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Division of Environmental Assessment and Restoration
February 25-26, 2020
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
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
<table>
<thead>
<tr>
<th>Indicator</th>
<th>Abbreviation</th>
<th>Unit of Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkalinity</td>
<td>Alk</td>
<td>mg/L</td>
</tr>
<tr>
<td>Calcium</td>
<td>Ca</td>
<td>mg/L</td>
</tr>
<tr>
<td>Chloride</td>
<td>Cl</td>
<td>mg/L</td>
</tr>
<tr>
<td>(Spring) Discharge*</td>
<td>None</td>
<td>(m³) /sec</td>
</tr>
<tr>
<td>Groundwater Levels*</td>
<td>GWLs</td>
<td>m</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Mg</td>
<td>mg/L</td>
</tr>
<tr>
<td>Potassium</td>
<td>K</td>
<td>mg/L</td>
</tr>
<tr>
<td>Sodium</td>
<td>Na</td>
<td>mg/L</td>
</tr>
<tr>
<td>Sulfate</td>
<td>SO4</td>
<td>mg/L</td>
</tr>
<tr>
<td>Total Dissolved Solids</td>
<td>TDS</td>
<td>mg/L</td>
</tr>
</tbody>
</table>

*Aquifer Potentials
Statistical Trend Tests

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

<table>
<thead>
<tr>
<th>Test</th>
<th>Abbreviation</th>
<th>Network</th>
<th>Sampling Frequencies</th>
<th>Trend Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wilcoxon Signed Ranks</td>
<td>WSR</td>
<td>Background</td>
<td>Infrequently</td>
<td>WSR</td>
</tr>
<tr>
<td>Regional-Kendall</td>
<td>RK</td>
<td>Trend</td>
<td>Monthly or Quarterly</td>
<td>WSR RK</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Springs</td>
<td>Mostly Quarterly</td>
<td>WSR RK</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Aquifer Potential</th>
<th>Trend Wells</th>
<th>Springs</th>
<th>Background Network Wells</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Direction</td>
<td>Test</td>
<td>Direction</td>
</tr>
<tr>
<td>Aquifer Potential</td>
<td>Down</td>
<td>R W</td>
<td>Down</td>
</tr>
<tr>
<td>Alk</td>
<td>Up</td>
<td>R</td>
<td>Up</td>
</tr>
<tr>
<td>Ca</td>
<td>Up</td>
<td>R</td>
<td>Up</td>
</tr>
<tr>
<td>Cl</td>
<td>Up</td>
<td></td>
<td>Up</td>
</tr>
<tr>
<td>K</td>
<td>Up</td>
<td>R</td>
<td></td>
</tr>
<tr>
<td>Mg</td>
<td>Up</td>
<td>R W</td>
<td>Up</td>
</tr>
<tr>
<td>Na</td>
<td>Up</td>
<td>R</td>
<td>Up</td>
</tr>
<tr>
<td>SO4</td>
<td></td>
<td></td>
<td>Up</td>
</tr>
<tr>
<td>TDS</td>
<td>Up</td>
<td>R</td>
<td>Up</td>
</tr>
</tbody>
</table>

R = RK test    \quad W = WSR test
Comparing median concentration (L-E)

Sites (176) with measurable change, upward concentrations in 70 percent of sites.
# Rates of Change for Selected Indicators (per decade)

<table>
<thead>
<tr>
<th>Springs</th>
<th>Discharge (m3/sec) / Dec</th>
<th>Na (mg/L) / Dec</th>
<th>Cl (mg/L) / Dec</th>
<th>TDS (mg/L) / Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Med of RK and WSR Estimates</td>
<td>-2.16</td>
<td>0.63</td>
<td>1.22</td>
<td>18.69</td>
</tr>
<tr>
<td><strong>Trend Wells</strong></td>
<td><strong>GWL (m) / Dec</strong></td>
<td><strong>Na (mg/L) / Dec</strong></td>
<td><strong>Cl (mg/L) / Dec</strong></td>
<td><strong>TDS (mg/L) / Dec</strong></td>
</tr>
<tr>
<td>Med of RK and WSR Estimates</td>
<td>-0.18</td>
<td>0.20</td>
<td>0.43</td>
<td>7.19</td>
</tr>
</tbody>
</table>

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

- Freshwater Lens
- Transition Zone: Mg, Ca, SO₄, Alk, Relict Seawater, Na, Cl, K, Florida Platform (Limestone)

Period of Below Normal Precipitation

- Reduced Freshwater Lens During Dry Period
- Potentiometric Surface / Water Table Drop
- Transition Zone: Mg, Ca, SO₄, Alk, Relict Seawater, Na, Cl, K, Florida Platform (Limestone)
Florida Precipitation

Annual Florida Rainfall: 1931-1990

Considered Baseline to be 1931-1990 (60 years)

Annual Florida Rainfall: 1991-2011

SERCC, 2014
1 inch = 2.54 cm
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

**Annual Florida Rainfall: 1991-2011**

<table>
<thead>
<tr>
<th>Years</th>
<th>Annual Mean</th>
<th>During study, but after 1998, annual rainfall decreased by 12%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1991-1998</td>
<td>147.07 cm (57.90 in)</td>
<td></td>
</tr>
<tr>
<td>1999-2011</td>
<td>129.46 cm (50.97 in)</td>
<td></td>
</tr>
</tbody>
</table>

SERCC, 2014

1 inch = 2.54 cm
**Recharge to FAS**

FAS (Bellino et al. 2018)

$\approx 19.00$ cm/yr

Assume recharge declined post 1999

$\approx -2.28$ cm/yr (linear?)

$\approx -27.36$ cm (cumulative)

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**Extraction from FAS**

GW extraction (Marella 2004)

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

$\approx 13\%$ of recharge (Important)

However, estimated extraction 1990-2010 (net decrease)

Relative to recharge, 1991-2011, effect of extraction is minor
Walton (2007) estimated rise (1950-1999) ≈ 0.3 cm/yr
For 1999-2011, cumulative total ≈ 3.6 cm

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

**Primary Driver**
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
Assume Sea level is rising

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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