H1 (Fitts)

1. The oceans cover about 71% of earth's surface, and other than ice-covered areas, there is no limit to the availability of water to evaporate. On the continents, evapotransipration is often limited by lack of water.

2. Low rates occur in polar latitudes because water is frozen much of the year and cold air can hold little water vapor. Low rates in north Africa and the Arabian peninsula are due to low levels of soil moisture in desert areas.

3. Answers vary with time. See the USGS waterwatch web site.

4. High infiltration and recharge are associated with permeable surface materials, flat topography, high precipitation rates, and land use/vegetation with low evapotranspiration rates.

5. Coarse-grained granular deposits have small capillary fringes because there is relatively little mineral surface area to attract water molecules and with larger pores the water molecules, on average, are farther from the mineral surfaces.

6. (a) 4.72 × 107 m3

(b) 3.62 yr

(c) 0.0396 m3 /sec

7. Overflow occurs between 5:00 and 6:00. Linear interpolation between these times estimates overflow at 5:27.8.

8. 0.99 m/sec

9. 1.1 in/yr

10. 7 in/yr (18 cm/yr)

11. (a) Fluxes into the lake are: Precipitation (P), inlet stream discharge (Si), overland flow (OF), interflow (IF), and groundwater inflow (Gi). Fluxes out of the lake are: Evapora-tion (E), outlet stream discharge (So), and groundwater outflow (Go).

b) 9.4 × 105 ft3 (2.7 × 104 m3)

c) The net of the four unknown fluxes is positive (into the lake). If we assume that overland flow and interflow are negligible, then $G_i - G_o \approx 9.4 \times 105$ ft3 , and there is more ground-water inflow than outflow at the lake bottom. So, with these assumptions, the lake is spring-fed to some degree. The net groundwater inflow is smaller than the contribution from precipitation and much smaller than the contribution of the inlet stream.

(d) Possibilities include:

• Install shallow wells around lake shore – where well levels exceed the lake level, flow is into the lake from the groundwater.

• Measure water temperatures along the bottom of the lake. Where spring discharge is high, the temperature may be anomalous. Summer would be better for this survey, because cold spring discharge will be denser and stay on the bottom.

• Repeat the measurements at a time when OF , E, and P are known to be low (winter in a cool climate would be good).

12. (a) The hydrologic balance equation in this case is

$$P + S_i + G - E - S_o = dV/dt$$

where P is precipitation, S_i and S_o are the inlet and outlet stream discharges, G is net groundwater inflow, E is evaporation, and dV/dt is the rate of change in reservoir volume.

H2 (Fitts)

1. 20,927 N.
2. $N/m^2 = kg\ m^{-1}\ sec^{-2}$.
3. $\simeq$ 1.0026 g/cm^3
4. Viscosity is a measure of the resistance to shear within a fluid. The viscosity of water is due to the attraction of polar water molecules for themselves and the weak hydrogen bonds that form between molecules.
5. 0.024 $N \cdot sec/m^2$
6. In a fine sand there is much more mineral surface area per volume of material and the attraction of pore water for these surfaces causes much lower pore water pressure (well below atmospheric pressure), which is what helps hold the sand castle together. In dry sand there is no pore water pressure, just atmospheric pressure in the pores.
7. Gage pressure is pressure relative to atmospheric pressure. A negative gage pressure is a pressure that is less than atmospheric pressure and a positive gage pressure is a pressure that exceeds atmospheric pressure. Absolute pressure is pressure relative to absolute zero pressure (zero force per area).
8. Porosity tends to be higher in well sorted materials than in poorly sorted materials. This is because in poorly sorted materials, there is a wide range of grain sizes, and smaller grains can pack between larger grains.
9. The porosity of pumice is quite high due to the large fraction of voids. However, many of these voids are sealed bubbles that do not participate in fluid flow. Therefore the effective porosity of pumice is much smaller than the porosity.

10.b) $n = 0.33$, $e = 0.49$, $\theta = 0.282$, $\rho_b = 1.81\ g/cm^3$

11. 2.140 g/cm^3

12. Assume a mineral density of 2700 kg/m^3 (2.70 g/cm^3). With this assumption, the mass of one cubic meter is 1748 kg.

13. a) Assumes a mineral density of 2650 kg/m^3 (2.70 g/cm^3). With this assumption, the mass of one cubic meter is 1952 kg.

b) $\rho_b = m_s / V_t = 2067\ kg/m^3$

c) $\rho_t = m_t / V_t = 2287\ kg/m^3$.

14. Gravitational potential energy (elevation head), elastic potential energy (pressure head), and kinetic energy (velocity head). Generally the velocity head is insignificant compared to the other two. The units of head are length.

15. 136.6 m
16. P = 819 lb/ft^2 . absolute pressure = $1.40 \times 10^5\ N/m^2$ = 2940 lb/ft^2.

17. (a) The flow is downward and head always decreases in the direction of flow. Therefore the

head increases in the upward direction.

(b) Water will flow into the top end of the well and exit the bottom end of it, because the well is a path of less resistance.

18. 430.2 ft (131.1 m)

19. Under a hurricane atmospheric pressure is lower, so the gage pressure is higher.

20. a) h = 267.4 m.

b) 22.4 m

c) 219,700 N/m2

21. a) hC = 476.69, hD = 472.17, and hE = 471.70. With heads known, pressures are computed using $p = (h - z)\rho g$.

c) There is generally an upward component, as indicated by the head differences between

the stream and wells D and E.

d) It enters at the top of the section everywhere except in the immediate vicinity of the

wetland and the stream. These two places are where the groundwater exits the subsurface.

H3 (Fitts)

1) 0.17 cm/min
2) Fourier's Law governs heat conduction in solids. For one-dimensional conduction in the x direction it is $q_{cx} = -\kappa^* \partial T/\partial x$ where q_{cx} is the energy conducted per time per unit area normal to the x direction (analogous to specific discharge), κ is the thermal conductivity (analogous to hydraulic conductivity), and T is temperature (analogous to hydraulic head).
3) For water to flow through fine-grained material, it must squeeze though many small, tortuous pores. In doing so, it must shear itself, which involves frictional resistance (see the discussion of water viscosity in Section 2.2.2). Flowing a given distance through fine-grained materials requires more shearing and viscous resistance than flowing the same distance through a coarse-grained material.
4) a) 51,000 ft^3 /day (1440 m^3 /day). The area A is normal to flow, one mile in horizontal length and 65 ft in the vertical.
   b) 0.15 ft/day (4.6 cm/day)
   c) 0.94 ft/day (29 cm/day)

5) a) h_A = 90.86 m, h_B = 88.50 m, h_C = 92.46 m.

b) Say the x direction is east and the y direction is north. $q_x = -0.0080$ m/day and $q_y = 0.047$ m/day.

d) 0.048 m/day

6) a) -3.6×10^{-4} m/day

b) -2.2×10^{-3} m^3 /day. The minus sign just means that the discharge is in the negative x direction.

c) -4.9×10^{-3} m/day

d) -0.074 m^3 /day

e) -9.3×10^{-4} m/day

7) 0.026 m/day

8) 8.3×10^{-13} m^2, 1.2×10^{-5} m/sec, 3.1×10^{-7} m/sec

9) Media with very large pores like karst limestone, porous basalt, or coarse gravel may have

turbulent flow. Large pores and high velocity promote turbulent flow. See the definition of

Reynolds number; turbulence occurs at high Reynolds numbers.

10) R_e = 16. Since Re > 10, this flow is probably turbulent and therefore not governed by Darcy's law.

11) a) 4.4 m/day.

b) 252 m^3 /day.

c) 7.9 m/day.

12) Heterogeneity is when a material property varies with location. Anisotropy is when, at a point, a material property varies with direction. Small scale heterogeneity in the form of thin layers of different K leads to anisotropy of a large-scale package of thin layers, with higher K parallel to the layers and lower K normal to the layers.

13) a) 2.2 m/day, 0.031 m/day

b) −0.021 m/day

c) 1.04 m

14) a) 35 ft^2 /day (3.3 m^2 /day)

b) 65 ft^2 /day (6.0 m^2 /day)

16) a) 0.012 cm/sec

b) 3.9×10^{-2} cm/sec

c) 1.9×10^{-2} cm/sec

17) 191 sec

18) 0.28 cm^3 /sec

19. Water is attracted to mineral surfaces and is “pulled” by these forces to form a film over the mineral surfaces. This pulling is like tension in a solid, reducing pore water pressures to below atmospheric pressure.

20) a) 230.80 m

b) 0.079

c) The flow is downward, toward the lower head.

d) −69 cm, In the fine sand soil, this corresponds to $\theta \approx 0.10$.

21 a) 12.89 m

b) $\theta = 0.22$.

22) Water will have an upward flow component any time the head decreases with increasing elevation. This can only occur if the pressure head decreases with elevation at a great enough rate to offset the increase in elevation head. Therefore, water content must decrease with elevation.

H2 (Lu & likos)

1. Temperature, pressure, and relative humidity are state variables that control the density of air.
2. Relative humidity (RH) is the ratio of absolute humidity in equilibrium with any solution to the absolute humidity in equilibrium with free water at the same temperature. RH is also equivalent to the ratio of vapor pressure in equilibrium with a given solution and the saturated vapor pressure in equilibrium with free water.
3. 47.53, ~ 50. Water is more sensitive to viscocity changes than air, changing by a magnitude of about 10, between 0. and 100.
4. 14.0 ^{o}C.
5. 89%
6. In a closed room ¯lled with humid air, a significant temperature rise will result in a decrease of relative humidity (RH) since RH is inversely proportional to temperature.
7. No, the vapor pressure of soil gas cannot be greater than saturation pressure at the same temperature and pressure.
8. Volumetric water content cannot be greater than 100% in unsaturated soil.
9. Degree of saturation (*S*) is a volume-based quantity.
10. When the temperature of unsaturated soil increases, the surface tension at the air-water interface decreases.
11. 1.110 kg/m3, 1.057 kg/m3, 80.76 kPa, 14.24 kPa
12. 0.51, 18.8.
13. a) 2.114 kPa
14. b) 15.507 g/m3
    c) 18.3
    d) 19.384 g/m3
    e) 30:43 kJ/kg
15. -189.7 kPa, -170.3 kPa

H3 (Lu & likos)

4. The water level of the tubes in the left side of the container will increase and the water level in the tubes in the right side of the container will decrease. Assuming that the contact angle does not change as water content changes, the tubes on the right side of the tank will completely evaporate and the tubes on the left side of the tank will fill up to reflect the change in water volume on the right.
5. a) 101.36 *kPa*
   b) 102.73 *kPa*

6. a) 1.44 *kPa* to 1.44 *MPa*
b) 99.86 *kPa* to -1.33 *MPa*
c) 3.167 *kPa* to 3.134 *kPa*
d) 100%, 98.96%

9. a) 2.335 to 2.337 kPa
b) 99.9 % to 100.0 %
c) -14.6 kPa to -145.5 kPa.

10. 1.5 m to 14.8 m.

11. b) 0.3, or 30 %.
c) 10 kPa.
d) Soil A is more fine-grained.
e) 0.02, or 2%.

H8 (Lu & likos)

1. Intrinsic permeability does not depend on °uid properties such as °uid density and viscosity. A sandy silt has an intrinsic permeability ranging from approximately 8 x 10^{-15} m^2 to 7 x 10^{-11} m^2, water conductivity ranging from 8 x 10^{-8} *m/s* to 7 x 10^{-4} *m/s*, and air conductivity ranging from 7 x 10^{-9} *m/s* to 7 x 10^{-5} *m/s*. For a sandy silt, water conductivity is higher than air conductivity.
2. The unsaturated hydraulic conductivity of a silt could be greater than the unsaturated hydraulic conductivity of a sand due to drainage of sand pores at an earlier air-entry head than for a silt. The lower hydraulic conductivity for the sand is a direct result of the uniform and fairly complete desaturation of the soil pores which limits the hydraulic pathways available for fluid particle flow. Silt has a higher air-entry head and as a result retains its pore water under a higher matric suction, maintaining water-filled pores to facilitate fluid flow.
3. A given unsaturated soil can have di®erent values of hydraulic conductivity for the same suction due to soil hysteresis. This hysteresis is strongly dictated by the difference between the geometry of fluid-filled pores and the contact angle for wetting and drying in solid-liquid interactions. As such, differing values for hydraulic conductivity can be obtained at the same matric suction under differing wetting, drying processes.
4. h = 9.17 *cm*
5. between 95% and 98%.

7. The required dip angle should be greater than or equal to 25.5^o.

8. At 0:5 *m* below the ground surface (1:5 *m* from the groundwater table), the matric suction head is approximately -0.80 *m* and the water content is approximately 0.34. For soil less than 0.5 *m* from the surface, the dominating driving force for the downward flow is gravity since the gradient of matric suction is small. For soil greater than 0.5 *m* from the surface, the dominating driving force for the downward flow is suction.