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Student Exercise – Subsurface Heterogeneity

Groundwater occurs in the geological formations of the subsurface. An understanding of how geological materials are distributed, how they formed, and the changes they have undergone is therefore of key importance to hydrogeologists, groundwater hydrologists, etc. In this exercise, we review the different processes that generate different geologic features/patterns, and explore ways for qualitatively and quantitatively characterizing the heterogeneity of the subsurface.

Students will answer all the critical questions that follow (or a subset, depending on the Instructor's discretion). A possible format for delivering student work is to submit a short, organized response (or Memo) that includes:

- A summary of the basic information covered in this exercise;
- Responses to all assigned questions;
- A discussion of broader implications (management and societal implications); and
- Any necessary technical material, appended as a Memo attachment.

PART I – FUNDAMENTALS OF REAL-WORLD HETEROGENEITY

Visit the Real World Heterogeneity Research Videos available in the MAGNET4WATER Digital Library: https://www.magnet4water.com/real-world-heterogeneity.html. View the contents the following subtabs:

- Salt River Bed, Arizona-1; Salt River Bed, Arizona-2; Salt River Bed, Arizona-3
- Sand and Gravel Aquifer, Switzerland
- Hunter Valley, Australia-1; Hunter Valley, Australia-2;
- Larger Hunter Valley, Australia-3; Larger Hunter Valley, Australia-4; …

<u>Question 1</u>

1a. Briefly describe the patterns / distributions of geologic materials shown in the different pictures. Consider: directionality; size of materials; scales of variability.

1b. What sort of geologic processes are responsible for these patterns / distributions of geologic materials? Be concise but clear. (HINT: Consider both continental environments and marine Environments)

Porosity and Permeability

Define porosity, hydraulic conductivity

View the contents for the following subtabs:

- Mt. Simon Aquifer, Illinois
- Roswell Basin, New Mexico'
- Borden Aquifer-1, Canada; Borden Aquifer-2;

<u>Question 2</u>

2a. In general, how does variability of porosity compare variability of permeability? Refer to / describe the specific examples presented in the subtabs listed directly above.

2b. How does the variability of groundwater levels and streamflow compare to geologic variability (porosity and permeability)?

2c. What challenges do these various scales of variability present in characterizing the subsurface at a site?

PART II – EMPIRICAL and SEMI-ANALYTICAL APPROACHES

Motivation: Small-scale heterogeneity (locally, isotropic) -> large-scale anisotropy (water resource perspective)

Effective parameters -> K averaged in horizontal, vertical directions

Kozeny-Carmen Equation

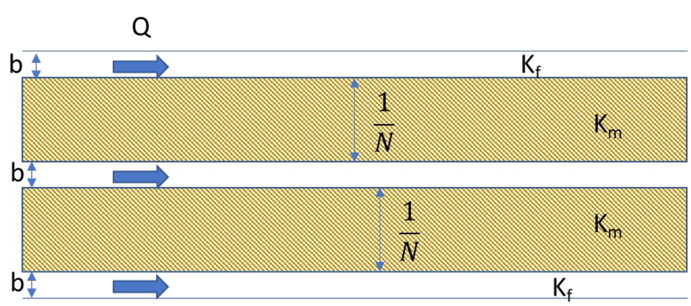
Hazen Equation

Gelhart (General)

Cubic Law (Flow in Fractured Rocks)

Show: Flow through fractured rock is proportional to the aperture (fracture) width.

where q is… J is…K_e is



B – fracture width

N – fractures per meter

K_m – conductivity of the solid rock matrix

K_f – conductivity of the fracture

Q – total volumetric flow through the rock

As discussed above, when flow is parallel to flow, effective hydraulic conductivity is calculated as

Typically, the fracture width is much less than the distance between fractures:

So that:

Also, the hydraulic conductivity of a fracture is typically much, much greater than that of the solid rock matrix:

So that:

Romm (1966) showed that for laminar flow between to smooth parallel plates (which we will use to represent an individual fracture) can be expressed as:

Therefore, combing (#) with (##)

The effective hydraulic conductivity of fluid flow through fractured rock is proportional to the cube of the fracture aperture (width). Thus, for a given gradient in head, flow through fractured rock is proportional to the cube of the fracture width.

Question 3

Briefly explain, in plain English language, the derivation of the Cubic Law.

PART III – STATISTICAL HETEROGENEITY

- Effects of K variability, correlation scales
- Plume spreading under different K realizations
  - Plume size is *O*(scale of variability)
  - Plume size is larger than the scale of variability
- Effects of anisotropic heterogeneity in vertical cross sections

  - $\Lambda_x >> \lambda_y$, $\Lambda_x \approx \lambda_y$

- Effects of multiple scales of K variability
- Impacts of pore-scale dispersion
- Impacts of porosity variabilities
- Impacts of partitioning coefficient
- Effects of interacting heterogeneities/variabilities