

- Hydraulic conductivity tensor

Given $\frac{\partial}{\partial x} H = -0.1$ and $\frac{\partial}{\partial z} H = 0$, one has the following equation for the specific discharge in the z direction:

$$q_z = -K_{zx} \left(\frac{\partial}{\partial x} H \right) - K_{zz} \left(\frac{\partial}{\partial z} H \right)$$

Because $\frac{\partial}{\partial z} H = 0$, one thus has $q_z = .1 K_{zx}$. However, $q_z = 0.001 \text{ cm/s} = 0.1 K_{zx}$. Thus $K_{zx} = 0.01 \text{ cm/s}$.

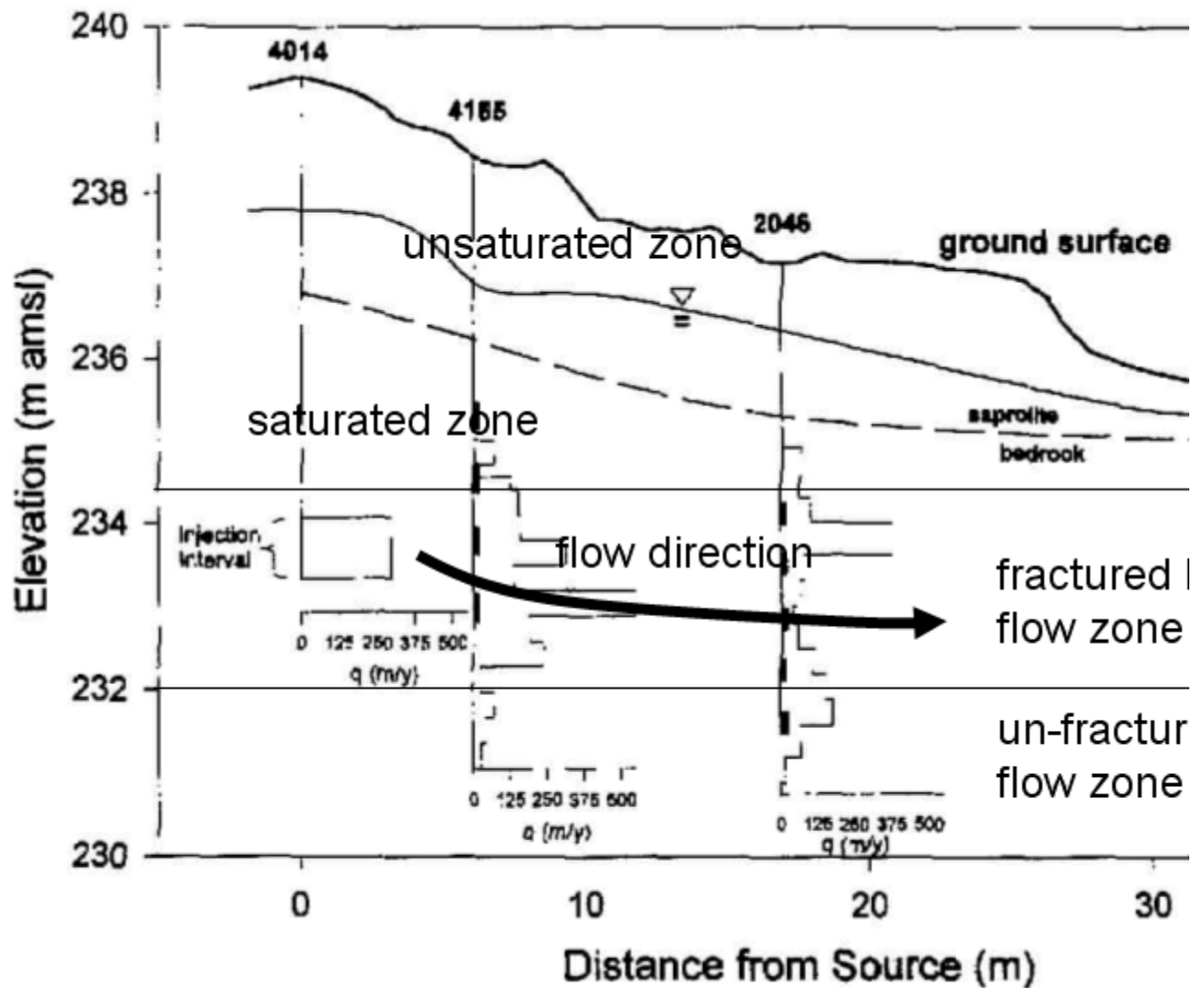
To calculate the specific discharge in the x direction, one notes that

$$q_x = -K_{xx} \left(\frac{\partial}{\partial x} H \right) - K_{xz} \left(\frac{\partial}{\partial z} H \right)$$

Because $\frac{\partial}{\partial x} H = 0.0$ and $\frac{\partial}{\partial z} H = 0.01$, one has $q_x = -K_{xz} \left(\frac{\partial}{\partial z} H \right) = -K_{zx} \left(\frac{\partial}{\partial z} H \right) = -0.01 * (-0.01) = 0.0001 \text{ cm/s}$.

- Conceptual model

The field site is vertically composed of a partially weather shale, the saprolite layer within which the groundwater table resides, and the bedrock, a sequence of interbedded shale-limestone. The saprolite is highly fractured. Beneath the saprolite in the bedrock, field tests indicate the existence of a highly fractured interval at 232.5 - 234.3 m above mean sea level, which may serve as a preferred groundwater flowpath from the upstream area (upper hill slope) to the stream at the lower hill slope. This flow regime essentially is confined on both direction at the top and bottom by a less fractured limestone-shale interbedded bedrock. The groundwater flow largely follows the hillslope, with specific discharge in the order of 300 - 500 m/yr in the highly fractured interval and much smaller (a few orders less) in the bedrock. The source of groundwater recharge, in general, from surface infiltration of precipitation and upstream area of the hillslope, in particular, for the highly fractured interval. With this information, the conceptual model may be obtained by modifying the cross section as follows:



With the given description and illustration, one may determine possible data gaps by indentifying the available data in the following list (in one of your handouts). Note here the underlined sections are those we have information:

Geology

Stratigraphy

Information

the sequence - in the illustration and narrative, we know there are saprolite above the bedrock; the bedrock can further be divided into fractured and un-fractured zones.

units—their lithology, thickness, extent, variability - we do have the illustration of lithology, thickness, extent, and vertical variability.

Illustrations

geologic column - no available data

measured section(s) - the cross section in the illustration is obtained from land survey and well logs.

well log(s) - not give explicitly.

cross section(s) - summarized in the illustration.

depth map(s)—to top of unit(s) - summarized in the illustration.

thickness map(s)—of unit(s) or interval(s) of interest - summarized in the illustration.

Structure

Information

dip/strike folds - not available.

faults fracture/joint systems - partial information available for fractures along the cross section; the fractured section of the bedrock is confined between 232.5-234.3 m above mean sea level.

Illustrations

geologic map—with dip, strike, folds, faults cross section(s) - not available.

structure map(s)—elevation of top of unit - summarized in the illustration.

Geomorphology

Information

relief - not available.

major landforms - not available.

Illustrations

topographic map - not available.

aerial photograph(s) - not available.

ground-level photograph(s) - not available.

Hydrology

Surface Water

Information

major features (rivers, lakes, etc.) properties - not available.

relationship to ground water - not available.

Illustrations

hydrograph(s) - not available.

flow-frequency plot(s) - not available.

gain/loss plot(s) - not available.

rating curve-stage versus discharge - not available.

flow data table - not available.

longitudinal profile - not available.

channel cross section(s) - not available.

water-quality table(s) - not available.

Soil Water

Information

thickness of vadose zone - included in the illustration.

nature of the medium - fractured and parent, un-fractured bedrock.

moisture content - - not available.

solute chemistry - not available.

Illustrations

profiles (moisture content/chemistry/texture versus depth) - not available.

maps (thickness of vadose zone, average moisture content, moisture at a certain depth,

average or maximum concentration of a given solute) - thickness of vadose zone is available and is about 1 - 2 meters.

logs (records of any boreholes in vadose zone) - not available.

Ground Water

Information

aquifer(s) - the aquifer is the fractured section of the bedrock between 232.5-234.3 m above mean sea level.

their characteristics water depth - the aquifer is confined; no potentiometric surface survey is available.

regional or perched? - the aquifer is not perched.

unconfined or confined? - the aquifer is confined.

recharge (area, mechanism, rate) flow (direction, rate, gradient) - from the illustration, it may be surmised that the recharge is from the upstream and rainfall; no recharge rates are available; the flow rates in the boreholes are given and range from less than 10 m/y to 500 m/y; flow directions apparently aligns with the cross section and the gradient (based on water table) is about

$$\left[\begin{array}{l} > (235.5 - 237.8) / 35.0; \\ \\ -0.06571428571 \end{array} \right.$$

discharge (area, mechanism, rate) - the discharge area is apparently the stream at the right-hand-side of the figure; the mechanism is most likely baseflow; no rate information is available.

water quality (constituents, variations across area) - not available.

Illustrations

well-records table (water-well data) well-construction diagrams - not available.

water-level map(s)-contours/flow directions for various aquifers, if different - water table is given for the unfractured bedrock/saprolite.

water-depth map-depth to regional water table, or first water - water table is given for the unfractured bedrock/saprolite.

water-quality table(s)-hydrochemical data - not available.

water quality maps (water type, concentration contours) water-quality diagrams (Piper, Stiff, etc) - not available.

Synthesis

Information

Any major geologic differences across area? - not available.

Relationship of surface, soil, and ground waters? - not available.

Water budget for area? - not available.

Geologic controls of hydrologic phenomena? - not available.

Illustrations

hydrogeologic column-relationship of stratigraphic and hydrostratigraphic units, their water-yielding properties - not available.

hydrogeologic cross section-stratigraphic units, hydrologic function (aquifer/aquitard), water level, equipotential contours, flow direction(s) - have the majority in the illustration except equipotential contours; we added flow direction.

- Fracture aperture

The equivalent grain size (in mm) may be estimated by the following interpolation

```
> d[13] := 0.46; d[7] := 0.24; (d[10] - d[7]) / (d[13] - d[7]) =  
(10.0 - 7) / (13 - 7);
```

$$d_{13} := 0.46$$

$$d_7 := 0.24$$

$$4.545454545 d_{10} - 1.090909091 = 0.5000000000$$

```
> d[10] := (10.0 - 7.0) / (13.0 - 7.0) * (d[13] - d[7]) + d[7];
```

$$d_{10} := 0.3500000000$$

in mm, or 0.035 cm; With the following constants,

```
> d[10] := d[10] * 0.1; rho := 1.0; g := 980.0; mu := 0.01; n :=  
0.32;
```

$$d_{10} := 0.03500000000$$

$$\rho := 1.0$$

$$g := 980.0$$

$$\mu := 0.01$$

$$n := 0.32$$

one may use the Kozeny-Carmen Bear empirical function, $K = \frac{\rho g n^3 d_{10}}{\mu (1 - n)^2 180}$, to estimate hydraulic conductivity, in cm/s, as:

```
> K := (rho * g) / mu * (n^3) / (1 - n)^2 * (d[10])^2 / 180.0;
```

$$K := 0.04726305267$$

Using the cubic law, one has the hydraulic conductivity for a planar fracture as $K = \frac{\rho g b^2}{12 \mu}$, or

$b = \sqrt{\frac{12 K \mu}{\rho g}}$. Numerically, the equivalent fracture aperture, in cm, is

```
> b := sqrt((12 * K * mu) / (rho * g));
```

$$b := 0.002405683390$$

```
>
```