SWAT Peer-Reviewed Literature: A Review

by

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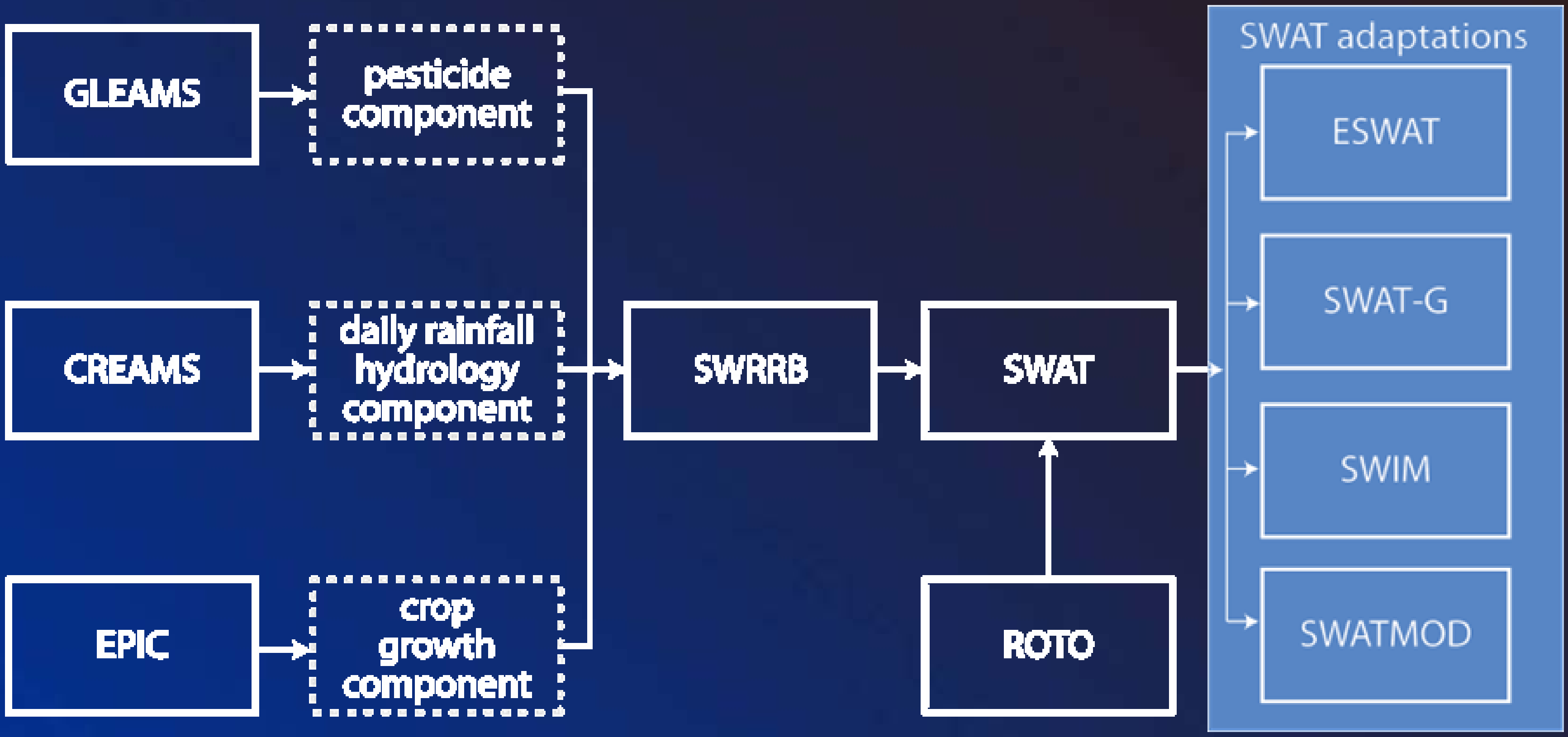
Presentation Overview

- SWAT History: key model development steps, interface developments, HUMUS system
- Brief overview of current set of SWAT papers
- Applications by subcategories including some examples
- Research needs

SWAT History

- SWAT development is a continuation of 30 years of USDA-ARS modeling experience
  - direct descendent of the SWRRB model
- First paper that reports use of SWAT published in 1993
- Major versions: SWAT94.2, SWAT96.2, SWAT98.1, SWAT99.2, SWAT2000
  - Now SWAT2003

SWAT History: Schematic of SWAT Development including well-known SWAT Adaptations



ESWAT

- van Griensven and Bauens (2001) and other papers

  - incorporates QUAL2E components; designed for integrated water quality studies

  - have performed sub-daily assessments of DO and other parameters

  - includes an automatic calibration routine

SWAT-G

- Modified version of SWAT99.2 (Eckhardt et al. 2002)
- More accurately simulates low mountain watersheds in Germany
- includes greater stomatal conductance sensitivity to atmospheric CO_2 – f(5 plant species)
- Incorporated RUSLE erosion equation

SWIM

- Derived from SWAT and the MATSALU model (Krysanova et al. 2005)
- Incorporates key hydrological processes applicable at both the mesoscale (100 – 10,000 km^2) and macroscale (> 10,000 km^2) watershed levels
- Similar to SWAT in many respects

GIS Interface Developments

- SWAT/GRASS was the original interface (Srinivasan & Arnold, 1994)
- ArcView-SWAT (AVSWAT) is now more widely used (Di Luzio et al., 2004)
- Automated Geospatial Watershed Assessment (AGWA) (Miller et al. 2002)
- Both AVSWAT and AGWA are imbedded in current version of USEPA BASINS package

GIS Interface Developments

- InputOutputSWAT (IOSWAT) (Haverkamp et al. 2005) incorporates several software tools:

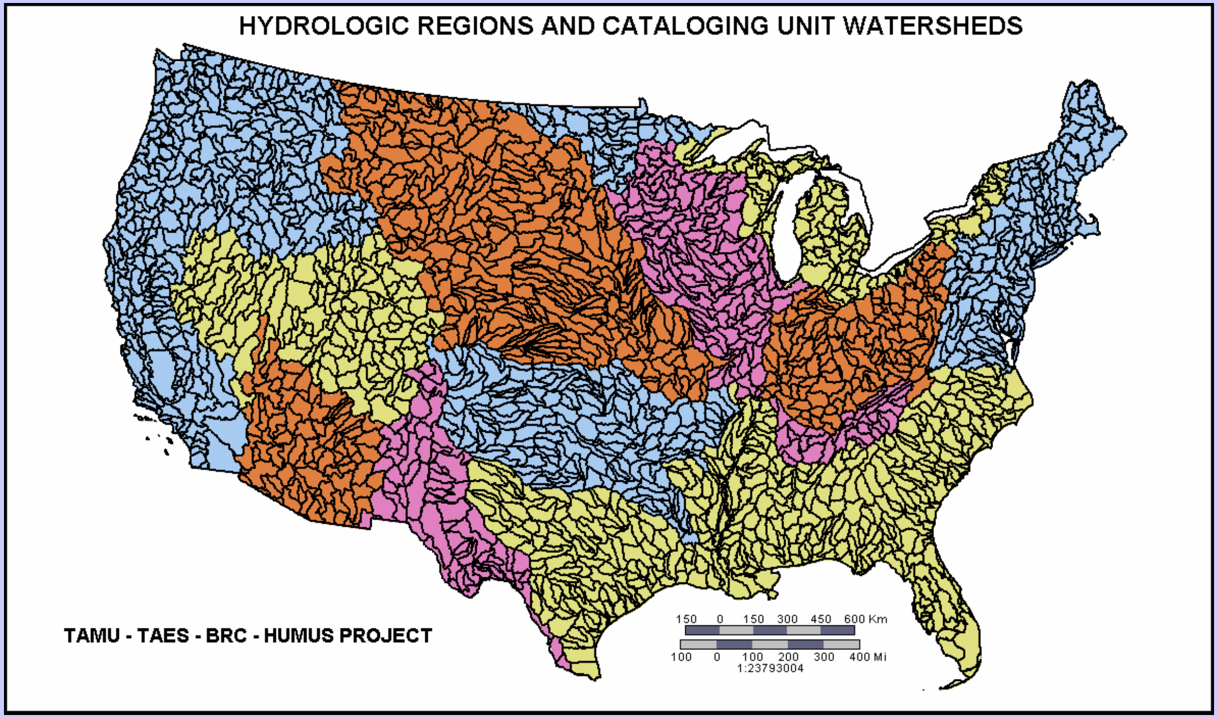
  - SWAT-G (or SWAT?), SWAT/GRASS, TOPAZ, SUSAT, and OUTGRASS

HUMUS I

- 1997 Resource Conservation Appraisal
  NRCS Report to Congress
- 2001 Interim RCA and National
  Conservation Program Update
- Validation of Flow and Sediment
- Scenarios
  Water Use-Buffers

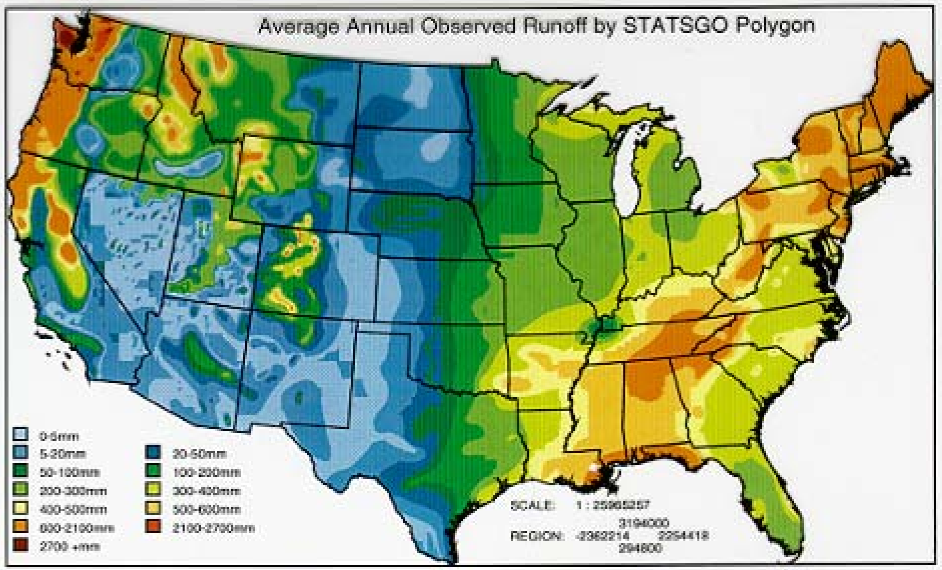
HUMUS II

SWAT River Basin Model
River Routing and Non-Ag Lands
Key Role in U.S. National CEAP Analysis

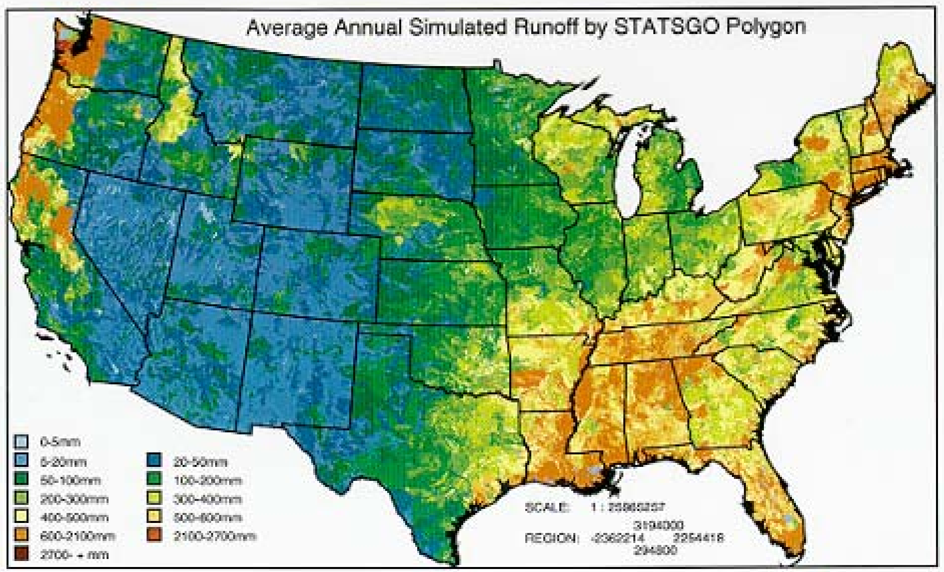


Validation of Flow and Sediment

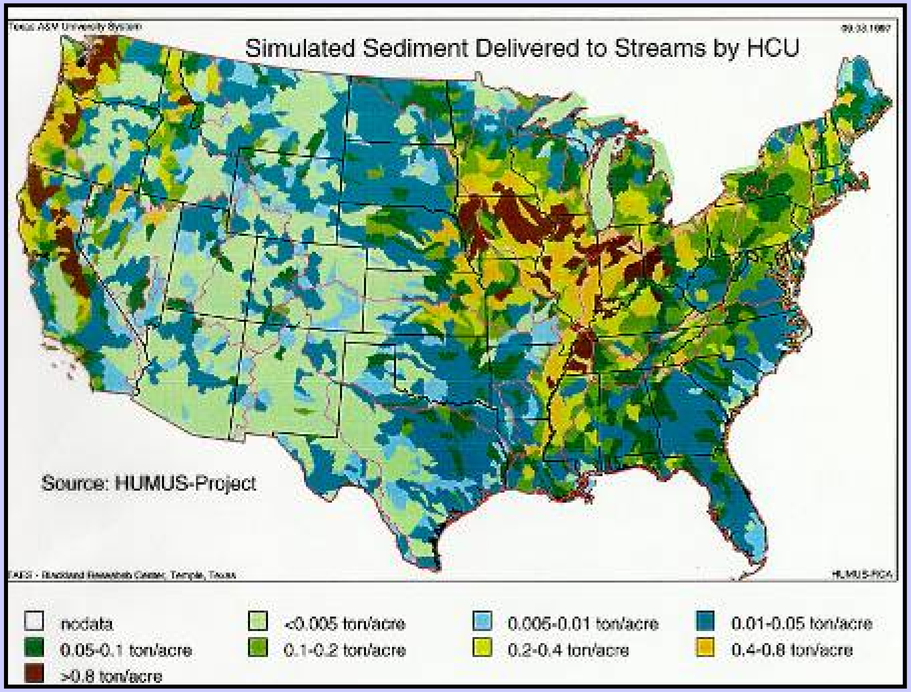
Observed (USGS)



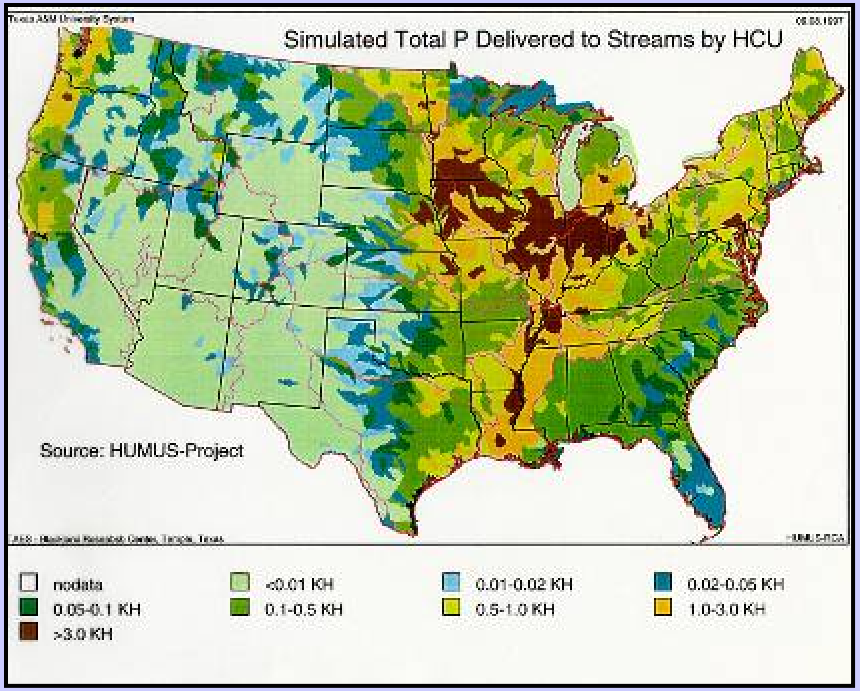
SWAT Simulated



HUMUS Results Point and Non Point Sources



Simulated Sediment Delivered to Streams by HCU



Simulated Total P Delivered to Streams by HCU

Current Status of Peer-Reviewed List

- 173 total articles on list (at least 5 more identified)

  - majority are cited in paper

- Two are in German; all others in English

- At least four are from published proceedings (quasi peer-reviewed?)

Current Status of Peer-Reviewed List

- Eight papers are general descriptions of SWAT or SWAT components, including comparisons with other models
- At least five papers have a “developmental” or pre-SWAT emphasis
  - e.g., SWRRB-ROTO description & baseflow separation approach
- Majority of remaining papers describe specific applications of SWAT or SWAT adaptations

SWAT Applications Overview

Primary Application Category	Flow Only	Flow & Pollutants
Hydrologic assessments	29	-
Climate change	21	3
Pollutant losses	-	21
Calibration techniques	5	3
HRU & other input effects	12	11
Interfaces with other models	6	9
Comparisons with other models	4	2
Adaptations of SWAT	14	7

Hydrologic Studies
Peer-Reviewed Papers

Hydrologic Studies

- Several hydrologic components in SWAT were developed and evaluated within EPIC, CREAMS, GLEAMS and SWRRB and excluded in the review

Country Geographic Count Alphabetically Arranged Likely More

Australia

1

Hydrologic Studies

- Sun and Cornish (2005) simulated 30 years of bore data from a 437 km^2 catchment
- Used SWAT to estimate recharge in the headwaters of the **Liverpool Plains in NSW, Australia**
- Determined that SWAT could estimate recharge and incorporate land use and land management at the catchment scale as compared to using the point source modeling approach.

Canada

2

Hydrologic Studies

- Chanasyk et al. (2002) simulated the impacts of grazing on hydrology and soil moisture, respectively, using small grassland watersheds under three grazing intensities in **Alberta, Canada**. They evaluated SWAT's ability to simulate low flow conditions that included snow-melt events.

Hydrologic Studies

- Mapfumo et al. (2004) tested the model's ability to simulate soil-water patterns in small watersheds under three grazing intensities in **Alberta, Canada.** Overall, the model was adequate in simulating soil-water patterns for all three watersheds with a daily time-step

India

1

Hydrologic Studies

- Gosain et al. (2005) assessed SWAT’s ability to simulate return flow after the introduction of canal irrigation in a basin in **Andra Pradesh, India**. SWAT provided the assistance water managers needed in planning and managing their water resources under various scenarios.

Spain
1

Hydrologic Studies

- SWAT adequately simulated the changing from wetlands to dry land for the Upper Guadiana river basin, **Spain**
- Conan et al. (2003)

United States

18

Arizona
1

Hydrologic Studies

- Hernandez et al (2000) utilized existing data sets for parameterizing SWAT to simulate hydrologic response to land cover change for a small semi-arid watershed (150 km2) in **southeastern, Arizona**

Mississippi
1

Hydrologic Studies

- SWAT had reasonable runoff simulation for 10 years for a watershed in **Northern Mississippi** (Bingner 1996)

Illinois

1

Hydrologic Studies

- **Illinois watershed** - successfully validated surface runoff, groundwater flow, groundwater ET, ET in the soil profile, groundwater recharge, and groundwater height parameters (Arnold and Allen, 1996)

Kentucky
1

Hydrologic Studies

- **Central Kentucky**, Spruill et al. (2000) validated SWAT and found poor peak flow values and recession rate predictions. They found that a much larger area contributed to streamflow than was described by topographic boundaries

Maryland
1

Hydrologic Studies

Maryland watershed, SWAT unable to simulate an extremely wet year, and when removed SWAT simulation was acceptable (Chu and Shirmohammadi, 2004)

Oklahoma
3

Hydrologic Studies

- Van Liew and Garbrecht (2003) evaluated SWAT's ability to predict streamflow under varying climatic conditions for three nested subwatersheds in the Little Washita River Experimental Watershed in southwestern Oklahoma and **found that SWAT could adequately simulate runoff for dry, average, and wet climatic conditions in one subwatershed**

Hydrologic Studies

- Deliberty and Legates (2003) used SWAT to simulate soil moisture conditions in **Oklahoma**.

Hydrologic Studies

- The impact of flood retarding structures on streamflow with varying climatic conditions in **Oklahoma** was investigated with SWAT by Van Liew et al. (2003)

Texas
6

Hydrologic Studies

- Interactions between surface and subsurface flow was developed by Arnold et al. (1993)
- Validated in a 471 km^2 in **Waco, TX**

Hydrologic Studies

- SWAT was used to identify water quality monitoring sites on a watershed in **Central Texas**, (Rosenthal and Hoffman, 1999)

Hydrologic Studies

SWAT streamflow was successfully validated for **Mill Creek watershed in Texas** (Srinivasan, et al., 1998a and 1998b)

Hydrologic Studies

- SWAT was applied to simulate wetland near **Dallas, TX** (Arnold 2001).

Hydrologic Studies

- Arnold et al. (1999) integrated GIS with SWAT to evaluate stream flow and sediment yield data in the **Texas Gulf Basin** with drainage areas ranging from 10,000 to 110,000 km2. Stream flow data from approximately 1,000 stream monitoring gages from 1960 to 1989 were used to calibrate and validate the model. Predicted average monthly stream flow data from three six-digit HUA were 5% higher than measured flows with standard deviations between measured and predicted within 2%

Wyoming
1

Hydrologic Studies

- Modifications performed by Fontaine et al. (2002) have clearly improved the snowmelt routine, as evidenced by an NSE increase from -0.70 to 0.86 for a six-year SWAT simulation of the **Upper Wind River Basin in Wyoming**.

Regional
3

Hydrologic Studies

- Groundwater recharge and discharge (base flow) results from SWAT were compared to filtered estimates for the 491,700 km^2 **Upper Mississippi River Basin** (Arnold et al., 2000)

Hydrologic Studies

Monthly streamflow was also validated against USGS flow at several gaging stations **across the US** (Arnold et al., 2000)

Hydrologic Studies

- As part of HUMUS annual runoff and ET were validated across the **entire US** using SWAT (Arnold et al., 1999)

Pollution Studies
Peer-Reviewed Papers

Pollution Studies

- Pollutant loss estimations are described in roughly 50 of the peer-reviewed papers

Pollution Studies

- Only one validation was conducted on pesticides

Pollution Studies

- Skip due to lack of time

Comparisons with other Watershed Models

Comparisons with other Watershed Models

- Shepherd et al. (1999) evaluated 14 models and found SWAT to be the most suitable for estimating phosphorus loss from a lowland English catchment

Comparisons with other Watershed Models

- **El-Nasr et al. (2005) found that both SWAT and MIKE-SHE simulated the hydrology of Belgium's Jeker river basin in an acceptable way.** However, MIKE SHE predicted the overall variation of river flow slightly better

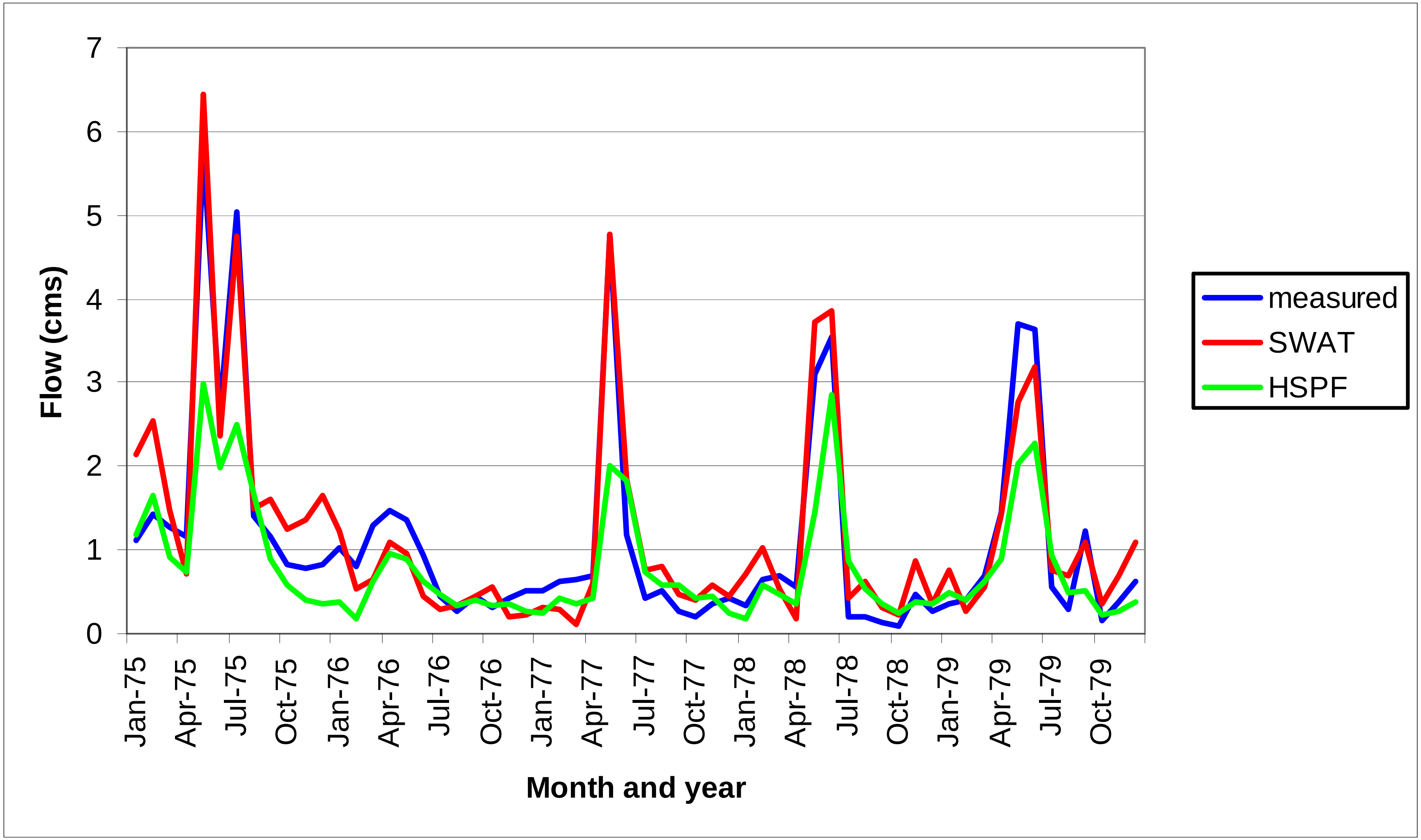
Comparisons with other Watershed Models

- Borah and Bera (2003; 2004) compared SWAT with several other watershed-scale models. In the 2003 paper, they report that DWSM, HSPF, SWAT, and other models have hydrology, sediment, and chemical routines applicable to watershed scale catchments, and **concluded that SWAT is a promising model for continuous simulations in predominantly agricultural watersheds**.

Comparisons with other Watershed Models

- Van Liew et al. (2003) compared the streamflow predictions of SWAT and HSPF on eight nested agricultural watershed within the Washita River Basin in southwestern Oklahoma. They found that differences in model performance were mainly attributed to the runoff production mechanisms of the two models. Furthermore, they **concluded that SWAT gave more consistent results than HSPF in estimating streamflow for agricultural watersheds under various climatic conditions and may thus be better suited for investigating the long term impacts of climate variability on surface water resources**

Monthly Measured vs. Predicted Streamflows for Subwatershed 522 within the Little Washita River Watershed, Oklahoma, USA



Adapted from Van Liew et al. 2003. Hydrologic simulation on agricultural watersheds: choosing between two models. *Trans. ASAE* 46(6):1539-1551

Comparisons with other Watershed Models

- Saleh and Du (2004) calibrated SWAT and HSPF with daily flow, sediment, and nutrients measured at five stream sites of the Upper North Bosque River watershed located in Central Texas. **They concluded that the average daily flow, sediment and nutrient loading simulated by SWAT were closer to measured values than HSPF during both the calibration and verification periods**.

Calibration / Sensitivity Analysis

- 2 papers report surface runoff / baseflow separation techniques

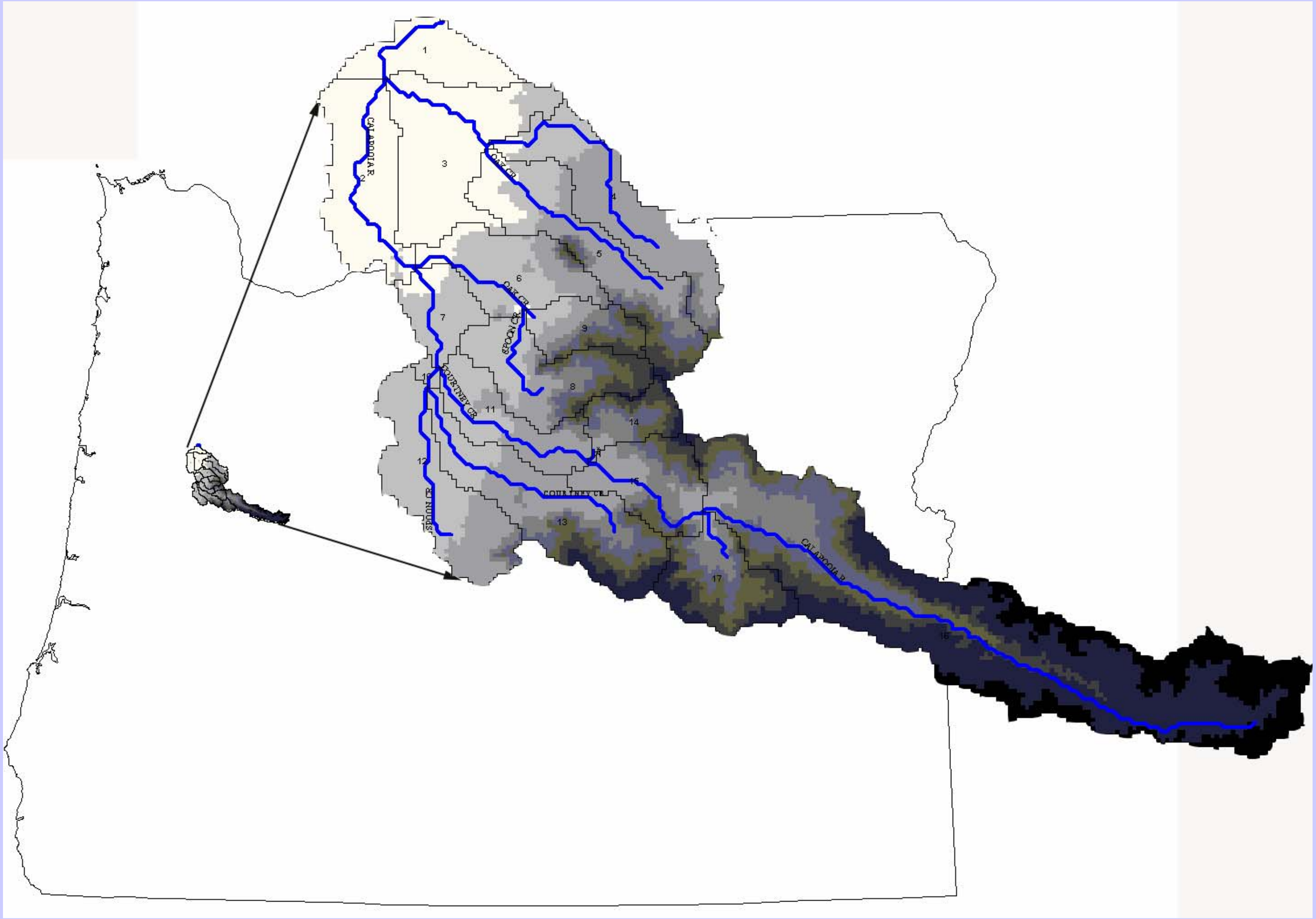
- Both general statistical procedures and auto-calibration techniques reported (especially with ESWAT & SWAT-G)
  - Monte Carlo approaches
  - **Shuffled Complex Evolution method**
  - PEST nonlinear parameter estimator

National Forage Seed Production Research Center (NFSPRC), Corvallis, Oregon, USA **Beowulf Cluster**

- 24 Pentium 4 processors (2.4 GHz) processor, 1 GB of RAM,– 12 with hyperthreading technology
- 24 port, 1 Gbit/s (gigabit/second) ethernet switch
- Integrated INTEL 10/100/1000 Mbps NIC
- 24 ports - KVM switches
- Linux, Fedora Core2, kernel version 2.6.5smp

Whittaker, G. 2004. Use of a Beowulf Cluster for estimation of risk using SWAT. *Agron. J.* 96:1495-1497

Location of the Calapooia watershed

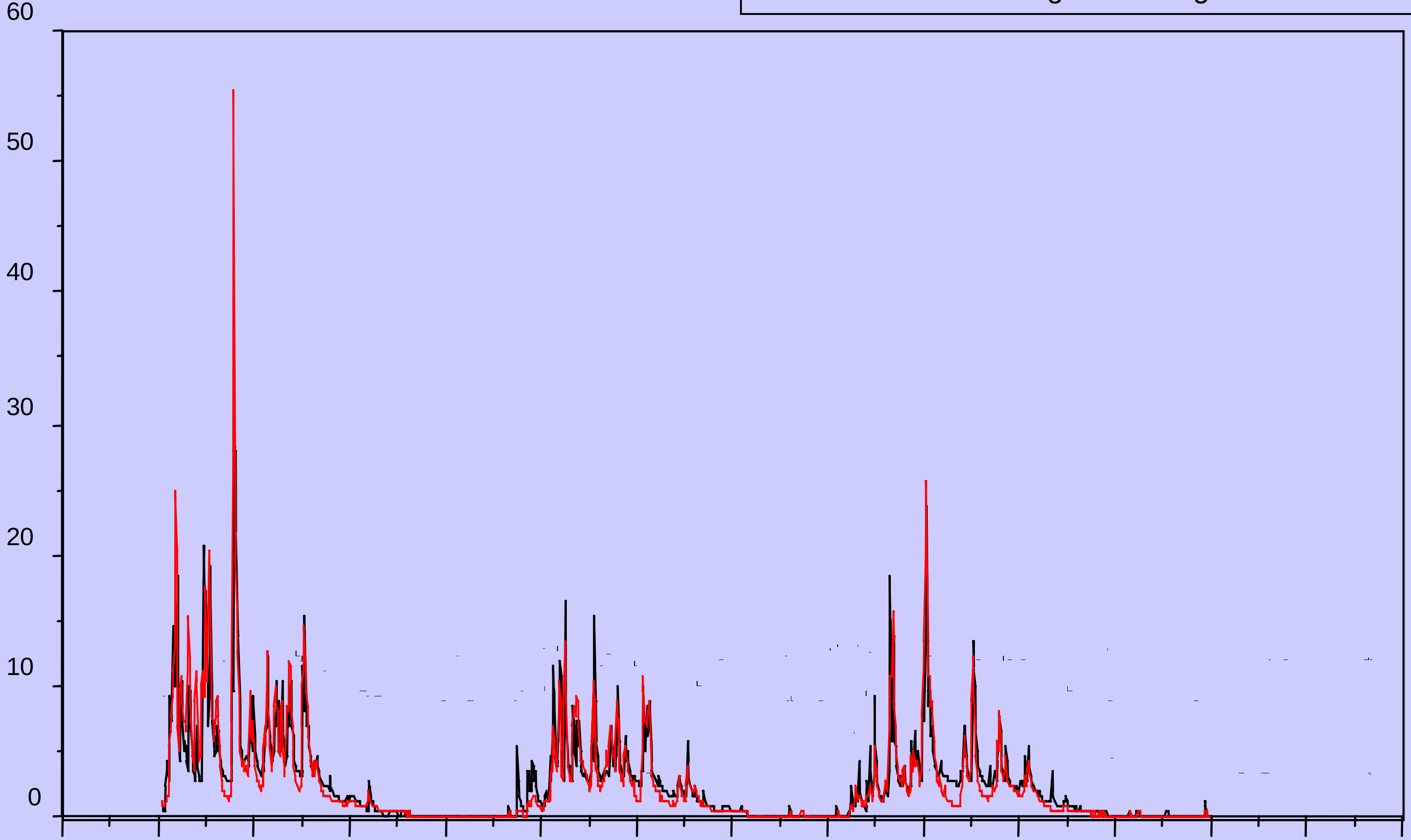


Whittaker, G. 2004. Use of a Beowulf Cluster for estimation of risk using SWAT. *Agron. J.* 96:1495-1497

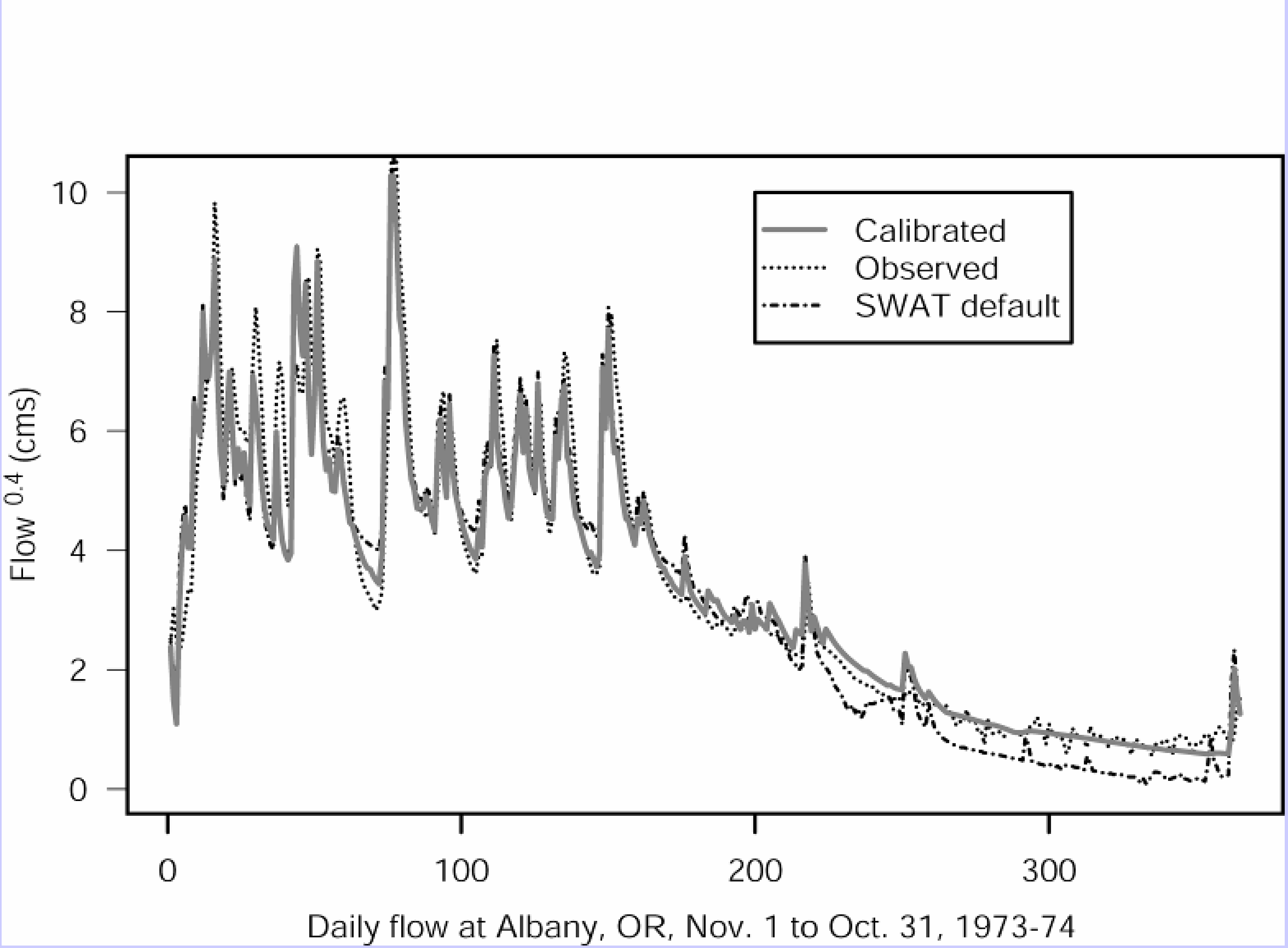
Auto-calibration of SWAT, Stream Flow on the Calapooia River

103 Parameters: curve number, gw.revap., etc in 17 sub-watersheds

Whittaker, G. 2004. Use of a Beowulf Cluster for estimation of risk using SWAT. *Agron. J.* 96:1495-1497



Selection from Pareto optimum set



Whittaker, G. 2004. Use of a Beowulf Cluster for estimation of risk using SWAT. *Agron. J.* 96:1495-1497

Climate Change

- Four papers report effects of sensitivity scenarios

- Remainder report impacts of GCM (& RCM) scenarios

  - all but 3 papers focus only on flow impacts

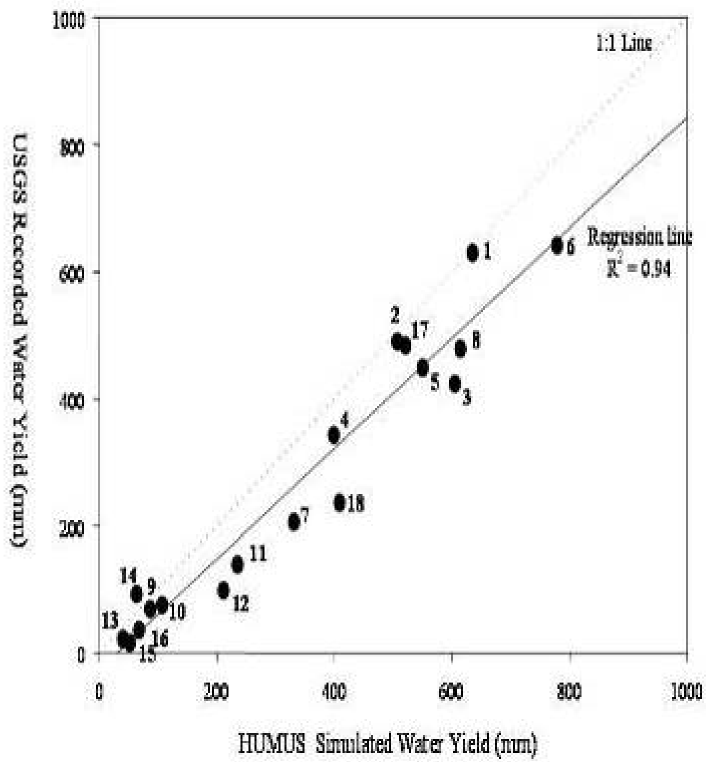
  - future water yields shifts as great as 342% (Missouri River Basin) have been reported

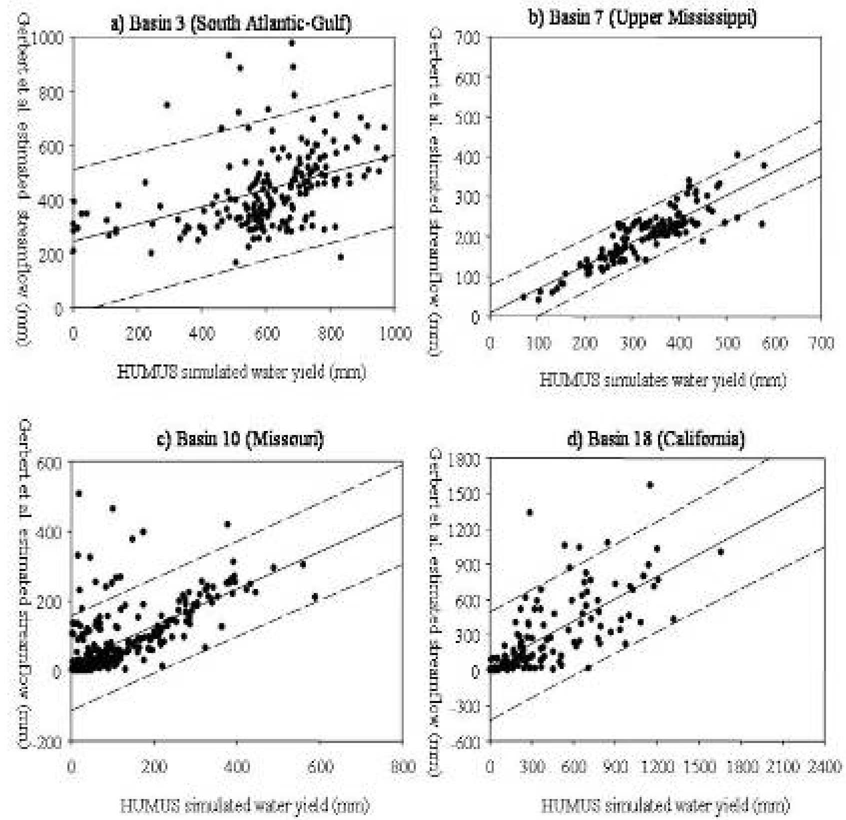
The Joint Global Change Research Institute

(A Collaboration of the Pacific Northwest National Laboratory and the University of Maryland)

- Several climate change studies using HUMUS
- Effects of HadCM2 projections for 2030 and 2095 for the conterminous U.S.
- El Niño/La Niña impacts on conterminous U.S.
- Volume 69 of *Climatic Change*
  - 9-part set of JGCRI papers (EPIC, HUMUS)
  - HUMUS featured in parts 2 and 4; results or other aspects discussed in 5 of the other papers

Simulated vs. observed water yield

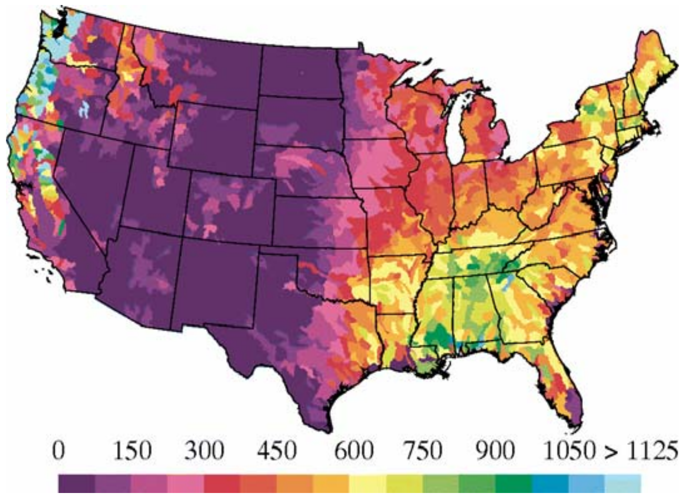




Thomson et al. 2005. Climate change impacts for the conterminous USA: an integrated assessment; Part 2: Models and Validation. *Clim. Change* 69:27-41

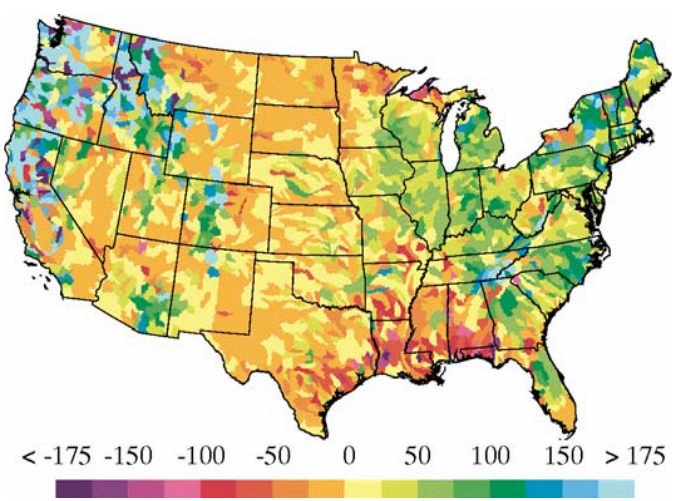
Annual Baseline Water Yield, and Deviations from Baseline Projected by HadCM2 for 2030 and 2095

Baseline



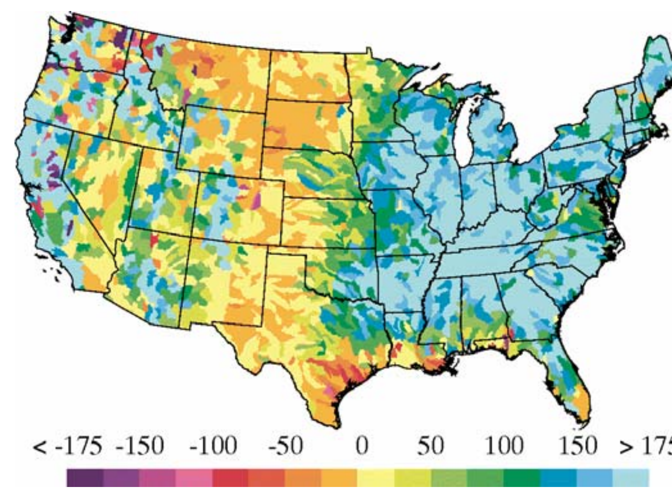
mm

2030



– mm

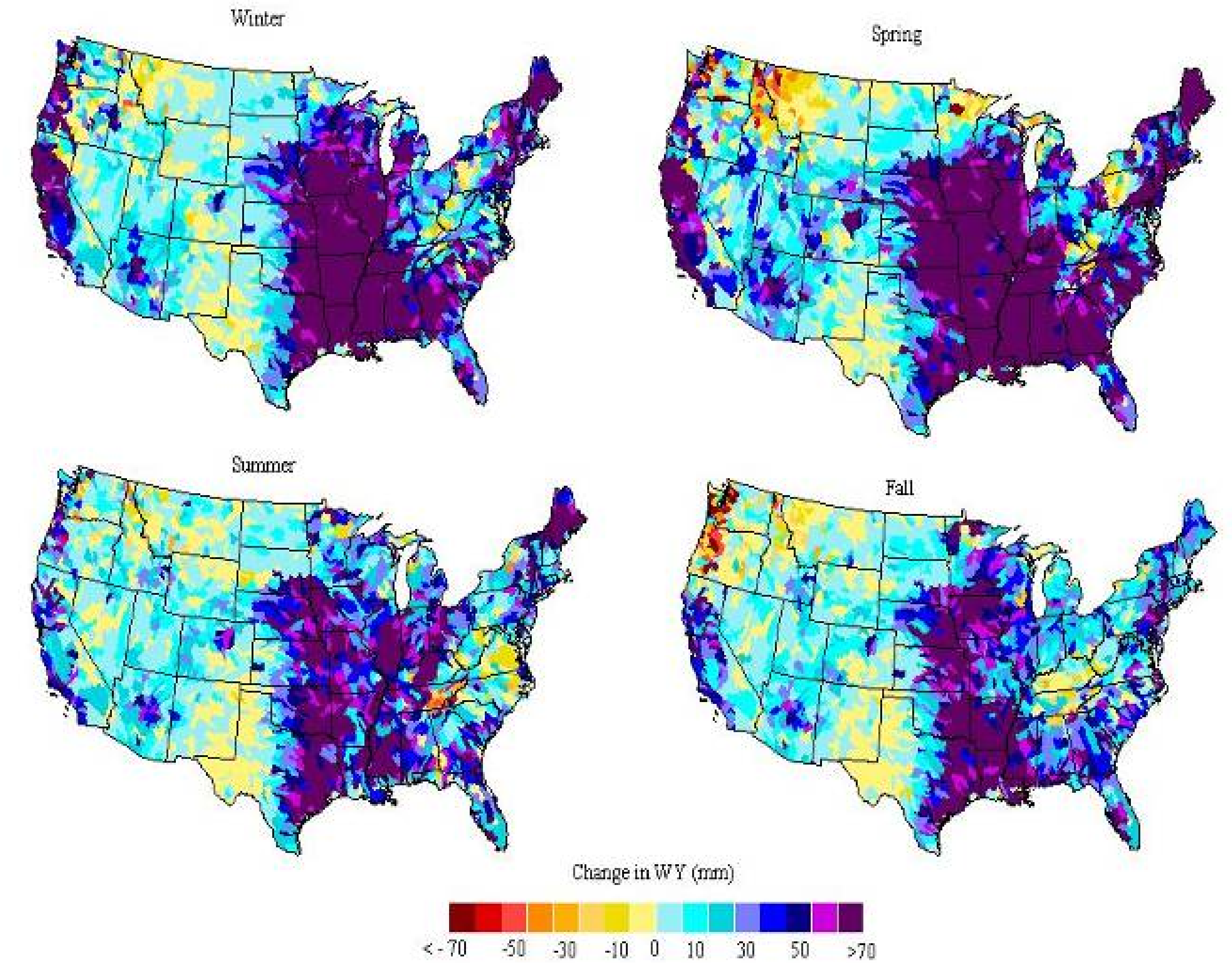
2095



– mm

Rosenberg et al. 2003. *Agric. and Forest Metero.* 39(1):137-148.

Simulated effects of strong El Niño on water yield



Thomson et al. 2003. Simulated impacts of El Niño/Southern Oscillation on United States Resources. *JAWRA* 39(1):137-148.

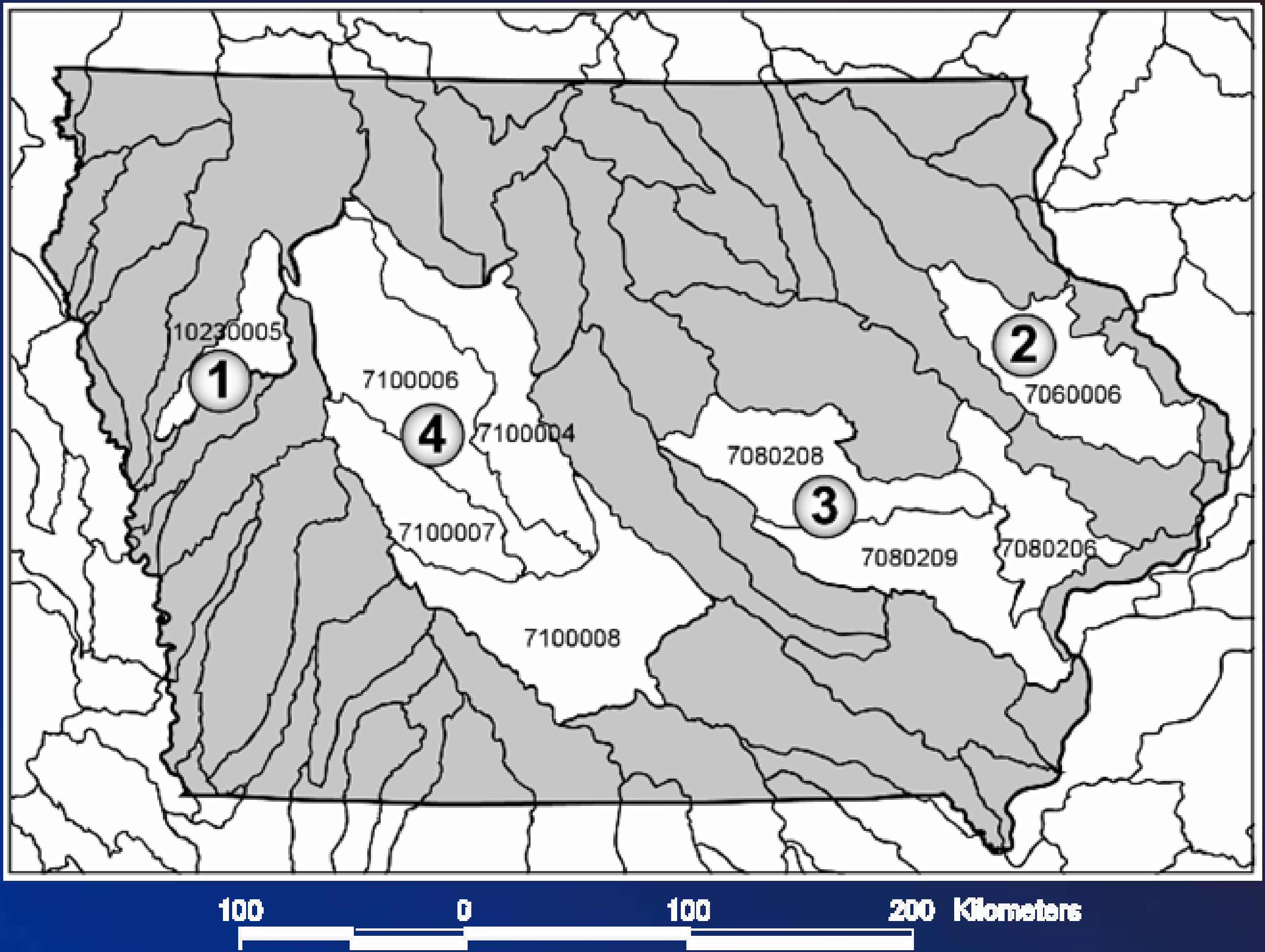
Effects of HRU, Subwatershed, and other Inputs on SWAT/SWAT-G Outputs

Primary Application Category	Flow Only	Flow & Pollutants
HRU and/or subwatershed effects	2	4
DEM, soil, and/or landuse data resolution effects	3	5
Actual and hypothetical landuse shifts	3	1
Impacts of climate data choice	3	1
CN vs. Green-Ampt	1	0

Key Findings

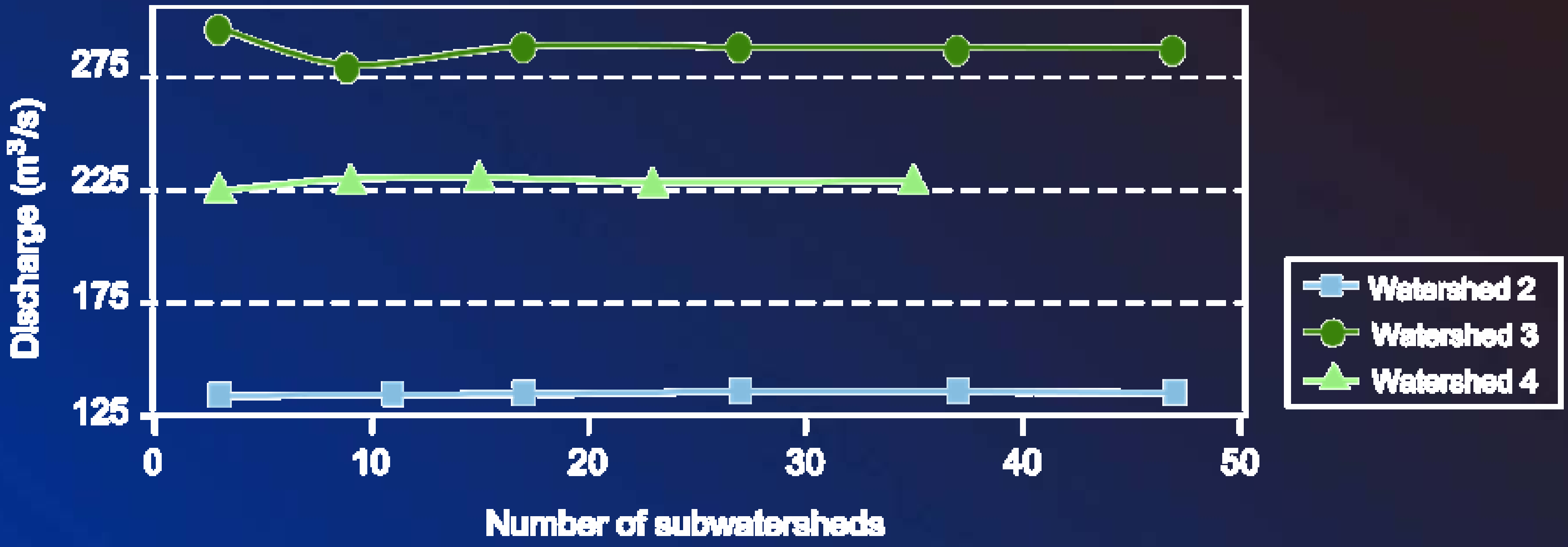
- Flow estimates are generally insensitive to HRU and/or subwateshed delineations, but pollutant loading estimates are sensitive
- SWAT flow and pollutant estimates are usually more accurate with higher resolution DEM, soil, & landuse data
- Flow & pollutant estimates are sensitive to historical landuse changes

Effects of Different HRU and Subwatershed Delineations for Four Large Watersheds in Iowa, USA



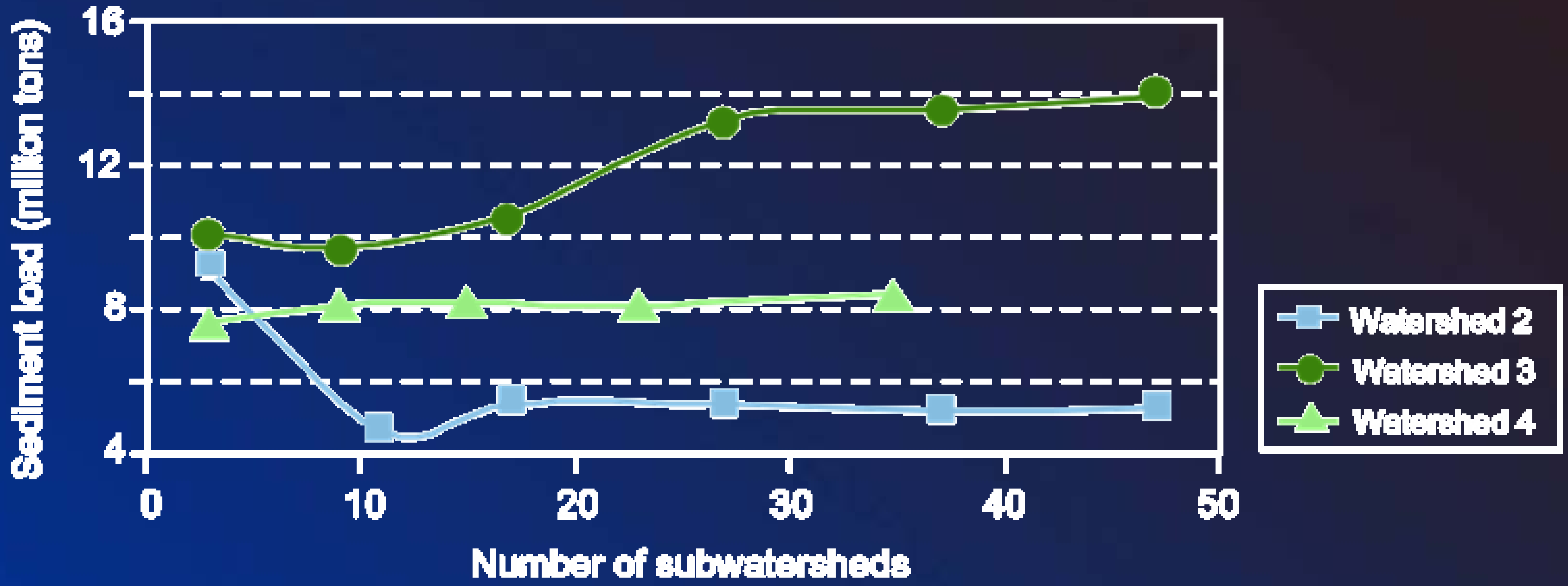
Jha et al. 2004. Effect of watershed subdivision on SWAT flow, sediment, and nutrient predictions. *JAWRA* 40(3):811-825

Effect of Increasing Numbers of Subwatersheds (& HRUs) on Flow



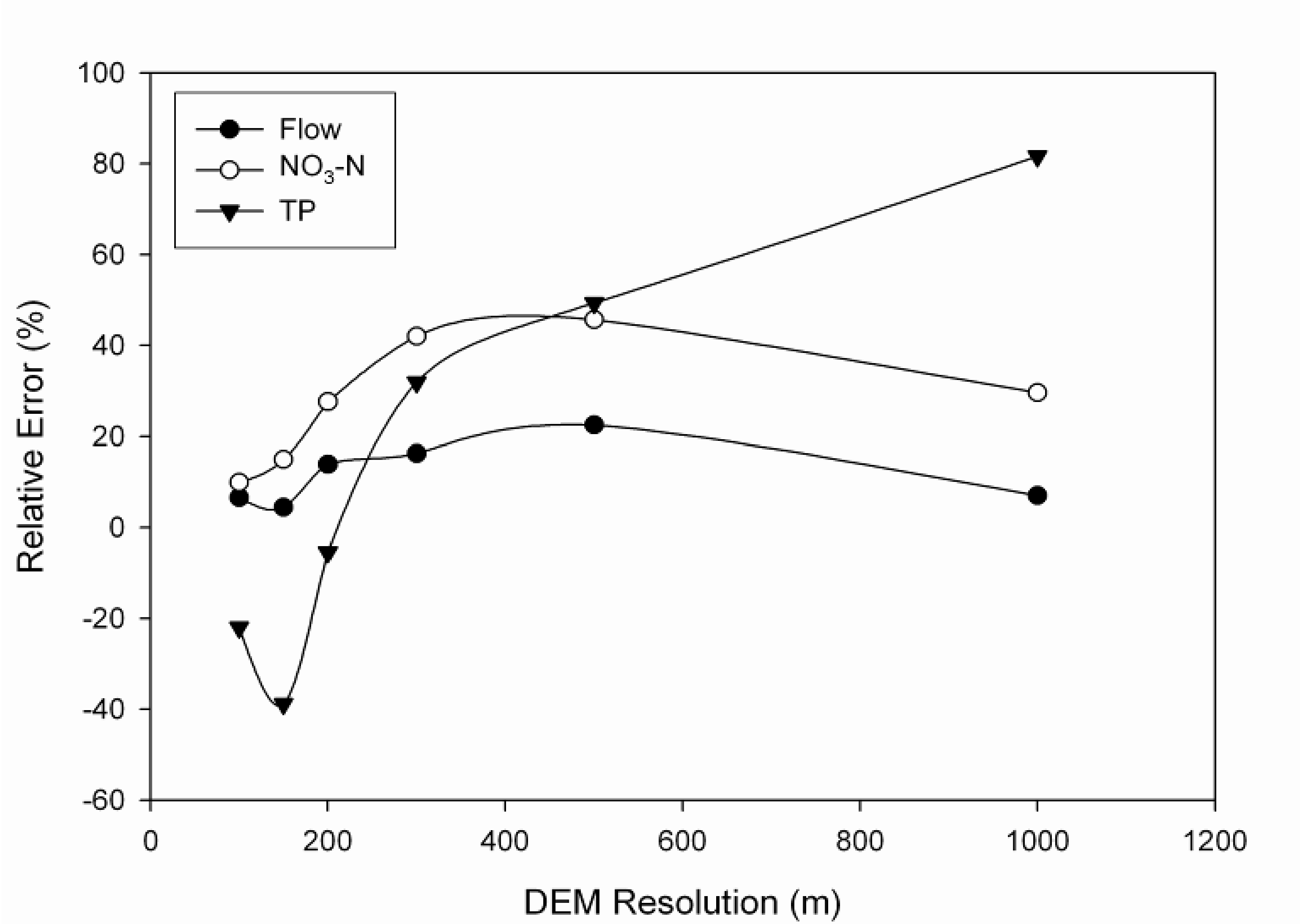
Jha et al. 2004. Effect of watershed subdivision on SWAT flow, sediment, and nutrient predictions. *JAWRA* 40(3):811-825

Effect of Increasing Numbers of Subwatersheds (& HRUs) on Sediment Yield



Jha et al. 2004. Effect of watershed subdivision on SWAT flow, sediment, and nutrient predictions. *JAWRA* 40(3):811-825

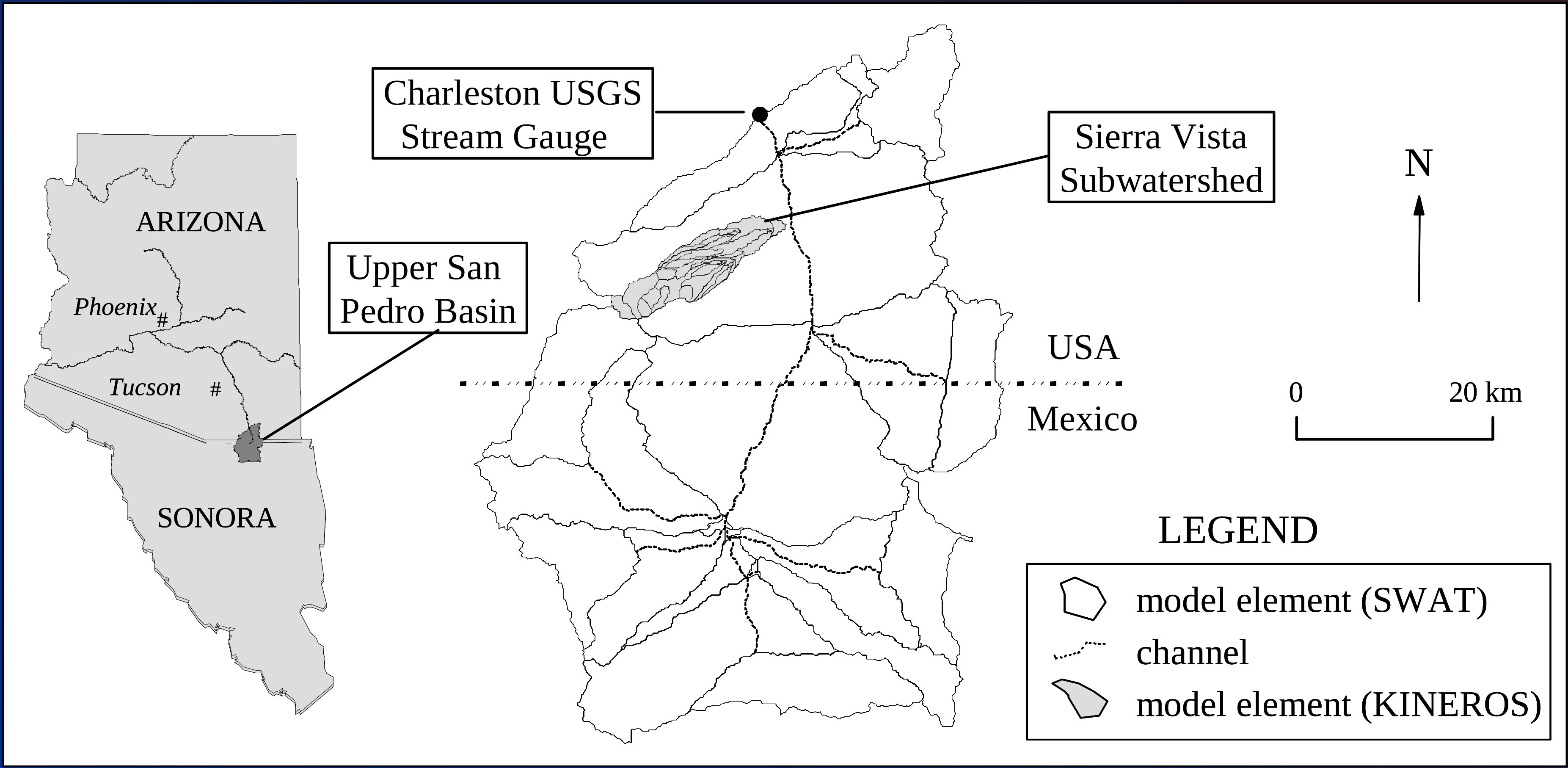
Effects of DEM Resolution on Flow, NO_3-N, and TP Predictions for the Moores Creek Watershed, Arkansas, USA



Chaubey et al. 2005. Effect of DEM data resolution on SWAT output uncertainty. *Hydrological Processes* 19: 621-628

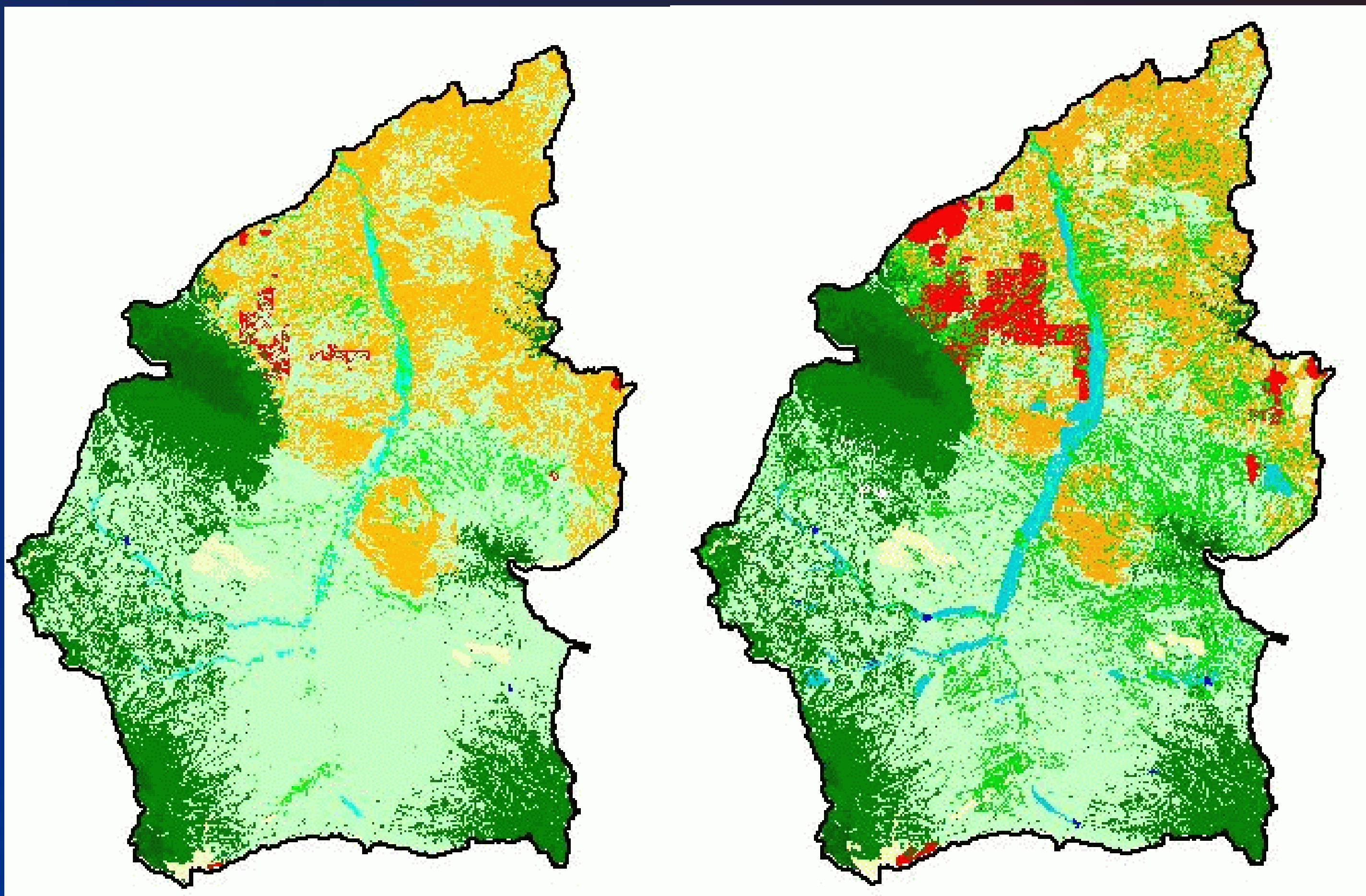
Location of Upper San Pedro Basin

SWAT and KINEROS modeling domains



Miller et al. 2002. Integrating landscape assessment and hydrologic modeling for land cover change analysis. *JAWRA* 38(4):915-929.

Land Cover Change Below Charleston Gage



1973 NALC Classification

1997 NALC Classification

LEGEND

- Forest
- Oak Woodlands
- Mesquite Woodlands
- Grasslands
- Desertscrub
- Riparian
- Agriculture
- Urban
- Water
- Barren / Clouds

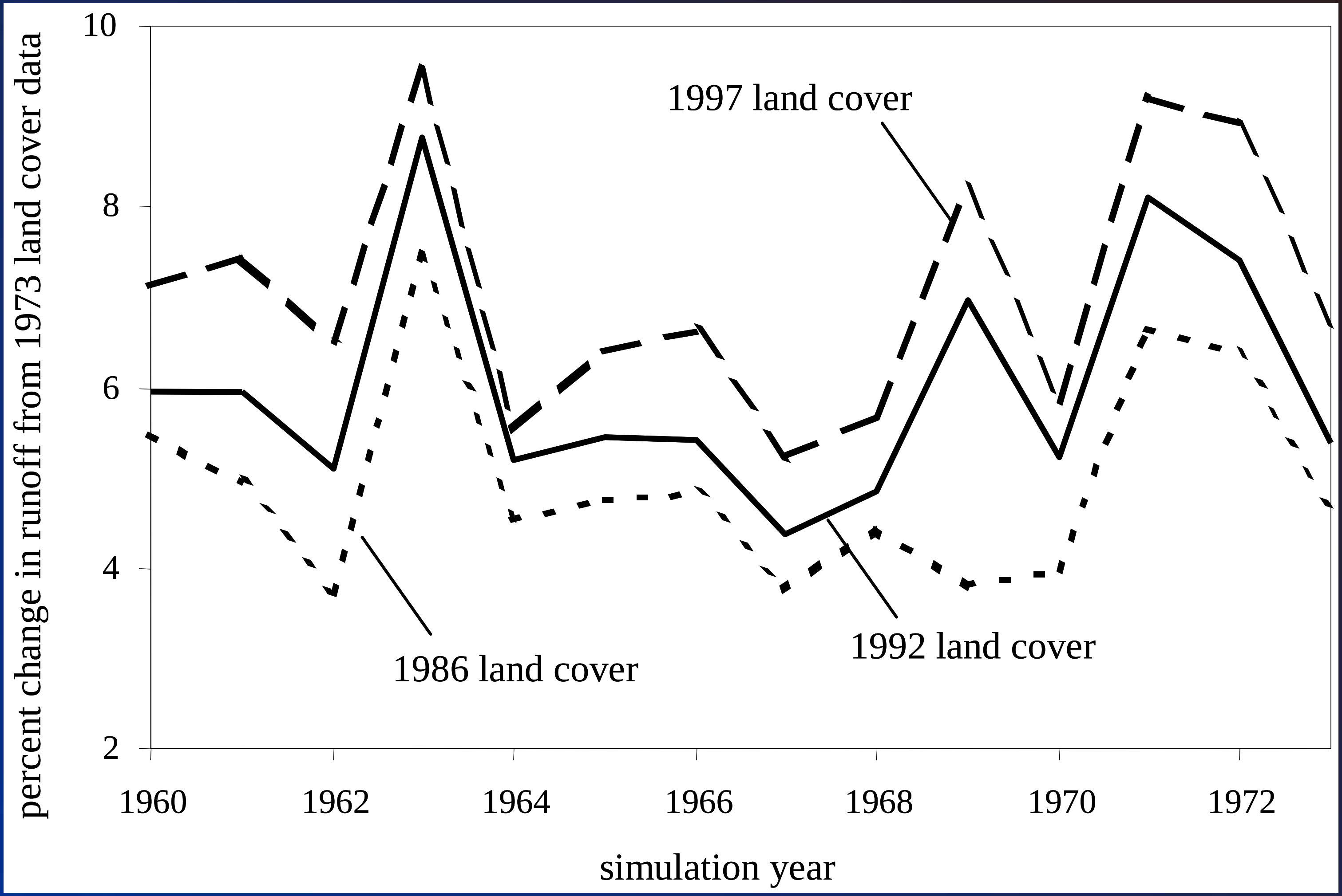
N

0 10 km

Miller et al. 2002. Integrating landscape assessment and hydrologic modeling for land cover change analysis. *JAWRA* 38(4):915-929.

Impact of Land Cover Change

% change in runoff simulated by SWAT



Miller et al. 2002. Integrating landscape assessment and hydrologic modeling for land cover change analysis. *JAWRA* 38(4):915-929.

SWAT Interfaces with other Models

- 10 papers report SWAT interfaces with economic models

  - variety of sectoral, farm-level, water valuation & other models

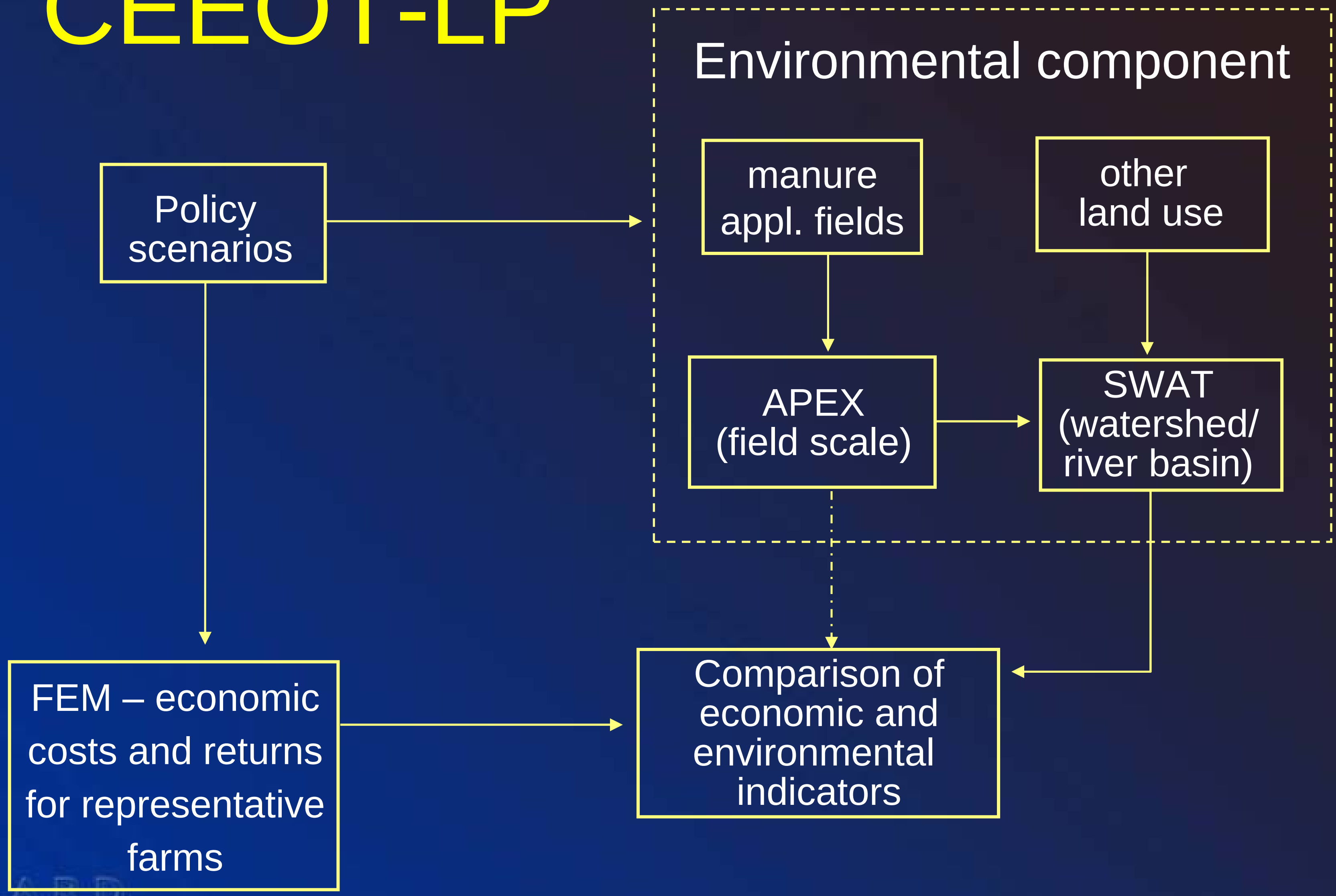
  - most report scenarios with pollutant outputs

- Six papers report interfaces between SWAT and MODFLOW groundwater model

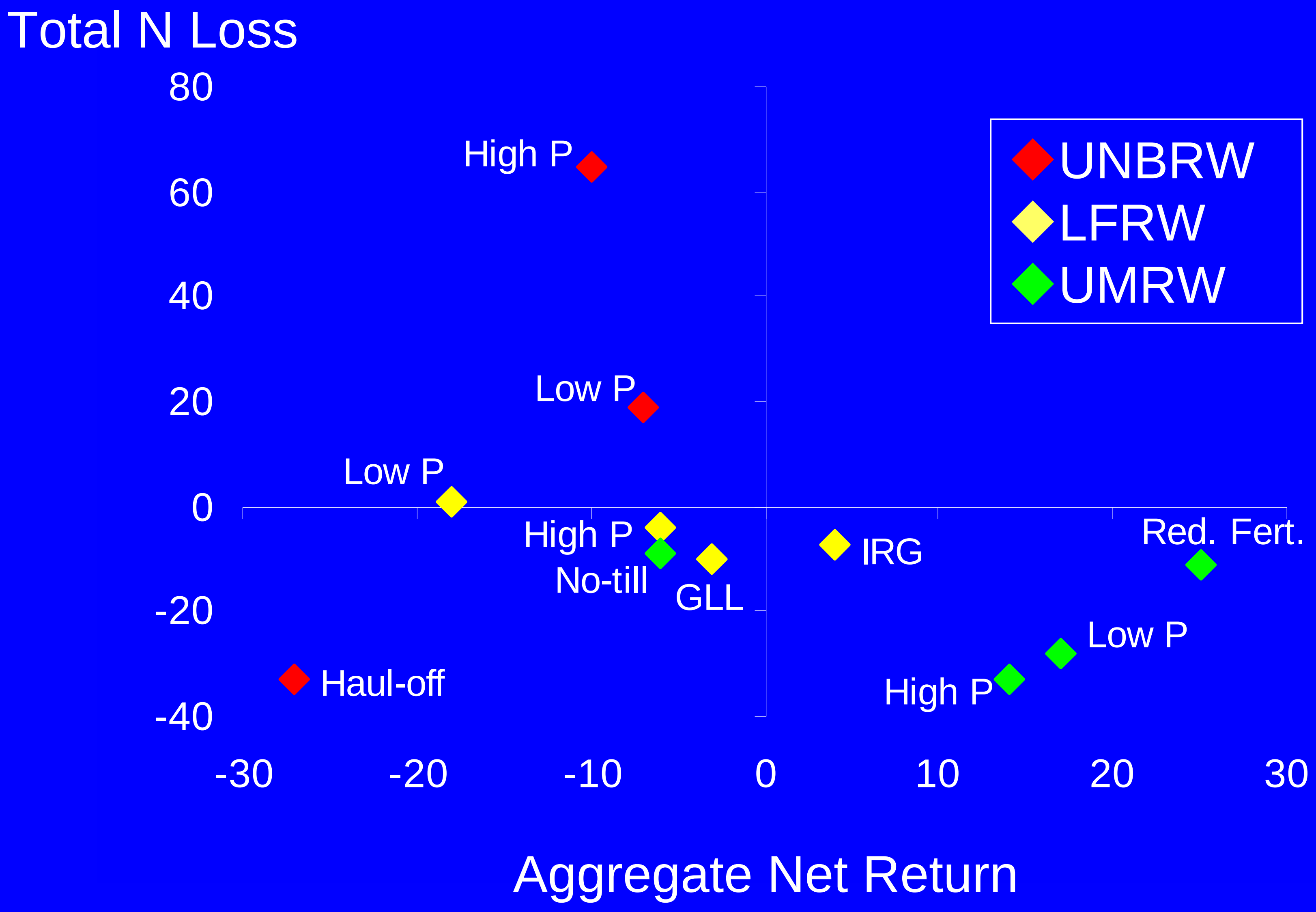
  - includes SWATMOD model

  - All but one report only flow results

CEEOT-LP


Environmental component
manure appl. fields
other land use
Policy scenarios
APEX (field scale)
SWAT (watershed/ river basin)
FEM – economic costs and returns for representative farms
Comparison of economic and environmental indicators

Total N Loss vs. Aggregate Net Returns
(% Change from Baseline)



SWAT-G Interfaces with other Models

- Proland – agricultural economy model
- YELL, ELLA, ANIMO – ecological (habitat) models
- Example: shifts in bird (Yellow Hammer) breeding habitat & hydrology as a function of land use and field size

More on SWAT Adaptations

- SWAT-DEG – predicts time series channel erosion and degradation (Allen et al. 2002)

  - incorporated into SWAT?

- Missouri River Reservoir SWAT – introduced revised reservoir management commands for the Missouri River, U.S. (Hotchkiss et al. 2000)

- SWAT-M; improved tile drain and pothole component (Du et al. 2005)
  - incorporated into SWAT2003

Location of Walnut Creek Watershed in Iowa

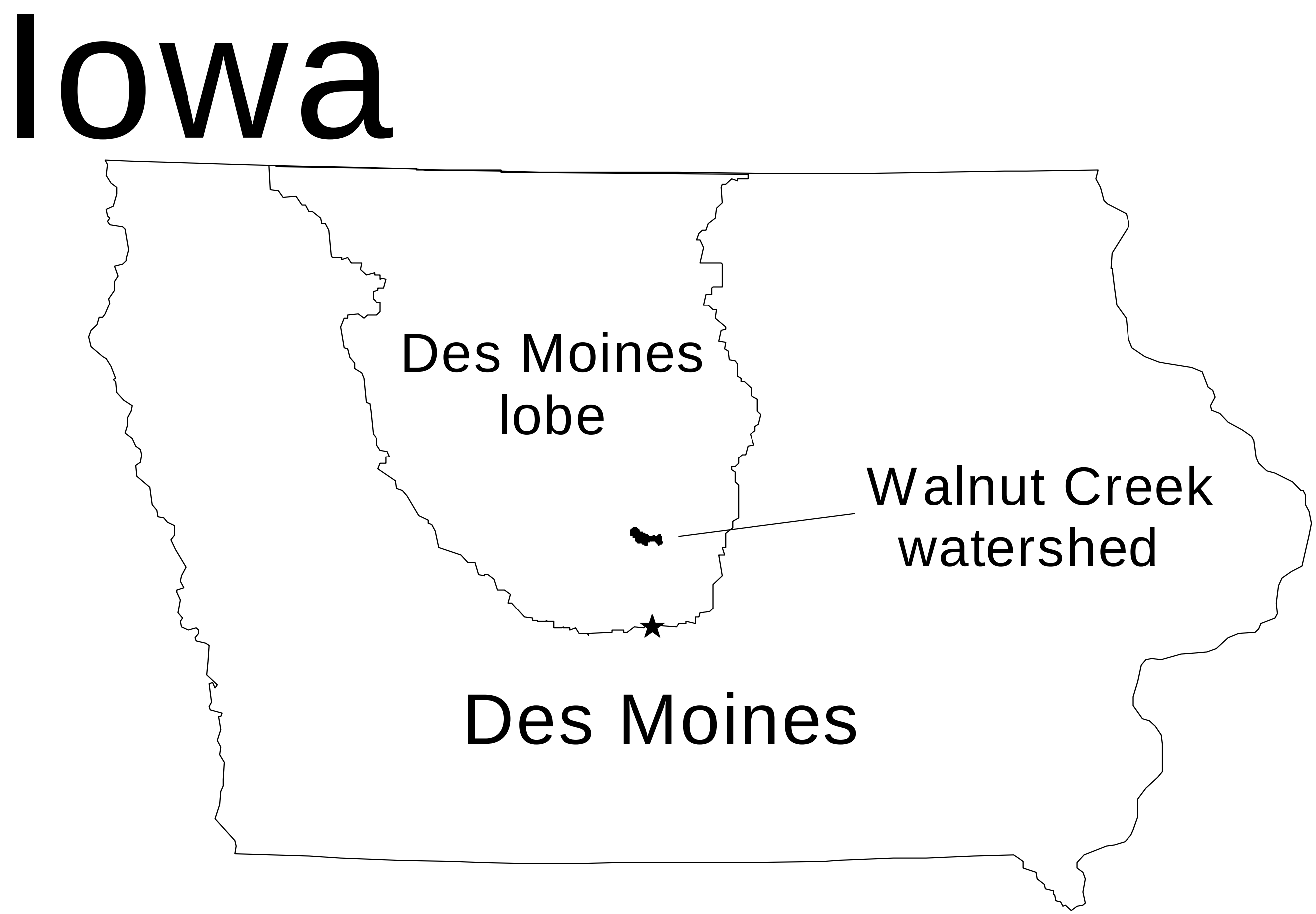
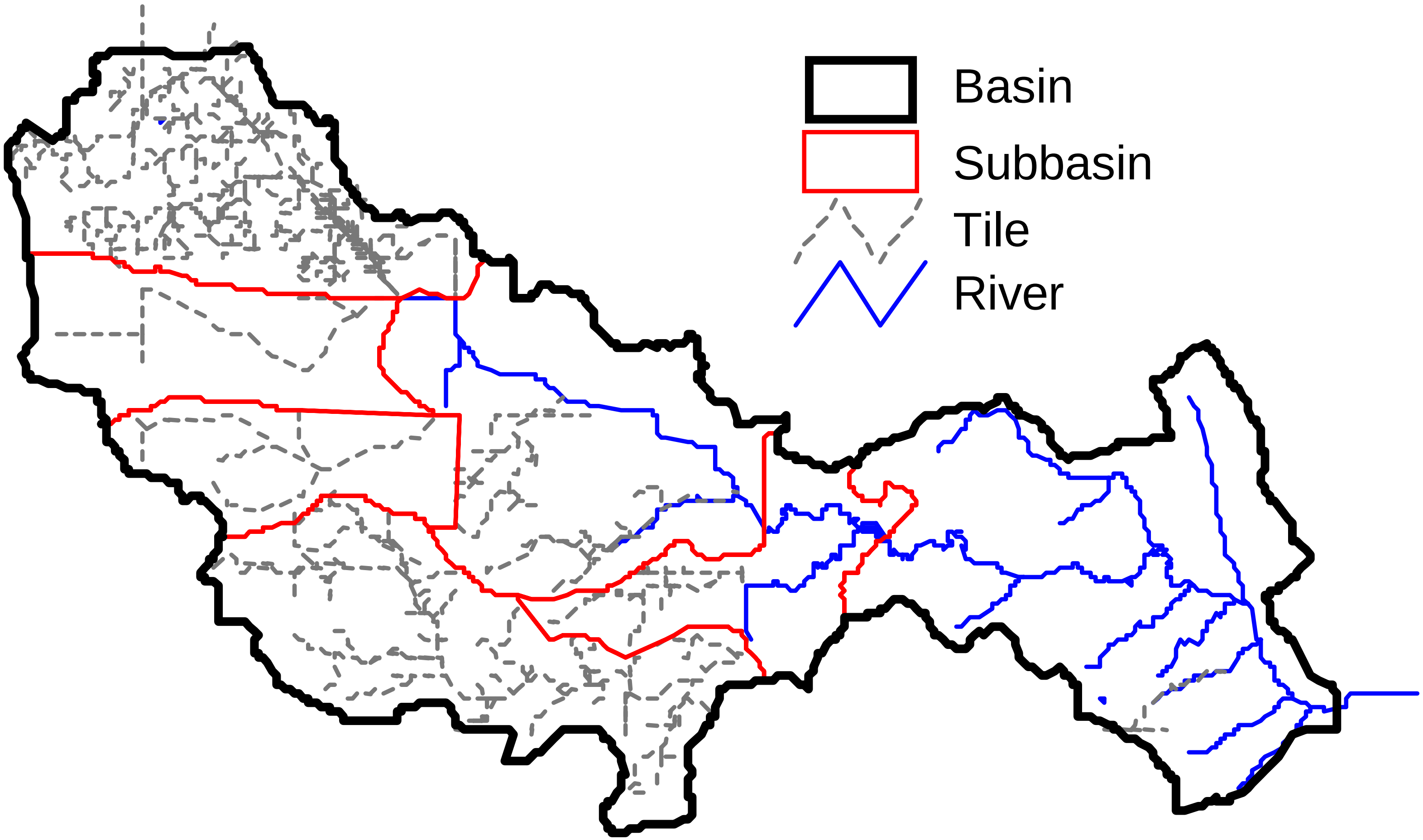


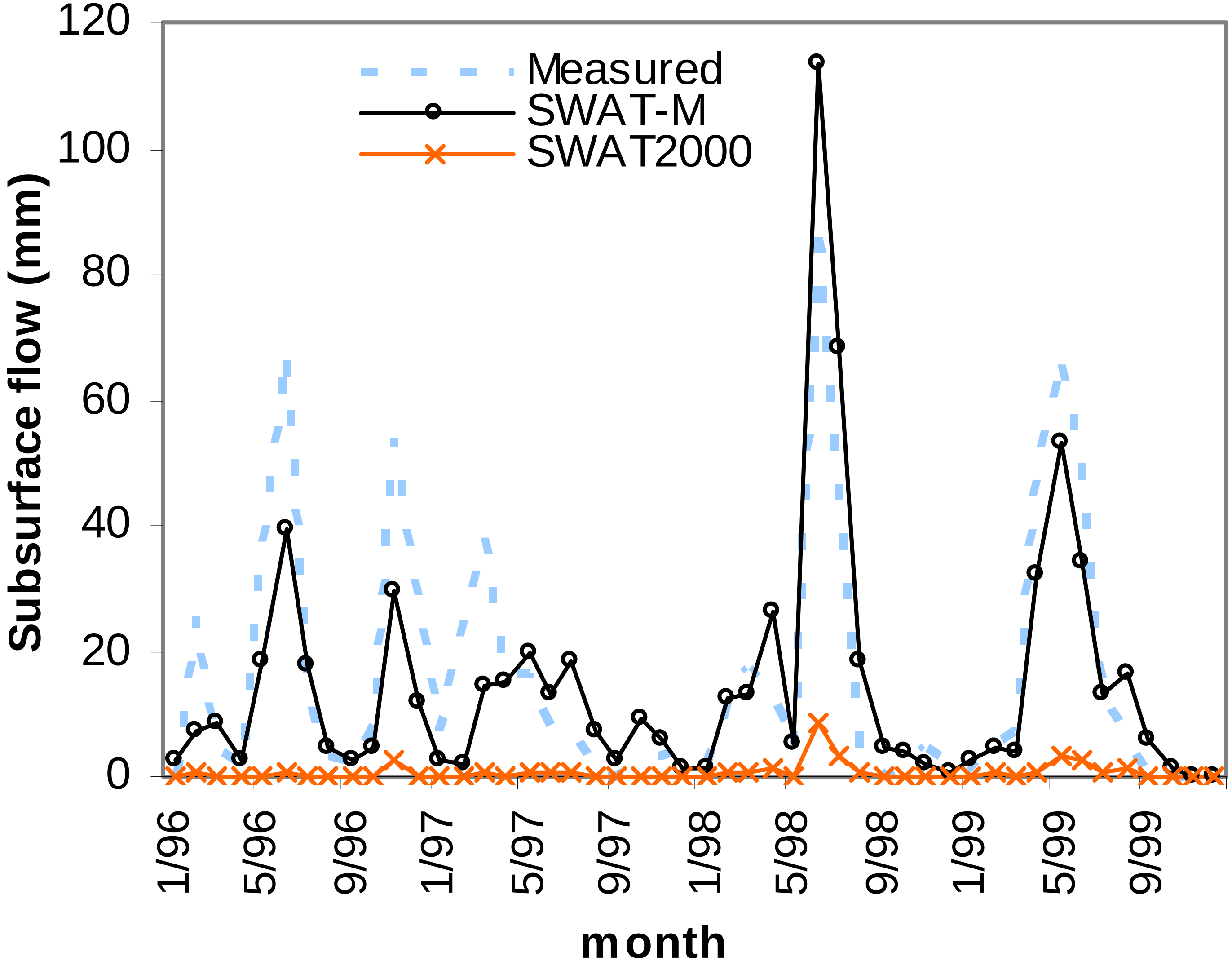
Figure provided by Dan Jaynes, USDA-ARS, National Soil Tilth Lab, Ames, Iowa

Location of Tile Drains in the Walnut Creek Watershed, Iowa, USA



Du et al. 2005. Development and application of SWAT to landscapes with tiles and potholes. *ASAE* 48(3):1121-1133.

Predicted vs. Measured Walnut Creek Tile Flows



Du et al. 2005. Development and application of SWAT to landscapes with tiles and potholes. *ASAE* 48(3):1121-1133.

Other SWAT Adaptations

- SWAP: Interface between SWAT and APEX – TIAER, Tarleton State Univ., Stephenville, TX, USA (see poster)
  - double cropping, filter strips, and other scenarios that SWAT can't simulate
- METROSWAT – Koh & others, Heriot-Watt Univ., Edinburgh, Scotland
  - incorporates a Monte Carlo Markov Chain approach for assessing parameter uncertainty
- Storm Event SWAT – Borah & others, Illinois State Water Survey, Champaign, Illinois, USA
  - operates on a 15 minute time step
  - simulates storm events more accurately

Dynamic Management SWAT

- TIAER, Tarleton State Univ., Stephenville, TX
- Dynamically changes HRU management during the course of a run
- Focus: dairy manure waste application fields in Upper N. Bosque River Watershed

  - function of user-defined soluble P concentrations at a specific soil depth

Research Needs

- Development of concentrated animal feeding operations and related manure application routines
- Spatially explicit hydrologic response units

Research Needs

- Stream channel degradation and sediment deposition need improvement
- Improved simulation of riparian zones and other conservation practices

Research Needs

- Improvement of autocalibration and uncertainty analysis tools
- Completion of a GIS interface using ArcGIS