Introduction to Soil and Water Assessment Tool (SWAT)

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Texas A&M University
SWAT model is developed by USDA-ARS and Texas A&M AgriLIFE Research

Webinar Logistics

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Water Quality Modeling Webinar Series

• Purpose: To help water quality professionals better understand water quality modeling and how models can be used to solve the problems facing water quality regulators.

• 12 webinars to date

• Webinars recorded and posted: https://www.epa.gov/tmdl/tmdl-modeling

Audience

• Water quality professionals

• Clean Water Act (CWA) regulators: TMDL, standards, wetlands, assessment, permitting, etc.

• Scientists, engineers, managers, students, attorneys

• Assumptions for audience members:
  • Have an understanding of basic hydrology, water quality, and land use principles, such as eutrophication, flow calculations, erosion processes, etc.

Introduction

• Raghavan Srinivasan
  • Regents Professor in Agricultural Engineer and Ecosystem Science and Management at Texas A&M University
  • 25 years experience
  • Led watershed modeling efforts to support numerous TMDLs, watershed management, and water protection plan efforts throughout the U.S. and around the world.

Introduction to Soil and Water Assessment Tool (SWAT)

SWAT model is developed by USDA-ARS and Texas A&M AgriLIFE Research
Why Models?

- To understand the river basin processes
- Status and trend of the river basin resources
- Quantify pressure from various sources
- Identify impacts due to pressures
- Evaluate the response of the river basin due to pressure reduction measures
- Use of models to optimize and enhance monitoring network

**General Description**

- Continuous Time
- Daily Time Step
- One Day — Hundreds of Years
- Distributed Parameter
- Comprehensive – Process Interactions
- Simulate Management
- Readily available input – Physically based

**Landscape Routing**

- Landscape Positions
  - (Flood Plain, Hillslopes, Divide)
- Riparian Zones

**Atmosphere, Soil, Climate, Land and Management**

**Yield**
- Plant Stress
- Weather

**Soil properties & attributes**
- Physical/chemical
- [terraces, waterways, subsurface drains, buffers, windbreaks, etc.]

**Crops (100+)**
- Crop sequences
- Cover crops
- Crop rotations

**Equipment (236)**
- Tillage
- Application (fertilizer, planters, tractors, harvesters)

**Fertilizers**
- Chemical and Manure

**Pesticides**
- Irrigation

**Sowing**
- Date
- Row spacing
- Plant population

**Landscape Units**

**SWAT Watershed System**

- Flood Plain
- Riparian Zone
- Hillslope HRUs

**SWAT**

http://swat.tamu.edu
ARS – Station G (Brushy Creek) at Riesel, Texas 1,734 ha

**Catena**
Three landscape units, divide hillslope, bottom valley

**Lumped**
One soil, land use

**Slope per grid**

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**SWAT Setup Configuration Examples**

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**Upland Processes**
- Weather
- Hydrology
- Sedimentation
- Plant Growth
- Nutrient Cycling
- Pesticide Dynamics
- Management
- Bacteria

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**Management**

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**Hydrologic Balance**
- Evaporation and Transpiration
- Surface Runoff
- Lateral Flow
- Return Flow
- Runoff from shallow aquifer
- Return to shallow aquifer
- Recharge to deep aquifer

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**Nitrogen Cycle**
- Atmospharic N fixation (lightning arc discharge)
- Symbiotic fixation
- Manures, wastes
- Fertilizer
- Harvest
- NH₃ volatilization
- Runoff
- Leaching
- Anaerobic conditions
- N₂O
- Denitrification
- Ammonia volatilization
- Nitrogen fixation
- NH₄⁺
- N₂
- NO
- NO₂⁻

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**Channel Processes**

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**SWAT Inputs and Outputs**

**Input Data**
- Soils
- Climate
- Precipitation
- Land Use/Vegetation Cover
- Topography
- Watershed or Subbasin Delineation
- Crop or Land Management
- Ponds or Reservoirs/Withdrawals
- BMPs
- Point source Pollution
- Atmospheric Deposition (wet/dry)

**Water Quality Outputs**
- Stream flow
- Sediment
- Organic N
- Organic P
- Nitrate
- Nitrite
- Ammonium
- Soluble P
- Pesticides
- CBOD
- Algae
- Dissolved Oxygen
- Bacteria
- Conservative Metals

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**SWAT Model Predictions**

(Daily, Monthly, Annual)
- Evapotranspiration
- Soil Water
- Runoff
- Infiltration
- Subsurface Flows
- Aquifer Recharge
- Irrigation Demand
- Stream Flows
- Sediment Yield
- Reservoir Levels
- Sedimentation
- Crop Biomass
- Crop Leaf Area
- Soil Fertility
- Fertilizer Demand
- Nutrient Losses
- Pesticide Losses
- Grazing Management
- Preferential Grazing
- Dairy and Feedlot Manure
- More

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**Additional User Options to setup SWAT**

- PET (Potential Evapotranspiration): *Penman-Monteith, Priestly-Taylor, or Hargreaves*
- Runoff: *Curve Number or Green & Ampt method*
- Channel Flow: *Variable Storage Coefficient or Muskingham-Cunge*
- Channel Water Quality: *QUAL2E On-Off Switch*

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**More User Options**

- ARC GIS 10.x (ArcSWAT)
- QGIS (Public Domain GIS) (QSWAT)
- SWAT-CUP (Calibration and Uncertainty Program)
- VIZSWAT (Output Visualization)
- Manuals in English, Spanish, Chinese, Korean, Portuguese

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**SWAT Strengths**

Upland Processes
- Comprehensive Hydrologic Balance
- Physically-Based Inputs
- Plant Growth – Rotations, Crop Yields
- Nutrient Cycling in Soil
- Land Management - BMP
  - Tillage, Irrigation, Fertilizer, Pesticides,
  - Grazing, Rotations, Subsurface Drainage,
  - Urban-Lawn Chemicals, Street Sweeping

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**SWAT Strengths & Limitations**

Channel Processes
- Flexible Watershed Configuration
- Water Transfer—Irrigation Diversions
- Sediment Deposition/Scour
- Nutrient/Pesticide Transport
- Pond, Wetland and Reservoir Impacts

Limitations
- Lake water quality modeling is simple
- Only sediment and flow can be simulated sub-daily
- Urban Conservation practices are limited and continue to improve
North Central Texas
Water Quality Project
Assessment of Cost-Effective BMPs to reduce TP level using SWAT in Cedar Creek Watershed, TX
Watershed Protection Plan Development
http://nctx-water.tamu.edu/

TRWD Reservoir and Watershed System

Water Quality Problem

Project Frameworks

Total N Loading (kg) by Land use
Total Phosphorous Reduction Goal

- Baseline (37 Years Average)

<table>
<thead>
<tr>
<th></th>
<th>Sediment (Ton)</th>
<th>Total N (Kg)</th>
<th>Total P (Kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Loading</td>
<td>450,000</td>
<td>1,419,380</td>
<td>188,670</td>
</tr>
</tbody>
</table>

35% TP reduction goal chosen by stakeholders after preliminary analysis of TP impacts on lake water quality.

- Practice Parameters
  - Filter Strips (15m width)
  - Grade Stabilization Structures
  - Grassed Waterways (In 33 subbasins with more than 75% Pasture)
  - Terrace (Cropland with >= 2% slope)
  - Conversion of Cropland to Grass – Pasture Planting
  - Prescribed Grazing

TP Reduction at 100% Adoption

<table>
<thead>
<tr>
<th>Practice</th>
<th>P Reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filter Strips (15m width)</td>
<td>-30.0</td>
</tr>
<tr>
<td>Grade Stabilization Structures</td>
<td>-2.3</td>
</tr>
<tr>
<td>Grassed Waterways (In 33 subbasins with more than 75% Pasture)</td>
<td>-2.0</td>
</tr>
<tr>
<td>Terrace (Cropland with &gt;= 2% slope)</td>
<td>-7.0</td>
</tr>
<tr>
<td>Conversion of Cropland to Grass – Pasture Planting</td>
<td>-35.0</td>
</tr>
<tr>
<td>Prescribed Grazing</td>
<td>-5.6</td>
</tr>
</tbody>
</table>

7 Selected BMPs from Economic Analyses

- Filter Strips: 50% adaptation rate
- Graded Stabilization Structures: 100% adaptation rate
- Critical Pastureland Planting (Grassed waterway): 20% adaptation rate
- Terrace: 15% adaptation rate
- WWTP (from level I to II): 100% adaptation rate
- Conversion Cropland to Grass: 20% adaptation rate
- Prescribed Grazing: 15.5% adaptation rate (62% from 25% Maximum)
- Total Reduction: 35% of TP (By adding up TP reduction)
TP Loading (kg/ha)

TP Loading by 6 BMPs
- Filter Strips
- Graded Stabilization Structures
- Terraces
- WWTP
- Conversion to Pasture
- Prescribed Grazing

TP Loading by 7 BMPs
- Filter Strips
- Graded Stabilization Structures
- Terraces
- WWTP
- Conversion to Pasture
- Prescribed Grazing

TP Loading by 8 BMPs
- Filter Strips
- Graded Stabilization Structures
- Terraces
- WWTP
- Conversion to Pasture
- Prescribed Grazing

Questions?

Urban Modeling Application
Comparing the Changes in Hydrology due to Different Development Regulations using Sub-Daily SWAT

Roger H. Glick, P.E., Ph.D.
Leila Gosselink, P.E.
Watershed Protection Department
City of Austin

LID Simulation Strategies

- SWAT sub daily simulation module
- Urban BMPs & LID (Green Infrastructure)

Study Watershed: Tributary to Gilleland Creek

City of Austin Ordinances:
Land Use & Controls

- Undeveloped [UND]
- Pre-Waterways Ordinances [Pre-ORD], <1974
  - No controls
  - Limited creek easements, >320 ac.
- Waterway Ordinance [WO], 1974-1986
  - Detention only
  - Wider easements, >320 ac
- Comprehensive Watershed Ordinance [CWO], 1986-present*
  - Detention and ½”+ sed-fil
  - Creek buffer and water quality transition zone, >320 ac
- Watershed Protection Ordinance [WPO], proposed
  - Detention and ½”+ sed-fil
  - Creek buffer, >64 ac (no WQTZ)

Undeveloped Land Use

Pre-Ord Land Use (<1974)
**WO Land Use (~1974-86)**

- Developed Conditions
  - Irrigation and fertilizer on lawns and commercial; except high slopes
  - Increased roughness & conductivity in channels
  - 100% of developed residential & commercial land treated by BMPs; some land uses excluded.
  - One large detention basin mid-basin (reach 9)

**Effects of Ordinances**

**CWO Land Use (1986-present)**

**WPO Land Use (proposed)**

**Model Scenarios**

- Developed Conditions
  - Irrigation and fertilizer on lawns and commercial; except high slopes
  - Increased roughness & conductivity in channels
  - 100% of developed residential & commercial land treated by BMPs; some land uses excluded.
  - One large detention basin mid-basin (reach 9)

**Impacts on Flooding**
Impacts on Erosion Potential

Gilkison Trib Cross-Section
Row 18

Impacts on Aquatic Life (cont.)

River Discharge Duration Curves

Conclusions of Urbanization study

- Development prior to regulations had negative impacts on flooding, erosion and aquatic life potential.
- Detention designed for large design rainfall events will not address the increased frequency of higher flow rates.
- Flood detention alone will not address issues of erosion and aquatic life (and may be detrimental).
- Austin regulations since CWO implementation have been beneficial with respect to flooding, erosion and aquatic life potential.

National Applications

- OMB requests for outcome-based reporting
- 2002 Farm Bill
- 40-fold increase in authorization for conservation programs call for better accountability
- Assessment to guide design and implementation of conservation programs
- 8-digit subbasins, APEX cultivated lands

CEAP Conservation Effects Assessment Program

- OMB requests for outcome-based reporting
- 2002 Farm Bill
- 40-fold increase in authorization for conservation programs call for better accountability
- Assessment to guide design and implementation of conservation programs
- 8-digit subbasins, APEX cultivated lands

CEAP
Conservation Effects Assessment Program


UMRB and OTRB – 12 digit simulations

- Scenarios on stover removal and switchgrass-miscanthus on marginal cropland
- Impact of stream flow, sediment and nutrients
- Estimation of grain yields, plant biomass and stover biomass yields
- Parameterized miscanthus and refined SWAT routines for switchgrass and miscanthus growth and yield

Questions?

What Is HAWQS?

- A national hydrology and water quality assessment system
- Spin-off of EPA HUMUS and USDA Conservation Effects Assessment Program (CEAP)
- Supports national-, regional-, and local environmental impact analyses
Number of Watersheds and HRUs in U.S. at different spatial scales

<table>
<thead>
<tr>
<th></th>
<th>8-Digit</th>
<th>10-Digit</th>
<th>12-Digit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Watersheds</td>
<td>2,110</td>
<td>15,479</td>
<td>83,015</td>
</tr>
<tr>
<td>Hydrologic</td>
<td>530,153</td>
<td>1,262,106</td>
<td>3,106,389</td>
</tr>
<tr>
<td>Response Units (HRU)</td>
<td>(~5.8 sq mi)</td>
<td>(~2.5 sq mi)</td>
<td>(~1 sq mi)</td>
</tr>
</tbody>
</table>

HUC 8 - Dallas County

Parts of 5 Subbasins

HUC 12 - Dallas County

43 Subbasins

HAWQS – highly visual and interactive

HAWQS – highly visual and interactive

Applications of HAWQS

Evaluate the impacts of
- Land/crop management (land use, fertilizer, tillage, crop rotations, irrigation, pesticides, etc.)
- Conservation practices (no-till, terraces, drainage systems, etc.)
- Pollution control (point, nonpoint, and atmospheric sources)
- Climate change and climate anomalies such as multi-year droughts (temperature, CO2, rainfall, etc.)
**Benefits of HAWQS**

- Public domain databases, tools, and technology, output visualization
- No GIS software or knowledge required
- "Standard" assessments through web-based architecture
- More complex analyses with additional desktop tools
- 90% reduction in time and effort for SWAT-based environmental assessments

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**National SWAT Applications**

- Simulated hydrologic and/or pollutant loss impacts of agricultural & municipal water use, tillage and cropping systems trends (HUMUS, USDA-NRCS, 1997)
- Assess benefits of different conservation practices at scale national scale (CEAP, USDA-NRCS, 2015)
- Perform U.S Environment Protection Agency Total Maximum Daily Load (TMDL) analyses for impaired waters (varies and on going)
- Quantify the impacts of climate change and climate anomalies such as multi-year droughts. (Johnson et. Al 2015, Fant et. Al 2017)
- U.S. Environmental Protection Agency HAWQS National Environmental Assessment (2017)

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**Next Generation of SWAT called SWAT+**

**SWAT+, a Completely Restructured Version of SWAT**

- Maintenance of code and input files
- Linkage of SWAT and other models
- Addition of new process subroutines

- HRUs, aquifers, channels, reservoirs, etc. are separate spatial objects → flexible spatial representation of interactions and processes within a watershed using "connect" files

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**SWAT+ Input Files**

- One file for each data type for each object
- One file for each data type with one line for each object
- Data files can be maintained as databases

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- FORTRAN - continue as language of choice for scientists/engineers.
- MODULAR - Extensive use of data structures and modules. Easier to maintain, link to other modules, and add process subroutines.
- RECODING - Spatial objects with new input/output data structure is complete. Continue recoding process subroutines and modules.

**VERSION CONTROL**

- Bit Bucket

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- Connect files → allow user to specify hydrograph output
- HRU-Soil and Plant
- Aquifer
- Channel
- Reservoir
- Export Coefficient
- Delivery Ratio
- Point Source
Watershed Configuration

- Subdivision of subbasins into HRUs
- Water areas defined as HRUs
- Separation of water and land areas within subbasins
- Water areas defined as ponds/reservoirs
- Definition of LSUs to aggregate HRUs
- HRUs represented by their entire area within a LSU during calculation of land phase processes
- More realistic simulation of water areas
- Improved simulation of landscape position, overland routing, and floodplain processes
- HRUs represented by a contiguous field with user-defined dimensions, actual HRU area used as expansion factor
- Calculation of land phase processes independent of HRU area

Advantages of SWAT+

- More realistic simulation of water areas
- Improved simulation of landscape position, overland routing, and floodplain processes
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Aquifers and Reservoirs

- Aquifers tied to HRUs
- Definition of one aquifer per HRU
- Any number of aquifers can be defined
- Facilitation of SWAT-MODFLOW linkage
- Placement of reservoirs as main channel at subbasin outlet
- Placement of reservoirs anywhere in the watershed
- More realistic representation of reservoir position and interactions with the landscape
- Any number of aquifers can be defined
- Facilitation of SWAT-MODFLOW linkage
- Placement of reservoirs as main channel at subbasin outlet
- Placement of reservoirs anywhere in the watershed
- More realistic representation of reservoir position and interactions with the landscape

Spatial Connections

- All spatial connections defined in one file (fig.fig)
- One connect file per spatial object to define outflow hydrograph, fractions, and receiving objects
- More flexibility in defining spatial interactions of objects within the watershed
- Easier to set up grid-based models

Advantages of SWAT+

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- Improved simulation of landscape position, overland routing, and floodplain processes
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SWAT is a product of over 50 years of USDA-ARS model development
More than 2900 peer reviewed articles were written in the development and use of the SWAT model for water quantity and quality research by the world wide user community
Partnership – Texas A&M, ARS, EPA, NRCS
Developing models, GIS, databases, applications
Public Domain with Source Code
Most Widely used for water quality, water supply, climate change, land use change

Questions?
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Questions?

Participation Certificate and Archive

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▪ Find future webinar registration links and a recording of today’s presentation on EPA’s Water Quality Modeling Workgroup Webpage:
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