NSci233 Notes- Weeks 10 to 12

Lesson Plan 6 - Infiltration Week 3 of 3

Charles Jason Tinant

4/16/2018

Important Updates

- PLEASE send the midterm if you have not done so already. I will be checking them again this week. I will be sending out a new schedule / syllabus soon with dates
- April 17 will be a work session - I will not be in class. The assignment is to complete this homework collaboratively. Please feel free to use the code below. Also, the book has graphs, equations, and discussion that will help with the homework. The Rmd file has graphs that can be adapted to answer most of the questions.
- Homework from Lesson Plans 1, 2, 3, 4, 5 is **due April 3rd**. Late homework will receive a lower grade.
- We are going to cover Chapter 3 - Infiltration, this chapter, and Chapter 4 - soil moisture and evaporation, in two weeks.
- The most recent versions of the lesson plans can be downloaded from https://github.com/cjtinant/NSci253_Notes

Student Learning Outcomes (SLOs) & Lesson Goals:

- *SLO1: Students will demonstrate proficiency in the components of the hydrologic cycle: precipitation, infiltration, runoff, and evapotranspiration* - Students will be able to generally describe physical characteristics of soils that lead to runoff and infiltration.
- *SLO2: Students are able to analyze components of the hydrologic with computer software* - Students will be generally able to read data into R, and perform some analysis using packages. Students will will be able to read arguments of a package from R Documentation.

Overview

Soil profiles are heterogeneous mixtures of solids, liquids, and gasses, and living things. A first approach in understanding infiltration and soil water processes is to physically classify the soils. Physical classification involves measuring or calculating sizes, volume, mass, and density of the soil particles and voids.

Reading Assignment

Chapter 2: Read sections 3.1 - 3.4. Scan sections 3.5 - 3.8

Homework Assignment

Please work together and turn in as proof of attendance on April 18 (does not need to be complete to prove that you were in class)

1. A particular soil, called Sue, has a physical composition of 40% silt, 20% clay, and 40% sand. What kind of soil is Sue?
2. What is the maximum depth of water that can be stored in the top 0.8 meter of a soil profile of Sue, which has a porosity of 0.4.
   your answer should be somewhere between 25 to 35 cm
   Determine the volumetric soil water content if the degree of saturation is 35%.
   your answer should be between 10% - 20%
3. A sample of the soil named Sue is placed in a weighing container with a mass of 20 grams. The weighing container plus soil is 150 grams. The sample is then put into a drying oven for 24-hours at 104 centigrade. The sample plus tin is cooled and reweighed. The final mass is 125 grams. What is the water content by mass?
   your answer should be between 20% - 30%
4. The dry bulk density of a soil sample of Sue is 1.68 grams per cubic cm. The density of particles was measured to be 2.8 grams per cubic cm. Find the porosity of the soil profile. *your answer should be exactly what was reported in problem 2*
   Find the specific gravity of the soil particles. *your answer should be between 2.6 - 3.0*
   Find the bulk density of a saturated soil sample. *your answer should be between 2.0 - 2.3 grams/cc*
5. Corn needs about 30 inches of water per year to grow. Western South Dakota gets less than 30 inches, so corn needs to be irrigated to grow in this part of the state. Figure 3.9 shows the wilting point of a soil named Sue is 1 inch per foot and the field capacity is 3.2 inches per foot.
   What is the plant available water for this soil? *should be greater than example because less clay in the soil*
   Determine the amount of water needed to increase soil water content in the root zone

(0.8 meters) of a soil named Sue from its wilting point (WP) to field capacity (FC). *your answer should be more than the answer from the example of 3.6 because the root zone is bigger and PAW is greater*

6. Write the definition of the following terms: infiltration, percolation, interflow, soil water, void, saturated, field capacity, hygroscopic soil water, capillary action, bulk density, dry bulk density, soil particle density, specific gravity, root zone, wilting point, plant available water (PAW)

Lecture Notes with R-code

```r
# If you need to you should 'install.packages("here")'
# library("tidyverse") # load the tidyverse package
# library("lubridate")
# library("janitor")
library("here")
here::here() # this checks where R thinks the working directory is...
```

```
## [1] "/Users/cjtinant/Google Drive/NSci253-master/NSci253_Notes"
```

Soil Water Relationships

- Soil profiles consist of heterogeneous mixtures of solid, liquid, and gaseous materials, and billions of microorganisms. Solid materials include particles of different sizes, shapes, and mineral composition.

- Soil particles consist primarily of disintegrated and decomposed rock fragments. These fragments are not created by simply crushing the rock. Instead, there are biologically-mediated oxidation, carbonization, and hydration processes occurring to make soil.
- A first approach in understanding infiltration and soil water processes is *physical soil classification* based on the size of the soil particles. We use clay, silt, and sand in soils classification. Figures 3.1 and 3.2 show different soils classification approaches. The size of the particles is important because the particles have interstial open spaces called *voids* or *pores* that hold water. And because clay particles can hold onto water through *capillary action*.
- Air or water fills the voids. If the voids are full, then the soil is *saturated*. Saturated soils hold more water than can be held under gravity. The extra water *percolates* drains downward to recharge groundwater and to flow laterally to recharge streams *interflow*. Once all of the water that can be held by the soil percolates to groundwater then the soil is at *field capacity*. We can think about the complex relationship of soil voids using math.

$$V_t = V_a + V_w + V_s$$

where V_t is the total volume of voids, V_a is the volume of air, V_w is the volume of water, and V_s is the volume of solids. The volume of voids, V_v can be found in the following way

$$V_v = V_a + V_w$$

Substuting the two equations above gives a mathematical description of porosity, n by

$$n = \frac{V_v}{V_t} = 1 - \frac{V_s}{V_t}$$

The amount of soil water content in a soil can be found by either volume or mass. *note that accurately measuring mass in the lab is pretty easy, relative to accurately measuring volume.* Soil water content is expressed as Θ_v, the volume of water in a soil sample divided by the total volume of the sample.

$$\Theta_v = \frac{V_w}{V_t} = S * n$$

Soil moisture content is the amount of moisture that fills soil pores. The percentage of pores that are filled with water is called the *degree of saturation, S*. The relationship between S, n, and Θ_v is shown above.

Example 3.1

What is the maximum depth of water that can be stored in the top three feet of a soil profile with a porosity of 0.5. Also, determine the volumetric soil water content if the degree of saturation is 60%.

```
# What is the maximum depth of water that can be stored in the top three
# feet of a soil profile with a porosity of 0.5.  Also, determine the
# volumetric soil water content if the degree of saturation is 60%.

# For max depth of stored water use vol_void = porosity * vol_tot

# 1. find vol_tot in cubic inches
depth_ft      <- 3      # ft
depth_in      <- depth_ft * 12      # 12 in = 1 ft
area_sq_in    <- 1          # square inch
vol_tot_cu_in <- depth_in * area_sq_in    # cubic inches

# 2. find the maximum volume of water that can be stored
porosity       <- 0.5
vol_void_cu_in <- porosity * vol_tot_cu_in

# 3. find the maximum depth of water that can be stored
vol_void_in    <- vol_void_cu_in/area_sq_in

# 4. find the amount of water in the soil at 60% saturation

# for water content at 60% saturation use Theta_v = perc_sat * porosity
perc_sat       <- 0.6  # unitless
Theta_v        <- perc_sat * porosity  # unitless
```

The depth of water is 18 inches and the volumetric soil water content at 60% saturation is 0.3 inches per inch (or cubic inches per cubic inch).

Gravimetric soil water content

The total mass of a soil profile is given below.

$$m_t = m_a + m_w + m_s$$

The soil water content can also be determined as a function of mass. In this case, it is called the *gravimetric soil water content*. We assume that the mass of air is negligible. The soil water content is the ratio of water mass to dry soil mass.

$$\Theta_g = \frac{m_w}{m_s}$$

The following example is typical for a soil lab technique.

Example 3.2

A sample of soil is placed in a weighing container with a mass of 25 grams. The weighing container plus soil is 140 grams. The sample is then put into a drying oven for 24-hours at 104 centigrade. The sample plus tin is cooled and reweighed. The final mass is 120 grams. What is the water content by mass.

```
rm(list=ls()) # remove all of the list of variables

# given
mass_tin            <-  25 # grams
mass_tin_soil_water <- 140 # grams
mass_tin_soil  <- 120 # grams

# Need to find water content by mass: mass_w / mass_total

# 1. need to subtract off the mass of the tin.
mass_soil_water = mass_tin_soil_water - mass_tin # grams
mass_soil = mass_tin_soil - mass_tin # grams

# 2. Find the mass of the water
mass_water = mass_soil_water - mass_soil # grams

# 3. find water content by mass
wat_cont_mass = mass_water / mass_soil
perc_sat_mass = 100 * wat_cont_mass
```

The water content is 21.05263 (grams per gram).

Soil density

The behavior of soil depends on the *bulk density* of the soill profile ρ_b, which is the mass of the soil per unit volume. It is related to other soil properties.

Bulk density:

$$\rho_b = \frac{m_t}{V_t}$$

Dry bulk density:

$$\rho_{dry} = \frac{m_s}{V_t}$$

The dry bulk density is related to the soil particle density, ρ_p and porosity, n.

$$\rho_{dry} = \rho_p(1-n)$$

The soil particle density, ρ_p is the mass of the dry soil divided by the soil volume $\frac{m_s}{V_s}$. Soil particle density depends on the underlying geology, but soil particles are often assumed to weigh 2.6 - 2.75 grams per cubic cm (160 - 175 lb/cu.ft).

This can be rearranged to find porosity.

$$1 - \frac{\rho_{dry}}{\rho_p} = n$$

The ratio of density of soil particles to the density of water is called *specific gravity*, where water is assumed to be 1.0 grams per cubic cm (62.4 lb/cu.ft).

$$G_s = \frac{\rho_p}{\rho_w}$$

The example below relates mass and volume through density.

Example 3.3

The dry bulk density of a soil sample is 84.24 lb/cu.ft, and the density of particles was measured to be 168.48 lb/cu.ft. Find the porosity of the soil profile and the specific gravity of the soil particles. Also find the bulk density of a saturated soil sample.

```
rm(list=ls()) # remove all of the list of variables

dens_dry_soil <-  84.24  # lb/cu.ft
dens_part     <- 168.48  # lb/cu.ft
```

```r
# 1. SI units are much easier to work with, so change to SI using density of water
# Density of water is: 1.0 g/cc = 62.4 lb/cu.ft
dens_water_Imp <- 62.4  # lb/cu.ft for the Imperial Units density of water

# These are all in grams per cubic cm after unit conversion
dens_dry_soil  <-  dens_dry_soil / dens_water_Imp  # changes it to g/cc
dens_part <- dens_part / dens_water_Imp  # changes it to g/cc
dens_water <- dens_water_Imp / dens_water_Imp # changes it to g/cc
# A check, dens_water should be 1.0)
rm(dens_water_Imp) # removes the unneeded variable

# 2. Use the equation for porosity above
porosity <- 1 - (dens_dry_soil/dens_part)

# 3. Finding the specific gravity of the soil is now pretty easy
#    because we are in SI units.
SpGrav_part <- dens_part / dens_water # unitless or  g/cc per g/cc

# note that pure quartz sand is 2.65 and feldspar is 2.6, so this soil
# is most likely derived from a granite.  In contrast, an iron oxide has
# a specific gravity of about 5.0.

# 4. Find density of saturated soil
#    First find the mass of the water filling the voids
mass_water_per_cc <- porosity * dens_water
dens_sat_soil <- dens_dry_soil + mass_water_per_cc # grams per cc

# you can take this back to Imperial units to check.  Note, we started
# with dry soil of 84 lb/ft3 and the particles weigh 168 lb/ft3
dens_sat_soil_imp <- dens_sat_soil * 62.4 # lb/ft3 so looks good.
```

The porosity of the soil profile is 0.5 (volume per volume). The specific gravity of the soil particles is 2.7 grams per cubic centimeter. The bulk density of a saturated soil sample is 1.85 grams/cc or 115.44 lb/cubic ft

Example 3.4 - Field capacity

Determine the amount of water needed to increase soil water content in the root zone (2 feet) of a clay loam soil from a critical value of 50% of field capacity to field capacity. The critical value is the point at which wilting occurs, the wilting point or WP. Figure 3.9 shows the water holding capacity for different kinds of soils. The figure shows that the wilting point for clay loam is 2 inches per foot of soil and the field capacity is 4 inches per foot of soil.

```r
rm(list = ls()) # remove all of the list of variables

wilt_point  <- 2   # inches water per foot soil
field_cap   <- 3.8 # inches water per foot soil
PAW         <- field_cap - wilt_point
wat_need_in_per_ft <- field_cap - wilt_point # inches water per foot soil

root_zone_ft     <- 2 # ft
wat_need_rootzone <- wat_need_in_per_ft * root_zone_ft
```