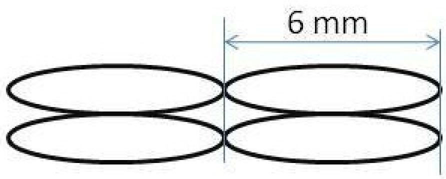
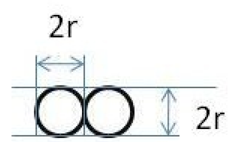
**Homework 1** - Due September 2, 2010

1. What is the porosity of a soil with ellipsoid grains arranged as follows? Let $r = 1.5$ mm represent the grain radius at its widest point. The volume of this ellipsoid is $V = 2\pi r^2 h/3$, where $h = 6$ mm is the length of the ellipsoid along the long axis.




(a) Plan view




(b) Side view

2. Provide a rough estimate (single value for each material) of the porosity of each of the following materials, and justify your values.
   (a) coarse sand
   (b) fine sand
   (c) mixture of coarse and fine sand

3. Three piezometers are installed in a confined aquifer to an elevation of 80 m above sea level. Piezometer A is located at $(x, y) = (1000 \text{ m}, 1000 \text{ m})$; Piezometer B is located at $(x, y) = (250 \text{ m}, 1500 \text{ m})$; and Piezometer C is located at $(x, y) = (-500 \text{ m}, 0 \text{ m})$. The land surface elevations of A, B, and C are 150 m, 130 m, and 145 m, respectively, above sea level. The depth to water in A, B, and C are 40 m, 44 m, and 45 m, respectively. For each piezometer, calculate the head relative to sea level, the pressure head, the elevation head, and the fluid pressure at its opening in the aquifer.

4. For the piezometers in the previous problem, calculate the hydraulic gradient (magnitude and direction). What is the flow direction?

5. For the previous problem, what would the head be at $(x, y, z) = (500 \text{ m}, 20 \text{ m}, 80 \text{ m})$? Why can you not determine the head at $(x, y, z) = (500 \text{ m}, 20 \text{ m}, 60 \text{ m})$?

6. A piezometer is screened at a depth of 20 m below land surface and records a pressure of 120 kPa on a pressure transducer. An immediately adjacent piezometer is screened at a depth of 12 m below the land surface, and the piezometer is filled with water to a depth of 8 m below the land surface. What is the vertical hydraulic gradient?

7. **Project:** Head was measured in several monitoring wells and pumping wells around a uranium roll front deposit at a site in Wyoming. A map of the site along with head measurements is shown in Figure 1. For these head measurements, draw the potentiometric surface. Use a contour interval of 2 ft.

8. **Project.** A stratigraphic cross section of a uranium roll front deposit is shown in Figure 2. The uranium deposit is in the "K" sandstone aquifer. Treating both the Upper and Lower "K" Sandstone units as one continuous aquifer, estimate its thickness.

9. **CVEN 5353 Only.** Consider a single layer of spherical sand grains arranged as shown in Figure 3.2a. What value of $\theta$ results in the lowest porosity? What is the porosity?

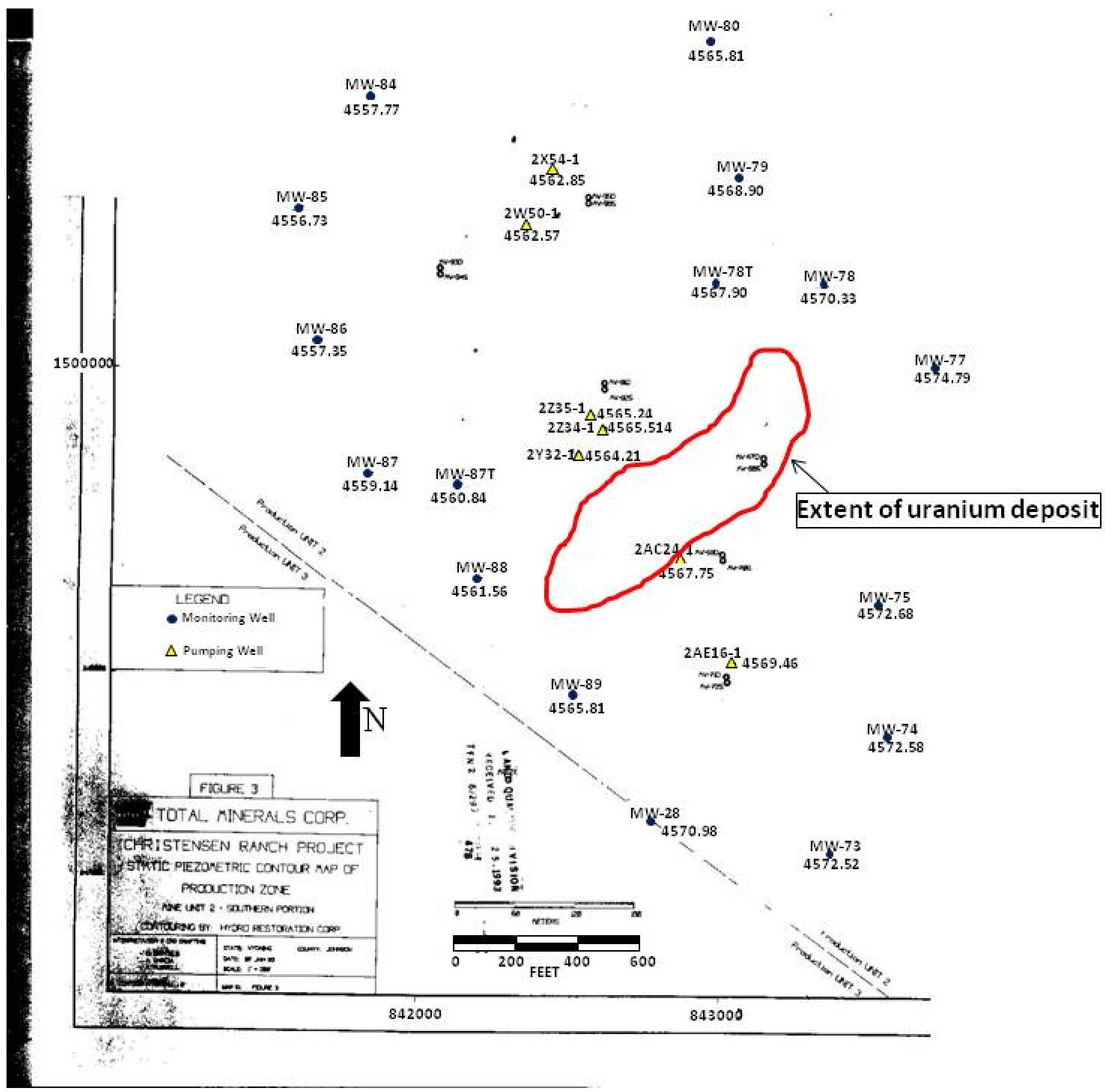



Figure 1: Well locations and water levels at uranium mine site. The red line denotes the extent of the uranium deposit that will be mined.

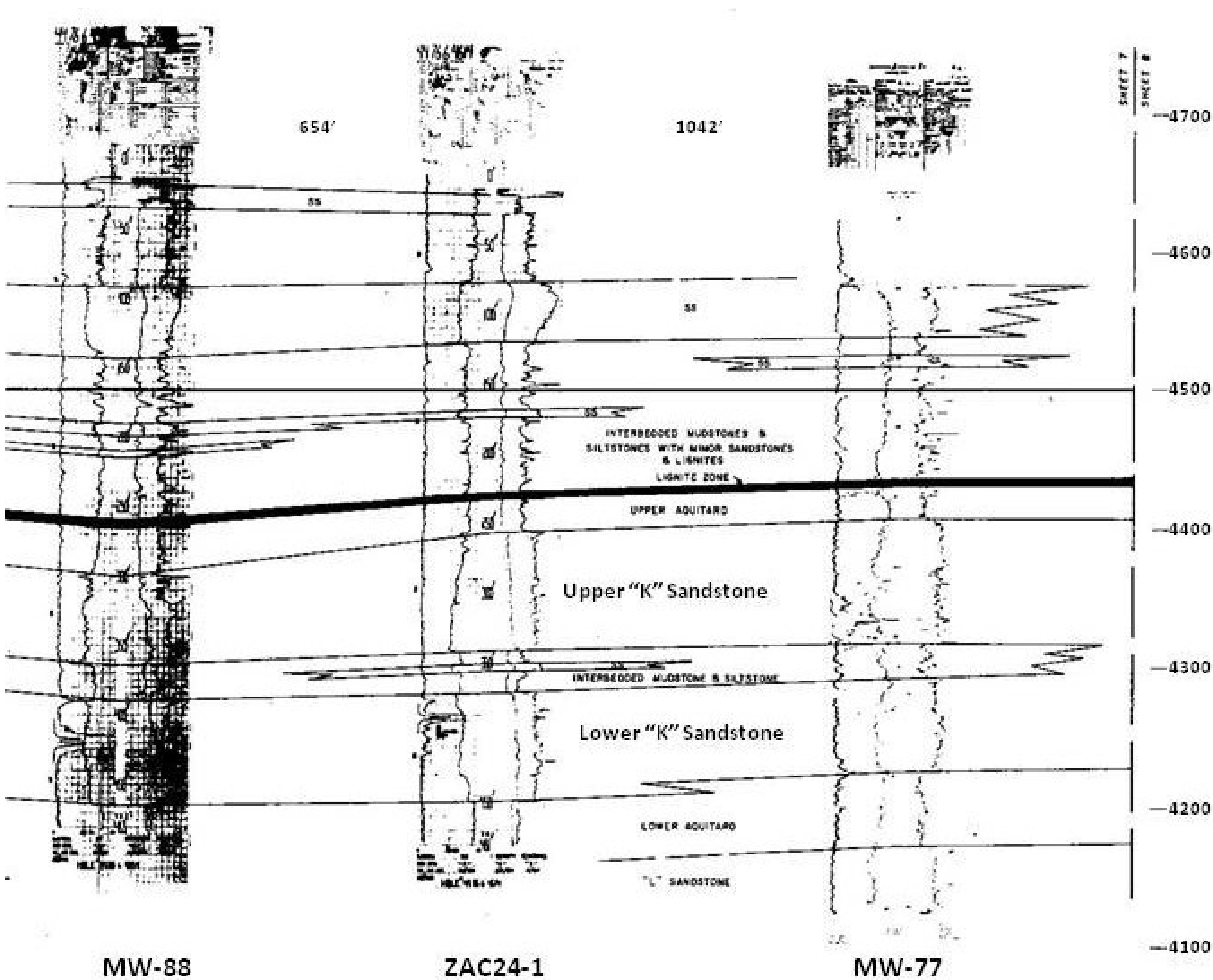



Figure 2: Stratigraphic cross section showing the Upper and Lower "K" Sandstone aquifer.

**Homework 2** - Due September 9, 2010

1. In the apparatus in Figure 3.3, let $\Delta\ell = 3.0$ ft, $Z_1 = 3$ ft, $Z_2 = 1$ ft, $h_1 = 4$ ft, $h_2 = 3.1$ ft, $A = 0.5$ ft$^2$, and $n = 0.2$.

   (a) If water flows downward through the apparatus at a rate of 2.6 ft$^3$/d, what is the hydraulic conductivity of the porous material?

   (b) What is the specific discharge?

   (c) What is the pore velocity?

   (d) How long would it take to fill a 100 mL beaker with water flowing out of this column?

2. In the previous problem, suppose the column is aligned in the vertical direction with $Z_1 > Z_2$, and $h_1$ and $h_2$ are unchanged.

   (a) How does the change in column orientation change the flow rate? Why?

   (b) What is the flow rate of water through the column if the porous material is replaced with clay?

   (c) How long would it take to fill a 100 mL beaker with water flowing out of the column filled with clay?

3. The hydraulic conductivity of a sand and gravel outwash formation on Cape Cod is measured to be 77 m/d. This measurement is made at a temperature of 20°C.

   (a) What is the permeability of the material?

   (b) What is the hydraulic conductivity (in m/d) of the formation at a temperature of 5°C?

   (c) Water from the Cape Cod aquifer discharges into the ocean. If the magnitude of the hydraulic gradient is 0.001 m/m at the interface between the aquifer and the ocean and does not change throughout the year, by what percentage does the flow rate of water from the aquifer to the ocean change between summer (assume a temperature of 20°C) and winter (assume a temperature of 5°C)?

4. A hydrological system consists of four horizontal formations. The hydraulic conductivities of the formations from top to bottom are 20 m/d, 15 m/d, 50 m/d, and 1 m/d, respectively. The thicknesses of the formations from top to bottom are 3 m, 1 m, 8 m, and 4 m, respectively. Calculate the equivalent horizontal and vertical hydraulic conductivities for the whole formation.

5. In the previous problem, if the flow direction in the uppermost layer is downward at angle of 25° relative to the vertical, calculate the flow direction in the remaining three formations.

6. **Project:** For your potentiometric surface from Homework 1, Problem 5, determine the direction of flow through the uranium deposit and the magnitude of the hydraulic gradient.

7. **CVEN 5353 Only.** Show that the average hydraulic conductivity of a layered system with flow parallel to layering is given by

$$\bar{K}_{\parallel} = \frac{\sum_i K_i b_i}{\sum_i b_i}$$

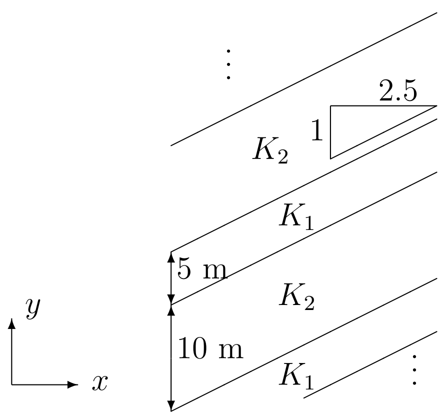
where $K_i$ is the hydraulic conductivity of layer $i$ and $b_i$ is the thickness of layer $i$.

**Homework 3** - Due September 16, 2010

1. 3.6

2. **Project:** In the ProjectData2010.xls spreadsheet on CULearn, constant head permeameter test data are shown for four wells. Three samples were taken from the "K" aquifer in each well, and were sized to fit in a constant-head permeameter column. The column diameter is 6.3 cm. The heights of the samples, head difference across the column during the test, and outflow volume during a three-minute sample period are all shown in the spreadsheet. Calculate the hydraulic conductivity of each sample, and the average hydraulic conductivity at for each well.

3. A aquifer has alternating layers of two different material types as shown in the figure below. If $K_1 = 0.25$ m/d and $K_2 = 1.2$ m/d, Calculate the hydraulic conductivity matrix.




4. For the system in the previous problem, if the hydraulic gradient is $\nabla h = 3\mathbf{i} - 2\mathbf{j}$, determine the magnitude and direction of the specific discharge, $\mathbf{q}$. Compare the direction of the hydraulic gradient to the direction of the specific discharge vector.

5. The hydraulic conductivity for an aquifer in two spatial dimensions is given by

$$\begin{gathered}\mathbf{K}_A = \begin{bmatrix} 5 & 6 \\ 3 & 2 \end{bmatrix} \quad \mathbf{K}_B = \begin{bmatrix} 12 & -2 \\ -2 & 8 \end{bmatrix} \quad \mathbf{K}_C = \begin{bmatrix} 8 & 0 \\ 0 & 8 \end{bmatrix} \\ \mathbf{K}_D = \begin{bmatrix} 0 & 4 \\ 4 & 0 \end{bmatrix} \quad \mathbf{K}_E = \begin{bmatrix} 5 & 0 \\ 0 & 12 \end{bmatrix} \\ \mathbf{K}_F = \begin{bmatrix} 2 & 2 \\ 2 & 2 \end{bmatrix} \quad \mathbf{K}_G = \begin{bmatrix} 5 & 16 \\ 16 & 10 \end{bmatrix} \end{gathered} \tag{1}$$

   where the units are in ft/d. For each hydraulic conductivity matrix, state whether the matrix represents an isotropic aquifer, represents an anisotropic aquifer, or is physically unrealistic. Justify your answers.

6. **CVEN 5353 Only.** Consider a homogeneous, anisotropic geologic formation, with layering aligned at an angle of $\theta$ relative to the $x$-axis (horizontal axis).

   (a) For $-\nabla h$ aligned at an angle of $\alpha$ relative to the $x$-axis, derive an expression for the direction of the specific discharge vector. Let the direction of the specific discharge be represented by an angle of $\beta$, relative to the $x$-axis. The expression for $\beta$ should be in terms of $K_{\perp}$, $K_{\parallel}$, $\theta$, and $\alpha$.

   (b) Show that flow is in the direction of $-\nabla h$ when the porous material is isotropic.

   (c) Show that flow is in the direction of $-\nabla h$ when $-\nabla h$ is in the direction parallel to layering.

   (d) Show that flow is in the direction of $-\nabla h$ when $-\nabla h$ is in the direction perpendicular to layering.

**Homework 4** - Due September 23, 2010

1. The Salt River Valley in central Arizona is an unconfined aquifer system with an area of approximately $10^9$ m$^2$. Approximately $4.6 \times 10^8$ m$^3$ of water is pumped from the aquifer system each year, and the water table drops about 2.8 m each year. What is the specific yield of the aquifer?

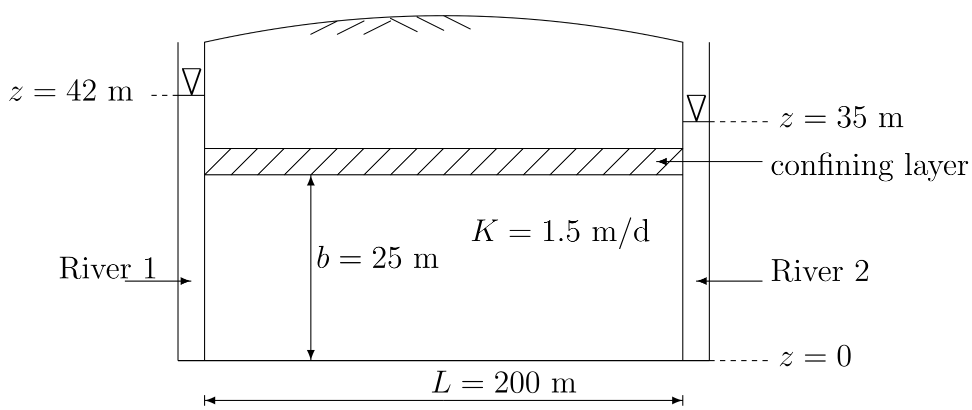
2. A 14-m thick confined aquifer consists of sand with a coefficient of consolidation of $2.1 \times 10^{-8}$ m$^2$/N, and a porosity of 0.35. Estimate the specific storage and the storage coefficient.

3. For the aquifer in the previous problem, if head drops by 20 m,

   (a) How much water is removed from the aquifer per unit area?

   (b) What is the change in porosity of the aquifer?

4. The confined aquifer in the figure is bounded on each side by rivers with different water levels. The aquifer is homogeneous and isotropic, and flow is steady and essentially horizontal.




   (a) For this aquifer, what is the governing equation of one-dimensional, steady groundwater flow, and what are the boundary conditions?

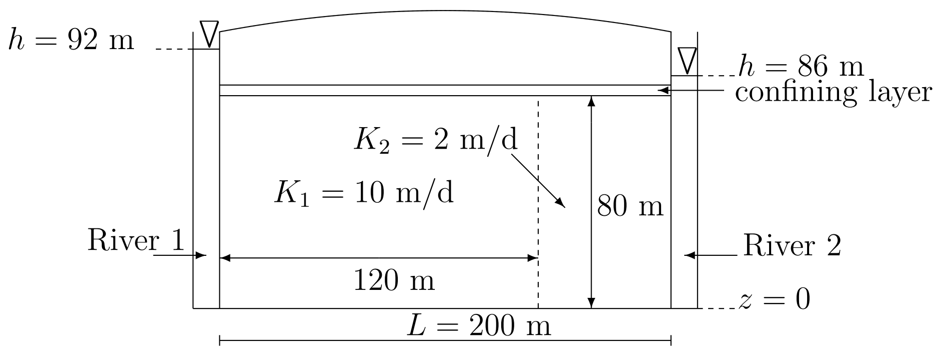
   (b) Solve the governing equation for $h(x)$.

   (c) Using the parameter values shown, calculate the head midway between the two rivers.

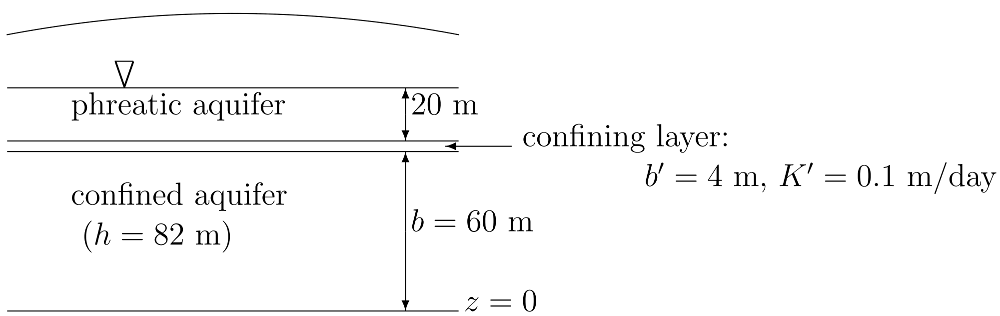
   (d) Calculate the specific discharge through this aquifer.

   (e) Repeat items (c) and (d) using $K = 4.0$ m/d.

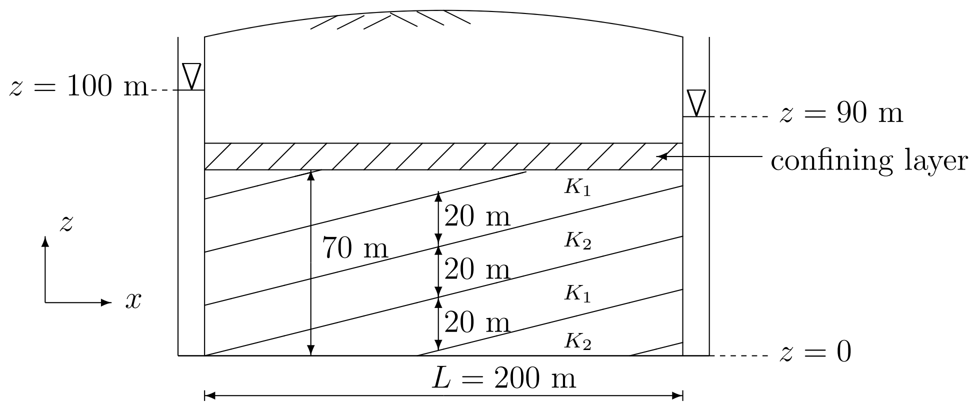
5. For the aquifer system shown in the figure, calculate the volumetric flow rate of water into River 2 over a 1 m length of river (i.e., 1 m into the page).




6. For the leaky aquifer system in the figure, calculate the leakage rate through the confining layer and specify its direction.

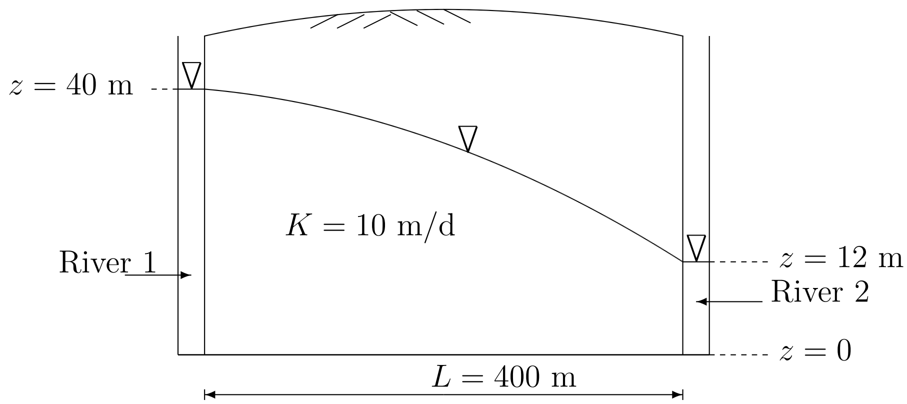


7. **CVEN 5353 only**
The confined aquifer shown below is comprised of alternating parallel layers of sandstone ($K_1 = 0.1$ m/d) and limestone ($K_2 = 2.0$ m/d) at a slope of 14°. Calculate the magnitude and direction of the specific discharge through this aquifer.



**Homework 5** - Due September 30, 2010

1. The unconfined aquifer in the figure is bounded on each side by rivers with different water levels. The aquifer is homogeneous and isotropic, and flow is steady and essentially horizontal.




   (a) For this aquifer, what is the governing equation of one-dimensional, steady groundwater flow, and what are the boundary conditions?

   (b) Solve the governing equation for $h(x)$.

   (c) Using the parameter values shown, calculate the head midway between the two rivers.

   (d) Calculate the flow rate (per unit width into the page) of water into River 2.

2. An agricultural field is made up of a soil with a hydraulic conductivity of 0.5 ft/d, and is bounded below by a clay layer that is 10 ft below the land surface. A drain system is installed to lower the water table. The drain pipes run along the length of the field, and are laid parallel to each other and are spaced 20 ft apart. The drain pipes are 6 ft below the land surface, thus the water level at the drains is maintained at a constant level of 6 ft below the land surface. If the recharge rate is 0.25 ft/d, what is the minimum depth to groundwater between the drain pipies? Since the drain pipes run the full length of the field and are parallel to each other, you can model this system as one-dimensional in the direction perpendicular to the drain pipes.

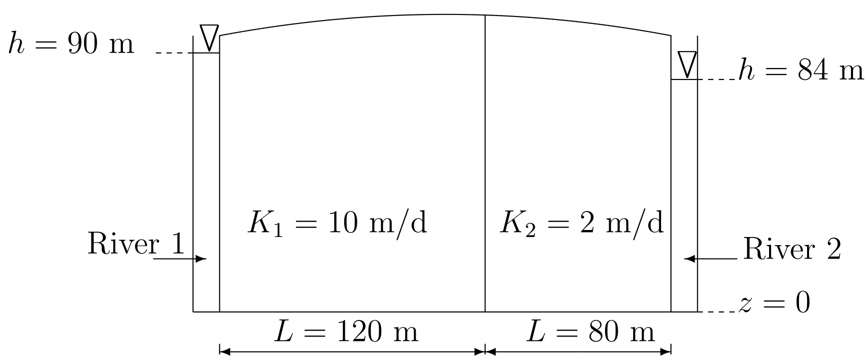
3. Repeat the previous problem, assuming that the aquifer is bounded below by a clay layer that is **8 ft** below the land surface.

4. Use results from MODFLOW and MODPATH to demonstrate that water will flow toward high permeability units and around low permeability units. You can use the same aquifer as you used in the in-class example. Select a 5-cell by 5-cell box about midway between the left boundary and the pumping well, and change the hydraulic conductivity inside this box. Rerun MODFLOW and MODPATH, and create particle paths running backward from the pumping well to show that

   (a) they converge on the boxed area if it is a high permeability unit

   (b) they diverge around the boxed area if it is a low permeability unit.

5. **CVEN 5353 only**
   For the aquifer system shown in the figure, calculate the head at the interface between the two different materials. Why is it not appropriate to treat this system as a homogeneous aquifer with $K = K_\perp$?



**Homework 6** - Due October 14, 2010

1. **Project:** Slug tests were conducted on three wells at the proposed ISL mining site. For each slug test, a volume of water was injected into the well, and head was recorded over time as the water level returned to its static level. All of the wells are cased holes with a radius of 0.5 ft. The screened interval is an open hole below the casing. Prepare a spreadsheet to automatically calculate the hydraulic conductivity at MW-78T using the slug test data and well specifications available in the ProjectData2010.xls file on CULearn. You must find the slope of the best-fit straight line for a plot of $\ln(s_o/s)$ vs. $t$. For a straight line defined as $y = mx$, with an intercept of 0, the equation for the slope of the best-fit straight line is:

$$m = \frac{\sum_{i=1}^{N} x_i y_i}{\sum_{i=1}^{N} x_i^2}$$

   where $N$ is the number of data points and $(x_i, y_i)$ are the coordinates of data point $i$. Use this equation in your spreadsheet to calculate the slope of the best-fit line, and use that slope to calculate the hydraulic conductivity of MW-78T. Submit a printout of your spreadsheet, along with hand-written sample calculations for all calculations in your spreadsheet.

2. **Project:** Use your spreadsheet from the previous problem to calculate the hydraulic conductivity for MW-87 and MW-89. Use the data available in ProjectData2010.xls on CULearn.

3. A well is pumped at a rate of 45 $m^3/d$ in a 17-m thick confined aquifer that initially has a constant head of 40 m. Head is measured in two nearby monitoring wells – Well 1 is a distance of 80 m from the pumping well, and Well 2 is a distance of 14 m from the pumping well. Initially, the head in the monitoring wells decreases over time, but eventually reaches a steady state, with a head of 36.1 m at Well 1 and a head of 25.9 m at Well 2. What is the hydraulic conductivity of the aquifer?

4. After 48 hours of pumping at a rate of 72 $ft^3/min$ in an unconfined aquifer, drawdown at two monitoring wells reaches a steady state condition. Monitoring well 1 is 40.1 ft from the pumping well and recorded a drawdown on 3.15 ft. Monitoring well 2 is 573 ft from the pumping well and recorded a drawdown of 0.28 ft. If the initial saturated thickness of the aquifer is 100 ft, what is the hydraulic conductivity of the aquifer?

5. 9.1

6. 9.3. Submit the plotted data with your match point clearly identified.

7. **CVEN 5353 Only**
For well hydraulics problems, it is useful to write the governing equation for groundwater flow in radial coordinates. For a homogeneous, isotropic aquifer, the groundwater flow equation in Cartesian coordinates is

$$\frac{S}{T}\frac{\partial h}{\partial t} = \frac{\partial}{\partial x}\left(\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(\frac{\partial h}{\partial y}\right) . \tag{2}$$

The equivalent equation in radial coordinates is

$$\frac{S}{T}\frac{\partial h}{\partial t} = \frac{\partial^2 h}{\partial r^2} + \frac{1}{r}\frac{\partial h}{\partial r} + \frac{1}{r^2}\frac{\partial^2 h}{\partial \theta^2} , \tag{3}$$

where $r = \sqrt{x^2 + y^2}$, $\tan\theta = y/x$, $x = r\cos\theta$, and $y = r\sin\theta$. Derive (3) from (2). You will have to use the chain rule on the derivatives with respect to $x$ and $y$, as follows:

$$\frac{\partial f}{\partial x} = \frac{\partial f}{\partial r}\frac{\partial r}{\partial x} + \frac{\partial f}{\partial \theta}\frac{\partial \theta}{\partial x} , \tag{4}$$

and a similar expression can be written for $\partial f/\partial y$. In (4), $f$ can represent $h$ when evaluating the derivatives inside the parentheses in (2), and it can represent $(\partial h/\partial x)$ when evaluating the outer derivatives in (2). The derivatives $\partial r/\partial x$ and $\partial r/\partial \theta$ can be evaluated from the expressions for $r$ and $\theta$ as functions of $x$ and $y$, where

$$\begin{aligned} \frac{\partial r}{\partial x} &= \cos\theta & \qquad \frac{\partial r}{\partial y} &= \sin\theta \\ \frac{\partial \theta}{\partial x} &= -\frac{\sin\theta}{r} & \qquad \frac{\partial \theta}{\partial y} &= \frac{\cos\theta}{r} \end{aligned}$$

So the chain rule simplifies to

$$\frac{\partial f}{\partial x} = \frac{\partial f}{\partial r}\frac{\partial r}{\partial x} + \frac{\partial f}{\partial \theta}\frac{\partial \theta}{\partial x} = \cos\theta\frac{\partial f}{\partial r} - \frac{\sin\theta}{r}\frac{\partial f}{\partial \theta} , \tag{5}$$

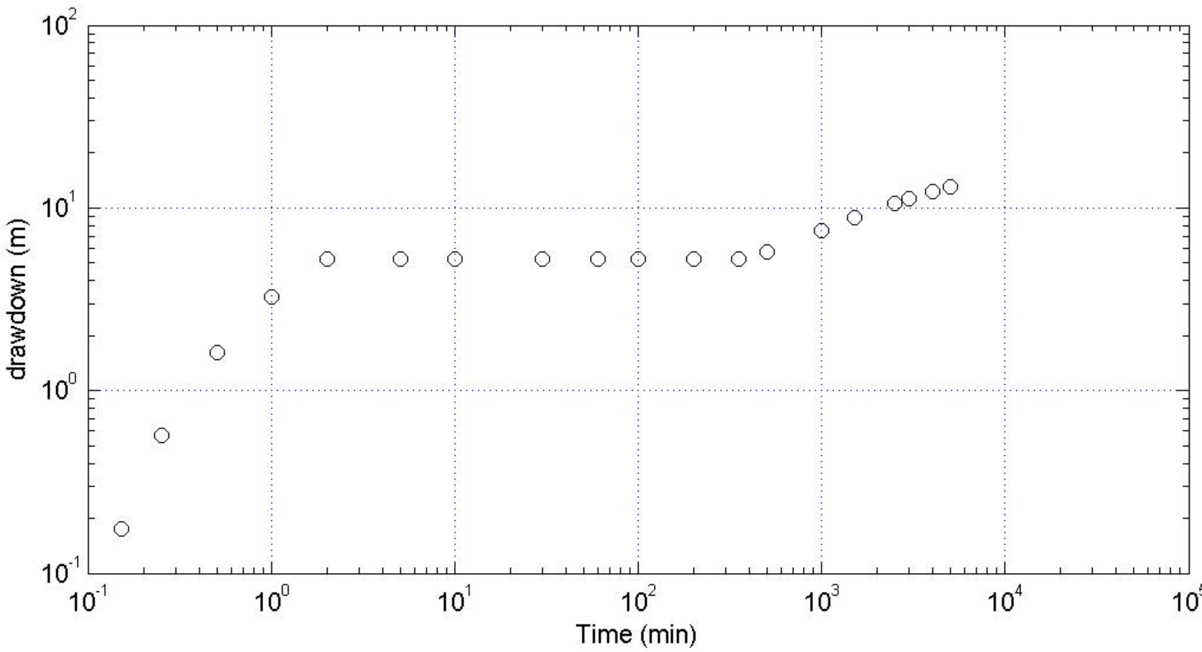
and

$$\frac{\partial f}{\partial y} = \frac{\partial f}{\partial r}\frac{\partial r}{\partial y} + \frac{\partial f}{\partial \theta}\frac{\partial \theta}{\partial y} = \sin\theta\frac{\partial f}{\partial r} + \frac{\cos\theta}{r}\frac{\partial f}{\partial \theta} . \tag{6}$$

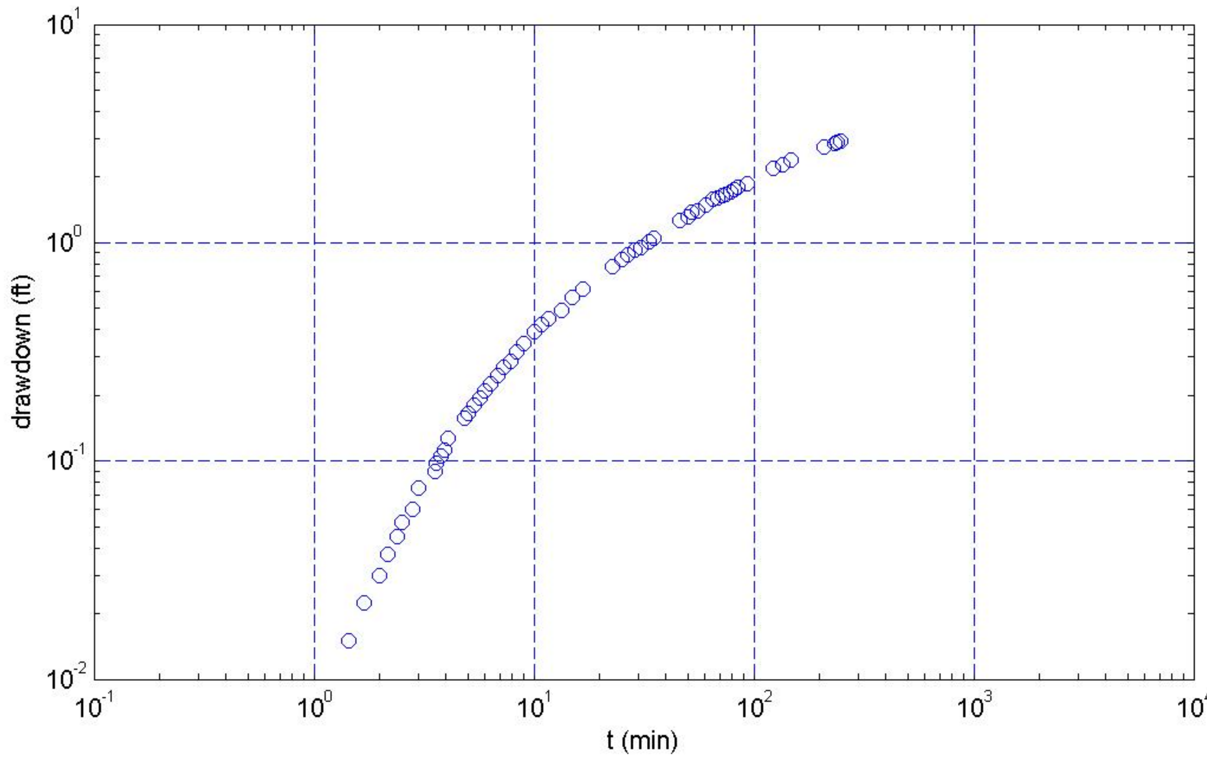
**Homework 7** - Due October 21, 2010

1. A well in a horizontal, homogeneous, confined aquifer is pumped at a rate of 10,000 $m^3$/day. Drawdown in measured at an observation well located 150 m from the pumping well, and is shown in Table 9.7 in the textbook. Use the Cooper-Jacob approximation to estimate the transmissivity and storage coefficient for the aquifer. The data are available in the spreadsheet on CULearn.

2. A well pumping at 72 $m^3$/min fully penetrates an unconfined aquifer with a saturated thickness of 30 m. Determine the transmissivity, storage coefficient, specific yield, and horizontal (radial) and vertical hydraulic conductivities using time-drawdown shown in the figure for an observation well 80 m away. Clearly identify your match point on the plot. The data are also available in a spreadsheet on the CULearn page.



3. Time-drawdown data is shown in the figure (and in a spreadsheet on the CULearn page) for an observation well in Pixley, California, that is 1,300 ft from a well that is pumping at a rate of 90 $ft^3$/min. The pumped well, which is 600 ft deep, obtains water from gravel, sand, sandy clay, and clay of the Tulare formation. The aquifer is confined from above by the Corcoran Clay Member, which is about 6 ft thick, above which is an unconfined aquifer that is about 200 ft thick. Calculate transmissivity and storativity for the Tulare formation. Clearly identify your match point on the plot.




4. **CVEN 5353 Only**
   Use the method described in Section 9.7 to solve problem 9.5 in the text. Use a pumping rate of 4500 $m^3$/d, and assume the drawdown data are measured after 2 hour of pumping.

**Homework 8** - Due October 28, 2010

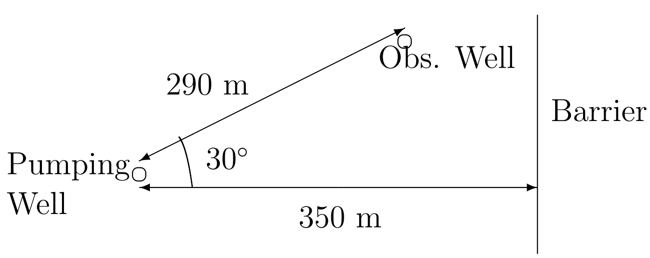
1. The town of Culver uses 22,000 $ft^3/d$ of water. From May 1 to September 1 (123 days), when streams are flowing full as a result of snowmelt, Culver uses surface water for its municipal drinking water supply. During the rest of the year (242 days), the town uses groundwater as its water supply. Groundwater is pumped from a shallow homogeneous confined aquifer that has a transmissivity of 16 $ft^2/d$ and a storage coefficient of $2.3 \times 10^{-4}$. The confined aquifer is hydraulically connected to wetlands that are 1000 ft from the drinking water supply well, so it is important that drawdown from the town's well does not impact the wetlands.

   (a) How much drawdown occurs in the confined aquifer near the wetlands from September 1 of one year to September 1 of the following year?

   (b) Culver is considering building a reservoir to store pumped groundwater. If they do, they will pump groundwater at a continuous rate throughout the year, storing the water in the reservoir during from May 1 to September 1 when it is not needed for the water supply. Assuming the reservoir is not hydraulically connected to the aquifer, how much drawdown will occur in the confined aquifer near the wetlands from September 1 of one year to September 1 of the following year under this scenario. Note that groundwater is pumped continuously, but it is only need to supply drinking water from September 1 to May 1.

   (c) Should Culver build the reservoir to limit drawdown at the wetlands?

2. A well is pumped at a rate of 0.035 $m^3/s$ near a boundary that is a barrier to flow (see figure below). The aquifer is confined, has a thickness of 20 m, a hydraulic conductivity of 32 m/day, and a storage coefficient of $3.2 \times 10^{-5}$. Determine the drawdown in the observation well after 10 hours of continuous pumping.



3. **Project:** A pumping test was conducted at the proposed ISL mining site. Well 2X34-1 was pumped at a rate of approximately 2.0 $ft^3$/min for 29 hours, and drawdown was recorded at 2Z35-1, MW-78, MW-79, MW-85, and MW-86. The drawdown data are available in the ProjectData2010.xls file and on log-log plots available on CULearn. Calculate the transmissivity and hydraulic conductivity of the aquifer using data from these four wells.

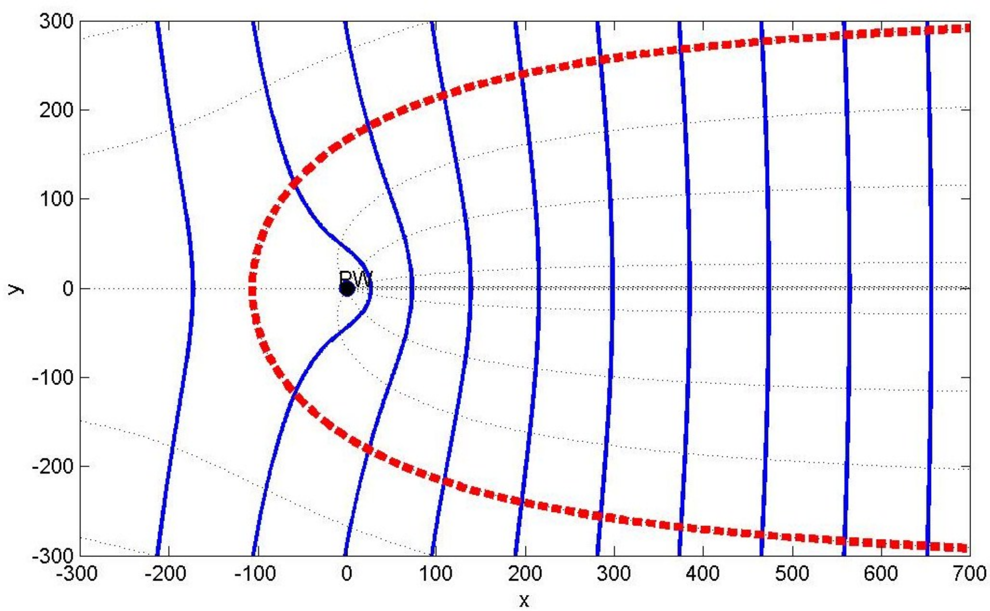
4. **Project:** From the previous problem, you should find that the hydraulic conductivity calculated from the drawdown at 2Z35-1 is much different than the hydraulic conductivity calculated from drawdown at the other wells. It can be argued, based on the permeameter data, that the hydraulic conductivity should not be that different. Explain why the hydraulic conductivity calculated using drawdown at 2Z35-1 is not representative of the true conditions. Hint: what assumptions were used to develop the method that you used for your analysis?

5. The steady-state capture zone of a pumping well is shown as the thick dashed line in the figure. Describe the relative change in the capture zone width and the location of the stagnation point under the following conditions. Give arguments supporting your descriptions.

   (a) The pumping rate is doubled.

   (b) The ambient hydraulic gradient is doubled.

   (c) The storage coefficient is doubled.



6. A two-dimensional aquifer has the following parameters: $T = 40$ ft$^2$/d, $S = 3 \times 10^{-4}$, thickness of 10 ft, porosity of 0.25, and an ambient hydraulic gradient of 0.02 in the $+x$ direction. Use FLOWNETz to draw the capture zone around a hydraulic containment system with two wells that are located at $(x, y) = (-200 \text{ ft}, 0)$ and $(x, y) = (200 \text{ ft}, 0)$. Use an injection and extraction rate of $Q = 400$ ft$^3$/d. Calculate (with equations, not by inspection) $x_o$ and $y_{\max}$ for this system.

7. For the previous problem, estimate the minimum travel time from the injection well to the pumping well.

8. **CVEN 5353 Only**
   A pumping test is conducted in a confined aquifer that has a recharge boundary. The location of the pumping well is $(x, y) = (0 \text{ m}, 0 \text{ m})$. Four observation wells are installed in the aquifer at the coordinates shown in the table. The pumping well is pumped at a rate of $Q = 6$ m$^3$/min, and drawdown is recorded at each of the observation wells. Drawdown data for each observation well are available in the spreadsheet on CULearn. Calculate the transmissivity and storage coefficient of the aquifer, and identify the location of the recharge boundary. Read pp. 301–306 for an explanation on how to solve this problem.

Table 1: Coordinates of observation wells.

| Observation Well | $x$ (m) | $y$ (m) |
|---|---|---|
| 1 | 0 | 100 |
| 2 | 0 | -100 |
| 3 | 100 | 0 |
| 4 | -100 | 0 |

**Homework 9** - Due November 11, 2010

1. 18.2. Use linear regression (not a curve-fitting algorithm such as trendline in Excel) to calculate the sorption parameters.

2. Estimate the parameters of the Langmuir sorption isotherm from the following data obtained from a batch sorption experiment. Use linear regression (not a curve-fitting program).

| Sample | C(mg/L) | S (mg/g) |
|---|---|---|
| 1 | 3.49 | 18.6 |
| 2 | 5.41 | 23.0 |
| 3 | 11.4 | 29.6 |
| 4 | 15.7 | 31.9 |
| 5 | 18.8 | 33.0 |
| 6 | 30.7 | 35.4 |
| 7 | 41.6 | 36.5 |
| 8 | 50.5 | 37.1 |

3. For the batch sorption data shown below, determine the best isotherm model (linear, Freundlich or Langmuir) and identify the sorption parameters. For this problem, it is fine to use the trendline in Excel to find the parameters.

| Sample | C(mg/L) | S (mg/g) |
|---|---|---|
| 1 | 10.5 | 36.8 |
| 2 | 21.8 | 46.0 |
| 3 | 27.7 | 48.4 |
| 4 | 40.9 | 51.6 |
| 5 | 50.3 | 53.0 |

4. The concentration of trichloroethylene (TCE) at a point A at $(x, y, z) = (0 \text{ m}, 0 \text{ m}, 0 \text{ m})$ in an aquifer is 0.045 mg/L. Calculate the advective mass flux across a unit area of aquifer at point A if the aquifer is homogeneous with $K = 0.2$ m/d, $n = 0.3$, and a uniform hydraulic gradient of

$$\nabla h = \begin{bmatrix} 0.02 \\ 0.015 \\ -0.001 \end{bmatrix}.$$

5. For the same aquifer described in the previous problem, the concentration of trichloroethylene (TCE) is also measured at three additional points as shown in the table. Calculate the diffusive mass flux.

| Point | Location | Concentration (mg/L) |
|---|---|---|
| B | $(1\text{ m}, 0, 0)$ | 0.042 |
| C | $(0, 1\text{ m}, 0)$ | 0.038 |
| D | $(0, 0, 1\text{ m})$ | 0.040 |

6. For the same aquifer described in the previous two problems, calculate the dispersive mass flux. Use $\alpha_L = 10$ m, $\alpha_{TH} = 1$ m, and $\alpha_{TV} = 0.5$ m. Compare the magnitude of the diffusive and dispersive mass fluxes. Is it reasonable to assume that diffusive mass flux is negligible? Why or why not?

7. **CVEN 5353 Only**
   Using the linear regression approach of minimizing the sum of the squares of the residuals $r_i = y_i - mx_i - b$, show that the best fit approximation to the Freundlich isotherm is

$$\begin{aligned} n &= \frac{N\sum_{i=1}^{N}\log C_i \log S_i - \sum_{i=1}^{N}\log C_i \sum_{i=1}^{M}\log S_i}{N\sum_{i=1}^{N}(\log C_i)^2 - (\sum_{i=1}^{N}\log C_i)^2} \\ K &= 10^{\left(\sum \log S_i - m\sum \log C_i\right)/N}. \end{aligned}$$

**Homework 10** - Due November 18, 2010

1. 19.3

2. In the Cape Cod tracer test, chemicals were released approximately instantaneously into the groundwater at injection wells that can be approximated as a point source. Figure 19.19 shows distributions of bromide, lithium, and molybdate at various times after the chemicals were released into the aquifer. Bromide is a non-sorbing solute, but lithium and molybdate sorb.

   (a) Estimate the groundwater velocity (magnitude and direction) in this aquifer.

   (b) Assuming lithium follows a linear sorption isotherm, estimate the retardation coefficient of lithium in this aquifer.

3. 19.5

4. Strontium is a sorbing solute with $K_d = 0.00126$ L/g for linear equilibrium sorption. If the bulk density of a soil is 1.42 g/cm$^3$ and the porosity is 0.15, what is the retardation coefficient of strontium?

5. A waste drum was illegally dumped in a shallow pit. Upon impact, the drum was punctured and instantaneously released a solution that contained 4000 g of chloride and 4000 g of strontium into the subsurface. The bottom of the shallow pit is approximately at the groundwater table; therefore, the solution entered the underlying aquifer as an instantaneous point source. Assume that the aquifer can be modeled as one-dimensional, with a cross-sectional area of 100 m$^2$, a groundwater velocity of 0.2 m/d, porosity of 0.12, and a longitudinal dispersivity is 10 m.

   (a) What chloride concentration can be expected in a monitoring well 100 m away at 100 d after the release?

   (b) What is the peak chloride concentration at $t = 100$ d after release?

   (c) At what location does the peak chloride concentration occur?

   (d) Does the peak chloride concentration exceed the drinking water standard for chloride?

6. Use the retardation coefficient for strontium from Problem 4 and the site description from Problem 5 to answer the following questions:

   (a) What is the peak strontium concentration at $t = 100$ d after the release?

   (b) At what location does the peak strontium concentration occur?

   (c) What is the relationship between your answers to Problems 4, 5c, and 6b?

7. A landfill is leaking an effluent with a sodium concentration of 1250 mg/L. It seeps into an aquifer that has a hydraulic conductivity of 9.8 m/d, a hydraulic gradient with a magnitude of 0.0040, and a porosity of 0.25. A monitoring well is located 25 m downgradient of the landfill. Assuming the system can be modeled as one-dimensional, calculate the sodium concentration at the monitoring well at $t = 100$ days, $t = 200$ days, and $t = 400$ days after the leak begins. Use a longitudinal dispersivity of 1.8 m. Compare the initial concentration to the concentration at $t = 400$ days.

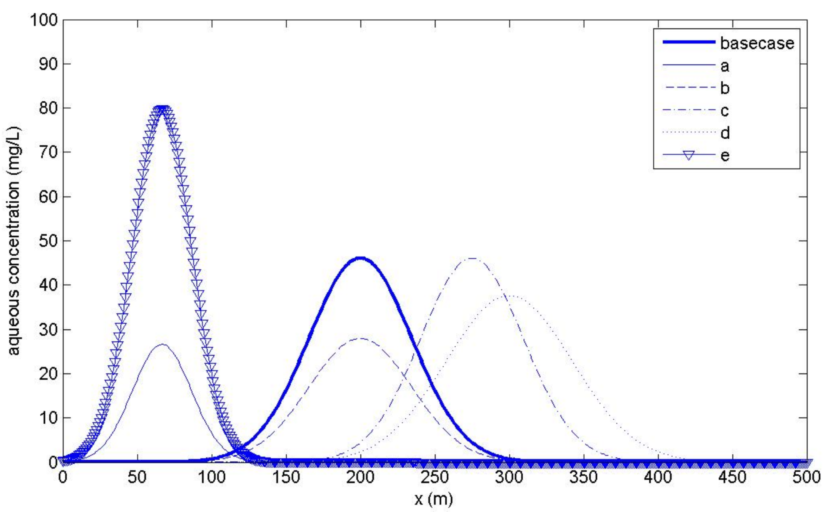
8. **CVEN 5353 Only**
   The figure below shows plots of concentration vs. position for point sources of contamination under several different scenarios. The base case (think solid line) is for a point source of a non-sorbing solute at $x_o = 0$ in an aquifer with $v = 1$ m/d and $n = 0.25$. The total mass is 1000 g, the longitudinal dispersivity is 3 m, and concentration is plotted at $t = 200$ d after release from the source. State which curves correspond to each of the following changes in conditions (with all other conditions being the same as the base case). (NOTE: There are extra curves, and some curves may match multiple conditions.)

   i. $t > 200$ d.

   ii. solute is a sorbing solute with linear sorption isotherm.

   iii. $v > 1$ m/d.

   iv. $x_o > 0$.



basecase
a
b
c
d
e
aqueous concentration (mg/L)
x (m)
0
10
20
30
40
50
60
70
80
90
100
0
50
100
150
200
250
300
350
400
450
500

**Homework 11** - Due December 2, 2010

1. 6.2

2. In a fine sand vadose zone, pressure head was measured to be $\psi = -120$ cm at a depth of 200 cm. Calculate effective saturation, volumetric water content, specific moisture capacity, and hydraulic conductivity (in m/day) for this location using the van Genuchten model.

3. The moisture content in a Yolo light clay vadose zone is measured to be 0.35 at a depth of 1.0 m below the land surface. Calculate the effective saturation, pressure head, specific moisture capacity, and hydraulic conductivity in (m/day) for this location using the Brooks-Corey model.

4. In Problem 3, what is the head at the measurement point if the datum is the land surface?

5. Tension head data was measured at several elevations in the vadose zone. The groundwater table is 200 cm below land surface. At which elevations, if any, is water moving upward? At which elevations, if any, is water moving downward?

| Height above water table (cm) | Pressure Head, $\psi$ (cm) |
|---|---|
| 180 | -60 |
| 160 | -80 |
| 140 | -110 |
| 120 | -130 |
| 100 | -140 |
| 80 | -130 |
| 60 | -100 |
| 40 | -60 |
| 20 | -30 |

6. Assume the soil in Problem 5 is Fresno medium sand. Calculate the specific discharge and groundwater velocity at an elevation of 160 cm above the water table.

7. **CVEN 5353 Only**
   Assuming hydrostatic conditions, what is the depth of the water table in Problem 3?