COMMUNICATING UNCERTAINTY IN MINE WASTE COVER PERFORMANCE MODELING

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Full Disclosure: I am only an Engineer!

I am neither a database professional nor or a statistician

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Why Mine Waste Covers?

- To answer this question we need to talk about two things
  - Closure **OBJECTIVES**
  - Cover **FUNCTIONS**

Johannesburg, South Africa

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Closure Objectives

Wismut, Germany

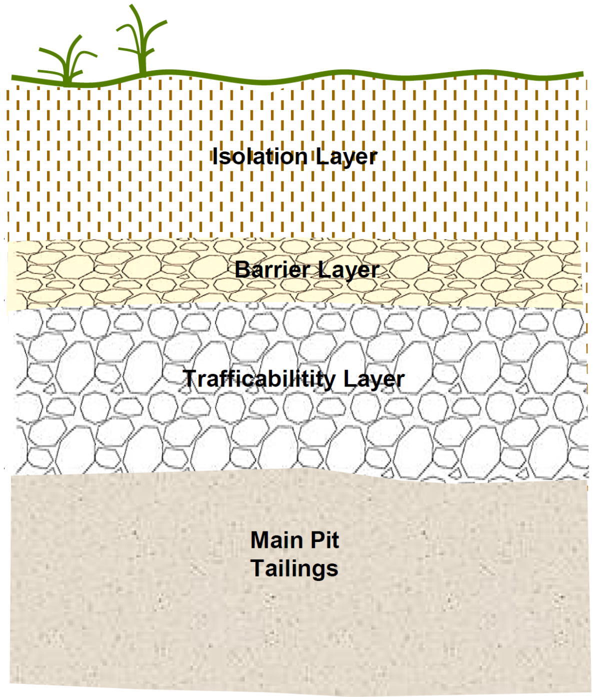
- Closure **Objectives** = fundamental reason/ motivation for doing closure work
- Reasons include
  - Remove health & safety risks
  - Prevent/remove/minimize environmental impacts
  - Reclaim social/economic land value
  - Regulatory compliance
  - Release bonds

Cover Function

- Cover is one **Tool** that can be used to achieve a Closure Objective

- Cover **Function** is the “work” that the cover must perform to achieve the Closure Objective

- Cover functions include
  - Radiation control
  - Seepage/leachate management
  - Promote vegetation
  - Etc.



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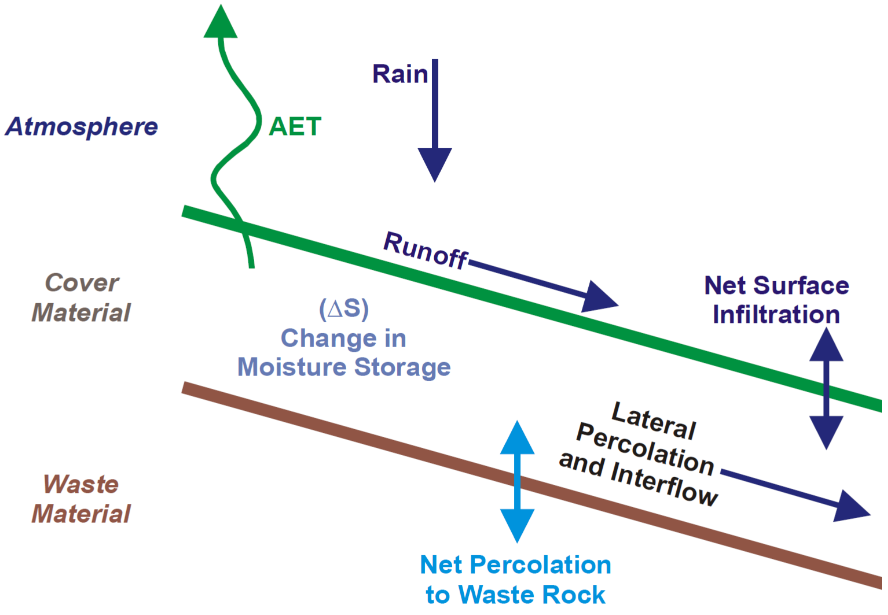
Infiltration Reduction Cover

- Define how much water will pass through the cover
- Typically do that through numerical modeling
- Design (or at least we should!) based on a specific infiltration range

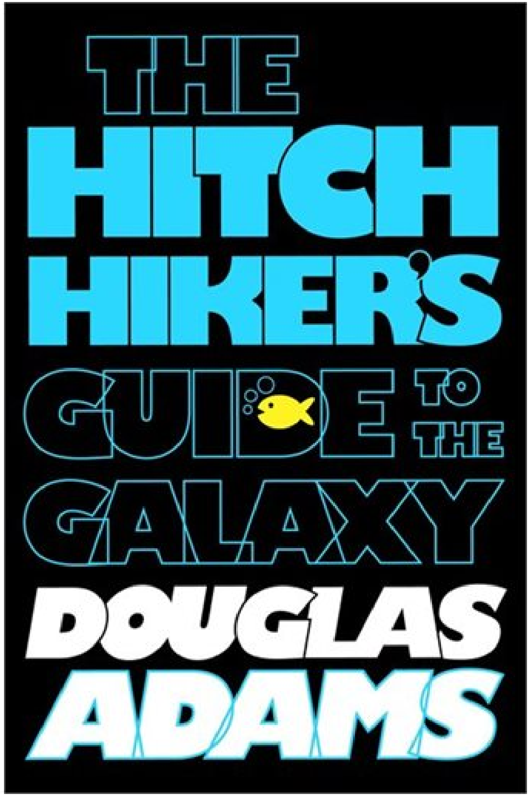
Cover Modeling

- Unsaturated flow modeling
- Numerically complex coupled models
- Surface flux boundary modeling
  - True SFB models
  - Pseudo SFB models



Ideal Model Outcome

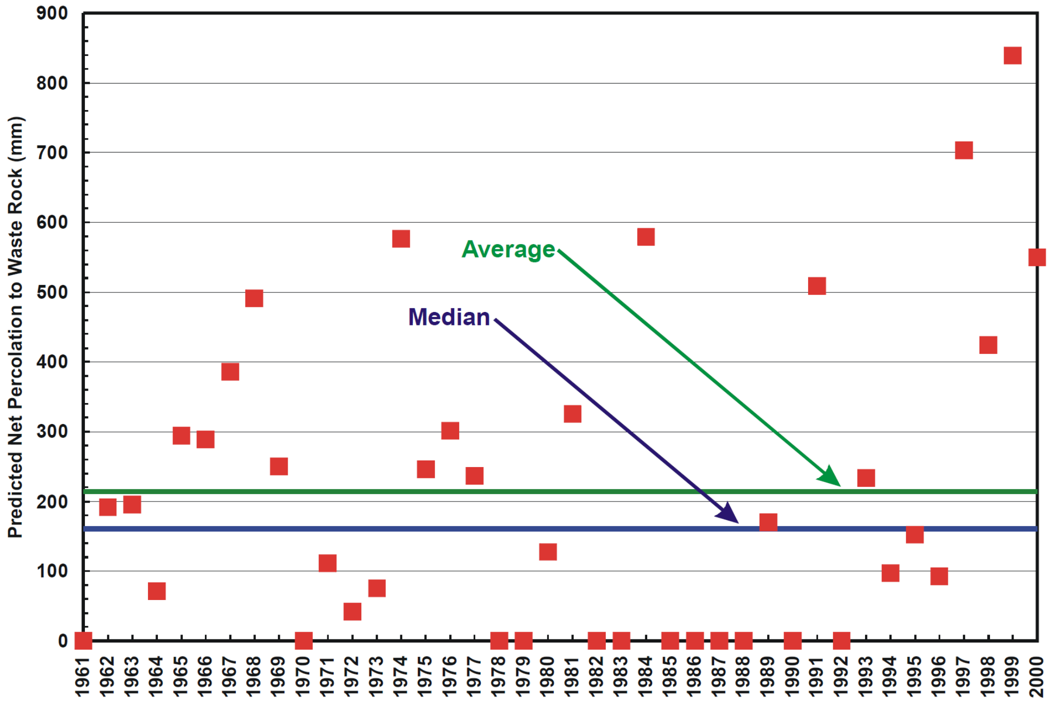
42



"Answer to the Ultimate Question of Life, the Universe, and Everything"

Realistic Model Outcome

- Answer varies widely based on range of variables or uncertainties
- What are these variables or uncertainties?



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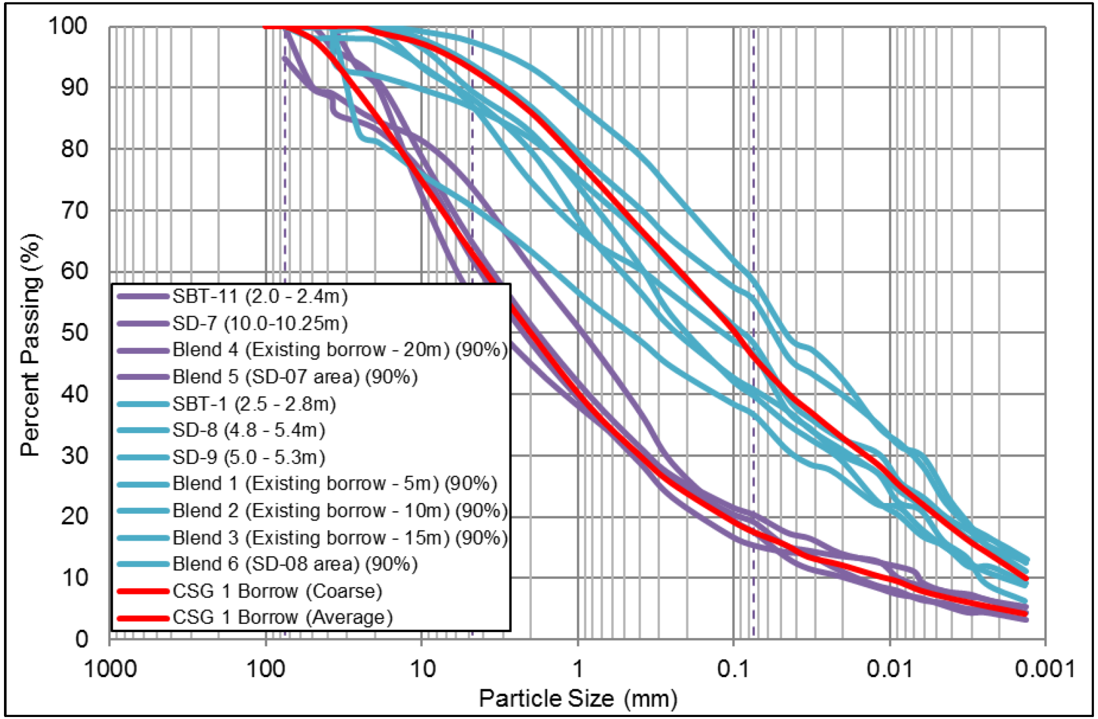
Material Heterogeneity



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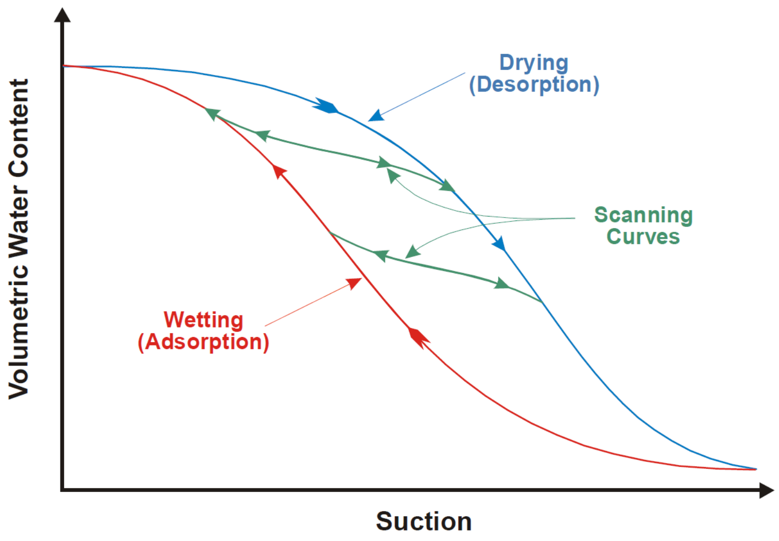
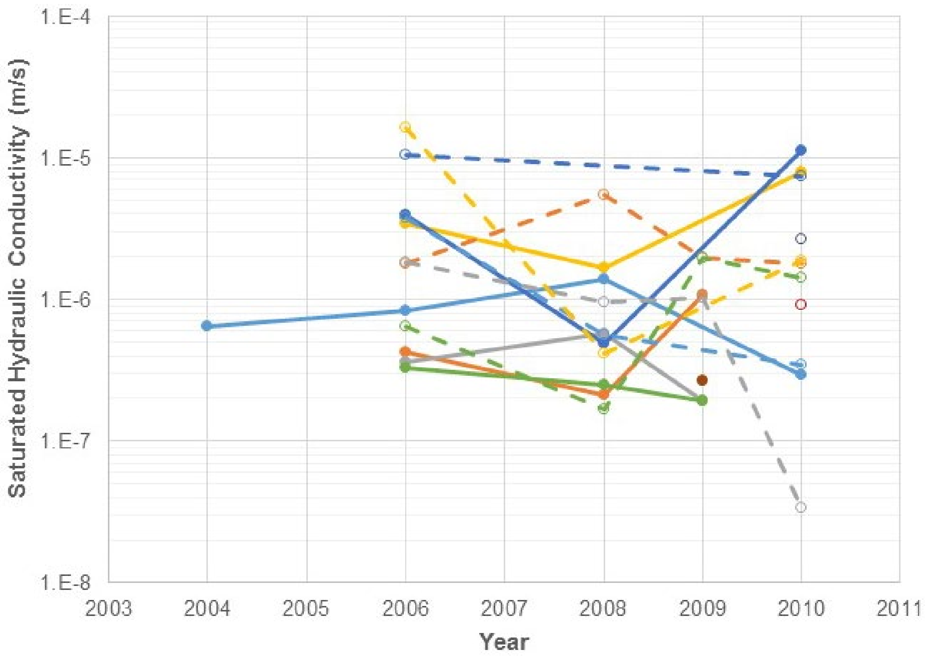
Material Evolution

Hysteresis



Changing Hydraulic Conductivity



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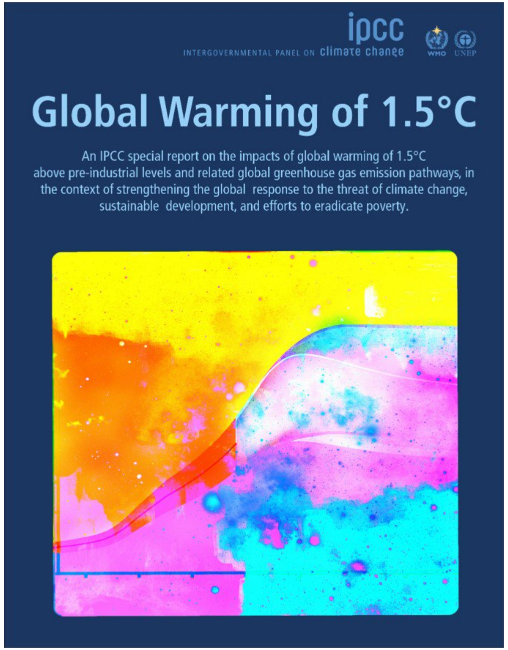
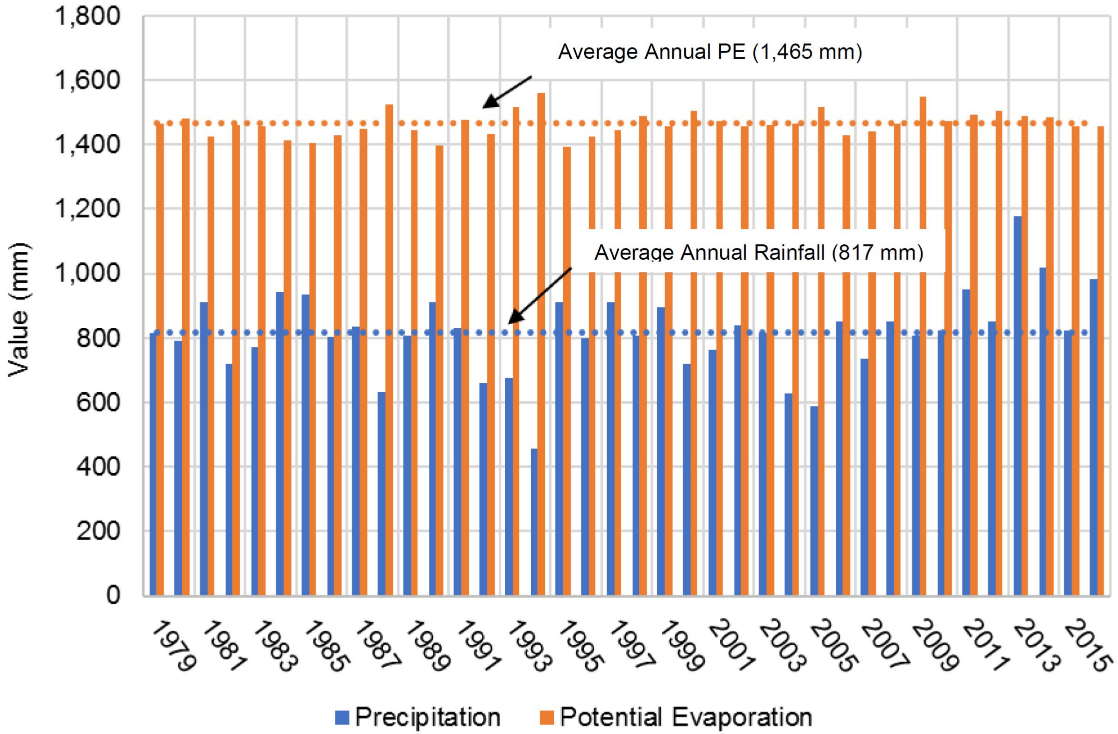
Climate Variability and Change





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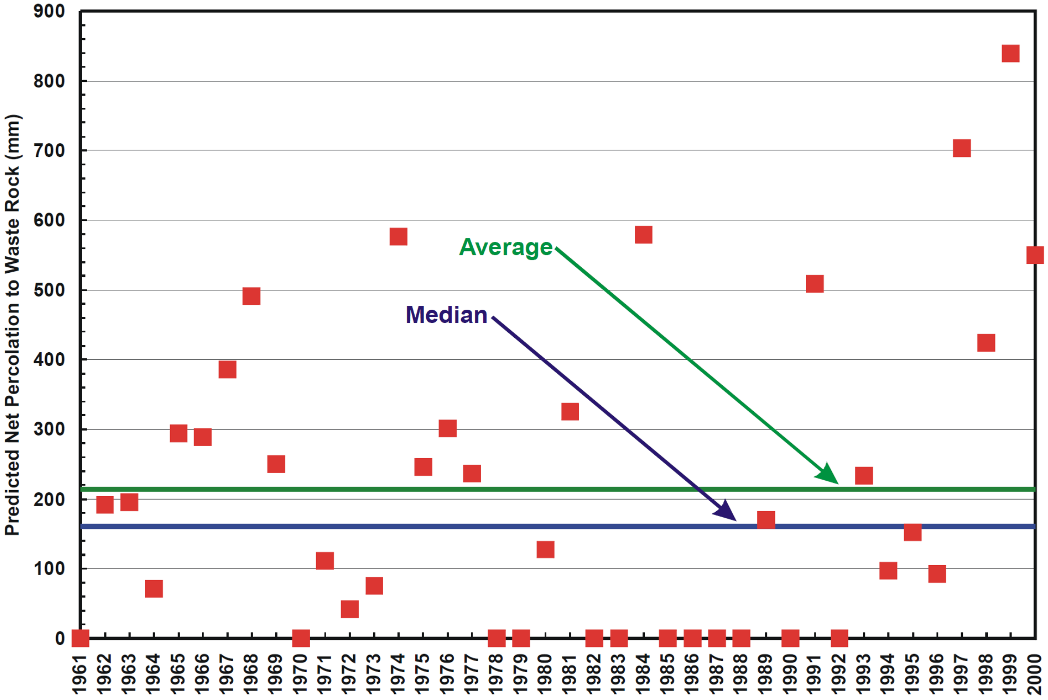
Antecedent Moisture Conditions



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Vegetation and Land Use Changes

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Geochemistry Changes

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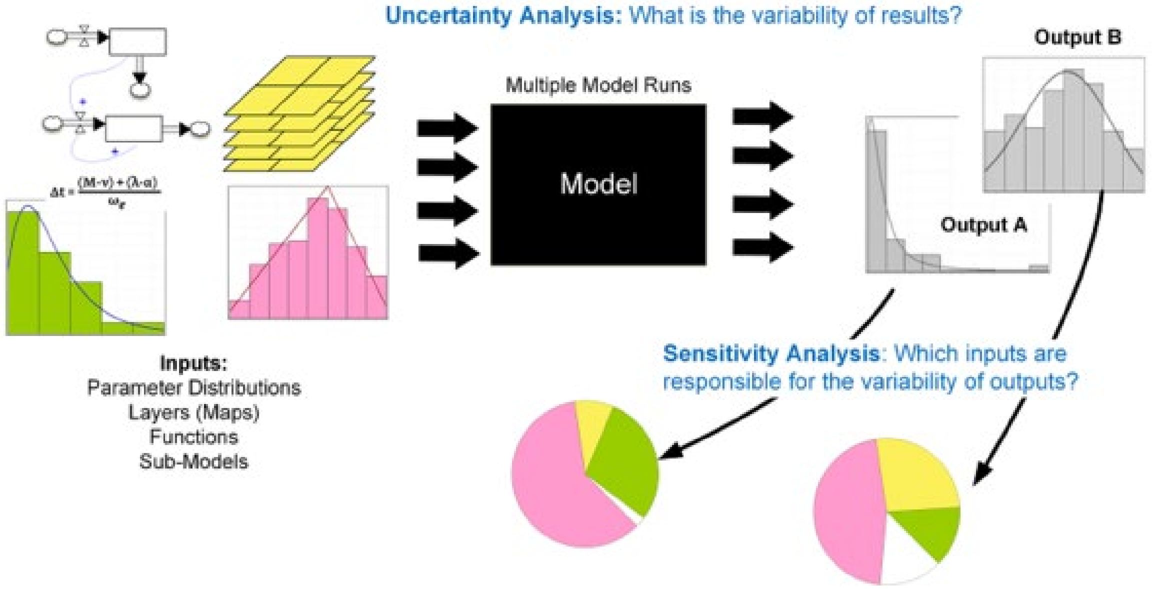
Sensitivity Analysis

- A "what if" technique that examines how a result will change if the original predicted data are not achieved or if an underlying assumption changes



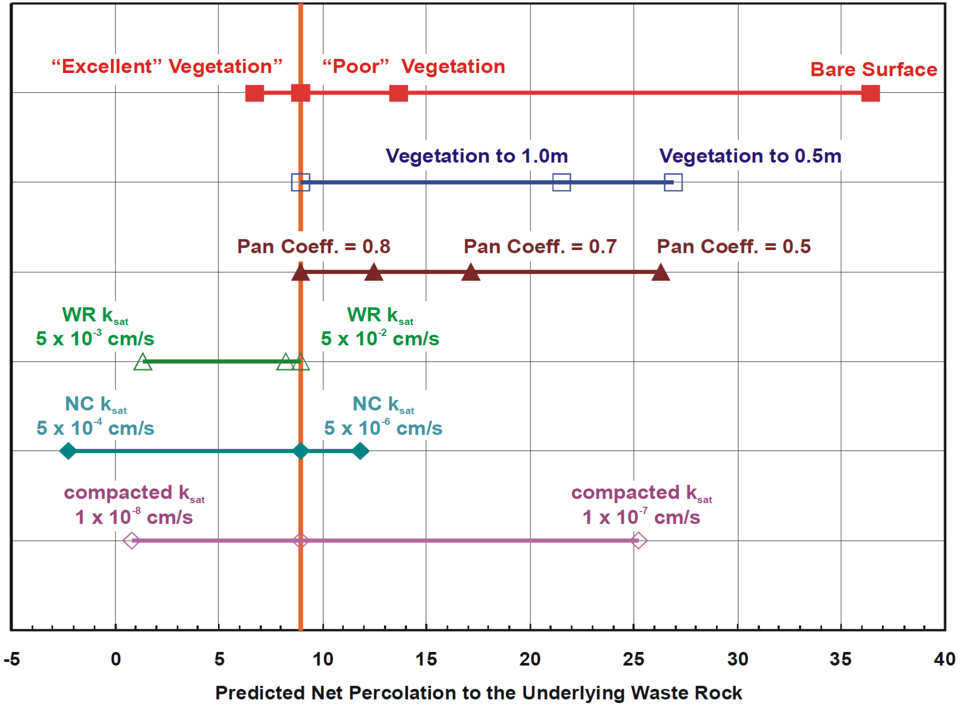
Traditional Avg/Max/Min Approach

Case #	Scenario	Yearly Net Percolation (% Annual Precip.)		
		Max.	Min.	Avg.
1	Base Case	35	0	8
2	Rainfall Allowed	35	0	8
3	Half Snow	21	0	3
4	Double Snow	69	0	20

- Historically most common approach
- Bookend uncertainty range
- Most misunderstood
- Very limited application in todays world

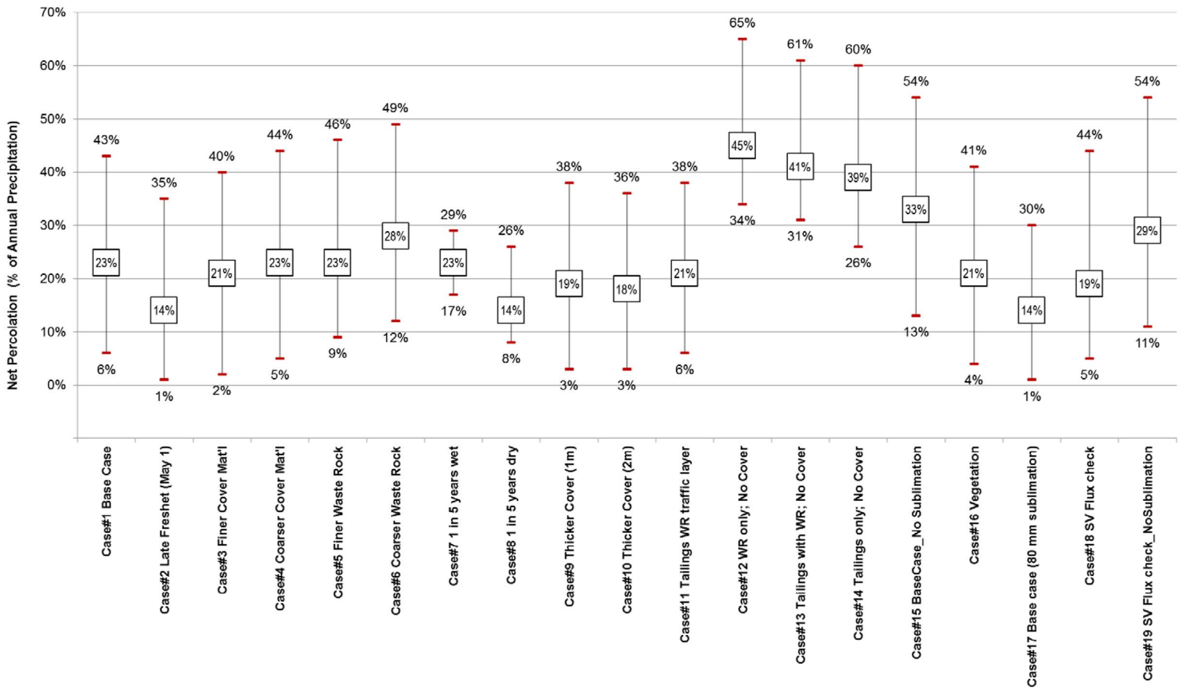
Tornado Plot Approach

- Accepted practice to present relative effect of different types of uncertainties
- Remains good approach to easily determine key system drivers



Box & Whisker Approach

- Bookend approach
- Good visualization of uncertainty outliers and range
- Simplifies uncertainty communication to non-technical stakeholders



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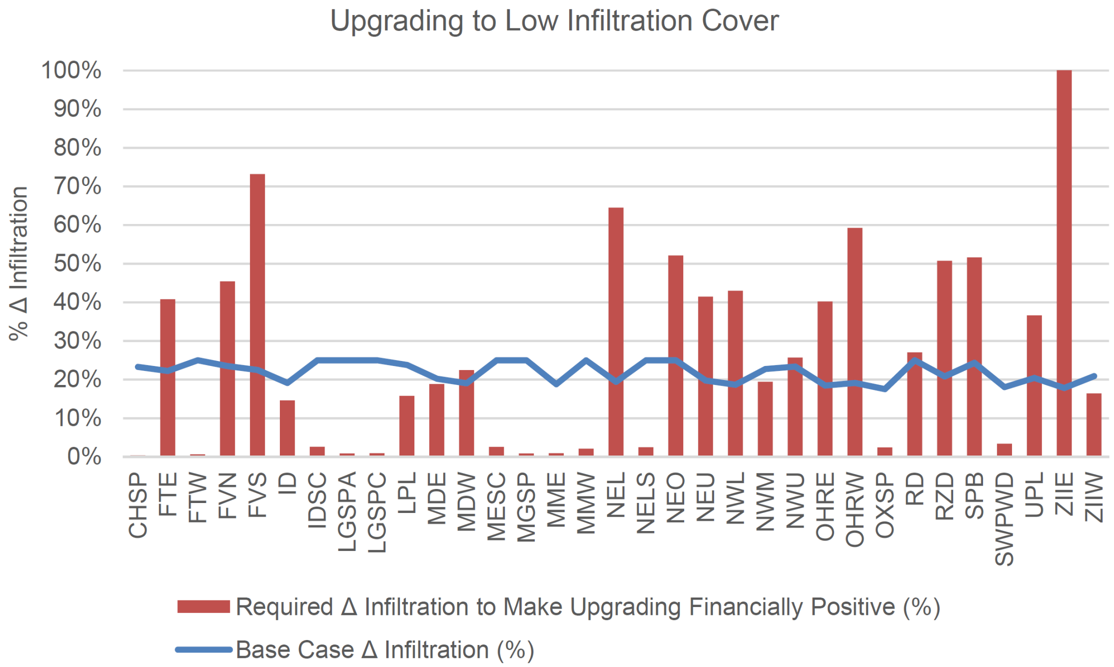
Counter Sensitivity Approach

- Approach is to check what uncertainties would "break" the model and evaluate the plausibility thereof
- Takes out guesswork in establishing sensitivity parameters
- Good way to communicate "red herrings"



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Limitation of all Sensitivity Approaches

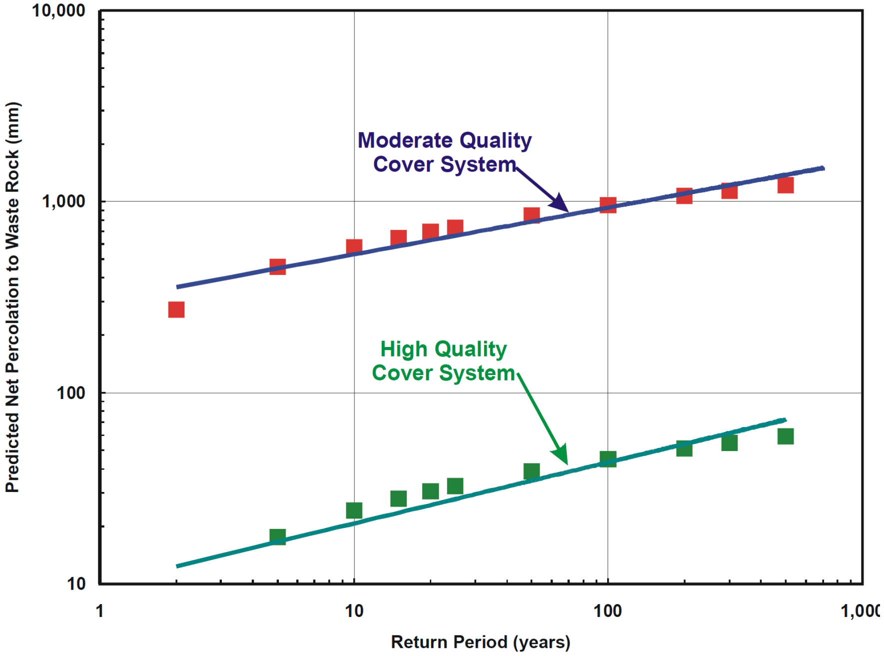
No weighting of uncertainties across parameters range

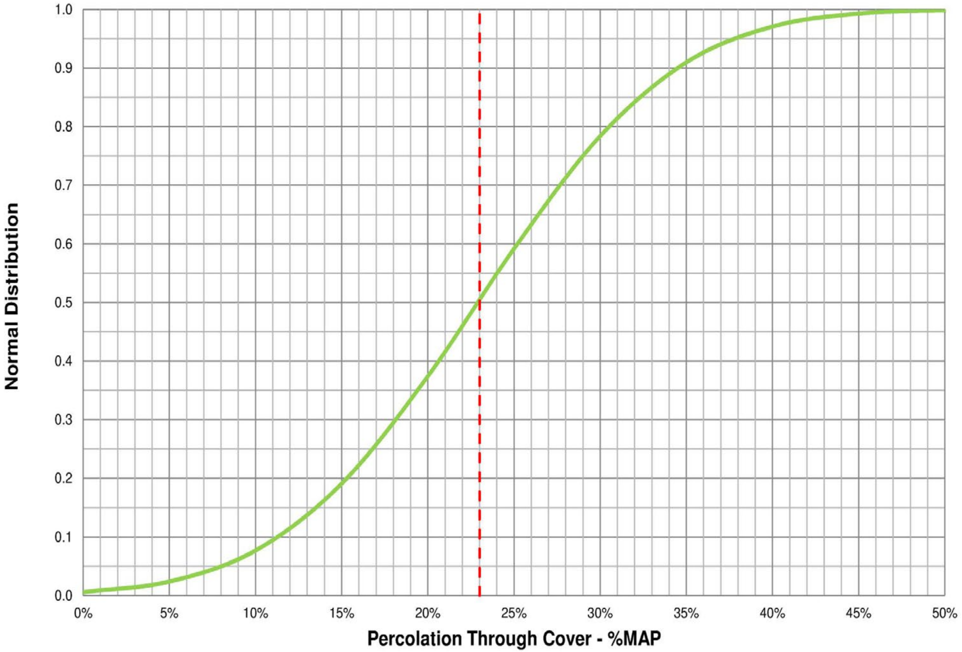
No weighting of uncertainties relative to each other

Bottom and top end result equally likely to occur

Communication of results to non technical stakeholders very challenging

Solution: Probability Approach





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Challenge with Probability Approach

- Broad Range of Uncertainties
  - Material heterogeneity & evolution
  - Climate variability and change
  - Antecedent moisture changes
  - Vegetation & land use change
  - Geochemistry change

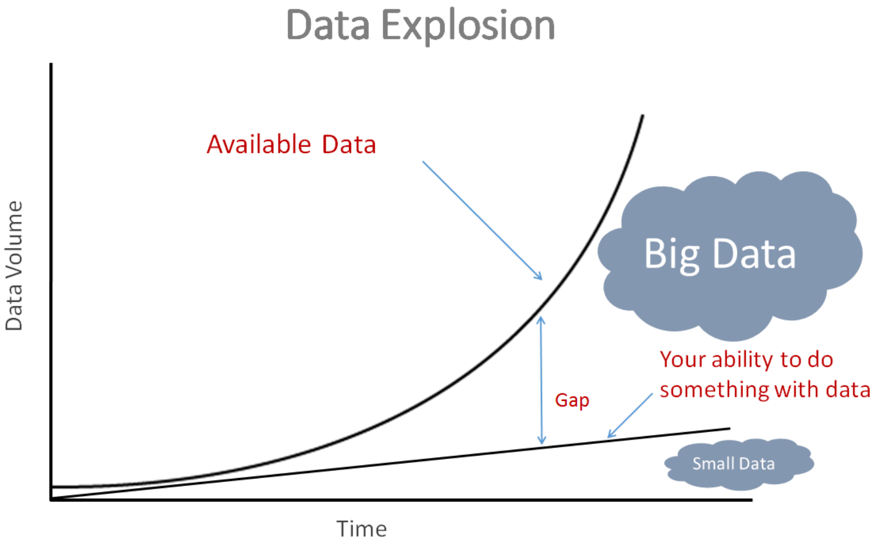
- Complex Numerical Solution
  - Highly non-linear
  - Time consuming and thus expensive

Solution: Advances in Computing

- Step 1: Data Management
- Step 2: Stochastic Modeling
- Step 3: Probability Distributions
- Step 4: Communicating Results

Data Explosion

- Temporal datasets grown exponentially
- Centralization via cloud-based computing (e.g. Amazon)
- Offers ready access but causes:
  - **Drain on time:** calculations involving big data is time consuming using spreadsheets
  - **Data processing limitations:** spreadsheet size limitations
- Require paradigm shift to access and process big data
- Two types of new tools:
  - Accessing data from external sources
  - Processing data and facilitating interpretation



Data Access Tools

- Access facilitated through Structured Query Language (SQL) routines
- Single commands, and no requirement to understand underlying database indexing
- Routines simple to write and use by engineers (with help from database professionals)

Data Processing Tools

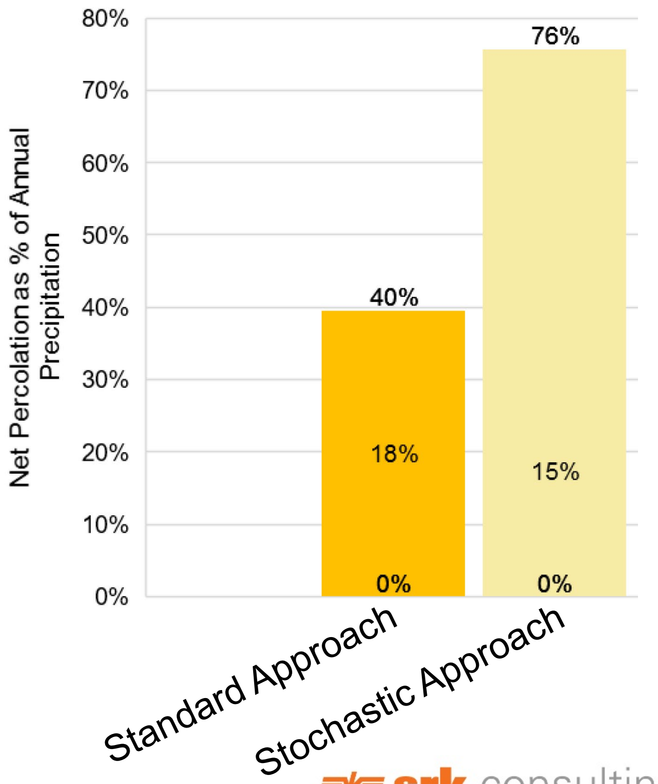
- Processing and analysis of big data can be done in one of two settings
  - Purpose built Graphic User Interfaces (GUIs)
    - GUIs can be more user-friendly but it lacks flexibility since analysis routines are limited to the imagination of the original programmers
  - Script-based programming
    - Script-based programming greatly increases flexibility by allowing direct editing of mathematical routines
    - Done through user-friendly programming languages, such as Python or R
    - Once mastered, it is relatively simple leap to advanced procedures that involve machine learning and neural networks

Stochastic Modeling

- Stochastic modelling based on premise of simulating phenomenon using random variables to gain a better understanding of output uncertainty
- Its core is the Monte Carlo method
  - Generating multiple realizations of problem through random sampling of input variables
  - Probability distributions for inputs are predefined and randomly sampled
  - Inputs repeatedly fed into deterministic equations and results integrated

Stochastic Modeling: Cover Example

- Goal was to model infiltration through cover system
- Used calibrated surface flux boundary model
- Generated variable inputs to allow Monte Carlo simulation
- Developed Python script to call and run models with variable inputs
- Script extracts results of each model to allow probabilistic expression of result



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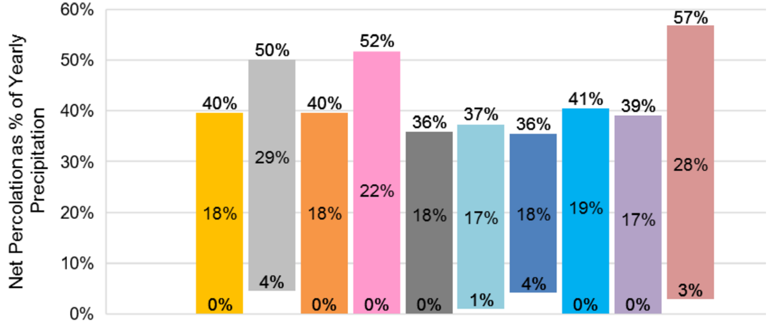
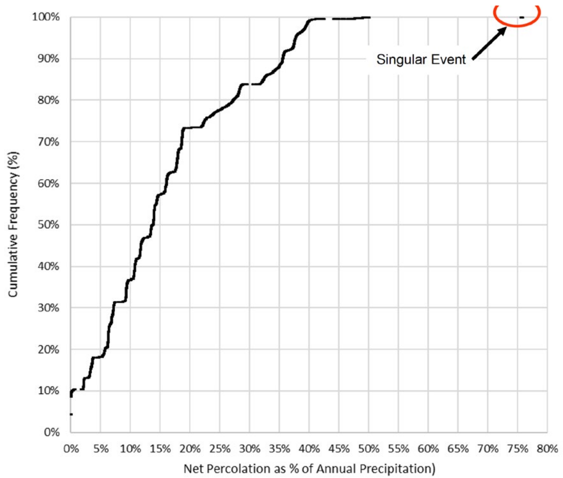
Cover Example Outcome





- Traditional approach suggested infiltration range between 0% and 60% of annual precipitation with all options equally weighted
- Stochastic approach demonstrated that there was a 90% probability that infiltration would be less than 35% of annual precipitation
- Less than 1% chance of infiltration approaching 60%

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Cover Example: Benefits

- We could run thousands of models with the push of a button
- Inputs and outputs are automated
- Results are presented as probabilistic ranges which allows for more informed communication of risks
- Ability to make informed engineering and cost decisions are greatly improved and easier to reconcile with engineering judgement

Closing Comments

- Every model should yield a result of 42!
- 42 means “the answer reflects the range of uncertainty of our problem”
- We have powerful tools to allow us to batch process large numbers of models to allow stochastic modeling
- The value proposition is improved understanding and communication of uncertainty

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