Soil and Water Assessment Tool (SWAT)

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Course objectives

- Get familiar with SWAT
  - What are the key processes, key parameters?
  - What are the main application domains?
- How can we set up a model (get a bit a feeling)?
- What are the main data needed?
Outline

- Introduction
- Hydrology
- Environmental processes
- SWAT for water policy
- Data
- Applications
SWAT

- Developed by Jeff Arnold at USDA/ARS Temple, Texas, USA
- GIS interface (ArcView): DEM, Landuse, Soils maps
- Open sources
- User and developers community
  - swatmodel.tamus.edu
What are the objectives of SWAT

- Simulation of processes at land and water phase
- Spatially distributed (different scales)
- Semi physically based / empirical approaches
- Simulation of changes (climate, land use, management etc.)
- **Water quantities**, incl. different runoff components
- **Water quality**: Nutrients, Sediments, Pesticides, Bacteria, (algae and oxygen), etc.

…. all that on a daily time step and at different spatial scales and (more or less) readily available data sets!!
WWW

http://swatmodel.tamus.edu/

Download software
Download source code
Documentation
User group mailing list!
Internet Forum

Publications
Applications
Philosophy (1)

Aims
- Management analysis
- Water, sediments, crops, nutrients, pesticides

Comprehensive – Process Interactions

Input
- Readily available input
- Physically based input
Philosophy (2)

- Long term simulations
- Continuous Time – Daily/hourly time step

Problem of computational efficiency

- Semi-distributed model
- Conceptual model
Interface

- GRASS (open sources GIS)
- Mapwindow (open sources GIS)
- AVSwat-X (ArcView)
- ArcSWAT (ArcGIS)
Structure

- Basin
- Subbasins (based on DEM)
  Weather, Routing
Channel Processes
Structure

• Basin
• Subbasins  
  Weather, Routing
• Hydrological Response Units  
  = Combination of soil type and land use properties
HRU Hydrologic Response Unit

A unique combination of land use and soil type

Soil map + Land use map
HRU (2)

GIS subbasin

Pixels : 20
Pixel area = A

GEO - REFERENCED

HRU parameters

Output 1 x A x 6
Output 2 x A x 5
Output 3 x A x 8
Output 4 x A x 1

NOT GEO - REFERENCED

Total output

HRU

# of pixels

Input ➔ Output 1

Input ➔ Output 2

Input ➔ Output 3

Input ➔ Output 4

1 unit area

SWAT DATABASES

UNESCO-IHE

Institute for Water Education
HRU’s in model

- Created on the basis of Land Use maps and Soil Maps + databases (with parameters)!!!
  - Soil map ↔ lookup table ↔ usersoil.dbf (swat2005.mdb)
  - Land use map ↔ lookup table ↔ crop.dbf (swat2005.mdb)
  - Slope classes (drived from DEM)
Preparing landuse data

Landuse

Look up table

Database (crop.dbf)

Landuse legend (raw)
Reclassified/overlaid Landuse
HRU Processes

- Hydrology
- Erosion
- Plant Growth
- Nutrient Cycling
- Pesticide Dynamics
- Agricultural Management
How is SWAT solving the problems?

Hydrologic Balance

Evaporation and Transpiration

Precipitation

Infiltration/plant uptake/Soil moisture redistribution

Revap from shallow aquifer

Percolation to shallow aquifer

Flow out of watershed

Recharge to deep aquifer

Surface Runoff

Lateral Flow

Return Flow

Root Zone

Vadose (unsaturated) Zone

Shallow (unconfined) Aquifer

Confining Layer

Deep (confined) Aquifer

Flow out of watershed
## Curve Number Values

(many more can be found in the manual)

<table>
<thead>
<tr>
<th>Land use</th>
<th>% impervious</th>
<th>Soil group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>Residential</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>51</td>
<td>68</td>
</tr>
<tr>
<td>25</td>
<td>54</td>
<td>70</td>
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<tr>
<td>30</td>
<td>57</td>
<td>72</td>
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<tr>
<td>38</td>
<td>61</td>
<td>75</td>
</tr>
<tr>
<td>65</td>
<td>77</td>
<td>85</td>
</tr>
<tr>
<td>Parking, roads, rofs</td>
<td>100</td>
<td>98</td>
</tr>
<tr>
<td>Cobbles</td>
<td>-</td>
<td>76</td>
</tr>
<tr>
<td>Commercial</td>
<td>85</td>
<td>89</td>
</tr>
<tr>
<td>Industry</td>
<td>72</td>
<td>81</td>
</tr>
<tr>
<td>Open (park, grass...)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 75% grass cover</td>
<td>-</td>
<td>39</td>
</tr>
<tr>
<td>50 to 75% grass cover</td>
<td>-</td>
<td>49</td>
</tr>
<tr>
<td>Meadow</td>
<td>-</td>
<td>30</td>
</tr>
<tr>
<td>Woods</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open</td>
<td>-</td>
<td>45</td>
</tr>
<tr>
<td>Dense</td>
<td>-</td>
<td>25</td>
</tr>
<tr>
<td>Agricultural land</td>
<td>-</td>
<td>62</td>
</tr>
</tbody>
</table>

\[
S = 25.4 \left( \frac{1000}{CN} - 10 \right)
\]

### Key parameter!

1) Wetness condition 2

2) 5 % slope

Empirical equations exist to adjust for different slopes
Curve Number Value Variations

Soil Groups

A  Deep sand, deep loess (low runoff potential)
B  Sandy loam, shallow loess (low to moderate runoff potential)
C  Clay-loam, shallow sandy loam (moderate to high runoff potential)
D  Heavy plastic clay, swelling soil, silty soil (high runoff potential)

Wetness conditions

CN1  Dry but above wilting point
CN2  Average
CN3  Above field capacity, near saturation

Empirical equations exists to calculate CN1 and CN3 from CN2
Subsurface flow

Infiltration

Upper soil layers

Percolation

Lateral flow

Loss

Deep aquifer

Shallow aquifer

Return flow
Groundwater flow

(Slide from W. Bauwens, 2006)
Erosion

- Modified Universal Soil Loss Equation (MUSLE)

\[ Y = 11.8 \left( V q_p \right)^{0.56} (K)(C)(PE)(LS) \]

- \( V \) = surface
- \( q_p \) = is the peak flow rate
- \( K \) = erodibility factor
- \( C \) = crop management factor
- \( PE \) = the erosion control practice factor
- \( LS \) = slope length and steepness factor.
Crop processes

- Planting
- Plant growth: water, nutrient uptake
- Harvesting, Grazing, Kill
Plant Growth
Nitrogen Cycle

Atmospheric N fixation

Symbiotic fixation

Fertilizer

manures, wastes and sludge

NH₃

runoff

fertilizer

NH₄⁺

ammonium fixation

clay

N₂

N₂O

denitrification

anaerobic conditions

leaching

nitrification

SOIL ORGANIC

MATTER

immobilization

mineralization

immobilization

NH₄⁺

ammonia volatilization

N₂O

leaching
Soil Organic Matter

$\text{H}_2\text{PO}_4^-$

$\text{HPO}_4^{2-}$

manures, wastes, and sludge

mineralization

immobilization

Adsorbed and fixed Inorganic Fe, Al, Ca, and clay

fertilizer

runoff

Harvest

manures, wastes and sludge

Phosphorous Cycle
Pesticide dynamics

Foliar Application

Degradation

Washoff

Surface Application

Infiltration

Leaching

Runoff

Degradation
Management

- Ponds, reservoirs
- Urban areas
- Agricultural management
Agricultural management (1)

- Crop Rotations
- Removal of Biomass as Harvest
- Conversion of Biomass to Residue
- Tillage / Biomixing of Soil
- Fertilizer Applications
- Grazing
- Pesticide Applications
- Filter strips
Agricultural management (2)

- Irrigation
- Subsurface (Tile) Drainage
- Water Impoundment (e.g. Rice)
Urban management

- Urban Areas
- Pervious/Impervious Areas
- Street Sweeping
- Lawn Chemicals
Data for SWAT

Ann van Griensven (UNESCO-IHE)
Data

- Weather data
  - Rainfall
    - Raingage and RADAR
  - Temperature
- Landuse data
  - Remote Sensing
- Land management
- Soils and its attributes
- Streamflow (quantity)
- Water quality
Databases in swat2005.mbd

- Soil
- Land cover / plant growth
- Tillage
- Fertilizer
- Pesticide
- Urban
- Weather generator
GIS integration
Data preparation (1)

- GIS maps:
  - DTM
  - Land use
  - Soil

- Databases (in swat2005.mdb)
  - Userwgn.dbf
  - Usersoil.dbf
  - Crop.dbf -> create crop.dat
Data preparation (2)

- Lookup tables
  - For soil
  - For land use

- Soil map ↔ lookup table ↔ usersoil.dbf
- Land use map ↔ lookup table ↔ crop.dbf
Preparing landuse data

Landuse

Look up table

Database (crop.dbf)

Landuse legend (raw)
Reclassified/overlaid Landuse
Data preparation (3)

- Rainfall data
  - Table with station names and locations (batch files)
  - Data file for each station

- Temperature data
  - Table with station names and locations
  - Data file for each station
Rainfall data file format
Temperature data file format
Data preparation (4)

- Climate stations
  - Table with station names and locations (batch file)
  - Userwgn.dbf with data for each station
Climate stations

Batch file

Userwgn.dbf

Microsoft Excel - wgnstations.dbf

Microsoft Excel - userrwn.dbf

Microsoft Excel - userwgn.dbf
Userwgn.dbf (long term climatic condition)

Rainfall Statistical parameters derivation

- Use pcpSTAT.exe
- Use ASCII text file format to create Input file (e.g. R002.txt)
- The line of input data file must be a blank
- One column of rainfall data values
- The record should start Jan 1 and End Dec. 31
- The missing rainfall values should be assigned -99.0

The outputs (e.g. R002.out)

- File 1 → R002.out: Statistical Analysis of Daily Precipitation data. Directly used in userwgn.dbf
- File 2 → mean_pcp.st: Average Daily precipitation in Month
- File 3 → totalpcp.sta: Total Monthly precipitation
Subbasin:

Input
- .sub: subbasin (area,...)
- .wgn: weather information (#gage or generate)
- .wus: water use
- .pnd: pond

Output: output.sub
HRU:

Input
- .hru: HRU information (area,...)
- .sol: sol data
- .chm: chemical composition soils
- .gw: groundwater
- .mgt: agricultural management (Curve number!)

Output: output.hru
River routing:

Input:
- .rte: river routing input (morphology, manning, ...)
- .swq: stream water quality

Output: output.rte
SWAT i/o files:

../Project/scenarios/default/sim#/txtinout
../Project/scenarios/default/sim#/tablesin
../Project/scenarios/default/sim#/tablesout
The use of SWAT within the Nile Basin

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Rainfall/runoff modelling
Rain gage data versus Satellite data: upper Kagera

<table>
<thead>
<tr>
<th></th>
<th>Calibration</th>
<th>Validation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ns</td>
<td>0.65</td>
<td>0.78</td>
</tr>
<tr>
<td>R²</td>
<td>0.67</td>
<td>0.79</td>
</tr>
<tr>
<td>RMSE</td>
<td>23.05</td>
<td>11.94</td>
</tr>
<tr>
<td>Volume deviation</td>
<td>-2.34</td>
<td>-3.55</td>
</tr>
</tbody>
</table>

Kagera Sub watershed

<table>
<thead>
<tr>
<th></th>
<th>Kagera</th>
<th>Sub watershed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (Km²)</td>
<td>8,393</td>
<td>8,393</td>
</tr>
<tr>
<td>Number of sub basins</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Number of HRUs</td>
<td>15</td>
<td>36</td>
</tr>
</tbody>
</table>
Rain gage data versus Satellite data: upper Kagera
Pangani River Basin (Ndomba)

Daily

R²=54.6%

Monthly

R²=65%

Annually IVF=100%

% of time discharge is equalled or exceeded

Average annual flow (m³/s)

Validation, R²=68%
Stochastic rainfall modelling: Kyoga

Results

Kyoga Basin
Limited gauging
Rainfall interpolation: Nzoia

Meteorological/Rainfall Stations
Nzoia and Yala Basins
Water scarcity
Drought indexes: upper Blue Nile

Lake Tana
-3.99 - 3
-2.99 - 2
-1.99 - 1
-0.99 - 0.5
-0.5 - 0.5
0.5 - 1
1 - 2
2 - 3

SMDI Jan, 2005
Water resources management...

*Jurgen Schuol & Karim Abbaspour*

**Blue water**

**Green water flow [mm/yr]**

- 1 - 50
- 51 - 150
- 151 - 250
- 251 - 400
- 401 - 550
- 551 - 700
- 701 - 850
- 851 - 1000
- 1001 - 1150
- 1151 - 1375

- Streams
- Lakes
- Countries
Erosion/sediment transport
Erosion transport in Pangani (Ndomba)

RESULTS AND DISCUSSIONS

SWAT simulations Vs Rating curve-sediment loads at 1DD1 (Annually), between January,1969 –December, 2005

Performance (TMC=28.7%).
• Rating curve demonstrates linearity
• SWAT model demonstrates nonlinearity i.e. Not all rainfalls deliver sediment to outlet
Blue Nile: Erosion transport
Getnet Dubale, UNESCO-IHE, 2009

- SWAT + SOBEK
Upper Kagera river: erosion
Environmental problems
Kirumi wetland
- Important part of ecosystem, supports lives of about 6000 people
- Situated on the lower end of the catchment
- It is important to include the wetland in the EFA process
Scenario analysis
DPSIR

- Driving force
- Pressure
- State
- Impact
- Response
Climate change and land use change impacts

Scenario 1 – year 2020

Scenario 2 – year 2020
Climate change and land use change impacts
Performances
Thank you!