Chapter 9: Soil Water

9.1 Soil & the Hydrologic Cycle

- Where is the water on earth – what are the “reservoirs”?  
  - (Where did all this water come from?)  
  - How much water moves from one reservoir to the next?  
  - How long does water stay in each reservoir – what is the “residence time”

- Why is soil water so limited?

9.2 Soil-Water Interactions

- The structure of water – it’s polar, with positive & negative ends  
  - (What causes charge?)  
  - Adhesion is the attraction of water to surfaces  
  - Cohesion is the attraction of water to other water molecules  
  - Capillarity is the combination of adhesion and cohesion

- The capillary rise equation predicts how water will rise in a soil  
  - It also predicts how large a pore must be to hold water against gravity  
  - (What is gravity?)  
  - Water is held on soil surfaces by capillarity

- Free Energy:
  - Total energy is the sum of forces: Gravity, Pressure, Inertia  
    - Balloon falls from the top of a building  
    - At the top, it’s gravitational potential  
    - As its falling, it loses potential, converts to inertia  
    - When it hits the ground, it converts from inertial to pressure  
  - For soil water, velocity (inertia) can be neglected  
  - We define the total head as the sum of elevation and pressure  
    - Hydrostatic conditions (like in a pool where water is calm) is when the head is constant in space  
    - A decrease in elevation is an increase in pressure  
    - Hydrodynamic is when water is moving (more later…)

9.3 Soil Water Content

- Porosity and Water Content => how much is void space, how much water in each void  
  - Volumetric (by volume) vs. gravimetric (by weight)  
  - Depth is volumetric water content over a specified depth of soil

- Characteristic Curve, tension at various water contents (or water contents at various tensions), saturated, field capacity, wilting point, air dry, oven dry, plant available water
9.4 Soil Water Movement

- Total head changes over space and time (hydrodynamic)
  - Elevation and pressure forces dominate
  - (What about other forces?)
  - Potentiometric map is like a contour map – it shows lines of constant total head (equipotentials)
  - Water moves downhill from high heads to low heads
  - The closer the equipotentials, the higher the gradient (slope)
  - Slope is called hydraulic gradient, which is change in head with distance
- Darcy’s law says that water flux (flow per unit area) is the product of the
  - Hydraulic gradient, or slope
  - Hydraulic conductivity, or permeability
- The pore velocity is different from the flux
- The hydraulic conductivity varies with soil type, gravel is big, clay is small
- Unsaturated hydraulic conductivity, reduced because pores are filled with air, not allowing water to pass

9.5 Plant Water Uptake

- Water film continuity – water is pulled from the atmosphere through the stomata, up the stem, from the roots, and out of the soil.
  - It takes lots of tension (negative pressure, or suction) to pull this hard
  - This is unlike animals, where the heart pushes our blood
  - Osmotic pressures (salt pumps) help along the way
- Plant available water – difference between
  - Field capacity, water drains through root zone too quickly
  - Wilting point, plant can’t pull hard enough
- Important factors – include
  - Rate of water uptake (too fast is bad)
  - Need to open stomata to get carbon dioxide, losing water
  - Soil moisture availability, limits plant growth

This week in lab…

- Meet downstairs
- We’ll demonstrated Moisture Characteristics Curves
Chapter 10. Precipitation and Evaporation

10.1 Conservation of Mass

- A new concept, that matter cannot be created or destroyed
  - (except for Einstein’s theory…)
- Inflows – outflows = Change in Storage per Unit Time
  - \( I - O = \Delta S / \Delta t \)

10.2 Precipitation

- Global Atmospheric Circulation
  - Atmosphere Layers (troposphere, stratosphere)
  - Atmosphere Zones (tropics, subtropics, polar)
  - Separated by fronts, jets
  - Development of Hadley Cells
- Lapse Rates
  - Wet, dry, adiabatic lapse rates
  - Air cools as it rises (PV = nRT)
  - Air holds less water as it cools (vapor pressure vs. temp)
  - Relative humidity is actual humidity divided by saturated
- Types of Precipitation Events
  - Frontal Storms
  - Convective Storms
  - MCC’s → Mesoscale Convective Complexes
  - Orographic Precipitation
  - Tropical Cyclones
  - Lake Effect Precipitation
- Temporal Variation
  - Depth-Duration Curve
  - Rainfall Intensity: Depth / Duration
  - Intensity-Duration Curve
  - Recurrence Interval, \( Tr = 1 / \text{probability} \)
- Geographic Variation
  - Arid, Semi-Arid, Humid, Super-Humid (Rainforest)
  - Seasonality – monsoons
  - Alteration by humans

10.3 Evapotranspiration

- Evaporation, nonbiotic, (from water, soils only)
  - Phase Change from liquid to vapor (gas)
- Condensation, change from gas to liquid
- Sublimation/Deposition, change between solid-gas
- Melting/Freezing, change between liquid-solid
  - Pan Evaporation – a measure of the potential, or maximum, evaporation
  - Energy is from solar radiation and sensible heat transfer
  - Driven by Vapor Pressure Deficit (VPD = es - ea)
  - \( E = k \cdot VPD = k (es - ea) \)
- Transpiration, by plants
  - Generally from soil, through roots, stems, leaves, stomata
  - A byproduct of respiration, but also helps to cool leaf surfaces
  - A function of leaf area index (LAI)
- Canopy Interception, Stemflow, Throughfall
  - Interception: Evaporation from plant canopy
  - Stemflow: Water collected on leaves, branches that flows down stem
  - Throughfall: Water that makes it through the plant canopy to the ground, some is direct throughfall (never touches a leaf), and the rest is dripfall (could actually be larger drops than the rain)
- Potential Evapotranspiration, PET
  - Combination of evaporation and transpiration
  - The maximum possible rate of water loss
  - Commonly set equal to pan evaporation, with a pan factor adjustment
- Actual Evapotranspiration
  - Rate determined by actual conditions, usually less than PET
  - \( AET = C_p \times \text{Pan} \)
  - Weighing Lysimeters, Mass Balance Equation
  - Gas Flux, Eddy Correlation
  - Watershed Studies, Mass Balance
- Predicting AET
  - \( AET = K_c \cdot K_s \cdot \text{PET} \)
    - \( K_c \) is a crop factor
    - \( K_s \) is a soil factor
  - Field Water Budgets
  - Mass Balance Equations
  - Irrigation Scheduling

10.4 Modifying our Water Budget
- Water storage and distribution
- Irrigation and Drainage
- Infiltration vs. Runoff
This week in lab...

- Meet downstairs
- We’ll go over (review)
  - characteristic curves
  - total head
  - water movement
Chapter 11. Infiltration, Streamflow, and Groundwater

11.1 Water Budgets

- Uses conservation of mass or volume to constrain the problem
- \( R = P - ET \)
  - \( R \) is runoff (streamflow, discharge)
  - \( P \) is precipitation (rainfall)
  - \( ET \) is evapotranspiration
- Examples (values are in depth, inches/yr)
  - Athens, \( P = 50, ET = 35, R = 15 \)
  - Seattle, \( P = 40, ET = 20, R = 20 \)
  - Olympic Mountains, \( P = 120, ET = 20, R = 100 \)
  - Tucson, \( P = 12, ET = 35, R = 0, \) ????
- Can also be written in volume (e.g., Acre-Feet)
  - Volume = Depth \( \times \) Area
  - \( Q = A \times R \)
- Mass balance equation:
  - \( \Delta S = I - O \)
    - Change in Storage = Inflows – Outflows
  - \( \Delta S = P - R - ET \)
  - Inflows = \( P + GW(\text{in}) \rightarrow \) Groundwater inflows
  - Outflows = \( Q + ET + GW(\text{out}) + W \rightarrow \) water withdrawals
  - \( \Delta S = \Delta S(\text{surfacewater}) + \Delta S(\text{groundwater}) + \Delta S(\text{soil}) \)

11.2 Infiltration

- Definition and Importance
  - Water movement into soil through the soil surface
  - Most precipitation in forests infiltrates, not so much in urban areas
  - Infiltrations moves down through the soil to the saturated zone, or is used by plants
  - Stormwater budget
    - \( P = F + I + O \)
    - \( F \) is soil infiltration,
    - \( I \) is canopy interception,
    - \( O \) is overland flow
- Maximum Infiltration Rates
  - Usually when soils are driest
  - Actual infiltration rates decline over time as soil pores fill with water
• **Land Use Impacts**
  o **Crop land case**
    ▪ Raindrops are like small bombs that destroy the soil structure, clogging pores, and forming a soil crust
    ▪ Result is “surface-limited infiltration”
    ▪ Mulch, crop residues, no-till agriculture forms a layer that reduces raindrop impact effects.
  o **Forested case**
    ▪ Thick organic layers help maintain surface soil infiltration
      • Reduces raindrop impact
      • Increases soil organic matter which promotes secondary porosity
    ▪ Fire destroys this layer, and adds organic varnishes on soil particles that reduce capillarity
    ▪ Forest roads and landings are prime areas for runoff generation
  o **Urban case**
    ▪ Lots of roofs, sidewalks, roads, parking lots,
    ▪ Impervious areas prevent infiltration, causing overland flow
    ▪ Stormwater from urban areas is a major national problem (MS4)
  • **Other Factors**
    o Subsurface features (Bt horizon, shallow rock) can also limit infiltration
    o May formed “perched” aquifers, or shallow, temporary saturated areas
    o Frozen soils may also limit infiltration

11.3 **Sources of Streamflow**
• Greeks and Romans had a different “hydrologic cycle”
• Our current understanding:
  o **Overland Flow** (sheet flow, surface runoff, Hortonian Flow)
    ▪ From impervious surfaces, or where P > F
    ▪ F decreases over time, so O increases over time
    ▪ Less capillary forces (like a dry vs. wet paper towel)
    ▪ Increasing depth of “wetting front”
  o **Interflow** (shallow subsurface flow)
    ▪ Slower than overland flow, but faster than groundwater flow
    ▪ Usually more common in hilly to steep terrain
    ▪ Also a source of temporary seeps, springs, flows on hillslopes
  o **Direct Precipitation** (channels, lakes, wetlands)
  o **Variable Source Areas**
    ▪ Regions close to streams that are saturated and conduct water directly to streams
- Baseflow (groundwater discharge)
  - Flow from aquifers to streams, sustains flows during droughts
- Streamflow behavior
  - Flow in a stream is a complex mixture from each of the sources
  - Land management alters these relationships
  - Many aquatic plants and animals depend on a specific behavior

11.4 Subsurface Water Movement
- Water in the subsurface (found in wells, mines, caves, springs)
- Water moves from high to low head (elevation plus pressure)
  - Measure water table (level) in wells where $p=0$, so that $h = z$
  - Pressures below the water table are positive, $p>0$ (saturated zone)
  - Pressures above water table are negative, $p < 0$ (unsaturated zone)
- Water table (or piezometric) maps are used to define the shape of the water surface across a region (much like a topographic map)
  - Water tables are higher away from streams, and below high points in the landscape
  - Water tables are lower near streams
- Water tables rise and fall seasonally due to percolation and recharge
  - Percolation is water moving downward through the unsaturated zone
  - Recharge is water that moves from the unsaturated zone (UZ) to the saturated zone (SZ)
  - Water tables fall when infiltration/percolation/recharge is low
  - Water tables rise when they’re high
- Several zones in the subsurface
  - Unsaturated zone (UZ), also called Vadose Zone, region above water table where $p<0$. May contain temporary, isolated, saturated, perched zones where $p > 0$
  - Saturated zone (SZ), also called Phreatic Zone, region below water table where $p>0$. Always has an unconfined (water table, surficial) aquifer and may have one or more confined aquifers.
- Types of Aquifers
  - Aquifer: Geologic medium that allows water to readily flow
  - Aquitard: Geologic medium that restricts (but does not prevent) flow
  - Aquiclude: Geologic medium that prevents water flow
  - Both aquitards and aquicludes can serve as confining units for underlying aquifers.
  - Unconfined Aquifer: An aquifer in the uppermost part of the saturated zone, not overlain by a confining layer
  - Confined Aquifer: A deeper aquifer where water is limited in upward movement by a confining layer (aquitard or Aquiclude)
  - Perched Aquifer: A temporarily saturated aquifer in the UZ
• Groundwater Flow to Streams
  o Water infiltrates into and then percolates downward through the UZ
  o Once recharged, the water moves horizontally toward discharge regions (seeps, springs).
  o A well may intercept this water.
    ▪ The region providing water called the “capture zone”
    ▪ “Wellhead protection zones” are used to protect water quality near the well.
• Groundwater Applications (Floridan Aquifer, Snoqualmie River)

11.5 Water Supply
• Water Use
  o Consumptive: Water used but not returned.
    ▪ For example, outdoor yard watering is mostly lost to ET
    ▪ Agricultural irrigation is also mostly consumptive
  o Non-Consumptive: Water used but then returned to the stream
    ▪ Dams use water to generate electricity, most goes on downstream
    ▪ So do thermo-electric power plants, although the water is usually hotter
    ▪ Cities tend to return most of their water, although the quality is not as good as it was originally
  o Inter-Basin Transfers (IBT)
    ▪ Movement of water from one basin to another
    ▪ Not technically a consumptive use
    ▪ But prevents downstream users from subsequent reuse
    ▪ May be beneficial during a flood, a problem during a drought
• Water Demand
  o Demand is elastic, meaning that the amount used depends on its price.
  o If water was $10/gallon, we’d probably use less
  o The amount we use is a function of our willingness to pay
  o We tend to waste water if it’s free
  o How much do you pay?

11.6 Stream Characteristics
• Our aquatic systems are a product of their environment, the primary factors being:
  o Climate
  o Geology
  o Topography/Topology
  o Sediment Loading
  o Soils
Vegetation

- Along with important drivers, such as:
  - Time since disturbance
  - Biogeographic Setting
  - Keystone species (humans, beaver, mollusks)
- These are all important relative to their
  - Channel Habitat Structure
  - Chemistry
  - Physical Conditions
  - Biota

This week in lab...

- Out on Riverbend Road, near the Greenhouses (vans provided)
- Rainfall Infiltration Experiments
  - A rainfall simulator will evaluate the effects of mulch on infiltration and runoff
  - Ring and borehole methods will be demonstrated for determining infiltration and percolation rates.
Chapter 12. Hydrologic Statistics and Hydraulics

12.1 Stream Hydrographs

- Hydrograph, plot of discharge (flow, streamflow) vs. time
  - Stormflow hydrograph, plot of flow just before, during, and after a storm
  - Peak flow, maximum flow during the storm
  - Unit flows, flows per unit area, usually a smaller peak and delayed for larger areas
  - Rising limb, part of storm hydrograph before the peak
  - Falling limb, or recession limb, part of hydrograph after peak
  - Stormflow volume, total amount of flow, the sum of all stormflow
  - Baseflow, part of hydrograph not associated with a storm, usually from lakes or groundwater
  - Hydrographs are seasonal – more baseflow in winter and spring

- Measurement Units
  - Cubic feet per second, cfs
  - Gallons per minute, gpm
  - Million gallons per day, mgd
  - Acre-feet per day, AF/day
  - Cubic meters per second, cumec
  - Liters per minute, Lpm

- Flow measurements
  - Discharge \( (Q) = \) Velocity \( (v) \times \) Cross Sectional Area \( (A) \)
    - \( Q = v A \)
    - Average \( v \) is near middle of stream
    - Find \( v \) at multiple points across the stream using a current meter
    - Best if stream is straight, uniform depth, no obstructions
  - Stage, height of water in river, \( h \)
    - Used to find streamflow, i.e., \( Q = f(h) \)
    - This is called the “Rating Curve”
  - Manning’s Equation
    - \( v = (1.49/n) R^{(2/3)} S^{(1/2)} \)
    - \( n \) is Manning roughness coefficient
    - \( R \) is hydraulic radius, \( R = A / P \), \( P \) is wetted perimeter
    - \( S \) is channel slope (actually the energy gradient)

12.2 Hydrologic Statistics

- Recurrence Intervals, a measure of flood frequency
  - Probability of an event, \( Tr = 1 / p \)
    - For \( p = .5/yr \), \( Tr = 2 \) yrs
For $p = .01/yr$ (1% in a year), $Tr = 100$ yr
- Building a dam can lower the flood probability (for small storms anyway)
- Hydrologists make a chart of the flood frequency by sorting observed floods (largest to smallest), and then plotting their magnitude against a plotting statistic (e.g., Weibull, Gringarten)

- **Flows in Ungaged Streams**
  - Peak flows; use an estimation equation, $Q_n = a A^b P^c$
  - Mean flows; use $Q = (P - E) A$
  - Unit Hydrograph Method: $Q_p = Q_o x (A/Ao) x (R/Ro)$
  - Curve Number Method: $Q = Po^2 / (Po + S)$, $S = 1000/CN - 10$
    - $CN = 95$ for parking lot
    - $CN = 60-70$ for ag areas

### 12.3 Effects of Land Management

- **Forest Management**
  - Harvesting reduces leaf area, decreasing ET, increasing water yield
  - Can increase runoff due to soil compaction (roads, yarding areas), reduction of infiltration (burning)
  - High lead or helicopter logging in steep areas to mitigate erosion
  - Increases NPS pollution (water temperature, sediment, etc)
  - BMPs (best management practices) to reduce NPS pollution
  - SMZs (streamside management zones) are a BMP

- **Agricultural Land Management**
  - Plowing increases soil loss, no-till helps reduce this
  - Contour plowing, filter strips slow runoff
  - Rotation of grazing, away from streams during winter, helps
  - NMPs (nutrient management plans) are used to minimize fertilizer runoff

- **Urban Land Use Management**
  - Stormwater management is key
    - Increase detention and retention
    - Detention basins, pervious surfaces, rain gardens, green roofs, dry wells
  - Channel structure is compromised
    - Concrete & stone channels (straight) replace natural (winding) channels
    - LWD (large woody debris) and other organic debris recruitment (inputs) and budgets change

- **Riparian Buffers**
  - Bank stability
  - Pollutant filtration
  - Denitrification
• Shade
• Organic debris recruitment
• Large woody debris recruitment
• Wildlife habitat
• Aesthetic
• Social/Educational

This week in lab…

• Streamflow measurements (quantity & quality)
• We often meet at Trail Creek, behind Mama’s Boy, at Dudley Park Greenway entrance. Confirm before going there…
Chapter 13. Erosion and Sedimentation

13.1 History and Significance

- Geologic vs. Accelerated Erosion
  - Geologic erosion is usually slow (except glaciers, floods, fire)
  - Humans accelerate erosion by land-disturbing activities
    - Compaction, reduced organic content, bare soil, fire

- Erosion in Early Agriculture
  - Loss of soil productivity, collapse of empires
  - Loss of harbors, navigation, trade

- Modern Erosion
  - Soil loss reduces crop productivity (onsite problems)
  - Siltation downstream (offsite problems)
  - Point source discharges (from pipes)
  - Nonpoint source discharges (from landscape)

13.2 Processes and Mechanisms

- Wind Erosion – much like water erosion
  - Suspension (moves in the air)
  - Saltation (hops along the ground), “stinging sand”
  - Creep (rolls along the ground)
  - Windbreaks help slow the air velocity near the ground

- Water Erosion
  - Raindrop splash (impact energy, big drops are heavier, faster)
  - Sheet erosion (overland flow, faster deeper water is worse)
  - Rill erosion (concentrated flow in small rivulets)
  - Gully erosion (concentrated flow in large, temporary channels)
  - Channel erosion (concentrated flow in permanent channels)

13.3 Water Erosion Prediction: USLE

- \[ A = R \times K \times LS \times C \times P \]
  - A: Annual Soil Loss factor (t/ac)
  - R: Rainfall factor
  - K: Soil factor
  - LS: Topographic factor
  - C: Vegetation factor
  - P: Conservation practices factor

- \[ A < T? \]
  - T (Acceptable Soil Loss) factor (t/ac)
13.4 Types of Measurements

- Turbidity
  - Water Clarity
  - JTUs, NTUs, FTUs, KTUs, Secchi
- Suspended Solids Concentration
  - Total mass of mineral sediments
  - Concentration, Load, Yield
- Bedload Transport
  - Mass flux on & near bottom of stream
  - Deadfall, load cells
- Comparison of Measures

13.5 Sampling Strategies

- Location (depth, bank, distance)
- Stage (low, normal, high)

13.6 Prevention Strategies

- Vegetative Cover
- Surface Stabilization
- Velocity Reduction
- Peak Flow Reduction
- Inspection and Maintenance

13.7 Sediment & Drinking Water

- Flocculants help to settle solids out of water (opposite of dispersants)
- Filters remove any residual solids
- Disinfection works to kill any residual pathogens

This week in lab…

- Meet downstairs
- Two objectives
  - Predicting Peak Discharge
  - Predicting Soil Erosion
  - We’ll see how changes in Georgia’s landscape have affected peak flows and erosion rates over time
Chapter 14. Wastes in Soil and Water

14.1 What is a Contaminant?
- Many substances are vital for life, but can be toxic
- For example, vitamin pills are a leading killer of children, who eat them like candy

14.2 Risk Assessment
- Used to quantify the risks associated with a potential contaminant
- Different risk pathways
  - Ingestion of soil
  - Leaching to groundwater
  - Runoff to surface water
  - Plant uptake
  - Animal uptake

14.3 What is Water Quality?
- Physical water quality
- Chemical water quality
- Biological water quality

14.4 Water Quality Attributes
- Physical Properties
  - Habitat
  - Shade
  - Bank and bed materials (sediment and substrate)
  - Turbidity
  - Temperature
  - Woody debris
  - Channel morphology (pools, riffles, runs, glides)
- Chemical Properties
  - Oxygen, Biochemical Oxygen Demand
  - pH/Acidity/Alkalinity
  - Nutrients
  - Dissolved solids
  - Toxics (metals, organics, radionuclides)
- Biological Properties
  - Pathogens
  - Exotic (Invasive) species
  - Indicator species or Guilds
  - Noxious plants
  - Biological Integrity

14.5 Overall Water Quality
- Point measurements (time and space) can be deceiving (both high or low).
An integrated measure of overall water quality can use indicator species, such as an index of biological integrity (IBI).

This uses benthic macroinvertebrates and/or fish species to evaluate overall water quality.

But states and federal governments have their rules and regulations related to water quality requirements.

These are often based on the “designated use” for the water, such as for fishing, drinking, etc.

Each designated use has a water quality requirement.

### 14.6 Waste Disposal

- **Wastewater**
  - Can be treated at a centralized wastewater treatment facility.
  - This water is returned to a river or can be used as part of a land application system.
  - Or can be treated and infiltrated onsite.

- **Recycling solid wastes to soils**
  - Some wastes (carbon, nutrients) are beneficial to plants.
  - Other wastes (toxics) are a concern to the environment.

### 14.7 Water Quality Regulation

- Differentiates between Point and Nonpoint Sources
- Point sources are regulated using NPDES permits
- Nonpoint sources often use BMPs
- Overall water quality can be managed using TMDLs (Total Maximum Daily Loads), which are determined by the assimilative capacity of the receiving waters.

This week in lab…

- Meet downstairs
- We’ll use the AA to analyze for toxic metals in your environment