CEE 491/591 — Groundwater Hydrology
Assignment 4: Hydraulic Conductivity and Layered Systems

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Module 3

Problem 1: Equivalent Hydraulic Conductivity and Flow in a Layered Aquifer (40 points)

A confined aquifer system consists of five horizontal, homogeneous, isotropic strata as described in the table below.

Layer	**Thickness, b_i (m)**	**K_i (m/day)**	**Soil Type**
1 (top)	4.0	8.5	Coarse sand
2	1.5	0.003	Clay
3	6.0	5.0	Medium sand
4	2.0	0.05	Silt
5 (bottom)	8.0	12.0	Gravel

(a) Compute the **equivalent horizontal hydraulic conductivity** K_h for the formation.

(b) Compute the **equivalent vertical hydraulic conductivity** K_v for the formation.

(c) Compute the **anisotropy ratio** K_h/K_v and comment on which layer(s) dominate the horizontal conductivity and which dominate the vertical conductivity.

(d) A regional hydraulic gradient of magnitude $|\nabla h| = 0.006$ is measured at an angle of 45° from the horizontal (i.e., equal horizontal and vertical gradient components). Compute the **horizontal and vertical components of the Darcy flux** (q_x and q_y), and determine the **magnitude and direction** of the resulting Darcy flux vector.

(e) Flow crosses from Layer 1 (coarse sand) into Layer 2 (clay). If a streamline in Layer 1 makes an angle of $\theta_1 = 15^\circ$ with the normal to the interface, compute the **refracted angle** θ_2 in Layer 2. Sketch the streamline path and comment on the physical meaning of the result.

Problem 2: Estimating Hydraulic Conductivity from Grain Size and Lab Tests (35 points)

A grain-size analysis of a sandy aquifer yields $d_{10} = 0.18$ mm and $d_{50} = 0.42$ mm. The measured porosity is $n = 0.35$. Water properties are $\rho_w = 998$ kg/m^3, $\mu = 1.002 \times 10^{-3}$ N $\cdot$ s/m^2, and $g = 9.81$ m/s^2.

(a) Estimate the hydraulic conductivity using the **Hazen equation** ($K = C\,d_{10}^2$) with $C = 100$ (where d_{10} is in cm and K is in cm/s). Report the result in both cm/s and m/day.

(b) Estimate the hydraulic conductivity using the **Kozeny–Carman equation**:

$$K = \frac{\rho_w\, g}{\mu} \cdot \frac{n^3}{(1-n)^2} \cdot \frac{d_{50}^2}{180}$$

Report the result in both cm/s and m/day.

(c) Compare the two estimates and discuss possible reasons for any differences.

A constant-head permeameter test is then performed on an undisturbed core sample from the same aquifer. The sample has a length of $L = 25$ cm and a cross-sectional area of $A = 80$ cm^2. Under a constant head difference of $\Delta h = 32$ cm, a volume of $V = 650$ cm^3 of water is collected in $t = 5$ minutes.

(d) Using Darcy's law, compute the **hydraulic conductivity** from the permeameter test. Report the result in cm/s and m/day.

(e) Compare this lab-measured value with your estimates from parts (a) and (b). Which estimate (Hazen or Kozeny–Carman) is closer to the lab measurement? Discuss possible sources of discrepancy.

Problem 3: Flow in Fractured Rock (25 points)

Below a sandy aquifer lies a fractured granite bedrock. Borehole imaging reveals a set of parallel, roughly horizontal fractures with the following properties:

- Average fracture aperture: $b = 0.2$ mm
- Average fracture spacing: $s = 1.5$ m (i.e., $N = 1/s$ fractures per unit length)

Use $\rho_w = 998$ kg/m^3, $\mu = 1.002 \times 10^{-3}$ N $\cdot$ s/m^2, and $g = 9.81$ m/s^2.

(a) Compute the **effective hydraulic conductivity** of the fractured rock in the direction parallel to the fractures using the cubic law:

$$K = \frac{N\,\rho_w\, g\, b^3}{12\,\mu}$$

Report the result in m/s and m/day.

(b) The overlying sandy aquifer has a hydraulic conductivity of approximately 5 m/day (use this as a representative value). If a horizontal hydraulic gradient of 0.01 acts across both formations, compute the **Darcy flux** in each and comment on the relative flow contributions.

(c) If the fracture aperture were to **double** (to $b = 0.4$ mm) due to tectonic activity, by what factor would the effective hydraulic conductivity change? Explain why this sensitivity matters in practice.

Submission

- You must complete **all problems in Excel** with **all formulas in-place** (no hard-coded intermediate values).
- Organize your workbook with a **separate, clearly labeled sheet for each problem**.
- On each sheet, clearly label all inputs (given data), intermediate calculations, and final answers **with units**.
- Upload the `.xlsx` file to **Brightspace** $\rightarrow$ **Assignments**.