Introduction to Soil and Water Assessment Tool (SWAT)

R. Srinivasan (r-srinivasan@tamu.edu)
Texas A&M University
SWAT model is developed by USDA-ARS and Texas A&M AgriLIFE Research

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Webinar Logistics

- To Ask a Question – Type your question in the "Questions" tool box on the right side of your screen and click "Send."
- To report any technical issues (such as audio problems) – Type your issue in the "Questions" tool box on the right side of your screen and click "Send" and we will respond by posting an answer in the "Questions" box.
- If you are experiencing audio quality issues using your computer speakers, please call into the phone number listed on your console.

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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

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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.

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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.

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Introduction to Soil and Water Assessment Tool (SWAT)

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

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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

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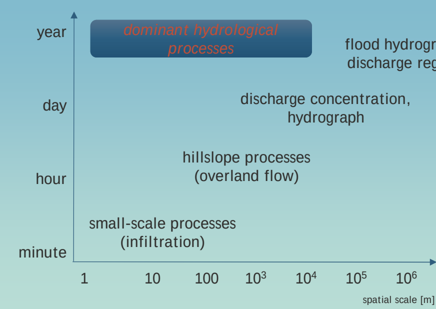

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SWAT http://swat.tamu.edu

General Description

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

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Atmosphere, Soil, Climate, Land and Management

Yield
Plant Stress
Water, Temp.,N, P

Environment concerns
Soil erosion, water ,N, P, Air (GHG)
Crop residues, Organic matter, Pesticides

Weather

Soil properties & attributes
Physical/chemical (terraces, waterways, subsurface drains, buffers windbreaks, etc.)

Crops (100+)
Crop sequence
Cover crops
Crop Rotations

Animal Prod.
Grazing
CAFO

Pesticides

Fertilizers
Chemical and Manure

Irrigation

Equipment (236)
Tillage, Application (fert/pest), Planters, tractors, harvesters

Sowing
Date
Row spacing
Plant population

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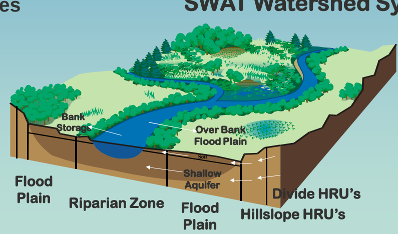
Landscape Routing

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

SWAT Watershed System



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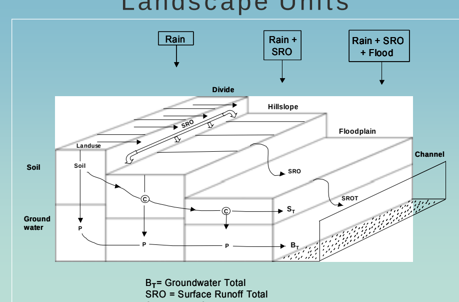
Landscape Units



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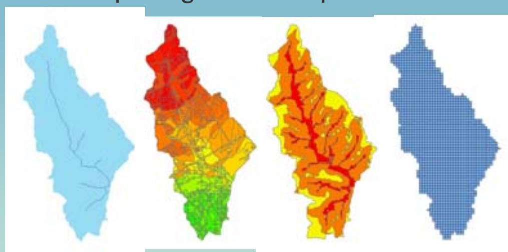
SWAT Setup Configuration Examples



Lumped
One soil, land use slope

HRU's
Lumped soil/land use overlay, no landscape routing

Catena
Three landscape units, divide Hillslope, valley bottom

Lumped
One soil, land use Slope per grid

ARS – Station G (Brushy Creek) at Riesel, Texas 1,734 ha

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SWAT

Upland Processes

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

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Soil & Water Assessment Tool SWAT

Management

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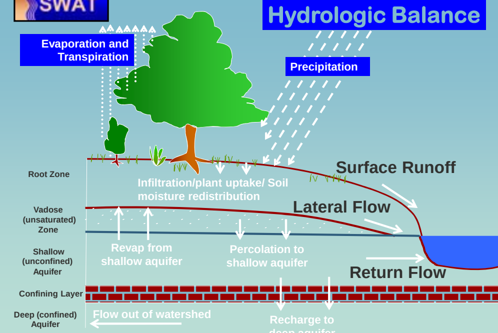
SWAT

Hydrologic Balance



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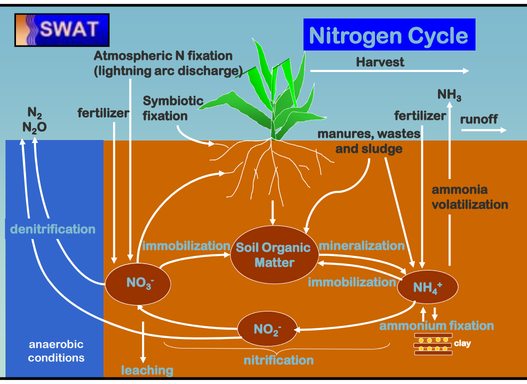
SWAT

Nitrogen Cycle



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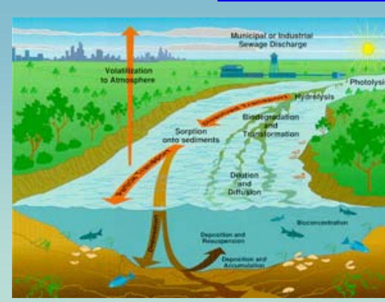
SWAT

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
- SWAT 2003, 2005, 2009, 2012, 2016

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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

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TMDL/WATERSHED PROTECTION PLAN

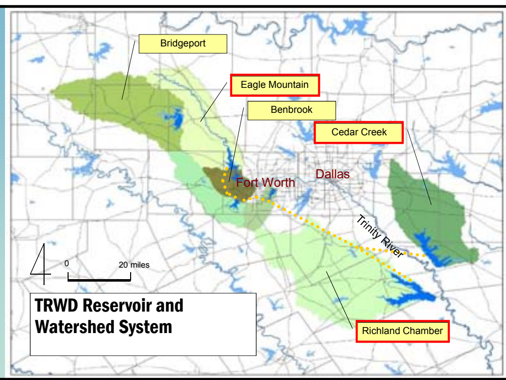
North Central Texas

Water Quality Project

Assessment of Cost-Effective BMPs to reduce TP level using SWAT in Cedar Creek Watershed, TX

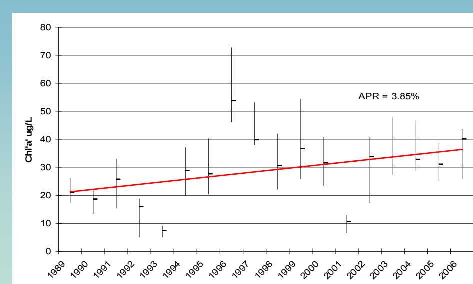
Watershed Protection Plan Development

http://nctx-water.tamu.edu/

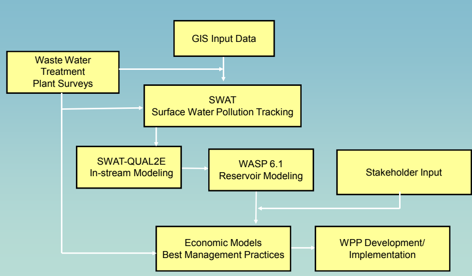


TRWD Reservoir and Watershed System

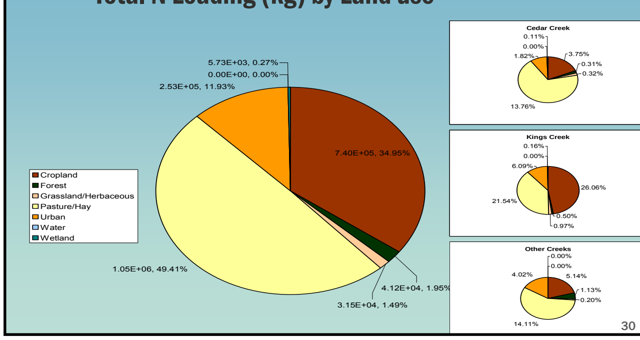
Water Quality Problem



Project Frameworks



Total N Loading (kg) by Land use



Total Phosphorous Reduction Goal

- Baseline (37 Years Average)

	Sediment (Ton)	Total N (Kg)	Total P (Kg)
Annual Loading	450,000	1,419,380	188,670

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

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BMPs studied in SWAT for this project

Practice	Parameters
Filter Strips (15m width)	filterw (.hru)
Grade Stabilization Structures	Slope > 3% → = 3%
Grassed Waterways (In 33 subbasins with more than 75% Pasture)	Manning's n → 0.15
Terrace (Cropland with >= 2% slope)	USLE P → 0.5, CN2 reduced by 3 (crop)
Conversion of Cropland to Grass – Pasture Planting	Land use change, CN2 change by soil
Prescribed Grazing	USLE C → 0.003

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TP Reduction at 100% Adoption

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

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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)**

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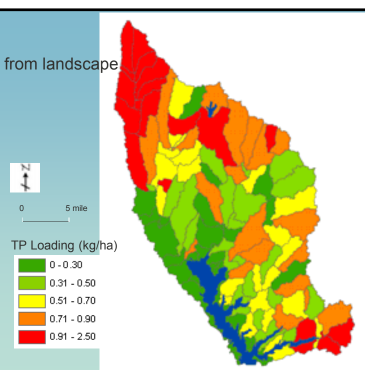
Baseline TP from landscape



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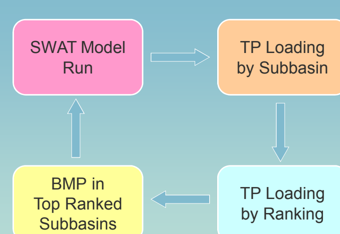

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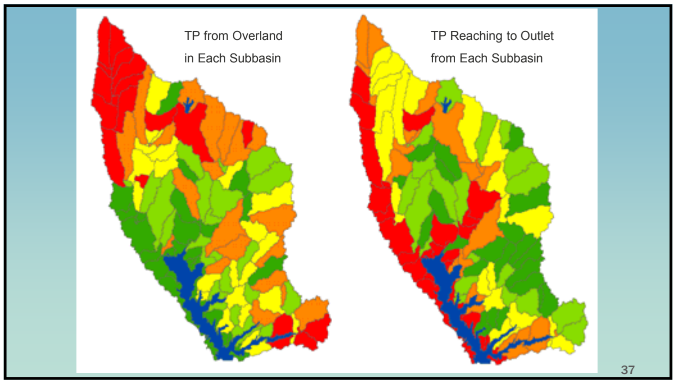
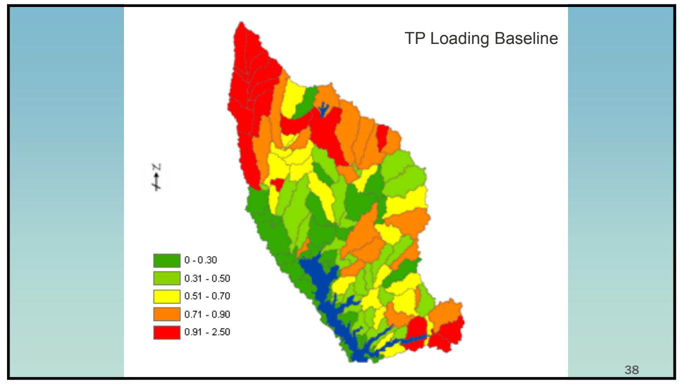
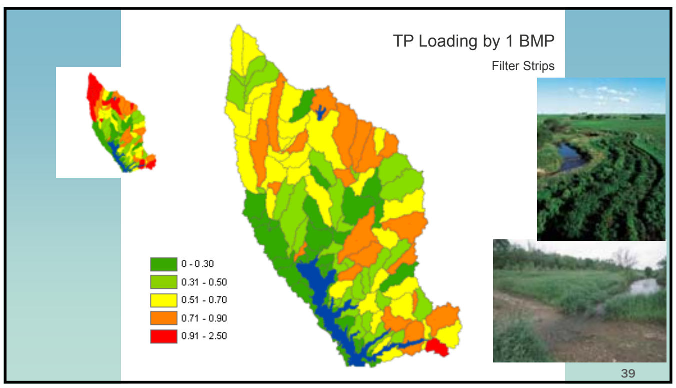
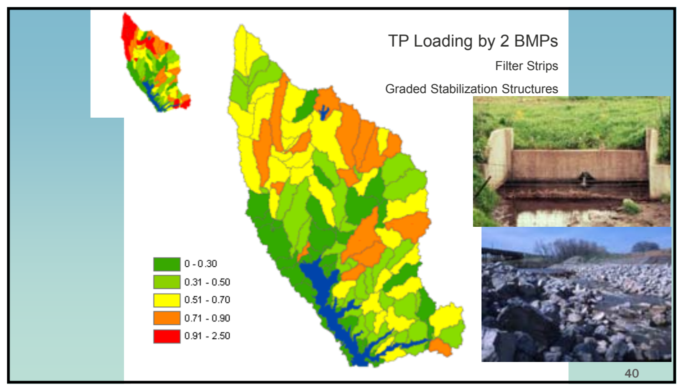
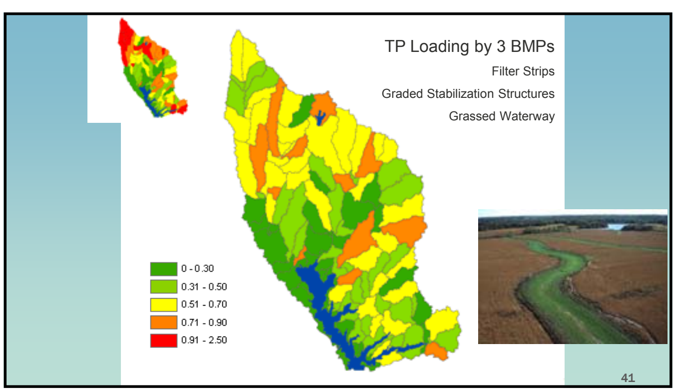
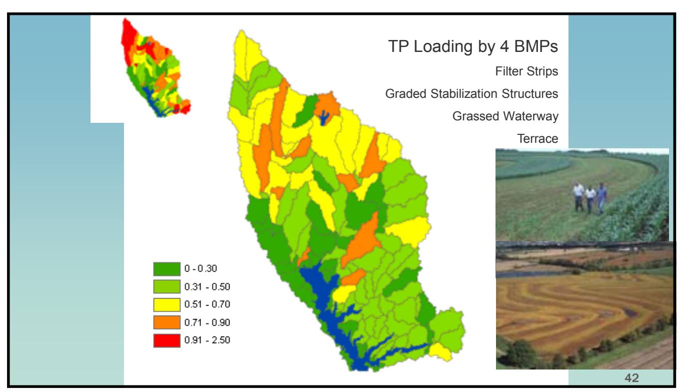

TP from Overland
in Each Subbasin
TP Reaching to Outlet
from Each Subbasin
37


TP Loading Baseline
N
0 - 0.30
0.31 - 0.50
0.51 - 0.70
0.71 - 0.90
0.91 - 2.50
38


TP Loading by 1 BMP
Filter Strips
0 - 0.30
0.31 - 0.50
0.51 - 0.70
0.71 - 0.90
0.91 - 2.50
39

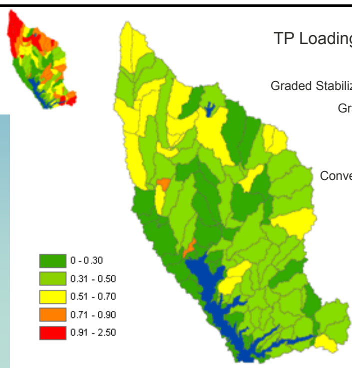

TP Loading by 2 BMPs
Filter Strips
Graded Stabilization Structures
0 - 0.30
0.31 - 0.50
0.51 - 0.70
0.71 - 0.90
0.91 - 2.50
40


TP Loading by 3 BMPs
Filter Strips
Graded Stabilization Structures
Grassed Waterway
0 - 0.30
0.31 - 0.50
0.51 - 0.70
0.71 - 0.90
0.91 - 2.50
41


TP Loading by 4 BMPs
Filter Strips
Graded Stabilization Structures
Grassed Waterway
Terrace
0 - 0.30
0.31 - 0.50
0.51 - 0.70
0.71 - 0.90
0.91 - 2.50
42

TP Loading by 6 BMPs

Filter Strips
Graded Stabilization Structures
Grassed Waterway
Terrace
WWTP
Conversion to Pasture



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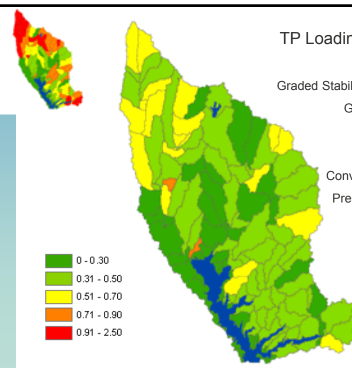
TP Loading by 7 BMPs

Filter Strips
Graded Stabilization Structures
Grassed Waterway
Terrace
WWTP
Conversion to Pasture
Prescribed Grazing 1



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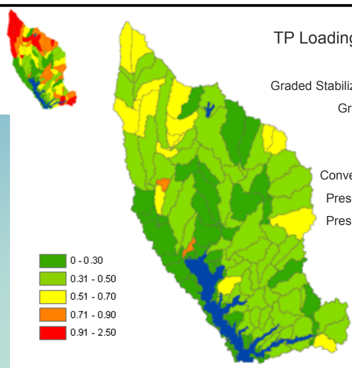
TP Loading by 7 BMPs

Filter Strips
Graded Stabilization Structures
Grassed Waterway
Terrace
WWTP
Conversion to Pasture
Prescribed Grazing 1
Prescribed Grazing 2



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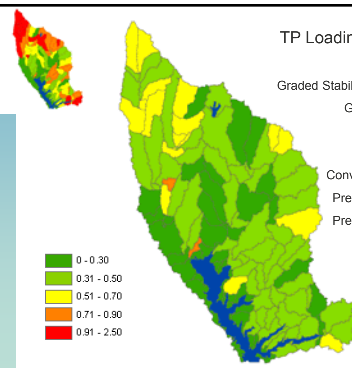
TP Loading by 8 BMPs

Filter Strips
Graded Stabilization Structures
Grassed Waterway
Terrace
WWTP
Conversion to Pasture
Prescribed Grazing 1
Prescribed Grazing 2
2000 Ft Buffer



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Questions?

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Urban Modeling Application

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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

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LID Simulation Strategies

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

Sub daily model
- ✓ SWAT modules for sub-hourly simulation
- ✓ Overland flow, stream flow, ponds, reservoirs, and point sources
- ✓ Soil erosion and sediment transport

Urban BMPs
- ✓ Sedimentation-Filtration basin
- ✓ Retention-Irrigation basin
- ✓ Detention pond
- ✓ Wet pond

Green Infrastructure
- ✓ Green roof
- ✓ Rain garden
- ✓ Cistern
- ✓ Porous pavement

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Study Watershed: Tributary to Gilleland Creek

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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)

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Undeveloped Land Use

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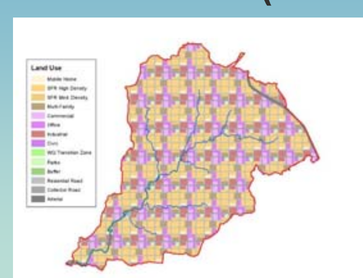
Pre-Ord Land Use (<1974)



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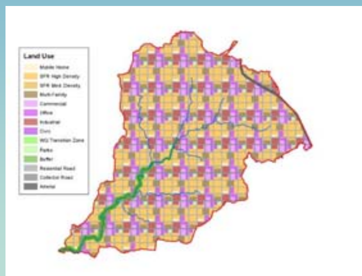
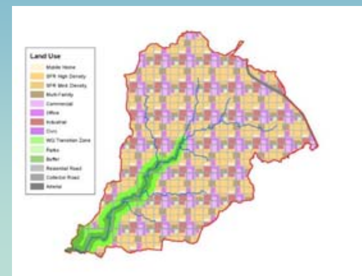
WO Land Use (~1974-86)



CWO Land Use (1986-present)



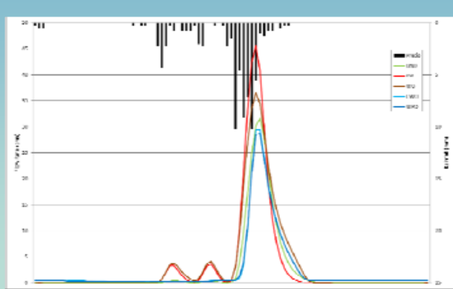
WPO Land Use (proposed)

Model Scenarios

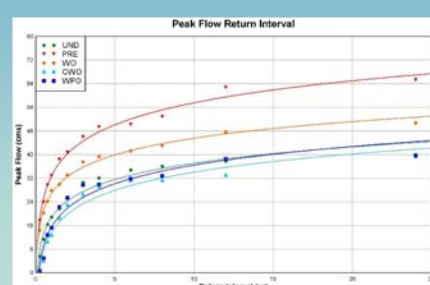
Developed Conditions

- 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)

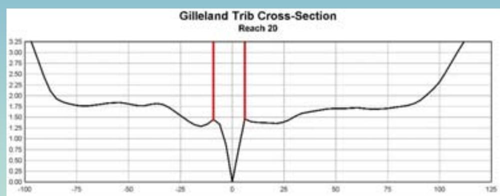
Effects of Ordinances



Impacts on Flooding



Impacts on Erosion Potential



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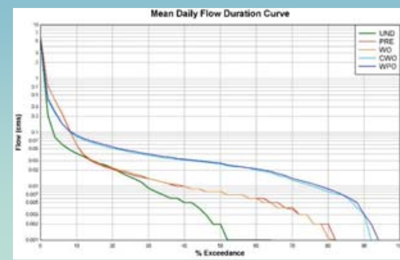
Impacts on Aquatic Life (cont.)



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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.

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National Applications

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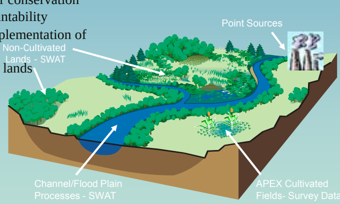
CEAP
Conservation Effects Assessment Program

- 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



https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/nra/ceap/

https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/nra/ceap/na/

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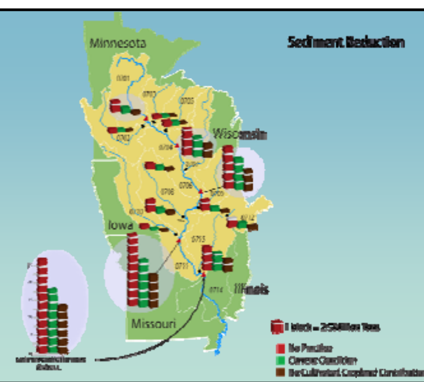

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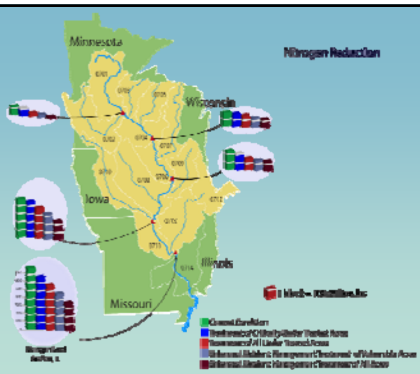
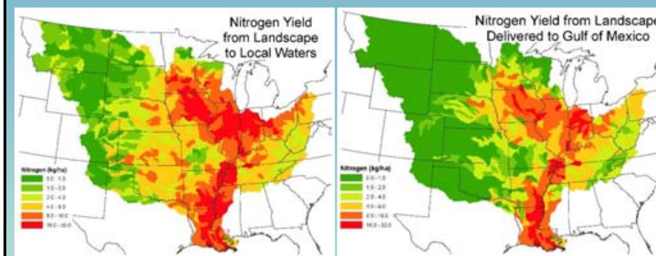


Mississippi River Basin



Nitrogen – Local and Delivered

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


Journal of Hydrology

A refined regional modeling approach for the Corn Belt – Experiences and recommendations for large-scale integrated modeling

Questions?

HAWQS

Hydrologic and Water Quality System

Design, Development and Deployment

Project Sponsored by US Environmental Protection Agency, Office of Water

R. Srinivasan
Texas AgriLife Research
Texas A&M University

J. Arnold
USDA-Agricultural Research Service
Grassland, Soil and Water Research Lab

http://epahawqs.tamu.edu

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

	8-Digit	10 -Digit	12- Digit
Watersheds	2,110	15,479	83,015
Hydrologic Response Units(HRU)	530,153 (~5.8 sq mi)	1,262,106 (~2.5 sq mi)	3,106,389 (~1 sq mi)

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HUC 8 - Dallas County

Parts of
5 Subbasins

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HUC 12 - Dallas County

43 Subbasins

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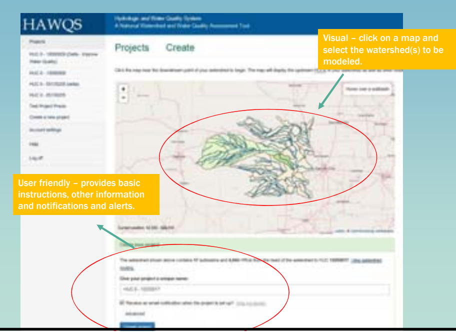
HAWQS – highly visual and interactive



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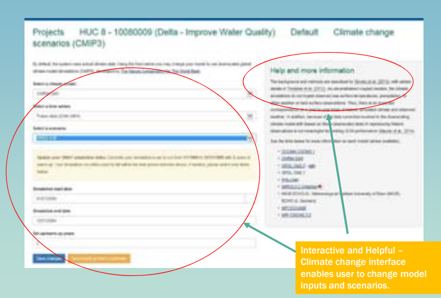
HAWQS – highly visual and interactive



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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.)

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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+

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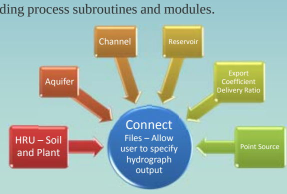
- FORTRAN - continue as language of choice for scientists/engineers.
- MODULAR – Extensive use of data structures and modules. Easier to maintain, link to other models, and add process subroutines.
- RECODING - Spatial objects with new input/output data structure is complete. Continue recoding process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

- VERSION CONTROL – Bit Bucket



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SWAT+ Input Files

SWAT	SWAT+	Advantages of SWAT+
• One file for each data type for each object	• One file for each data type with one line for each object	• Reduced number of input files • Decrease in run time • Data files can be maintained as databases

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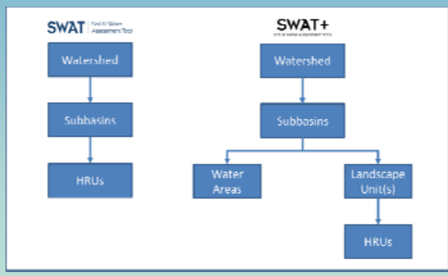
Watershed configuration



Watershed Configuration

SWAT	SWAT+	Advantages of SWAT+
• 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	• More realistic simulation of water areas • Improved simulation of landscape position, overland routing, and floodplain processes
• HRUs represented by their entire area within a LSU during calculation of land phase 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

Aquifers and Reservoirs

SWAT	SWAT+	Advantages of SWAT+
• Aquifers tied to HRUs • Definition of one aquifer per HRU	• Aquifers independent from HRUs	• Any number of aquifers can be defined • Facilitation of SWAT-MODFLOW linkage
• Placement of reservoirs on 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

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

Tested Extensively and Proven Technology

- 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?

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Participation Certificate and Archive

- If you would like to obtain participation certificates, type the link below into your web browser:

  http://www.tetratech-ffx.com/certificate/certificate12.pdf

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

  https://www.epa.gov/tmdl/tmdl-modeling

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