Hydraulic groundwater modeling

- Week 1

- Introduction to (prognostic, numerical) modeling

Course structure

- Week 1: Introduction to (numerical) modeling
- Week 2: Governing equations for groundwater flow
- Week 3: From the field application to simulation
- Week 4: Spatial discretization techniques
- Week 5: Temporal discretization and stability concerns
- Week 6: Features of realistic groundwater models

Separating different kinds of models

- **Conceptual**: A schematic approximation of a system used to understand its character
- **Analog / Sandbox**: A reproduction of the natural system with reduced scale and complexity to study a singular phenomenon
- **Physical / Mathematical**: A set of governing equations and constitutive relationships with suitable boundary and initial conditions to describe the natural setting
- **Numerical**: A computer-based approximation of the mathematical model

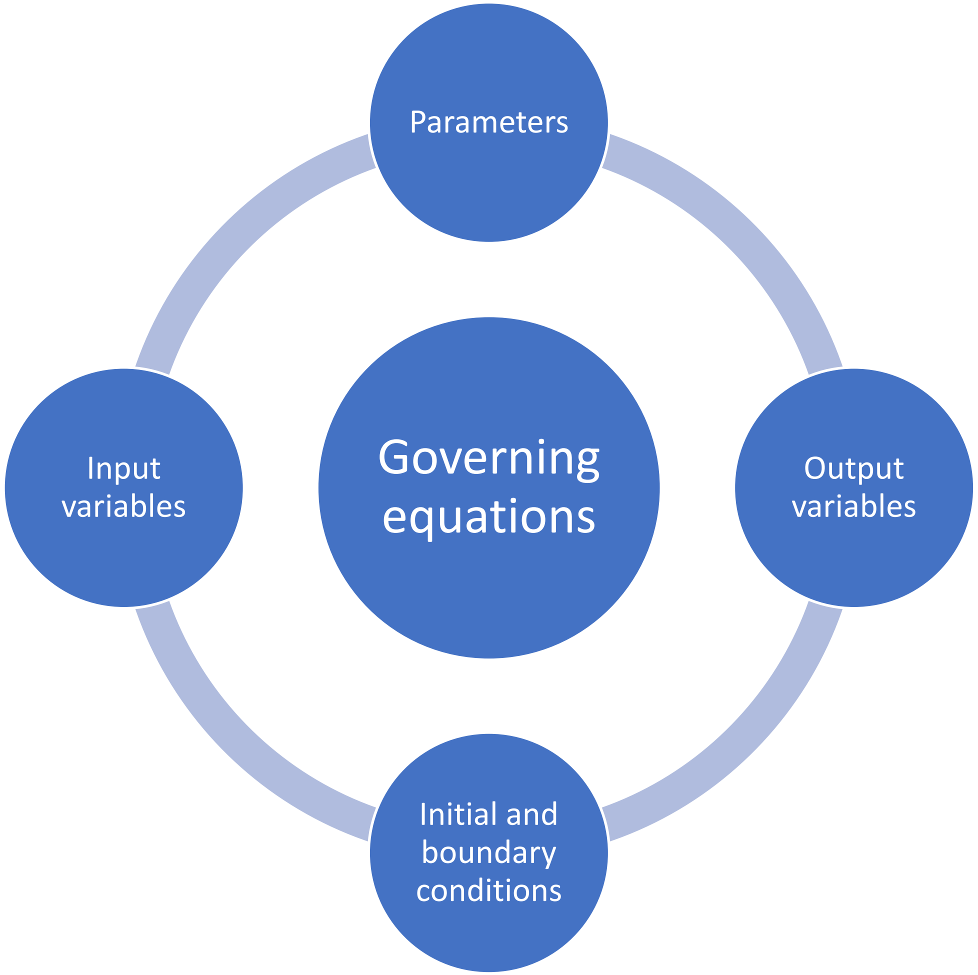
Models…

- test a hypothesis
- reduce complexity
- isolate processes
- assess quantities not accessible in the field
- enable scenario testing and parameter variations

Mathematical and numerical modeling

- Most natural problems lack an analytical solution, due to:
  - Geometrical complexity (heterogeneity)
  - Initial and boundary conditions
  - Coupled mathematical equations
- Numerical approximation: Discrete points in time and space
  - Easy scenario testing
  - Isolate physical processes
  - Study non measurable quantities
- Improved process understanding

Concept of mathematical modeling



Deterministic and stochastic models

- Deterministic model:
  - all variables are free from random variation
  - model follows a definite law of certainty
  - Cause – effect relationship
- Stochastic model:
  - any of the variables are random variables with distribution of probability
  - using linear/multiple correlations and regressions to relate dependent (e.g., discharge) to independent variables (e.g. precipitation).
- Mixed form
  - Use stochastic distribution of parameters / IC / BC in a deterministic model (e.g., for representing heterogeneity)

Empirical models

- Based on observation and result.
- NOT based on physical laws.
- Based on regression between input (e.g. precipitation) and output (e.g. discharge).
- Coefficients are determined through calibration.
- Coefficients do not have a physically sound meaning.
- Only valid for the calibrated data set!
- Used if little is known about the processes.

Inverse and prognostic modeling

- Prognostic / Forward modeling: From model to data
  - Parameters, physical processes given.
  - Calculate variables (pressure, temperature).

- Inverse modeling: From data to model
  - Measured values used to estimate parameters of the subsurface
  - Includes a forward operator
  - Iterative procedure
  - Stationary or quasi-transient solutions
  - Primarily used in Geophysics and Meteorology

Transient and stationary models

- Definitions based on temporal evolution
- If the model is time dependent, it is called:
  - transient, dynamic, unsteady, non-steady state, non-stationary.

- If the model is time independent, it is called:
  - stationary, steady, steady state.

- Quasi-transient models are a succession of stationary situations.

Verification and validation

- A numerical model needs to be verified and validated!
- Verification:
  - Process of confirming that the model is correctly implemented with respect to the conceptual model (software bugs, etc.), e.g., done by comparison with analytical solution.
  - True for commercial software and most professional tools.
- Validation:
  - Checking that the model has a satisfactory range of accuracy within its domain of applicability consistent with the intended application of the model. This includes its parameterization, geometry and physical assumptions.
  - Needs to be done for each single model application!

Lessons learned

- So many different kinds of models (learn the vocabulary)!