1. The piezometer readings measured for an example “site” are shown below (piezometer reading at the nearest grid “node” in feet above sea level, each “square” 100’ per side)

<table>
<thead>
<tr>
<th></th>
<th>200</th>
<th>208</th>
<th>212</th>
<th>226</th>
</tr>
</thead>
<tbody>
<tr>
<td>206</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>208</td>
<td>212</td>
<td>220</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>211</td>
<td>212</td>
<td>218</td>
<td>222</td>
<td></td>
</tr>
<tr>
<td></td>
<td>212</td>
<td>218</td>
<td>221</td>
<td>230</td>
</tr>
</tbody>
</table>

(a) Which direction is groundwater flowing at point “X” and what is the hydraulic gradient and fluid potential gradient? [2 pts]

- Draw equipotential lines of head
- Groundwater flow is perpendicular to these lines in the direction of decreasing head. Therefore flow is **north-northwest**.

  Hydraulic gradient = \( \frac{dh}{dl} = \frac{2'}{75'} = 0.027 \text{ ft/ft} \) (may vary a bit based on how equipotential lines are interpolated. Hydraulic gradient changes somewhat across the site).

  Fluid potential gradient = \( \frac{d(h \times g)}{dl} = 0.027 \text{ ft/ft} \times 32.2 \text{ ft/s}^2 = 0.87 \text{ ft/s}^2 \)

(b) If a slug of chloride “tracer” is injected at “X” and the “peak” concentration is measured 8 months later at the nearest down-gradient well, estimate the hydraulic conductivity of the soil. (assume that a laboratory test determined that the void ratio for the soil was 0.4) [2 pts]

- nearest down-gradient well is D which is 325’ from spill to D in 8 months
- Darcy’s Law: \( v = K \left( \frac{dh}{dl} \right) / ne \)

  Calculate effective porosity (ne) from void ratio (e),
  assume all pore space is effective
  \( ne = e / (1 + e) = 0.4 / 1.4 = 0.286 \)
\[ K = \frac{v \Delta e}{(dh/dl)} = \frac{325'}{8 \text{ mo}} \times \frac{0.286}{0.027 \text{ ft/ft}} = 430 \text{ ft/mo} = 5 \times 10^{-5} \text{ m/s} \]

(c) Assuming that a “spill” of benzene and anthracene occurred at point “X”, how long would it take the “peak” of each of these contaminants to arrive at the nearest down-gradient well? What would the measured conc vs time of these contaminants look like? Sketch an approximate plume picture of a “non-retarded” spill component, benzene, and anthracene after 1 year. (assume: bulk density of soil 1800 kg/m3; soil 1% organic content by weight) [4 pts] list any other assumptions used

Benzene and anthracene will be retarded compared to the groundwater.
Assume linear sorption so that:
\[ R = \frac{V_{gw}}{V_{contam}} = 1 + (p_b K_d / n) \]
\[ K_d = f_{oc} \times K_{oc} \] (look up Koc in Appendix A of LaGrega HazWaste Mgmt)

\[ K_d\text{-benzene} = 0.01 \times 83 \text{ mL/g} \quad K_d\text{-anthra} = 0.01 \times 1.40 \times 10^4 \text{ ml?g} \]

\[ R\text{benz} = 1 + (1.8 \text{ g/mL} \times 0.83 \text{ mL/g} / 0.286) = 6.22 \]
\[ R\text{anthra} = 1 + (1.8 \times 1.40 \text{ ml/g} / 0.286) = 882 \]

\[ V_{benz} = \frac{V_{gw}}{R} \rightarrow \text{Dist/time-benz} = \frac{\text{Dist/time-gw}}{R} \Rightarrow \text{time-benz} = R \times \text{time-gw} \]

Time-benz = R × tgw = 6.22 × 8 mo = 50 months or approx. 4.1 years
Time-anthr = R × tgw = 882 × 8 mo = 7056 months or approx 588 years

Conc vs time, after 4.1 years have a peak for benzene with a bits of spread, and after 588 years have the peak of the anthracene curve with more spread.

After 1 year: no retardation = 325’ × 12 mo/8 mo = 490 ft migration
Benzene 325’ × 1 yr/4.1 yr = 80 ft migration
Anthracene 325’ × 1 yr / 588 yr = 0.5 ft migration

plume of anthracene a “dot”, more spread of benzene around a mid-pt 80 ft downgradient

2. If a hazardous waste site has a subsurface contaminant source of pollution to the groundwater (such as DNAPL), would down-gradient drinking water wells be more threatened if: [2 pts] (list any assumptions you used to make your decision)

MORE threat = greater likelihood of near-term contamination

aquifer is medium sand or aquifer is clay
higher permeability of sand vs clay

soil has high carbon content or soil has low carbon content
less retardation with low carbon due to less sorption to soil

there is more infiltration or there is less infiltration
more infiltration generally causes more water flow and movement through residually DNAPL-contaminated soil which solubilizes more contaminant into groundwater

site is in an arctic environment or site is in the temperate zone
may be slower biodegradation in arctic BUT lower solubility at lower temperature would probably dominate