LEVERAGING OPEN SOURCE OPTIONS TO IMPROVE GROUNDWATER MODELING CAPABILITIES, VALIDATION, AND VERIFICATION

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Parsons

Groundwater Modeling: Advancements and Applications

AGENDA

Introduction

Advances in Modeling

1. Deterministic vs Probabilistic

2. Advances

- PEST, PEST ++, PEST_HP
- Iterative Ensemble Smoother

3. Utilities – GUI's

Comparison of Groundwater modeling methods

- Spreadsheets
- Commercial Products
- FloPy
- Fortran

Advantages and Disadvantages of Open Source compared to Closed Source commercial products

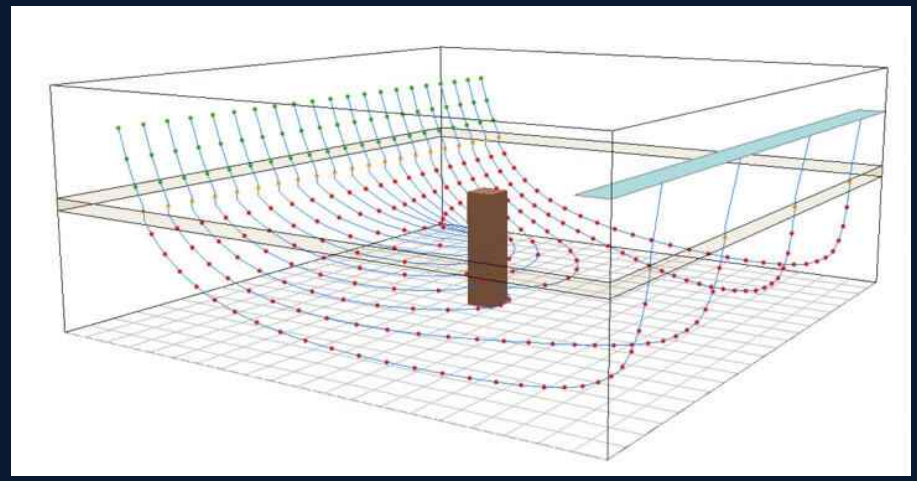
INTRODUCTION

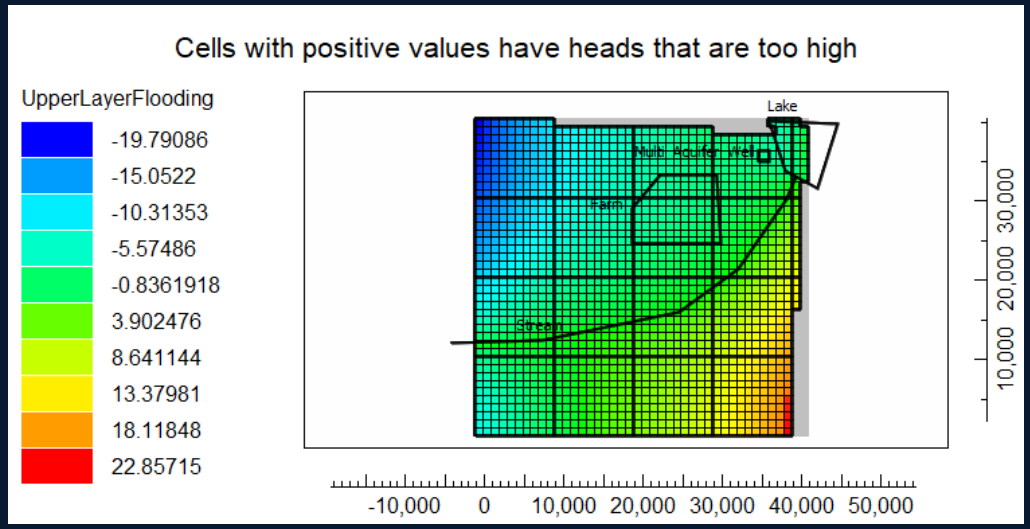
Groundwater Modeling usages

I. Fate and Transport Modeling
    I. Transport packages and MODPATH can achieve this

II. Remedial technique decision making
    I. Modeling different scenarios of groundwater flow and effects on the water table

III. Groundwater elevation forecasting
    I. Predicting water table characteristics through time





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DETERMINISTIC MODELS

Deterministic models have “one” answer

These model types have no prior distribution component and produce the same output every time

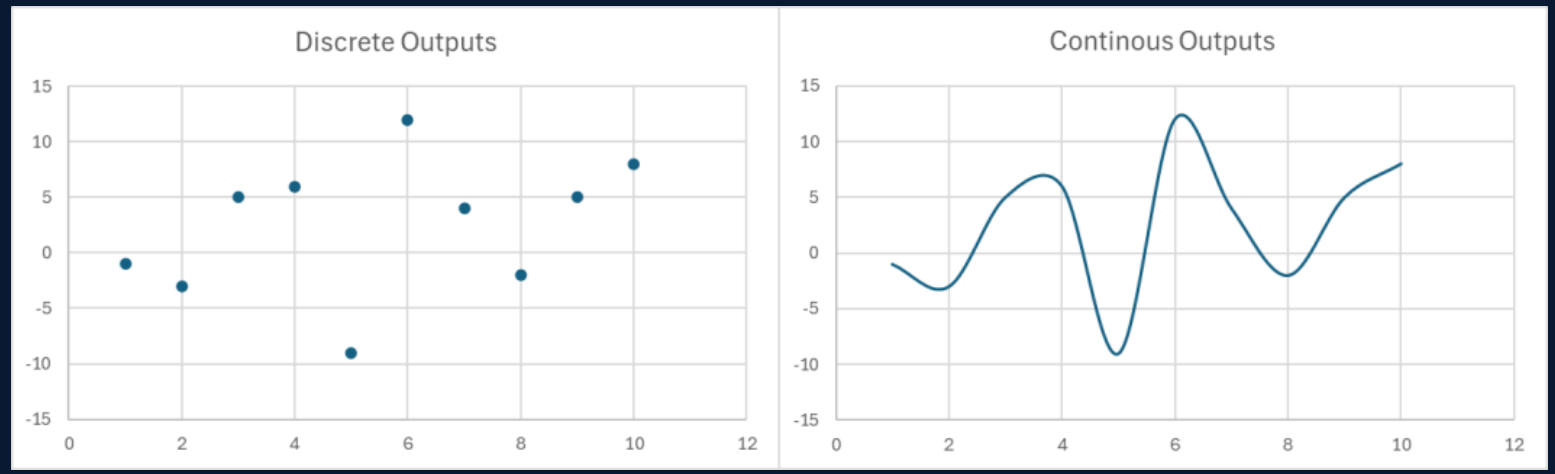
Models are based on differential equations that describe systems, but require large amounts of data to ascertain adequate results

Model outputs can be “continuous” or “discrete”

Deterministic models tells you “Based off of your question, this is the answer”

Steady state, heterogenous, anisotropic

Same inputs yield identical results



PROBABILISTIC MODELS

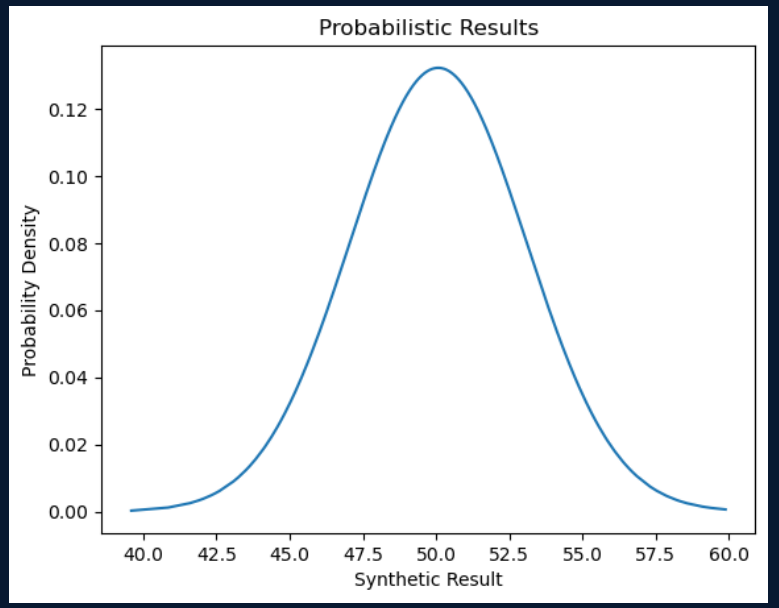
Probabilistic (Stochastic) models have multiple probable answers

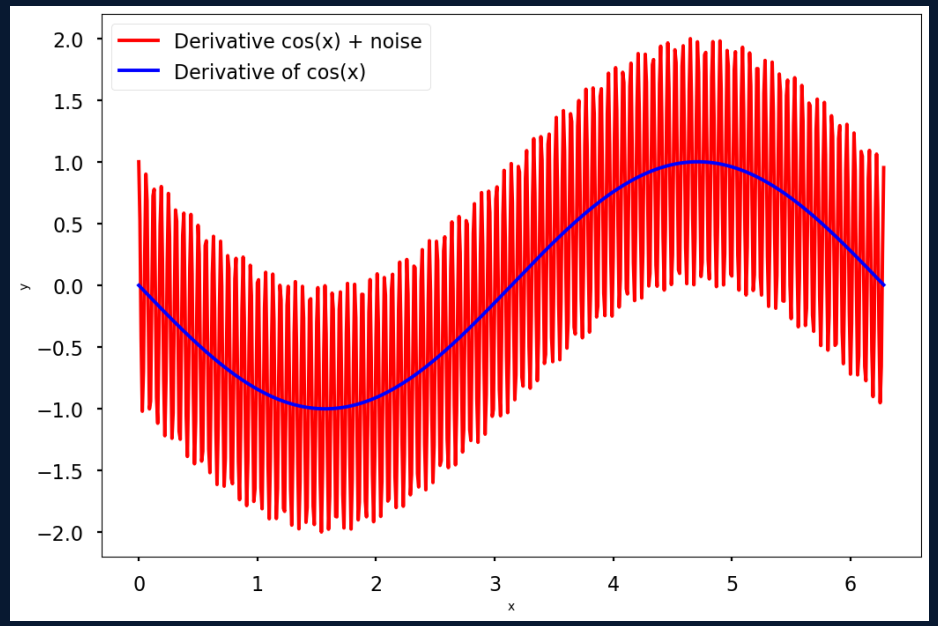
Stochastic models implement randomness and noise to obtain numerous results

Models consider data sample sizes, uncertainty in data parameters, and intangibles (inputs that can't be quantified) when solving for model outputs

Model outputs can be "continuous" or "discrete"

Stochastic models will tell you "Based off of your question, this is a suite of probable answers"



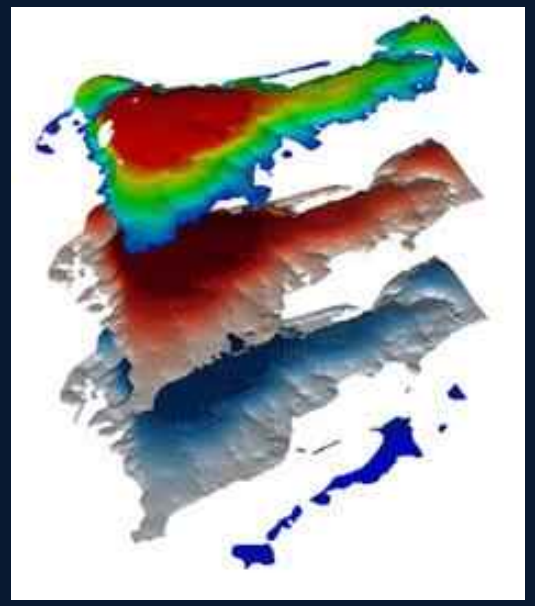


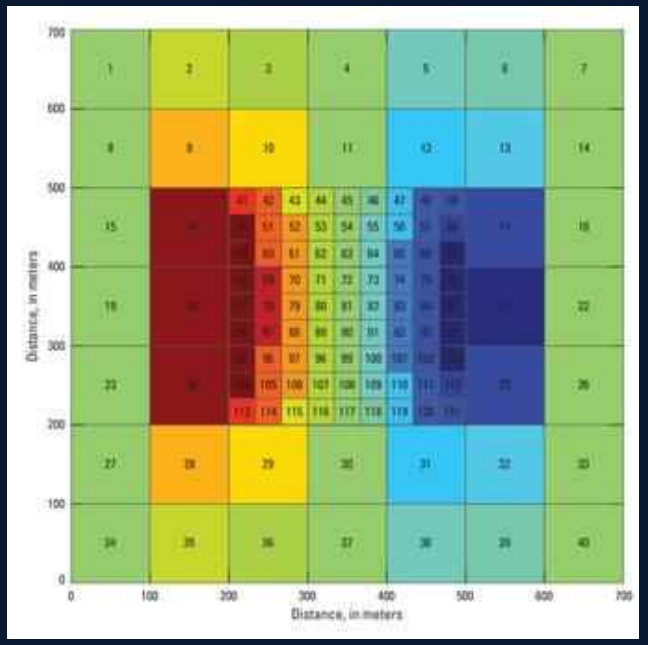
DETERMINISTIC AND STOCHASTIC MODELING IN GROUNDWATER MODELING

Groundwater modeling is typically used with MODFLOW, through various versions (MODFLOW 2005, MODFLOW-USG, MODFLOW-6, etc.)

MODFLOW is an inherently deterministic model that will determine model outputs identically with identical inputs between model runs

To improve model calibration without intensive data collection and implementation, Stochasticity needs to be introduced





Standard MODFLOW parameters
Hydraulic Conductivity
Storage and Storativity
Recharge (Infiltration)
Constant head boundaries

Image credits USGS

ADVANCES IN MODELING

Improvements in stochastic modeling have occurred in recent years.

I. PEST
    I. Parameter Estimation Tool
II. PEST_HP
    I. Highly parallelized environment
III. PESTPP
    I. Iterative Ensemble Smoother

PEST – Parameter Estimation Tool

Uses model parameters as inputs and solves the model using a wide range of inputs and reduces uncertainty in the model parameters

PEST_HP – Highly Parallelized Environment

Similar to PEST, but has been optimized for parallel model runs; allowing for faster estimation of parameters and reduction of the uncertainty

PESTPP – Iterative Ensemble Smoother

Uses a Kalman Smoother, optimized for posterior uncertainty analysis in cases where non-linearity exists between model parameters and outputs – creating a parameter field based off the uncertainty of the prior

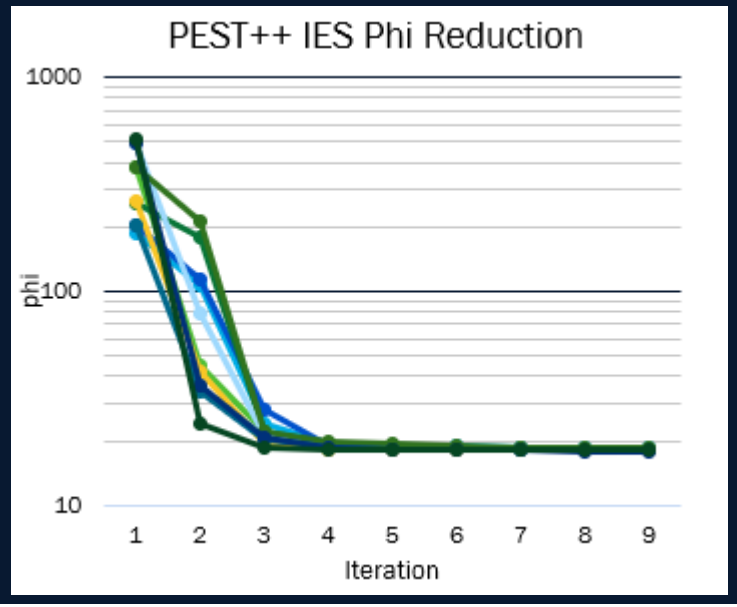
ADVANCES IN MODELING

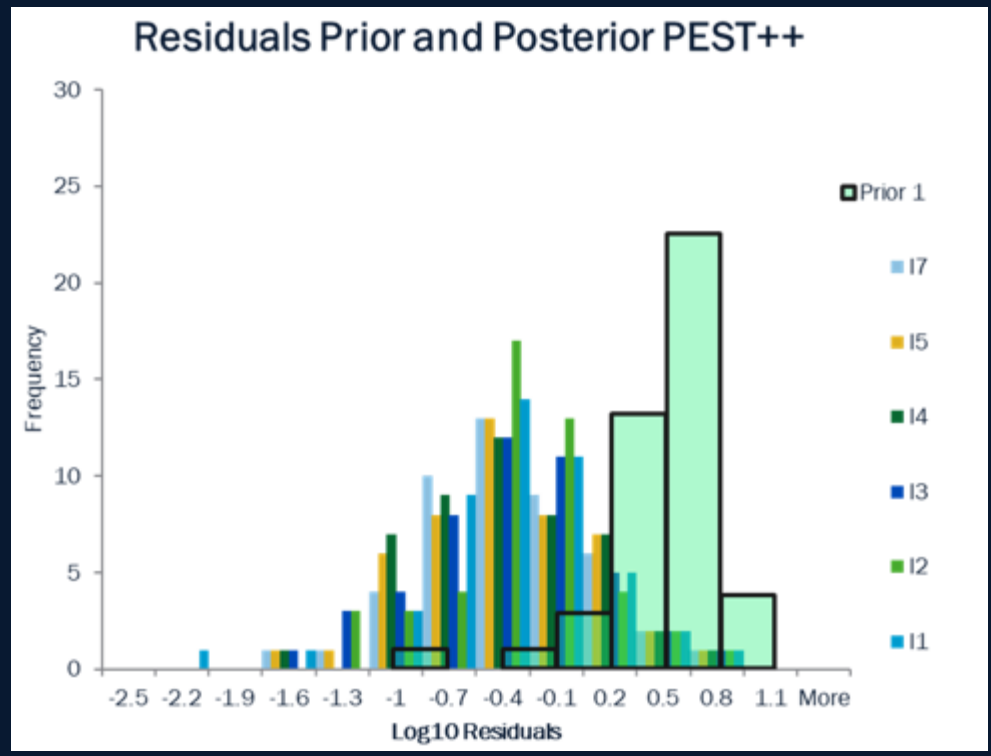
User supplies samples of the prior parameter probability distribution

PEST++ runs an iterative parameter adjustment process

Samples become part of posterior parameter probability distribution

Generation of a suite of random parameter fields can be generated to process a field of model outputs and conduct uncertainty analysis



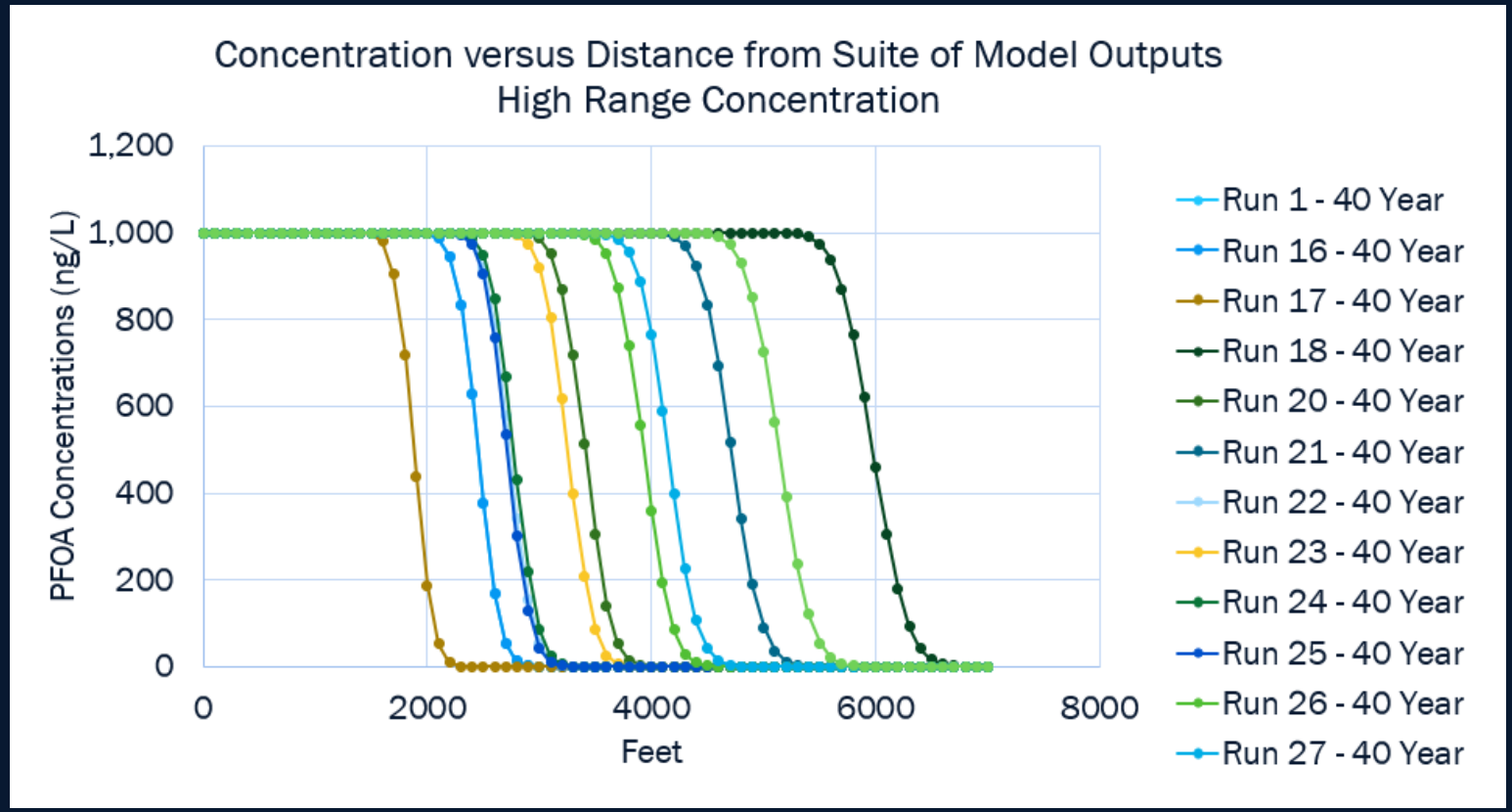


ADVANCES IN MODELING

A suite of results is obtained using a stochastic model

Using this suite of results, uncertainty can be derived through model calibration

Evaluating uncertainty of multiple possible scenarios can allow for more succinct parameter estimations

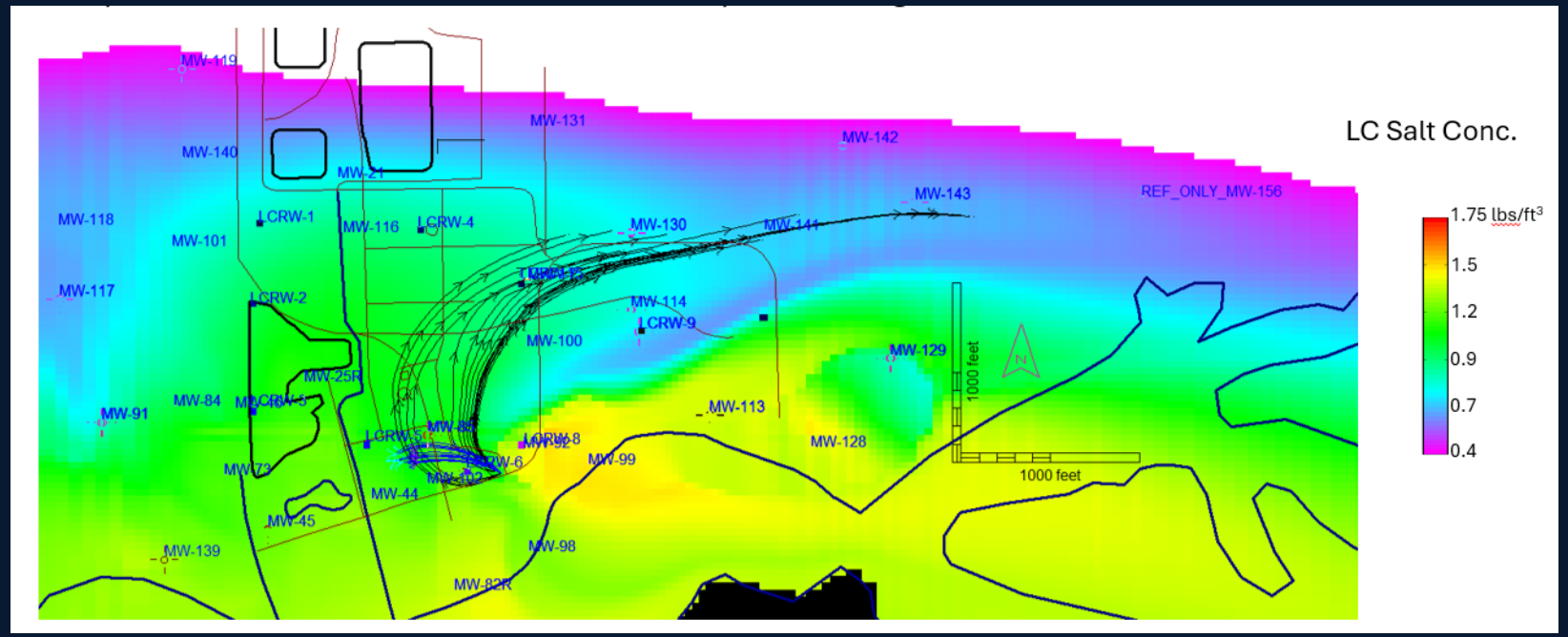


ADVANCES IN MODELING

Density effects can be modeled with greater accuracy leveraging stochastic methods

MODFLOW-USG has transport functions built in that provide more intuitive Fate and Transport modeling previously requiring a coupled model.

Site Example: Redirection of groundwater plume parallel to River



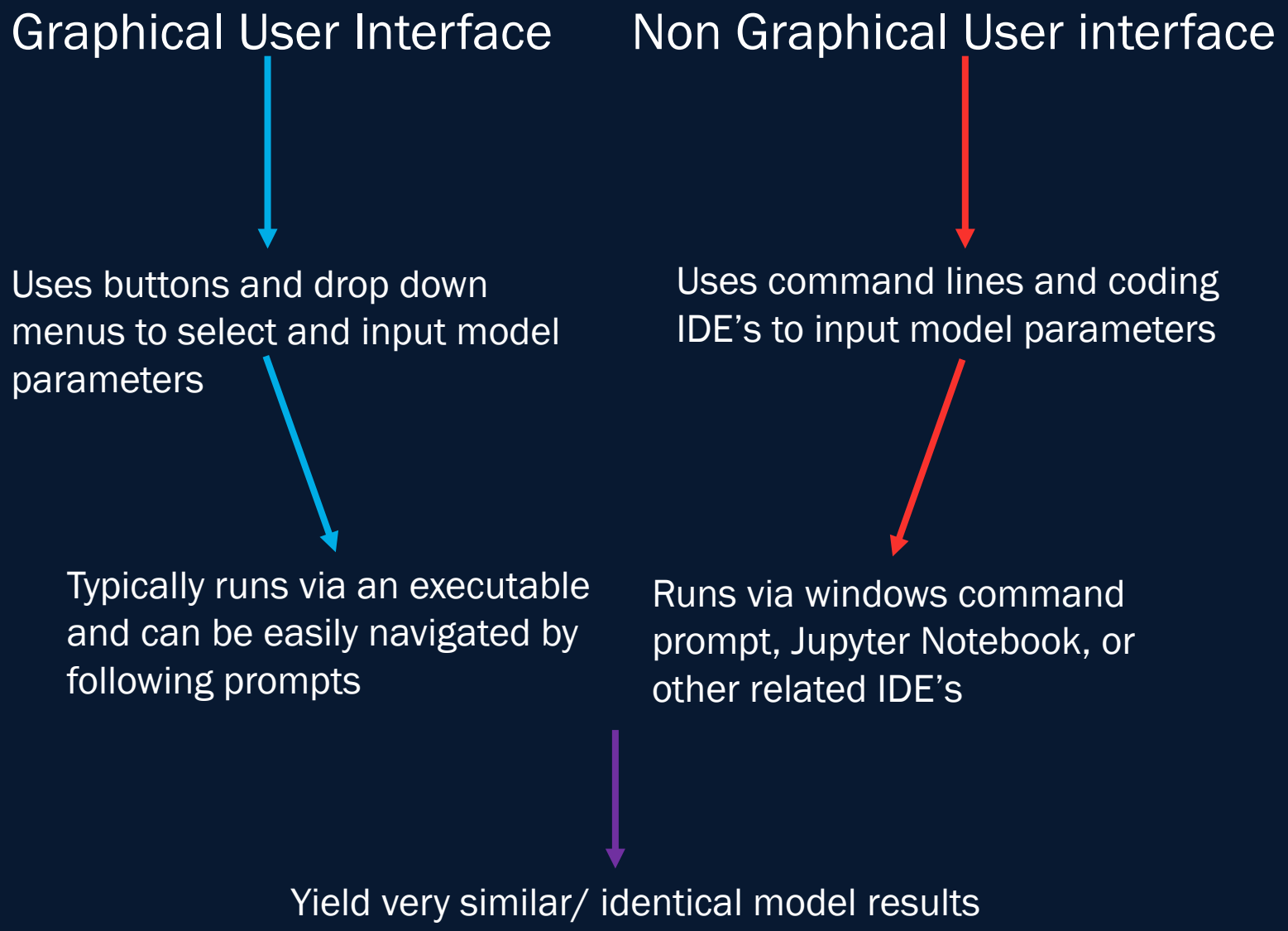
UTILITIES – GRAPHICAL USER INTERFACES

There are more than one option for creating a groundwater model with MODFLOW

I. Graphical User Interfaces (GUI)
   I. Commercial Products
   II. Model Muse
   III. Visual MODFLOW

II. Non Graphical User Interfaces
   I. Spreadsheets
   II. FloPy
   III. Fortran

There are advantages and disadvantages for the various methods



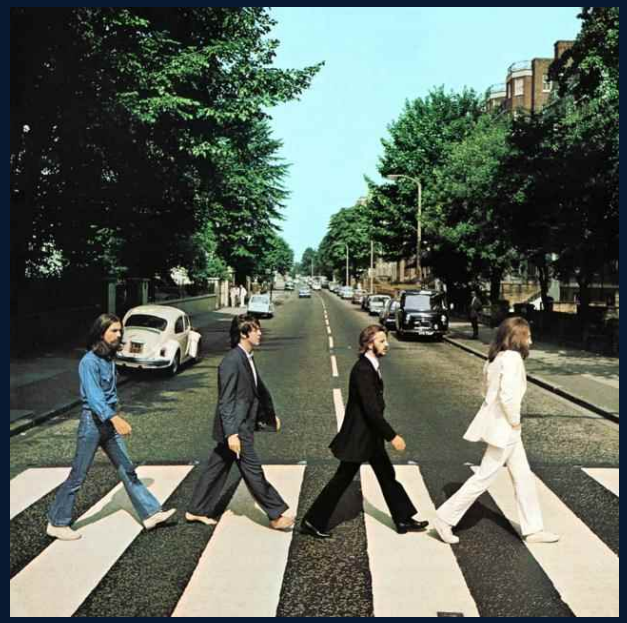
MODELING VEHICLES

Spreadsheets are similar to walking to your destination

Closed source commercial products with GUI's are like taking a bus, they will get you to your destination but the path is more rigid with less customization

FloPy is a Tesla, it can get you where you are going, is customizable, and is the new standard of non-GUI modeling

Fortran is the red Ferrari from Magnum PI. A classic that has everything needed and is well revered. But it is becoming dated



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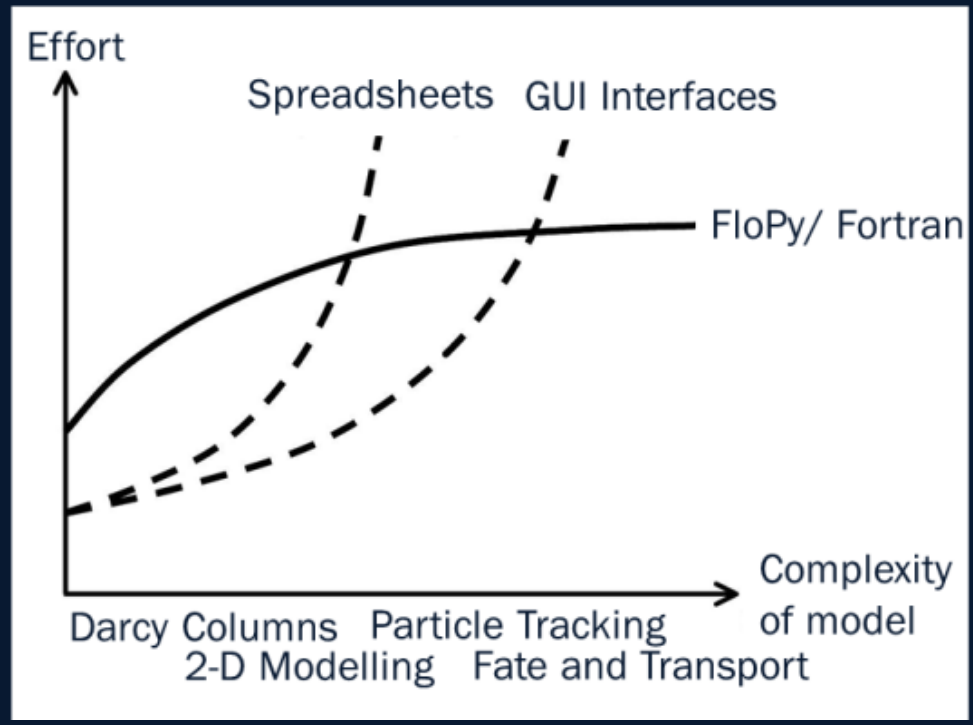
COMPARING OPEN SOURCE TO CLOSED SOURCE

Different methods provide different results when creating a model

Open source methods are typically inexpensive/free but have learning curves associated with their use

Closed source methods can be easier to pick up and provide improved visualization, but sacrifice usability of model features

Open Source	Closed Source
Expanded flexibility in model domain discretization	Easier to pick up for non experts
Can have faster run times	Background processes create data files
Free to use and publicly available	Improved visualization while creating model
Model runs can be highly customizable	“One Stop Shop”



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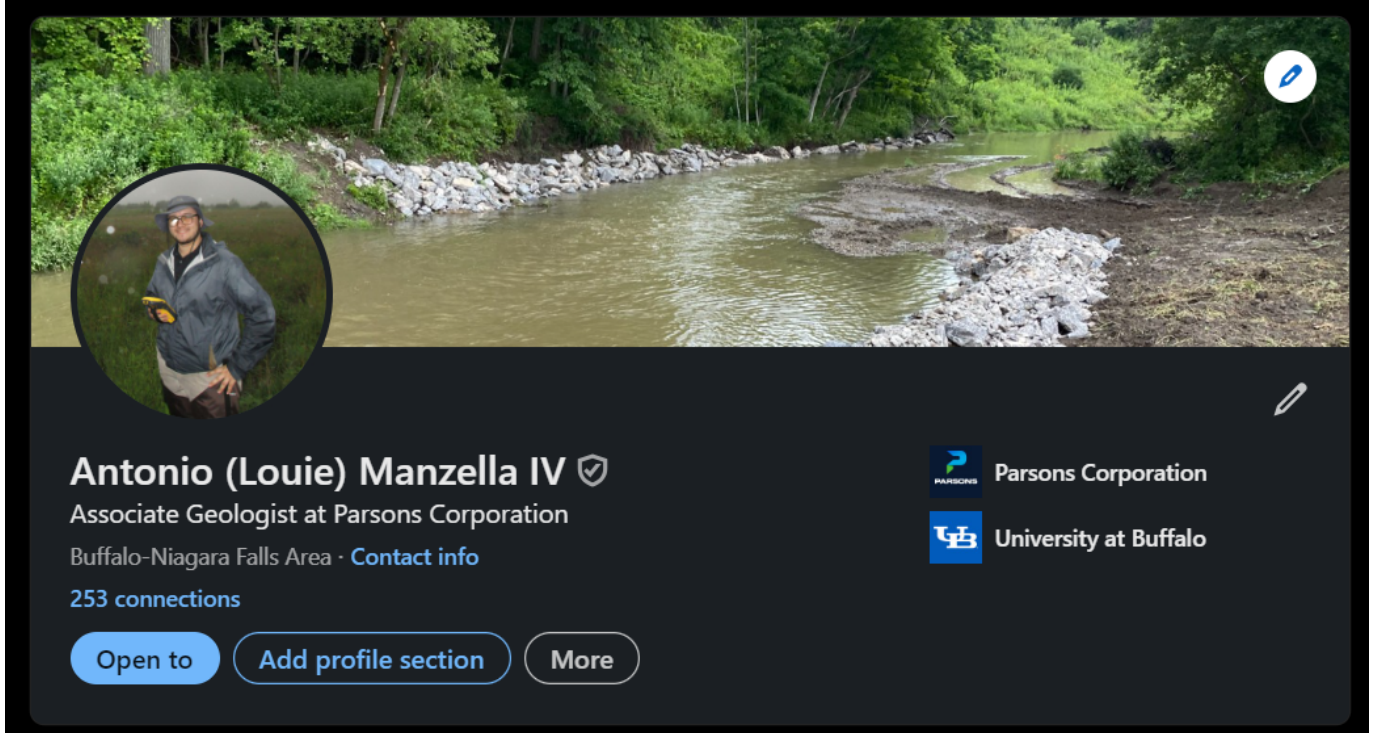
THANKS FOR ATTENDING MY PRESENTATION



ACKNOWLEDGEMENTS TO FELLOW PARSONS STAFF AND JAMES SCHUETZ FOR ENCOURAGEMENT AND SUPPORT

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