NSci233 Notes - Weeks 3 - 5

Water Resources - Updated 5/02/2018

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2/06/2018

Updates following Feb 6 lecture

- We will be having a supplementary / make-up class on Friday, Feb 25 from 1-4 PM to work with R-Studio.

Overview

Hydrology is the study or knowledge of water. A beautiful thing about, and the main challenge of hydrology is the amount of available water differs over both time and space. Humans are also affecting the available amount of water on a global scale through infrastructure. A growing human population and a warming planet will have impacts on water distribution and on the interaction of human populations with water.

This week we will take a first look at the hydrologic cycle, water resources and society by learning some ways to get data into RStudio. We are also going to experiment with the interactive use of RStudio for lecturing and note taking.

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 the hydrologic cycle, water resources and society, and hydrologic data analysis.
- *SLO2: Students are able to analyze components of the hydrologic with computer software* - Students will be generally able to read 'Tidyverse' code, read in data into R, join data tables, and perform some basic manipulation tasks

Readings

- Read / skim pages 4 - 16 in Exploratory Data Analysis with R by Roger Peng. The file is in the Readings_and_Programs folder in Google Drive.
- Read sections 2.1 - 2.4 of the text

Homework

You are welcome to turn in a file in Rmd, pdf, html or Word. Upload the file into a folder with your name in Google Drive.

- 1. Vocabulary - Summarize the terms: precipitation, infiltration, evapotranspiration, runoff, and groundwater as given on pages 8 & 9 of your text.
- 2. Unit conversion - What are the global amounts of water withdrawn in cubic kilometers per year?
- 3. Water Distribution - Is ground water a renewable resource? Use Table 1.8 to identify how long it takes for a drop of water removed from an aquifer to be replaced.
- 4. Sustainability - Much of Africa is a semi-arid climate, like Western SD. Add a mutate statement to 'water_balance' below to calculate the percentage of precipitation that is evaporated. Notice also there is little ground water, relative to other regions.
- How does this help to explain why there is a low ratio of water being withdrawn to precipitation?
- How does a changing climate and an increasing population make people this region more vulnurable to drought?
- Discuss parallels between Africa and Reservations in the Midwest and Southwest in terms of water resources.

Lecture Notes - Interactive

Hydrologic Cycle

The hydrologic cycle refers to the constant motion of the 300 million cubic miles of water on the earth's surface between various **storages**: atmosphere, above-ground terrestrial storages, soil vadose zone, aquifers, lakes and streams, the ocean, and ice. The movement from one storage to another is a **hydrologic process** evaporation, precipitation, transpiration, infiltration, runoff, percolation, and stream flow.

Water Withdrawals

Quantifying water by its withdrawal and societal use is a way to think about the hydrologic cycle. The FAO estimates that on average 110,000 km^3 of water falls on land each year as precipitation. Globally, two-thirds of precipitation is evaporated or transpired. The remaining volume of water flows into rivers and aquifers. This volume is the total amount of renewable freshwater.

```r
library(tidyverse)
library(janitor)
```

```r
# How much precipitation is available each year as renewable freshwater?
# ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
# you can create a new code chunk by pressing either the 'Insert'
# button above or by pressing: 'Ctrl' + 'Alt' + 'I'

# you can read in data into R using the assignment operator '<-' to
# assign a value to a variable.  This property makes it easy to
# do math in R.  The difficult thing is variable naming.

# I included the following units in the variable names:
#   km3 - cubic kilometers
#   _yr - per year

precip_km3_yr    <- 110000   # this figure is from page 1 of the text
evap_km3_yr      <- 2/3 * precip_km3_yr
ren_water_km3_yr <- precip_km3_yr - evap_km3_yr
```

The **renewable freshwater resources** are the volume of water available (in this case per year) as surface water (water flowing into streams and lakes) and ground water (water flowing into aquifers).

Humans have built infrastructure to extract water to meet sociatal needs, **water withdrawals**. Some of the withdrawn water is returned to surface and ground water, **renewable**

water use, and some of the withdrawn water is evaporated or transpired, **water consumption**.

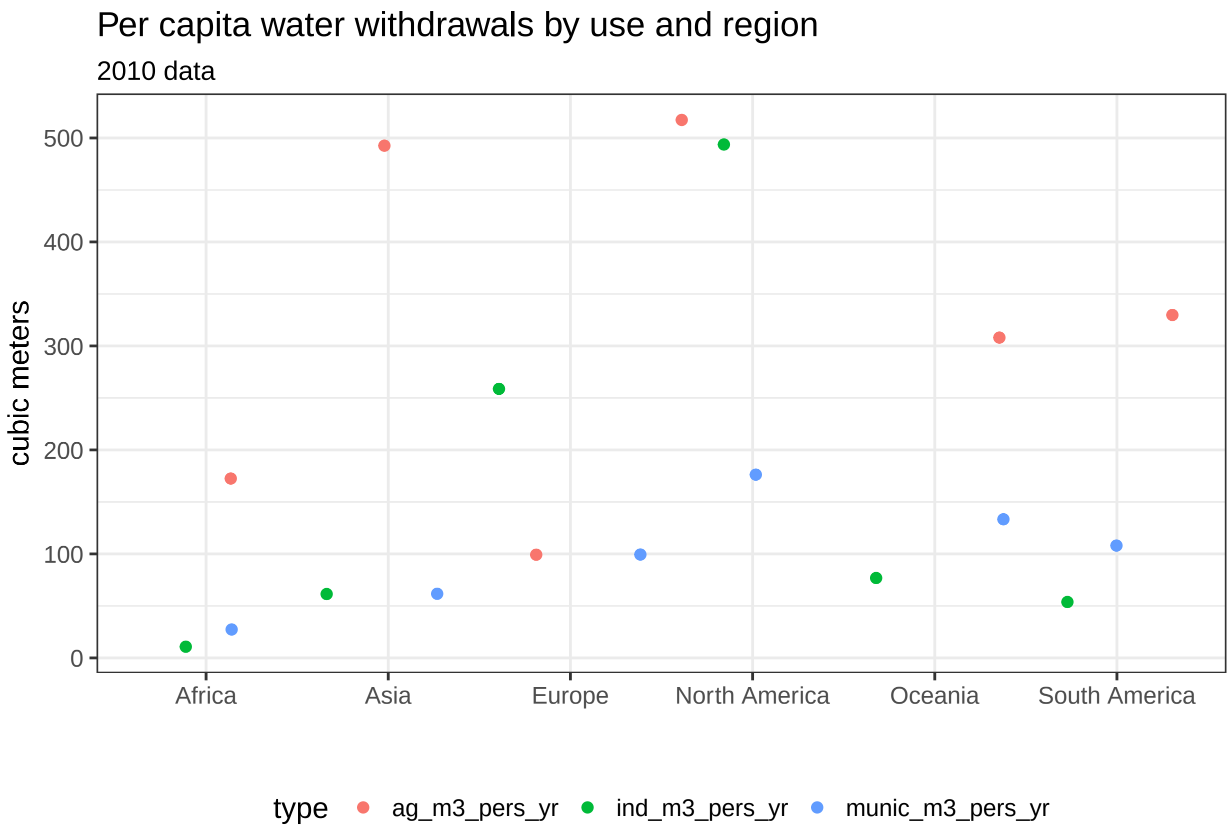
```
# How much water in 2010 was withdrawn by region and in total?
# ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
library(tidyverse) # load the tidyverse package

# we can quickly add data together in R rather than read it in from a
# .csv file using the 'concatinate' function, c().  Than using the
# 'tidyverse', we can easily bind rows and columns together.

# We are using the data from Table 1.3 from the text
# ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
# 1. make vectors of region names (strings) and withdrawals (numbers)
region <- c("Africa", "North America", "South America", "Asia",
               "Europe", "Oceania")
withdraw_bill_m3_yr <- c(214, 634, 195, 2545, 333, 18)

# 2.  Turn the vecters into data.frames, which are easier to work with in R
region <- as.data.frame(region)
withdraw_bill_m3_yr <- as.data.frame(withdraw_bill_m3_yr)

# 3. bind the data.frames together
water_withdraw <- bind_cols(region, withdraw_bill_m3_yr)

# 4. clean up by removing the data.frames you don't need
rm(region, withdraw_bill_m3_yr)

# 5. Use 'View' or click on 'water_withdraw' in the global environment
# to check to if it looks ok.

# 6. Use 'sum()' to find the global volume of water withdrawals.
world_withdraw <- sum(water_withdraw$withdraw_bill_m3_yr)
print(world_withdraw)
```

```
## [1] 3939
```

Last week I said that growing areas of concern are an increasing human population that is stressing water resources, and global warming that is having an increasing impact on global food and water supplies.

```
# We can add to our data table using 'join'.
# We are also using a 'pipe operator' %>% to make reading
# the code a little bit easier.

# First, bring in a table of regional use
```

```r
regional_use <- read_csv("regional_use.csv") %>%
  select(-X1)   # this gets rid of a useless column

# Next, use a 'full_join' to join the tables together by similiar regions.
water_withdraw <- full_join(water_withdraw, regional_use, by = "region")

rm(regional_use)
# If these steps were performed correctly, you should have the first
# six rows of Table 1.3.  We can find out how much water is being
# being used per capita using the 'mutate' function to create a new column

water_withdraw <- water_withdraw %>%
  mutate(withdraw_m3_pers_yr  = withdraw_bill_m3_yr / pop_mill *
                          ((10^9)/(10^6))) %>%
  arrange(desc(withdraw_bill_m3_yr))

# Sometimes percentages are difficult relate.  This changes the percentages
#   to how much water per person is going into different water uses
water_withdraw <- water_withdraw %>%
  mutate(ag_m3_pers_yr = withdraw_m3_pers_yr * agric_perc/100) %>%
  mutate(ind_m3_pers_yr = withdraw_m3_pers_yr * indust_perc/100) %>%
  mutate(munic_m3_pers_yr = withdraw_m3_pers_yr * munic_perc/100) %>%
  arrange(desc(ag_m3_pers_yr))

# Sometimes, a graphic helps to to see what is happening in a data-set.
#  1. Gather the data to graph it easier.
water_withdraw2 <- water_withdraw %>%
  select(-(2:7)) %>%
  gather(key = type, val = vol_m3, -region)

# 2. Create the graph.
ggplot(water_withdraw2, aes(x = region, y = vol_m3, color = type)) +
  geom_jitter() +
  labs(title = "Per capita water withdrawals by use and region",
       subtitle = "2010 data") +
  ylab("cubic meters") +
  xlab("") +
  theme_bw() +
  theme(legend.position = "bottom")
```



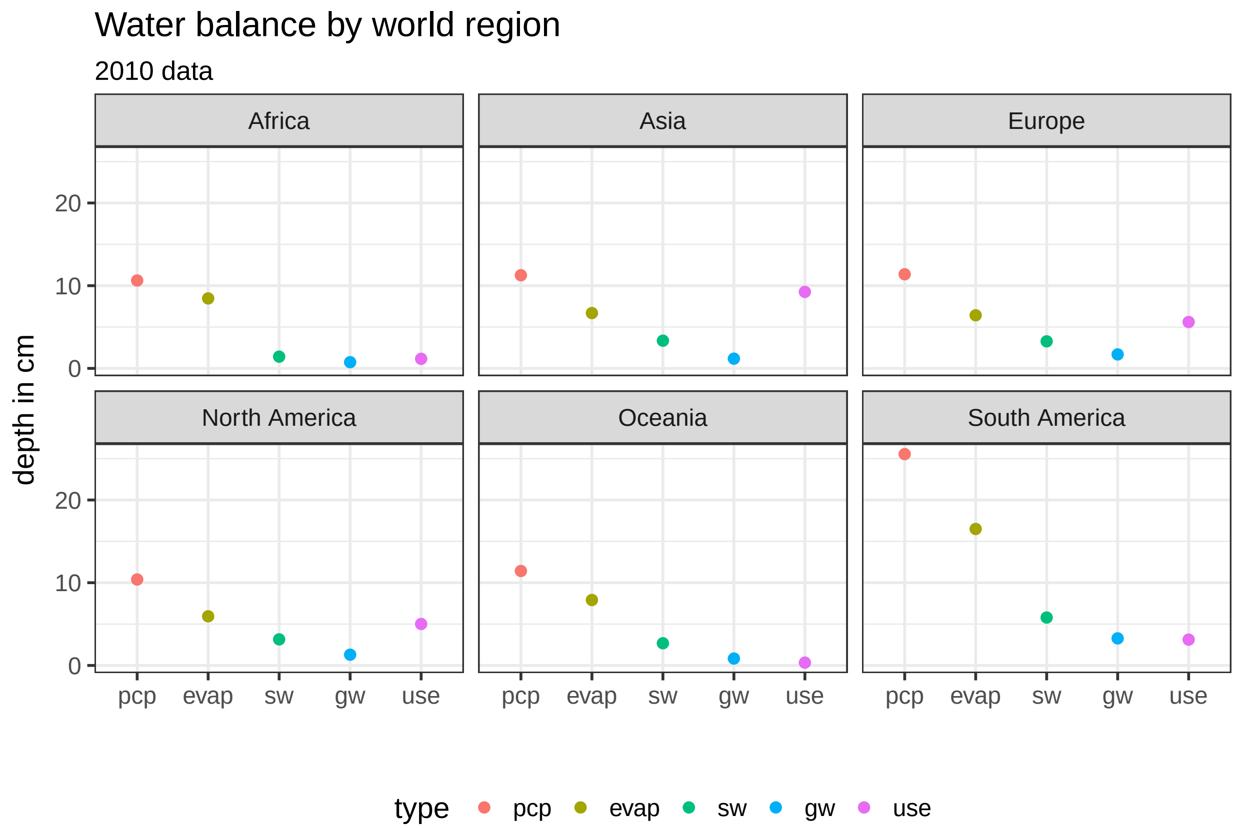
The graph above is why they say in the United States that "whiskey is for drinking and water is for fighting over…". In North America, about equal amounts of water are withdrawn for industry and agriculture. Also, note North America uses approximately twice the world average for municipal use.

The graph above shows water withdrawal, which is different from water consumption. A majority of industrial and municipal water is discharge as wastewater; however, a substantial portion of agricultural water is consumed. And much of the water used for agriculture is ground water, which is not a renewable resource.

So, how does this information work together to help us make water resource decisions? One take away from the exercise above is that you need to have data in a format that allows you to look at the data across categories. Above, we normalized the data by per-capita. Below, we are going to normalize the data by area. Consider that flow rate is volume per time $Q = [m^3/year]$ Volume is made up of depth times area $V = [m^3] = d[m] * A[m^2]$. So, to compare water volumes across regions of different size, we can divide the volume of water per year for a region by the area of the region to find the depth.

```
water_balance <- water_withdraw %>%
  select(region, withdraw_bill_m3_yr) %>%
  rename(withdraw_bill_m3 = withdraw_bill_m3_yr)

balance_tabl <- read.csv("water_balance.csv") %>%
  select(-X)
```

```r
water_balance <- full_join(water_balance, balance_tabl)

# bill = 10^9
# mill = 10^6
# km^2 = 10^6 m
# So, for the equation withdraw_bill_m3 / area_mill_km^2, the
# units are 10^9 m3 / 10^12 m3 -> 1/10^3 m3
# so, using 1 m = 10^2 cm, we can get to cm if we divide the equation by 10

water_balance <- water_balance %>%
  mutate(withdraw_cm = withdraw_bill_m3 / (10 * area_mill_km2)) %>%
  mutate(withdraw_cm = round(withdraw_cm, digits = 2)) %>%
  arrange(desc(withdraw_cm)) %>%
  mutate(withdraw_precip_rat = withdraw_cm/precip_cm) %>%
  mutate(withdraw_precip_rat = round(withdraw_precip_rat, digits = 2))

# Sometimes, a graphic helps to to see what is happening in a data-set.
#  1. Gather the data to graph it easier.
water_balance2 <- water_balance %>%
  select(-withdraw_bill_m3, -area_mill_km2, -withdraw_precip_rat) %>%
  rename(pcp = precip_cm) %>%
  rename(gw = gw_runoff_cm) %>%
  rename(sw = sw_runoff_cm) %>%
  rename(evap = evaporation_cm) %>%
  rename(use = withdraw_cm) %>%
  gather(key = type, val = depth_cm, -region) %>%
  mutate(type = as.factor(type))

#  1. set up print order of the factors
water_balance2$type <- factor(water_balance2$type,
                              levels = c("pcp", "evap", "sw", "gw", "use"))

# 2. Create the graph.
ggplot(water_balance2, aes(x = type, y = depth_cm, color = type)) +
  geom_point() +
  facet_wrap(~region) +
  labs(title = "Water balance by world region",
       subtitle = "2010 data") +
  ylab("depth in cm") +
  xlab("") +
  theme_bw() +
  theme(legend.position = "bottom")
```


Water balance by world region
2010 data
Africa
Asia
Europe
North America
Oceania
South America
depth in cm
0
10
20
pcp
evap
sw
gw
use
type