Development of an integrated tailings simulation model using System Dynamics and GoldSim

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NSERC CRSNG

Agenda

- **Introduction**: System Dynamics and Causal Loop Diagrams (CLD)

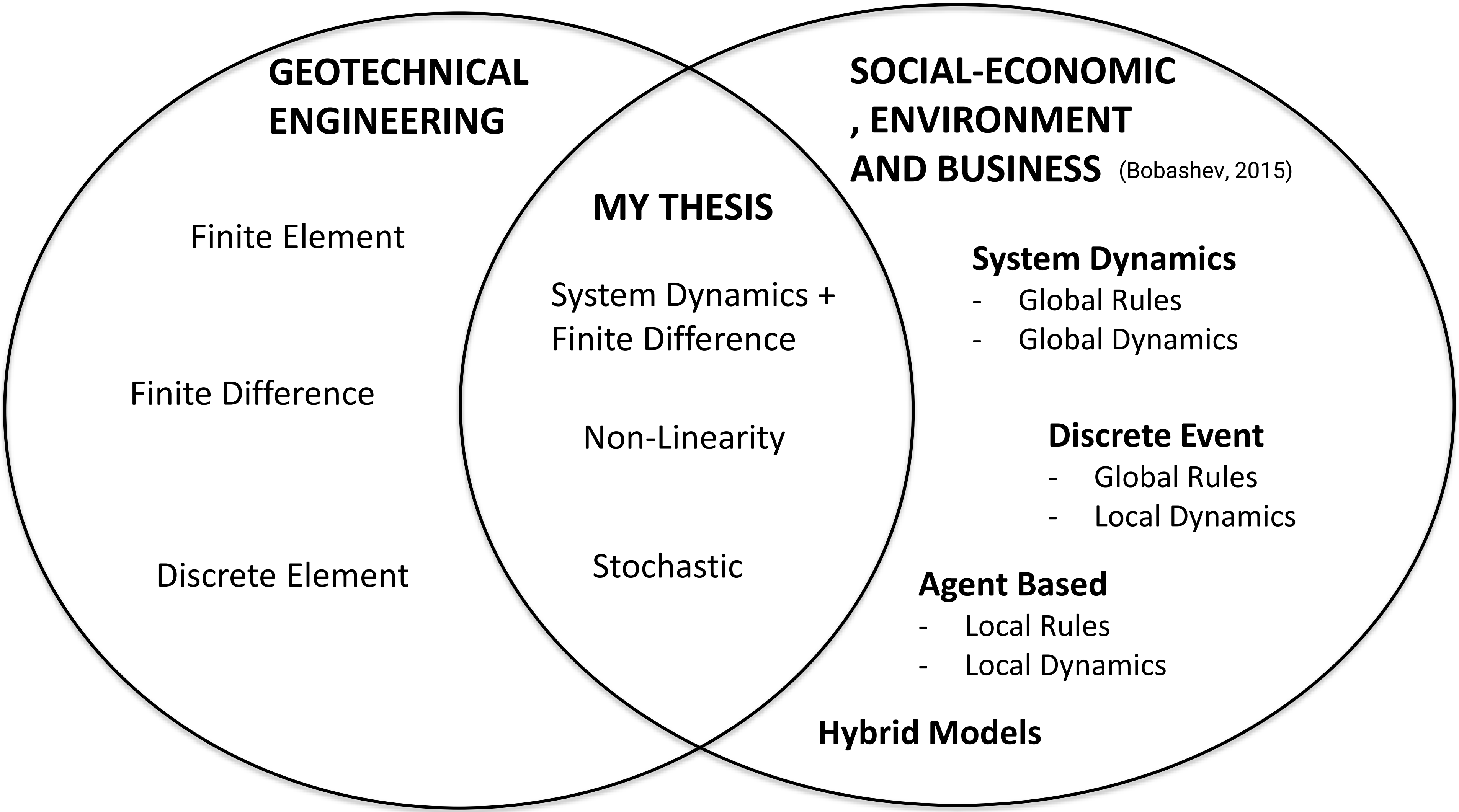
- **Case Study**: Soil Water Dynamics of Tailings Cap

  - Part I: Modelling Process

  - Part II: Results

- **Concluding Remarks**

The Modelling Universe



What is System Dynamics?

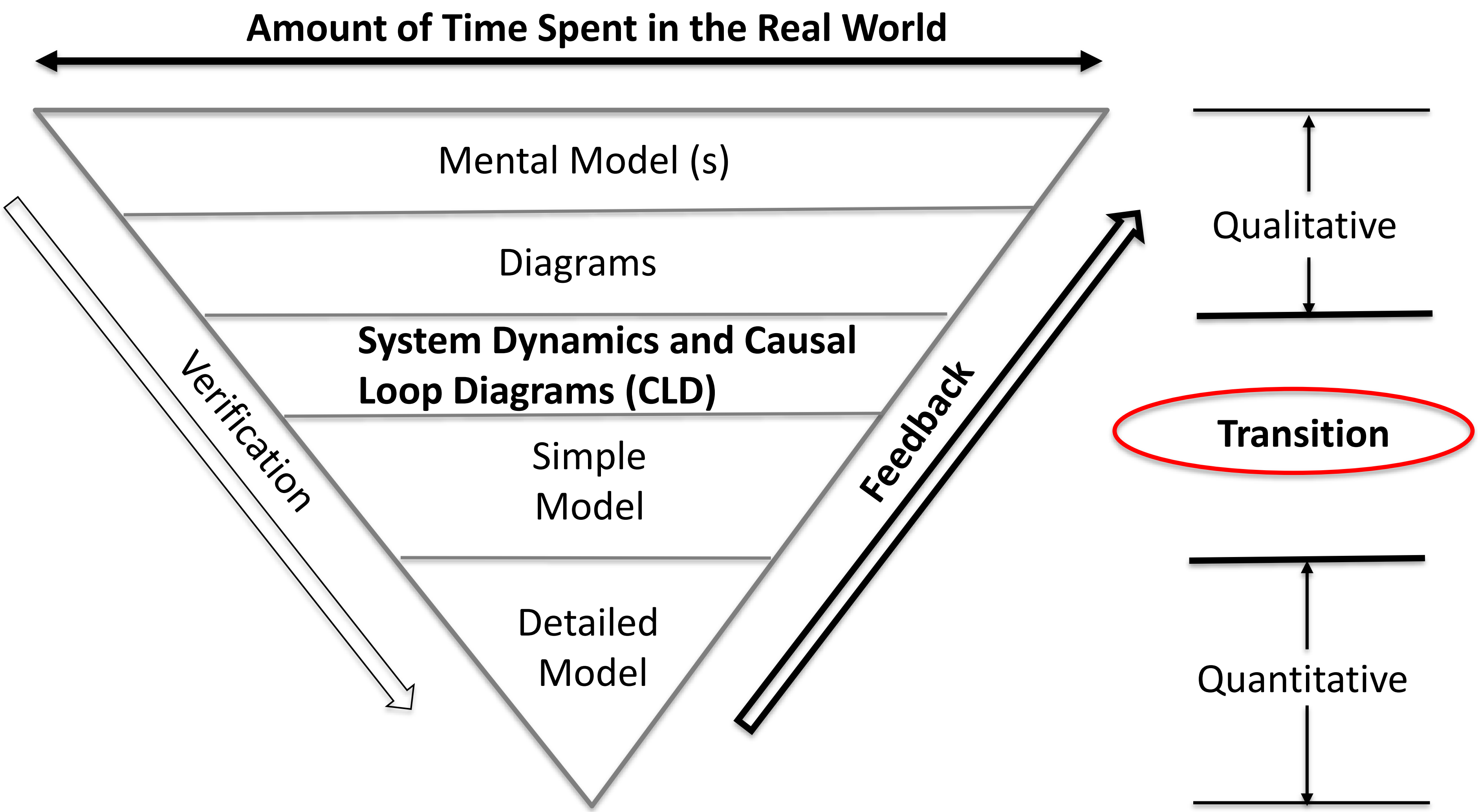
– Developed by Jay Forrester at MIT's Sloan Business School in the 50s:

To model complex inter-relationships between elements within a system or multiple systems.

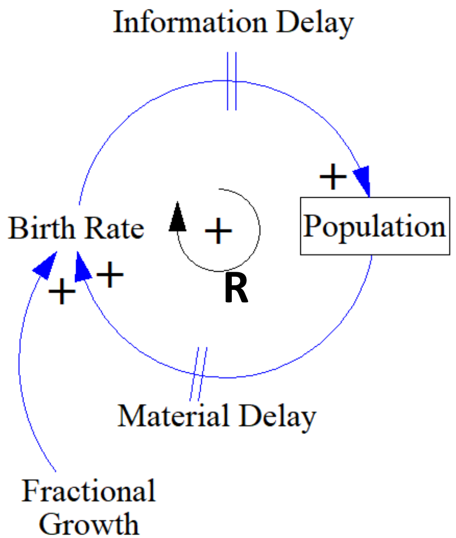
- Feedbacks, Feedbacks and Feedbacks

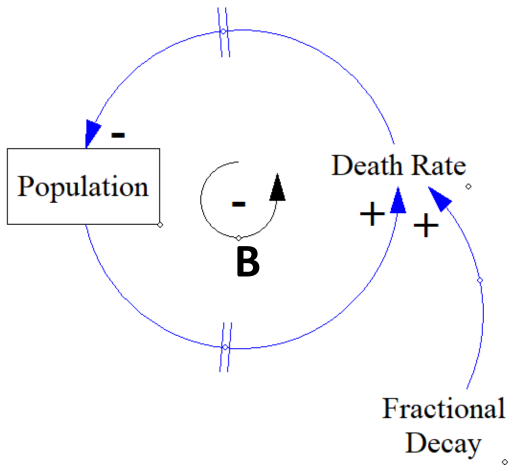
– Applications in Public Health, Management Consulting, Water Resource Management, Public Policy, International Relations, Defense and Securities etc.

System Dynamics Modelling Process

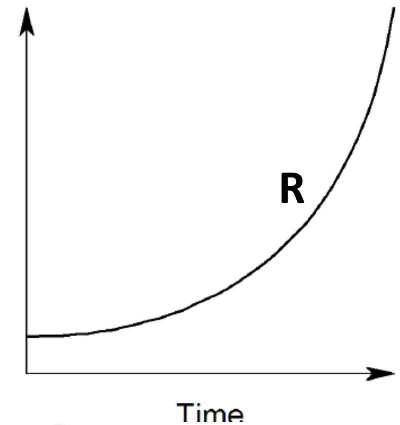


A Simple Example of Causal Loop Diagrams

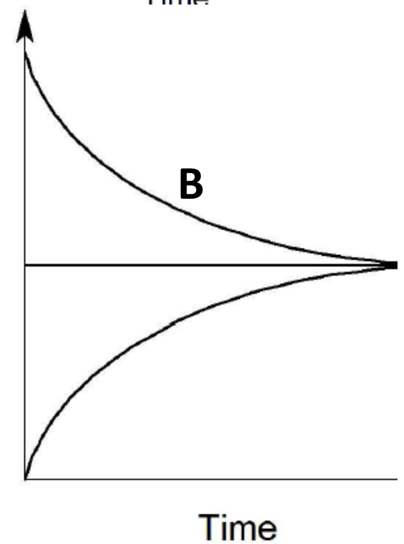




R: Reinforcing



B: Balancing



Modified from Sternman, 2000

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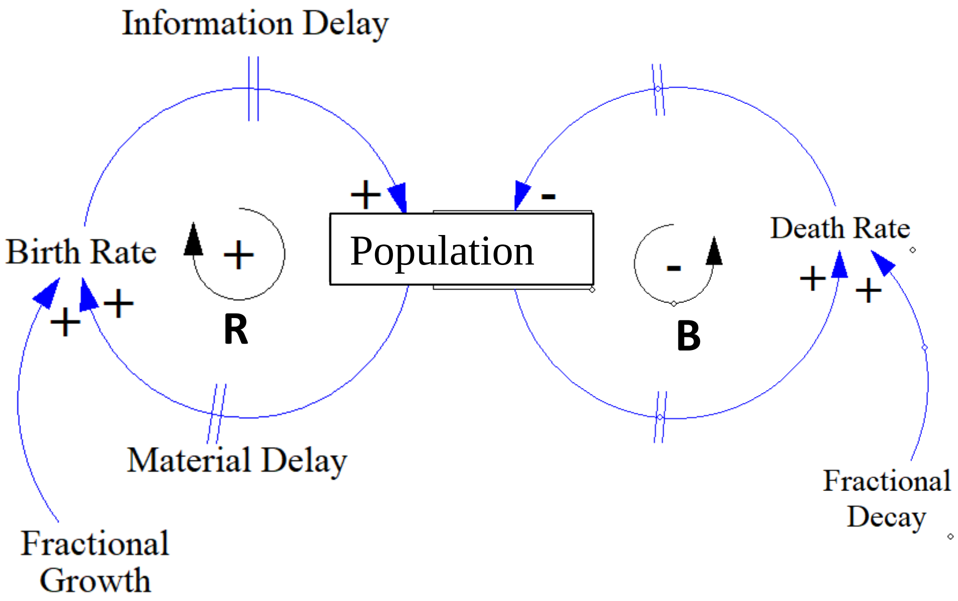

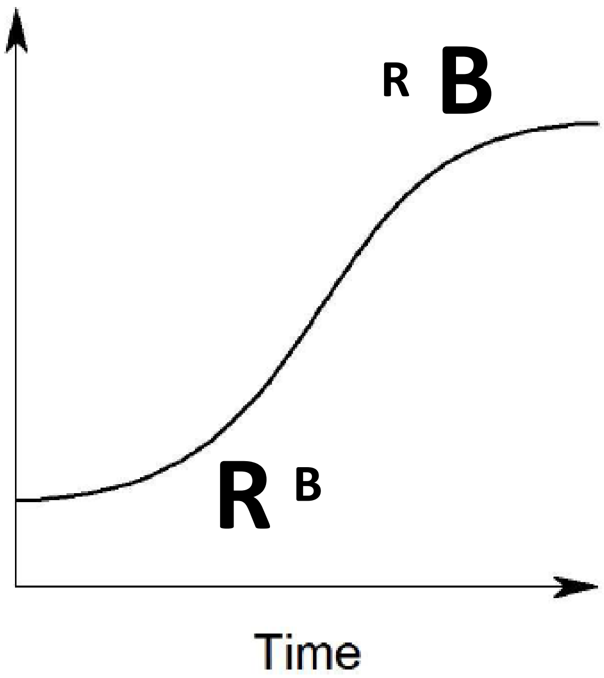

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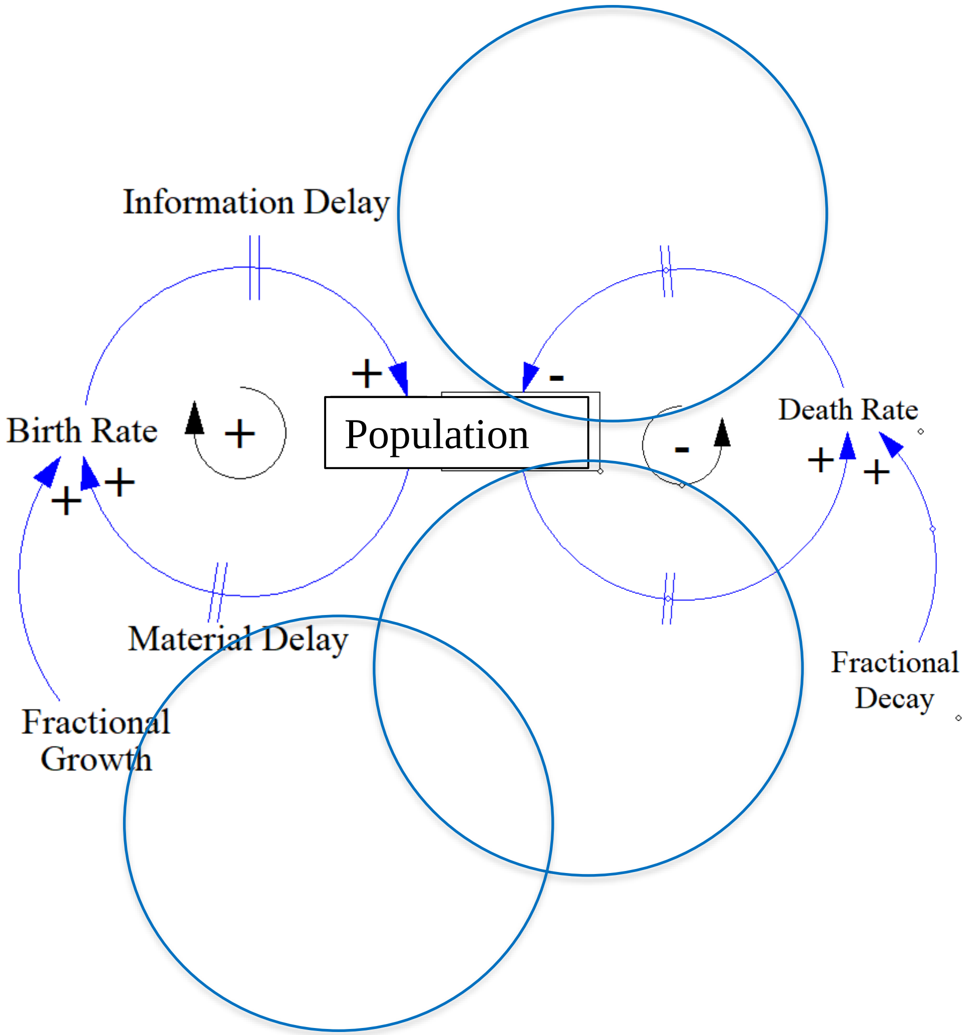
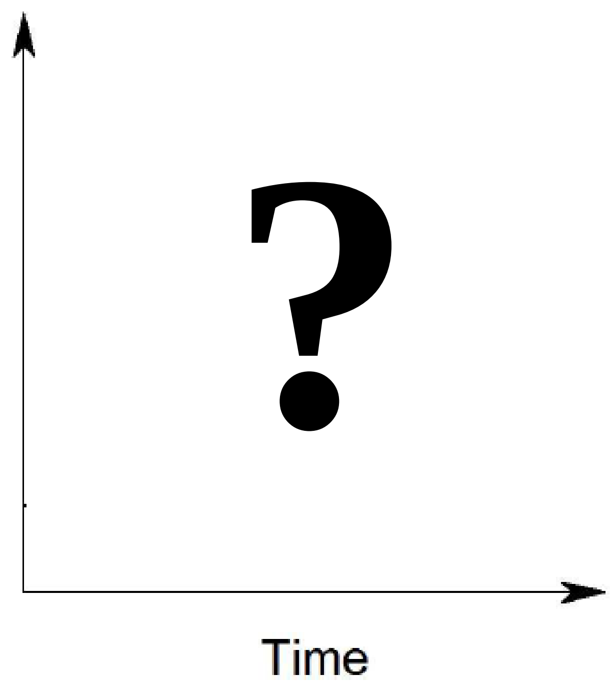




Modified from Sternman, 2000

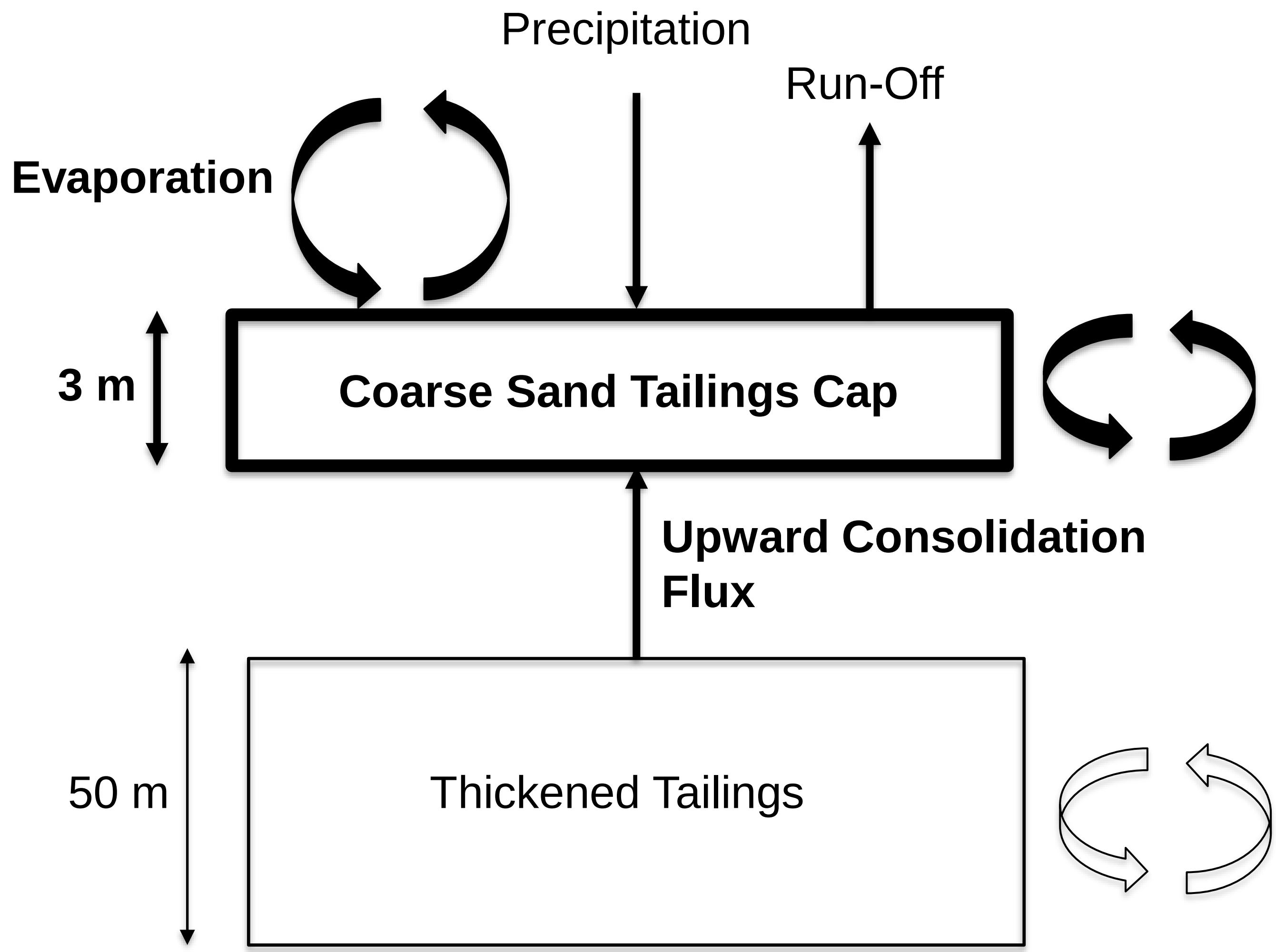
Case Study

Soil Water Dynamics of Tailings Cap

Part I: Model Building Process

Part II: Simulation and Analysis

Step 0 – Conceptualization



Step 1: Pick the Governing Equations

Vol Water Content

$$\theta(h) = \begin{cases} \theta_r + \dfrac{\theta_s - \theta_r}{[1 + |\alpha h|^n]^m} & h < 0 \\ \theta_s & h \geq 0 \end{cases}$$

Hydraulic Conductivity

$$K(\theta) = \begin{cases} K_s S_e^{1/2}[1 - (1 - S_e^{1/m})^m]^2 & S_e < 1 \\ K_s & S_e = 1 \end{cases}$$

Relative Saturation

$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r}$$

Inter-Layer Transmission Rate

$$f_i = -\frac{1}{2}[K_{i-1}(\theta_{i-1}) + K_i(\theta_i)]\left(\frac{h_i - h_{i-1}}{\frac{L_{i-1} + L_i}{2}} - 1\right)$$

Evaporation-Suction Model

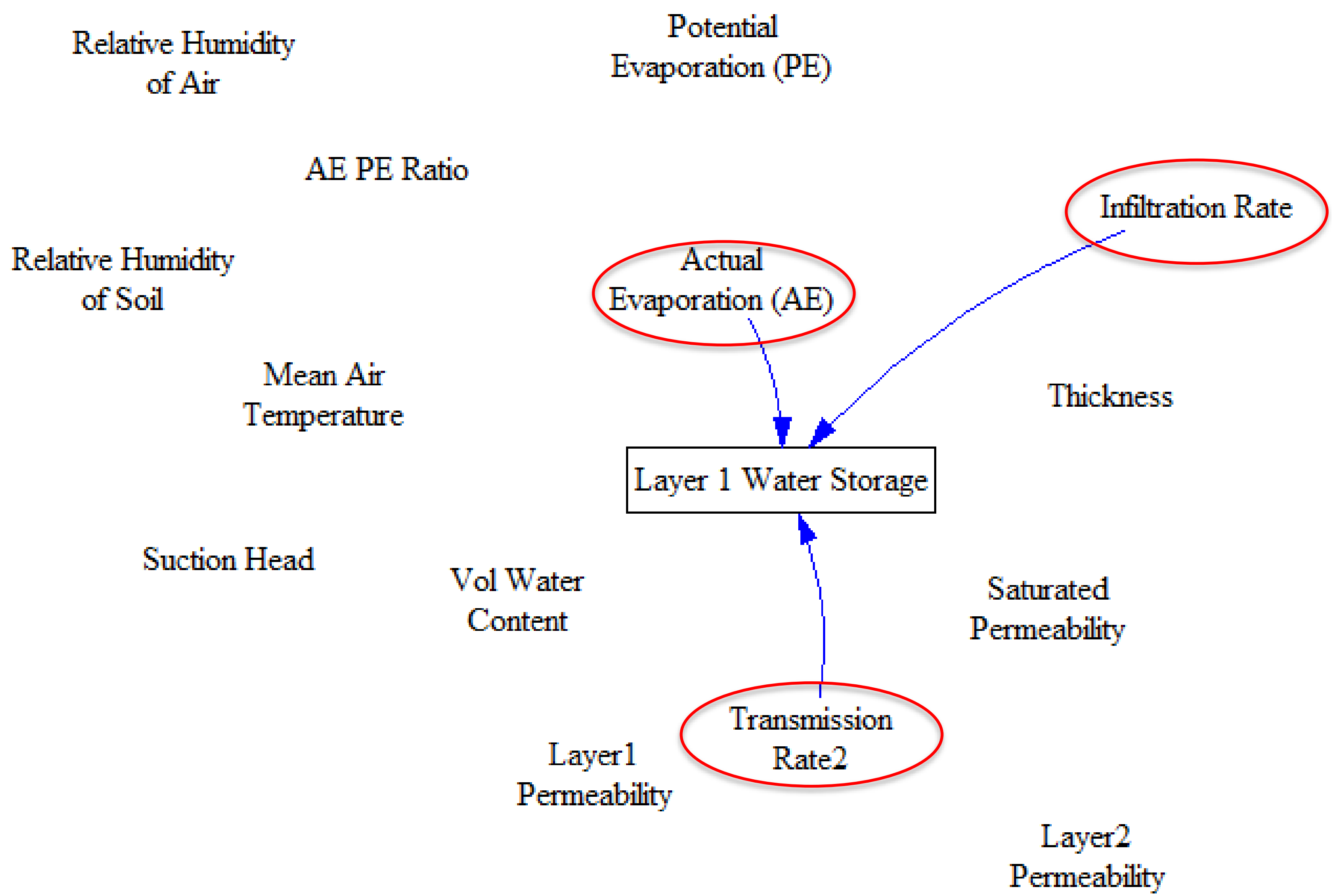
$$h_r = \exp\left(\frac{\Psi g W_v}{RT}\right)$$

Actual Evaporation Rate

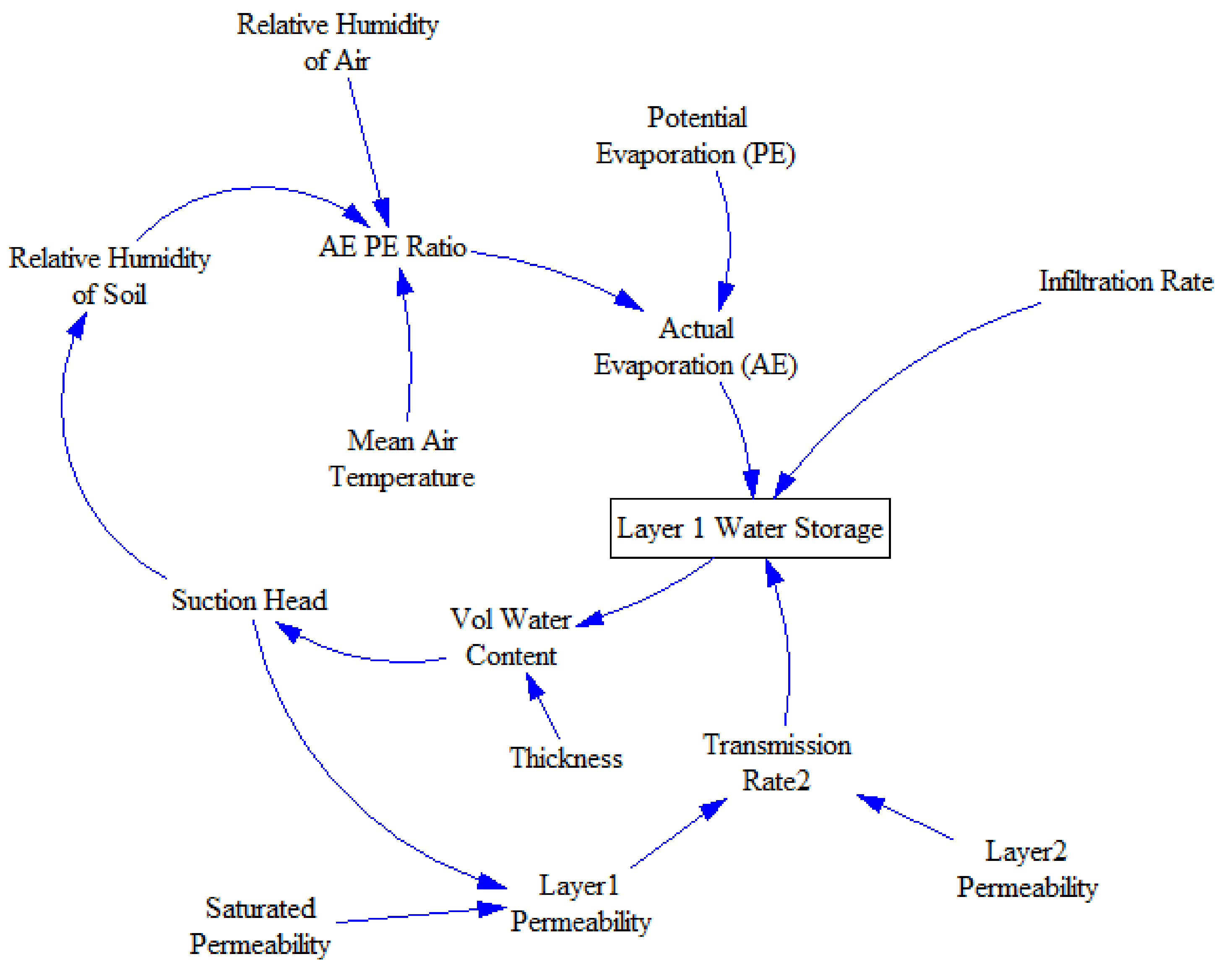
$$\frac{\mathrm{AE}}{\mathrm{PE}} = \left[\frac{\exp\left(\frac{\Psi g\, W_v}{RT}\right) - h_a}{1 - h_a}\right]$$

Van Ganutchen - Maulem (1980) ; Wilson et al (1997); Huang et al (2011)

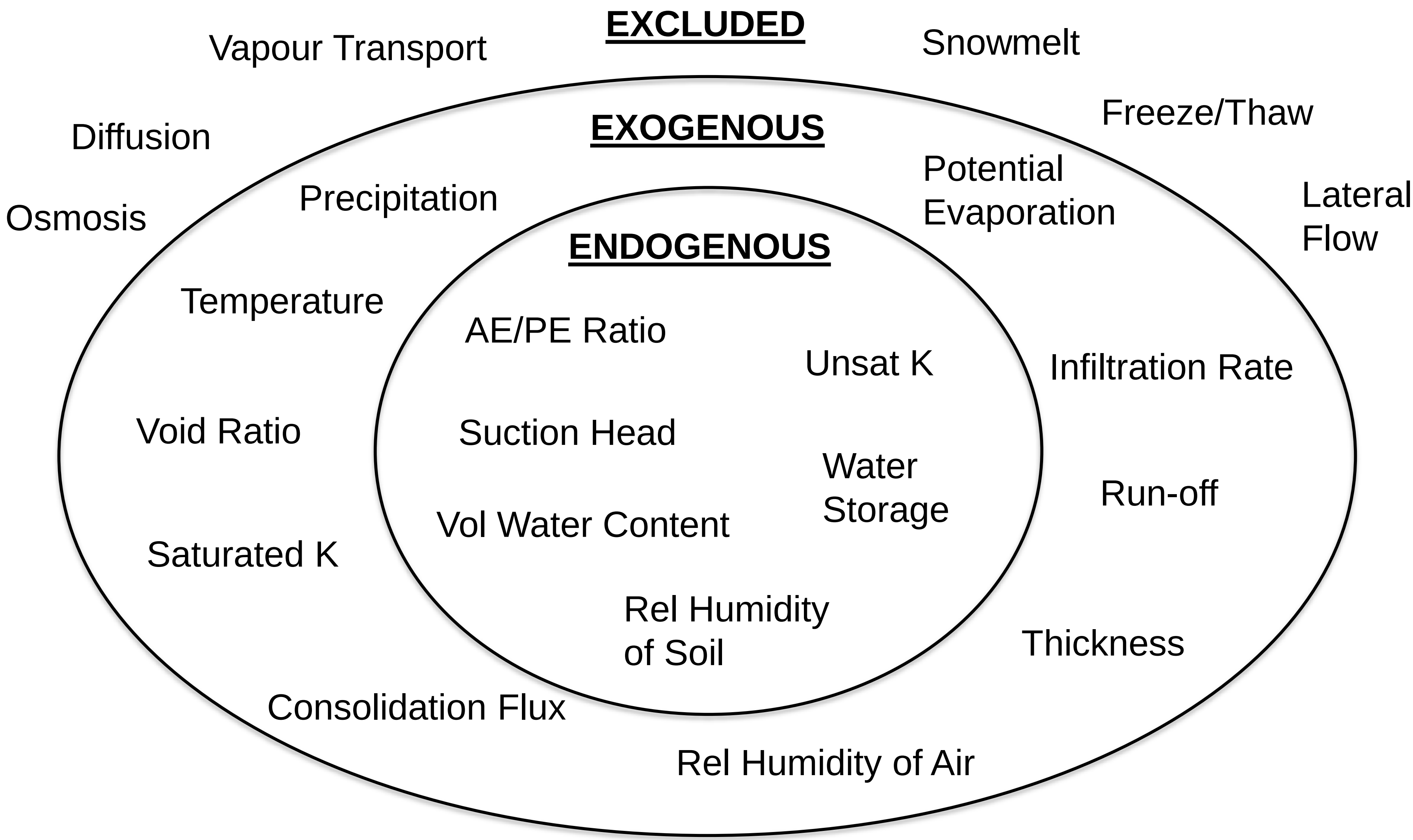
Step 2: List relevant variables; identify the stock(s) and flows



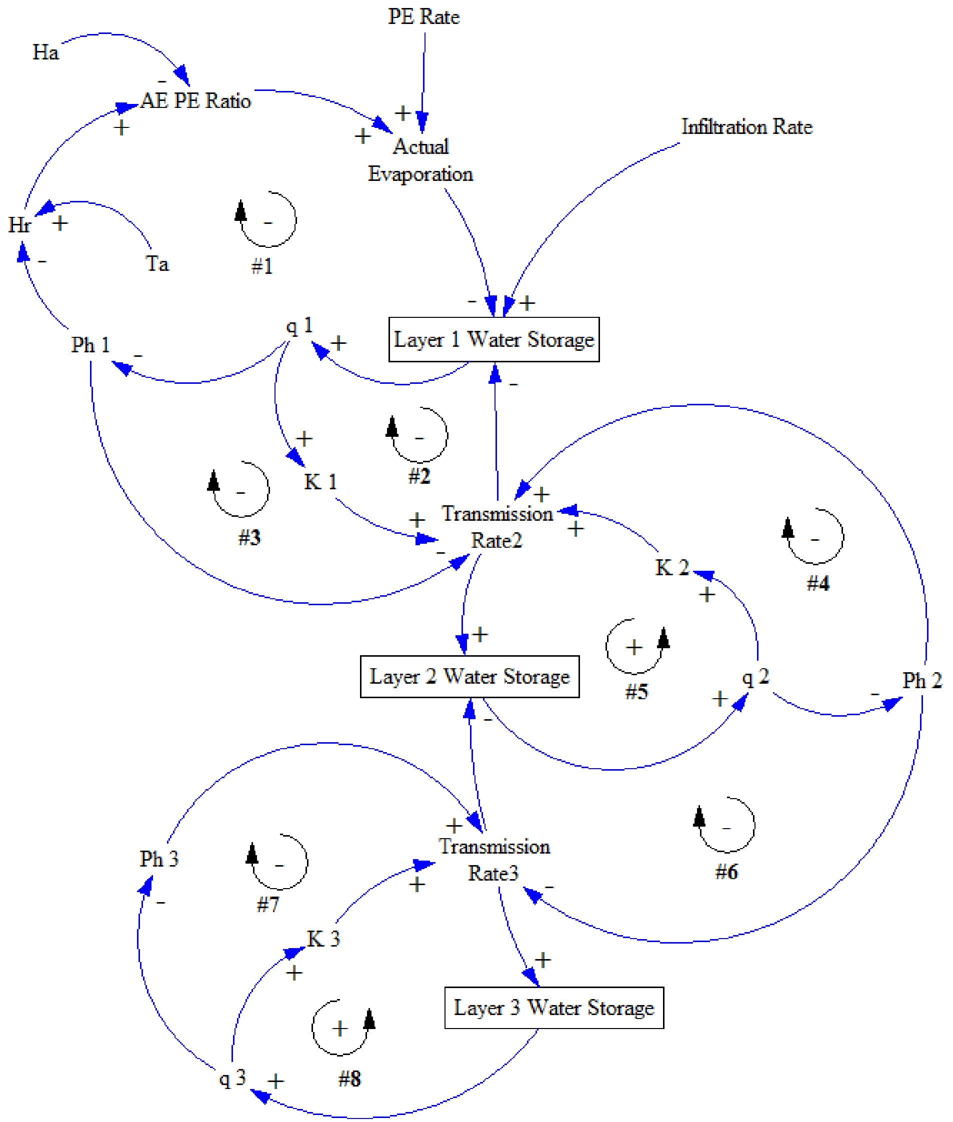
Step 3: Construct the preliminary CLD; Identify feedbacks; discuss and debate



Step 4: Use the Bull's Eye Diagram to identify the boundary of the model / system



Step 5: Build the partial CLD; add polarity signs and identify feedback structures



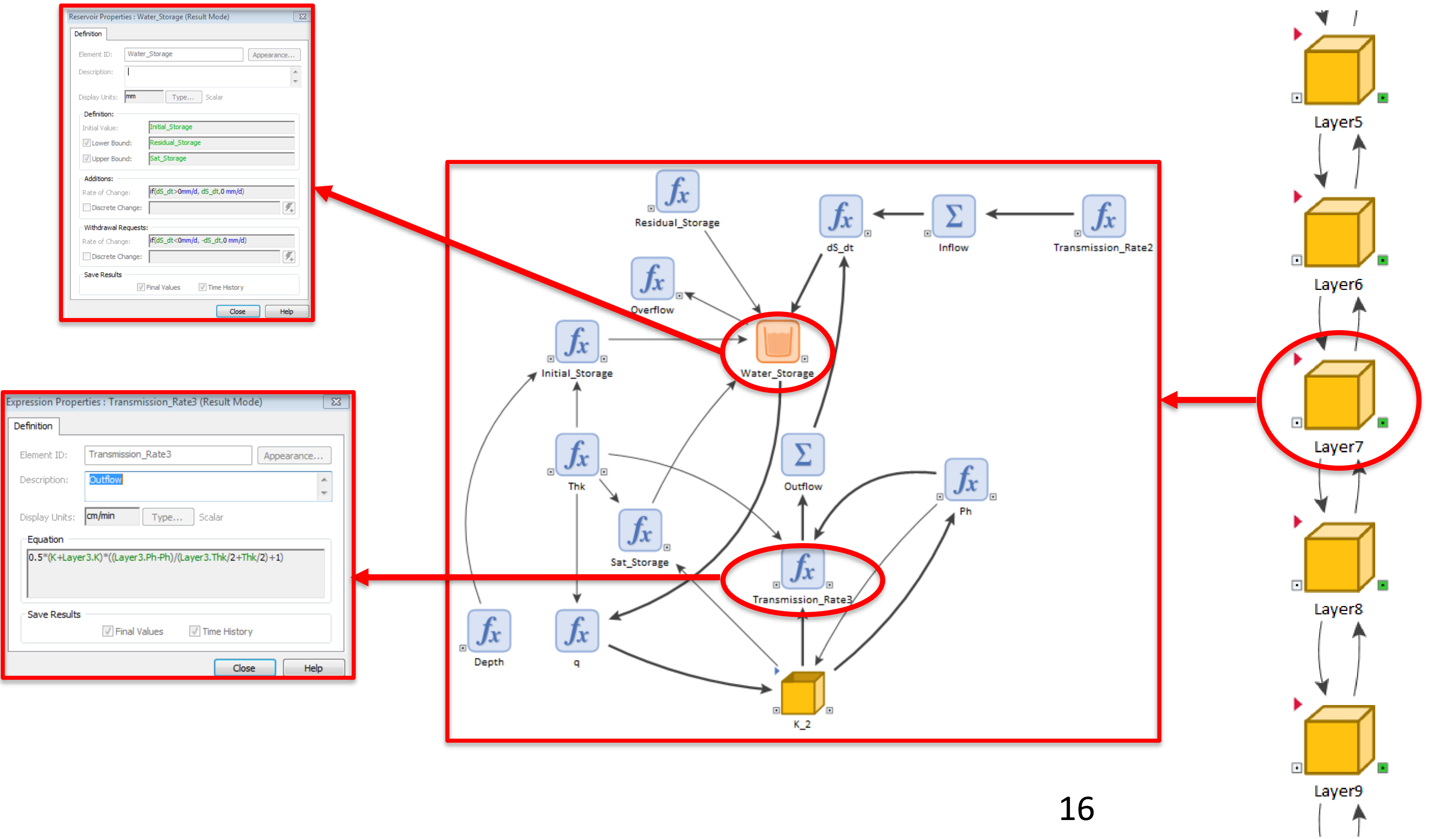
Negative (Balancing) Loop

- Suction-Driven
- Dominates when evaporation > precipitation

Positive (Reinforcing) Loop

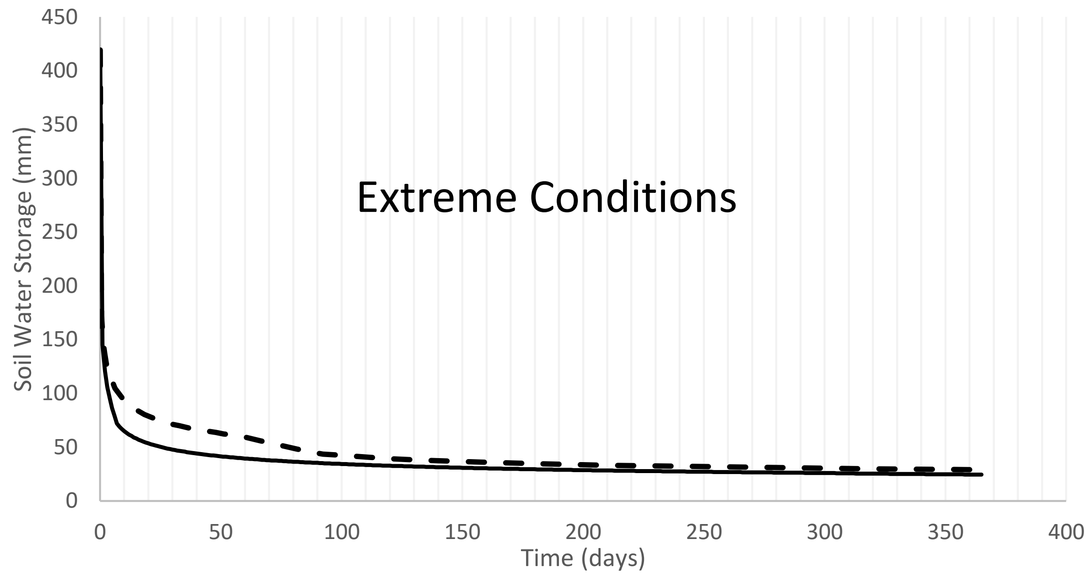
- Infiltration-Saturation Driven
- Dominates when precipitation > evaporation or when wetting front arrives

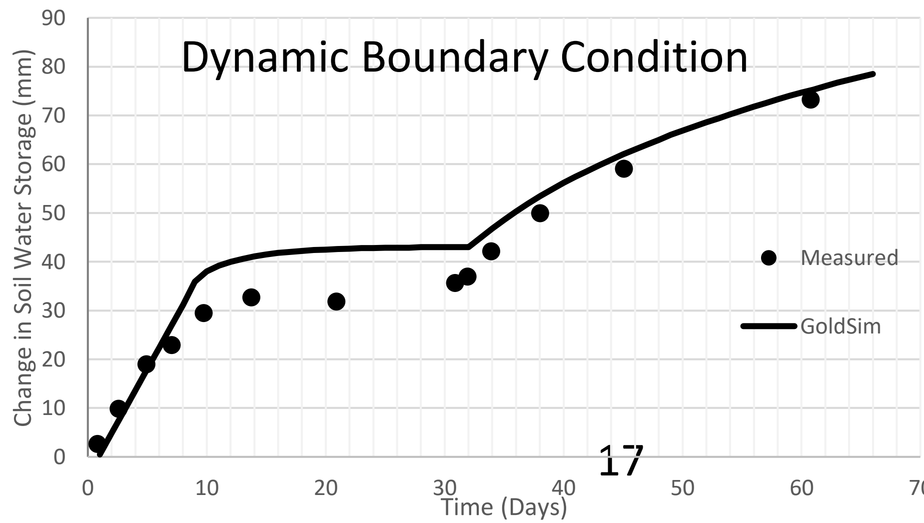
Step 6: Transform CLDs into GoldSim



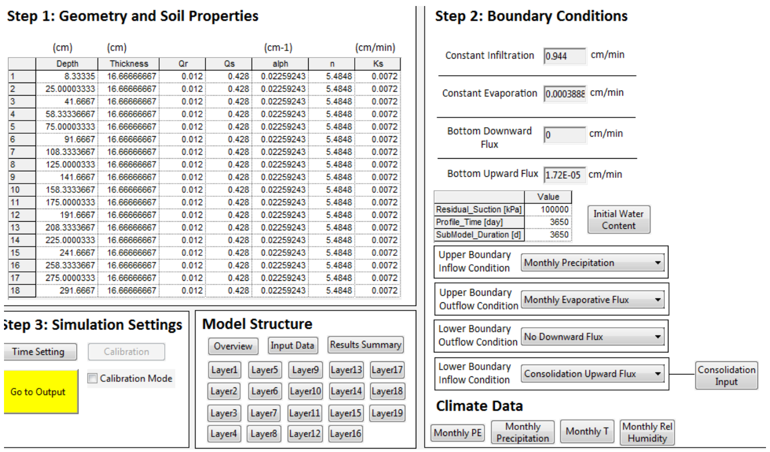
Step 7: Validation

Step 7: Run and validate simple models under a variety of conditions and different materials.



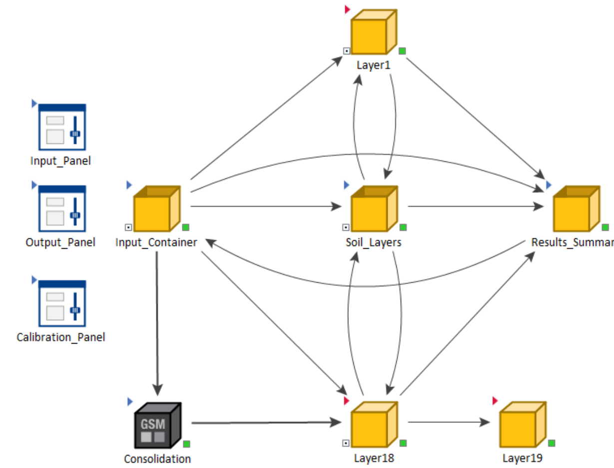


Step 8: Visualization and User Interface

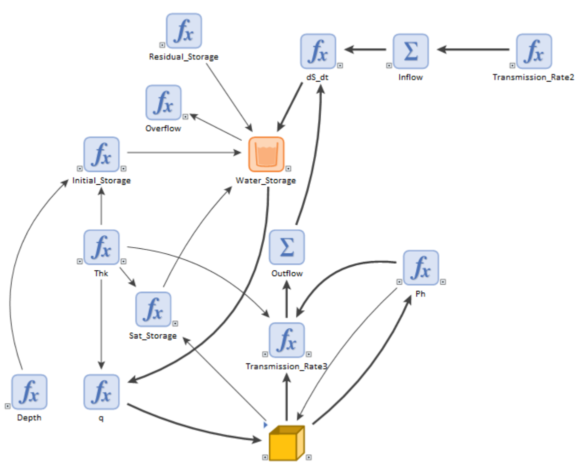


User Input

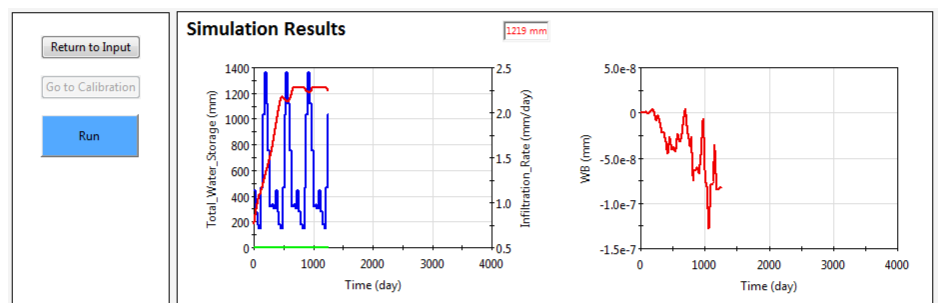
User sees what the modeler sees



Model Overview



Layer Setup



Real-Time Simulation Results

Final Steps

Step 9:
Go back to the Bull's Eye Diagram if required as part of the iterative and participatory modelling process

Step 10:
Parameter Estimation (Case Study)

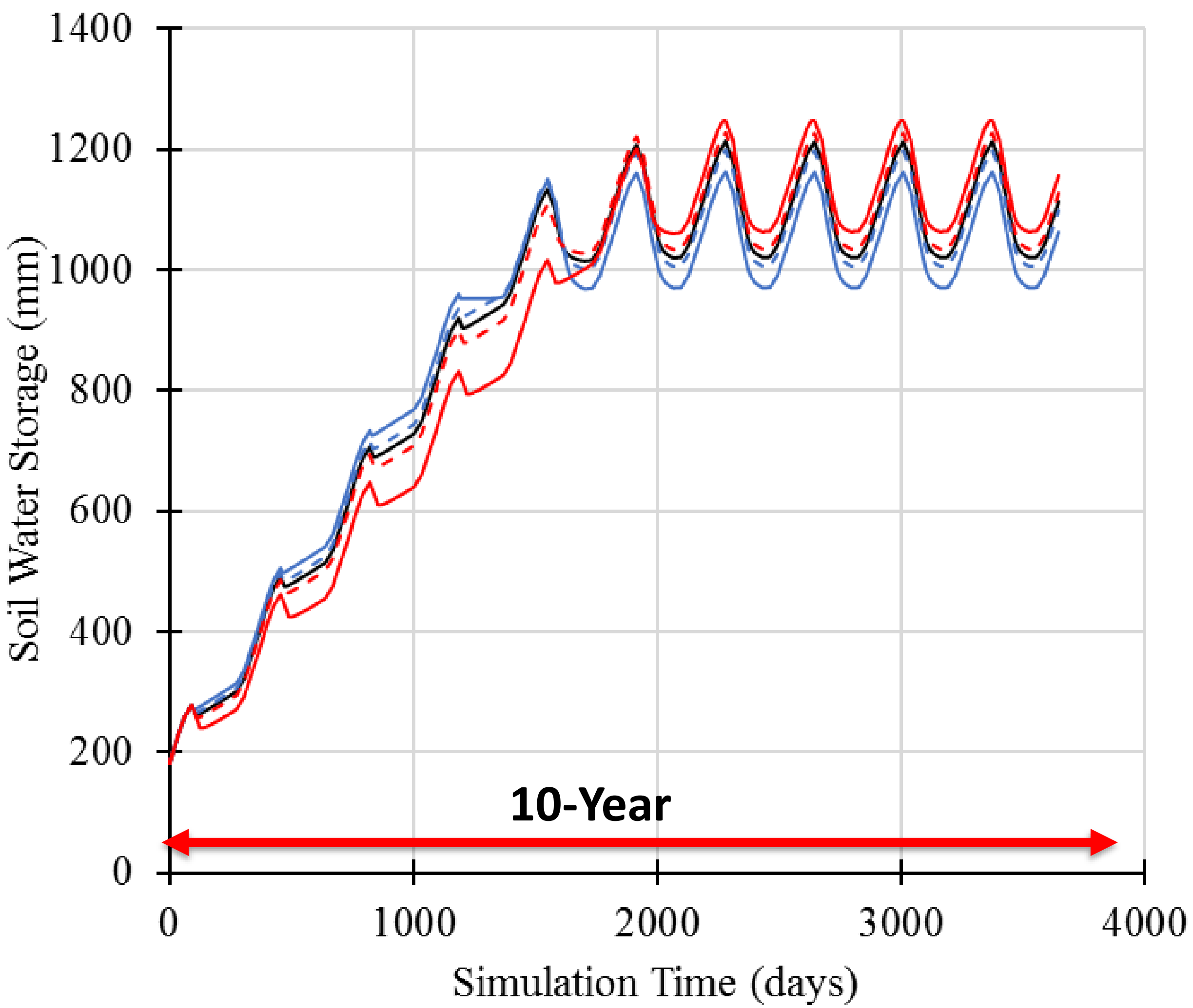
Step 11:
Simulation and Sensitivity Analysis (Case Study)

Soil Water Dynamics of Tailings Cap

Part I: Model Building Process

Part II: Simulation and Analysis

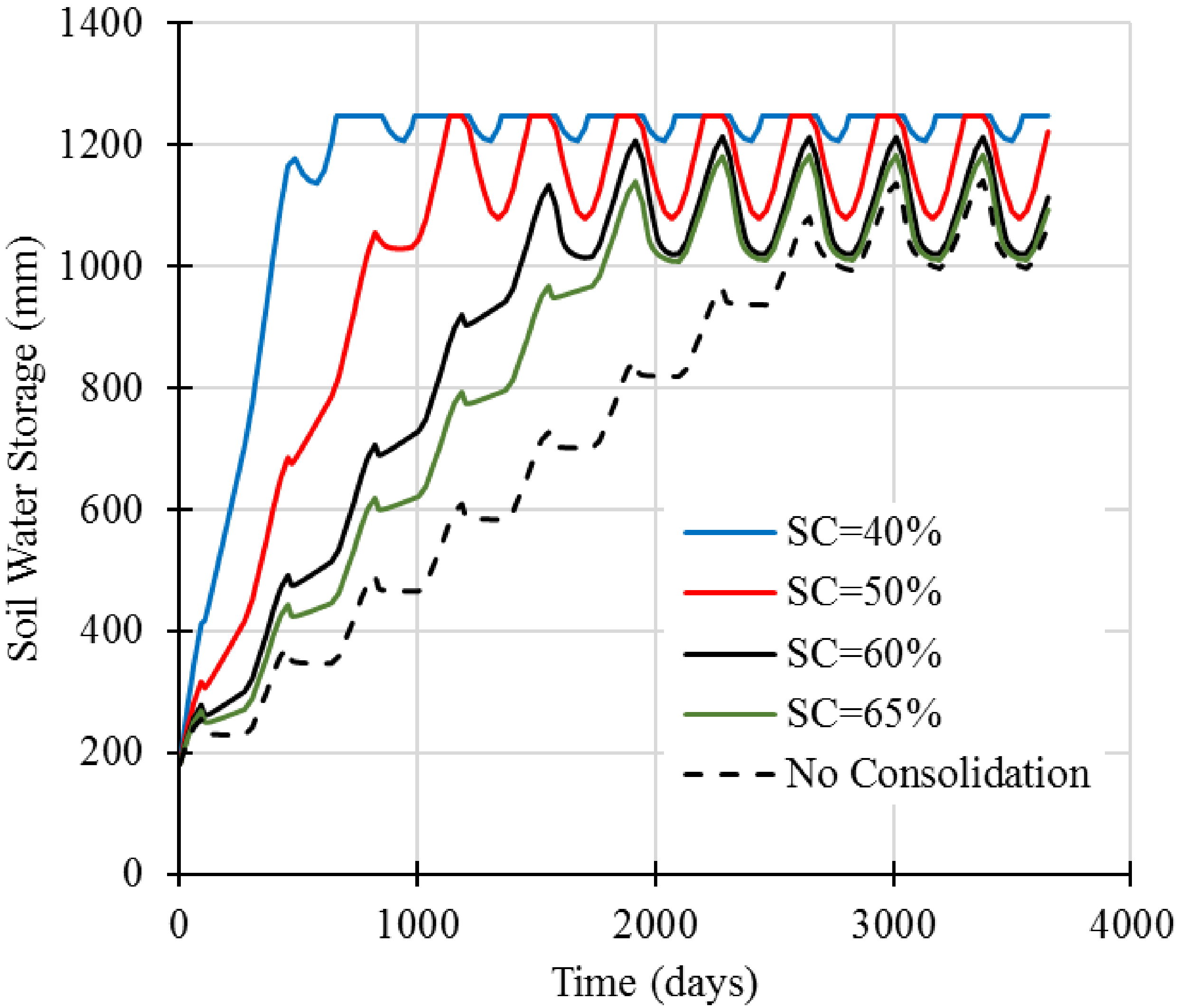
Global Dynamics– Total Water Storage



Vary Saturated Hydraulic Conductivity of CST

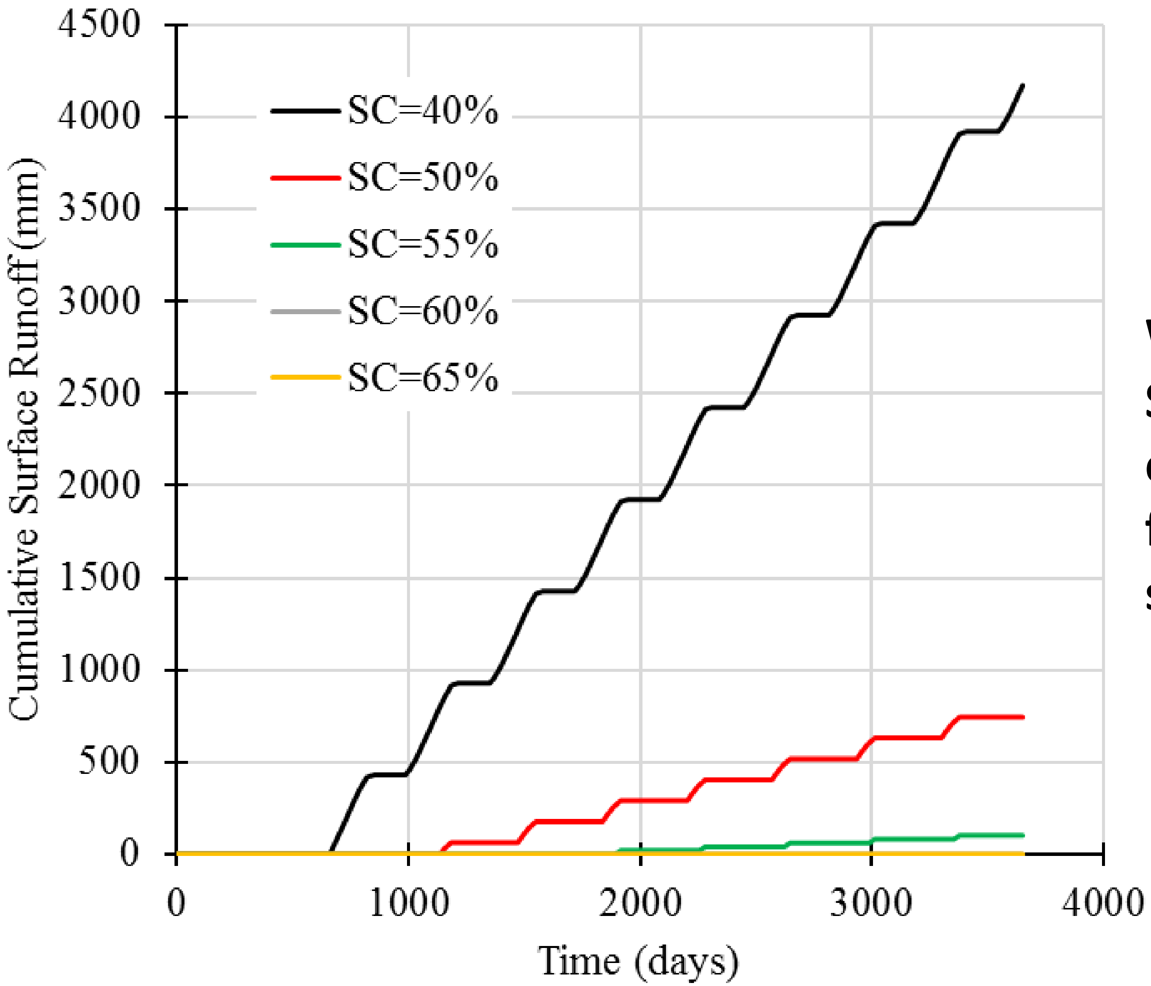
Initial SC of TT = 60%

Global Dynamics– Total Water Storage



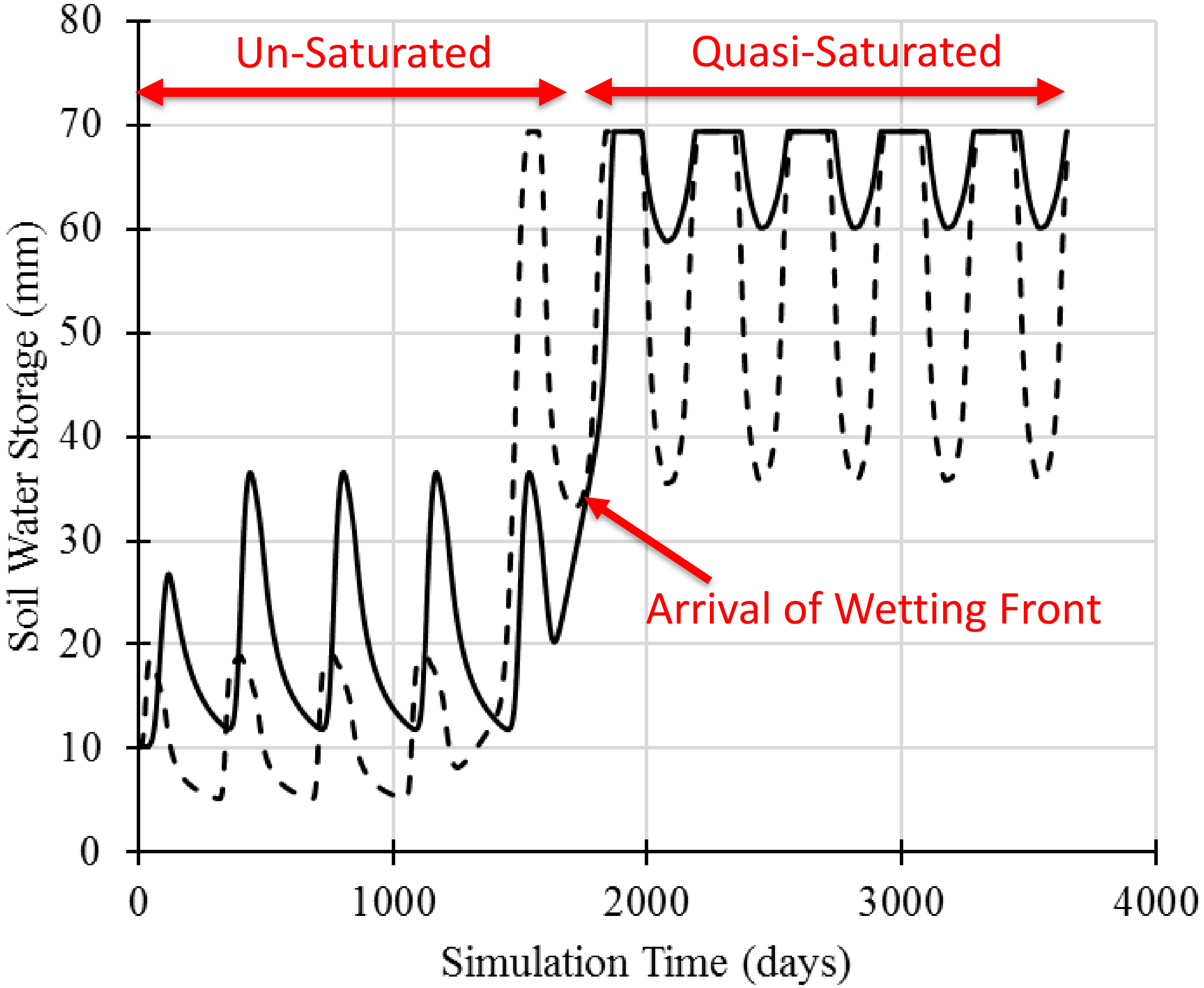
Vary Initial SC of TT
Same CST Ks in all scenarios

Global Dynamics– Cumulative Runoff



What is the minimum initial SC of TT required to prevent consolidation release water from daylighting at the surface?

Local Dynamics - Layer 4 (Depth: 52 cm)



Dashed Line: Higher Ks
Solid Line: Lower Ks

Concluding Remarks

- **Why System Dynamics?**
  - Feedback Structures
  - Rigorous Qualitative Process
  - Foster thinking and shared understanding through participatory modelling exercises
  - Ability to model soft variables

Concluding Remarks

- **Limitations**
  - Poor Capture of Spatial Variation
  - Over-Simplification
  - Over-Complexity
  - Complacency?

Acknowledgements

- **Dr Nicholas Beier**

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Software Support:

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FSCA (Dr Silawat Jeeravipoolvarn)