Comparison of Flow Calibration Using NEXRAD and Surface Rain Gauge Data in ArcSWAT

Presenter:
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Location

Choptank River Watershed

- Basin Boundary
- Landuse:
  - Agriculture: 1070 km² or 52%
  - Developed: 96 km² or 5%
  - Feedlots: 11 km² or 1%
  - Forest: 542 km² or 25%
  - Wetlands: 39 km² or 2%
  - Water: 300 km² or 15%

N
Site Characteristics

Watershed Area: ~50 km²

Dominant Upland Soils:
  • Ingleside Sandy Loam

Slopes: 2-5%

Land Uses:
  • Agriculture (~61%)
  • Forest (~33%)
  • Developed (~5%)
  • Water (~1%)

Baseflow: ~65% of total flow (Bachman et al. 1998)

Rain Gauges: None within the watershed
Problem Statement

- Weather data **drives** hydrologic/water quality models
- The accuracy of model simulations depend on the **availability** and **quality** of weather data
- Precipitation measured from **surface rain gauges** used most of the time
- Surface rain gauges often **insufficient in number** and therefore lack the ability to account for spatial variability of rainfall

- Remotely sensed radar data, **Next Generation Radar (NEXRAD)**
- **Spatially distributed** estimates of rainfall

- Considering there are no rain gauges within the study watershed, how well does SWAT estimate observed streamflow using rainfall data from gauges located outside of the watershed compared to NEXRAD data?
Objectives

- Evaluate the ability of SWAT to accurately estimate streamflow using rainfall data from NEXRAD and surface rain gauges located outside of the watershed
- Sensitivity, calibration, and validation analyses were conducted on the watershed
- Demonstrated use of NEXRAD_SWAT, a new tool developed to incorporate NEXRAD data into ArcSWAT
Methodology: Sensitivity

- Latin-Hypercube One-At-a-Time (LH-OAT) method (van Griensven et al., 2006)

- Sensitivity Index calculated by averaging the partial effect sensitivity indices for each interval of each parameter.

\[
S_{i,j} = \left| \frac{100 \times \left( \frac{M(e_{i,...,e_i^*,e_{i+1},...,e_p}) - M(e_{i,...,e_p})}{M(e_{i,...,e_i^*,e_{i+1},...,e_p}) + M(e_{i,...,e_i,e_{i+1},...,e_p}/2)} \right)}{f_i} \right|
\]

where \(M(\cdot)\) is the model output function, \(f_i\) is the fraction that parameter \(e_i\) is changed, and \(i\) is the number of parameters.
Methodology: Calibration

- Optimization method: Parameter Solutions (Parasol) (van Griensven and Meixner, 2007)
  - Algorithm: Shuffled Complex Evolution (SCE)
  - Global search algorithm that minimizes a single or multiple objective functions
    - SSQ and/or SSQR

\[
SSQ = \sum_{i=1,n} \left[ x_{i, measured} - x_{i, simulated} \right]^2
\]
Methodology: Calibration/Validation

- Calibrate GB watershed under 3 precipitation scenarios
- Precipitation Data
  - Two surface rain gauges
    - Royal Oak, MD
    - Chestertown, MD
  - NEXRAD data without correction
- Simulation Years 2004-2007
  - 1-year spin-up 2004
  - Calibration period 2005-2006
  - Validation period 1/1/07- 4/15/07
Surface Rain Gauges

- Chestertown, MD
  ~ 16 mi from GB Outlet

- Greenwood, DE
  ~ 23 mi from GB Outlet

- Royal Oak, MD
  ~ 24 mi from GB Outlet

- Vienna, MD
  ~ 37 mi from GB Outlet
Methodology: Next Generation Radar (NEXRAD)- NEXRAD_SWAT

- NEXRAD_SWAT (Zhang and Srinivasan, 2009)
- Extension of ArcGIS 9.x
- Output spatial precipitation map for distributed hydrologic model (grid format)
- NEXRAD precipitation with no additional corrections or evaluates and corrects NEXRAD data using rain gauge data
- Geostatistical Methods:
  - Simple kriging with varying local means
  - Kriging with external drift
  - Regression kriging
  - Co-kriging
Methodology: NEXRAD_Swat

- Data Needs

  - Hourly NEXRAD MARFC – Operational Multisensor Precipitation Estimator (MPE) data, XMRG format (compressed, binary format by month), all hourly data placed in 1 folder (NOAA-NWS)
  
  **uncompress and transform to ASCII grid format**

  - Rain gauge shape file

  - Daily precipitation records for each rain gauge in text format

  - Subbasin shape file (avg. precip. for each subbasin) same projection as rain gauge shape file
Methodology: NEXRAD_SWAT
Results: Sensitivity

- 13 parameters used in calibration based on sensitivity analysis
- Two methods used to obtain the proper water balance
  1. Include all sensitive parameters in auto-calibration
  2. Adjust CN, Rchrg_Dp, and Alpha_Bf before, and do not include in auto-calibration
- Including curve number and recharge to the deep aquifer in the automated calibration provided best results

<table>
<thead>
<tr>
<th>Rank</th>
<th>Sensitive Parameter</th>
<th>$S_i$ Sensitivity Index</th>
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<tbody>
<tr>
<td>1</td>
<td>Cn2</td>
<td>1.55</td>
</tr>
<tr>
<td>2</td>
<td>Rchrg_Dp</td>
<td>0.88</td>
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<tr>
<td>3</td>
<td>Esco</td>
<td>0.65</td>
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<tr>
<td>4</td>
<td>Gwqmn</td>
<td>0.54</td>
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<tr>
<td>5</td>
<td>Alpha_Bf</td>
<td>0.25</td>
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<tr>
<td>6</td>
<td>Sol_Z</td>
<td>0.22</td>
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<tr>
<td>7</td>
<td>Sol_Awc</td>
<td>0.21</td>
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<tr>
<td>8</td>
<td>Blai</td>
<td>0.08</td>
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<tr>
<td>9</td>
<td>Timp</td>
<td>0.07</td>
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<tr>
<td>10</td>
<td>Ch_K2</td>
<td>0.07</td>
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<tr>
<td>11</td>
<td>Canmx</td>
<td>0.06</td>
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<tr>
<td>12</td>
<td>GW_Revap</td>
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<tr>
<td>13</td>
<td>Slope</td>
<td>0.02</td>
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<tr>
<td>14</td>
<td>Sol_K</td>
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<td>15</td>
<td>Surlag</td>
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<td>Revapmn</td>
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<td>GW_Delay</td>
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<td>18</td>
<td>Ch_N2</td>
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<td>19</td>
<td>Smtmp</td>
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</tr>
<tr>
<td>20</td>
<td>Biomix</td>
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Results: Royal Oak/Chestertown/ NEXRAD Calibration and Validation

Table 1. Calibration and validation performance measures for daily streamflow using Royal Oak, Chestertown, and NEXRAD rainfall data.

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<td></td>
<td>NSE</td>
<td>$r^2$</td>
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<tr>
<td><strong>Calibration Period</strong></td>
<td></td>
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<td>0.42</td>
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<td></td>
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<td>(0.57)</td>
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Rain Gauge and NEXRAD

Royal Oak Rain Gauge Daily Streamflow Validation (1/1/07-4/15/07)

Royal Oak Temperature Data

Streamflow (cms)

0 2 4 6 8 10 12 14 16

Time (day)


Observed
Simulated

NEXRAD Daily Streamflow Validation (1/1/07-4/15/07)

Royal Oak Temperature Data

Streamflow (cms)

0 2 4 6 8 10 12 14 16

Time (day)


Observed
Simulated

A B C
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Rain Gauge and NEXRAD

Chestertown Rain Gauge Daily Streamflow Validation (1/1/07-4/15/07)

Chestertown Temperature Data

NEXRAD Daily Streamflow Validation (1/1/07-4/15/07)

Chestertown Temperature data
Results: Annual Precipitation for Chestertown Rain Gauge

Annual Precipitation at Chestertown Gauge (2004-2008)
Conclusions

- For a watershed with no internal rain gauges, use of external gauge data should not only consider closeness to the watershed, but also the direction of storm patterns. In this case the gauge located NW of the watershed provided better precipitation input.

- In the above case, NEXRAD precipitation generally provided better estimates of flow due to better accounting of spatial variation of rainfall. NEXRAD rainfall data can be a good alternative where gauge data is not available or gauges are not located within the general storm path.

- However, NEXRAD rainfall data will not always provide better estimates of streamflow than rain gauge data. In this case, streamflow was overestimated using NEXRAD rainfall data during a dry period and rain gauge data provided better estimates.
Thank you!
Raingauge point shape file

Each rain gauge’s rainfall records in text format

NEXRAD data in compressed binary format

Input data

Input each time step’s rainfall to the corresponding raingauge point

Uncompress each time step’s NEXRAD data and transform them into ASCII grid format

Data processing functions

Identify the pairs of raingauge and NEXRAD estimated records

Evaluate the accuracy of the original NEXRAD and calibrating NEXRAD using Raingauge data

Output the spatial precipitation map in GIS grid format, and calculate the evaluation coefficients (e.g., EB, MAE, EE, and Rvar)
Annual Precipitation at Chestertown Gauge (2004-2008)

Avg. Annual = 1038 mm

Annual Precipitation at Royal Oak Gauge (2004-2008)

Avg. Annual = 1189 mm