Evaluating a Process-Based Mitigation Wetland Water Budget Model

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Overview

• Mitigation Failures
• Current Method of Mitigation Design
• Objectives
• Field Site
• Integrated Pierce Method Model
• MODFLOW-2005 model
• Results
• Conclusions
wetlands impacted or destroyed? mitigate!

- Mandated by law
- Must:
  - Restore
  - Create
  - Enhance
  - Preserve

hydrology + vegetation + soils = wetland
Incorrect water levels are the leading cause of failed mitigation wetlands

• South Florida Water District – 62.5% of projects exhibited hydrological problems

• Most significant project design problem identified – improper water levels

Erwin (1991)
currently, mitigation sites are designed to simplify the water budget by creating a perching system.
hydraulic resistance due to vegetation can influence water levels

In densely vegetated wetland systems, outflow is determined, all or in part, by hydraulic resistance due to vegetation

(Kadlec, 1990)
Overall project objectives...

1. Determine the accuracy of water level predictions by a Pierce water balance method model, and a process-based MODFLOW model

2. Evaluate seasonal effects in model performance

3. Determine the sensitivity of models to select input parameters
the modeling site...
Cedar Run Wetland Bank

Completed in October 2001 by Wetland Studies and Solutions Inc.
Prince William County, VA
Pre-mitigation
Post mitigation
water level data were collected in the southern cell via USACOE standard observation well installations
weather data were collected using an onsite weather station

- Daily precipitation
- Daily temperature
the water budget models...
The Integrated Pierce Method Model
The Integrated Pierce Method Model

- Curve Number
- Total Area
- Constructed Wetland Area
- Existing Wetland Area
- Average Depth to Weir
- Monthly Thornthwaite's PET
- Pond/Wetland Substrate Permeability
- Initial Fill Depth Assumption
- Infiltration Rate
- Precipitation Distribution
- Net Contributing Area
- Runoff Calculation (SCS CN)
- Monthly Rainfall Total
- Average Depth to Weir
- No
- Outflow Calculation (calculated water level - depth to weir)
- Output outflow depth
- Output Monthly Water Elevation
- Output Monthly Water Elevation (equal to depth of weir)
The Integrated Pierce Method Model

Water Level Calculation

Water Level > Depth to Weir

Outflow Calculation (calculated water level - depth to weir)

Yes

Output Outflow Depth

Output Monthly Water Elevation (equal to depth of weir)

No

Output Monthly Water Elevation
Evapotranspiration Package

Recharge Package (Precipitation)

MODFLOW-2005

Drain Return Package (Inter-cell flow)

Well Package (Inflow)
the wetland was represented as...

- Layer 1: Surface water
- Layer 2: Clay loam soil
- Unconfined aquifer
- Confined/unconfined aquifer

3-m grid size
the wetland was represented as…

- **Vegetation (20- x cm)**
- **Vegetation (10-20 cm)**
- **Surface / Vegetation (0-10 cm)**
- Sub-surface
vegetation conductivities were calculated from community collections and measurements of momentum absorbing area (maa)
### Hydraulic Conductivity, $k$

#### $K$ (m/s) Spring/Summer

<table>
<thead>
<tr>
<th>Zone</th>
<th>0-10 cm</th>
<th>10-20 cm</th>
<th>20-30 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone 1</td>
<td>2.67</td>
<td>2.55</td>
<td>2.40</td>
</tr>
<tr>
<td>Zone 2</td>
<td>1.49</td>
<td>1.50</td>
<td>1.42</td>
</tr>
<tr>
<td>Zone 3</td>
<td>2.26</td>
<td>2.22</td>
<td>2.22</td>
</tr>
</tbody>
</table>

#### $K$ (m/s) Fall/Winter

<table>
<thead>
<tr>
<th>Zone</th>
<th>0-10 cm</th>
<th>10-20 cm</th>
<th>20-30 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone 1</td>
<td>2.38</td>
<td>2.79</td>
<td>2.96</td>
</tr>
<tr>
<td>Zone 2</td>
<td>2.00</td>
<td>1.84</td>
<td>2.82</td>
</tr>
<tr>
<td>Zone 3</td>
<td>2.63</td>
<td>2.82</td>
<td>2.42</td>
</tr>
</tbody>
</table>
Integrated Perce Method (IPM)
Thornthwaite’s PET
Monthly Time Step

Integrated Perce Method with FAO P-M (IPM-FAO)
FAO Penman-Monteith Reference Crop PET
Monthly Time Step

MODFLOW-2005 (Modflow)
FAO Penman-Monteith Reference Crop PET
Daily Time Step
Uncalibrated
the modeling results...
annual error statistics

Integrated Pierce (Thornthwaite) 206% 25.7 cm 30.3 cm 1.34 -0.97
Integrated Pierce (FAO - 56 P - M) 181% 15.0 cm 18.9 cm 0.83 0.23
MODFLOW - 2005 151% 14.8 cm 16.4 cm 0.73 0.42

IPM, IPM-FAO, MODFLOW
<table>
<thead>
<tr>
<th>Model</th>
<th>Intercept</th>
<th>p-value</th>
<th>Slope</th>
<th>p-value</th>
<th>Relative Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrated Pierce (Thornthwaite’s)</td>
<td>2.28</td>
<td>0.51</td>
<td>0.22</td>
<td>0.03</td>
<td>38.39</td>
</tr>
<tr>
<td>Integrated Pierce (FAO-56 P-M)</td>
<td>-13.99</td>
<td>0.0005</td>
<td>0.95</td>
<td>1.8e-06</td>
<td>12.48</td>
</tr>
<tr>
<td>MODFLOW-2005</td>
<td>-3.95</td>
<td>0.47</td>
<td>0.42</td>
<td>2.7e-05</td>
<td>10.37</td>
</tr>
</tbody>
</table>
growing season error statistics
sensitivity analysis

### Water Levels from Changing ET

<table>
<thead>
<tr>
<th>Percent Change in Parameter</th>
<th>ET</th>
<th>k</th>
</tr>
</thead>
<tbody>
<tr>
<td>-75%</td>
<td>1.26</td>
<td>NC*</td>
</tr>
<tr>
<td>-50%</td>
<td>1.52</td>
<td>-0.001</td>
</tr>
<tr>
<td>-25%</td>
<td>2.32</td>
<td>NC*</td>
</tr>
<tr>
<td>-10%</td>
<td>5.18</td>
<td>-0.020</td>
</tr>
<tr>
<td>10%</td>
<td>-5.24</td>
<td>-0.017</td>
</tr>
<tr>
<td>25%</td>
<td>-2.07</td>
<td>-0.015</td>
</tr>
<tr>
<td>50%</td>
<td>-0.93</td>
<td>-0.034</td>
</tr>
<tr>
<td>75%</td>
<td>-0.61</td>
<td>NC*</td>
</tr>
</tbody>
</table>

*Indicates model non-convergence
revisiting the objectives…
MODFLOW-2005 most accurately predicted water levels on an annual basis.

Determine the accuracy of water level predictions by a Pierce water balance method model, and a process based MODFLOW model.

$\text{MAE} = 14.8 \text{ cm}$

$\text{NSE} = 0.42$
Seasonality affects modeling results. IPM-FAO most accurately predicted water levels during the growing season. Evaluate seasonal effects in model performance.

\[
\text{MAE} = 11.2 \text{ cm} \\
\text{NSE} = 0.48
\]

Poiani and Johnson (1993) – Calibrated predictions within 10 cm of observed 75% of time

Su and others (2000) – Calibrated wetland model, standard error = 19 cm
IPM-FAO and MODFLOW-2005 showed sensitivity to changes in ET. MODFLOW-2005 was not significantly sensitive to changes in $k$. As such, ET estimation methods need to be carefully chosen, calculated with site-specific data.
implications

> Results will guide future wetland water budget modeling, especially wetland mitigation related
  - ET critical for estimation
  - Improved pre-construction modeling will potentially increase mitigation success

> While IPM-FAO better seasonally, MODFLOW has advantages
  - Daily time step
  - Assess design variances (soils, topography)
future work

- Improved ET estimation
- Wetland Crop Coefficients
- $k$ calculation improvements for wetlands with higher veg. density
- Incorporation of local groundwater hydrology!
Questions?

Piedmont Wetlands Research Program

Thank you:
Tess Thompson, Cully Hession, Lee Daniels, Candice Piercy, Laura Teany, Karen Hall, Denton Yoder

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