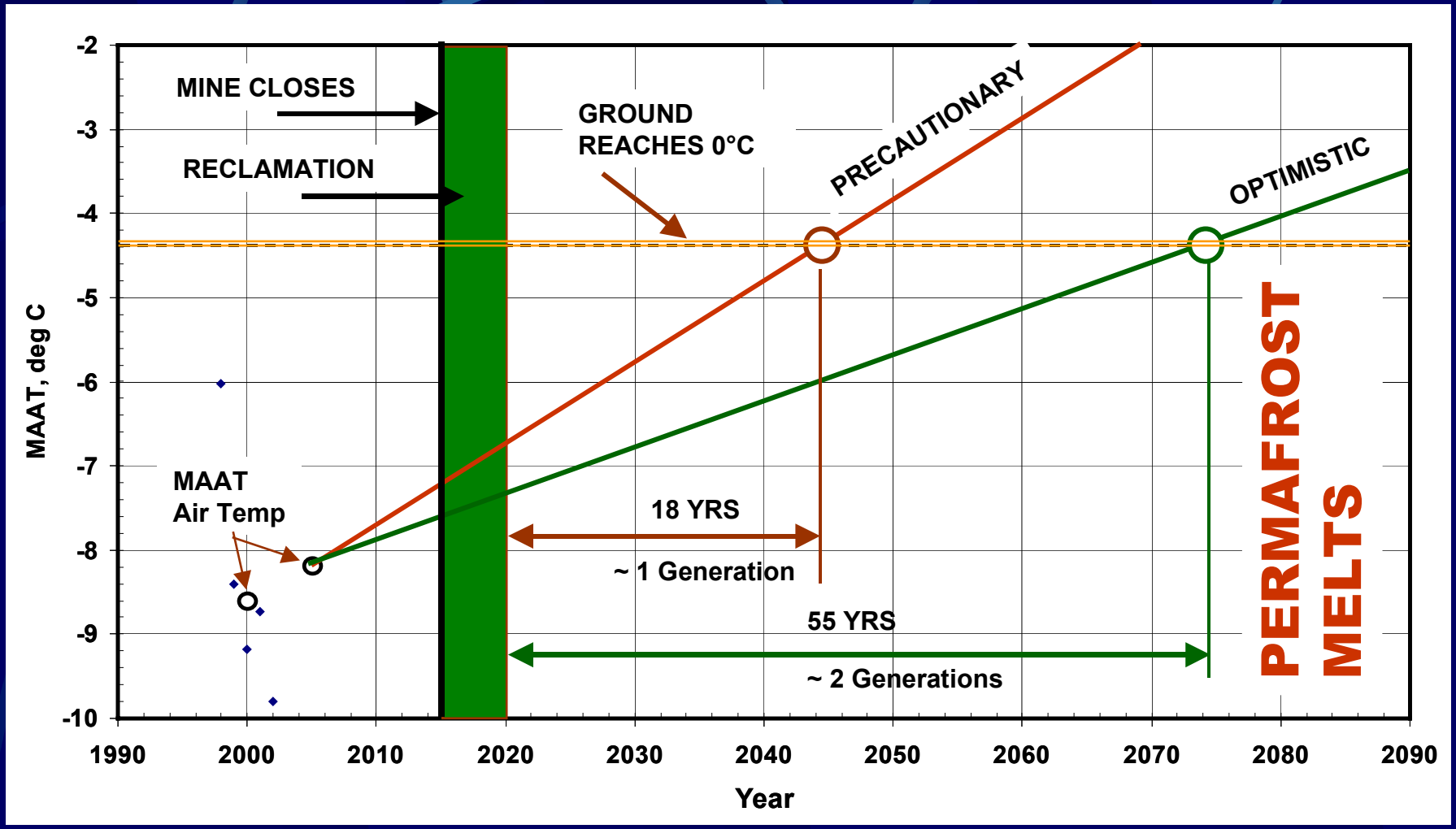
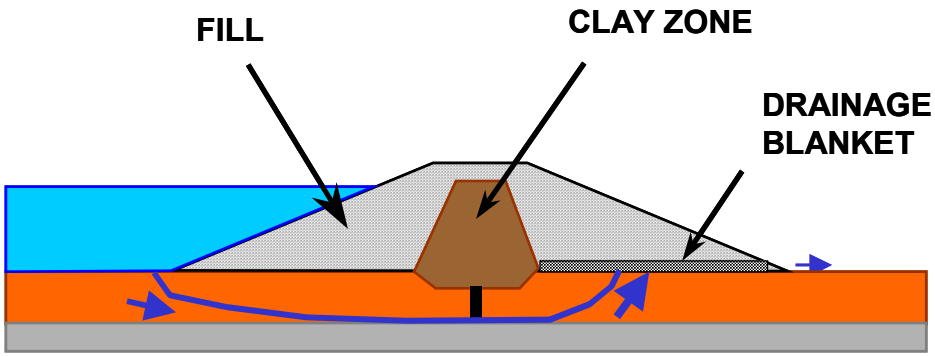
Ekati Model


MINE CLOSES
RECLAMATION
GROUND
REACHES 0°C
PRECAUTIONARY
OPTIMISTIC
MAAT
Air Temp
18 YRS
~ 1 Generation
55 YRS
~ 2 Generations
PERMAFROST
MELTS
MAAT, deg C
-2
-3
-4
-5
-6
-7
-8
-9
-10
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
Year

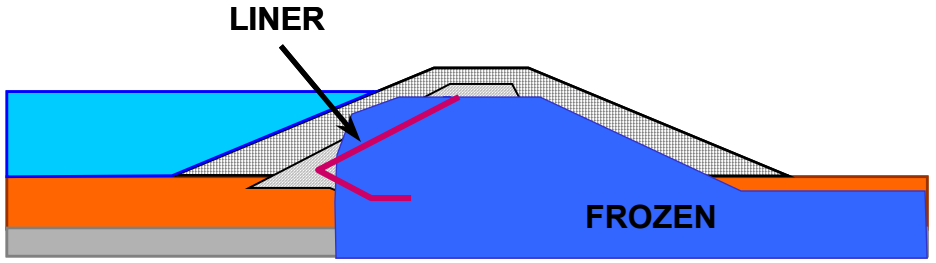
DAM CONCEPTS

- Dam impounds at least 30,000m^3 water
- Design includes physical stability and hydrology
- Has to be maintained and inspected regularly

DAM DESIGN CONCEPTS



WARM REGIONS

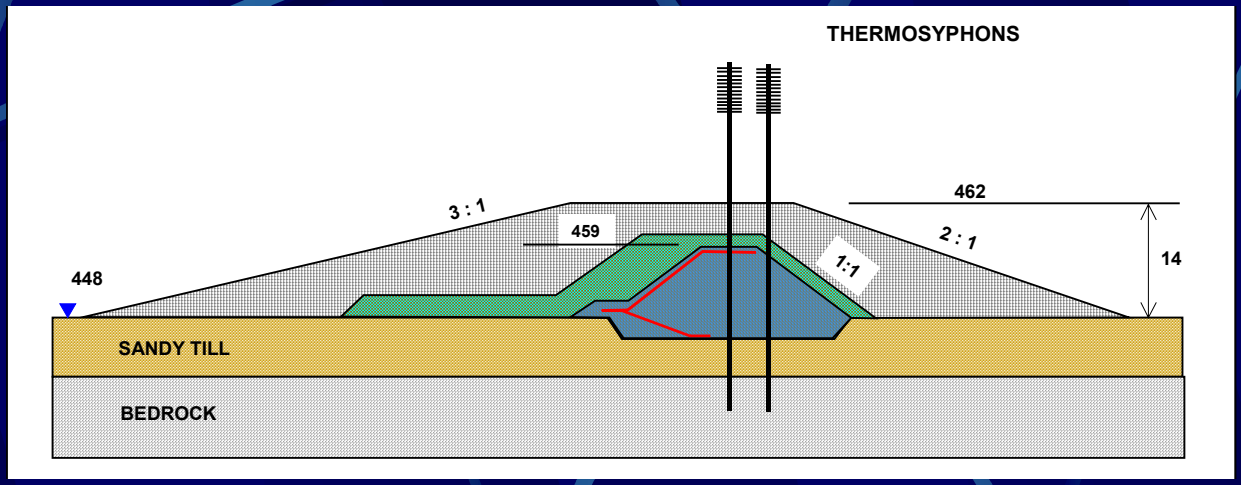


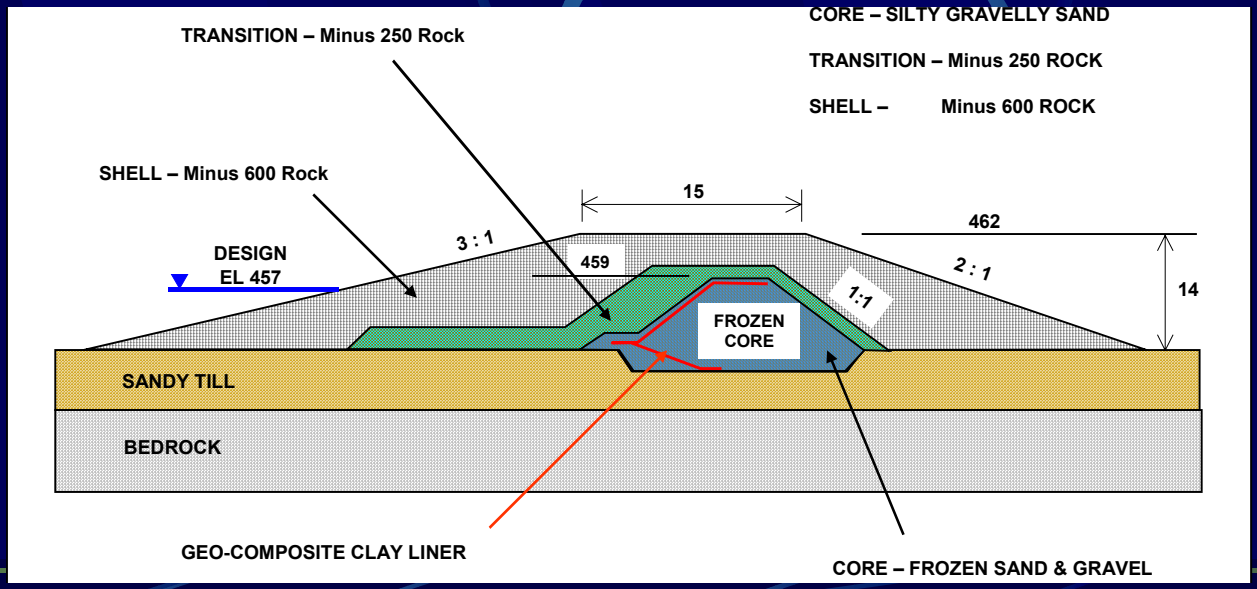
PERMAFROST REGIONS

Effect of Climate Warming on Dams in Permafrost

- Most dams in permafrost are not designed for thawed foundations
  - Unpredictable seepage with dam having no control measures
  - Differential settlement of dam may lead to cracking and wash-out
- Dams after project closure will require maintenance & inspection in perpetuity
  - Costs for above will be high

OUTLET DAM, EKATI





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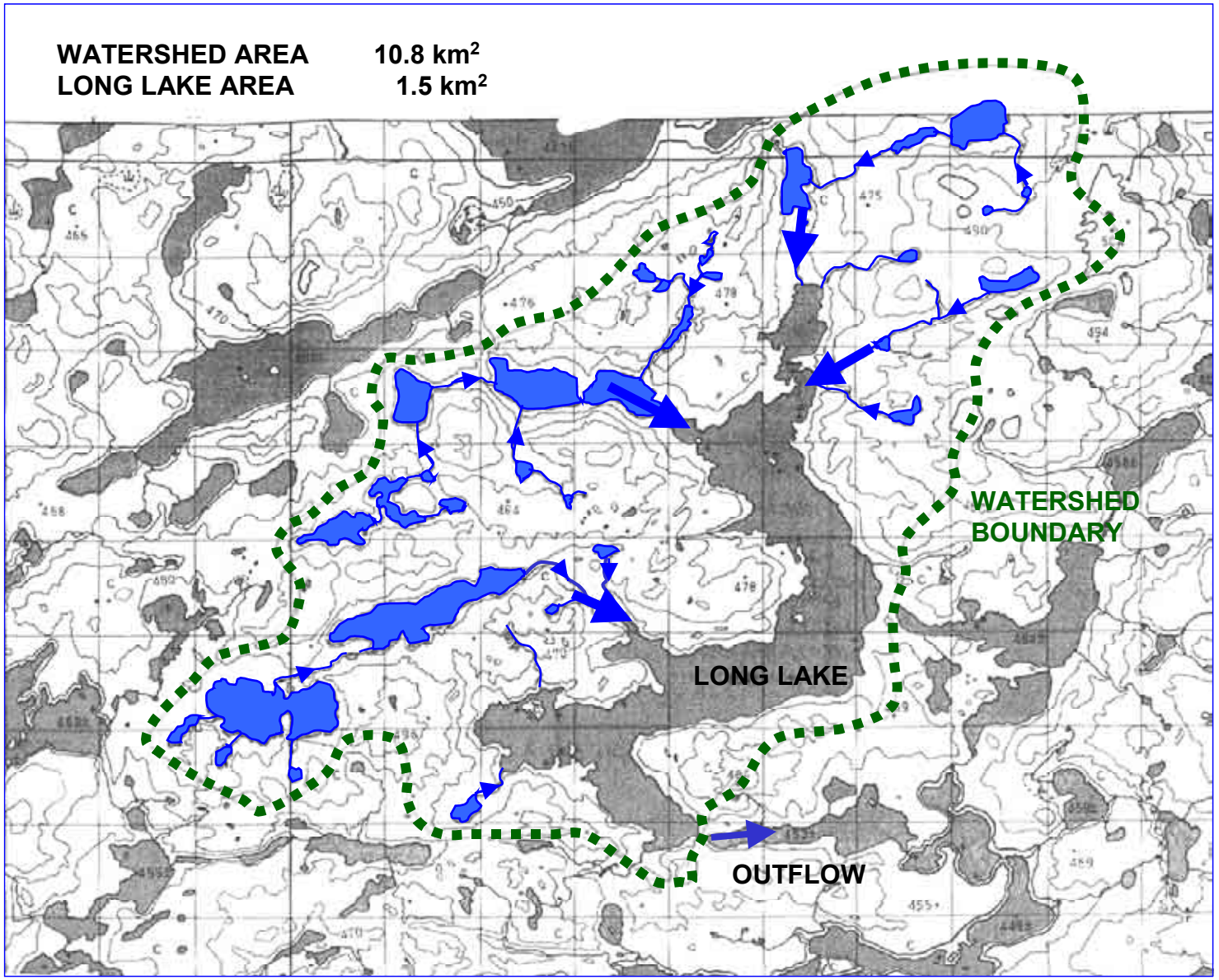
After climate warming

- Maintain dam
  - Need to modify to handle seepage & differential settlement
  - Continuous maintenance & inspection
- Eliminate dams on closure
  - Drain and breach
  - Or convert tailings dam to earth buttress
  - Proposed Lupin closure plan

EKATI TAILINGS AREA

- Constructed in Long Lake contained by large watershed
- Tailings are greatly erosion prone and water quality of tailings pore is unknown
- Drainage path is may revert through filled Long Lake



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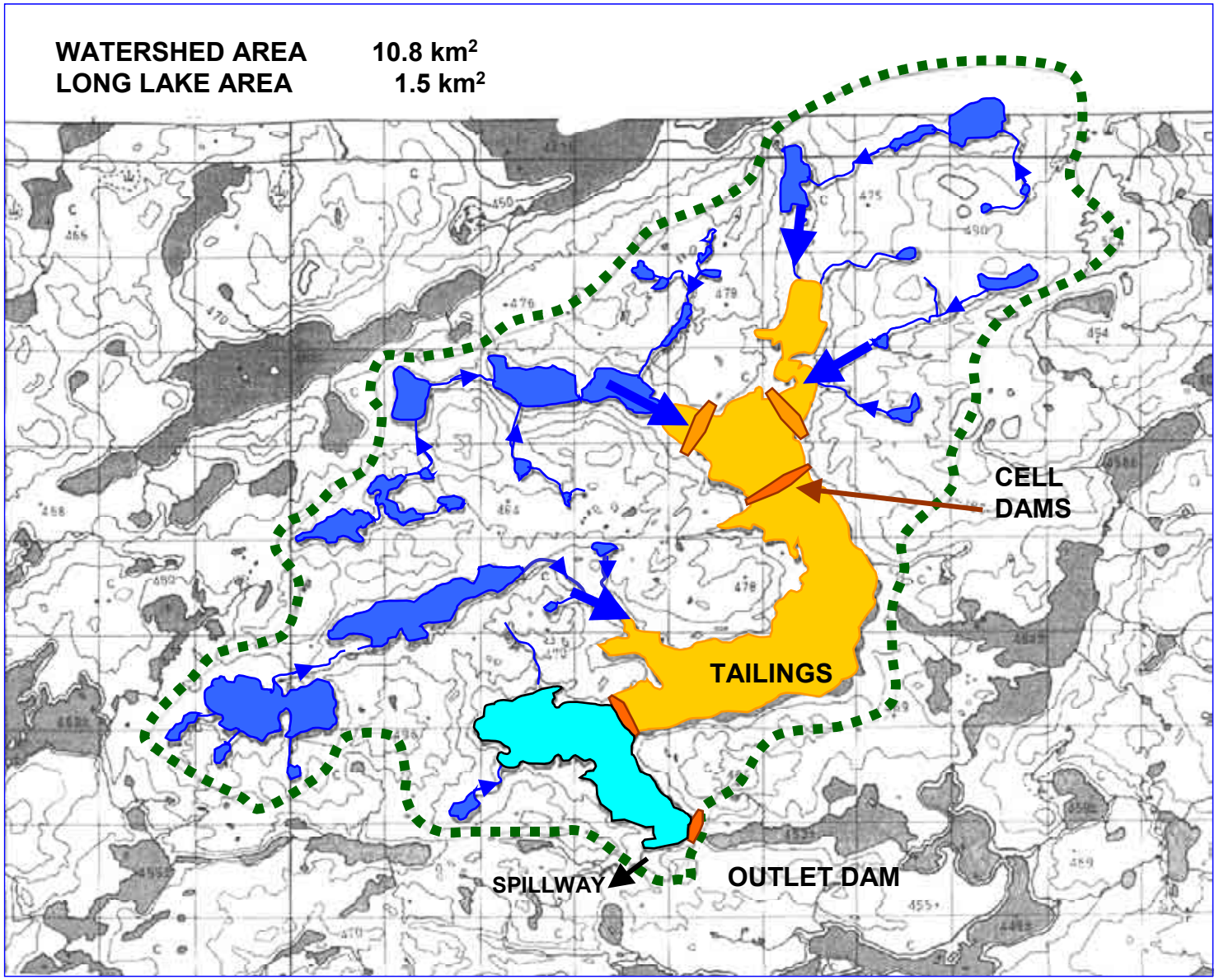
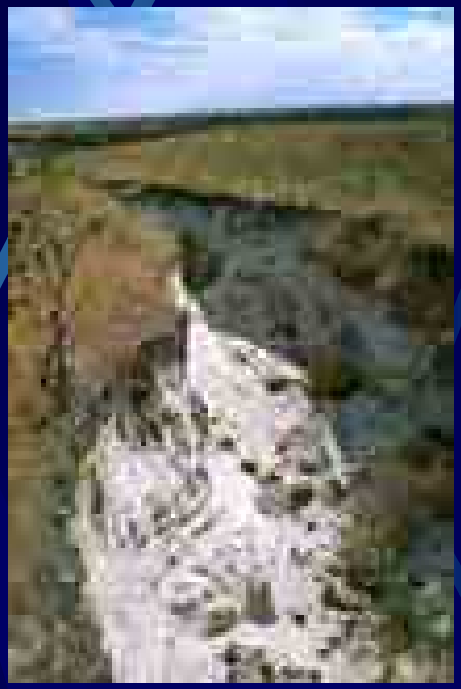

WATERSHED AREA 10.8 km²
LONG LAKE AREA 1.5 km²
CELL DAMS
TAILINGS
SPILLWAY
OUTLET DAM

Tailings surface erosion important issue

SURFACE



GULLY

Dam buttress erosion

Major Closure Issues

- Long-term closure definition
- Redirecting old drainage path through Long lake
- Erosion control of tailings surface
- Differential settlement of tailings surface due to melting of entrapped ice
- Dams
  - Diversion, Long Lake & tailings buttresses
- Mine Rock Dumps
- Site access after closure

Long-term closure definitions

- Project closure & completion reclamation (2015 & 2020?)
- Detailed monitoring (5 years?)
- Walk-away closure design – confirmation monitoring for 20 years
- Based on permafrost encapsulation & leaving dams & diversion channel
  - Monitoring & maintenance in perpetuity

Redirecting old drainage path through Long lake

- Stability of drainage has to consider 20 years and beyond
- On long-term basis original drainage will try to return to Long Lake
- How will upstream drainage be handled?
- How will surface drainage from large tailings surfaces be handled?

Erosion control of tailings surface

- Tailings highly erodable
- Vegetation not sufficient for large surface drainage areas
- May need to: divide tailings areas, armour cover and direct in erosion proof channels

Differential settlement of tailings surface due to melting of entrapped ice

- climate warming will cause entrapped ice to melt and tailings surface to settle differentially
- Will effect drainage and erosion
- Issues: cover design, time for problems and how to resolve these.

Dams
Diversion, Long Lake & tailings buttresses

- Different closure treatments
- Diversion
  - Water quality
- Long Lake
  - Have to breach
- Tailings buttress
  - Long-term stability and erosion

Mine Rock Dumps

- What is the geochemistry of rock types
- Permafrost encapsulation will not work even with air circulation rock zones
- Rock dump landscape

Site Access

- How will long-term access be provided, if needed

Closure Design

- Many issues have to be addressed
- Important to define the closure criteria
- Regulatory guidelines are needed


Thaw will ruin their ride