PERMAFROST-SUPPORTED LINEAR INFRASTRUCTURE RISK ANALYSIS SOFTWARE

Permafrost engineering research program
Programme de recherche en ingénierie du pergélisol

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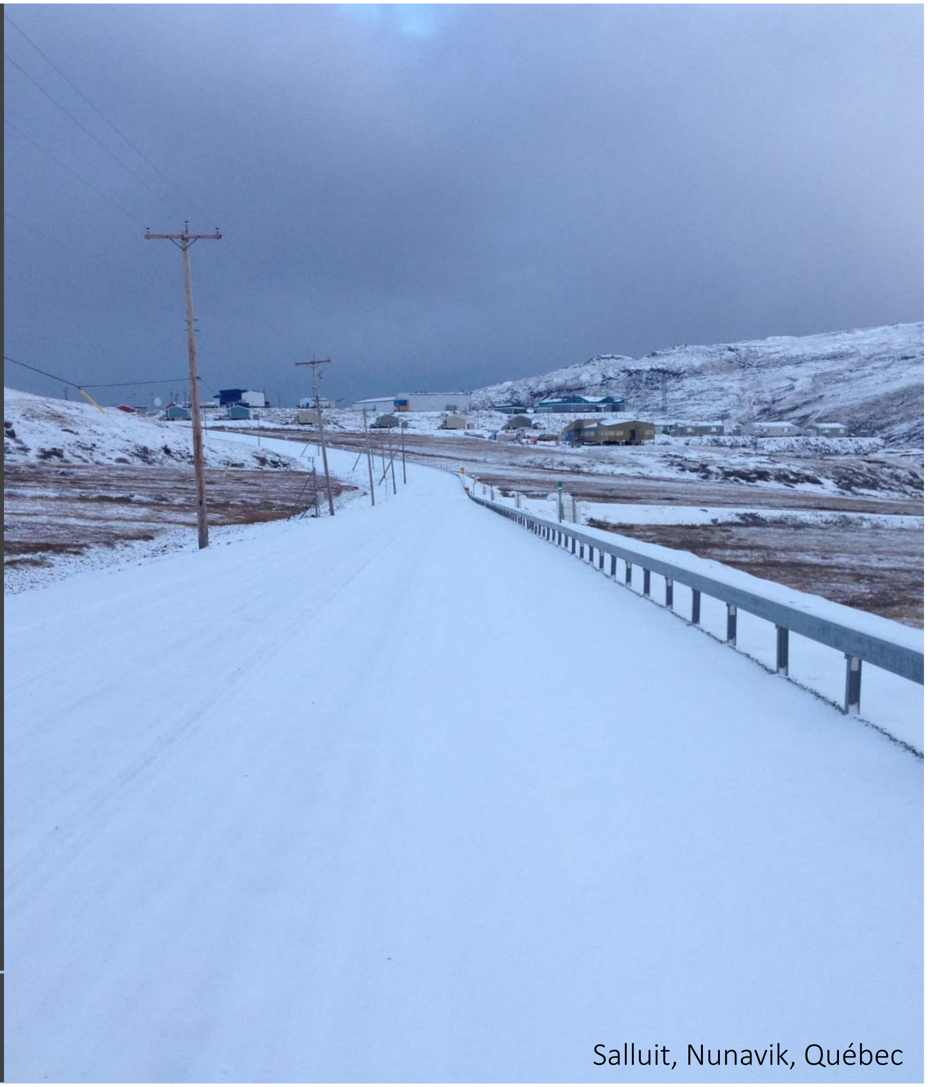
Arquluk Symposium February 2018 Whitehorse, YT



Salluit, Nunavik, Québec

PROJECT OBJECTIVE

To **create** a quantitative risk analysis **methodology** and **tool** for embankment-supported infrastructure on permafrost **utilizing** site conditions, physical and/or empirical engineering calculations and consequences.

DEFINITIONS AND TERMINOLOGY

- **Danger**

  an event or process causing damage
- **Hazard**

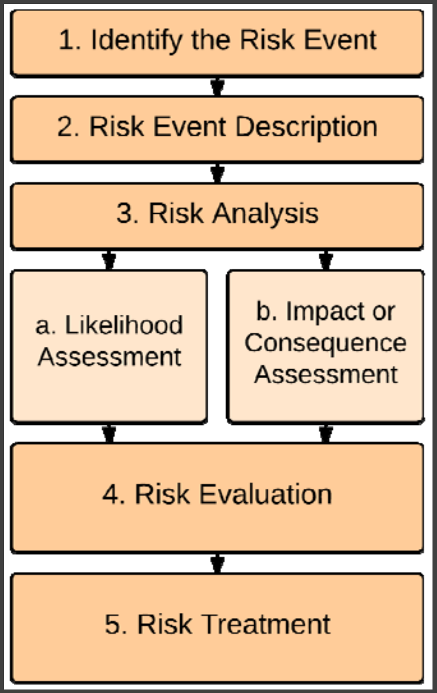
  probability of a danger's occurrence within a time frame
- **Random Variable**

  uncertain input parameter
- **Consequence**

  cost of repair & damage from a danger's occurrence

ST ANDREWS
CHURCH + 1901.

RISK ANALYSIS PROCESS


1. Identify the Risk Event
2. Risk Event Description
3. Risk Analysis
a. Likelihood Assessment
b. Impact or Consequence Assessment
4. Risk Evaluation
5. Risk Treatment

Similar to descriptions from Public Safety Canada 2011

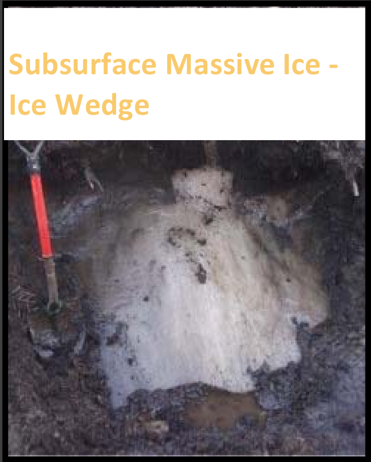
R = H x C x V

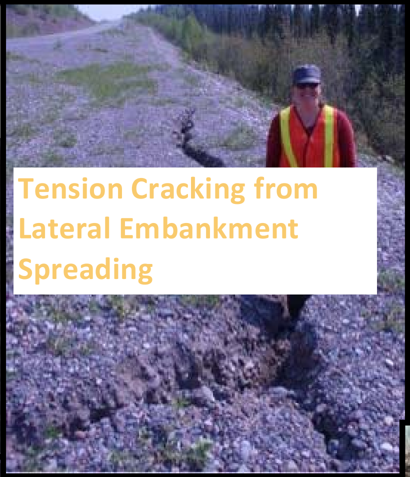
- R = Risk
- H = Hazard
- C = Consequence
- V = Vulnerability

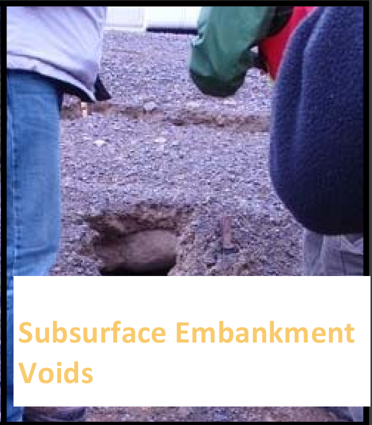
Quantitative

- H from past experience or uncertainty calculation
- C calculated from expected damage
- V function of H severity and C

HAZARD IDENTIFICATION & DESCRIPTION


Subsurface Massive Ice - Ice Wedge


Tension Cracking from Lateral Embankment Spreading

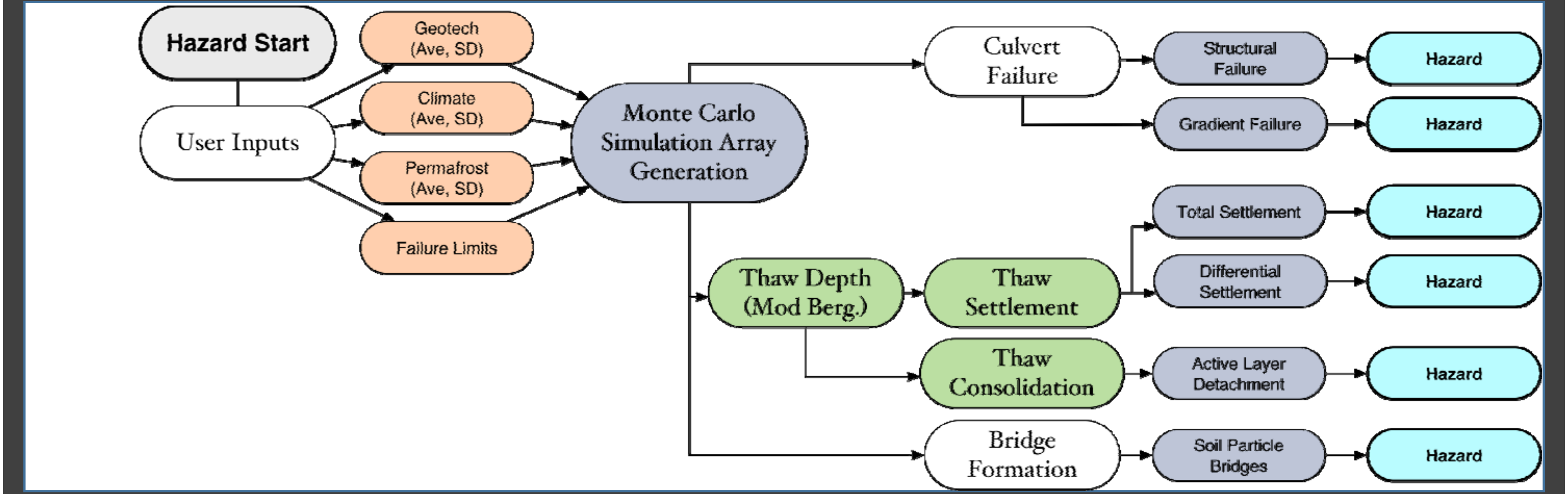

Subsurface Embankment Voids

Localized Thaw Settlement

Thermal Erosion Induced Karsting

Drainage Ditch Thermal Erosion

PROGRAM DESIGN – HAZARD ANALYSIS PROCESS

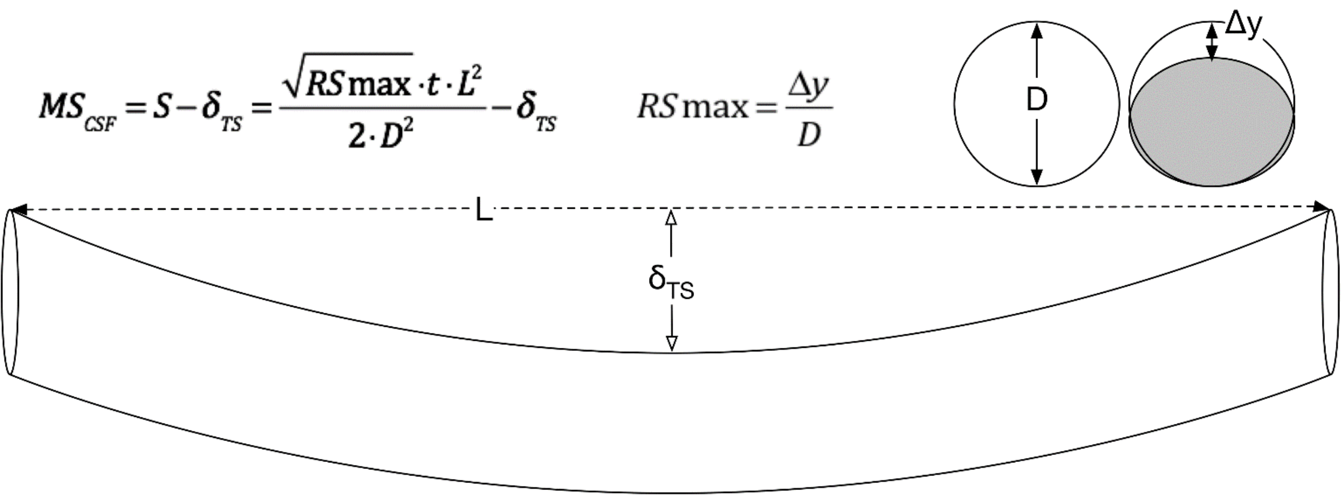

Hazard Start
User Inputs
Geotech (Ave, SD)
Climate (Ave, SD)
Permafrost (Ave, SD)
Failure Limits
Monte Carlo Simulation Array Generation
Culvert Failure
Structural Failure
Gradient Failure
Thaw Depth (Mod Berg.)
Thaw Settlement
Total Settlement
Differential Settlement
Thaw Consolidation
Active Layer Detachment
Bridge Formation
Soil Particle Bridges
Hazard
Hazard
Hazard
Hazard
Hazard
Hazard

HAZARD DEFINITIONS – CULVERT FAILURE

Gradient Failure

- FS comparing current and allowable culvert slopes
- Assumes settlement occurs only at the culvert entrance

HAZARD DEFINITIONS – CULVERT FAILURE



$$MS_{CSF} = S - \delta_{TS} = \frac{\sqrt{RS\max} \cdot t \cdot L^2}{2 \cdot D^2} - \delta_{TS} \qquad RS\max = \frac{\Delta y}{D}$$

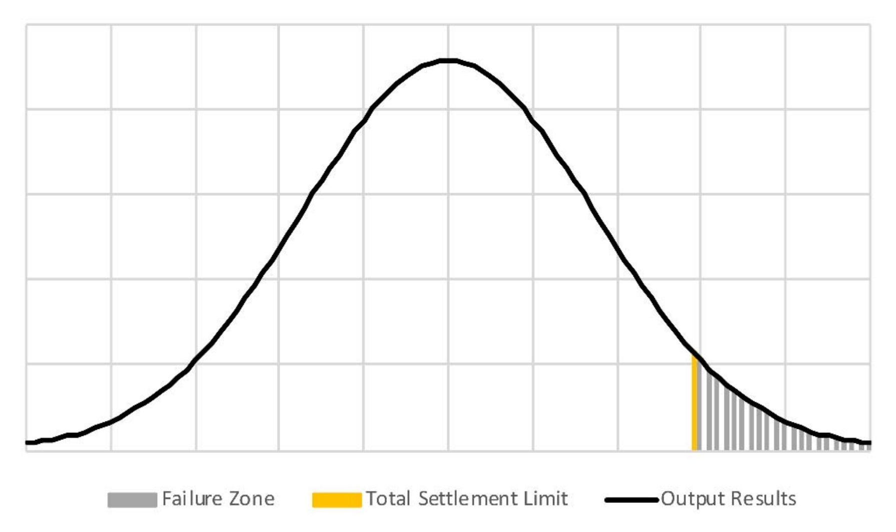
Structural Failure

- MS comparing settlement and ring strain at failure
- Assumes settlement occurs only at the culvert centerline

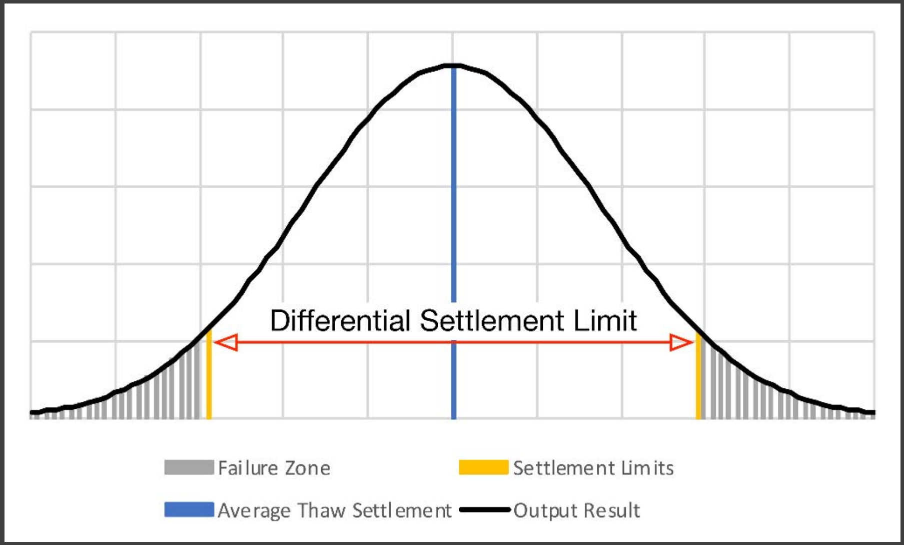
HAZARD DEFINITIONS – THAW SETTLEMENT

Thaw Settlement

- Modified Berggren – 1D thaw depth analysis
- Luscher & Afifi (1973) thaw strain correlations



Total Thaw Settlement Hazard

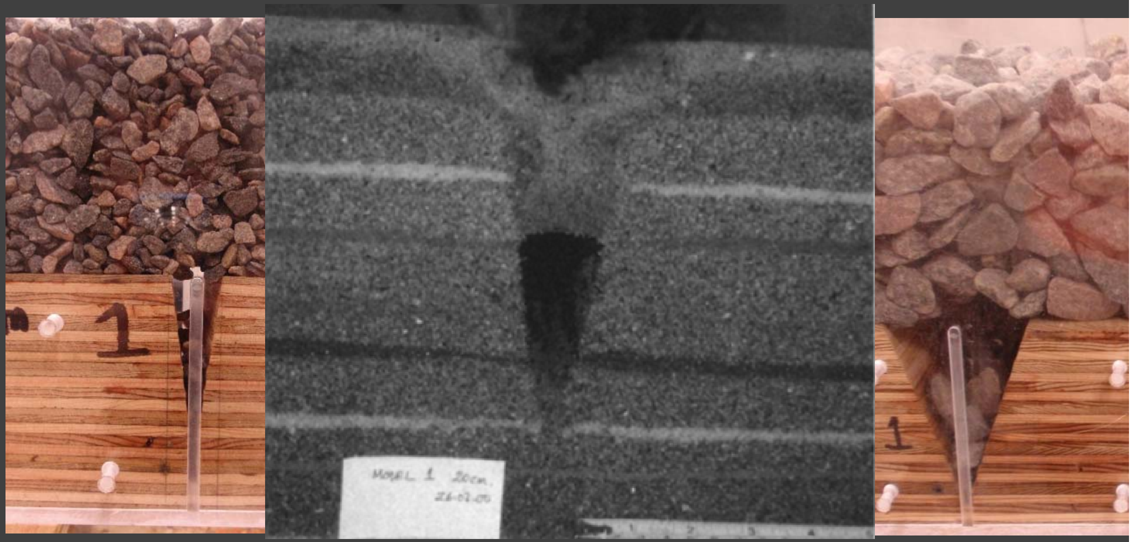


Differential Thaw Settlement Hazard

HAZARD DEFINITIONS – OTHER HAZARDS

Particle Bridge Formation

- Common bridging ratios (width/particle size) range from 4 to 9.5
  - Confirmed with lab testing
  - Bridging ratio correlated with probability of occurrence
- Bridging may occur for large-grained fill embankments



HAZARD DEFINITIONS – OTHER HAZARDS

Active Layer Detachment Slides

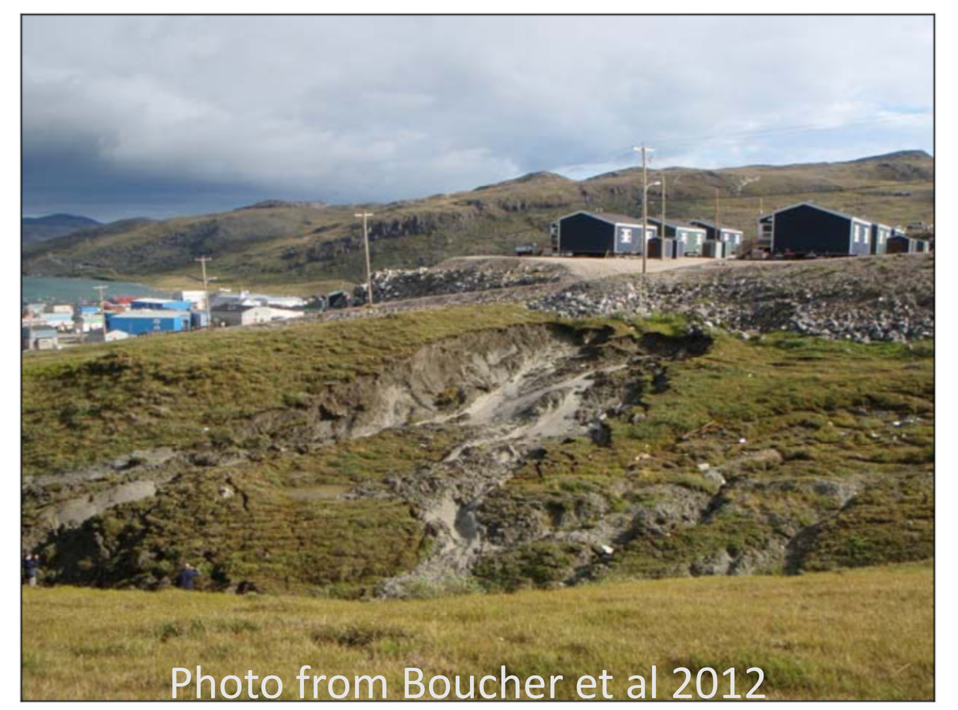
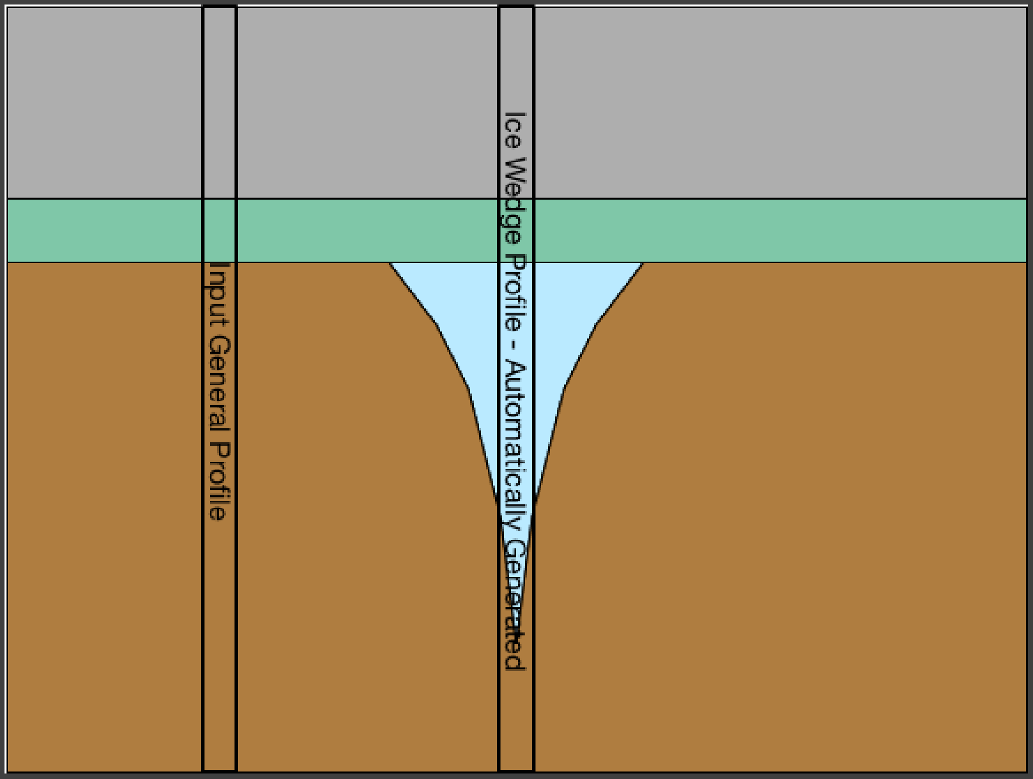


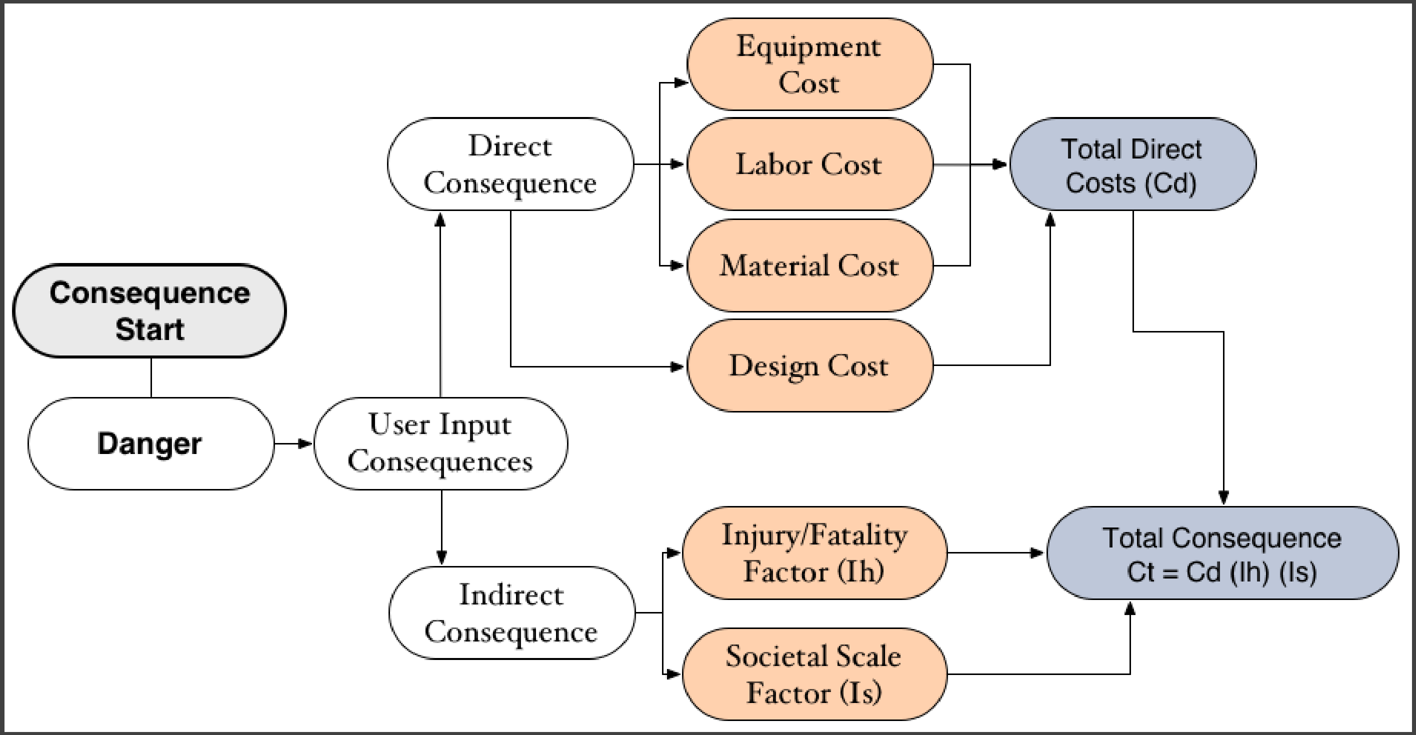
Photo from Boucher et al 2012

HAZARD DEFINITIONS – ICE WEDGE OPTION

- Program Generates Profile
- Assumes Ice
  - Below user input depth
  - 100% thaw strain
  - Hazards are not compared to the standard analyses


Input General Profile
Ice Wedge Profile - Automatically Generated

PROGRAMMING DESIGN - CONSEQUENCES


Consequence Start
Danger
User Input Consequences
Direct Consequence
Indirect Consequence
Equipment Cost
Labor Cost
Material Cost
Design Cost
Total Direct Costs (Cd)
Injury/Fatality Factor (Ih)
Societal Scale Factor (Is)
Total Consequence Ct = Cd (Ih) (Is)

EXCEL SPREADSHEET TOOL

- Monte Carlo Simulation – User Choice
  - # of simulations
  - Dangers to be analyzed
  - Hazard limits
  - Thermal conductivity calculation method (Côté and Konrad 2005 or Kersten 1949)

- PDFs
  - Moisture Content (Normal or Lognormal)
  - Normal distribution for all remaining parameters

- VBA Macro in Excel
  - Master Input sheet
  - Individual sheets for each analysis section

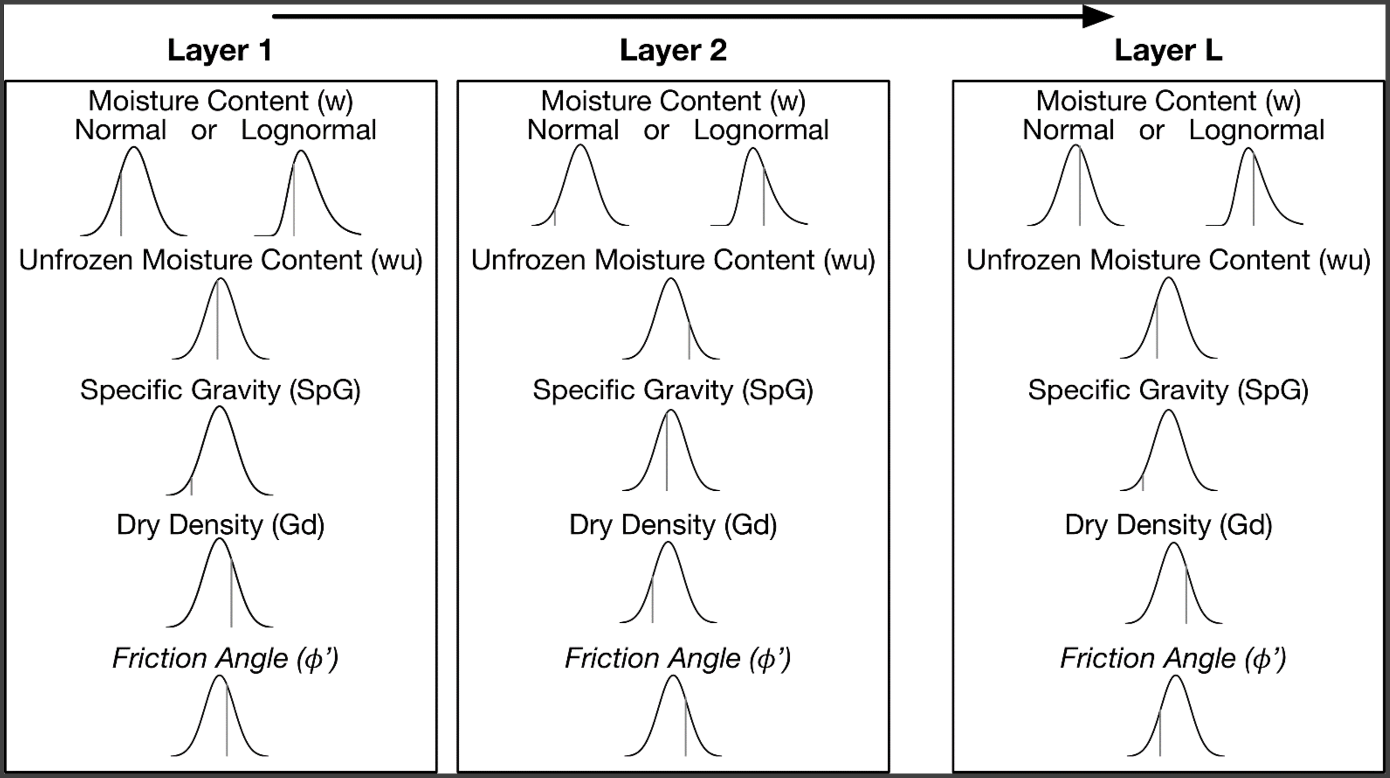
Input Parameters

Climate/Surface - ATI, n, Permafrost Temp, ts

Area – AL Depth, IW Depth, Slope

Soil (each layer) - w, w_u, γ_d, SpG, k_s

MONTE CARLO CALCULATION PROCESS



Layer 1

Moisture Content (w)
Normal or Lognormal

Unfrozen Moisture Content (wu)

Specific Gravity (SpG)

Dry Density (Gd)

Friction Angle (ϕ')

Layer 2

Moisture Content (w)
Normal or Lognormal

Unfrozen Moisture Content (wu)

Specific Gravity (SpG)

Dry Density (Gd)

Friction Angle (ϕ')

Layer L

Moisture Content (w)
Normal or Lognormal

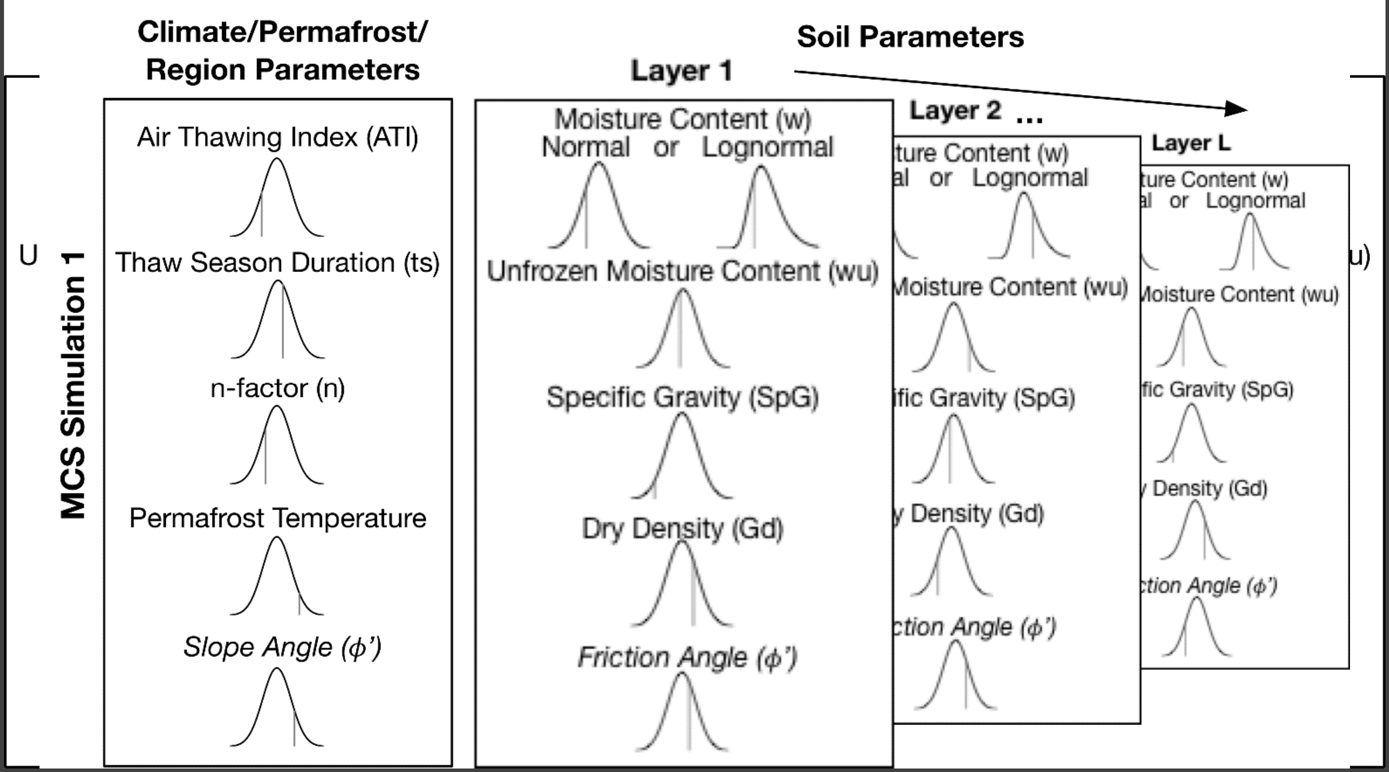
Unfrozen Moisture Content (wu)

Specific Gravity (SpG)

Dry Density (Gd)

Friction Angle (ϕ')

MONTE CARLO CALCULATION PROCESS


Climate/Permafrost/
Region Parameters
Soil Parameters
Layer 1
Layer 2 ...
Layer L
U
MCS Simulation 1
u)
Air Thawing Index (ATI)
Thaw Season Duration (ts)
n-factor (n)
Permafrost Temperature
Slope Angle (ϕ')
Moisture Content (w)
Normal or Lognormal
Unfrozen Moisture Content (wu)
Specific Gravity (SpG)
Dry Density (Gd)
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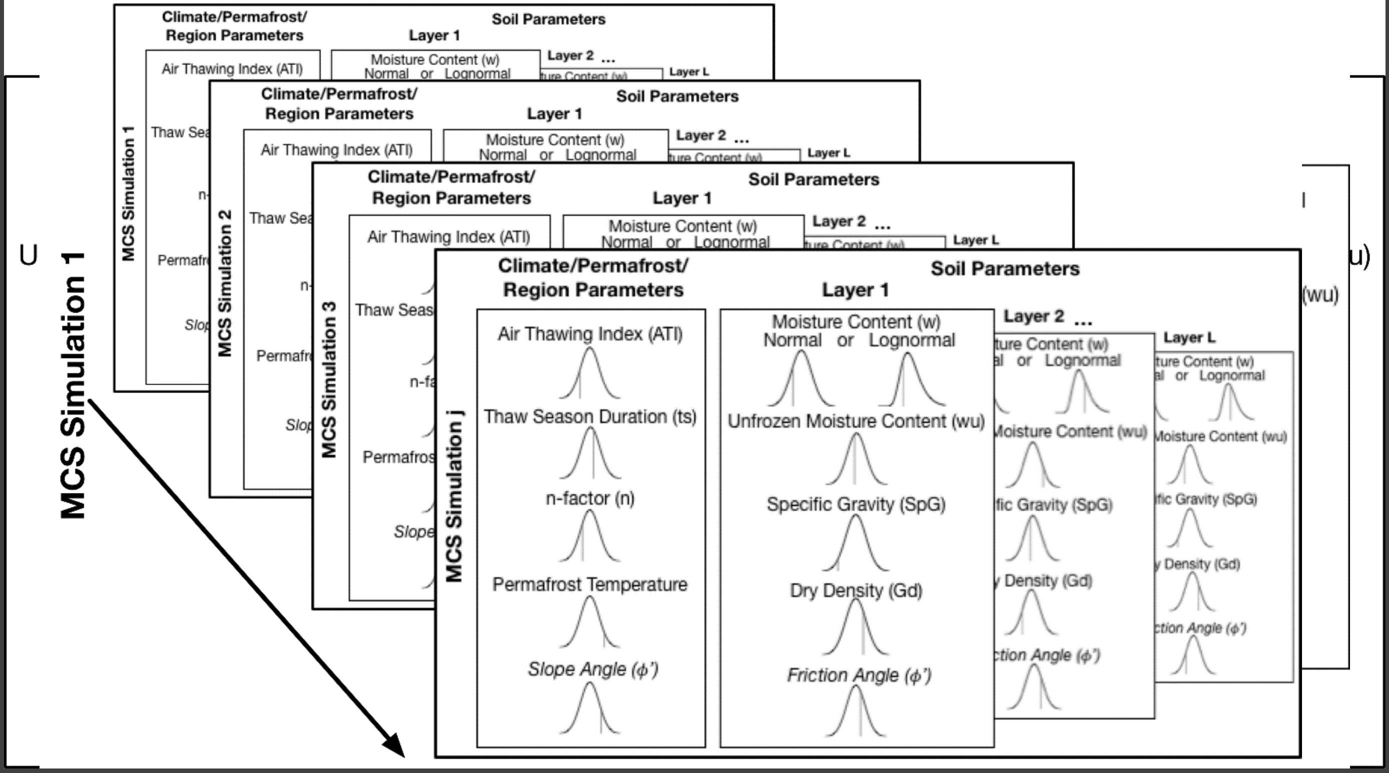
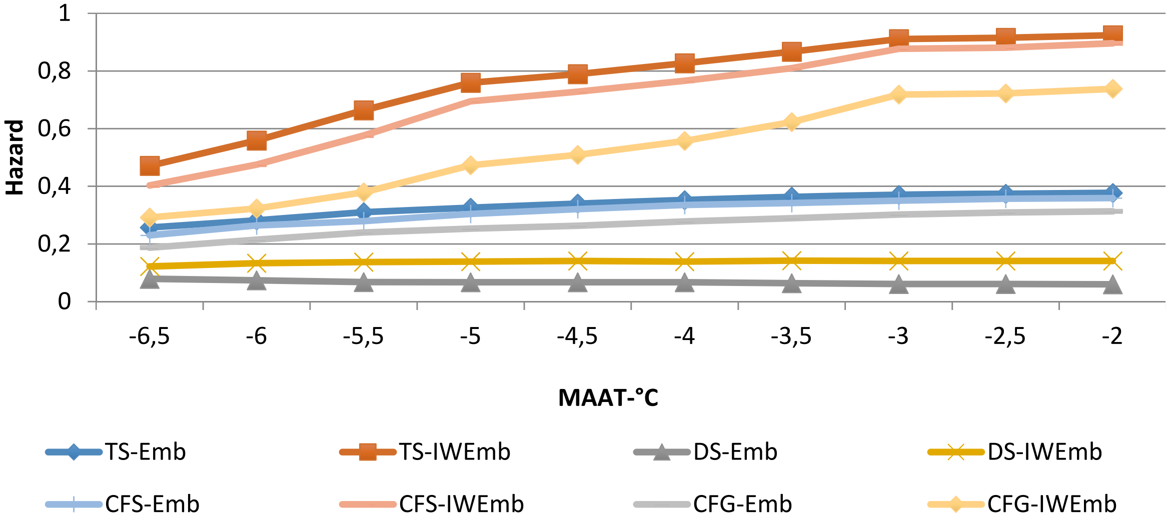
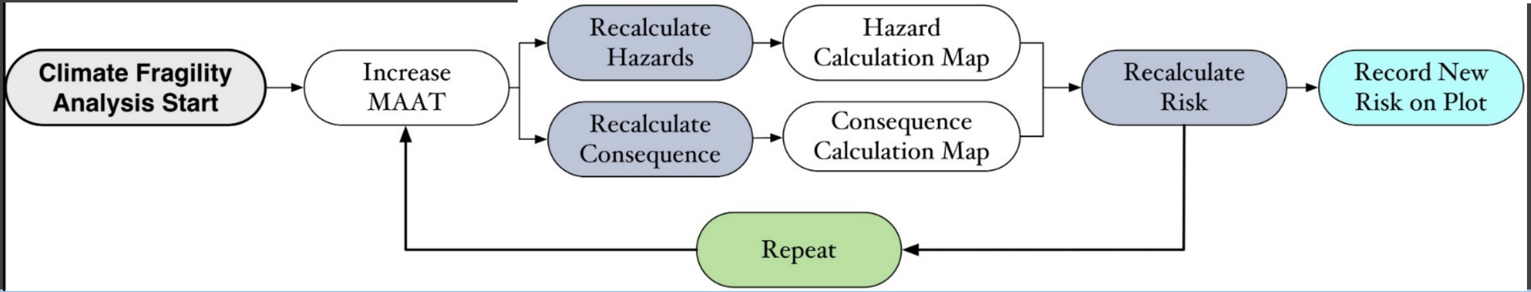
MONTE CARLO CALCULATION PROCESS


MCS Simulation 1
MCS Simulation 2
MCS Simulation 3
MCS Simulation j
Climate/Permafrost/ Region Parameters
Soil Parameters
Layer 1
Layer 2 …
Layer L
Air Thawing Index (ATI)
Thaw Season Duration (ts)
n-factor (n)
Permafrost Temperature
Slope Angle (ϕ')
Moisture Content (w)
Normal or Lognormal
Unfrozen Moisture Content (wu)
Specific Gravity (SpG)
Dry Density (Gd)
Friction Angle (ϕ')

CLIMATE WARMING FRAGILITY ASSESSMENT

- Sinusoidal Annual Temperature Model
- Increase Mean Annual Air Temperature (MAAT)
  - Thawing index
  - Thaw season duration





Climate Fragility Analysis Start

Increase MAAT

Recalculate Hazards

Recalculate Consequence

Hazard Calculation Map

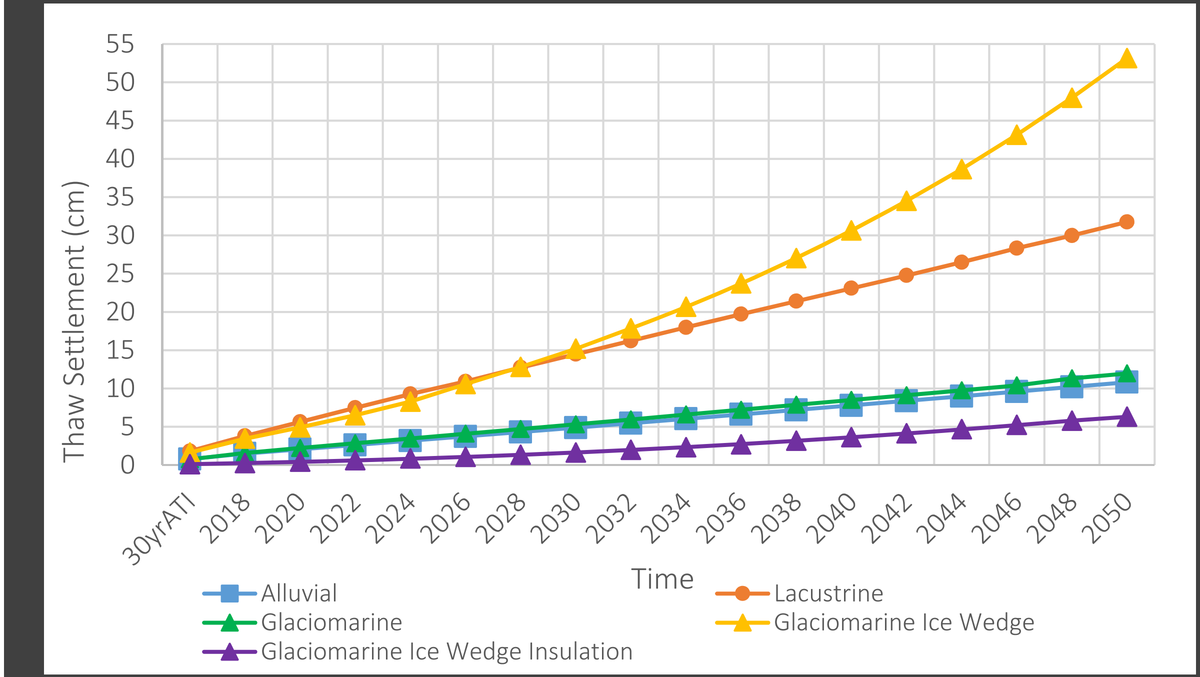
Consequence Calculation Map

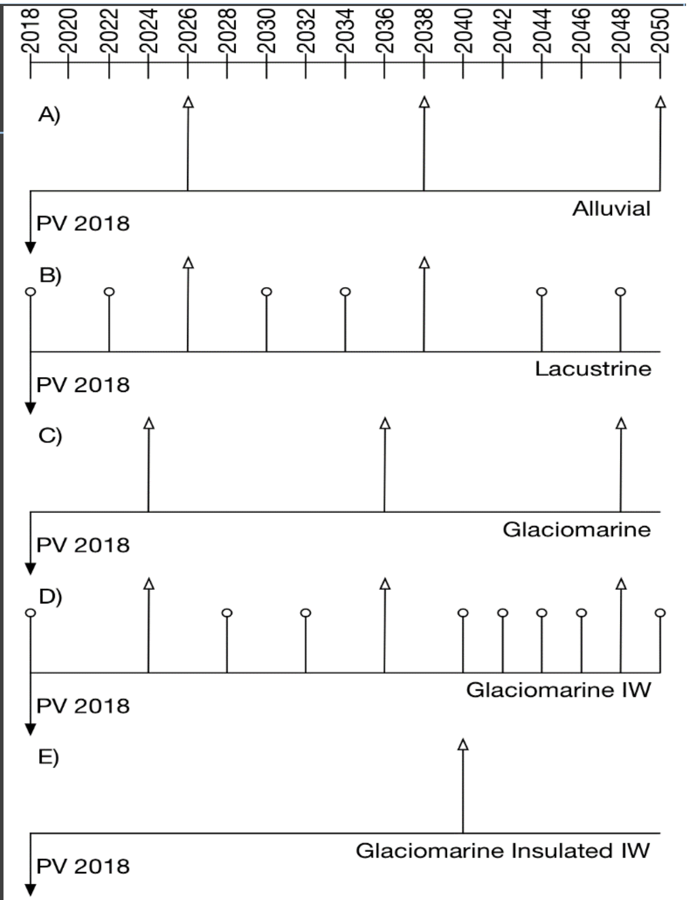
Recalculate Risk

Record New Risk on Plot

Repeat

EXTENSIONS AND USES

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C)
Glaciomarine
PV 2018
D)
Glaciomarine IW
PV 2018
E)
Glaciomarine Insulated IW
PV 2018

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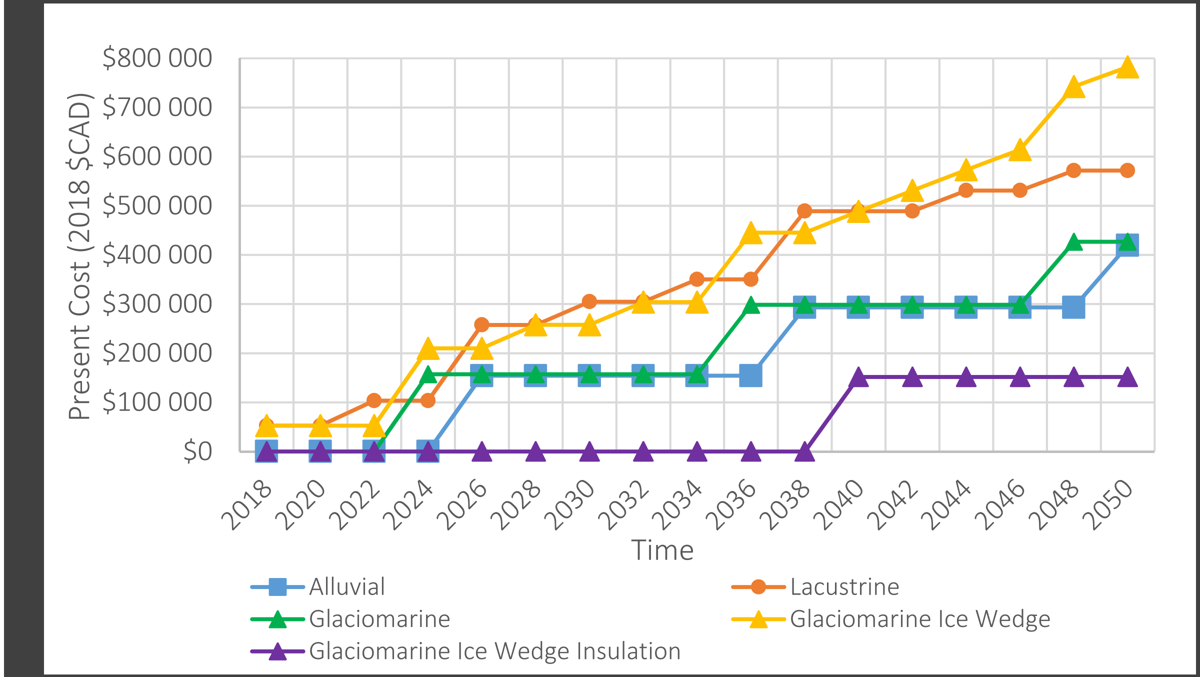

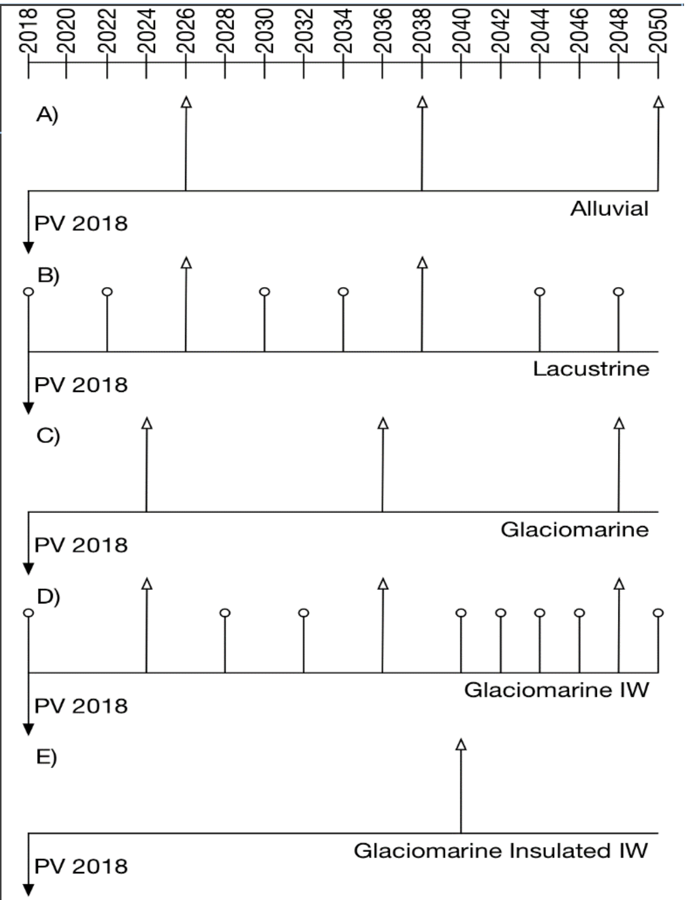
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THANK YOU!

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