New methods for wetland water budgeting: WetBud

Tess Wynn Thompson and W. Lee Daniels, Virginia Tech
Rich Whittlecar, Old Dominion University
Zach Agioutantis, Technical University of Crete

Students: Kerby Dobbs, Matt Gloe, John McLeod, Eric Neuhaus, O. Waverly Parks, Candice Piercy, Tracy Thornton, Cal Smith
Topics

1. Background
2. Initial Studies
3. WetBud Capabilities and Interface
4. Verification Studies
Wetlands provide habitat, improve water quality, control erosion, and store flood water.

Since the 1780’s, about 53% of all US wetlands have been lost.

(Dahl, 2000)

from Mitch and Gosselink, 1993
Wetland restoration and creation can help offset the effects of wetland loss.

South Florida Water District – 62.5% of projects exhibited hydrologic problems

Erwin (1991)

Many restored and created wetlands are too wet to effectively function

from Dahl, 2000 (US Fish and Wildlife)

Cole & Brooks (2000)
Piedmont Wetlands: the interface between uplands, groundwater, and surface water
A “simple” way to create a mitigation wetland is to create a perched system.
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The diagram illustrates the following components:
- Precipitation
- Evapotranspiration
- Inflow
- Outflow
- Groundwater

It is assumed that groundwater is negligible.
A “simple” way to create a mitigation wetland is to create a perched system. Can work on uplands with low permeability.
In most wetlands, Groundwater can seep IN and OUT many places

Ignore GW? the wetland can be “too wet”
Hydraulic resistance due to vegetation is typically ignored

(Kadlec, 1990)
Hydraulic resistance due to vegetation is typically ignored

In designed wetland systems, Outflow is determined, all or in part, by hydraulic resistance due to vegetation

(Kadlec, 1990)
Wetland Water Budget Modeling

- Document known water budget methodologies;
- Document existing design and construction issues;
- Assess existing software and individual process models;
Modflow was tested as a possible tool to model wetlands

*Field study conducted by W. Cully Hession and Andrea Ludwig*
Wetland was modeled in MODFLOW as a two-layer aquifer system.

Layer 1: Surface water
Unconfined aquifer

Layer 2: Clay loam soil
Confined/Unconfined aquifer

Error ranged from -4.3 cm to 1.4 cm with a mean error of -1.1 cm.

- close to the survey and digitization error
Modflow was also tested as a possible tool to model wetlands at Cedar Run 3 Wetland Bank
Water level data were collected in the southern cell via USACOE standard observation well installations.
the wetland was represented as...

- Vegetation (20-x cm)
- Vegetation (10-20 cm)
- Surface / Vegetation (0-10 cm)
- Sub-surface
The Pierce model with FAO-Penman ET and Modflow performed best.
Wetland Water Budget Modeling

- Document known water budget methodologies;
- Document existing design and construction issues;
- Assess existing software and individual process models;
- Develop a library of historic rainfall data;
- Classify each year as “dry,” “typical,” or “wet”;
- Develop model inputs based on Piedmont soil conditions;
- Provide additional model capability:
  1. Sloped wetlands
  2. Groundwater inputs
  3. Vegetation resistance
- Test model using data sets developed from two field sites;
Pierce’s model for depressional wetlands

- **SW\textsubscript{in}**
- **Ppt**
- **ET**
- **SW\textsubscript{out}**
- **Stream**
- **Soil Perm.**
- **GW\textsubscript{out}**
WetBud – Advanced Version

Setup for a Piedmont valley bottom mitigation site

Vegetation

Loose surface soil w/ added OM

Saprolite rotted bedrock

Outlet

Stream gravel

Compacted subsoil/berm
WetBud – Advanced Version

Setup for a Piedmont valley bottom mitigation site

Vegetation

Loose surface soil w/ added OM

Outlet

Saprolite rotted bedrock

Stream channel

Stream gravel

Compacted subsoil/ berm
WetBud - Advanced Version

Setup for a Piedmont valley bottom mitigation site

Vegetation

Wetland Substrate

Outlet

Saprolite rotted bedrock

Compacted subsoil/berm

Stream channel
Building WetBud Model(s)

1. Create Project and Scenario
   2. Build weather data
   3. Determine WND years w/ WETS tables
   4. User determines inputs and outputs
      1. Calculate ET for WDN years (Thornthwaite, Penman)
      2. Calculate $SW_{in}$ using Curve Numbers
      3. Input $GW_{in}$ or calculate using $W_{em}$ (well data)
      4. Input or calculate $Gw_{out}$
      5. Input or calculate overbank flow
Create Project and Scenario

Basic

Project Scenarios

General | Watershed Data | Inputs and Outputs | PET Options | Management | Periods | Advanced Model

Code
SW_Thorn

Description
15

Custom Range

Elevation
183

Latitude
36.6

Longitude
-77.55

Nearest Weather Station (Airport)
TW4036

Analysis Options:
- Simple Solution (fast)
- Advanced Solution (Modflow)
- Both

Specify Analysis Range:
- Use Custom Range (mm/yy/yy)

From 1995-mm
To 1996-mm

2009-01
2012-05

Comment:
Create Project and Scenario

Advanced
Building WetBud Model(s)

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   5. Input or calculate overbank flow
Build weather data
Building WetBud Model(s)

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Determine WND years w/ WETS tables:

#1: Which years have WET (or DRY or NORM) total ppt?

30-yr record of annual precipitation

<table>
<thead>
<tr>
<th>1980</th>
<th>2010</th>
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</thead>
</table>
Determine WND years w/ WETS tables:

#1: Which years have WET (or DRY or NORM) total ppt?

30-yr record of annual precipitation

<table>
<thead>
<tr>
<th>Year</th>
<th>DRY Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>29.32, 29.62, 29.95, 30.67, 31.74, 32.57, 33.82, 34.99, 35.77, 35.84, 35.94, 35.96, 36.16, 36.38, 36.63, 37.57, 37.73, 38.07, 39.57, 39.80, 40.23, 40.60, 40.84, 41.41, 46.02, 47.33, 50.32, 50.50, 51.02, 51.89, 51.97</td>
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<table>
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<th>Year</th>
<th>NORM Values</th>
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</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>WET Values</th>
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</thead>
<tbody>
<tr>
<td>1980</td>
<td>30.67, 31.74, 32.57, 33.82, 34.99, 35.77, 35.84, 35.94, 35.96, 36.16, 36.38, 36.63, 37.57, 37.73, 38.07, 39.57, 39.80, 40.23, 40.60, 40.84, 41.41, 46.02, 47.33, 50.32, 50.50, 51.02, 51.89, 51.97</td>
</tr>
</tbody>
</table>

Rank order annual ppt. values

Make splits with WETS Table Statistics
Determine WND years w/ WETS tables:

#1: Which years have WET (or DRY or NORM) total ppt?

30-yr record of annual precipitation

Select the median value in each split

- **Dry**: 1988
  - 35.33"

- **Normal**: 1994
  - 42.04"

- **Wet**: 1975
  - 50.50"
Determine WND years w/ WETS tables:

#2: Did 1975 have a WET "spring"?

2

Do a WETS analysis for each Spring month

<table>
<thead>
<tr>
<th>D</th>
<th>J</th>
<th>F</th>
<th>M</th>
<th>A</th>
<th>M</th>
<th>J</th>
<th>.......</th>
</tr>
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<tbody>
<tr>
<td>N</td>
<td>D</td>
<td>W</td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>2</td>
<td>1</td>
<td>3</td>
<td></td>
<td></td>
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<tr>
<td>x1</td>
<td>x2</td>
<td>x3</td>
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<tr>
<td>2+2+9=</td>
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<td></td>
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<td></td>
<td></td>
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</tbody>
</table>

(6 to 18)
Determine WND years w/ WETS tables:

#2: Did 1975 have a WET “spring”?

\[2 + 2\]

Do a WETS analysis for each Spring month.
Determine WND years w/ WETS tables:

#2: Did 1975 have a WET “spring”?

2   +2   +3

<table>
<thead>
<tr>
<th>D</th>
<th>J</th>
<th>F</th>
<th>M</th>
<th>A</th>
<th>M</th>
<th>J</th>
<th>......</th>
</tr>
</thead>
</table>

Do a WETS analysis for each Spring month

\[
\begin{array}{ccc}
\# & \# & \# \\
W & N & W \\
3 & 2 & 3 \\
x_1 & x_2 & x_3 \\
3+4+9 &= 16 \\
3+4+9 &= 16 \\
(6 \text{ to } 18)
\end{array}
\]
Determine WND years w/ WETS tables:

#2: Did 1975 have a WET “spring”?

2  +2  +3  +3

Do a WETS analysis for each Spring month

(6 to 18)
Determine WND years w/ WETS tables:

#2: Did 1975 have a WET “spring”?

2 + 2 + 3 + 3 = 10

Score determines if Spring is WND

4-6 : DRY
7-9 : NORM
10-12: WET
Determine WND years w/ WETS tables:

#2: Did 1975 have a WET “spring”?

2 +2 +3 +2 = 10

D J F M A M J ......
N N W W

Score determines if Spring is WND

4-6 : DRY
7-9 : NORM
10-12: WET

A Year is WET if both the Spring and the Annual Precipitation are both WET
Determine WND years
Building WetBud Model(s)

1. Create Project and Scenario
2. Build weather data
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4. User determines inputs and outputs

1. Calculate ET for WDN years
   (Thornthwaite, Penman)
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Calculate ET for WND years
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\[ GW_{in} = K \ A \ \Delta h/\Delta x \]

(for Month B)

Water level in aquifer estimated by \( W_{em} \) calc’ns

\( \Delta h/\Delta x \)

Ground level at toeslope

A: cross-section of uphill end
$W_{em} = \text{“Effective Monthly Recharge”}$

$W_{mo} = \text{“Monthly Recharge”} = Ppt_{mo} - ET_{mo}$
Effective Monthly Recharge: $W_{em}$

A time-weighted average recharge value

$$W_{em} = \sum_{a=1}^{n} W_{mo} \times d^a - 1$$

- $W_{em}$: Effective Monthly Recharge
- $n$: # preceding months
- $W_{mo}$: Each month’s recharge (Ppt - ET)
- $d^a$: Response-decay factor (<1.0)
To predict the water table in Month A, how many month’s $W$ must you use?

$n = 6$

$W + W + W + W + W + W = W_{em}$
How much influence do past months have on water levels in Month A?

\[ W + W + W + W + W + W + W = W_{em} \]

\[ W + W + W + W + W + W + W = W_{em} \]

\[ d = 0.99 \]

\[ d = 0.85 \]
How much influence do past months have on water levels in Month A?

\[
\text{J} \quad \text{J} \quad \text{A} \quad \text{S} \quad \text{O} \quad \text{N} \quad \text{D} \quad \text{J}
\]

\[
d = 0.99 \quad W + W + W + W + W + W + W = W_{em}
\]

\[
d = 0.85 \quad W + W + W + W + W + W + W = W_{em}
\]

Must run every combination of \( n \) and \( d \) to find the best for prediction.
Matrix of correlation coefficients ($R^2$)

<table>
<thead>
<tr>
<th>n: # of antecedent months</th>
<th>0.99</th>
<th>0.9</th>
<th>0.85</th>
<th>0.8</th>
<th>0.7</th>
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<td>0.1135</td>
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<td>0.5405</td>
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</tr>
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</table>
$W_{em}$ vs Measured Head (2003-2005)

Filtered well data
(effects of recent rain removed)

$n = 18$, $d = 0.90$, $l = 0.25$

$R^2 = 0.87$
Verification of $W_{em}$ Calculations


- USGS Well Record
- Estimated by $W_{em}$ Model

Monthly Head (ft)


Calibration Period
\[ W_{em} = \text{“Effective Monthly Recharge”} \]

\[ W_{mo} = \text{“Monthly Recharge”} = Ppt_{mo} - ET_{mo} \]

Must have at least 6 months of water level measurements from a well just uphill of site.
\[ W_{em} = \text{“Effective Monthly Recharge”} \]
\[ W_{mo} = \text{“Monthly Recharge”} = Ppt_{mo} - ET_{mo} \]

Must have at least 6 months of water level measurements from a well just uphill of site

Can reconstruct GW levels using weather data for times with no well data
Input $GW_{in}$ or calculate using $W_{em}$
Building WetBud Model(s)

1. Create Project and Scenario
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   3. Input $GW_{in}$ or calculate using $W_{em}$ (well data)
5. Input or calculate $GW_{out}$
6. Input or calculate overbank flow
GW_{out} = K A \frac{\Delta h}{\Delta x} \quad (for\ Month\ B)

Water level at end of Month A

Water level below outlet

A: cross-section of downhill end
Input or calculate $GW_{out}$
WetBud is being tested at four sites

Cedar Run 3 Wetland Bank
completed in October 2001 by WSSI
Bender Farms Wetland Bank
completed by Acorn Environ
Pocahontas State Park
natural toeslope-floodplain wetland
Powhatan WMA
natural toeslope-terrace wetland
WetBud is being tested at four sites

Cedar Run 3 Wetland Bank
completed in October 2001 by WSSI

Bender Farms Wetland Bank
completed by Acom Environ

Pocahontas State Park
natural toeslope-floodplain wetland

Powhatan WMA
natural toeslope-terrace wetland
Cross-section of Pocahontas State Park study site

Vertical black bars indicate locations and approximate depths of boreholes used for stratigraphic correlations. Dashed lines represent inferred contacts.

Granitic saprolite
Medium-fine sand
Dense, sandy clay
Micaceous clayey sand
Sandy loam
Fibrous muck
Silty clay loam
Coarse sand
Coarse sand and gravel

VE = ~ 4x

- Kerby Dobbs 2013
Basic Model output: toe-slope water level

Pocahontas State Park study site

Addition of GW_{in} to WetBud

Basic Model improved prediction

- Observed
- Predicted
- Predicted (No groundwater)

- Kerby Dobbs 2013
WetBud is being tested at four sites

Cedar Run 3 Wetland Bank
completed in October 2001 by WSSI
Bender Farms Wetland Bank
completed by Acom Environ
Pocahontas State Park
natural toeslope-floodplain wetland
Powhatan WMA
natural toeslope-terrace wetland
Basic Model output: toe-slope water level

Powhatan WMA study site

Addition of GW_{in} to WetBud
Basic Model improved prediction

- Observed
- Predicted
- Predicted (No groundwater)

- Kerby Dobbs 2013
Cedar Run 3
Basic Model Results

Cedar Run 3 SW Basic Model Results

Average Monthly Well Data
Penman Basic Model Results
Thornthwaite Basic Model Results
Ongoing Work

- Fully integrating Wem
- Overbank flow routines
- Advanced model wizard
- Completing testing (5 sites)
- Developing output for use in wetland hydrologic assessments;
- Developing an instruction manual;
- Developing training materials and workshops