Homework 5

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Data Loading

```
# Load provided data
network <- st_read("network.gpkg")
```

```
## Reading layer `network' from data source
##   `C:\Users\rohan\Documents\PLAN_372\plan372-day2\plan372_hmks\exercises-main\network.gpkg'
##   using driver `GPKG'
## Simple feature collection with 91 features and 3 fields
## Geometry type: LINESTRING
## Dimension:     XY
## Bounding box:  xmin: -80.2405 ymin: 35.4168 xmax: -78.3724 ymax: 36.122
## Geodetic CRS:  WGS 84
```

```
connected_points <- st_read("connected_points.gpkg")
```

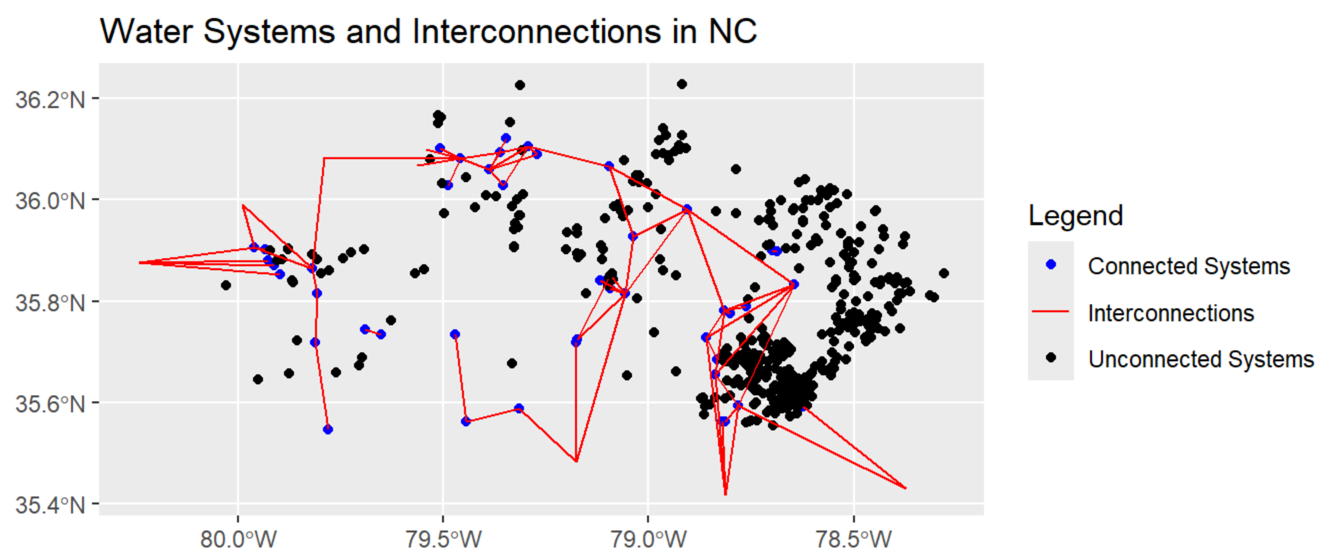
```
## Reading layer `connected_points' from data source
##   `C:\Users\rohan\Documents\PLAN_372\plan372-day2\plan372_hmks\exercises-main\connected_point
s.gpkg'
##   using driver `GPKG'
## Simple feature collection with 46 features and 2 fields
## Geometry type: POINT
## Dimension:     XY
## Bounding box:  xmin: -79.9611 ymin: 35.5472 xmax: -78.62274 ymax: 36.122
## Geodetic CRS:  WGS 84
```

```
unconnected_points <- st_read("unconnected_points.gpkg")
```

```
## Reading layer `unconnected_points' from data source
##   `C:\Users\rohan\Documents\PLAN_372\plan372-day2\plan372_hmks\exercises-main\unconnected_poi
nts.gpkg'
##   using driver `GPKG'
## Simple feature collection with 399 features and 2 fields
## Geometry type: POINT
## Dimension:     XY
## Bounding box:  xmin: -80.02972 ymin: 35.55504 xmax: -78.28097 ymax: 36.22856
## Geodetic CRS:  WGS 84
```

Question 1

```
ggplot() +
  geom_sf(data = connected_points, aes(color = 'Connected Systems')) +
  geom_sf(data = unconnected_points, aes(color = 'Unconnected Systems')) +
  geom_sf(data = network, aes(color = 'Interconnections')) +
  scale_color_manual(values = c("blue", "red", "black")) +
  labs(title = "Water Systems and Interconnections in NC",
       color = "Legend")
```



Question 2

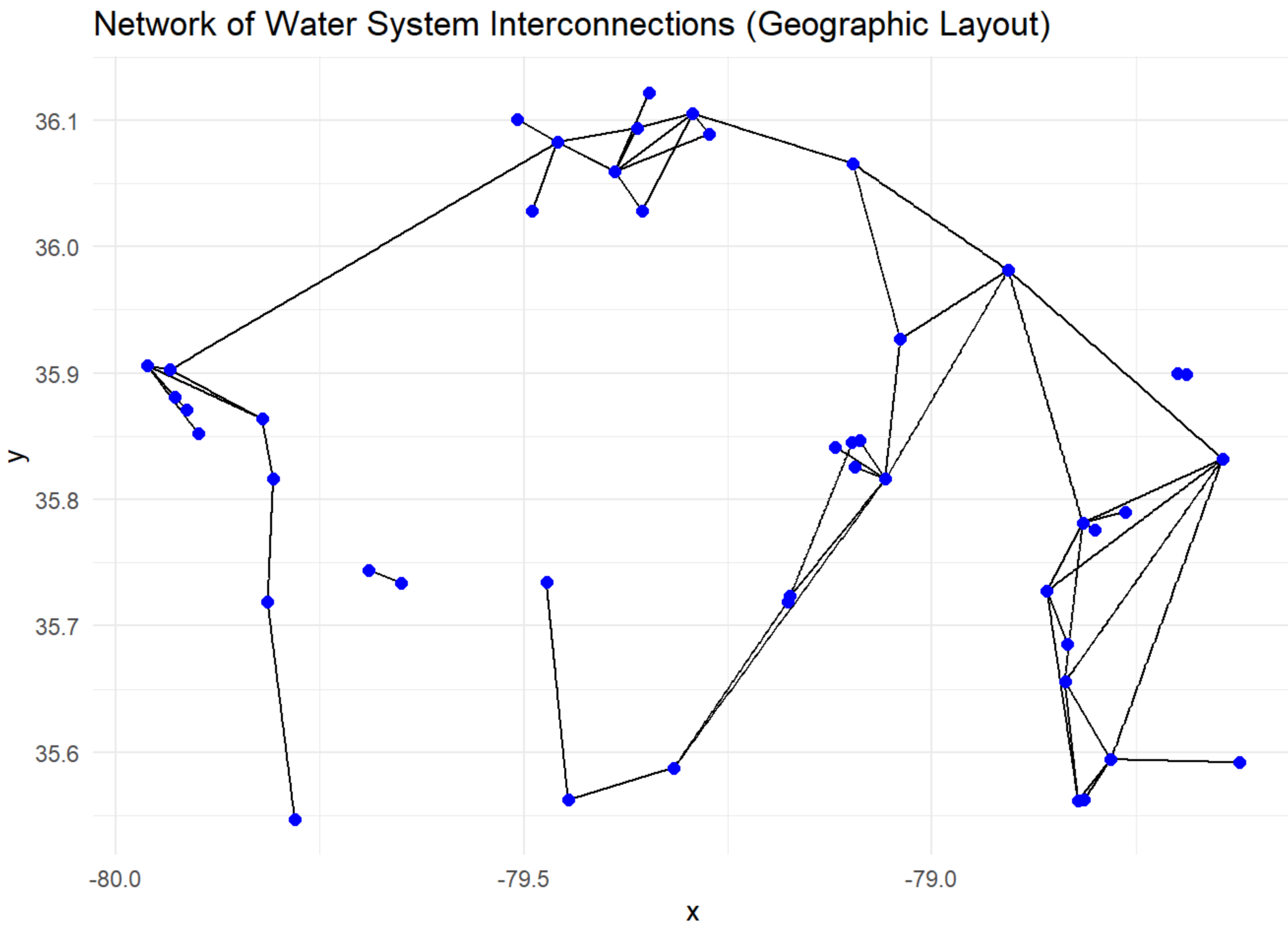
```
# Build nodes directly from connected points
nodes <- connected_points %>%
  mutate(nodeID = row_number())

# Create edge table
graph_edges <- network %>%
  mutate(edgeID = row_number())

# Extract start and end points properly
start_points_sf <- st_cast(network, "POINT")[seq(1, nrow(network) * 2, 2), ]
```

```
## Warning in st_cast.sf(network, "POINT"): repeating attributes for all
## sub-geometries for which they may not be constant
```

```
end_points_sf <- st_cast(network, "POINT")[seq(2, nrow(network) * 2, 2), ]
```

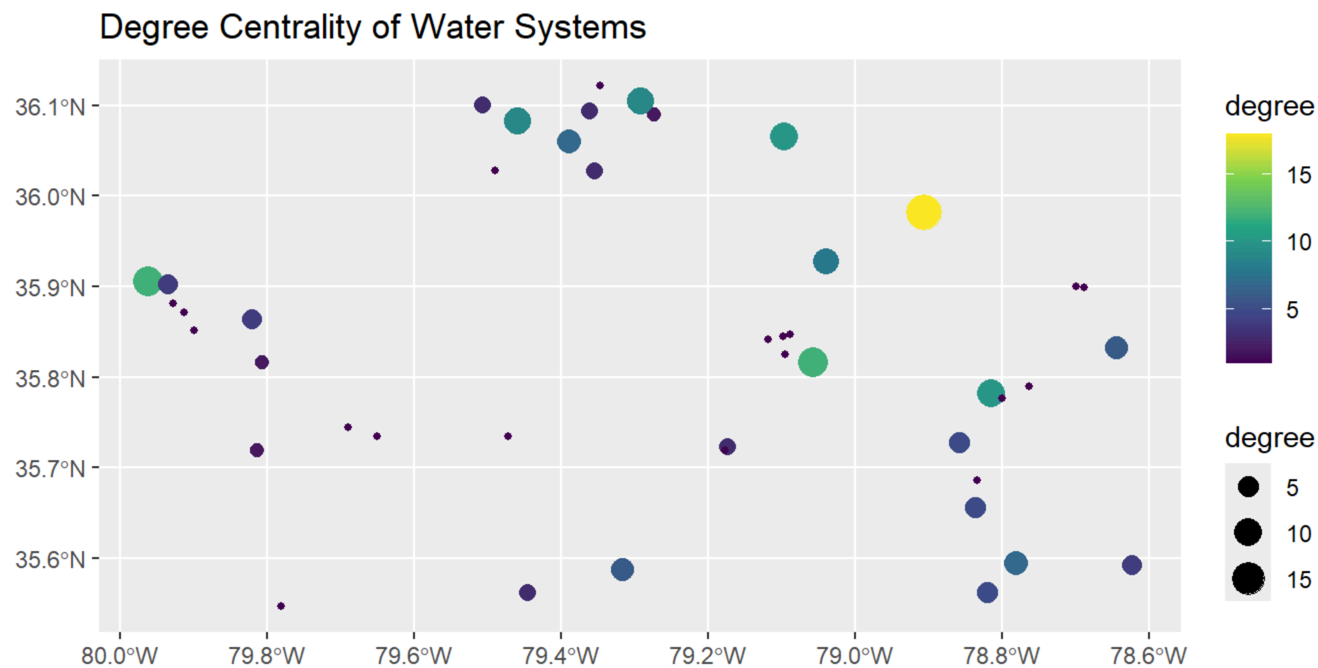
```
## Warning in st_cast.sf(network, "POINT"): repeating attributes for all
## sub-geometries for which they may not be constant
```

```
# Find nearest nodes
source_nodes <- st_nearest_feature(start_points_sf, connected_points)
target_nodes <- st_nearest_feature(end_points_sf, connected_points)

edges <- graph_edges %>%
  mutate(from = source_nodes, to = target_nodes)

# Create graph
graph <- tbl_graph(nodes = nodes,
                   edges = as_tibble(edges),
                   directed = FALSE)

# Extract coordinates
coords <- st_coordinates(connected_points)

# Plot network using geographic layout
ggraph(graph, layout = 'manual', x = coords[,1], y = coords[,2]) +
  geom_edge_link(color = "black") +
  geom_node_point(color = "blue", size = 2) +
  labs(title = "Network of Water System Interconnections (Geographic Layout)") +
  theme_minimal()
```

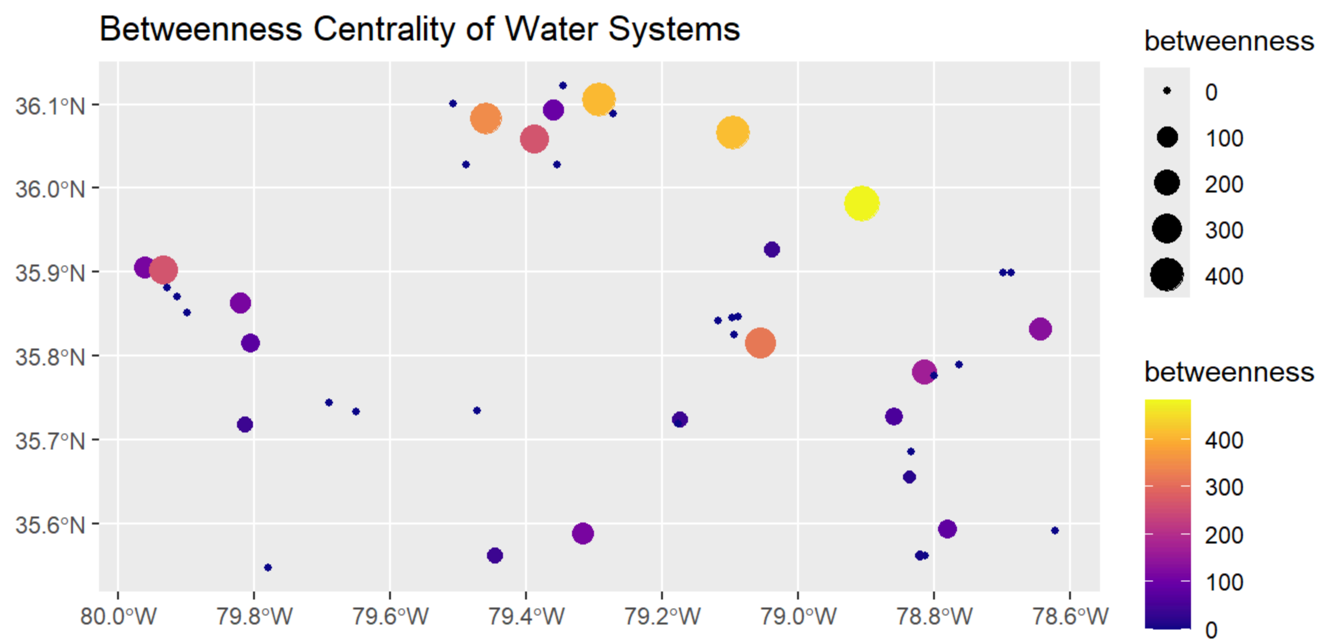


Question 3

```
# Calculate centralities
graph <- graph %>%
  activate(nodes) %>%
  mutate(degree = centrality_degree(),
         betweenness = centrality_betweenness(weights = NULL))

# Map Degree Centrality
ggplot() +
  geom_sf(data = graph %>% activate(nodes) %>% as_tibble() %>% st_as_sf(),
          aes(size = degree, color = degree)) +
  scale_color_viridis_c() +
  labs(title = "Degree Centrality of Water Systems")
```




```
# Map Betweenness Centrality
ggplot() +
  geom_sf(data = graph %>% activate(nodes) %>% as_tibble() %>% st_as_sf(),
          aes(size = betweenness, color = betweenness)) +
  scale_color_viridis_c(option = 'plasma') +
  labs(title = "Betweenness Centrality of Water Systems")
```



The analysis shows that water systems with high degree or betweenness centrality are key to ensuring reliability and resilience. Protecting and maintaining these systems will enhance the robustness of North Carolina's water interconnection network.

Question 4

Shortest path from Cary to OWASA: The shortest path from Cary to OWASA would involve the systems geographically located between Cary and Chapel Hill/Carrboro. Based on the network structure in North Carolina, water would likely need to pass through Morrisville and Durham before reaching OWASA.

Cities water passes through (Cary to OWASA):

Cary

Morrisville

Durham

Chapel Hill/Carrboro (OWASA)

Shortest path from Raleigh to OWASA: If OWASA considered purchasing water from Raleigh instead, the water would have to travel a longer distance. The path would likely pass through Garner, then Cary or Morrisville, then Durham, and finally Chapel Hill/Carrboro.

Cities water passes through (Raleigh to OWASA):

Raleigh

Garner

Cary or Morrisville

Durham

Chapel Hill/Carrboro (OWASA)

Comparison: The distance from Cary to OWASA is significantly shorter than from Raleigh to OWASA. This means purchasing from Cary would not only cost less due to less distance but would also involve fewer intermediate transfers, reducing potential challenges. Thus, Cary is the better supplier.

Question 5

Options for Liberty: The Town of Liberty can consider connecting to nearby interconnected systems such as:

Burlington

Asheboro

Greensboro (although slightly farther)

Among these, Burlington is the closest interconnected system to Liberty.

Challenges Liberty would face:

High Infrastructure Costs: Building new pipelines and physical connections between Liberty and Burlington would require significant investment in design, permitting, construction, and maintenance.

Capacity and Water Availability: Liberty must ensure Burlington has sufficient water surplus to reliably meet Liberty's additional demand without risking shortages for either community.

Negotiation of Contracts: A legal agreement would need to be negotiated outlining water rates, volume, duration of supply, and emergency contingencies.

Regulatory Approvals: Liberty would need approval from environmental and state regulatory agencies for building the interconnection and making cross-jurisdictional water transfers.

Emergency Planning: Both Liberty and Burlington would need to plan for drought conditions or water main breaks, ensuring that the interconnection is resilient to supply disruptions.

Conclusion: Connecting to Burlington would be the most feasible and cost-effective solution for Liberty, but it requires careful planning to overcome financial, legal, and logistical challenges.

Extra Credit

```
# (Simulate counties since no shapefile was given)
# Assign random counties just for analysis purposes
set.seed(123)  # for reproducibility
connected_points$County <- sample(c("Wake", "Durham", "Orange", "Guilford", "Alamance"), nrow(co
nnected_points), replace = TRUE)
unconnected_points$County <- sample(c("Wake", "Durham", "Orange", "Guilford", "Alamance"), nrow
(unconnected_points), replace = TRUE)

# Summarize connected systems
connected_summary <- connected_points %>%
  st_drop_geometry() %>%
  group_by(County) %>%
  summarize(Connected_Systems = n())

# Summarize unconnected systems
unconnected_summary <- unconnected_points %>%
  st_drop_geometry() %>%
  group_by(County) %>%
  summarize(Unconnected_Systems = n())

# Merge the two summaries
county_summary <- full_join(connected_summary, unconnected_summary, by = "County") %>%
  replace_na(list(Connected_Systems = 0, Unconnected_Systems = 0))

county_summary
```

```
## # A tibble: 5 × 3
##   County   Connected_Systems Unconnected_Systems
##   <chr>                <int>               <int>
## 1 Alamance                10                  81
## 2 Durham                   9                  85
## 3 Guilford                 6                  75
## 4 Orange                  11                  78
## 5 Wake                    10                  80
```

Counties with fewer financial resources and lower population density tend to have more unconnected water systems. This shows a need for targeted investment in rural areas to improve water infrastructure and ensure reliable access across the state.

Link to Github

https://github.com/rohanun/PLAN372HW5 (https://github.com/rohanun/PLAN372HW5)