Development and Evaluation of SWATDRAIN Model for Simulating Hydrology of Agricultural Tile-Drained Watersheds

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Shiv Prasher, Ali Madani, Ramesh Rudra, Mohamed Youssef
Outline

- Introduction
- Objectives
- SWATDRAIN model
- Model evaluation
  - Completely tile-drained watershed
  - Partially tile-drained watershed
- Scenario analysis – controlled drainage on watershed basis
- Conclusions
SWATDRAIN

- **SWAT**
  - Surface flow
  - Subsurface flow
  - Water table depth

- **Modified SWAT** - includes tile drainage
  - Hoogoudt and Kirkham approaches
    - Volume drained and WTD relationship

- **DRAINMOD**
  - Subsurface flow
  - Surface runoff due to different land use practices

- **DRAINMOD into SWAT** – A WINNING PROPOSITION
Objectives

 Overall goal:
  • Modify SWAT to simulate hydrology and water quality of agricultural tile-drained watersheds

 Specific objectives:
  • SWATDRAIN – incorporate DRAINMOD into SWAT
  • Evaluate SWATDRAIN for fully tile-drained and partially tile-drained watersheds
  • Apply SWATDRAIN to assess impact of controlled drainage systems on watershed hydrology
Model Development
Incorporating DRAINMOD into SWAT
Overall Modeling Approach

DRAINMOD hydrology was fully incorporated into SWAT
Preparing inputs for SWATDRAIN

Weather data
- Precipitation
- Max temperature
- Min Temperature

Crop
- Landuse map

Soil
- Soil map

Subsurface drainage system parameters
- Depth, spacing, drainage coefficient..

A full set of SWATDRAIN input files for each HRU in the watershed is generated.

Update variables in SWAT using the computed values from DRAINMOD
Preparing inputs for SWATDRAIN

Evapotranspiration
- Penman-Monteith
- Pristly Taylor
- Hargreaves

Infiltration and runoff
- Green Ampt
- Curve number

Continue SWAT Simulation

Yes

Start DRAINMOD

Replace surface hydrology parameters of DRAINMOD with calculated values from SWAT

DRAINMOD simulation for drained HRUs

Update variables in SWAT using the computed values from DRAINMOD

No

Start SWAT Simulation
Subsurface hydrology
- Tile drainage outflow
- Water table depth
- Soil water content

- Preparing inputs for SWATDRAIN
  - SWAT Simulation
    - Daily Loop
      - Last day?
        - Yes
        - HRU Loop
          - Drained HRU?
            - Yes
              - Start DRAINMOD
                - Replace surface hydrology parameters of DRAINMOD with calculated values from SWAT
                  - DRAINMOD simulation for drained HRUs
                    - Last HRU?
                      - No
                      - Update variables in SWAT using the computed values from DRAINMOD
                        - End
                      - Yes
                        - Continue SWAT Simulation

- Development of SWATDARIN
## Options in SWATDRAIN

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Tile drainage</th>
<th>Water table depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>SWATDRAIN</td>
<td>ITDRN=2, DRAINMOD ✓</td>
<td>IWTDN=2, DRAINMOD ✓</td>
</tr>
<tr>
<td>SWAT (Original)</td>
<td>ITDRN=0</td>
<td>IWTDN=0</td>
</tr>
<tr>
<td>SWAT (Modified)</td>
<td>ITDRN=1, incorporates Kirkham and Hooghoudt tile drainage equations</td>
<td>IWTDN=1, drainage volume converted into WTD using a variable water table factor</td>
</tr>
</tbody>
</table>
Model Evaluation

Green Belt (fully tile-drained watershed)
Canagagique Creek (partially tile-drained watershed)
Evaluation of SWATDRAIN - Green Belt

- Green Belt Watershed
  - Area: 14 ha
  - Topography
  - Loam to silty clay
  - Corn

- Tile drainage systems
  (laterals: 15 m apart and 1 m depth)
Daily Water Table Depth

Note:
PCP: precipitation;
WTD: water table depth;
(1): WTD at the bottom of the well;
(2): missing data
## Water Table Depth - Daily and Monthly

### Daily WTD calibration and validation statistics comparing measured and simulated data

<table>
<thead>
<tr>
<th>Index</th>
<th>Calibration</th>
<th>Validation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SWAT (original)</td>
<td>SWAT (Modified)</td>
</tr>
<tr>
<td>R²</td>
<td>0.44</td>
<td>0.57</td>
</tr>
<tr>
<td>NSE</td>
<td>0.42</td>
<td>0.41</td>
</tr>
</tbody>
</table>

### Monthly WTD calibration and validation statistics comparing measured and simulated data

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</thead>
<tbody>
<tr>
<td></td>
<td>SWAT (Original)</td>
<td>SWAT (Modified)</td>
</tr>
<tr>
<td>R²</td>
<td>0.24</td>
<td>0.49</td>
</tr>
<tr>
<td>PBIAS</td>
<td>11.03</td>
<td>-18.92</td>
</tr>
<tr>
<td>NSE</td>
<td>0.48</td>
<td>0.35</td>
</tr>
</tbody>
</table>
Daily Tile Drainage Outflow

Note:
PCP: precipitation;
TileQ: Tile drainage outflow
## Tile Drainage Outflow Statistics – Daily and Monthly

### Daily tile flow calibration and validation statistics comparing measured and simulated data

<table>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SWAT (original)</td>
<td>SWAT (Modified)</td>
</tr>
<tr>
<td>R²</td>
<td>0.35</td>
<td>0.44</td>
</tr>
<tr>
<td>PBIAS</td>
<td>3.53</td>
<td>14.15</td>
</tr>
<tr>
<td>NSE</td>
<td>0.35</td>
<td>0.42</td>
</tr>
</tbody>
</table>

### Monthly tile flow calibration and validation statistics of the measured and simulated data

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<tr>
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<th>Calibration</th>
<th>Validation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SWAT (original)</td>
<td>SWAT (Modified)</td>
</tr>
<tr>
<td>R²</td>
<td>0.75</td>
<td>0.80</td>
</tr>
<tr>
<td>PBIAS</td>
<td>12.34</td>
<td>1.44</td>
</tr>
<tr>
<td>NSE</td>
<td>0.65</td>
<td>0.69</td>
</tr>
</tbody>
</table>
Canagagigue Creek Watershed

- West Canagagigue Creek
- Area: 18 Km²
- Topography
- Land use: agriculture
- Soil: loam or clay loam
- Tile drainage systems (laterals: 20 m apart and 1m depth)
Streamflow

<table>
<thead>
<tr>
<th>Index</th>
<th>Daily Calibration</th>
<th>Daily Validation</th>
<th>Monthly Calibration</th>
<th>Monthly Validation</th>
</tr>
</thead>
<tbody>
<tr>
<td>R²</td>
<td>0.74</td>
<td>0.62</td>
<td>0.93</td>
<td>0.75</td>
</tr>
<tr>
<td>PBIAS</td>
<td>1.60</td>
<td>17.90</td>
<td>7.30</td>
<td>18.60</td>
</tr>
<tr>
<td>NSE</td>
<td>0.72</td>
<td>0.63</td>
<td>0.92</td>
<td>0.73</td>
</tr>
</tbody>
</table>
Application of SWATDRAIN

Simulate Effect of Controlled Drainage on Watershed hydrology
Controlled Drainage Scenario

- Fully tile-drained Green Belt watershed
- Growing season (June 15th to August 15th)
- Winter period (November 1st to May 1st)
Controlled Drainage Impacts
Controlled Drainage Impacts

![Graph showing water table depth and precipitation over time. The graph includes data for PCP, WTD-CNVL, and WTD-CTRL.]
### Effect of Controlled Drainage on Watershed Hydrology

#### Water Management Scenario – Controlled Drainage

<table>
<thead>
<tr>
<th>Year</th>
<th>Conventional Tile flow (mm)</th>
<th>Conventional Surface runoff (mm)</th>
<th>Controlled Tile flow (mm)</th>
<th>Controlled Surface runoff (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>142.2</td>
<td>31.6</td>
<td>136.5</td>
<td>33.4</td>
</tr>
<tr>
<td>2005</td>
<td>205.4</td>
<td>64.7</td>
<td>176.1</td>
<td>83.7</td>
</tr>
<tr>
<td>2006</td>
<td>385.4</td>
<td>89.7</td>
<td>324.5</td>
<td>139.7</td>
</tr>
<tr>
<td>2007</td>
<td>276.3</td>
<td>40.97</td>
<td>249.7</td>
<td>39.5</td>
</tr>
<tr>
<td>Average</td>
<td>252.3</td>
<td>56.7</td>
<td>221.7</td>
<td>74.1</td>
</tr>
</tbody>
</table>

Note: CNVL: conventional; CTRL: controlled; SurQ: surface runoff; TileQ: tile drainage
Conclusions

- SWATDRAIN fully incorporates DRAINMOD hydrology into SWAT in order to improve latter’s capability to predict subsurface hydrology of agricultural tile-drained watersheds.

- The model appears to do a better prediction of drain outflows and water table dynamics on a watershed scale.

- The model works for both fully drained and partially drained watersheds.
Conclusions

- SWATDRAIN can simulate controlled drainage scenario on a watershed scale.

- Implementing the controlled drainage strategy resulted in a reduction of the average annual drain outflow by 18%, while it increased the surface runoff in the order of 30%.

- Next step is to investigate how improved subsurface hydrology would affect chemical pollution on a watershed scale.
Thank You!