<table>
<thead>
<tr>
<th>Title</th>
<th>Numerical simulation of integrated terrestrial processes over the East River (Dongjiang) in South China</th>
</tr>
</thead>
<tbody>
<tr>
<td>Author(s)</td>
<td>Chen, J</td>
</tr>
<tr>
<td>Citation</td>
<td>The PRAGMA 20th Workshop cum HKU Centennial IT Conference on Grid Applications and Research collaboration (PRAGMA20), Computer Centre, The University of Hong Kong, Hong Kong, China, 2-4 March 2011.</td>
</tr>
<tr>
<td>Issued Date</td>
<td>2011</td>
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<tr>
<td>URL</td>
<td><a href="http://hdl.handle.net/10722/140745">http://hdl.handle.net/10722/140745</a></td>
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<tr>
<td>Rights</td>
<td>This work is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License.</td>
</tr>
</tbody>
</table>
Numerical Simulation of Integrated Terrestrial Processes over the East River (Dongjiang) in South China

Ji Chen

Department of Civil Engineering
The University of Hong Kong
Acknowledgement:

HK CPU/RGC HKU7022_PPR_2: Assuring Hong Kong's water supply: learning the lessons of the 1963 drought

Groups:
- Hong Kong Observatory, Water Supplies Department
- Pearl River Water Resources Commission in Guangzhou
- Xinfengjiang Reservoir Authority in Heyuan

Research Cooperators:
- WU Yingping, CHAN Shu Ning, ZHANG Runrun
Study area

- Drainage area: 25,325 km²
- Mainstem length: 562 km
- Total reservoir storage capacity: $18.2 \times 10^9$ m³
- XFJR is the biggest reservoir in the basin
- Water supply for:
  - Hong Kong, Shenzhen, Heyuan, Huizhou, Dongguan, Guangzhou
- 80% of fresh water supply in Hong Kong is from the East River
The East River water and the water supply in Hong Kong
Xinfengjiang Reservoir (XFJR)

Started: Oct 1959

Storage capacity: 14 billion m$^3$
Effective storage: 6.4 billion m$^3$

Field Trip: Oct 14, 2007
Water Resources in the East River
WRAP

• Developed by Prof. Ralph A. Wurbs and his students in Texas A&M University, USA, in the late 1980s

• **Priority-based simulation system**
  – Available streamflow is allocated to each water right in turn in ranked priority order
  – The most senior water right (with the highest priority) can get water required first

• **Modeling and analysis of river/reservoir system operations under the effects of**
  – Water supply diversions
  – Basic streamflow requirements (for environmental and navigation purpose)
WRAP Main Structure

1. Ranking water rights in priority order
2. Reading natural streamflow and evaporation rate
3. Carrying out simulation for each water right as follows:

   Move to next water right

   - Determining diversion/streamflow target
   - Determining amount of water available to the right
   - Making diversion and reservoir releases
   - Adjusting streamflow at all CPs
   - Recording simulation results of the right
Control Points of the East River Basin
Xinfengjiang Reservoir

- Only Xinfengjiang Reservoir is included
- The reservoir contains 76% of total reservoir storage capacity in the East River basin
- Total capacity: 13.89 billion m³
  - Conservative capacity: 6.49 billion m³
  - Inactive capacity: 4.31 billion m³
  - Flood control capacity: 3.09 billion m³
Water Right Priority Order

Water availability for each water user is affected by the water right priority

Two different priority orders:

• City Direction Priority Order
• D-I-A Priority Order
City Direction Priority Order

- the priority is assigned to the cities and regions according to their location (upstream to downstream) and their importance, i.e.

  HK > SZ > HY > HZ > DG > GZ

- for each city, its priority is assigned according to the types of water usage, i.e.

  Domestic > Industrial > Agricultural > Streamflow Requirement

- the salinity suppression requirement at SL, BL and the minimal instream flow requirement in HY should be satisfied first before any water diversion
D-I-A Priority Order

• for each city, priority is assigned according to the types of water usage, i.e.

  **Domestic > Industrial > Agricultural > Streamflow Requirement**

• the priority is assigned to the cities according to their location (upstream to downstream) and the GDP i.e.

  **HK > SZ > HY > HZ > DG > GZ**

• the salinity suppression requirement at SL, BL and the minimal instream flow requirement in HY should be satisfied first before any right water diversion
## Main Settings in Simulations

<table>
<thead>
<tr>
<th>Main Parameters</th>
<th>Settings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of simulation period in month</td>
<td>12 months (the 1963 water year)</td>
</tr>
<tr>
<td>Starting month of each cycle</td>
<td>Starting at October for each simulation</td>
</tr>
<tr>
<td>Reservoir initial storage</td>
<td>Different storages for each simulation</td>
</tr>
</tbody>
</table>
Mean $R_v(\%)$ of each water right with different initial reservoir storage at the beginning of Oct \textit{(CC (conservative capacity))}

<table>
<thead>
<tr>
<th>City</th>
<th>10%CC</th>
<th>50%CC</th>
<th>70%CC</th>
<th>90%CC</th>
</tr>
</thead>
<tbody>
<tr>
<td>HK(D)</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
</tr>
<tr>
<td>HK(O)</td>
<td>93.78</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
</tr>
<tr>
<td>SZ(D)</td>
<td>80.07</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
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<tr>
<td>SZ(I)</td>
<td>66.67</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
</tr>
<tr>
<td>SZ(A)</td>
<td>77.90</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
</tr>
<tr>
<td>HY(D)</td>
<td>66.67</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
</tr>
<tr>
<td>HY(I)</td>
<td>66.67</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
</tr>
<tr>
<td>HY(A)</td>
<td>41.70</td>
<td>66.58</td>
<td>85.44</td>
<td>100.00</td>
</tr>
<tr>
<td>HZ(D)</td>
<td>66.67</td>
<td>91.67</td>
<td>100.00</td>
<td>100.00</td>
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<tr>
<td>HZ(I)</td>
<td>60.39</td>
<td>85.39</td>
<td>100.00</td>
<td>100.00</td>
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<tr>
<td>HZ(A)</td>
<td>36.08</td>
<td>61.08</td>
<td>94.78</td>
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<tr>
<td>DG(D)</td>
<td>57.11</td>
<td>82.11</td>
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<td>DG(I)</td>
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<tr>
<td>DG(A)</td>
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<td>63.80</td>
<td>74.30</td>
<td>100.00</td>
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<tr>
<td>GZ(D)</td>
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<td>75.00</td>
<td>83.33</td>
<td>100.00</td>
</tr>
<tr>
<td>GZ(I)</td>
<td>50.00</td>
<td>75.00</td>
<td>83.33</td>
<td>100.00</td>
</tr>
<tr>
<td>GZ(A)</td>
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<td>63.80</td>
<td>74.30</td>
<td>100.00</td>
</tr>
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</table>
Mean $R_v(\%)$ of each water right with different initial reservoir storage at the beginning of Oct (CC (conservative capacity))

<table>
<thead>
<tr>
<th>D-I-A</th>
<th>10%CC</th>
<th>50%CC</th>
<th>70%CC</th>
<th>90%CC</th>
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<tbody>
<tr>
<td>HK(D)</td>
<td>100.0</td>
<td>100.00</td>
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<td>100.00</td>
<td>100.00</td>
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<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
</tr>
<tr>
<td>HY(D)</td>
<td>66.67</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
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<tr>
<td>HZ(D)</td>
<td>66.67</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
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<tr>
<td>DG(D)</td>
<td>66.67</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
</tr>
<tr>
<td>GZ(D)</td>
<td>66.67</td>
<td>91.67</td>
<td>100.00</td>
<td>100.00</td>
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<tr>
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<td>100.00</td>
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</tr>
<tr>
<td>DG(I)</td>
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<td>83.33</td>
<td>100.00</td>
<td>100.00</td>
</tr>
<tr>
<td>GZ(I)</td>
<td>58.33</td>
<td>83.33</td>
<td>100.00</td>
<td>100.00</td>
</tr>
<tr>
<td>SZ(A)</td>
<td>70.90</td>
<td>82.50</td>
<td>100.00</td>
<td>100.00</td>
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<tr>
<td>HY(A)</td>
<td>35.51</td>
<td>55.71</td>
<td>79.55</td>
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<tr>
<td>HZ(A)</td>
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<td>53.70</td>
<td>80.00</td>
<td>100.00</td>
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<td>63.80</td>
<td>74.30</td>
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<tr>
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<td>63.80</td>
<td>74.30</td>
<td>100.00</td>
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</tbody>
</table>
Hydrologic Processes
Introduction of SWAT (Soil & Water Assessment Tool)

★ Development
Developed in the USDA-ARS in the 1990s

★ Objective
Predict the impact of climate change and land management practices on water, sediment and agricultural chemical yields.

★ Application
Contributed by several federal agencies (USA EPA, NRCS, etc.)

★ Components
- Weather
- Hydrology
- Soil erosion
- Pollutant transportation
  - Runoff
  - Sediment
  - Nutrients
  - Base Flow
  - Crop Growth
  - Evaporation
  - Pesticides
  - Land Management
Hydrologic cycle in SWAT (Soil and Water Assessment Tool)

\[ SW_t = SW_o + \sum_{i=1}^{t} (R_{day,i} - Q_{surf,i} - E_{act,i} - W_{seep,i} - Q_{lat,i}) \] (mm/d)

(Neitsch et al. 2005)
Terrestrial Hydrologic Cycle in SWAT

Precipitation

Rainfall

Snowfall

Snowmelt

Infiltration

Precipitation

Soil Water

Irrigation

Soil Evap.

Plant Transp.

Lateral Flow

Perc.

Surface Runoff

Tran. Loss

Pot-hole

Pond

Wet-land

Revap.

Shallow Aquifer

Water Use (Irrigation)

Deep Aquifer

Channel Flow

Baseflow
Main Inputs to SWAT

- **DEM data** (Topographic features)
- **Soil data**
  - **Soil Texture** (Percentage of silt, clay, and sand)
  - **Characteristics** (Soil depth, Bulk density, $K_{sat}$, etc.)
- **Land Use data**
- **Weather data**
  - **Precipitation**
  - **Air Temperature**
  - **Wind Speed**
  - **Solar Radiation**
  - **Relative Humidity**
- **Crop Growth**
  - **Planting/Harvesting date**
  - **PHU (Potential Heat Unit) for the maturity of crop**
- **Land Management**
  - **Tillage**
  - **Irrigation**
  - **Fertilization**
  - **Pesticide**
  - **Harvest / Kill Operation**
Major Outputs

Hydrologic Output
- Runoff
- Sediment
- Evaporation
- Soil water

Water Quality Output
- Nitrogen
  - Organic N
  - NO\textsubscript{x}-N
- Phosphorus
  - Organic P
  - Mineral P
- BOD
- DO
**HRUs Distribution**

Subbasin can be divided into hydrologic response units (HRUs), each HRU possesses unique landuse / soil attributes / management.

**Based on Land Use & Soil Type**

**How to distribute HRUs for a subbasin**

```
  | A | B | C |
---|---|---|---|
A  | 1 | 2 | 1 |
B  | 2 | 2 | 1 |
C  | 1 | 3 | 3 |
```

Land Use  +  Soil Type  =  Land Use / Soil Type

![Map of land use and soil type distribution]

<table>
<thead>
<tr>
<th>Sub #</th>
<th>Land Use</th>
<th>Soil Type</th>
<th>Hydr. Group</th>
<th>HRU #</th>
<th>CN2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>FRST</td>
<td>LAT</td>
<td>C</td>
<td>1</td>
<td>77</td>
</tr>
<tr>
<td>2</td>
<td>FRST</td>
<td>LAT</td>
<td>C</td>
<td>2</td>
<td>77</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>30</td>
<td>URHD</td>
<td>PAD</td>
<td>D</td>
<td>102</td>
<td>87</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
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<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>AGRL</td>
<td>RED</td>
<td>B</td>
<td>109</td>
<td>77</td>
<td></td>
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</table>
## Calibration

<table>
<thead>
<tr>
<th>Drainage area controlled by</th>
<th>Observation</th>
<th>Calibration</th>
<th>Validation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>33yr</td>
<td>21yr</td>
<td>12yr</td>
</tr>
<tr>
<td></td>
<td>31yr</td>
<td>19yr</td>
<td>12yr</td>
</tr>
</tbody>
</table>

### Parameter Description

#### Base flow recession constant ($\alpha_{gw}$)
- **Description**: Base flow recession constant
- **Range**: $0 – 1$
- **Calibrated Value**
  - Longchuan: 0.003
  - XFJ: 0.0054
  - Boluo: 0.0054

#### Soil evaporation compensation factor ($esco$)
- **Range**: $0.001 – 1$
- **Calibrated Value**
  - Longchuan: 0.999
  - XFJ: 0.999
  - Boluo: 0.999

#### Plant uptake compensation factor ($epco$)
- **Range**: $0.001 – 1$
- **Calibrated Value**
  - Longchuan: 0.001
  - XFJ: 0.001
  - Boluo: 0.001

#### Groundwater “revap” coefficient ($gw_{revap}$)
- **Range**: $0.02 – 0.2$
- **Calibrated Value**
  - Longchuan: 0.05
  - XFJ: 0.02
  - Boluo: 0.2

#### Deep aquifer percolation fraction ($rchrg_dp$)
- **Range**: $0 – 1$
- **Calibrated Value**
  - Longchuan: 0.1
  - XFJ: 0.016
  - Boluo: 0.5
Validation

Daily streamflow at Boluo (Validation period)

Evaluation

<table>
<thead>
<tr>
<th></th>
<th>Relative Bias</th>
<th>Correlation Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily flow</td>
<td>– 0.16</td>
<td>0.87</td>
</tr>
</tbody>
</table>
Water balance - over watershed

Annual Mean Item | Value (mm/d)
--- | ---
PCP | 3.798
ET | 1.484
Flow | 2.155
ET/PCP | 40.1%
SF/PCP | 56.7%

\[ y = 1.2094x^{-0.8459} \]
\[ R^2 = 0.9416 \]
Spatial distribution of hydrologic components

Annual average (1951 – 2000)

Precipitation (mm/yr)  

Surface Runoff (mm/yr)
Spatial distribution of hydrologic components

Annual average (2000)

Soil Water (mm)
**Reservoir operation - Reservoirs in ERB**

**Xinfengjiang**
- Built: 07/1958
- Operated: 05/1960
- Cap.: $14 \times 10^9 \text{m}^3$

**Boluo**
**Reservoir operation** - simulated by SWAT

Controlled outflow with target release

\[
\text{Outflow} = \frac{V - V_{\text{targ}}}{ND_{\text{targ}}}
\]

\[V_i = V_{i-1} + I n - E v p - S e e p\]

\[V_{\text{targ}}\] Target reservoir volume for a given day

The same value for all the days in each month

\[ND_{\text{targ}}\] Number of days required for the reservoir to reach target storage
Reservoir operation - simulated by SWAT

Volume

Outflow
A New Reservoir Simulation Scheme

Storage $V(i)$

<table>
<thead>
<tr>
<th>Operation Purpose and Equation for Computing Outflow, $O(i)$ (m$^3$/d), on a given day $i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V(i) &gt; V_p$</td>
</tr>
<tr>
<td>$V_p \geq V(i) &gt; V_d$</td>
</tr>
<tr>
<td>$V(i) \leq V_d$</td>
</tr>
</tbody>
</table>

$\bar{O}(i)$: Target seasonal outflow

$\alpha$, $\beta$, $\gamma$: Coefficients

$ND_{avg}$: Average number of days

$I_{30}(i)$, $\sigma_{30}(i)$: 30-day average inflow and inflow standard deviation

$k$ (mon): Monsoon factor

$V_c$, $V_p$, $V_d$: Critical, flood control, and dead levels

$V(i)$: Storage on a given day $i$
### Comparison and Evaluation

<table>
<thead>
<tr>
<th>Variable</th>
<th>Scheme</th>
<th>Monthly Statistical Terms</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>RMSE</td>
<td>NSE</td>
</tr>
<tr>
<td><strong>Storage</strong></td>
<td>I (Target release)</td>
<td>1.87</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td>II (Mechanism based scheme)</td>
<td>1.57</td>
<td>0.50</td>
</tr>
<tr>
<td><strong>Outflow</strong></td>
<td>I</td>
<td>6.9</td>
<td>0.19</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>6.0</td>
<td>0.38</td>
</tr>
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</table>
## Four hydrologic processes in SWAT

<table>
<thead>
<tr>
<th>Hydrologic Processes</th>
<th>Calculation and Parameters involved</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Overland flow</strong></td>
<td>( Q_{\text{surf}} = \frac{(R_{\text{day}} - I_a)^2}{(R_{\text{day}} - I_a + S_a)} ) ( S_a )</td>
<td>without considering direct overland flow from saturated area</td>
</tr>
</tbody>
</table>
| **Revap**                     | \( W_{\text{revap}} = \beta_{\text{revap}} \cdot E_0 \) \( \beta_{\text{revap}} \) | • to be calibrated  
  • time invariant  
  • spatially unchanged |
| **Baseflow**                  | \( Q_{b,i} = Q_{b,i-1} \cdot e^{-\alpha_{gw} \Delta t} + W_r \cdot (1 - e^{-\alpha_{gw} \Delta t}) \) \( \alpha_{gw} \) | to be calibrated  
  \( f(W_r) \) |
| **Percolation to deep aquifer** | \( W_{\text{deep, mx}} = \beta_{\text{deep}} W_{\text{rchrg}} \) \( \beta_{\text{deep}} \) | • to be calibrated  
  • this amount of water is returned to hydrologic cycle only by pumping |
Saturated Area and Water Table Depth

- Saturated area and its expansion
  (Dunne and Leopold, 1978)

- Saturated fraction
  \[ \frac{f_{rs}^r}{A} = \frac{A_c}{A} = f(\lambda, \bar{z}, \xi) \]

- Topographic Index
  \[ \alpha \ln \frac{A}{\tan \beta} \]
  \( \alpha \) is the upstream contributing area
  \( \tan \beta \) is the local slope
  (Beven and Kirkby 1979)
## Integrated of SWAT-TOPMODEL

<table>
<thead>
<tr>
<th>Hydrologic Processes</th>
<th>Calculation and Parameters involved</th>
<th>Strengths</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Revap</strong></td>
<td><strong>Saturated fraction</strong></td>
<td><strong>Temporal and spatial varying</strong></td>
</tr>
<tr>
<td></td>
<td>[ f_{r_{sat}} = \frac{A_{c}}{A} = \int_{x \geq (\xi \cdot \bar{z} + \lambda)} f(x) , dx ]</td>
<td>[ f_{r_{sat}} = f(\lambda, \bar{z}, \xi) ]</td>
</tr>
<tr>
<td></td>
<td>( x = ) Topographic Index = ( \ln \frac{a}{\tan \beta} )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( f(x) ) Probability distribution of TI</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( \lambda ) Mean value of TI</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( \bar{z} ) Basin average water table depth</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( \xi ) Decay factor of soil</td>
<td></td>
</tr>
<tr>
<td><strong>Baseflow</strong></td>
<td><strong>Basin lateral transmissivity</strong></td>
<td><strong>Quick surface runoff</strong></td>
</tr>
<tr>
<td></td>
<td>( Q_b = AT_0 e^{-(\lambda + \xi \cdot \bar{z})} )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( T_0 = k_{xx}(0)/\xi ) Saturated lateral hydraulic conductivity at the surface</td>
<td></td>
</tr>
<tr>
<td><strong>Overland flow</strong></td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rainfall falling on the saturated area enters channel directly</td>
<td></td>
</tr>
</tbody>
</table>
## Revap simulation

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Model</th>
<th>Revap</th>
<th>Comparison period</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>SWAT</td>
<td>$f(\text{PET})$</td>
<td>Jan and Mar</td>
</tr>
<tr>
<td>II</td>
<td>SWAT-TOPMODEL</td>
<td>$f(\text{PET}, f_{\text{sat}})$</td>
<td>Mid Sep</td>
</tr>
</tbody>
</table>

![Graph showing saturated fraction, Revap by scenario I and II, and groundwater table depth over time]
## Evaluation

### Scenario I: SWAT
### Scenario II: SWAT-TOPMODEL

<table>
<thead>
<tr>
<th>Model</th>
<th>Period</th>
<th>Mean Observed</th>
<th>Mean Simulated</th>
<th>PB (%)</th>
<th>NSE</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Calibration</td>
<td>818.64</td>
<td>831.17</td>
<td>1.53</td>
<td>0.84</td>
<td>0.93</td>
</tr>
<tr>
<td></td>
<td>Validation</td>
<td>808.88</td>
<td>847.34</td>
<td>4.75</td>
<td>0.82</td>
<td>0.91</td>
</tr>
<tr>
<td>SWAT</td>
<td>Calibration</td>
<td>818.64</td>
<td>833.82</td>
<td>1.85</td>
<td>0.80</td>
<td>0.93</td>
</tr>
<tr>
<td></td>
<td>Validation</td>
<td>808.88</td>
<td>854.05</td>
<td>5.59</td>
<td>0.77</td>
<td>0.91</td>
</tr>
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<td>SWAT-TOPMODEL</td>
<td>Calibration</td>
<td>818.64</td>
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<td>0.91</td>
</tr>
</tbody>
</table>

![Scatter plot with regression lines and equations]

Regression equations:
- Scenario II: $y = 1.073x - 19.137$, $R^2 = 0.8331$
- Scenario I: $y = 0.9129x + 108.95$, $R^2 = 0.8354$
Soil Erosion
Land Phase

Sediment in surface runoff (MUSLE)

\[ \text{sed} = 11.8 \cdot (Q_{\text{surf}} \cdot q_{\text{peak}} \cdot \text{area}_{\text{hru}})^{0.56} \cdot K_{\text{USLE}} \cdot C_{\text{USLE}} \cdot P_{\text{USLE}} \cdot LS_{\text{USLE}} \cdot CFRG \]

- \( \text{sed} \): mass of soil erosion (ton)
- \( q_{\text{peak}} \): peak runoff (m\(^3\)/s)
- \( \text{area}_{\text{hru}} \): area of HRU (ha)
- \( K_{\text{USLE}} \): soil erodibility factor
- \( C_{\text{USLE}} \): factor of land cover and management
- \( P_{\text{USLE}} \): conservation practice factor
- \( LS_{\text{USLE}} \): account for the factor of topography
- \( CFRG \): coarse fragment factor
Sediment Erosion

Land Phase

(2) Sediment in lateral & groundwater flow

\[ sed_{lat} = \frac{(Q_{lat} + Q_{gw}) \cdot area_{hru} \cdot conc_{sed}}{1000} \]

- \( sed_{lat} \): sediment loading in lateral and groundwater flow (ton)
- \( Q_{lat} \): lateral flow for a given day (mm H\textsubscript{2}O)
- \( Q_{gw} \): groundwater flow for a given day (mm H\textsubscript{2}O)
- \( area_{hru} \): area of the HRU (km\textsuperscript{2})
- \( conc_{sed} \): concentration of sediment in lateral and groundwater flow (mg/L)
Sediment Erosion

Water Phase

\[
conc_{\text{sed, ch, mx}} = C_{sp} \cdot v_{\text{ch, pk}}^{sp\text{exp}}
\]

- \(conc_{\text{sed, ch, mx}}\) maximum conc. of sed. transported (ton/m\(^3\) or kg/L)
- \(C_{sp}\) coefficient defined by the user
- \(v_{\text{ch, pk}}\) peak channel velocity (m/s)
- \(sp\text{exp}\) exponent defined by the user

Normally varies between 1.0 and 2.0 and was set at 1.5 in the original Bagnold stream power equation (Arnold et al., 1995).

\[
\begin{align*}
  v_{\text{ch, pk}} &= \frac{q_{\text{ch, pk}}}{A_{ch}} \\
  q_{\text{ch, pk}} &= \text{prf} \cdot q_{\text{ch}}
\end{align*}
\]

- \(prf\) peak rate adjustment factor
- \(q_{\text{ch}}\) average rate of flow (m\(^3\)/s)
- \(A_{ch}\) cross-sectional area of flow
Sediment Erosion

Water Phase

\[
\text{conc}_{\text{sed}, \text{ch}, \text{i}} > \text{conc}_{\text{sed}, \text{ch}, \text{mx}}
\]

Deposition is the dominant process and the net amount of sediment deposited

\[
\text{sed}_{\text{dep}} = (\text{conc}_{\text{sed}, \text{ch}, \text{i}} - \text{conc}_{\text{sed}, \text{ch}, \text{mx}}) \cdot V_{\text{ch}}
\]

\[
\text{conc}_{\text{sed}, \text{ch}, \text{i}} < \text{conc}_{\text{sed}, \text{ch}, \text{mx}}
\]

Degradation is the dominant process and the net amount of sediment reentrained

\[
\text{sed}_{\text{deg}} = (\text{conc}_{\text{sed}, \text{ch}, \text{mx}} - \text{conc}_{\text{sed}, \text{ch}, \text{i}}) \cdot V_{\text{ch}} \cdot K_{\text{CH}} \cdot C_{\text{CH}}
\]

- \(K_{\text{CH}}\) is the channel erodibility factor (cm/hr/Pa)
- \(C_{\text{CH}}\) is the channel cover factor

Final amount of SS

\[
\text{sed}_{\text{ch}} = \text{sed}_{\text{ch}, \text{i}} - \text{sed}_{\text{dep}} + \text{sed}_{\text{deg}} \quad \text{(ton)}
\]

Sediment transported out of the reach

\[
\text{sed}_{\text{out}} = \text{sed}_{\text{ch}} \cdot \frac{V_{\text{out}}}{V_{\text{ch}}} \quad \text{(ton)}
\]
Soil Erosion and Sediment Transport

Sediment yield (t/ha)
- 0
- 1 - 37
- 38 - 182
- 183 - 257
- 258 - 409

Net deposition (t/km)
- 0 - 40
- 41 - 521
- 522 - 2741
- 2742 - 99242

- River
- Station
- Flow Gauge

Maps showing sediment yield and net deposition across different regions.
Water Quality
The transport of nutrients from land areas into streams and water bodies is a normal result of soil weathering and erosion processes.

- Governing movement of mineral and organic forms of nitrogen and phosphorus from land areas to the stream network.
NPS and PS Pollution

Water Phase

- Determine the loadings of water, sediment, nutrients and pesticides to the main channel in land phase hydrologic cycle

- Keep track mass flow and models the transformation of chemicals in the stream

NPS: Loadings from land areas

PS: Loadings from sources not associated with a land areas
Parameters which affect water quality and can be considered pollution indicators include nutrients, total solids, biological oxygen demand and microorganisms (Loehr, 1970; Paine, 1973).

The SWAT in-stream water quality algorithms incorporate constituent interactions and relationships used in the QUAL2E model (Brown and Barnwell, 1987).
NPS and PS Pollution

Water Phase (NPS & PS)

(0) Algae

Simulate algal growth in the stream

Why?

- During the day, algae increase the stream’s DO via photosynthesis.
- At night, algae reduce the stream’s DO via respiration.
- As algae grow and die, they form part of the in-stream nutrient cycle.

How?

Growth and decay of algae/chlorophyll a is calculated as a function of the growth rate, the respiration rate, the settling rate and the amount of algae present in the stream.
NPS and PS Pollution

Water Phase - N

$\Delta \text{orgN}_{\text{str}} = (\alpha_1 \cdot \rho_a \cdot \text{algae} - \beta_{N,3} \cdot \text{orgN}_{\text{str}} - \sigma_4 \cdot \text{orgN}_{\text{str}}) \cdot TT$

$\Delta \text{orgN}_{\text{str}}$ change in organic nitrogen concentration (mg N/L)

$\alpha_1$ fraction of algal biomass that is nitrogen (mg N/mg algal biomass)

$\rho_a$ local respiration or death rate of algae (day$^{-1}$ or hr$^{-1}$)

$\text{algae}$ algal biomass concentration at the beginning of the day (mg alg/L)

$\beta_{N,3}$ rate constant for hydrolysis of orgN to ammonia N (day$^{-1}$ or hr$^{-1}$)

$\text{orgN}_{\text{str}}$ organic nitrogen concentration at the beginning of the day (mg N/L)

$\sigma_4$ rate coefficient for organic nitrogen settling (day$^{-1}$ or hr$^{-1}$)

$TT$ flow travel time in the reach segment (day or hr)
NPS and PS Pollution

Water Phase - P

(1) \( \text{orgP} \)

\( \text{orgP} \rightarrow \text{soluble inorganic P} \)

algal biomass P \( \rightarrow \) \( \text{orgP} \)

\( \text{orgP} \) settling (sed.)

\[ \Delta \text{orgP}_{str} = \left( \alpha_2 \cdot \rho_a \cdot \text{algae} - \beta_{P,4} \cdot \text{orgP}_{str} - \sigma_5 \cdot \text{orgP}_{str} \right) \cdot TT \]

\( \Delta \text{orgP}_{str} \) change in organic P concentration (mg P/L)

\( \alpha_2 \) fraction of algal biomass that is P (mg P/mg alg biomass)  

\( \rho_a \) local respiration or death rate of algae (day\(^{-1}\) or hr\(^{-1}\))

\( \text{algae} \) algal biomass concentration at the beginning of the day (mg alg/L)

\( \beta_{P,4} \) rate constant for mineralization of organic phosphorus (day\(^{-1}\) or hr\(^{-1}\))

\( \text{orgP}_{str} \) organic P concentration at the beginning of the day (mg P/L)

\( \sigma_5 \) rate coefficient for organic phosphorus settling (day\(^{-1}\) or hr\(^{-1}\))

\( TT \) flow travel time in the reach segment (day or hr)
Seasonal variation of stream water quality

NH3-N: constant PS load
  Low conc. in wet season

NO3-N: PS and NPS loads
  Planting & Fertilization (Apr & Aug)
  Eluviation (Mar)

Critical period for nutrient:
  Ending of dry season ➔
  Beginning of wet season
NPS pollution load

NO3-N (kg/ha)
- 0.0 - 0.4
- 0.5 - 0.8
- 0.9 - 4.8
- 4.9 - 5.6
- 5.7 - 8.4
- 8.5 - 18.3

Organic P (kg/ha)
- 0.0 - 0.1
- 0.2 - 2.1
- 2.2 - 4.1
- 4.2 - 10.9
- 11.0 - 12.9
- 13.0 - 20.0
Conclusions

This study focused on the improvement of our understanding of the integrated terrestrial processes over the East River (Water, Sediment, Nutrients, Reservoir operation and Land management)

- **Water resources**: to overcome the projected water shortage induced by the drought condition as in 1963, 70% conservative capacity of Xinfengjiang reservoir would be filled

- **Reservoir simulation**: A mechanism-based numerical scheme for a multiyear and multipurpose reservoir is developed

- **Model integration**: Hydrologic representation in SWAT are enhanced physically by integrating TOPMODEL features

- **Sediment & Water quality**: Soil erosion and NPS pollution features are analyzed, with identification of critical area and critical period
Thank you!