Week Two

I. Why study evaporation and precipitation
   A. think in terms of the hydrologic cycle
   B. our interest is GW flow
      1. source of GW is infiltration
      2. infiltration, GW are tough to measure
      3. runoff, ET, precipitation are much easier to measure
         a) measurement errors on the order of 5-10%
         b) seems large but really isn’t
   C. continuity lets us estimate GW flow
   D. Units of evaporation and precipitation
      1. length
      2. multiplication by area gives volume

II. Precipitation
   A. process
      1. air mass cools to dew point
      2. vapor condenses onto nuclei
      3. droplets are small, held aloft by air currents
      4. combine by collision and fall
         a) snowflakes grow by crystal growth
      5. drops evaporate while they fall
   B. cooling by adiabatic expansion
      1. rising air mass must cool
      2. pressure declines
      3. gas law implies cooling
   C. air rises by
      1. frontal collision
         a) moving warm front
            (1) gentle interface
            (2) light rain, large area
         b) moving cold front
            (1) abrupt interface
            (2) violent storms
      2. convection
         a) uneven surface heating
         b) warm air rises, cold slides underneath
      3. orographic uplift
         a) topography forces air upwards
         b) local effects can be extreme
            (1) Albuquerque

III. Measuring precipitation
   A. rain gauge
      1. types
a) recording gages
b) manually operated

2. usually underestimate rain
a) updrafts around opening
   (1) light rain, snow
   (2) particularly susceptible
b) splash
   (1) heavy rain
   (2) hail

3. bioperturbation

B. snow pack
1. crucial in many regions
   a) primary source of water
   b) gauge flood potential
2. more difficult to measure than rain
   a) rain gauges don’t work
3. weight not depth is important
   a) reported in equivalent water depth
   b) Alta, Squaw valley
4. techniques
   a) snow surveys (tube)
   b) snow pillows
   c) satellite imaging
      (1) snow absorbs some bands
          (a) radar
          (b) IR
      (2) calibrated to ground truth
      (3) covers large areas

C. Doppler radar
1. integrates over large areas
2. beam spreads with distance from source
3. measures density at altitude
4. not so good for ground rain in dry regions

D. basin wide estimates
1. lots of rain gauges out there
2. all are point measurements
3. need to be averaged over an area
4. headaches
   a) uniform grid would be optimal
   b) sites are chosen for convenience
      (1) usually in low areas
      (2) high rugged terrain under sampled
5. averaging methods
   a) simple average
b) contouring
   (1) isohyets are lines of equal rainfall
   (2) allows operator interpretation (terrain etc.)
   (3) results are often storm specific
   (4) computer solutions need to be trained
   (5) may go berserk near boundaries
   (6) averaged isohyets often correlate elevation to rainfall

c) Thiessen polygons
   (1) divides the basin into sub-regions
   (2) each region surrounds a measurement point
   (3) precipitation assumed constant within each region

IV. What happens to rain?
   A. evaporates as it falls
      1. pyramid lake example
      2. snow can also melt and evaporate
   B. falls directly onto surface water (oceans, lakes, streams)
   C. intercepted by vegetation
      1. evaporates
      2. runs down stalk
      3. adsorbed by plant (negligible)
      4. drunk by animals/insects (rain forest)
      5. plant fills and water drips through
   D. hits the ground
      1. absorbed by snow pack
      2. runs off on the surface
      3. depression storage (puddles)
         a) evaporates
         b) infiltrates
         c) puddle fills up and it runs off
      4. infiltrates into ground
         a) taken up by plants
         b) interflow to streams
         c) hits groundwater table

V. Evaporation
   A. change from liquid to vapor
      1. requires ~590 calories of heat
      2. continuous process
         a) always simultaneous with condensation
            (1) some molecules are condensing
            (2) others are evaporating
         b) we’re interested in the net balance
B. definitions

1. **absolute humidity**
   a) # of grams water in a cubic meter of air

2. **saturation humidity**
   a) equilibrium humidity
   b) equal numbers condensing and evaporating
   c) function of T, P, chemical species present
   d) table in book is a function of T, neglects
      (1) pressure (barometric and elevation)
      (2) chemical composition

3. **relative humidity = absolute/saturation (%)**

4. **dew point**
   a) temperature where condensation begins, fog/dew
   b) ~590 calories released per gram of condensate

C. where evaporation happens

1. small amount occurs from bare soil, rock
2. biologic effects come under transpiration
3. we'll focus on free water
   a) the big source
   b) oceans, lakes, rivers

D. driving forces

1. vapor pressure gradient
   a) energy level in the fluid
   b) relative humidity in the air
2. surface area

E. what we can measure

1. vapor pressure gradient (surface free energy)
   a) expensive to measure directly
   b) measurements are local
   c) use analogs instead
      (1) water temperature
      (2) air temperature
      (3) relative humidity
      (4) wind speed (moves vapor away)
2. surface area
   a) physical size
   b) wave action (also adds energy)

F. Land pans

1. 4 ft diameter, 10 inch high galvanized pans
2. water is kept at 7-8 inches depth
3. placed about 1 ft above ground
   a) keeps temperature close to air
4. evaporation calculated from continuity
5. usually next to a rain gauge
6. often placed near body of water
   a) correction coefficient is needed (<1)
   b) land pan loss is higher than reservoir
      (1) temperature change is faster
         (a) heat loss through sides, bottom
         (b) shallow depth

7. problems
   a) rain, splash
   b) wind
   c) bioperturbation (birds)
   d) does not account for waves
      (1) surface area, energy

G. nomograph
1. empirical method to estimate surface water evaporation
   a) calibrated to years of data
   b) done for surface water bodies of a given size
      (1) wave/wind relation changes with size

2. example data
   a) mean daily air temperature = 75 degrees F
   b) solar radiation = 500 langleys
   c) mean daily dew point T = 50 degrees
   d) wind movement = 200 miles/day

VI. Transpiration
A. moves water from roots to atmosphere
   1. osmotic pressure draws water into roots
   2. capillary pressure moves it to leaves
   3. exits through ‘pores’ on leaves (stomata)
   4. occurs
      a) only in growing season
      b) only during photosynthesis (daylight)
   5. only about 1% of water is retained as plant mass

B. water intake is driven by osmotic pressure
   1. concentration gradient across membrane
   2. must overcome capillary pressure in soil
   3. each plant type has a maximum osmotic pressure
      a) as soil gets drier, capillary pressure gets big
      b) wilting point occurs when plant can’t draw water

C. important categories of plants
   1. phreatophytes
      a) plants that 'tap' the groundwater system
      b) can pump at a high rate even in the desert
      c) roots need to be in the groundwater
      d) big problem in irrigated southwest
      e) willow, red cedar
2. xerophytes
   a) desert rain
      (1) infrequent
      (2) short duration
      (3) shallow penetration
   b) roots spread out laterally to capture water
   c) transpiration small
   d) stomata may close

3. hydrophytes
   a) submerged root systems
   b) amount of water loss is similar to evaporation

VII. Evapo-transpiration

A. evaporation and transpiration are similar processes
   1. in the field it is not possible to separate the two
      a) maybe brine lakes?, open ocean, desert
   2. so the loss of water is treated as a combined parameter

B. potential ET
   1. fluid loss if there is no deficiency of water for ET
   2. maximum in summer, minimum in winter,
   3. in spring there may be more water than potential ET
   4. in summer there is usually less
      a) stored water (field capacity) is used first
      b) then ET will approximate precipitation
      c) system stores water after the summer peak is over
   5. between field capacity and wilting point,
      a) rate of ET under this model is an open question
   6. Mojave desert has a potential ET of over 400 inches/yr.

C. measuring ET
   1. empirical data
      a) collated over time
      b) works over large areas
      c) basis for a number of computer models
   2. lysimeter
      a) large container sunk in the ground
      b) holds soil, plants, and maybe critters
      c) water balance is performed
         (1) water in/out
         (2) change in soil moisture
         (3) change in plant mass

D. importance of ET
   1. major use of water
      a) except extremely humid, cool climates
      b) lots of runoff in such areas (Oregon, BC)
   2. linked to hydrologic cycle through continuity
3. if ET goes up
   a) run-off and/or groundwater recharge go down
   b) vice versa if ET drops

E. vegetative changes can significantly effect hydrologic system
   1. increased runoff
      a) deforestation
      b) change to shallow rooted grasses
   2. decreased runoff
      a) changing hardwood to conifers
      b) conversion of farmland to forest

F. urbanization
   1. increases runoff at wet times
   2. decreases runoff at dry times
      a) pavement heat increases air circulation

VIII. Porosity and the water table
A. pore/void space water table (better definition later)
   1. virtually all soils and rocks have some sort of holes
      a) variety of sizes
   2. water/air is free to move through the pore space

B. water table (better definition later)
   1. pores near the surface aren’t all filled
   2. at some depth most all pores are full of water
   3. for now we’ll call this the water table
   4. more correct (Pw = Pa)
   5. elevation generally follows the surface topography
   6. streams and lakes may form part of the water table

IX. Infiltration
A. definition
   1. leakage from the surface into the subsurface
   2. water moves downward towards the water table

B. soil has a finite capacity to absorb water, function of:
   1. soil permeability
   2. soil porosity
   3. disturbance (burrows, vegetation, compaction, etc..)
   4. moisture content

C. Horton assumed
   1. soil first absorbs water like a sponge
      a) rate = fo
   2. gradually moves to equilibrium infiltration capacity
      a) steady state flux (fc)
   3. potential infiltration rate (fp) is an exponential decay
      a) fp = fc + (fo-fc)e^-kt
   4. actual infiltration rate in time will be a function of:
      a) potential infiltration rate
b) precipitation rate
5. this equation is a big time oversimplification
6. for practical usage k and f0 are difficult to determine

D. Under Hortons model
1. if rain is hitting the ground faster than it can be absorbed
2. it first ponds up
3. when depression storage is filled, runs off
4. this phenomena is rarely observed in the field except
   a) soil is barren, compacted, or saturated
   b) is referred to as Horton overland flow

E. other models
1. Holtan, Huggins and Monke, Stanford Watershed
   a) more complex than Horton’s
2. all work best when rainfall exceeds the maximum infiltration
3. below that soil moisture becomes a factor

F. experimental measurement of infiltration
1. hard to measure
   a) depends on soil moisture, varies in space time
   b) soil properties vary in space (macro-pores)
   c) instability
   d) micro-topography
   e) all of these factors are linked non-linearly
2. rainfall simulators
   a) measure runoff
   b) mass balance calculation
3. infiltration ring
   a) flood the system
   b) measure rate of replenishment
4. hydrograph separation,
   a) subtract baseflow from discharge
   b) sum up event run-off, divide by area
   c) requires good data
      (1) precipitation
      (2) E-T
      (3) stream flow

X. Gaining, losing, and neutral streams
A. source of water to streams
   1. get water from run-off
   2. lose water by emptying into lakes etc.
   3. lose water through evaporation
   4. streams also interact with the groundwater system

B. gaining streams (effluent)
   1. gain water from the ground water system
2. Water entering streams is referred to as base flow.
3. Typically occurs in temperate environments.
4. Form topographic lows in the groundwater table.
5. Ground water flows towards them.
6. Stream surface is part of the water table.
   a) Resistance to flow is much less than in the ground.
   b) Streams respond much faster to fluctuations.
7. Glacial outwash terrain of the upper midwest.
   a) Stream starts at a small spring at a notch point.
   b) Grows over stretches with no feeder streams.
   c) Flows even in periods of no rain.
   d) Usually cool water.
8. In mountainous terrain.
   a) Develop at abrupt changes in geology.
   b) Unlikely to grow over continuous distances.

C. Neutral streams.
1. Neither gain nor lose water to the water table.
2. Surface is part of the water table.
3. Occur in swampy lowlands or tropical environments.
   a) Ground is nearly flat.
   b) Essentially saturated to the surface.
4. Not a really robust condition.
   a) Change in stream level ends neutrality.
5. Extremely high permeability soils facilitate neutrality.
6. Amenable to quicksand.

D. Losing streams (influent).
1. Lose water to the groundwater table.
   a) May be directly connected to groundwater.
   b) May also be separated by an unsaturated zone.
2. Water table mounds below losing streams.
3. Losing streams typically occur in arid environments.
   a) Ephemeral streams.
      (1) Snow melt.
      (2) Flash flood activity over low permeability (hard rock often mountainous) units, because losing streams dissipate flow they are often transitory in nature.

E. Change in stream status.
1. A stream can be gaining or losing.
   a) Along different reaches.
   b) At different times of the year.
   c) Common in Oklahoma, Texas.
2. Can result from an abrupt change in water level.
   a) Stream is part of the water table.
b) much more responsive than the porous media

3. pumping lowers the local water table
   a) often done intentionally
      (1) draw surface water into water supply wells
      (2) natural filtration
      (3) talk about supply wells for Dayton, Ohio
         (a) Great Miami River

F. identifying status (gaining, losing)
   1. hydrologic equation
      a) performed a water balance
      b) losing has a net decrease in flow downstream
      c) gaining has a net increase in flow downstream

XI. Measuring stream flow
A. basics
   1. units
      a) volume (L3) per unit time
      2. typically cfs, mgd, acre-feet/day

B. harder to measure than flow through a pipe or open channel
   1. scour/deposition
   2. obstructions
   3. strange cross-section
   4. uneven friction
   5. meandering

C. weirs
   1. dam the river, force flow through a notch
      a) note that the weir should have a thin edge
      b) often a notched steel plate is built into the dam
   2. empirical equation relates
      a) weir type
      b) weir dimensions
      c) height of water behind notch
      d) flow rate
      e) not dimensionally correct
   3. occasionally used to measure flow during pump tests
   4. types of weirs
      a) V-notch weir (90° notch)
         \[ Q = 1.379 H^{5/2} \]
      b) \[ Q = \text{discharge in } m^3/s \]
         \[ H = \text{backwater height above weir crest in } m \]
c) rectangular weir
\[ Q = 1.84(L - 0.2H)H^{2/3} \]

d) \( Q \) – discharge in \( m^3/s \)
\( L \) – length of weir crest in \( m \)
\( H \) – backwater height above weir crest in \( m \)

e) 

D. gaging
1. measures water velocity in the stream
2. device looks like a wind speed indicator
   a) bullet shaped housing
   b) mounted on a staff (pygmy meter)
   c) winch and cable rigs are used on big streams
3. velocity is measured across the stream
   a) regular intervals across the cross-section
   b) measured at 0.6 times stream depth
   c) assumed to be average velocity

E. stage heights
1. assumes a stable cross section
   a) channel isn’t changing
2. flow rate will be directly correlated to river stage
   a) elevation of water surface
3. the stage height is converted to flow
   a) calibration curve based on gaged data
   b) must be checked frequently
   c) can’t work for floods above the calibration curve
      (1) once the river exceeds its banks small increases in stage result in large increases in flow
4. the USGS measures the stage at numerous locations
   a) often at highway bridges
      (1) stable x-section
      (2) easy access
   b) gaging station
      (1) stilling well
      (2) data acquisition/relay system

F. Manning equation
1. used when other methods are impossible
   a) during transients
   b) flow above the rating curve
   c) no gaging station
$V = \frac{1.49 R^{\frac{2}{3}} S^{\frac{1}{2}}}{n}$

$V$ – average velocity $\frac{ft}{s}$

$R$ – hydraulic radius $ft$

$S$ – slope of the stream surface $\frac{ft}{ft}$

$n$ – roughness coefficient

2. relates average water velocity to
   a) hydraulic radius
   b) slope of the water table
   c) empirical measure the 'Manning Coefficient'

   (1) represents frictional losses,
   (a) mountain streams
       (i) high resistance to flow
       (ii) $n \approx 0.05$
       (iii) real empirical
   (b) concrete ditches
   (c) low resistance to flow
   (d) $n = 0.12$
   (e) much less empirical

   (2) USGS publishes photographs of streams
   (3) used to estimate the Manning coefficient.

3. multiply average by cross-section to get flow

XII. Stream hydrographs

A. plot of stream discharge in time at a single location
   1. USGS data can be seen on their web site
   2. used in water balance studies
   3. can also be used to estimate infiltration

B. shape of the hydrograph
   1. series of peaks overlain on one another
   2. each peak represents the addition of water
   3. peaks rise rapidly, then decay exponentially

C. effects of a storm
   1. initial rise is from water falling on the stream
   2. discharge increases in response to overland flow
   3. peak is hours after the storm begins
   4. flow decreases as overland flow declines
   5. water is released from bank storage
   6. discharge declines
       a) gaining stream gets base flow from GW
       b) losing stream dries up