Passive Saline Encroachment in the Floridan Aquifer System (1991-2011)

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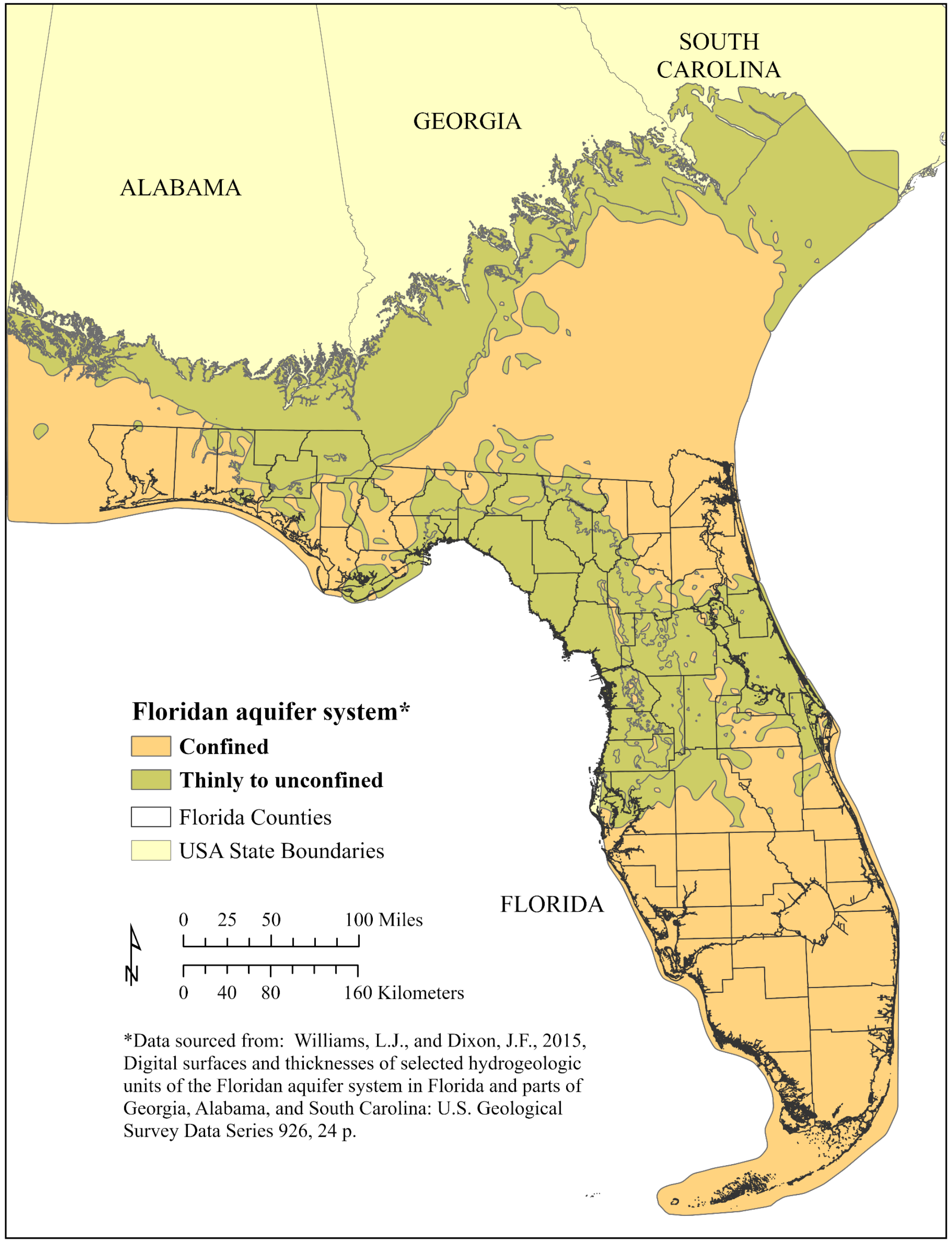
Objectives

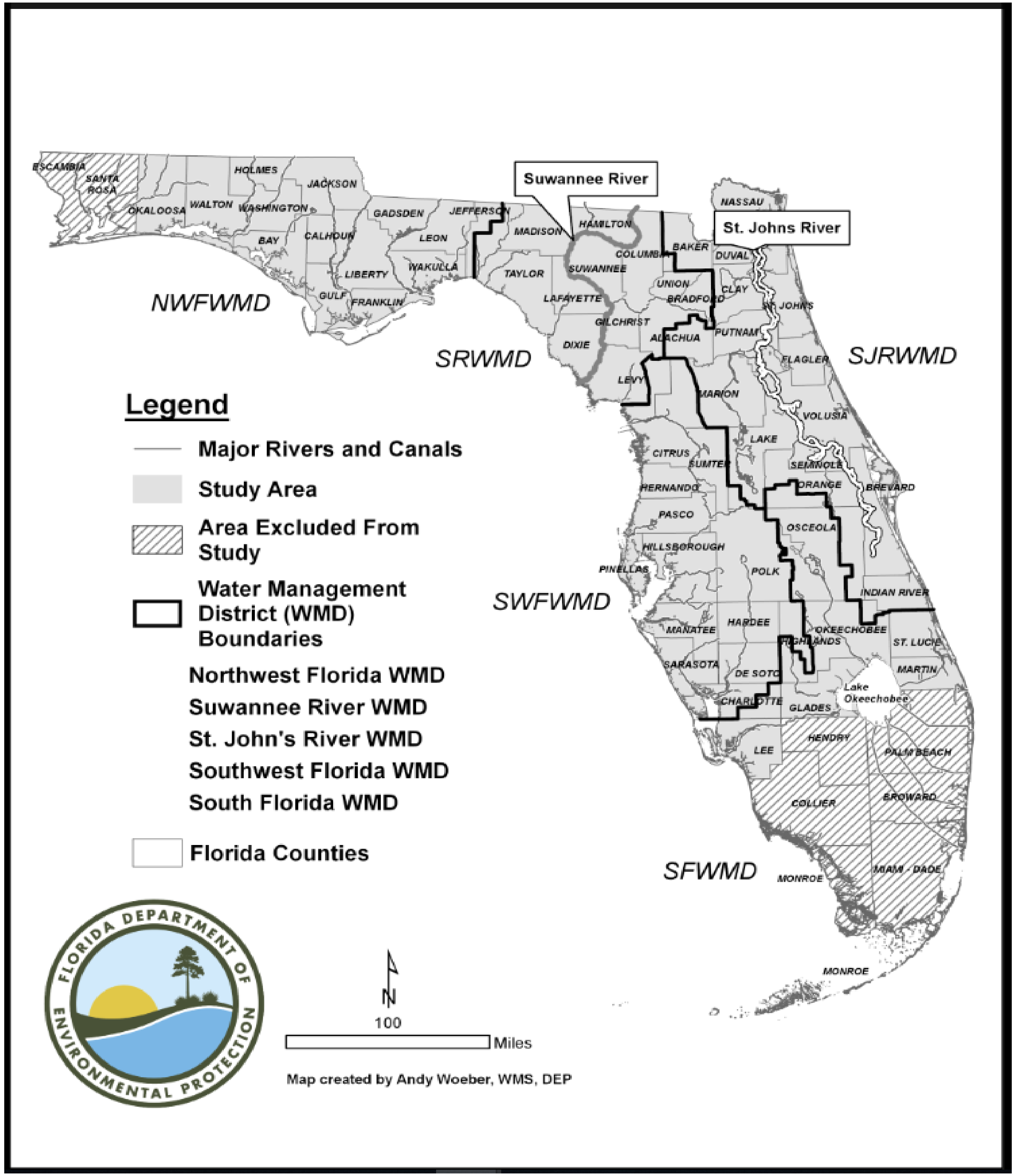
For Period of Record (1991-2011)

1) Did water quality changes occur in the Floridan aquifer system (FAS)?
2) If changes were observed;
   a) Estimate areal extent of changes
   b) Estimate rates of change
   c) Discuss plausible drivers of change

Extent of FAS

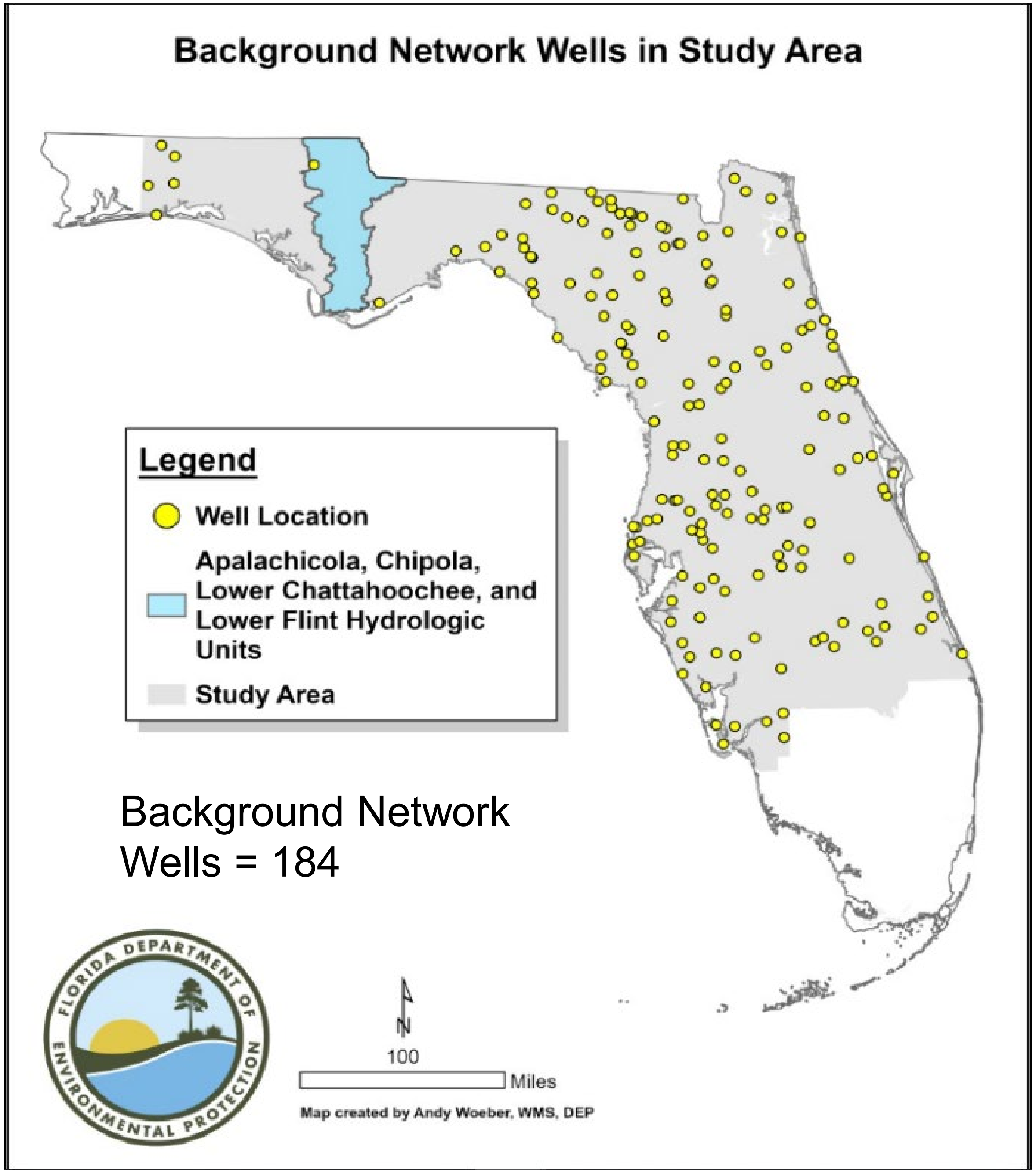


Study Area



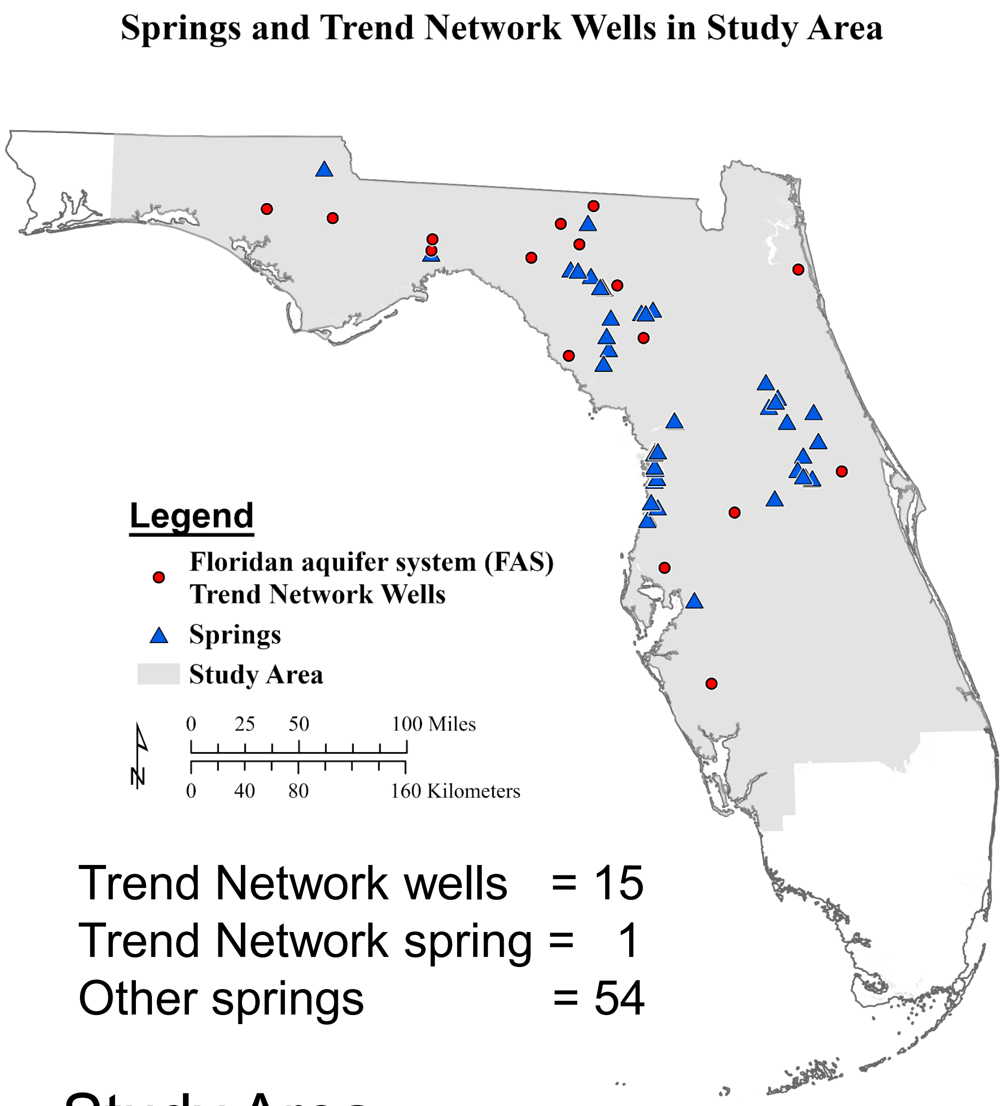
Suwannee River
St. Johns River
NWFWMD
SRWMD
SJRWMD
SWFWMD
SFWMD
Legend
Major Rivers and Canals
Study Area
Area Excluded From Study
Water Management District (WMD) Boundaries
Northwest Florida WMD
Suwannee River WMD
St. John's River WMD
Southwest Florida WMD
South Florida WMD
Florida Counties
ESCAMBIA
SANTA ROSA
OKALOOSA
WALTON
HOLMES
WASHINGTON
JACKSON
BAY
CALHOUN
GADSDEN
JEFFERSON
LEON
LIBERTY
WAKULLA
GULF
FRANKLIN
MADISON
HAMILTON
TAYLOR
SUWANNEE
COLUMBIA
BAKER
NASSAU
DUVAL
UNION
BRADFORD
CLAY
ST. JOHNS
LAFAYETTE
GILCHRIST
DIXIE
ALACHUA
PUTNAM
FLAGLER
LEVY
MARION
VOLUSIA
LAKE
CITRUS
SUMTER
SEMINOLE
ORANGE
BREVARD
HERNANDO
PASCO
OSCEOLA
HILLSBOROUGH
PINELLAS
POLK
INDIAN RIVER
MANATEE
HARDEE
OKEECHOBEE
HIGHLANDS
ST. LUCIE
SARASOTA
DE SOTO
MARTIN
CHARLOTTE
GLADES
Lake Okeechobee
HENDRY
LEE
PALM BEACH
COLLIER
BROWARD
MIAMI - DADE
MONROE
N
100
Miles
Map created by Andy Woeber, WMS, DEP

Background Network Wells



Background Network Wells = 184

Trend Network Wells and Springs



Trend Network wells = 15
Trend Network spring = 1
Other springs = 54

Study Area
≈ 73% of FL

Indicators

Indicator	Abbreviation	Unit of Measure
Alkalinity	Alk	mg/L
Calcium	Ca	mg/L
Chloride	Cl	mg/L
(Spring) Discharge*	None	(m^3) /sec
Groundwater Levels*	GWLs	m
Magnesium	Mg	mg/L
Potassium	K	mg/L
Sodium	Na	mg/L
Sulfate	SO4	mg/L
Total Dissolved Solids	TDS	mg/L

*Aquifer Potentials

Statistical Trend Tests

Test	Abbreviation
Wilcoxon Signed Ranks	WSR
Regional-Kendall	RK

Network	Sampling Frequencies	Trend Test
Background	Infrequently	WSR
Trend	Monthly or Quarterly	WSR RK
Springs	Mostly Quarterly	WSR RK

WSR Test

- Before-After Test
- Divide data at each site into three periods: early (E), middle (M), and late (L).
  - E = 1991-1997
  - M = 1998-2004
  - L = 2005-2011
- Determine median at each site for each period
- Discard M data and compare L to E medians at each site

RK Test

- Tests for trend at each site, then tests for overall trend for region
- Minimizes effect of serial and spatial correlation

Methodology for Study

- For both WSR and RK tests
  - Ho: No change [in median (WSR) or slope (RK)]
  - Ha: Change
  - Two sided test; alpha = 0.10
    - Results adjusted for effect of multiple comparisons (Benjamini-Hochberg procedure)

Autocorrelation (AC)

- WSR tests: took steps to account for AC
  - **Serial**: Median value of 7-yr periods

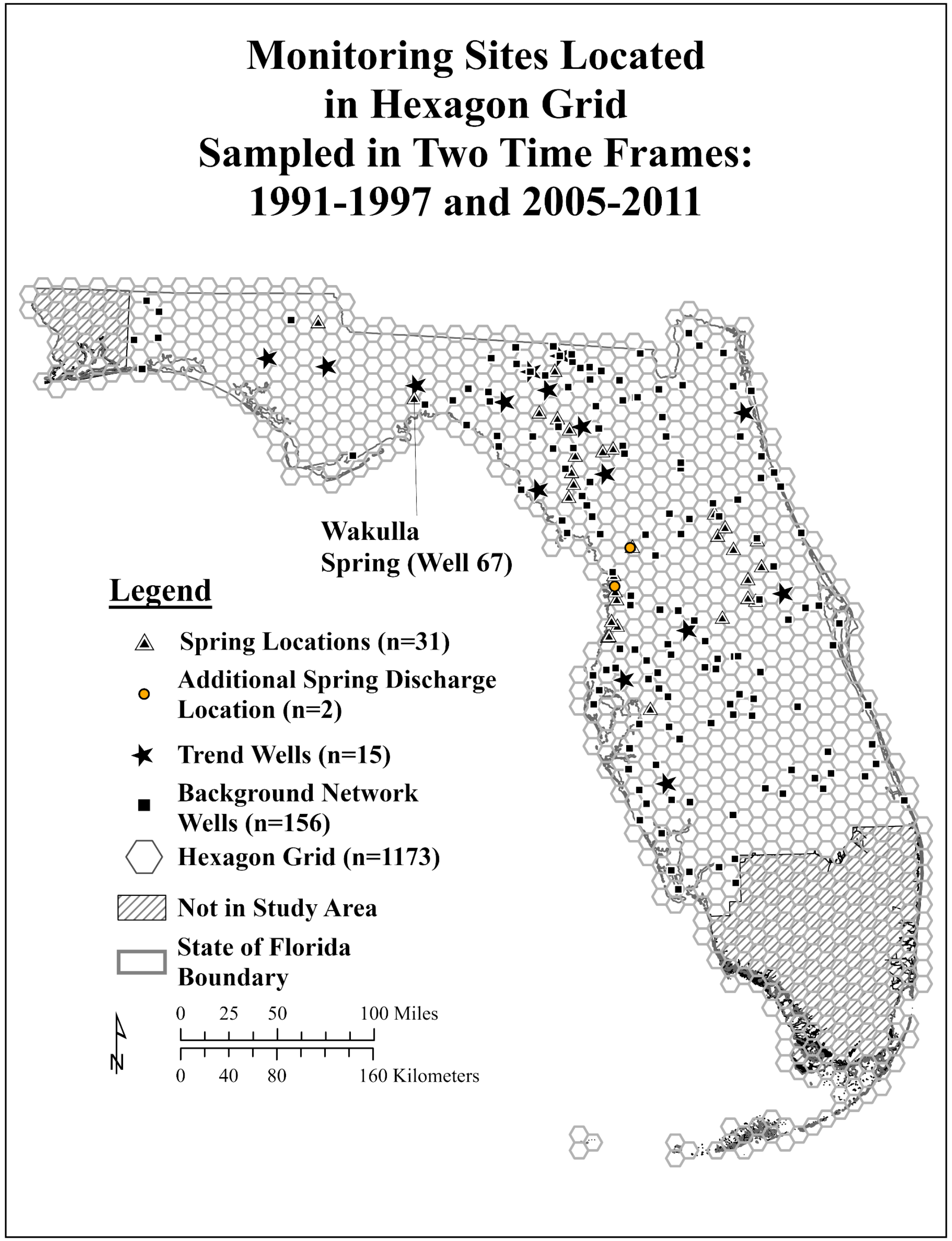
  - **Spatial**: Built on work of Boniol (2002), based on chloride
    - Kriging exercise in St. John's River WMD: range = 15,240 m
    - For the study constructed 927 hexagons (diam = 15,240 m)
    - Plotted all sites on hexagon coverage
      - If more than one site located in a hexagon, randomly selected one site to represent hexagon.

Sites in Hexagon Grids Sampled in Early (E) and Late (L) Periods

Total Sites = 202

Simple Random sample

202 / 927 hexagons (Study Area)



Significant Results

	Trend Wells		Springs		Background Network Wells	
	Direction	Test	Direction	Test	Direction	Test
Aquifer Potential	Down	R W	Down	W	Down	W
Alk	Up	R	Up	R W	Up	W
Ca	Up	R	Up	R W	Up	W
Cl			Up	R W	Up	W
K			Up	R		
Mg	Up	R W	Up	R	Up	W
Na	Up	R	Up	R W		
SO4			Up	R W		
TDS	Up	R	Up	R W	Up	W
R = RK test W= WSR test						

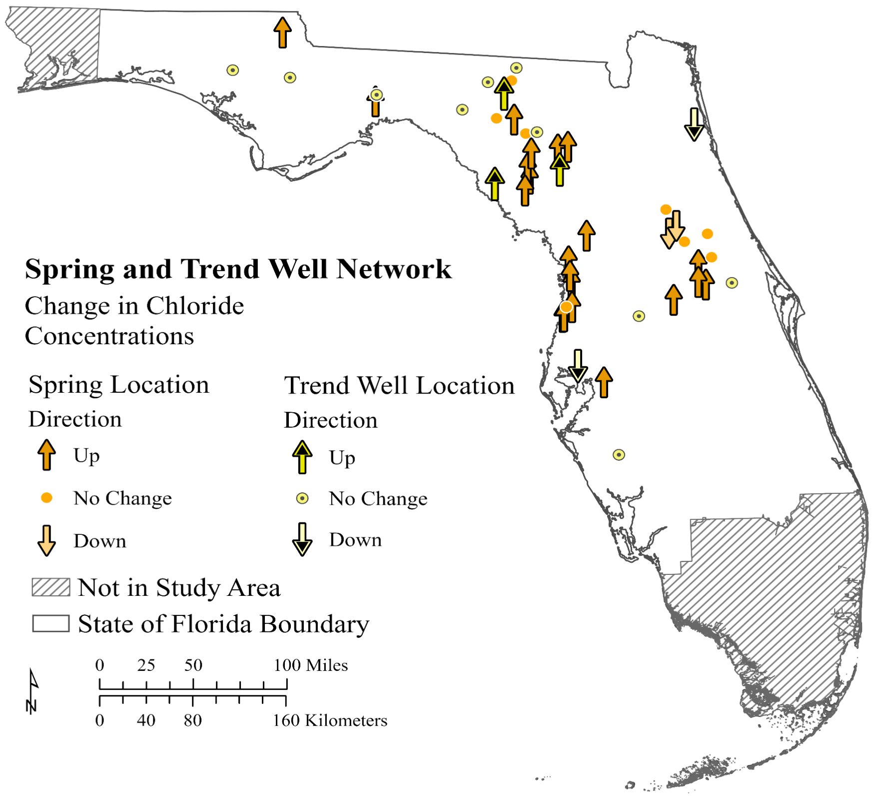
Direction of Chloride Changes

Irregular Sampling

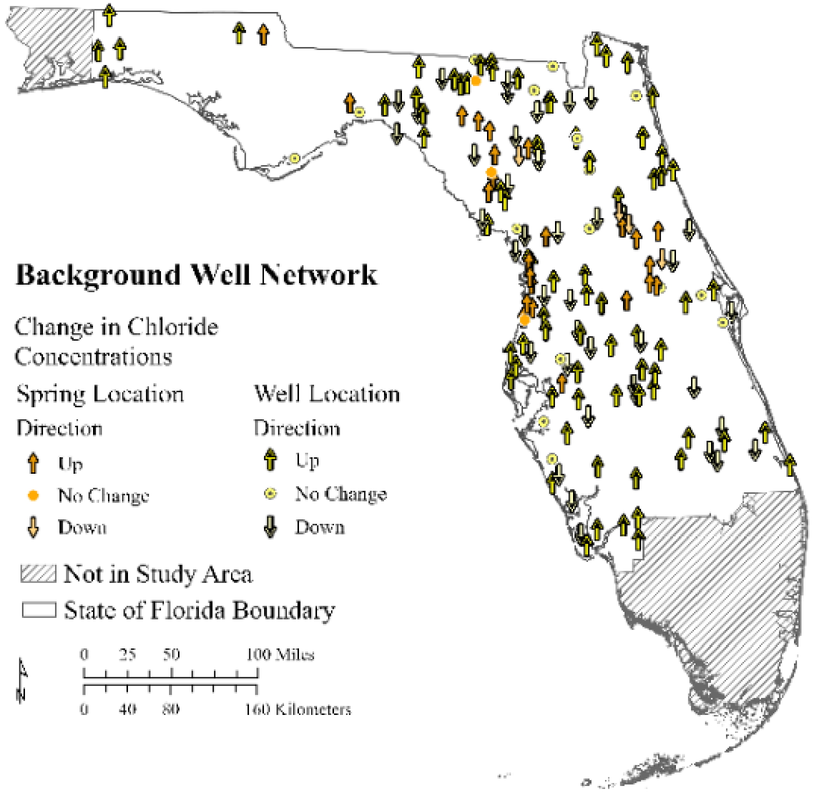
Comparing median concentration (L-E)

Sites (176) with measurable change, upward concentrations in 70 percent of sites

“Semi-regular” Sampling (quarterly or monthly)



Irregular Sampling



Rates of Change for Selected Indicators (per decade)

Springs	Discharge (m3/sec) / Dec	Na (mg/L) / Dec	Cl (mg/L) / Dec	TDS (mg/L) / Dec
Med of RK and WSR Estimates	-2.16	0.63	1.22	18.69
Trend Wells	GWL (m) / Dec	Na (mg/L) / Dec	Cl (mg/L) / Dec	TDS (mg/L) / Dec
Med of RK and WSR Estimates	-0.18	0.20	0.43	7.19

Relative magnitude of change: 2% – 6%

Plausible Drivers of Change

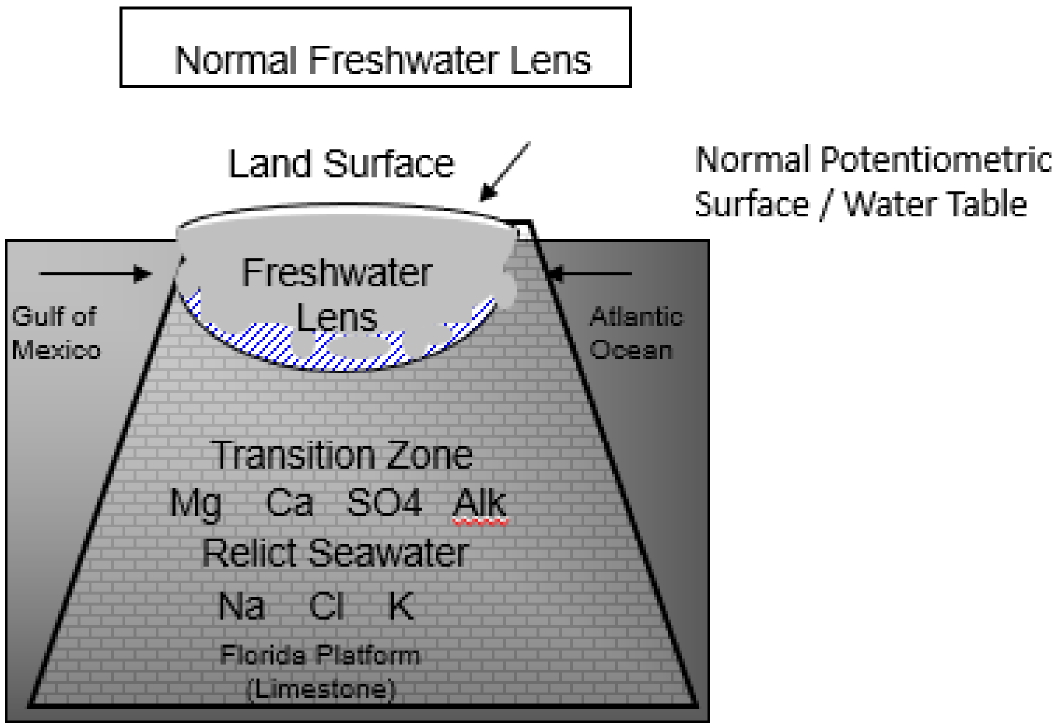
1) Below Normal Rainfall; loss of recharge to FAS
2) Groundwater Extraction
3) Rising sea levels

Conceptual Model

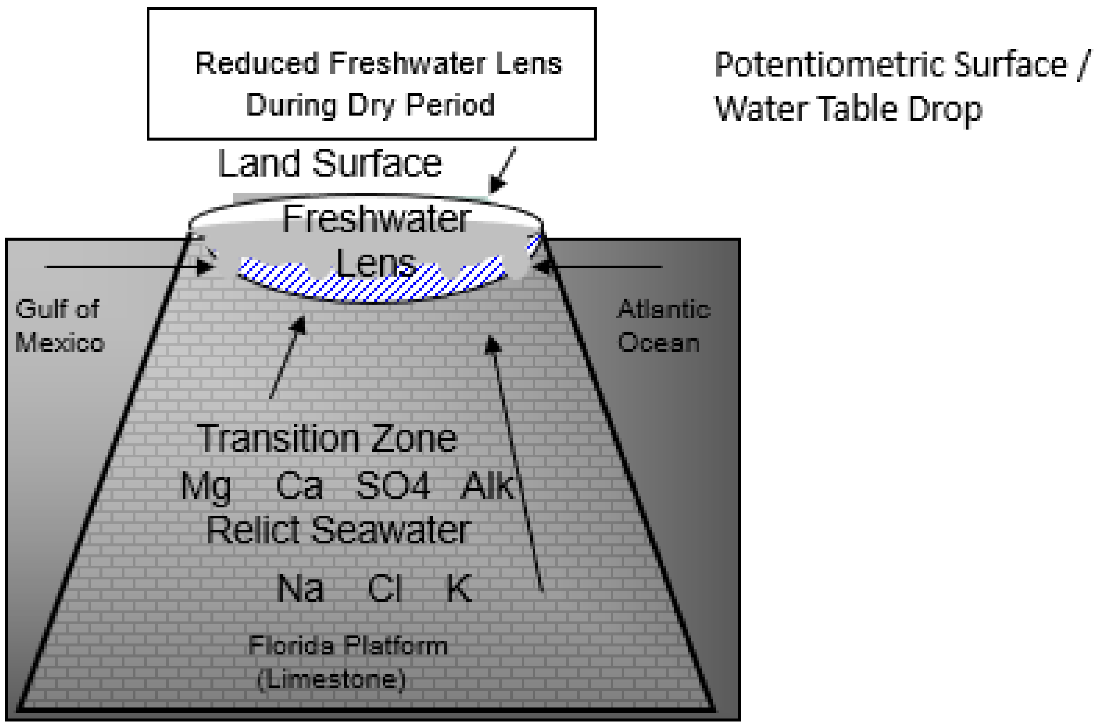
Carbonate Aquifer System Near Coast

- Assume Sea level is static. If aquifer potentials decline;

1. Probability of saline encroachment increases along coasts,
2. Probability of deep, mineralized groundwater to migrate upward increases.

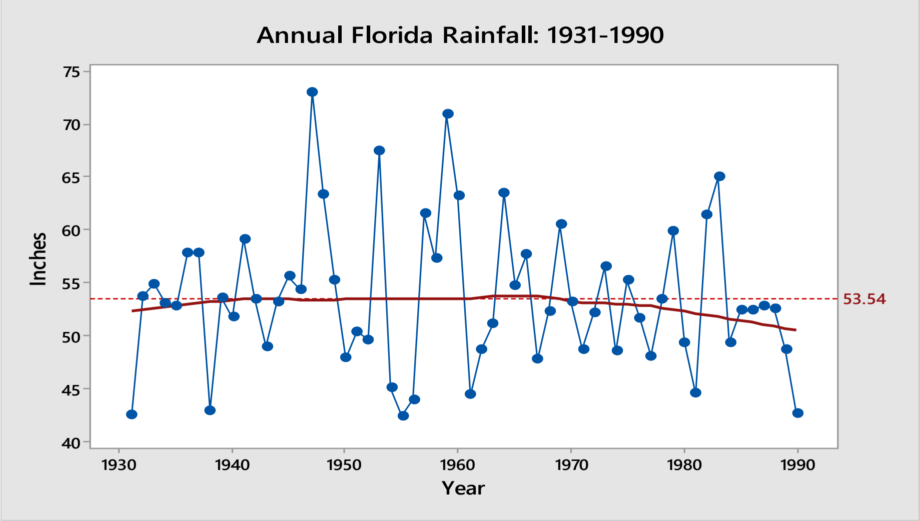


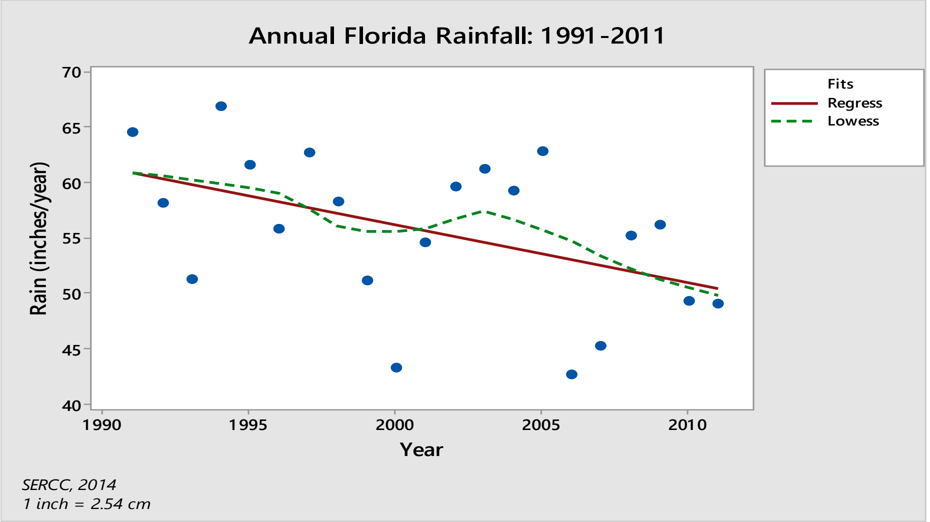
Period of Normal Precipitation



Period of Below Normal Precipitation

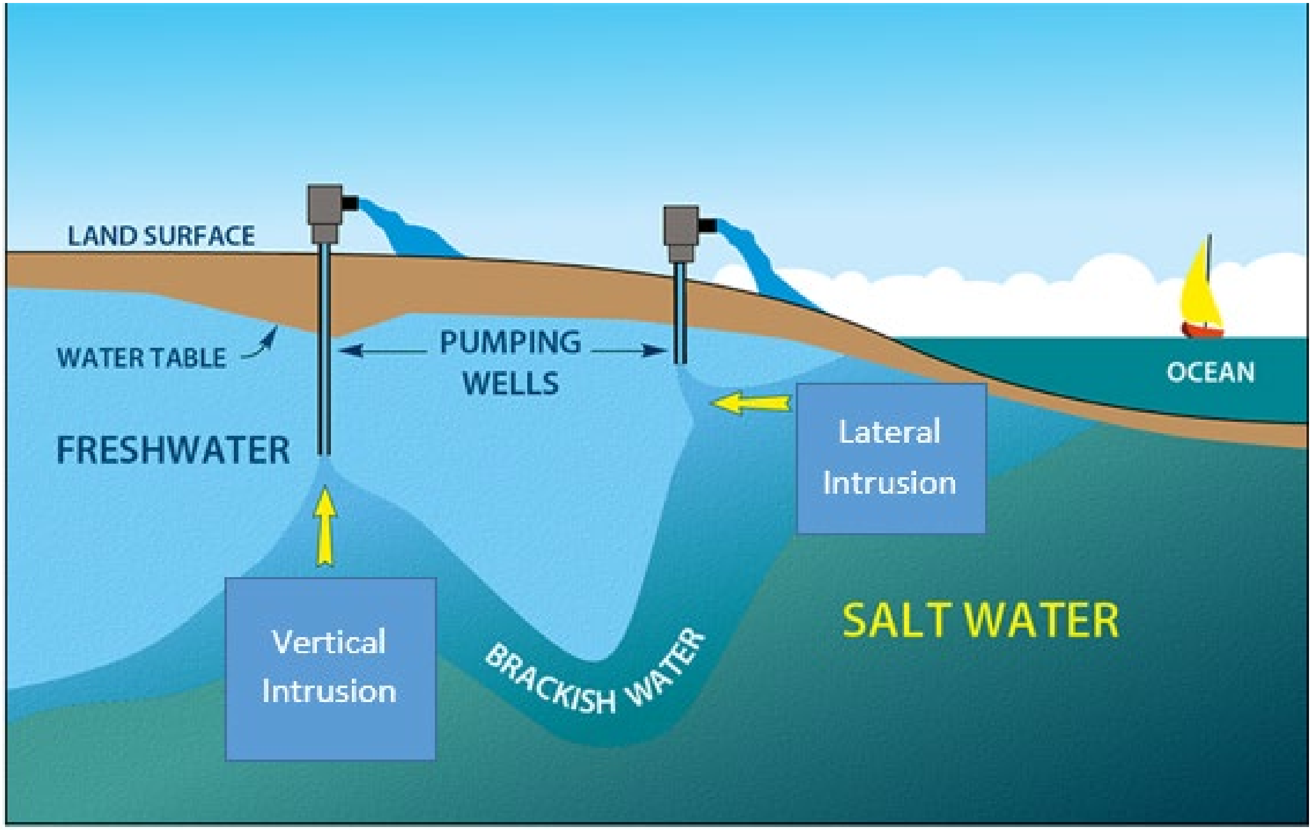
Florida Precipitation





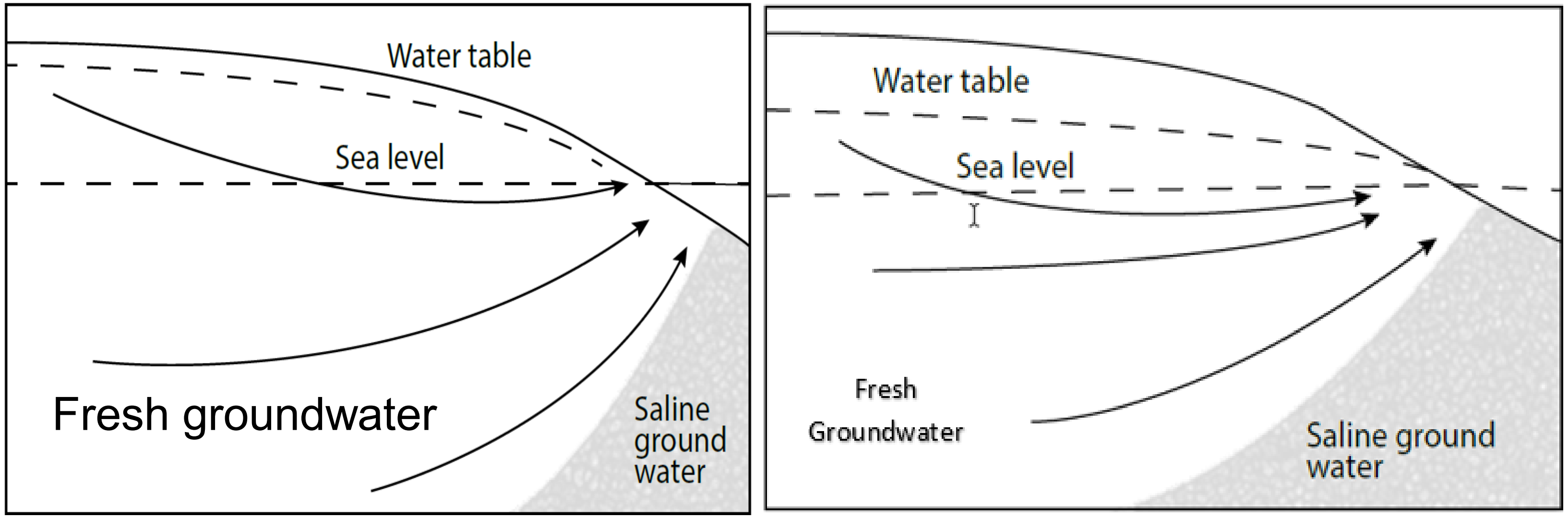
Considered Baseline to be 1931-1990 (60 years)

GW Extraction and Encroachment



Unconfined coastal aquifer depicting vertical and horizontal encroachment induced by pumping (modified from SJRWMD 2017)

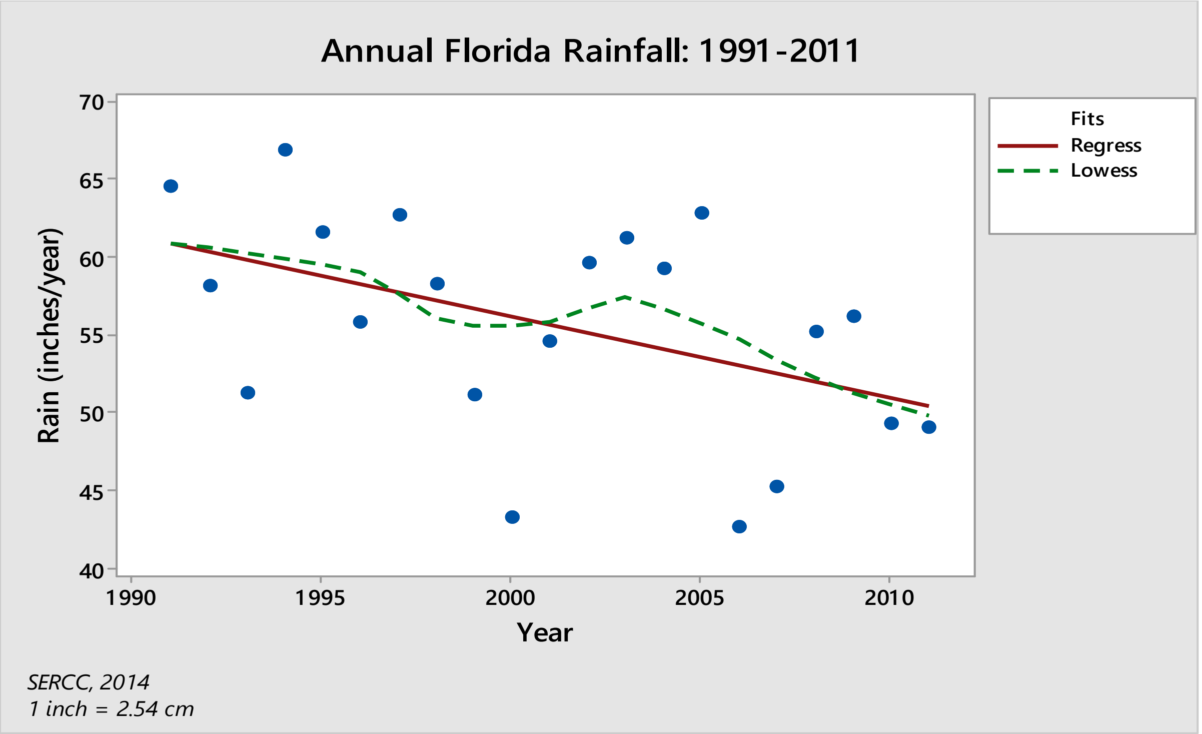
Passive Encroachment (Fetter 2001)



1. When some fresh GW diverted from aquifer, yet hydraulic gradient still slopes towards FW/SW boundary

2. May take hundreds of years for boundary to shift a significant distance

Decreasing Precipitation → Recharge



Years	Annual Mean
1991-1998	147.07 cm (57.90 in)
1999-2011	129.46 cm (50.97 in)

During study, but after 1998, annual rainfall decreased by 12%

Recharge to FAS

FAS (Bellino et al. 2018)

≈ **19.00** cm/yr

Assume recharge declined post 1999

≈ -2.28 cm/yr (linear?)

≈ **-27.36** cm (cumulative)

Extraction from FAS

GW extraction (Marella 2004)

Used 1990 as baseline (**2.39** cm/yr)

≈ 13% of recharge (**Important**)

However, estimated extraction 1990-2010 (**net decrease**)

Relative to recharge, 1991-2011, effect of extraction is minor

Sea-Level Rise

Walton (2007) estimated rise (1950-1999) ≈ **0.3 cm/yr**

For 1999-2011, cumulative total ≈ **3.6** cm

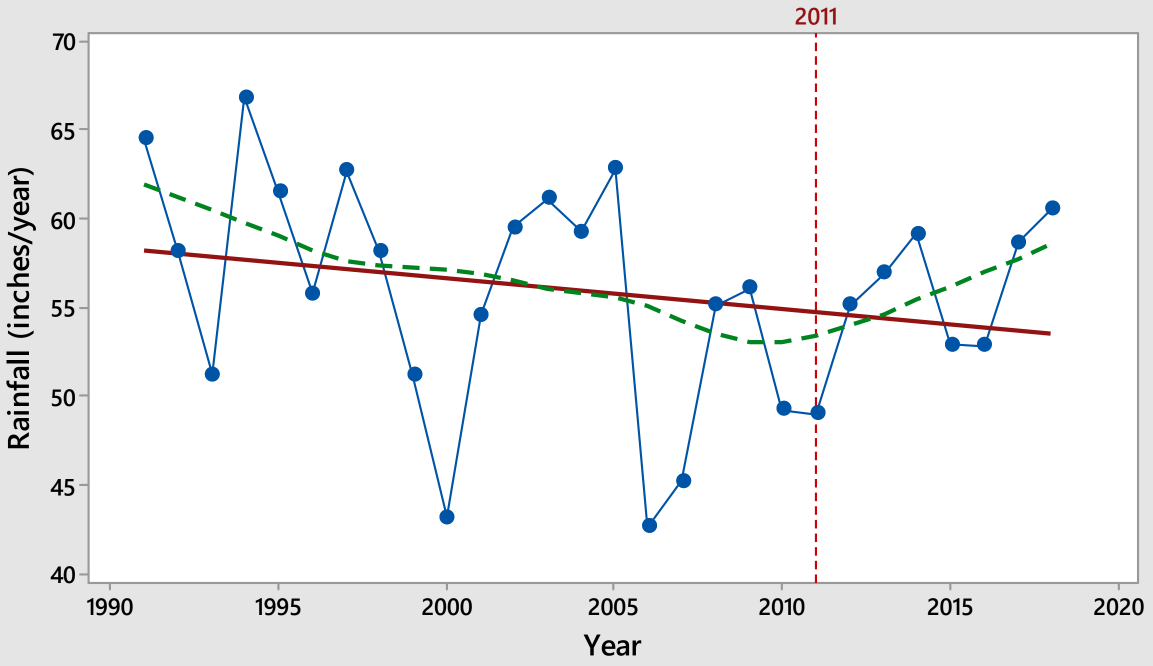
Relative to recharge reductione, effect of sea-level rise is minor

<u>Primary Driver</u>

Reduction in **rainfall**, and subsequent reduction in **recharge**

Precipitation 1991-2018

Can Florida Recover? If steady state, eventually yes



Southeast Regional Climate Center 2019
in inch = 2.54 cm

Conceptual Model

non-steady state model

Assume Sea level is <u>rising</u>

Independent of precipitation

- Passive encroachment will continue

Importance of Study

- Passive encroachment observed in FAS
- Changes: large in areal extent (at least 73%), but small relative percent change (2%-6%)
- Mostly driven by reduction in precipitation/recharge
- If steady state conditions: trends could reverse
- However, with sea level rise, understanding passive encroachment becomes imperative

Questions?

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