Dissertation

Improved Methodologies for Modeling Storage and Water Level Behavior in Wetlands

by

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Committee

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- Mark Rains, Ph.D. – Associate Professor, Geology
- Kenneth Trout, Ph.D. – Research Associate, CEE
Acknowledgements

- Terry Lee – US Geological Survey
- Doug Leeper – Southwest Florida Water Management District
- Michael Hancock – Southwest Florida Water Management District
Wetlands

- Important role in the hydrology watersheds

- Influence
  - Water storage
  - Surface water runoff
  - Groundwater recharge

From Lee et al. (2009)
Wetlands – Regional Scale

- Hundreds or thousands of wetlands in a region or study area
  - 20% Land surface in SWFWMD
  - 29% Florida (Lee et al. 2009)
Hydrologic Modeling Implications

- Without reasonable wetland
  - Hydraulic information
  - Storage information

- Hydrologic models may produce inaccurate estimates
  - Stream flows
  - Groundwater recharge
  - Flood plain delineation
  - Wetland sustainability

- May not accurately represent or predict the system water balance
Accurate Hydrologic Models

- Water resource engineers and hydrologists

Better define:

- Surface and subsurface water level fluctuations associated with wetlands
- Movement of water into and out of wetlands
- Surface and subsurface water storage of wetlands

- All wetlands in a hydrologic study area
Problem – Limited or No Hydrologic Data

- Wetland surface water storage data
  - Detailed bathymetry maps
  - Developed from extensive surveys

- Wetland surface water and groundwater elevation data
  - Collected using monitoring wells
    - Within the wetland extents
    - Surrounding uplands

- Largely determined
  - With a guess
  - Through model calibration
How can we REASONABLY quantify the cumulative effect wetlands have on a:

- Watershed
- Hydrologic region (e.g. west-central Florida)

Use in large hydrologic models
- Tampa Bay Water
- Integrated Hydrologic Model
Dissertation Contributions

1) New Wetland and Lake Storage Model
   - Describe above bed storage characteristics

2) New Insight into Wetland Water-Level Behavior
   - Probabilistic Analysis (Frequency Analysis)
   - Characterize wetland water-level fluctuations

3) New Insight on Wetland Groundwater Recharge Characteristics
   - Probabilistic Analysis (Frequency Analysis)
Wetland and Lake Stage-Storage Model

Wetland Stage-Storage Characteristics

General Model Development and Evaluation
Wetland Bathymetry Data Sets

**Development data set**

- West-central Florida
  - 5 Cypress
  - 5 Marsh
  - 17 Lakes
- North Dakota
  - 10 pothole
- Saskatchewan, Canada
  - 10 pothole

<table>
<thead>
<tr>
<th>Statistic</th>
<th>$A_o$ (x10^3 m^2)</th>
<th>$h_o$ (m)</th>
<th>$V_o$ (x10^3 m^3)</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
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<td>StD</td>
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<td>190</td>
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<tr>
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<th>$h_o$ (m)</th>
<th>$V_o$ (x10^3 m^3)</th>
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<td>13,665</td>
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<tr>
<td>Max</td>
<td>14,700</td>
<td>18.0</td>
<td>106,000</td>
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</table>

**Validation data set**

- 21 Lakes in west-central Florida
- Independent
Method - Wetland Stage-Storage Model

- Stage-storage Model*
  - Power-function
  - Used to predict wetland storage
  - Absence of survey data
  - **Assumption**: Circular Paraboloids

- New fitting “shape” parameter \( (m) \)
  - Describing stage-storage behavior
  - Developed using a iterative process

- Shape parameters
  - Developed for specific wetlands
  - General parameters
    - Multiple wetlands
    - Various wetland groups

\[
V(h) = \left( \frac{A_o h_o}{m} \right) \left( \frac{h}{h_o} \right)^m
\]

- \( V(h) \) = pool volume @ stage \( h \)
- \( A_o \) = Maximum pool area
- \( h_o \) = Maximum pool depth

*(Nilsson et al. 2008)

\[
V = \frac{1}{2} \pi r_o^2 h
\]
Wetland GIS Extents and Bathymetry Survey Locations

GIS Wetland Extents

Stage-Storage Profile

Volume (m$^3$)

h (m)
Results – Specific Model Shape Parameters ($m$)

- Individual wetland parameters
  - 1.3 – Pothole
  - 5.1 – Lake
Results – Optimal General Model Storage Parameters / Errors

- **Category parameters**
  - 2.7 – Cypress
  - 2.5 – Marsh
  - 2.0 – Pothole (Canada)
  - 1.5 – Pothole (N.D.)
  - 2.5 – Lake
  - **2.3 – All Wetlands and Lakes**

- **Category volumetric errors**
  - 46% - Cypress
  - 32% - Marsh
  - 12% - Pothole (Canada)
  - 15% – Pothole (N.D.)
  - 42% - Lakes
  - **46.4% - All wetlands and lakes**

\[ V_{ARE} = \frac{1}{k} \sum_{i=1}^{k} \left[ \text{ABS} \left( \frac{(V_{Vh})_i - (V_{GIS})_i}{(V_{GIS})_i} \right) \right] \times 100\% \]
Results – Model Representations

a) Cypress Wetland (W05)

Gen Err = 170%

b) St. Denis Wetland (S92)

Gen Err = 12%

c) Pothole Wetland (P7)

Gen Err = 52%

d) Lake (Calm)

Gen Err = 36%

\[
V_{ARE} = \frac{1}{k} \sum_{i=1}^{k} \left[ ABS \left( \frac{(V_{h})_i - (V_{GIS})_i}{(V_{GIS})_i} \right) \right] \times 100\%
\]
Results – Validation Data Set Storage Errors

- Validation data set
  - Independent data set
  - 21 Lakes in west-central Florida

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Lake Characteristics</th>
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<td>$A_o$ x10^3 m^2</td>
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<tr>
<td>Mean</td>
<td>107</td>
</tr>
<tr>
<td>StD</td>
<td>91.6</td>
</tr>
<tr>
<td>Min</td>
<td>9.41</td>
</tr>
<tr>
<td>Max</td>
<td>332</td>
</tr>
</tbody>
</table>

\[
V(h) = \left( \frac{A_o h_o}{m} \right) \left( \frac{h}{h_o} \right)^m
\]

\[
h(V) = \left( h_o \right)^{\left( \frac{1}{m} \right)} \left[ \frac{V}{\left( \frac{A_o h_o}{m} \right)} \right]
\]

- Storage errors
  - $m = 2.3$ Mean Error = 47.2%
  - $m = 2.5$ Mean Error = 38.0%

- Stage errors
  - $m = 2.3$ Mean Error = 14.6%
  - $m = 2.5$ Mean Error = 13.2%
Wetland Water Level Frequency Analysis

Empirical and Analytical Distribution Functions

Wetland Water Level (hydroperiod) Characterization

Groundwater Recharge Characteristics
Wetland Water Elevation Data Sets

- Southwest Florida Water Management District (SWFWMD)

- Long-term water elevation data
  - Collected over seven years
  - Paired wetland monitoring wells
    - Wetland well – surface and subsurface water levels
    - Upland well – groundwater levels

- 56 Isolated wetlands in the northern Tampa Bay Region
  - 36 Cypress
  - 9 Marsh
  - 5 Cypress-marsh
  - 3 Hardwood
  - 3 Wet prairie
Physiographic regions are broad-scale subdivisions based on terrain texture, rock type, and geologic structure and history.
### Wetland Characteristics

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Regional Wetlands</th>
<th>Cypress</th>
<th>Marsh</th>
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</thead>
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<tr>
<td></td>
<td>$A \times 10^3 \text{ m}^2$</td>
<td>$P \times 10^2 \text{ m}$</td>
<td>$h_o \text{ (cm)}$</td>
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<tr>
<td>Mean</td>
<td>51.7</td>
<td>9.3</td>
<td>76.1</td>
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<tr>
<td>Min</td>
<td>1.1</td>
<td>1.5</td>
<td>36.0</td>
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<tr>
<td>Max</td>
<td>392.9</td>
<td>50.4</td>
<td>250.2</td>
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<table>
<thead>
<tr>
<th>Statistic</th>
<th>Cypress-Marsh</th>
<th>Hardwood</th>
<th>Wet Prairie</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$A \times 10^3 \text{ m}^2$</td>
<td>$P \times 10^2 \text{ m}$</td>
<td>$h_o \text{ (cm)}$</td>
</tr>
<tr>
<td>Mean</td>
<td>40.0</td>
<td>8.6</td>
<td>138.8</td>
</tr>
<tr>
<td>Min</td>
<td>15.5</td>
<td>4.6</td>
<td>74.7</td>
</tr>
<tr>
<td>Max</td>
<td>59.7</td>
<td>14.8</td>
<td>250.2</td>
</tr>
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</table>
SWFWMD well and staff gauge locations
Empirical Distribution Functions (EDFs)

- Developed
  - Wetland surface and subsurface water elevation data
  - Upland groundwater elevation data

- Identify respective wetland hydrologic behavior
  - Periods of inundation and dry conditions
  - Periods of groundwater recharge
Empirical Distribution Functions (EDFs)

- Discrete step function
  - \( f_s(p_m) \) is the relative frequency
  - \( x \) is an observation

- Relative frequency (\( p_m \))
  - Point estimate of exceedance probability
  - \( m \) is the rank
  - \( N \) is the sample size

\[
F_s(p_x) = \sum_{m=1}^{x} f_s(p_m)
\]

\[
p_m = \frac{m}{(N + 1)}
\]
Results – Empirical Distribution Functions

Chart A - Wetland EDFs

Chart B - Upland EDFs

Chart C - Wetland EDF Trends

Chart D - Upland EDF Trends
Application – Impacted Wetland Identification

- Waste water treatment plant
- Spray field
- Artificially raise the water-table

Greatly depressed water levels
Falling cypress tress
Application – Cypress-Marsh Wetland
Application – Impacted Wetland Identification

- Waste water treatment plant
- Spray field
- Artificially raise the water-table

Greatly depressed water levels
Falling cypress tress
Application – Cypress Wetland
Application – Impacted Wetland Locations

EDF Outliers

11 High
9 Low

WellFields
GreenSwamp
LAKE UPLAND
NORTHERN GULF COASTAL LOWLANDS
WESTERN VALLEY

Impacted Wetlands
- High EDF
- Low EDF

Kilometers

CROSS BAR RANCH
STARKEY
SOUTH PASCO
ELDRIDGE WILDE
MORRIS BRIDGE
HILLSBOROUGH
POLK
SUMTER
HERNANDO
PASCO
PINELLAS
### Results – Dry Bed and Normal Pool Index (Relative Frequency)

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Regional Wetlands</th>
<th>Cypress Marsh</th>
<th>Hardwood</th>
<th>Wet Prairie</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>F(DB)</td>
<td>F(NP)</td>
<td>$h_0$ (cm)</td>
<td>F(DB)</td>
</tr>
<tr>
<td>Mean</td>
<td>0.39</td>
<td>0.96</td>
<td>74.4</td>
<td>0.38</td>
</tr>
<tr>
<td>Min</td>
<td>0.02</td>
<td>0.76</td>
<td>36.0</td>
<td>0.02</td>
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<tr>
<td>Max</td>
<td>0.86</td>
<td>0.99</td>
<td>250.2</td>
<td>0.86</td>
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**Cypress-Marsh**

<table>
<thead>
<tr>
<th>Statistic</th>
<th>F(DB)</th>
<th>F(NP)</th>
<th>$h_0$ (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>0.35</td>
<td>0.99</td>
<td>131.4</td>
</tr>
<tr>
<td>Min</td>
<td>0.05</td>
<td>0.98</td>
<td>62.2</td>
</tr>
<tr>
<td>Max</td>
<td>0.64</td>
<td>0.99</td>
<td>250.2</td>
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</table>

**Hardwood**

<table>
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<tr>
<th>Statistic</th>
<th>F(DB)</th>
<th>F(NP)</th>
<th>$h_0$ (cm)</th>
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<tbody>
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<td>Mean</td>
<td>0.36</td>
<td>0.95</td>
<td>87.4</td>
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<td>Min</td>
<td>0.23</td>
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<tr>
<td>Max</td>
<td>0.45</td>
<td>0.99</td>
<td>104.5</td>
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**Wet Prairie**

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<th>F(DB)</th>
<th>F(NP)</th>
<th>$h_0$ (cm)</th>
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<tr>
<td>Mean</td>
<td>0.70</td>
<td>0.97</td>
<td>56.1</td>
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<tr>
<td>Min</td>
<td>0.49</td>
<td>0.95</td>
<td>37.2</td>
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<tr>
<td>Max</td>
<td>0.85</td>
<td>0.99</td>
<td>85.3</td>
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**Image:**

- **UIDSite 183 - Marsh Isolated:**
  - Staff Gauge
  - Wetland Well
  - Upland Well

(A) Streamflow and wetland interaction diagram.
Recharge Characteristics
Groundwater Recharge Characteristics

- Head difference ($dH$)
  - Wetland water elevations, $W(h)$
  - Upland groundwater elevations, $U(h)$

- Matched water elevation records
  - Based on collection date, $t$
    - Entire data record (7 years)
    - Seasonal records
      - Peak wet season (March – May)
      - Peak dry season (July – September)
      - Extreme water-table elevations

$$ (dH)_t = W(h)_t - U(h)_t $$
Temporal Data

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<thead>
<tr>
<th>Statistic</th>
<th>Separation Distance (m)</th>
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<td>Range</td>
<td>142</td>
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Recharge Conditions, F(dH = 0)

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<th>Mean</th>
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<tbody>
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<td>All</td>
<td>59%</td>
<td>62%</td>
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<tr>
<td>Dry</td>
<td>61%</td>
<td>66%</td>
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<tr>
<td>Wet</td>
<td>47%</td>
<td>47%</td>
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Summary and Conclusions
Conclusions – New Wetland and Lake Storage Model

- Describe above bed storage characteristics of wetlands

Analytical method
- 2 physical parameters ($A_o$ and $h_o$)
- A single wetland shape parameter
- Describe the storage characteristics of wetlands and lakes
- Acceptable and quantifiable errors

Storage model has good predictive capability
- Wetland categories
- Various groups of wetlands

Shape parameters
- Used as a calibration factor in hydrologic models

Reduced cost in surveying wetlands by obtaining
- $A_o$ from GIS databases
- $h_o$ from minimal wetland surveys
Conclusions – New Insight into Wetland Water Level Behavior

- Probabilistic Analysis (Frequency Analysis)
- Characterize wetland water-level fluctuations
  - Provide insights into interactions between wetland
    - Surface water levels
    - Groundwater levels
- Identify the specific water level indices and general behavior
  - West-central Florida wetlands
  - Wetland types
  - Regional groups
  - 61% - Standing water present in wetlands
  - 4% - Normal pool markers exceeded
Conclusions – New Insight into Wetland Water Level Behavior

- Probabilistic Analysis (Frequency Analysis)

- Recharge features
  - 59% - Overall
  - 61% - Dry season
  - 47% - Wet season

- Check the calibration of hydrologic models

- Empirical distribution functions were used to
  - Identify potentially impacted wetlands
    - High water levels
    - Low water levels


Questions