Week Four

I. The Darcy experiment
   A. Darcy was trying to design water filtration units
      1. clean the water
      2. not clog up
      3. pass sufficient fluid to meet needs
      4. not too much head loss
   B. conclusions
      1. for any given filtration material (sand)
      2. a proportionality constant (K) relates steady flow (Q) to:
         a) cross-sectional area
         b) sample length (L)
         c) head drop (Dh)

II. Introduction to head and hydraulic gradient
   A. head (h) is a measure of potential energy
      1. taken at any point in a body of water
      2. height to which water will rise in a vertical open tube
   B. flow can only occur from a place of high h to one of lower h
   C. hydraulic gradient
      1. rate of change in hydraulic head in a specific direction
         a) in real world, varies in all directions
         b) we often constrain directions for simplicity
      2. dimensionless

III. Permeability/Hydraulic Conductivity
   A. hydraulic conductivity (K)
      1. units of L/T (cm/s or ft/day)
      2. composite property
         a) varies with fluid (viscosity, density)
            (1) temperature, salinity affect K
            (2) standard for reporting K is at 15.6 C
            (3) 25 C is commonly
                 (a) more practical temperature (77 F)
            b) also varies with media properties (pore geometry)
   B. intrinsic permeability (k or Ki)
      1. units of L^2
         a) also darcys which are ~ 1x 10-8 cm^2)
         b) common in petroleum literature
      2. property of the media alone (pore geometry)
      3. often referred to as a shape factor
   C. permeability
      1. old term for hydraulic conductivity
      2. no longer used
      3. often confused with intrinsic permeability
4. remember the units are different (L/T vs. L^2)

D. K (and k) are average properties
   1. they don't have any meaning at an infinitesimal point
   2. however, we treat them as continuous variables

IV. Permeameters, measuring K

A. constant head permeameter
   1. simplest methodology
   2. flow is forced through a sample of constant cross-section
   3. flow is held steady
      a) inlet, outlet heads are constant
      b) sample is brought to equilibrium
   4. gives K, which is converted to k
   5. measurements
      a) Dh
      b) Q
      c) sample area
      d) sample length
   6. used for unconsolidated sediments
      a) poor for low K materials
         (1) hard to control boundaries
         (2) hard to measure Q
         (3) evaporation is a big problem
   7. components
      a) sample tube
      b) porous plates
         (1) support sample
         (2) distribute flow
         (3) K should be higher than sample
      c) manifolds
      d) piezometers
      e) drip point
      f) fluid source
   8. headaches
      a) boundary effects
      b) sample packing
      c) trapped air

B. falling head permeameter
   1. transient test used for clays and rocks (low k)
   2. components
      a) sample tube
      b) porous plates
      c) manifolds
      d) drip point
      e) inlet tube
3. flow through the sample comes from vertical inlet tube
4. flow rate is determined by change in level
5. flow rate varies through test
6. this may take hours to weeks
7. careful measurements are essential
8. prevention of evaporation is essential

C. air permeameter
1. air is much less viscous than water
   a) allows measurement of low k materials
   b) rapid measurement of high k materials
   c) allows 1 sided measurements off of rock faces
2. flow follows a variant of Darcy’s Law
   a) accounts for compressibility

D. empirical measures
1. relate k to grain size distribution
   a) Hazen, Shepherd, Cozeny-Karman
2. typically take the form of \( k = C_d^2 \)
3. may also consider spread in the grain size distribution

V. Specific discharge (q)
A. for 1-D flow, \( Q = Aq \)
1. \( q \) represents some average velocity
2. \( q \) called specific discharge, Darcy flux
3. \( q = -K(\frac{dh}{dx}) \)
B. seepage velocity (v) or actual water velocity
1. \( v = q \) implies porosity = 1
2. this is not true for porous media
3. water must actually move faster than \( q \)
4. \( v = q/ne \), where \( ne \) = effective porosity

VI. Hydrogeologic units
A. aquifer
1. geologic unit capable of providing a water source
2. definition is relative
   a) in glacial outwash, sands may act as an aquifer
   b) in bedrock areas it may be a limestone
   c) in some places silt may act as an aquifer
B. confining layer - (aquifuge, archaic terminology)
1. geologic unit that is essentially impermeable (no flow)
2. bounds (above or below) an aquifer
C. leaky confining layer - (aquitard, archaic terminology)
1. relatively low permeability unit
2. bounds a more permeable unit
   a) a silt may confine a sand
   b) act as aquifer if is between two clay units,
3. a lot of water can move through some leaky units
a) e.g., Ogalalla or Long Island aquifers
b) fed through leaky confining layers

4. leaky units also tend towards regional subsidence
   a) collapse when water pressure drops
   b) e.g., Las Vegas, Long Beach

VII. Types of aquifers

A. unconfined aquifer - (phreatic, water table aquifer)
   1. bounded on top by the water table
      a) thickness changes with the water table
         (1) drops in drought, or near pumping
         (2) rises during infiltration
   2. usually relatively high permeability materials
   3. often connected to streams and lakes
   4. may be recharged through the vadose zone
   5. often productive
   6. easily contaminated

B. confined aquifer - (artesian)
   1. confining layer overlays an aquifer material
   2. may form as a result of
      a) deposition on a regional dip
      b) topography variation
      c) up warping
      d) intermontane sequences
   3. water originates from
      a) up gradient outcrop area
      b) regional leakage

C. perched aquifer
   1. above the water table
   2. flat impermeable layer intercepts downward leakage

D. show a sequence of aquifers at this point

VIII. Potentiometric surface (piezometric)

A. potentiometric surface
   1. describes energy state in a given confined aquifer
   2. taken as the height to which water would rise in a well
   3. may be a function of depth of measurement
      a) often assumed not to be
      b) changes with depth imply non-horizontal flow
   4. surface is different for stacked aquifers
      a) flow may in different directions

B. equipotential lines
   1. contour lines of constant head
   2. in reality these are 3-d surfaces
   3. we almost always assume them to be lines

C. map contours indicate the general direction of GW movement
1. flow is perpendicular to contours
2. assumes media properties are uniform (homogeneous, isotropic)

D. contour spacing
1. close spacing implies a steep gradient, could be from
   a) high flow rate
   b) low conductivity
   c) change in aquifer geometry (getting smaller)
2. wide spacing implies a shallow gradient, could be from
   a) low flow rate
   b) high conductivity
   c) change in aquifer geometry (spreading out)

E. potentiometric surface and surface topography
1. strong relationship for unconfined aquifers
2. no relationship for confined aquifers

F. artesian aquifer
1. potentiometric surface is above the land surface
2. water will flow without a pump
3. an unconfined aquifer cannot be artesian

G. gradient of potentiometric surface
1. often don't have enough wells to do a contour map
2. 3 points are needed to determine the direction and magnitude of the hydraulic gradient
3. method
   a) draw lines connecting the wells
   b) measure map distance between each pair
   c) choose points of equal elevation along at least two lines
   d) draw lines connecting the lines of equal elevation
   e) gradient is perpendicular to lines

IX. Water table
A. surface where water pressure equals atmospheric pressure
1. only applicable to unconfined aquifers
2. analogous to a potentiometric surface
B. head is more variable in an unconfined aquifer
1. shape of the aquifer changes
   a) time
   b) space
2. non-horizontal flow is highly likely
3. h may change significantly along a vertical line
C. shape of water table
1. flat in the absence of flow
2. a sloping WT indicates GW is flowing
   a) flow moves from high to low
b) driving force is gravity
3. GW discharge generally occurs in topographic lows
4. water table generally follows the surface topography
   a) shallow in valleys
   b) deep under hills and mountains

D. surface of streams and lakes may be part of the WT
1. lakes are flat spots in the water table map
2. contours point upstream along a gaining stream
3. contours point down stream around a losing stream

X. **Aquifer characteristics**

A. transmissivity (T)
   1. product of vertical aquifer thickness and K
   2. $T = Kb$
   3. units of $L^2/T$
   4. often more useful than K
   5. carries implicit assumption that flow is horizontal

B. storativity (S)
   1. $S$ volume of water stored or released from the aquifer
      beneath a unit square of surface area per unit drop in head
   2. dimensionless
   3. specific storage

C. specific storage (Ss)
   1. amount of water released from a unit volume of aquifer
      material per unit drop in head due to compression of the aquifer
      and water within

   $$S_s = \rho_w g (\alpha + n\beta)$$

   2. $\alpha$ – aquifer compressibility
   3. $\beta$ – water compressibility
   4. aquifer compression occurs in response to a change in
      effective stress
      a) water pressure supports the overlying materials
      b) lower the pressure and stress increases

D. Specific yield (Sy)
   1. fractional volume of water released from an aquifer under
      gravity drainage
   
      $$ne = Sy + Sr$$ where Sr is specific retention, the water held back
      against gravity drainage

E. confined vs. unconfined aquifers
   1. confined aquifers generally release water through only Ss
   2. release from an unconfined aquifer is $Sy + Ss$, much
      larger

XI. **homogeneity**
A. homogenous means properties are uniform in space
B. heterogeneous means properties vary in space
C. isotropic means properties are the same in all directions
D. anisotropic properties vary with direction
E. a homogenous aquifer can be anisotropic, and vice versa
F. we often assume homogenous and isotropic, but nature rarely is

XII. REV concept
A. porosity is a non-directional property but it can vary in space
B. plot Std. of porosity as a function of sample size
C. introduce REV concept
   1. this is not a measurable quantity
   2. it is a concept regarding how to think about the material
D. REV will be different for different materials, parameters
   1. e.g., porosity, K, D