R Advanced Spatial Lessons

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Contents

Prerequisites

Lessons presented here are a continuation of the Geospatial workshop using R of Data Carpentry described more specifically for the Lawrence Berkeley National Lab: Sep 27-28, 2017.

This content is setup for now using bookdown (using the bookdown-demo) for expediency, and meant to eventually be folded into the Software Carpentry style.

Chapter 1

Tidy Spatial Analysis

1.1 Overview

Questions

- How to elegantly conduct complex spatial analysis by chaining operations?
- What is the percent area of water by region across the United States?

Objectives

- Use the `%>%` operator (aka "then" or "pipe") to pass output from one function into input of the next.
- Calculate metrics on spatial attributes.
- Aggregate spatial data with metrics.
- Display a map of results.

1.2 Prerequisites

R Skill Level: Intermediate - you've got basics of R down.

You will use the `sf` package for vector data along with the `dplyr` package for calculating and manipulating attribute data.

```
# load packages
library(tidyverse)  # load dplyr, tidyr, ggplot2 packages
library(sf)         # vector reading & analysis

# set working directory to data folder
# setwd("pathToDirHere")
```

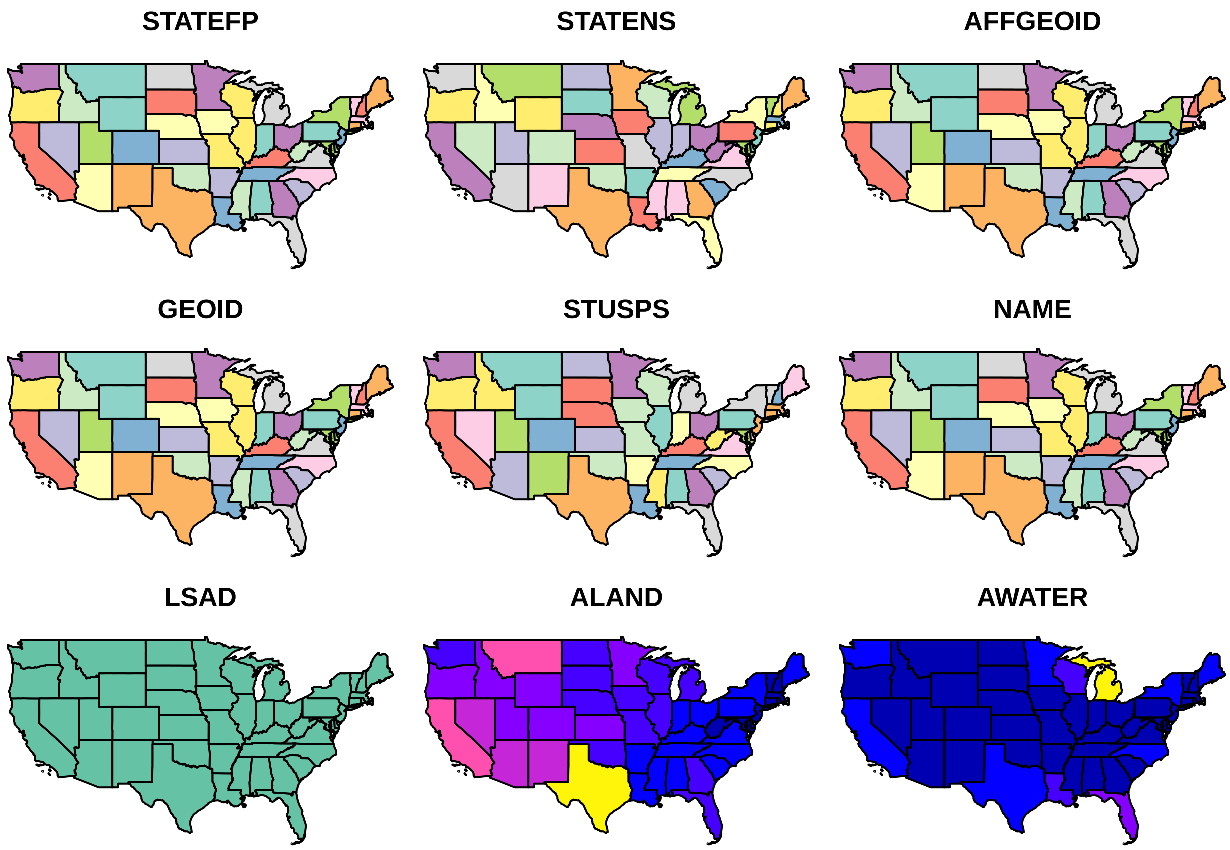
1.3 States: read and plot

Similar to Lesson 9: Handling Spatial Projection & CRS in R, we'll start by reading in a polygon shapefile using the `sf` package. Then use the default `plot()` function to see what it looks like.

```
# read in states
states <- read_sf("data/NEON-DS-Site-Layout-Files/US-Boundary-Layers/US-State-Boundaries-Census-2014.shp
```

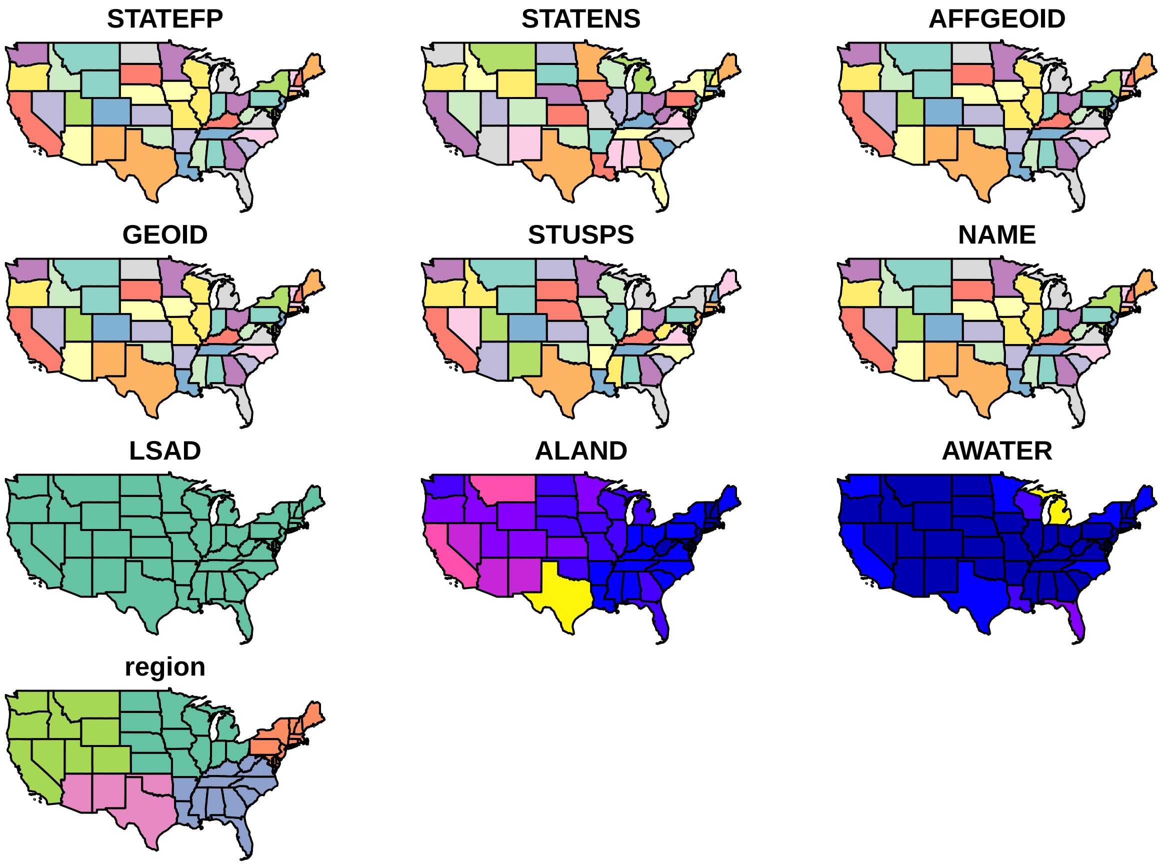
```r
# plot the states
plot(states)
```

```
## Warning: plotting the first 9 out of 10 attributes; use max.plot = 10 to
## plot all
```



Notice the default plot on `sf` objects outputs colorized values of the first 9 of 10 columns. Use the suggestion from the warning to plot the 10th column.

```r
# plot 10th column
plot(states, max.plot = 10)
```




```
# show columns of the data frame
names(states)
```

```
##  [1] "STATEFP"   "STATENS"   "AFFGEOID" "GEOID"    "STUSPS"    "NAME"
##  [7] "LSAD"      "ALAND"     "AWATER"   "region"   "geometry"
```

```
# look at table
glimpse(states)
```

```
## Observations: 58
## Variables: 11
## $ STATEFP  <chr> "06", "11", "12", "13", "16", "17", "19", "21", "22",...
## $ STATENS  <chr> "01779778", "01702382", "00294478", "01705317", "0177...
## $ AFFGEOID <chr> "0400000US06", "0400000US11", "0400000US12", "0400000...
## $ GEOID    <chr> "06", "11", "12", "13", "16", "17", "19", "21", "22",...
## $ STUSPS   <chr> "CA", "DC", "FL", "GA", "ID", "IL", "IA", "KY", "LA",...
## $ NAME     <chr> "California", "District of Columbia", "Florida", "Geo...
## $ LSAD     <chr> "00", "00", "00", "00", "00", "00", "00", "00", "00",...
## $ ALAND    <dbl> 403483823181, 158350578, 138903200855, 148963503399, ...
## $ AWATER   <dbl> 20483271881, 18633500, 31407883551, 4947080103, 23977...
## $ region   <chr> "West", "Northeast", "Southeast", "Southeast", "West"...
## $ geometry <simple_feature> MULTIPOLYGONZ(((-118.593969..., MULTIPOLYG...
```

```
# convert to tibble for nicer printing
as_tibble(states)
```

```
## Simple feature collection with 58 features and 10 fields
## geometry type:  MULTIPOLYGON
```

```
## dimension:      XYZ
## bbox:           xmin: -124.7258 ymin: 24.49813 xmax: -66.9499 ymax: 49.38436
## epsg (SRID):    4326
## proj4string:    +proj=longlat +datum=WGS84 +no_defs
## # A tibble: 58 x 11
##    STATEFP  STATENS    AFFGEOID GEOID STUSPS                 NAME  LSAD
##      <chr>    <chr>       <chr> <chr>  <chr>                <chr> <chr>
##  1      06 01779778 0400000US06    06     CA           California    00
##  2      11 01702382 0400000US11    11     DC District of Columbia    00
##  3      12 00294478 0400000US12    12     FL              Florida    00
##  4      13 01705317 0400000US13    13     GA              Georgia    00
##  5      16 01779783 0400000US16    16     ID                Idaho    00
##  6      17 01779784 0400000US17    17     IL             Illinois    00
##  7      19 01779785 0400000US19    19     IA                 Iowa    00
##  8      21 01779786 0400000US21    21     KY             Kentucky    00
##  9      22 01629543 0400000US22    22     LA            Louisiana    00
## 10      24 01714934 0400000US24    24     MD             Maryland    00
## # ... with 48 more rows, and 4 more variables: ALAND <dbl>, AWATER <dbl>,
## #   region <chr>, geometry <simple_feature>
```

```r
names(states)
```

```
##  [1] "STATEFP"  "STATENS"  "AFFGEOID" "GEOID"    "STUSPS"   "NAME"
##  [7] "LSAD"     "ALAND"    "AWATER"   "region"   "geometry"
```

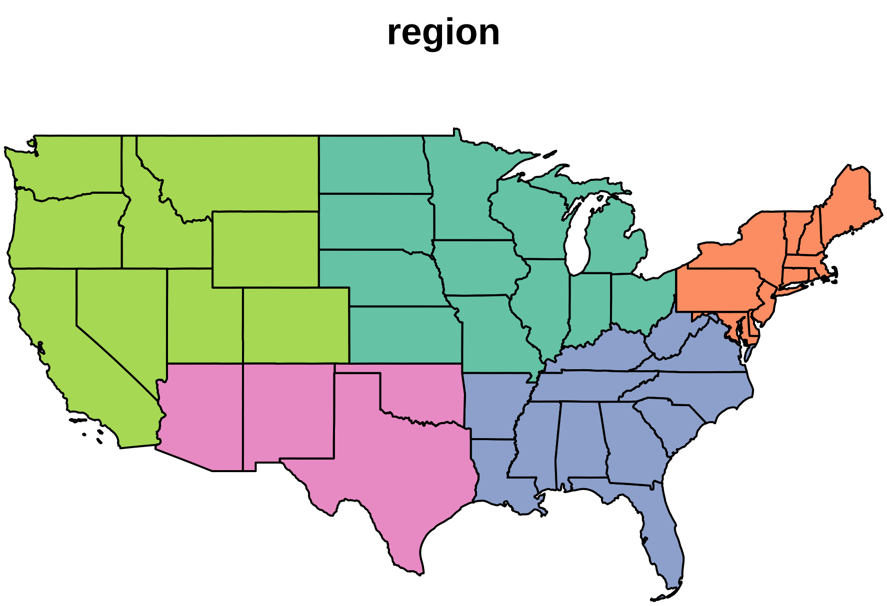
```r
# inspect the class(es) of the states object
class(states)
```

```
## [1] "sf"         "tbl_df"     "tbl"        "data.frame"
```

The class of the `states` object is both a simple feature (`sf`) as well as a data frame, which means the many useful functions available to a data frame (or "tibble") can be applied.

To plot the column of interest, feed the "slice" of that column to the `plot()` function.

```r
plot(states['region'])
```



Question: To motivate the spatial analysis for the rest of this lesson, you will answer this question: "***What***

is the percent water by region?"

1.4 Challenge: analytical steps?

Outline a sequence of analytical steps needed to arrive at the answer.

1.4.1 Answers

1. **Sum** the area of water (`AWATER`) and land (`ALAND`) per region.
2. **Divide** the area of water (`AWATER`) by the area of land (`ALAND`) per region to arrive at percent water.
3. Show **table** of regions sorted by percent water.
4. Show **map** of regions by percent water with a color ramp and legend.

1.5 Regions: calculate % water

- Use the `%>%` operator (aka "then" or "pipe") to pass output from one function into input of the next.
  - In RStudio, see menu Help > Keyboard Shortcuts Help for a shortcut to the "Insert Pipe Operator".
- Calculate metrics on spatial attributes.
  - In RStudio, see menu Help > Cheatsheets > Data Manipulation with dplyr, tidyr.
- Aggregate spatial data with metrics.

```
regions = states %>%
  group_by(region) %>%
  summarize(
    water = sum(AWATER),
    land  = sum(ALAND)) %>%
  mutate(
    pct_water = water / land * 100 %>% round(2))

# object
regions
```

```
## Simple feature collection with 5 features and 4 fields
## geometry type:  GEOMETRY
## dimension:      XYZ
## bbox:           xmin: -124.7258 ymin: 24.49813 xmax: -66.9499 ymax: 49.38436
## epsg (SRID):    4326
## proj4string:    +proj=longlat +datum=WGS84 +no_defs
## # A tibble: 5 x 5
##      region        water         land pct_water          geometry
##       <chr>        <dbl>        <dbl>     <dbl>  <simple_feature>
## 1   Midwest 184383393833 1.943869e+12  9.485380 <MULTIPOLYGON...>
## 2 Northeast 108922434345 8.690661e+11 12.533273 <MULTIPOLYGON...>
## 3 Southeast 103876652998 1.364632e+12  7.612063 <MULTIPOLYGON...>
## 4 Southwest  24217682268 1.462632e+12  1.655761 <POLYGONZ((-9...>
## 5      West  57568049509 2.432336e+12  2.366780 <MULTIPOLYGON...>
```

Notice the geometry in the column. To remove the geometry column pipe to `st_set_geometry(NULL)`. To arrange in descending order use `arrange(desc(pct_water))`.

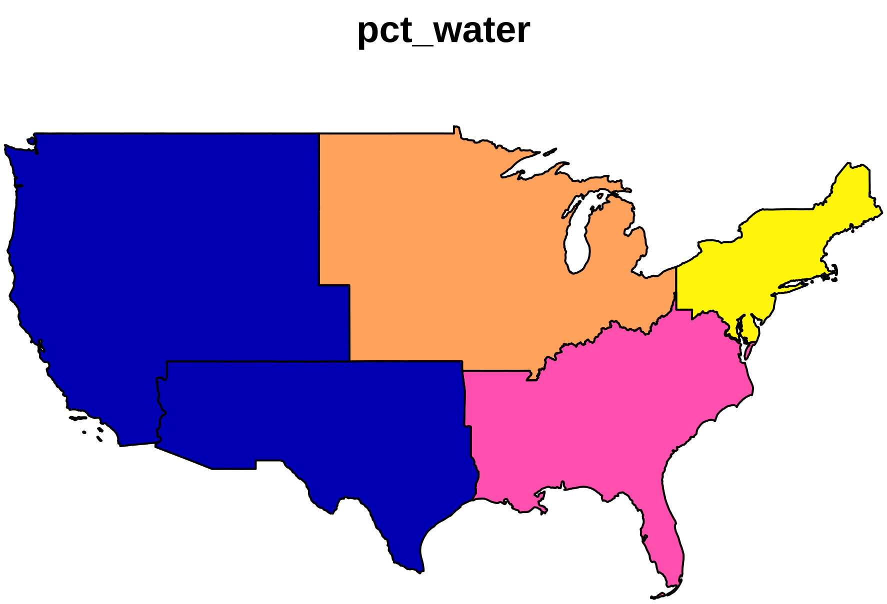
```
# table
regions %>%
  st_set_geometry(NULL) %>%
  arrange(desc(pct_water))
```

```
## # A tibble: 5 x 4
##      region        water         land pct_water
##       <chr>        <dbl>        <dbl>     <dbl>
## 1 Northeast 108922434345 8.690661e+11 12.533273
## 2   Midwest 184383393833 1.943869e+12  9.485380
## 3 Southeast 103876652998 1.364632e+12  7.612063
## 4      West  57568049509 2.432336e+12  2.366780
## 5 Southwest  24217682268 1.462632e+12  1.655761
```

1.6 Regions: plot

Now plot the regions.

```
# plot, default
plot(regions['pct_water'])
```



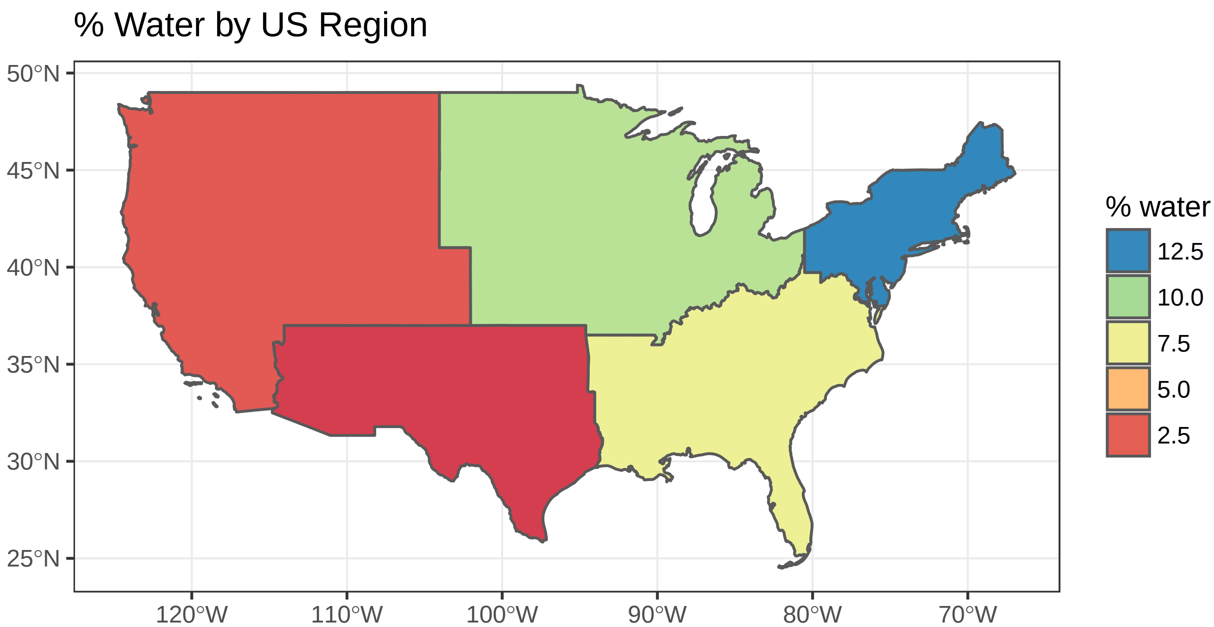
1.7 Regions: ggplot

The `ggplot2` library can visualise sf objects.

- In RStudio, see menu Help > Cheatsheets > Data Visualization with ggplot2.

```
# plot, ggplot
ggplot(regions) +
  geom_sf(aes(fill = pct_water)) +
  scale_fill_distiller(
    "pct_water", palette = "Spectral", direction=1,
    guide = guide_legend(title = "% water", reverse=T)) +
```

```
  theme_bw() +
  ggtitle("% Water by US Region")
```



1.8 Regions: recalculate area

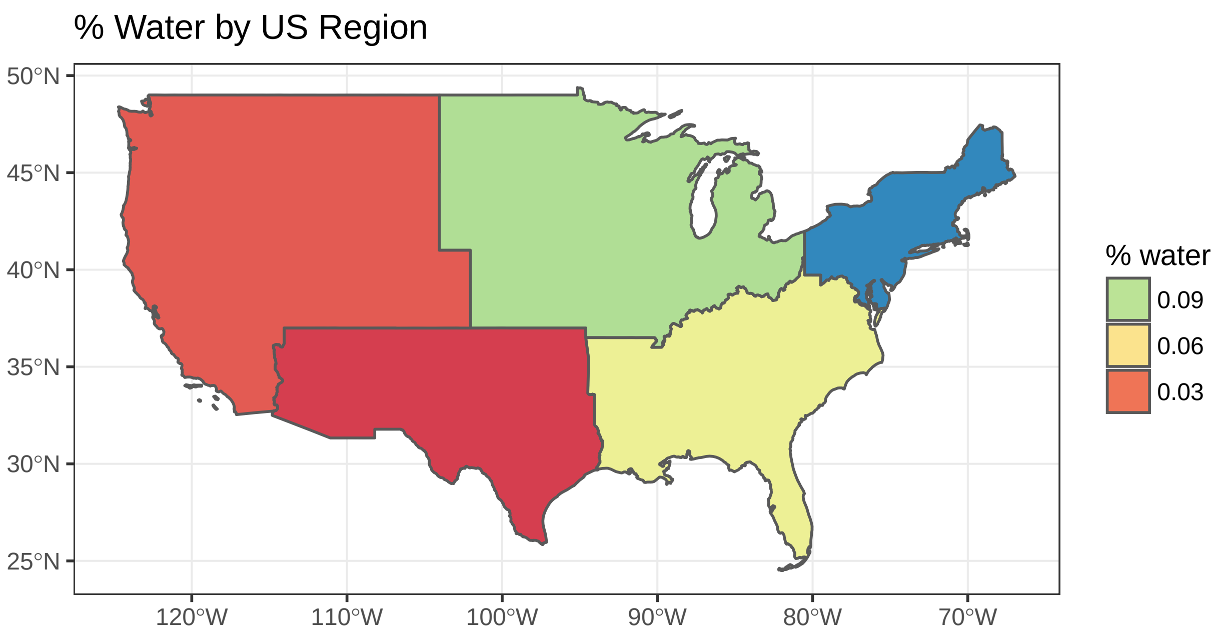
So far you've used the `ALAND` column for area of the state. But what if you were not provided the area and needed to calculate it? Because the `states` are in geographic coordinates, you'll need to either transform to an equal area projection and calculate area, or use geodesic calculations. Thankfully, the `sf` library provides area calculations with the `st_area()` and uses the `geosphere::distGeo()` to perform geodesic calculations (ie trigonometric calculation accounting for the spheroid nature of the earth). Since the `states` data has the unusual aspect of a z dimension, you'll need to first remove that with the `st_zm()` function.

```
library(geosphere)
library(units)

regions = states %>%
  mutate(
    water_m2 = AWATER %>% set_units(m^2),
    land_m2  = geometry %>% st_zm() %>% st_area()) %>%
  group_by(region) %>%
  summarize(
    water_m2 = sum(water_m2),
    land_m2  = sum(land_m2)) %>%
  mutate(
    pct_water = water_m2 / land_m2)

# table
regions %>%
  st_set_geometry(NULL) %>%
  arrange(desc(pct_water))
```

```
## # A tibble: 5 x 4
```

```
##      region        water_m2          land_m2    pct_water
##       <chr>         <units>          <units>      <units>
## 1 Northeast 108922434345 m^2 9.117041e+11 m^2 0.11947126 1
## 2   Midwest 184383393833 m^2 1.987268e+12 m^2 0.09278233 1
## 3 Southeast 103876652998 m^2 1.427079e+12 m^2 0.07278971 1
## 4      West  57568049509 m^2 2.467170e+12 m^2 0.02333363 1
## 5 Southwest  24217682268 m^2 1.483765e+12 m^2 0.01632178 1
```

```r
# plot, ggplot
ggplot(regions) +
  geom_sf(aes(fill = as.numeric(pct_water))) +
  scale_fill_distiller(
    "pct_water", palette = "Spectral", direction=1,
    guide = guide_legend(title = "% water", reverse=T)) +
  theme_bw() +
  ggtitle("% Water by US Region")
```



1.9 Challenge: project & recalculate area

Use `st_transform()` with a USA Contiguous Albers Equal Area Conic Projection that minimizes distoration, and then calculate area using the `st_area()` function.

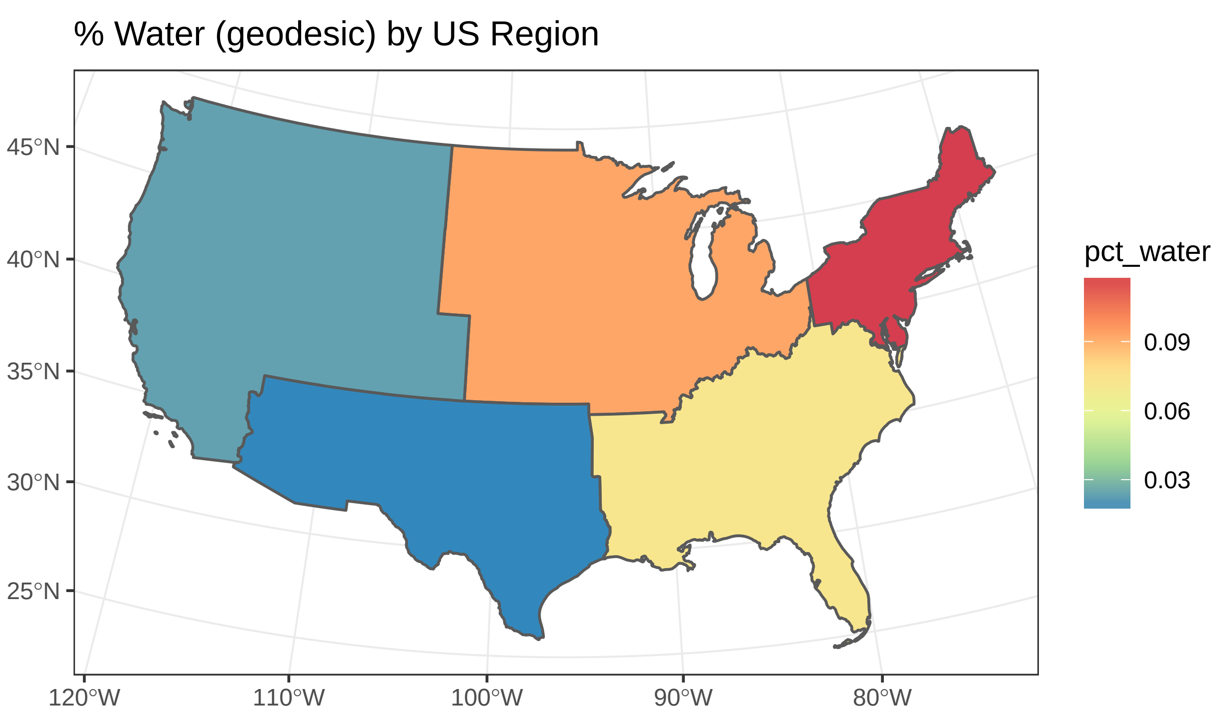
1.9.1 Answers

```r
library(geosphere)
library(units)

# Proj4 of http://spatialreference.org/ref/esri/usa-contiguous-albers-equal-area-conic/
crs_usa = '+proj=aea +lat_1=29.5 +lat_2=45.5 +lat_0=37.5 +lon_0=-96 +x_0=0 +y_0=0 +ellps=GRS80 +datum=N

regions = states %>%
```

```
  st_transform(crs_usa) %>%
  mutate(
    water_m2 = AWATER %>% set_units(m^2),
    land_m2  = geometry %>% st_zm() %>% st_area()) %>%
  group_by(region) %>%
  summarize(
    water_m2 = sum(water_m2),
    land_m2  = sum(land_m2)) %>%
  mutate(
    pct_water = water_m2 / land_m2)

# table
regions %>%
  st_set_geometry(NULL) %>%
  arrange(desc(pct_water))
```

```
## # A tibble: 5 x 4
##      region        water_m2          land_m2    pct_water
##       <chr>         <units>          <units>      <units>
## 1 Northeast 108922434345 m^2 9.117031e+11 m^2 0.11947138 1
## 2   Midwest 184383393833 m^2 1.987266e+12 m^2 0.09278246 1
## 3 Southeast 103876652998 m^2 1.427078e+12 m^2 0.07278973 1
## 4      West  57568049509 m^2 2.467167e+12 m^2 0.02333367 1
## 5 Southwest  24217682268 m^2 1.483758e+12 m^2 0.01632185 1
```

```
# plot, ggplot
ggplot(regions) +
  geom_sf(aes(fill = as.numeric(pct_water))) +
  scale_fill_distiller("pct_water", palette = "Spectral") +
  theme_bw() +
  ggtitle("% Water (geodesic) by US Region")
```



1.10 Key Points

- The `sf` package can take advantage of chaining spatial operations using the `%>%` operator.
- Data manipulation functions in `dplyr` such as `group_by()`, `summarize()` and `mutate()` work on `sf` objects.
- Area can be calculated a variety of ways. Geodesic is preferred if starting with geographic coordinates (vs projected).

Chapter 2

Interactive Maps

2.1 Overview

Questions

- How do you generate interactive plots of spatial data to enable pan, zoom and hover/click for more detail?

Objectives

Learn variety of methods for producing interactive spatial output using libraries:

- `plotly`: makes any ggplot2 object interactive
- `mapview`: quick view of any spatial object
- `leaflet`: full control over interactive map

2.2 Things You'll Need to Complete this Tutorial

R Skill Level: Intermediate - you've got basics of R down.

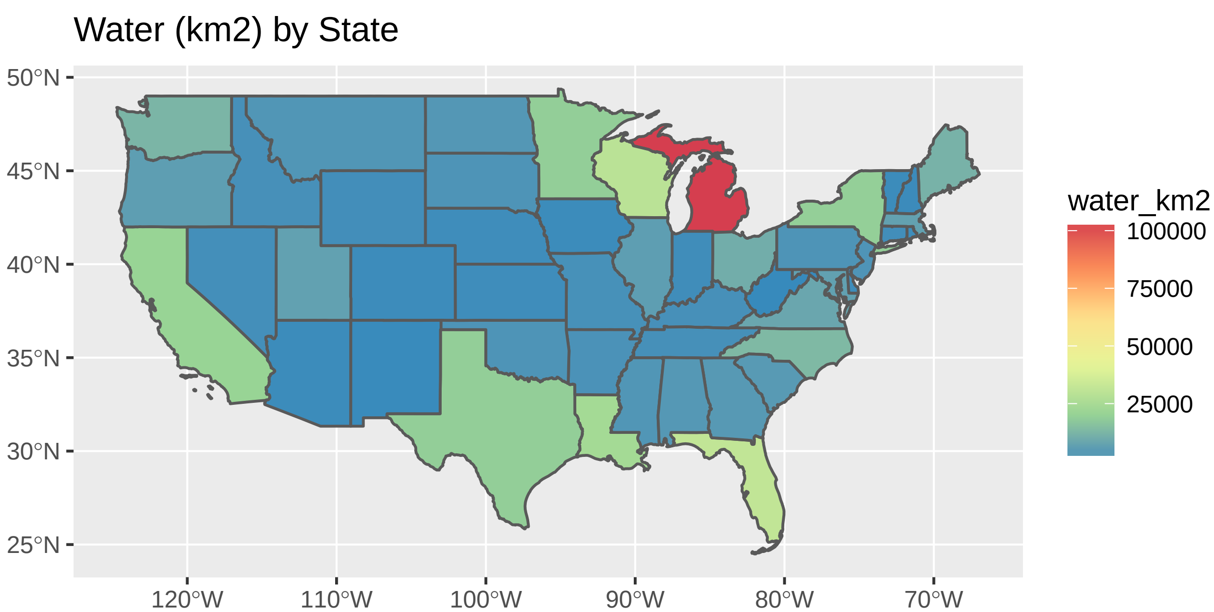
We will continue to use the `sf` and `raster` packages and introduce the `plotly`, `mapview`, and `leaflet` packages in this tutorial.

```
# load packages
library(tidyverse)  # loads dplyr, tidyr, ggplot2 packages
library(sf)         # simple features package - vector
library(raster)     # raster
library(plotly)     # makes ggplot objects interactive
library(mapview)    # quick interactive viewing of spatial objects
library(leaflet)    # interactive maps

# set working directory to data folder
# setwd("pathToDirHere")
```

2.3 States: ggplot2

Recreate the ggplot object from Lesson 1 and save into a variable for subsequent use with the `plotly` package.

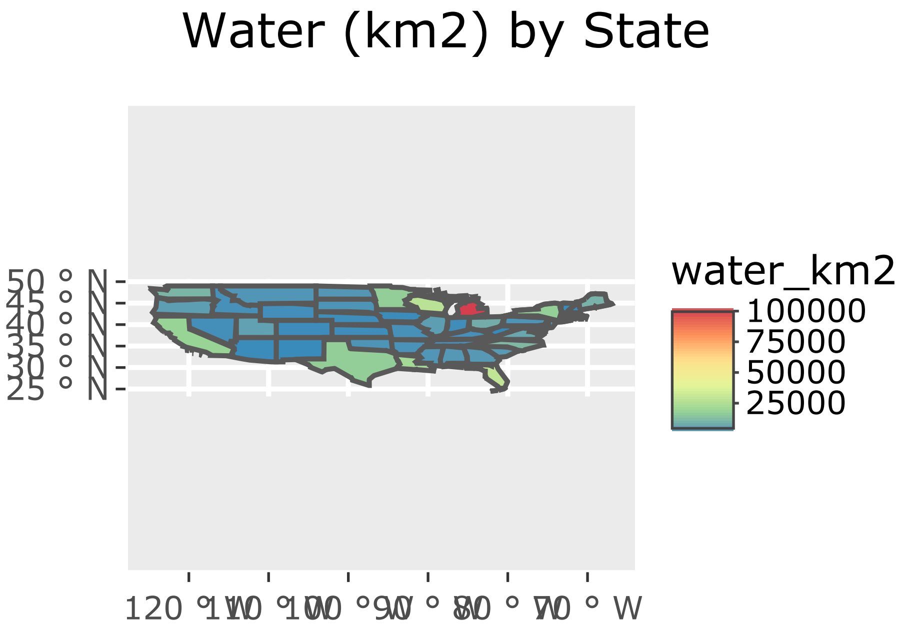
```r
# read in states
states <- read_sf("data/NEON-DS-Site-Layout-Files/US-Boundary-Layers/US-State-Boundaries-Census-2014.shp
  st_zm() %>%
  mutate(
    water_km2 = (AWATER / (1000*1000)) %>% round(2))

# plot, ggplot
g = ggplot(states) +
  geom_sf(aes(fill = water_km2)) +
  scale_fill_distiller("water_km2", palette = "Spectral") +
  ggtitle("Water (km2) by State")
g
```



2.4 States: plotly

The `plotly::ggplotly()` function outputs a ggplot into an interactive window capable of pan, zoom and identify.

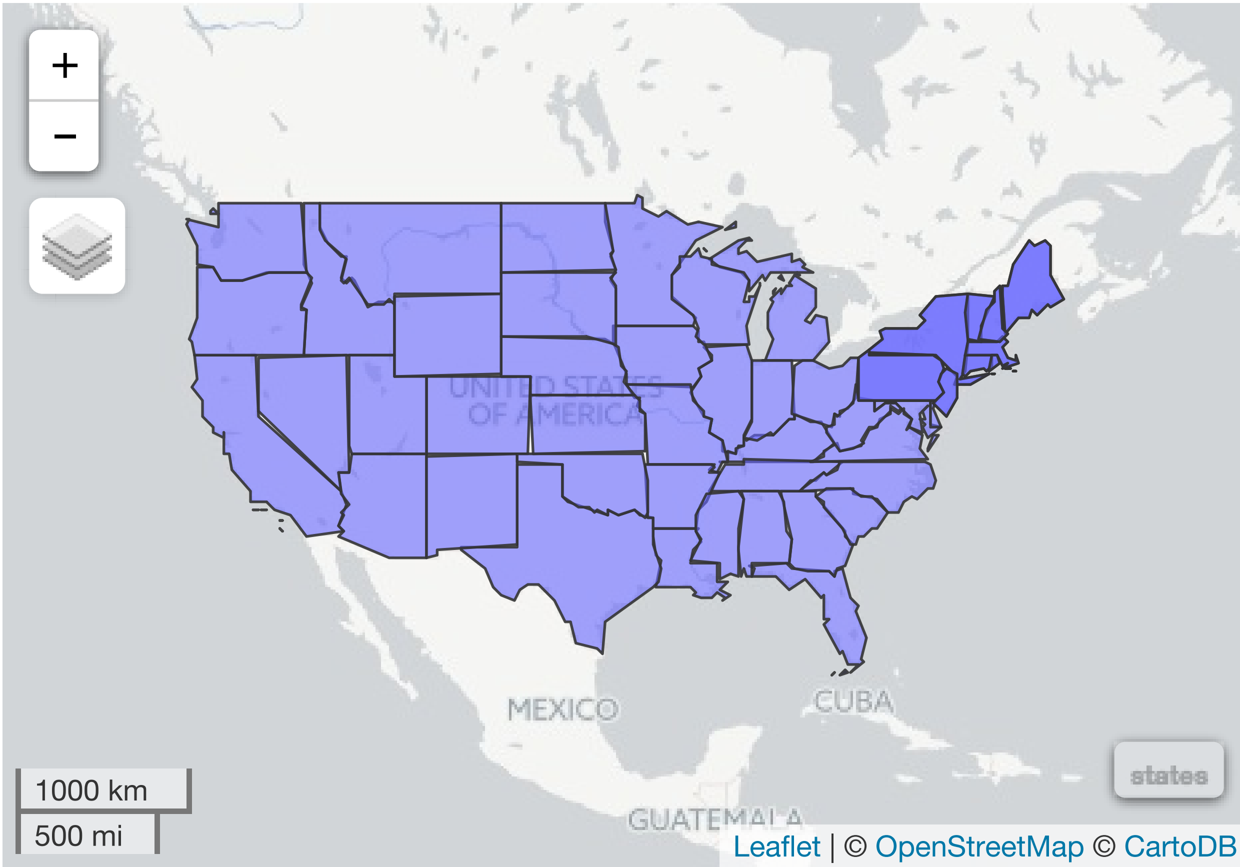
```r
library(plotly)

ggplotly(g)
```



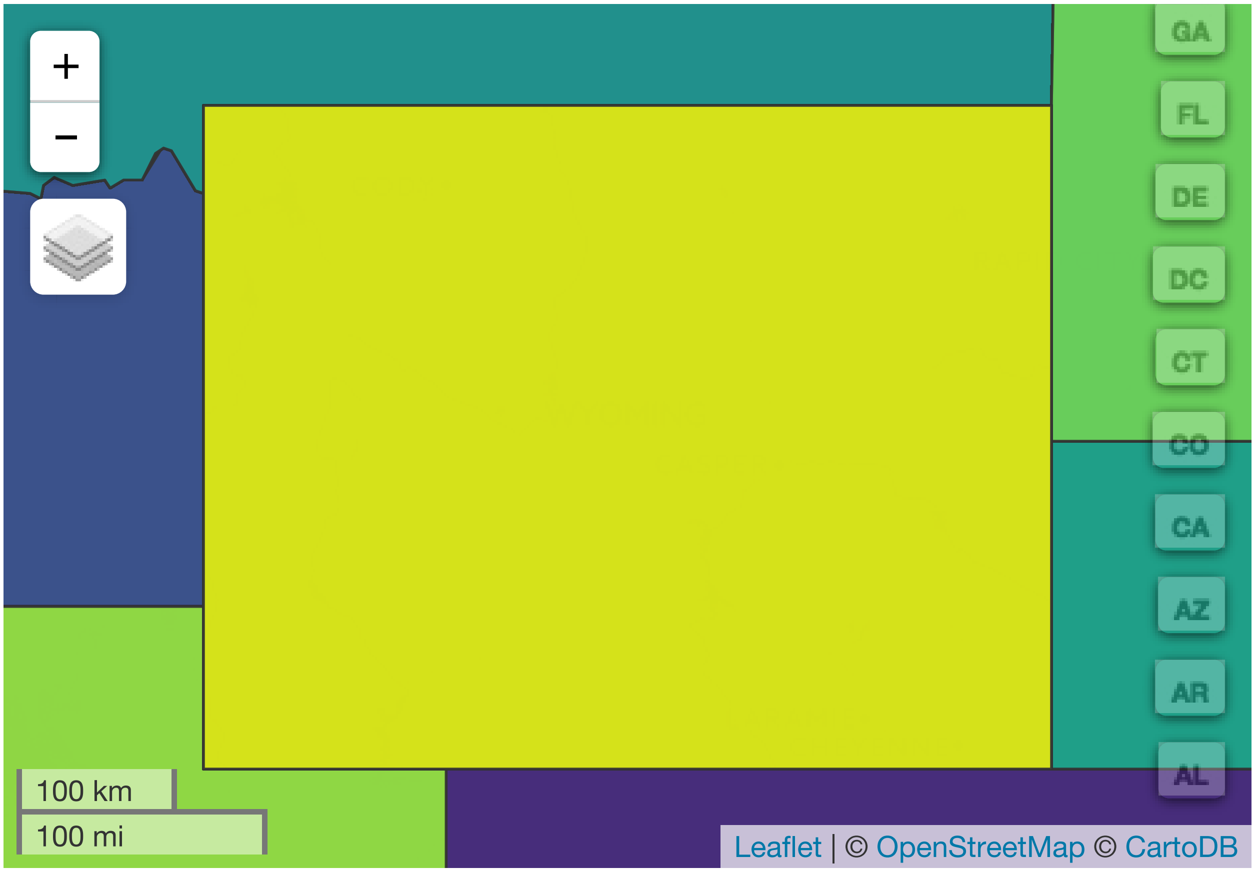
2.5 States: mapview

The `mapview::mapview()` function can work for a quick view of the data, providing choropleths, background maps and attribute popups. Performance varies on the object and customization can be tricky.

```
library(mapview)

# simple view with popups
mapview(states)
```



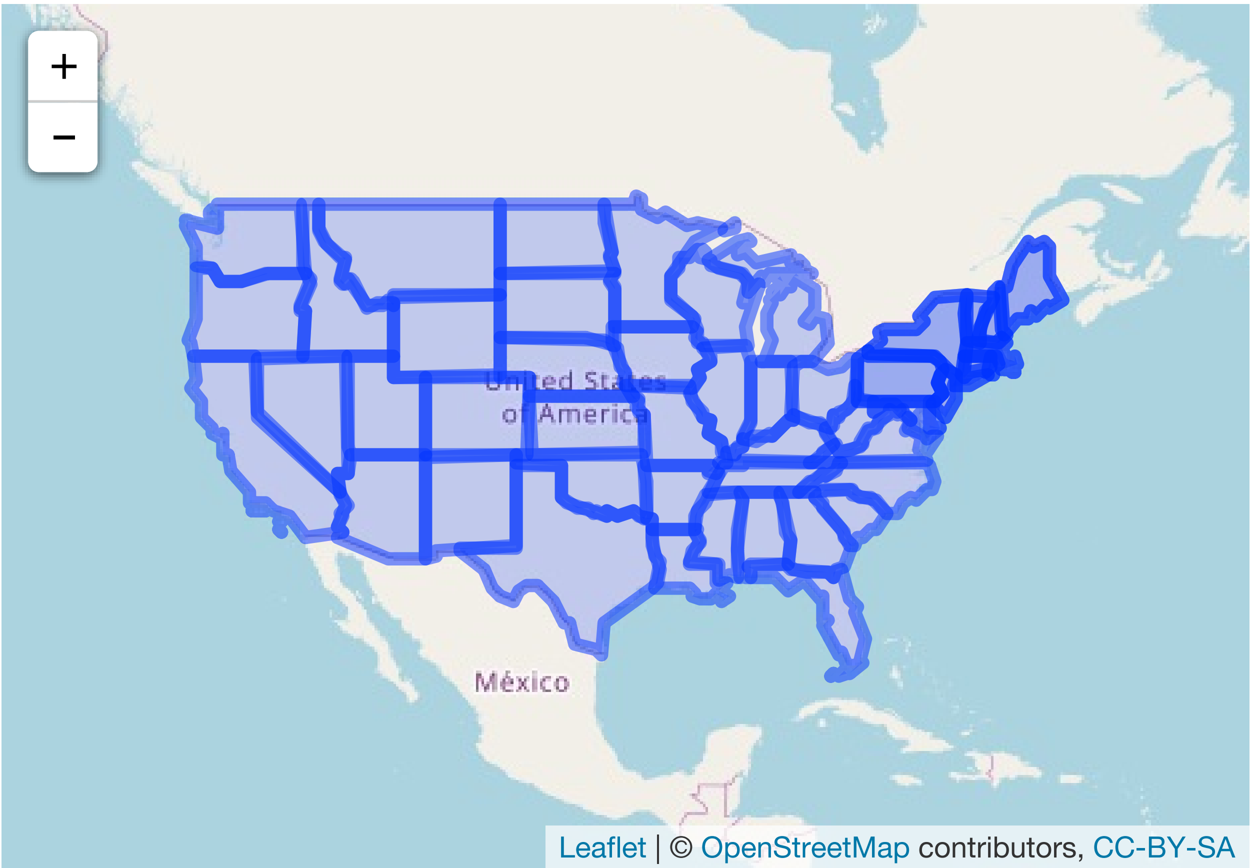

```
# coloring and layering
mapview(states, zcol='water_km2', burst='STUSPS')
```



2.6 States: leaflet

The `leaflet` package offers a robust set of functions for viewing vector and raster data, although requires more explicit functions.

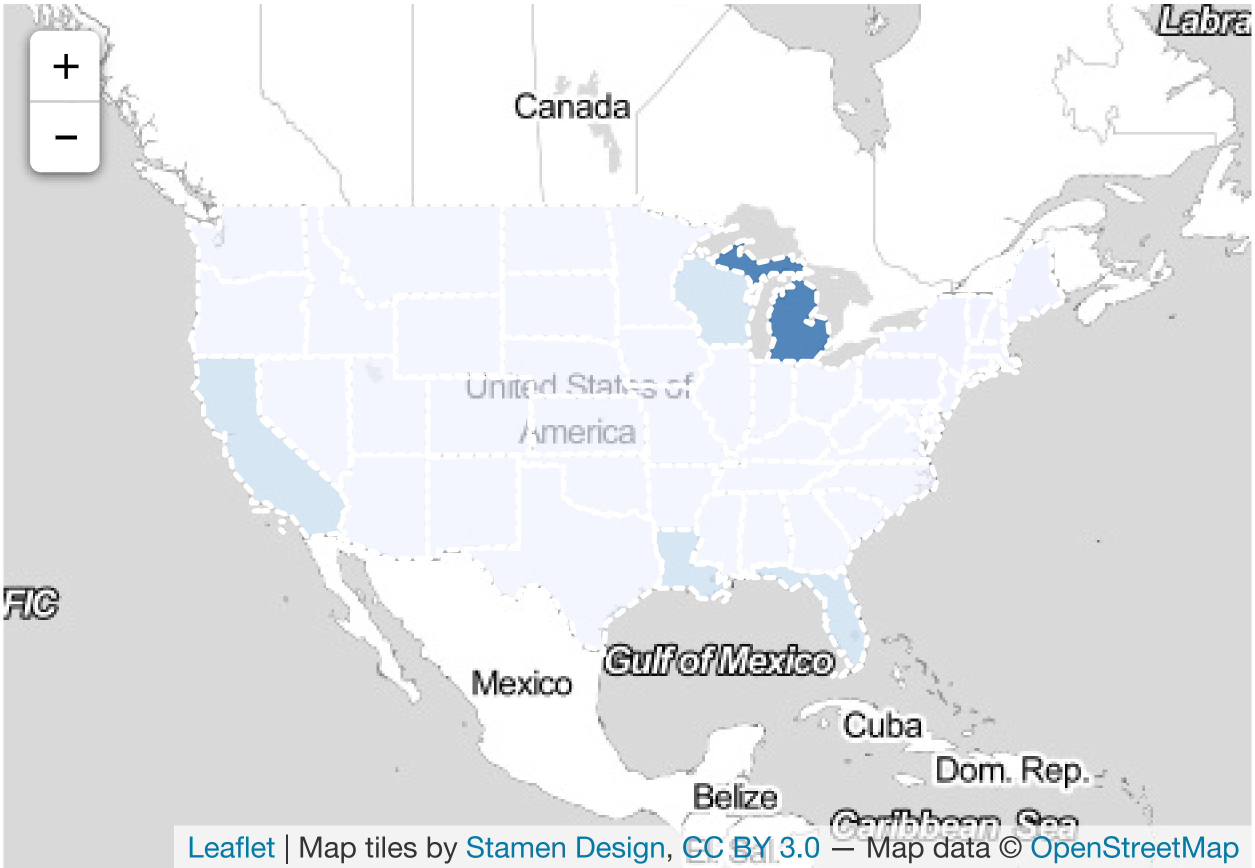
```
library(leaflet)

leaflet(states) %>%
  addTiles() %>%
  addPolygons()
```



2.6.1 Choropleth

Drawing from the documentation from Leaflet for R - Choropleths, we can construct a pretty choropleth.

```
pal <- colorBin("Blues", domain = states$water_km2, bins = 7)


leaflet(states) %>%
  addProviderTiles("Stamen.TonerLite") %>%
  addPolygons(
    # fill
    fillColor   = ~pal(water_km2),
    fillOpacity = 0.7,
    # line
    dashArray   = "3",
    weight      = 2,
    color       = "white",
    opacity     = 1,
    # interaction
    highlight = highlightOptions(
      weight = 5,
      color = "#666",
      dashArray = "",
      fillOpacity = 0.7,
      bringToFront = TRUE))
```

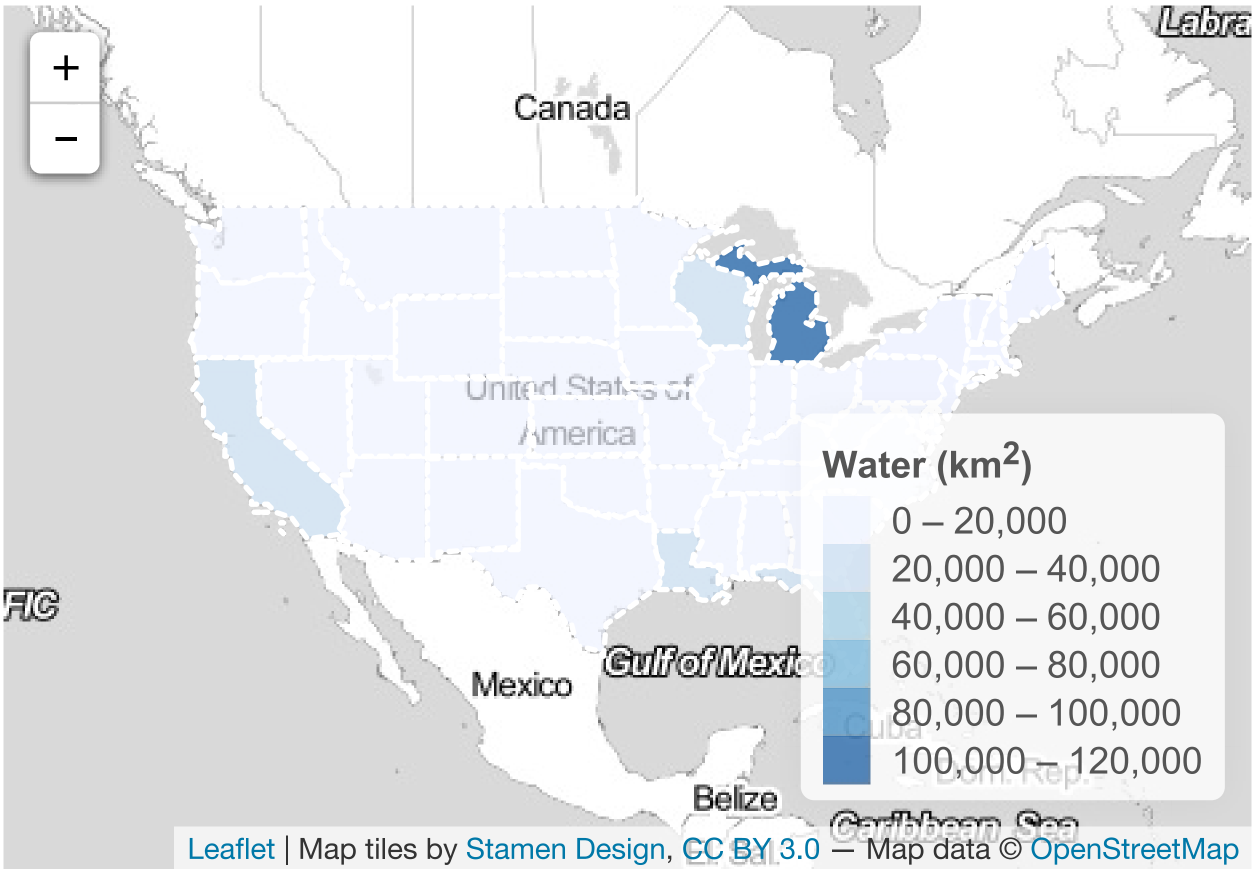


2.6.2 Popups and Legend

Adding a legend and popups requires a bit more work, but achieves a very aesthetically and functionally pleasing visualization.

```
library(htmltools)
library(scales)

labels <- sprintf(
  "<strong>%s</strong><br/> water: %s km<sup>2</sup>",
  states$NAME, comma(states$water_km2)) %>%
  lapply(HTML)

leaflet(states) %>%
  addProviderTiles("Stamen.TonerLite") %>%
  addPolygons(
    # fill
    fillColor   = ~pal(water_km2),
    fillOpacity = 0.7,
    # line
    dashArray   = "3",
    weight      = 2,
    color       = "white",
    opacity     = 1,
    # interaction
```

```
    highlight = highlightOptions(
      weight = 5,
      color = "#666",
      dashArray = "",
      fillOpacity = 0.7,
      bringToFront = TRUE),
  label = labels,
  labelOptions = labelOptions(
    style = list("font-weight" = "normal", padding = "3px 8px"),
    textsize = "15px",
    direction = "auto")) %>%
  addLegend(
    pal = pal, values = ~water_km2, opacity = 0.7, title = HTML("Water (km<sup>2</sup>)"),
    position = "bottomright")
```

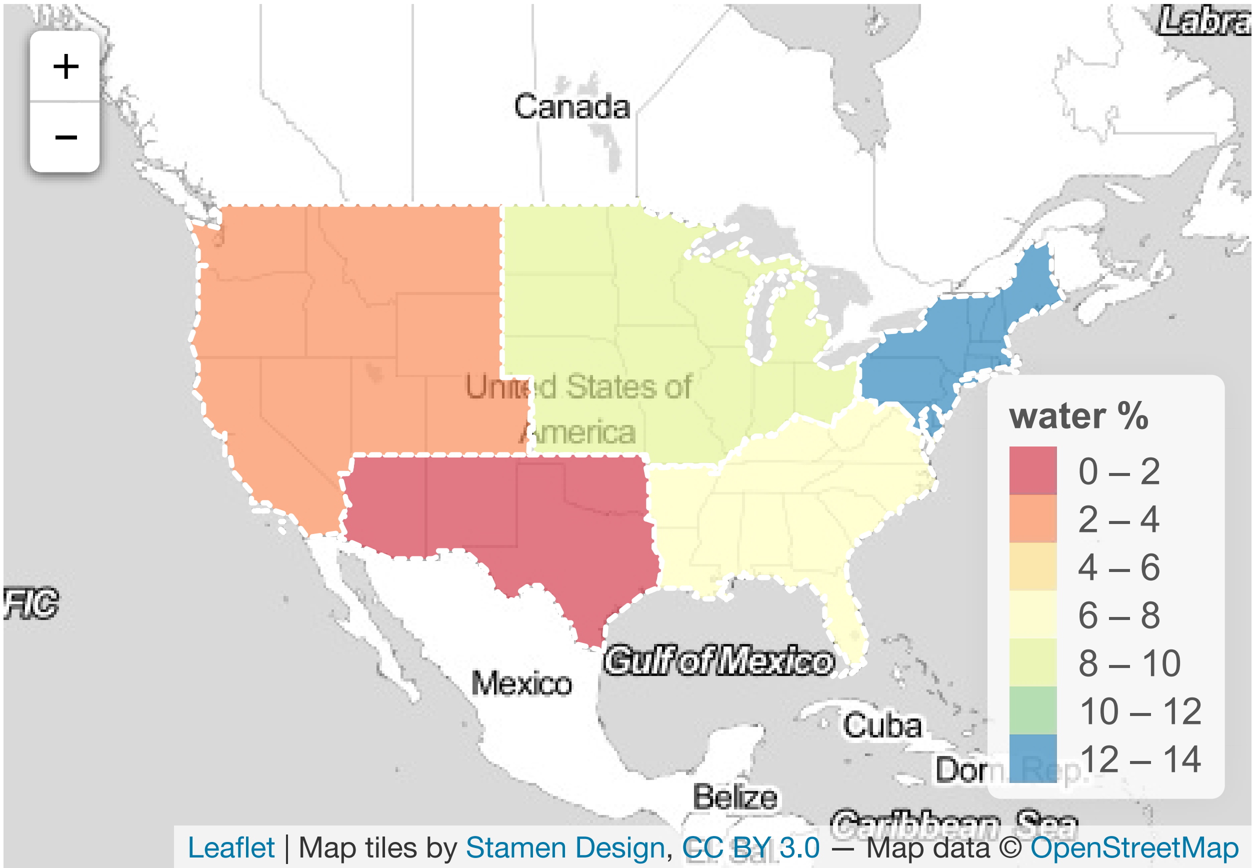


2.7 Challenge: leaflet for regions

Use Lesson 1 final output to create a regional choropleth with legend and popups for percent water by region.

2.7.1 Answers

```
regions = states %>%
  group_by(region) %>%
  summarize(
    water = sum(AWATER),
    land  = sum(ALAND)) %>%
  mutate(
    pct_water = (water / land * 100) %>% round(2))

pal <- colorBin("Spectral", domain = regions$pct_water, bins = 5)

labels <- sprintf(
  "<strong>%s</strong><br/>water: %s%%",
  regions$region, comma(regions$pct_water)) %>%
  lapply(HTML)

leaflet(regions) %>%
  addProviderTiles("Stamen.TonerLite") %>%
  addPolygons(
    # fill
    fillColor   = ~pal(pct_water),
    fillOpacity = 0.7,
    # line
    dashArray   = "3",
    weight      = 2,
    color       = "white",
    opacity     = 1,
    # interaction
    highlight = highlightOptions(
      weight = 5,
      color = "#666",
      dashArray = "",
      fillOpacity = 0.7,
      bringToFront = TRUE),
  label = labels,
  labelOptions = labelOptions(
    style = list("font-weight" = "normal", padding = "3px 8px"),
    textsize = "15px",
    direction = "auto")) %>%
  addLegend(
    pal = pal, values = ~pct_water, opacity = 0.7, title = "water %",
    position = "bottomright")
```



2.8 Raster: leaflet

TODO: show raster overlay using NEON raster dataset example

2.9 Key Points

- Interactive maps provide more detail for visual investigation, including use of background maps, but is only relevant in a web context.
- Several packages exist for providing interactive views of data.
- The `plotly::ggplotly()` function works quickly if you already have a ggplot object, which is best for static output.
- The `mapview::mapview()` function can work for a quick view of the data, providing choropleths, background maps and attribute popups. Performance varies on the object and customization can be tricky.
- The `leaflet` package provides a highly customizable set of functions for rendering of interactive choropleths with background maps, legends, etc.

Tidy Spatial Analysis

- Tidy spatial data in R: using dplyr, tidyr, and ggplot2 with sf

Interactive Maps

- Visualization in R - 2016-04-15-UCSB workshop

- `leaflet`
- `mapedit`
- `mapview`