Deducing Dominant Drivers of Discharge Dynamics: Simultaneously Testing Multiple Causal Hypotheses of Changes in Spring Flow

UF Water Institute Symposium
February 25th, 2020
Nathan Reaver
Acknowledgements

Why is Flow in Silver Springs Declining?
Florida Fish and Wildlife Foundation
Contract No. PFS 1819-06
Silver Springs Flow Decline

![Graph showing flow decline over time]

Discharge (CMS) vs. Year

- Discharge values range from 0 to 40 CMS.
- Year range from 1940 to 2020.

The graph illustrates a decline in discharge over time, with fluctuations in the early years, followed by a more pronounced decline after 2000.
Silver Springs Flow Decline

![Graph showing discharge (CMS) over years from 1940 to 2020, with a clear trend of decline.](image-url)
Why is Flow in Silver Springs Declining?
Why is Flow in Silver Springs Declining?

Proposed flow decline mechanisms

H1-Springshed area decline
H2-Recharge decline due to climate shifts
H3-Groundwater pumping
H4-Landuse change
H5-Ghyben-Herzberg principle
H6-Vegetative “damming” of the spring
H7-Surficial aquifer “damming” of the spring
Proposed flow decline mechanisms

H1-Springshed area decline
H2-Recharge decline due to climate shifts
H3-Groundwater pumping
H4-Landuse change
H5-Ghyben-Herzberg principle
H6-Vegetative “damming” of the spring
H7-Surficial aquifer “damming” of the spring

Howard T. Odum Florida Springs Institute (2014). Silver Springs Restoration Plan
Why is Flow in Silver Springs Declining?

Proposed flow decline mechanisms

H1-Springshed area decline
H2-Recharge decline due to climate shifts
H3-Groundwater pumping
H4-Landuse change
H5-Ghyben-Herzberg principle
H6-Vegetative “damming” of the spring
H7-Surficial aquifer “damming” of the spring
Why is Flow in Silver Springs Declining?

Proposed flow decline mechanisms

H1-Springshed area decline
H2-Recharge decline due to climate shifts
H3-Groundwater pumping
H4-Landuse change
H5-Ghyben-Herzberg principle
H6-Vegetative “damming” of the spring
H7-Surficial aquifer “damming” of the spring
Why is Flow in Silver Springs Declining?

Proposed flow decline mechanisms

H1-Springshed area decline
H2-Recharge decline due to climate shifts
H3-Groundwater pumping
H4-Landuse change
H5-Ghyben-Herzberg principle
H6-Vegetative “damming” of the spring
H7-Surficial aquifer “damming” of the spring
Proposed flow decline mechanisms

H1-Springshed area decline
H2-Recharge decline due to climate shifts
H3-Groundwater pumping
H4-Landuse change
H5-Ghyben-Herzberg principle
H6-Vegetative “damming” of the spring
H7-Surficial aquifer “damming” of the spring
Proposed flow decline mechanisms

H1-Springshed area decline
H2-Recharge decline due to climate shifts
H3-Groundwater pumping
H4-Landuse change
H5-Ghyben-Herzberg principle
H6-Vegetative “damming” of the spring
H7-Surficial aquifer “damming” of the spring

Barlow, Paul M. (2003). Ground Water in Freshwater-Saltwater Environments of the Atlantic Coast. USGS. Retrieved on 2009-03-21. Figure B-1
Why is Flow in Silver Springs Declining?

Proposed flow decline mechanisms

H1-Springshed area decline
H2-Recharge decline due to climate shifts
H3-Groundwater pumping
H4-Landuse change
H5-Ghyben-Herzberg principle
H6-Vegetative “damming” of the spring
H7-Surficial aquifer “damming” of the spring
Proposed flow decline mechanisms

H1-Springshed area decline
H2-Recharge decline due to climate shifts
H3-Groundwater pumping
H4-Landuse change
H5-Ghyben-Herzberg principle
H6-Vegetative “damming” of the spring
H7-Surficial aquifer “damming” of the spring

Knowles et al. 2010
Proposed flow decline mechanisms

H1-Springshed area decline
H2-Recharge decline due to climate shifts
H3-Groundwater pumping
H4-Landuse change
H5-Ghyben-Herzberg principle
H6-Vegetative “damming” of the spring
H7-Surficial aquifer “damming” of the spring
Simultaneously Testing Multiple Hypotheses

Land Surface

Groundwater System Dynamics

Groundwater Dependent Ecosystem

Recharge

Discharge

Feedbacks
Simultaneously Testing Multiple Hypotheses

Process-Inclusive Model

Soil Storage

H

Upper Floridan $h_U, S_U$

Lower Floridan $h_L, S_L$

Saltwater interface or aquiclude

$A_g$

$Q_{VP}$

$\Theta_a$

$\eta_a$

$\rho_a, D_a$

$R_{UL}, Q_{UL}$

$R_U, Q_U$

$R_L, Q_L$

Spring Pool/Run

Spring Run Mouth

Surficial Aquifer

$A_s$

$P$

$E$

$\eta_S$

$\Theta_S$

$\rho_s, D_s$

$h_s, S_s$
Proposed flow decline mechanisms

H1-Springshed area decline – **allow time varying springshed area**

H2-Recharge decline due to climate shifts – **drive model with climate observations**

H3-Groundwater pumping – **drive model with pumping estimates**

H4-Landuse change - **allow time varying soil storage capacity**

H5-Ghyben-Herzberg principle – **storativity of lower aquifer**

H6-Vegetative “damming” of the spring – **allow time varying river resistance**

H7-Surficial aquifer “damming” of the spring – **size of surficial aquifer**
Simultaneously Testing Multiple Hypotheses

Calibrating to Data:

\[ \Pr(H|D) \propto \Pr(D|H)\Pr(H) \]
Simultaneously Testing Multiple Hypotheses

Available Data:

- Spring Discharge
- Spring Run Discharge
- Spring Pool Elevation
- Upper Floridan Elevation

Available Groundwater Observations

Process-Inclusive Mechanistic Model

\[ P(D | H) P(H) \]

Calibration

\[ P(H | D) \]

Likelihood of Biophysical Processes
Simultaneously Testing Multiple Hypotheses

Available Data:

- Spring Discharge
- Spring Run Discharge
- Spring Pool Elevation
- Upper Floridan Elevation

Available Groundwater Observations

Process-Inclusive Mechanistic Model

\[ \Pr(D|H) \Pr(H) \]

Calibration

\[ \Pr(H|D) \]

Likelihood of Biophysical Processes
Simultaneously Testing Multiple Hypotheses

Spring Discharge

$NSE = 0.78$
Proposed flow decline mechanisms

H1-Springshed area decline
H2-Recharge decline due to climate shifts
H3-Groundwater pumping
H4-Landuse change
H5-Ghyben-Herzberg principle
H6-Vegetative “damming” of the spring
H7-Surficial aquifer “damming” of the spring
Proposed flow decline mechanisms

H1-Springshed area decline
H2-Recharge decline due to climate shifts
H3-Groundwater pumping
H4-Landuse change
H5-Ghyben-Herzberg principle
H6-Vegetative “damming” of the spring
H7-Surficial aquifer “damming” of the spring
Proposed flow decline mechanisms

H1-Springshed area decline
H2-Recharge decline due to climate shifts
H3-Groundwater pumping
H4-Landuse change
H5-Ghyben-Herzberg principle
H6-Vegetative “damming” of the spring
H7-Surficial aquifer “damming” of the spring
Simultaneously Testing Multiple Hypotheses

Proposed flow decline mechanisms

H1-Springshed area decline
H2-Recharge decline due to climate shifts
H3-Groundwater pumping
H4-Landuse change
H5-Ghyben-Herzberg principle
H6-Vegetative “damming” of the spring
H7-Surficial aquifer “damming” of the spring
Proposed flow decline mechanisms

H1-Springshed area decline
H2-Recharge decline due to climate shifts
H3-Groundwater pumping
H4-Landuse change
H5-Ghyben-Herzberg principle
H6-Vegetative “damming” of the spring
H7-Surficial aquifer “damming” of the spring

Barlow, Paul M. (2003). Ground Water in Freshwater-Saltwater Environments of the Atlantic Coast. USGS. Retrieved on 2009-03-21. Figure B-1
Proposed flow decline mechanisms

H1-Springshed area decline
H2-Recharge decline due to climate shifts
H3-Groundwater pumping
H4-Landuse change
H5-Ghyben-Herzberg principle
H6-Vegetative “damming” of the spring
H7-Surficial aquifer “damming” of the spring
Simultaneously Testing Multiple Hypotheses

Proposed flow decline mechanisms

H1-Springshed area decline
H2-Recharge decline due to climate shifts
H3-Groundwater pumping
H4-Landuse change
H5-Ghyben-Herzberg principle
H6-Vegetative “damming” of the spring
H7-Surficial aquifer “damming” of the spring
Flow Decline Attribution

Calibrated model vs. Observed Data

10-year Average Spring Discharge (CMS)

Year

1940 1960 1980 2000
Flow Decline Attribution

Calibrated model vs. Observed Data

Stationary Climate
Calibrated model vs. *Observed Data*

*Stationary Climate*

*Stationary Springshed Area*
Calibrated model vs. **Observed Data**

- Stationary Climate
- Stationary Springshed Area
- Remove Groundwater Pumping
Flow Decline Attribution

Calibrated model vs. Observed Data
- Stationary Climate
- Stationary Springshed Area
- Remove Groundwater Pumping
- Stationary River Roughness

10-year Average Spring Discharge (CMS)

Year
1940 1960 1980 2000
Calibrated model vs. Observed Data

Stationary Climate

Stationary Springshed Area

Remove Groundwater Pumping

Stationary River Roughness

• 45% (3.2 m³/s) can likely be attributed to climate
• 30% (2.0 m³/s) can likely be attributed to springshed area changes
• 16% (1.1 m³/s) can likely be attributed to pumping
• 10% (0.7 m³/s) can likely be attributed to change roughness
Flow Decline Attribution

No Saltwater Interface

No Surficial Aquifer
Stage Discharge Relation
Flow decline mechanisms

H1-Springshed area decline
H2-Recharge decline due to climate shifts
H3-Groundwater pumping
H4-Landuse change
H5-Ghyben-Herzberg principle
H6-Vegetative “damming” of the spring
H7-Surficial aquifer “damming” of the spring

<table>
<thead>
<tr>
<th>Hypothesis</th>
<th>Dynamics likely occurring within groundwater system</th>
<th>Impacts long-term average spring flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1</td>
<td>Yes</td>
<td>Yes, directly</td>
</tr>
<tr>
<td>H2</td>
<td>Yes</td>
<td>Yes, directly</td>
</tr>
<tr>
<td>H3</td>
<td>Yes</td>
<td>Yes, directly</td>
</tr>
<tr>
<td>H4</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>H5</td>
<td>Yes</td>
<td>Yes, indirectly</td>
</tr>
<tr>
<td>H6</td>
<td>Yes</td>
<td>Yes, directly</td>
</tr>
<tr>
<td>H7</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>
Future of Flow in Silver Springs

**Current Trends Likely to Increase or Maintain Spring Flow**
1. Average rainfall appears to be in an increasing trend.
2. The springshed area is currently increasing in size.
3. The Manning’s roughness is currently declining.
4. The springshed appears to be entering a “humid phase”
5. The average evaporative ratio currently declining
6. The rate of groundwater pumping appears to have leveled off

**Current Trends Likely to Decrease Spring Flow**
1. Average PET appears to be in an increasing trend, which will likely continue with global climate change.
2. If groundwater pumping rates could increase with projected growing population.
3. Future increases in submerged aquatic vegetation cover, for example the expansion of the invasive *Hydrilla verticillate* could drive small flow declines by increasing Silver River and/or Ocklawaha River stage
Acknowledgements
Questions?