# Regional, Passive, Saline Encroachment in Major Springs of the Floridan Aquifer System (1991-2020)

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# Third Investigation of Regional/Statewide, Passive Saltwater Encroachment

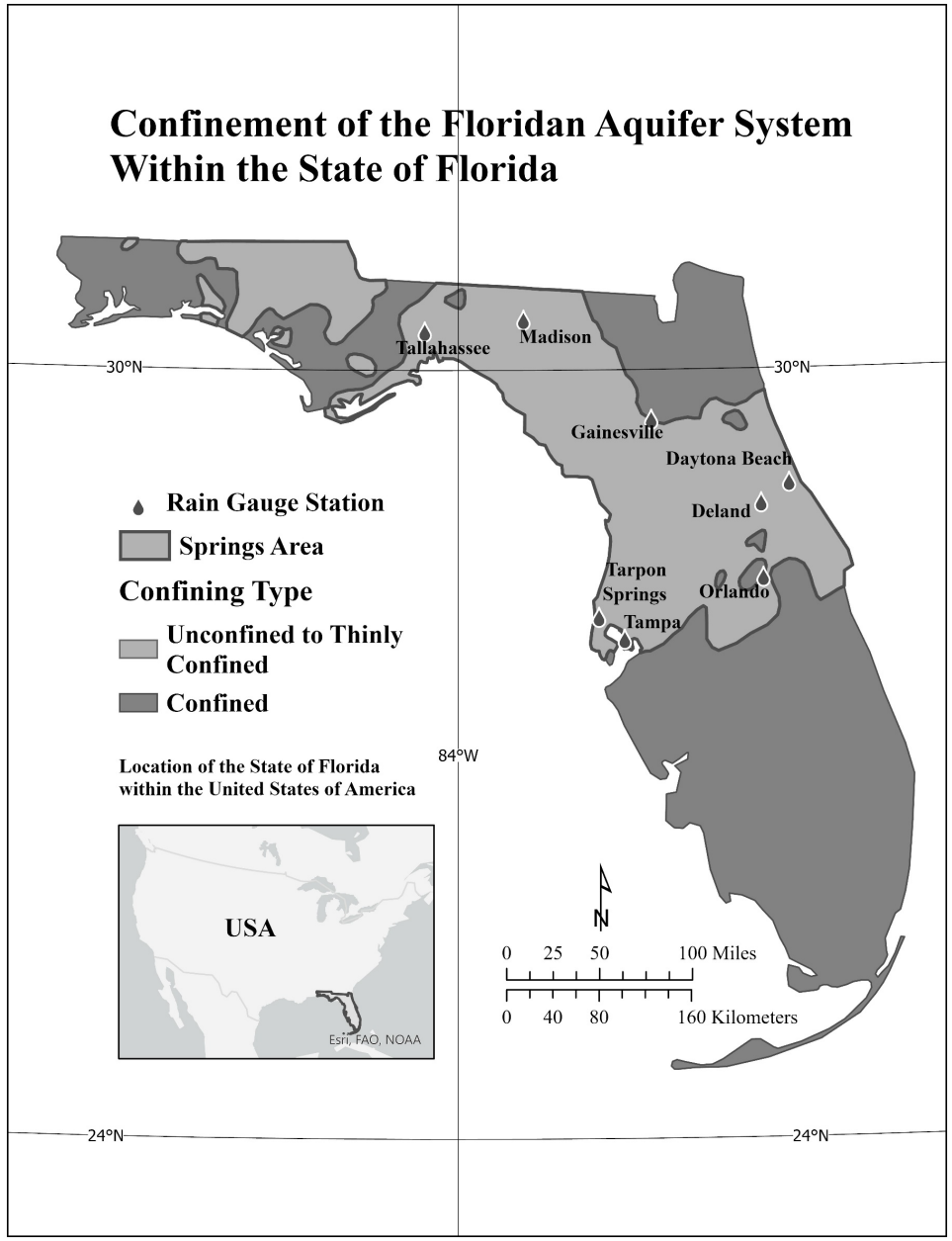
1. **Springs and wells, mostly in Floridan aquifer system (FAS), 1991-2003** (Copeland et al., 2011)

2. **Springs and wells in the FAS 1991-2011** (Copeland and Woeber, 2021)

3. **Springs in the FAS, 1991-2020** (Copeland et al., 2021)

Unconfined to thinly confined FAS
(≈ 40% of FL)

**Springs Area = Study Area**



# Springs and Study Objectives

## Springs

A. Major springs (1st and 2nd magnitude springs)

B. Sufficient data for 30 years of analysis (1991-2020)

## Objectives

1. Determine if passive encroachment occurred, and if so:
2. Estimate its areal extent
3. Estimate rates of changes
4. Discuss plausible drivers

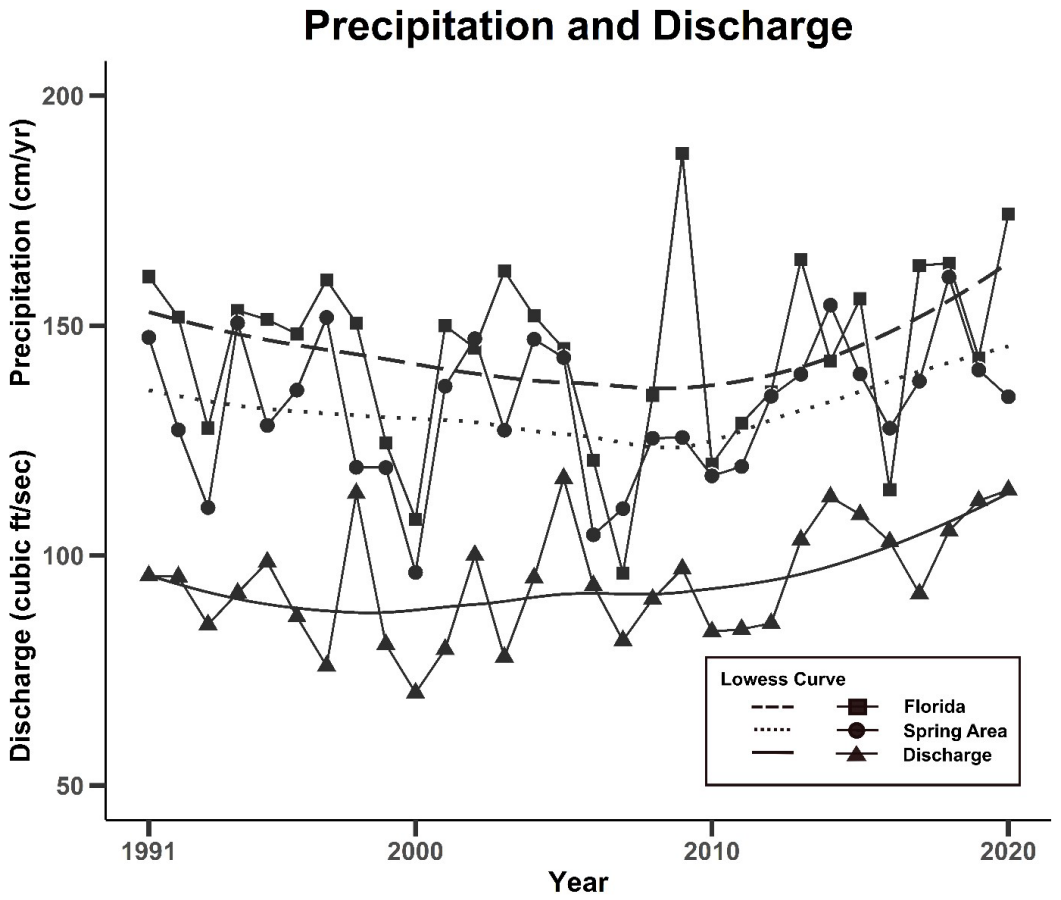
# Indicators and Methods

## Indicators

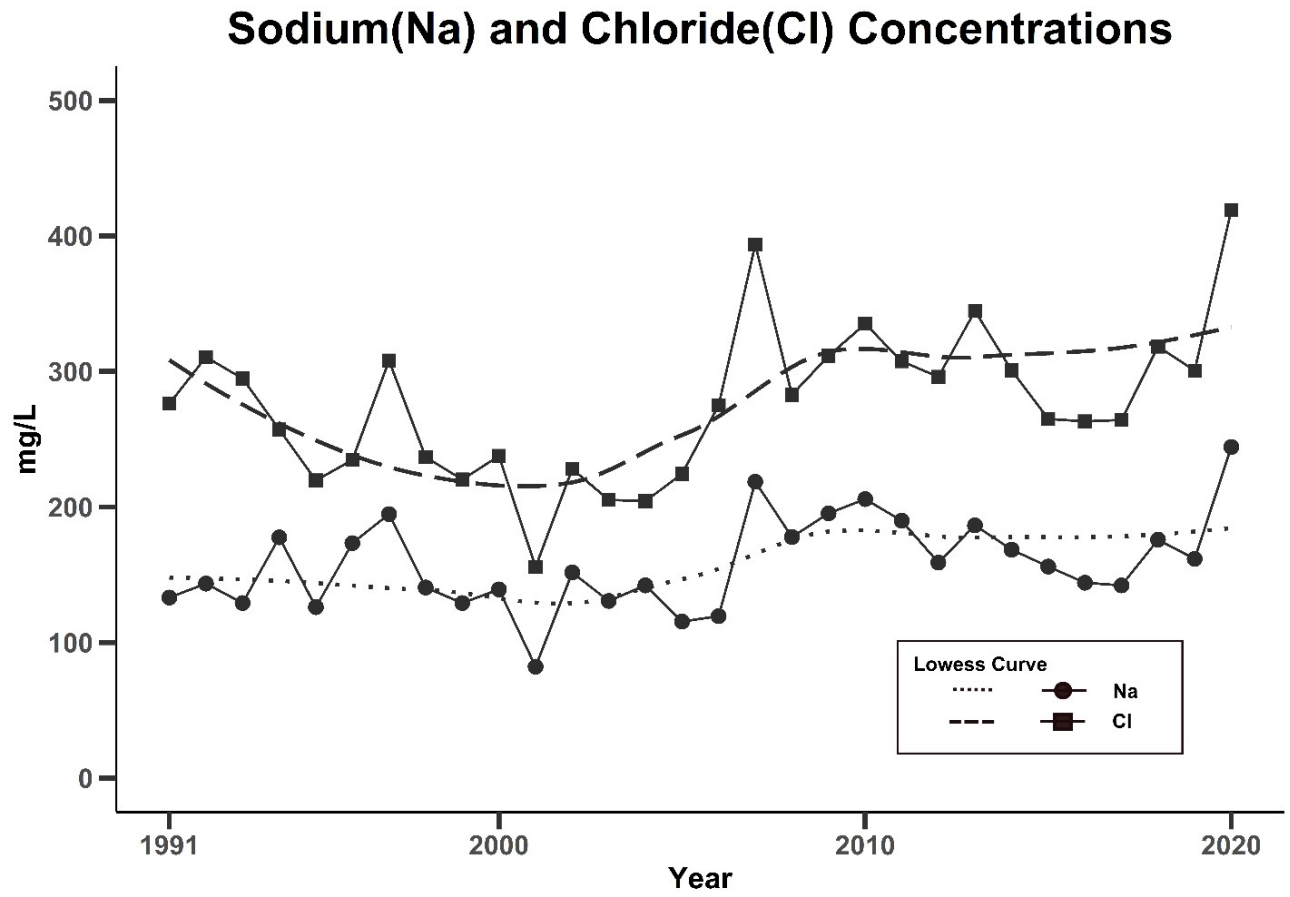
- **Precipitation (Annual Means)**
- **Discharge (Annual Means)**
- **Na and Cl (positively skewed), and for this reason used (Annual Medians)**

## Methods

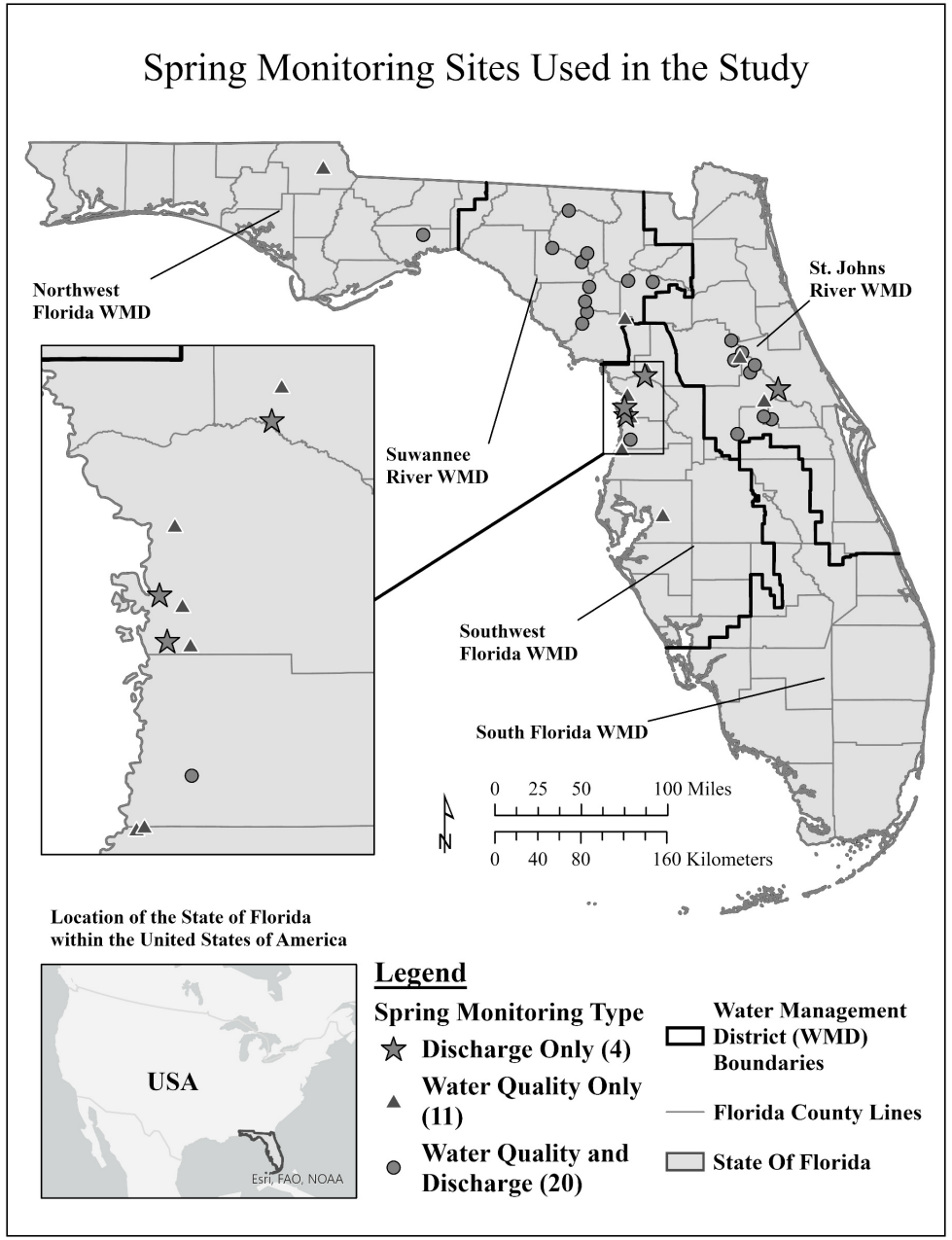
- **Statistical analyses conducted in R freeware programming language**
- **The Regional Kendall Test (RKT)**
  - **Null hypothesis – no change in slope; Alternate hypothesis – change in slope; alpha pre-set at 0.10**


Precipitation and Discharge
Precipitation (cm/yr)
Discharge (cubic ft/sec)
200
150
100
50
1991
2000
2010
2020
Year
Lowess Curve
Florida
Spring Area
Discharge

Title


Sodium(Na) and Chloride(Cl) Concentrations
500
400
300
200
100
0
mg/L
1991
2000
2010
2020
Year
Lowess Curve
Na
Cl

# Spring Monitoring Sites Used in the Study



# Divided Study into Periods and Regions

| Period | Region |
|---|---|
| Entire Period (1991-2020) | 1. Springs Area, 2. NWFWMD and SRWMD Region, 3. SJRWMD Region, 4.SWFWMD Region |
| | |
| Early Period (1991-2011) (Same as Earlier Study) | 1. Springs Area, 2. NWF and SR WMD Region, 3. SJRWMD Region, 4.SWFWMD Region |
| | |
| Late Period (2006-2020) (Last half of Study) | 1. Springs Area, 2. NWFWMD and SRWMD Region, 3. SJRWMD Region, 4.SWFWMD Region |

# Adjustments for Autocorrelation (AC)

**Annual means and medians minimally affected by serial AC**

**Spatial AC**

- **Built on work of Boniol** (2002)**, based on Chloride**
- **Kriging exercise in the St. Johns River WMD: range = 15,240 m**
- **For study, constructed 1173 hexagons across FL, with diameter = 15,240 m**
- **Plotted all monitoring sites on hexagon coverage**

  **If more than one site located in a hexagon, randomly selected one site**

  **Precipitation = 8 sites, Discharge = 24 sites/springs, Na and Cl = 31 springs**

## Regional Kendall Test Results 1991-2020

| Indicator | Stations | Years | Units | Sen Slope | p-value |
|---|---|---|---|---|---|
| **Florida Springs Area** | | | | | |
| **Rain** | 8 | 30 | cm/yr | -0.049 | 0.594 |
| **Discharge** | 24 | 30 | $(m^3)(sec)/yr$ | -0.045 | 0.459 |
| **Na** | 31 | 30 | (mg/L)/yr | 0.056 | **<0.001** |
| **Cl** | 31 | 30 | (mg/L)/yr | 0.135 | **<0.001** |
| **NWFWMD and SRWMD Region** | | | | | |
| **Rain** | 3 | 30 | cm/yr | 0.119 | 0.302 |
| **Discharge** | 11 | 30 | $(m^3)(sec)/yr$ | 0.330 | 0.281 |
| **Na** | 12 | 30 | (mg/L)/yr | 0.005 | **<0.001** |
| **Cl** | 12 | 30 | (mg/L)/yr | 0.135 | **<0.001** |

## Regional Kendall Test Results 1991-2020

| Indicator | Stations | Years | Units | Sen Slope | p-value |
|---|---|---|---|---|---|
| **SJRWMD Region** | | | | | |
| **Rain** | 3 | 30 | cm/yr | -0.298 | 0.377 |
| **Discharge** | 9 | 30 | $(m^3)(sec)/yr$ | -0.136 | **0.020** |
| **Na** | 9 | 30 | (mg/L)/yr | 0.111 | **<0.001** |
| **Cl** | 10 | 30 | (mg/L)/yr | 0.170 | **<0.001** |
| **SWFWMD Region** | | | | | |
| **Rain** | 2 | 30 | cm/yr | 0.358 | **0.014** |
| **Discharge** | 4 | 30 | $(m^3)(sec)/yr$ | 0.659 | 0.224 |
| **Na** | 9 | 30 | (mg/L)/yr | 0.085 | **<0.001** |
| **Cl** | 9 | 30 | (mg/L)/yr | 0.248 | **<0.001** |

## Regional Kendall Test Results E (1991-2011) and L (2006-2020) Periods

| | Stations | Sen Slope | P-value | Stations | Sen Slope | P-value |
|---|---|---|---|---|---|---|
| **Period** | **Early (1991-2011)** | | | **Late (2006-2020)** | | |
| | **Springs Area** | | | | | |
| **Rain** | 8 | -0.237 | 0.293 | 8 | 0.270 | 0.364 |
| **Discharge** | 24 | -0.670 | 0.226 | 24 | 0.550 | **0.019** |
| **Na** | 31 | 0.086 | **<0.001** | 31 | 0.015 | 0.244 |
| **Cl** | 31 | 0.138 | **<0.001** | 31 | 0.135 | **<0.001** |
| | **NWFWMD and SRWMD Region** | | | | | |
| **Rain** | 3 | -0.281 | 0.129 | 3 | 1.200 | **0.011** |
| **Discharge** | 11 | -0.849 | 0.133 | 11 | 0.163 | **0.007** |
| **Na** | 12 | 0.083 | **<0.001** | 12 | -0.028 | **0.024** |
| **Cl** | 12 | 0.071 | **0.002** | 12 | 0.075 | **0.006** |

## Regional Kendall Test Results 1991-2020

| | Stations | Sen Slope | P-value | Stations | Sen Slope | P-value |
|---|---|---|---|---|---|---|
| **Period** | **Early (1991-2011)** | | | **Late (2006-2020)** | | |
| | **SJRWMD Region** | | | | | |
| **Rain** | 3 | -1.104 | 0.253 | 3 | 2.460 | 0.006 |
| **Discharge** | 9 | -0.062 | 0.497 | 9 | 0.100 | 0.131 |
| **Na** | 10 | 0.086 | **<0.001** | 10 | 0.085 | **0.011** |
| **Cl** | 10 | 0.103 | 0.164 | 10 | 0.224 | **<0.001** |
| | **SWFWMD Region** | | | | | |
| **Rain** | 2 | -0.237 | 0.293 | 2 | 0.270 | 0.364 |
| **Discharge** | 4 | -0.990 | 0.220 | 4 | 6.050 | **<0.001** |
| **Na** | 9 | 0.089 | **<0.001** | 9 | 0.067 | **0.006** |
| **Cl** | 9 | 0.200 | **<0.001** | 9 | 0.163 | **<0.001** |

# Conceptual Model

**All Freshwater aquifer systems (including FAS) are lumped together into Freshwater lens**

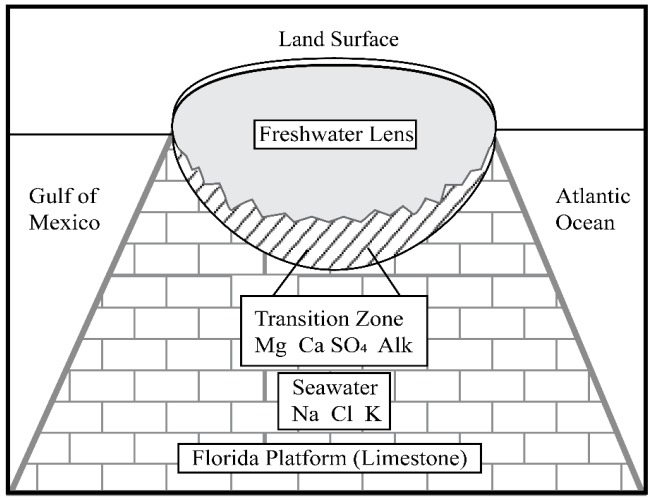
Top: Normal (Rainfall) Times

Bottom: Extended Dry Period

Sea - Level Rise:
Similar situation to bottom

Normal Freshwater Lens

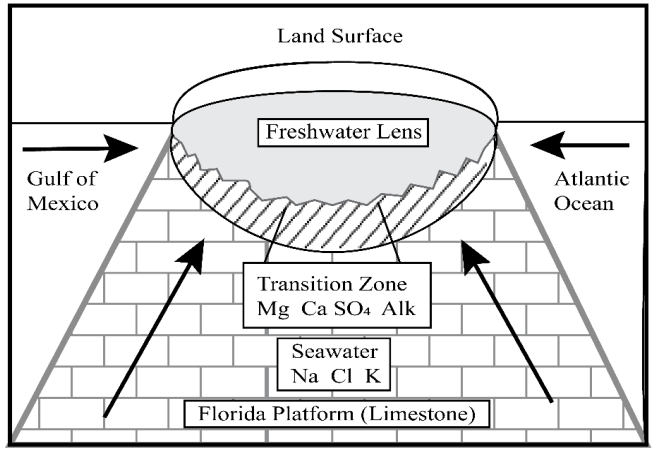
Spring Discharge and Water Table are Relatively High




(A)

Reduced Freshwater Lens
During Dry Period

Spring Discharge and Water Table Decline




(B)

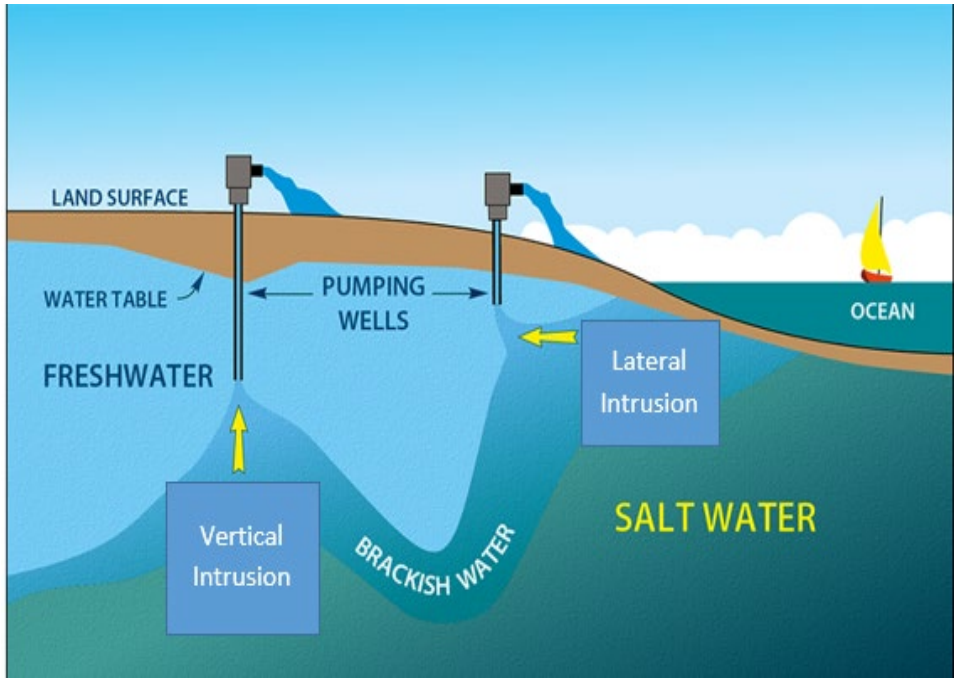
# Passive Saltwater Encroachment

**Fetter** (2001) **– Occurs when some fresh GW is diverted from an aquifer, yet the hydraulic gradient is still sloping toward saltwater–freshwater boundary until it reaches an equilibrium position.**

**Movement is slow. It may take hundreds of years for the boundary to shift a significant distance.**

# Active Versus Passive Encroachment

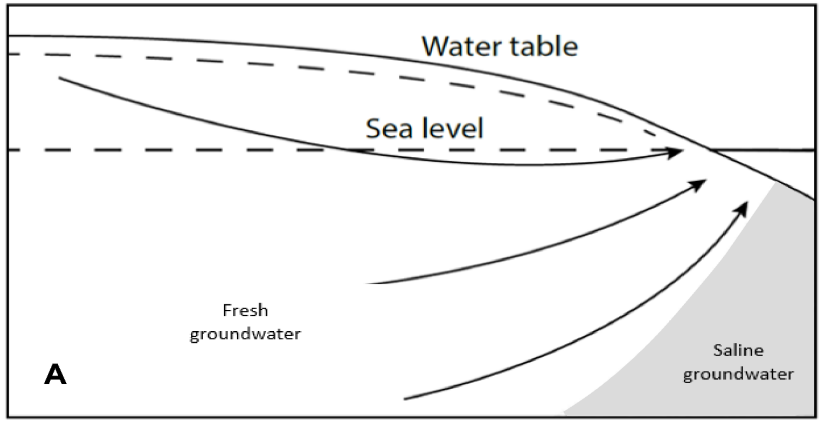
**Active**

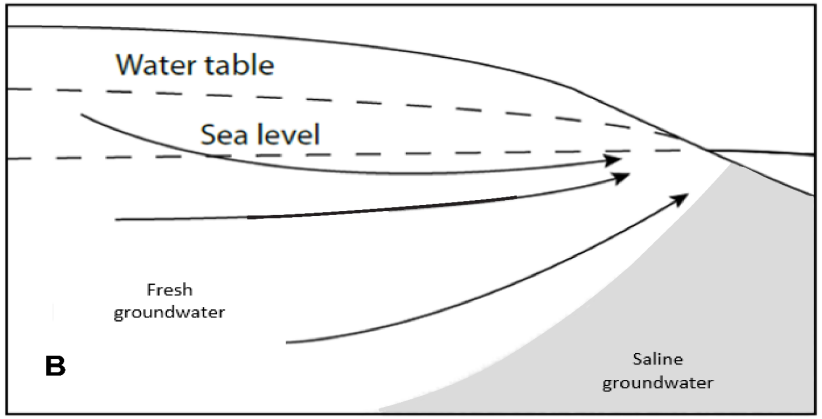



(Modified from SJRWMD, 2017)

**Passive**

(Fetter, 2001)



# Potential Drivers

1. **Decreasing Rainfall and a Resultant Decreases in Recharge to FAS**
2. **Groundwater Extraction**
3. **Sea-Level Rise**

# Decreasing Rainfall and Consequent Decreasing Recharge?

**Florida suffered a severe draught, 1999-2002** (Verdi et al., 2006)

**Rainfall in Florida is related to climatic oscillations. E.G. Atlantic Multidecadal Oscillation (AMO) and El Nino-Southern Oscillation.** (Kelly and Gore, 2008; Canfield et al., 2018)**.**

**Note, FL's rainfall decreased from mid 1970s to mid 2000s and has increased since. Possibly related to AMO.**(Climate Data,2021)

# Recharge and Groundwater (GW) Extraction?

**Recharge to FAS ≈ 19.0 cm/yr** (Bellino et al., 2018)

**USGS** (Marella, 2015) **indicated that FL's GW extraction has decreased from 1990 – 2012 .**

**Decrease related to WMD conservation efforts** (U.S. Environmental Protection Agency, 2017)**.**

**Since GW extraction declined during study, it is not a major driver of observed changes.**

# Sea-Level Rise

**NOAA reported that sea-level rose on 8.76 cm (0.29 ft) between 1993 and 2019** (NOAA, 2021); **about 0.32 cm/yr.**

**For the 30-year study, sea-level rise not considered as important as Climate cycle.**

**However, by 2100, sea-level rise predicted to be 1.2 m to 2.5 m** (US EPA, 2017)**. In future, the impact of sea-level rise on FAS chemistry is expected to increase.**

# Rate of Increase and a Question

| | Sodium | Chloride |
|---|---|---|
| Increase | (30 - yr Total) (mg/L) | (30 - yr Total) (mg/L) |
| Median | 1.68 | 4.05 |
| Mean | 17.67 | 65.43 |

**Med concentrations of Na increased 19.7%, and for Cl it increased 33.0%.**

**Na and Cl increased statistically. Is there a practical significance?**

**More of a practical uneasiness!**

**Changes occurred over an area as large as the Spring Area of Florida (≈ 40%).**

**Changes occurred over multiple decades.**

# Unresolved Issues

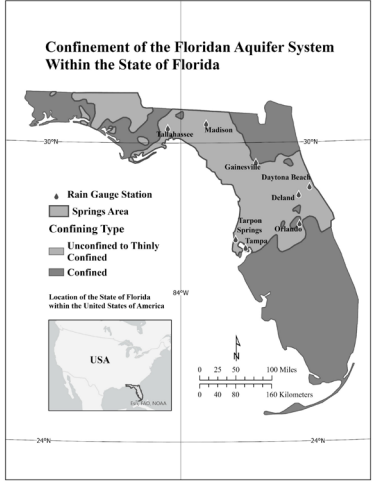
**Assuming the AMO is a major driver of rainfall, Florida will likely experience increased rainfall for the next several decades.**

- **Most Floridians will likely be more concerned with surface-water flooding than saline encroachment.**

**Why worry about saline encroachment?**

- **Eventually, rainfall will enter a declining state. When it does, there will likely be an increase in the rate of sea-level rise.**

# Key Findings




**Concentrations of Na and Cl increased in Florida Spring water over a large portion of Florida.**

**For multiple decades, Florida has experienced passive saltwater encroachment**

# What is Florida Doing?

- **The Florida Water Resource Monitoring Council, through the Salinity Workgroup, established a Coastal Salinity Monitoring Network in Florida, including the Spring Area.**
  - **Data, stored in agency databases, are being sent to the Water Information Network (WIN) database at Florida DEP.**
  - **Once complete, the Workgroup will work on developing methods to assist in the monitoring of saline encroachment.**

- **Resilient Florida Grant Program** (from F.S. 380.093) **includes funding for the local planning for sea-level rise.**

# Questions

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