Evaluation of Model Calibration and Uncertainty Analysis with Incorporation of Watershed General Information

Haw Yen
R. Bailey, M. Ahmadi , M. Arabi, M. White, J. Arnold

July 17, 2013
2013 International SWAT Conference
Toulouse, France

TEXAS A&M AGRILIFE RESEARCH

Outline

- Overview
- Calibration of Watershed Models
- Manual and Auto-Calibration
- Constrained Optimization for Watershed Model Calibration
- Case Study & Results
- Discussion & Conclusion

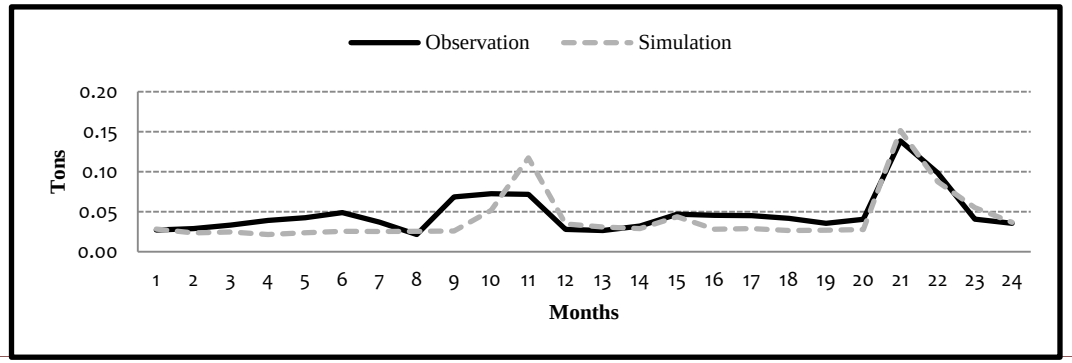
Overview

- Advanced technology in computer science
  - Complex watershed simulation models
  - Distributed in space & process-based
  - Long term simulations with large amount of data

- Development of complex watershed models
  - Evaluate impact from climate changing, various human activities on issues such as:
    - Availability of water resources
    - Water quality
    - Watershed management

Calibration of Watershed Models

- Why and how do we calibrate?
  - Model parameters can be case sensitive
  - Before conducting model simulation for various scenarios
    - To ensure model responses are close to natural responses
    - To minimize the "differences" between observed/simulated data by adjusting values of model parameters
  - "Differences" can be calculated as?
    - Error statistics (ex. RMSE, PBIAS, 1-NS)



Calibration Techniques (1/3)

- Manual Calibration
  - Manual tuning model parameters
  - Easier to get familiar with the watershed system
  - IT IS SLOW!!!
    - Time consuming
    - Extremely difficult to apply for multi-site, multi-variable problems

Calibration Techniques (2/3)

- Auto-Calibration
  - Calibration implementing mathematical/statistical theorems
  - IT IS Fast!!! (automated optimization process)
  - Full understanding of the model is required
    - Selection of the objective function
    - Parameter ranges (upper/lower bounds) must be assigned carefully

Calibration Techniques (3/3)

- Objective function of automated optimization process
  - Mathematical equation to be minimized

$$RMSE:\ OF = \sum_{m=1}^{M} \sqrt{\frac{1}{N_m} \sum_{n=1}^{N} \underbrace{[y_{n,sim}^{m} - y_{n,obs}^{m}]}_{\text{error term}}^{2}}$$

- Behavior definition
  - Statistical thresholds in evaluating model performance
  - To ensure calibrated results satisfy many statistics

Performance Rating	Nash-Sutcliffe Coefficient	PBIAS (%)	
		Streamflow	NOX
Very Good	0.75 < NSE ≤ 1.00	PBIAS < ±10	PBIAS < ±25
Good	0.65 < NSE ≤ 0.75	±10 ≤ PBIAS < ±15	±25 ≤ PBIAS < ±40
Satisfactory	0.50 < NSE ≤ 0.65	±15 ≤ PBIAS < ±25	±40 ≤ PBIAS < ±70
Unsatisfactory	NSE ≤ 0.50	PBIAS ≥ ±25	PBIAS ≥ ±70

General Performance Ratings, Moriasi et al. (2007)

Constrained Optimization (1/2)

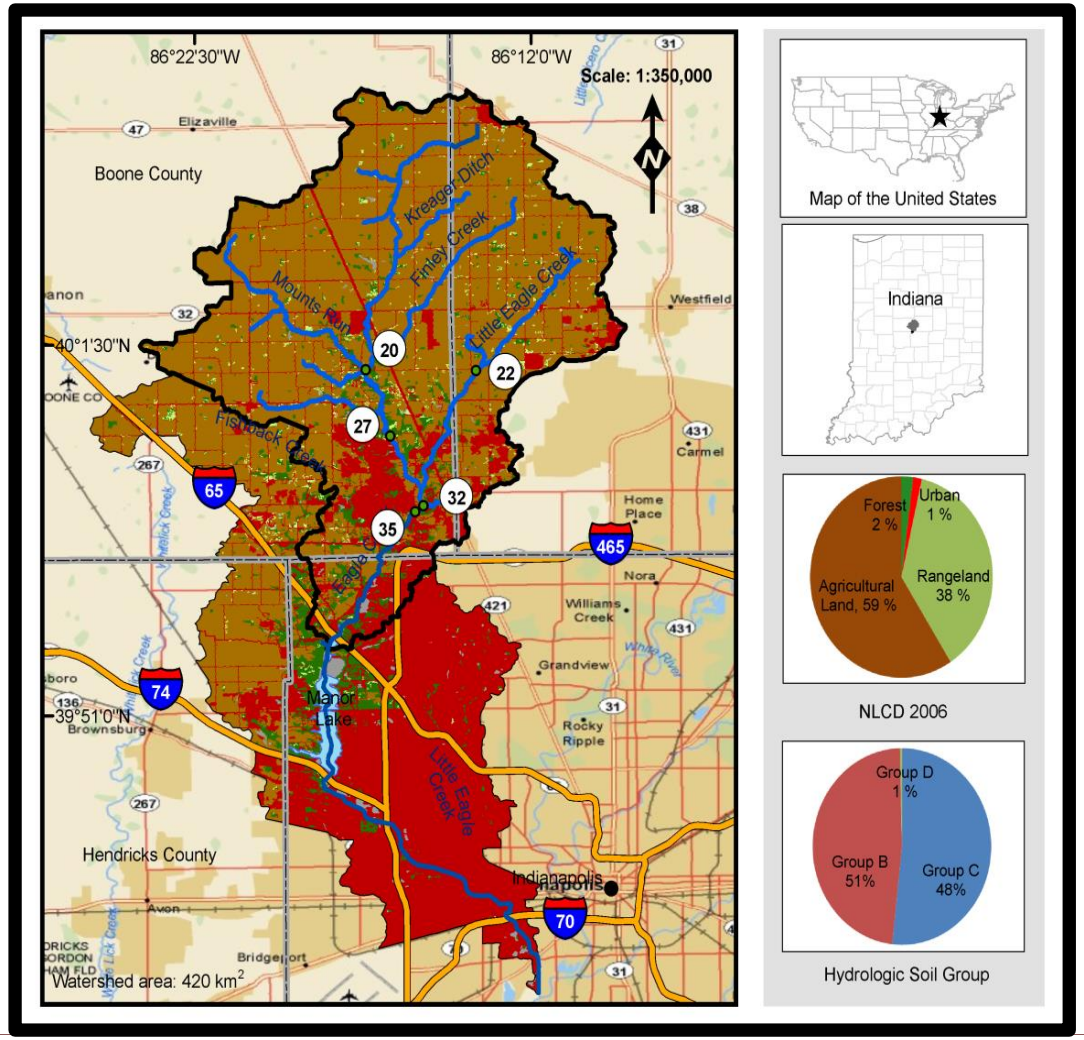
- Intra-watershed responses
  - (X) Time varying responses
    - Hydrograph, water quality in time series
  - (O) A general system response (intra-watershed responses) in terms of summative quantities
    - Ex. Crop yield, accumulated mass of biodegeneration, amount of nutrient leaching
  - Calibration without considering intra-watershed responses
    - Actual watershed behavior could be violated
    - Excellent but useless statistics
    - Results are “precisely wrong”
    - Calibrated model parameters are not applicable

Constrained Optimization (2/2)

- Examples of intra-watershed responses (Midwest region of the United States)
  - Annual denitrification (DENI)
    - From 0 to 50 kg/ha/yr (David et al., 2009)
  - Ratio that NO3 loadings to streams from subsurface flow (SSQ Ratio) versus all NO3 loadings
    - No less than 60% (Schilling, 2002)

Case Study Area

- Eagle Creek watershed
  - Central Indiana, USA
  - 248km²
  - Available data
    - 1997~2003
    - Streamflow (1 site)
    - NOX (4 sites)



Case Study Settings (1/2)

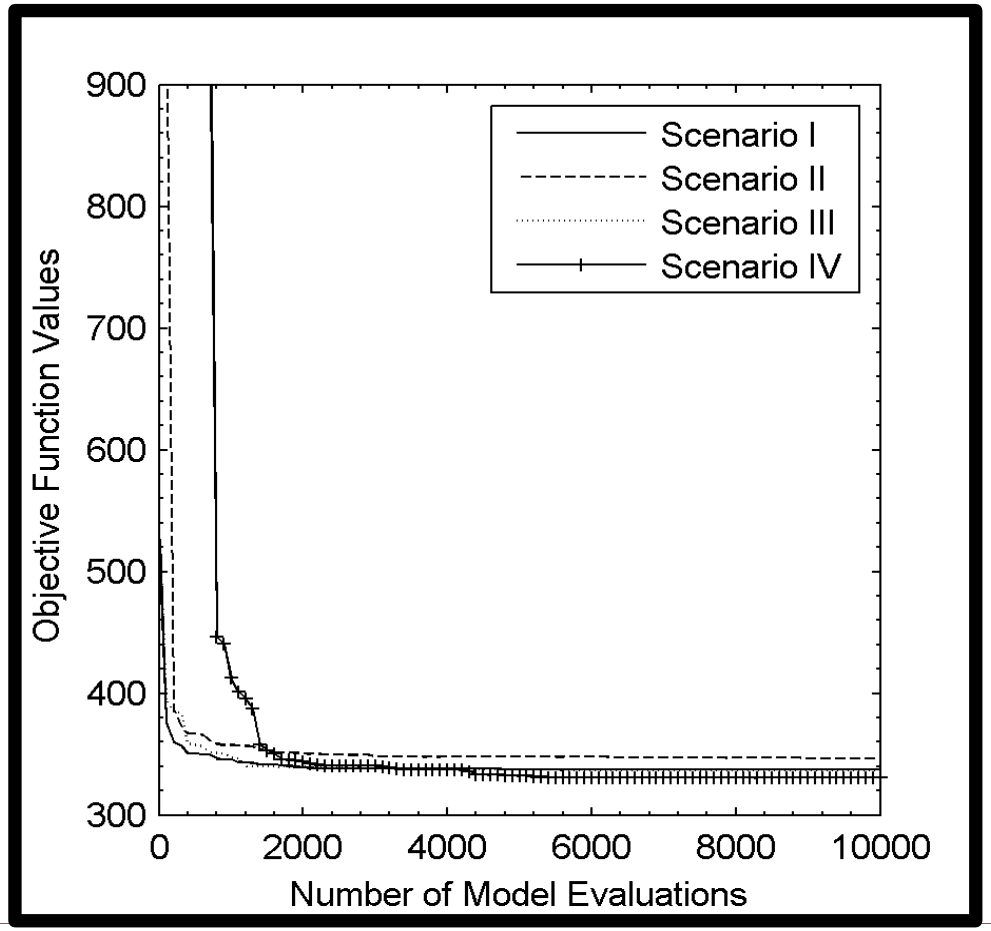
- Basic settings
  - Daily streamflow + Monthly Total Nitrate (28 parameters)
  - Objective function (Ahmadi et al., 2012)
  - Simulation length
    - Calibration (1997~2000) / Validation (2001~2003)
  - Sampling technique of auto-calibration
    - Dynamically Dimensioned Search (Tolson and Shoemaker, 2007)

Case Study Settings (2/2)

Case Scenarios	Settings
Scenario I	Calibration without any constraints
Scenario II	Calibration+ Constraint (DENI, unit: kg/ha) $\rightarrow \quad 0 \leq DENI \leq 50$
Scenario III	Calibration + Constraint (SSQ Ratio) $\rightarrow \; 0.60 \leq SSQ\ Ratio \leq 1.00$
Scenario IV	Constraints (Both) $\rightarrow \begin{cases} 0 \leq DENI \leq 50 \\ 0.60 \leq SSQ\ Ratio \leq 1.00 \end{cases}$

Results (1/6)

- Objective function values



Results (2/6)

- Percentage of parameter samples that satisfy the behavior definition

Case Scenarios	Behavior Rate (%)		
	Satisfactory	Good	Very Good
Scenario I	78.73	71.39	19.97
Scenario II	64.40	29.50	0.07
Scenario III	1.91	0.03	0.00
Scenario IV	60.78	1.22	0.00

Results (3/6)

- Best results with corresponding DENI & SSQ Ratio

Period	Scenario	Nash-Sutcliffe Efficiency Coefficient (NSE)					DENI (kg/ha/yr)	SSQ Ratio
		35 (STR)	32 (NOX)	27 (NOX)	22 (NOX)	20 (NOX)		
Calibration 1997~2000	Scenario I	0.91	0.95	0.91	0.85	0.84	257.3	0.13
	Scenario II	0.87	0.82	0.78	0.49	0.87	21.4	0.68
	Scenario III	0.89	0.89	0.88	0.75	0.86	175.3	0.60
	Scenario IV	0.87	0.72	0.88	0.66	0.94	33.1	0.67
Validation 2001~2003	Scenario I	0.77	0.10	0.13	-0.55	0.37	278.5	0.11
	Scenario II	0.61	0.23	0.47	-0.13	0.67	25.1	0.66
	Scenario III	0.70	0.20	0.38	-0.53	0.58	205.0	0.50
	Scenario IV	0.60	0.43	0.58	0.15	0.72	39.0	0.64

Results (4/6)

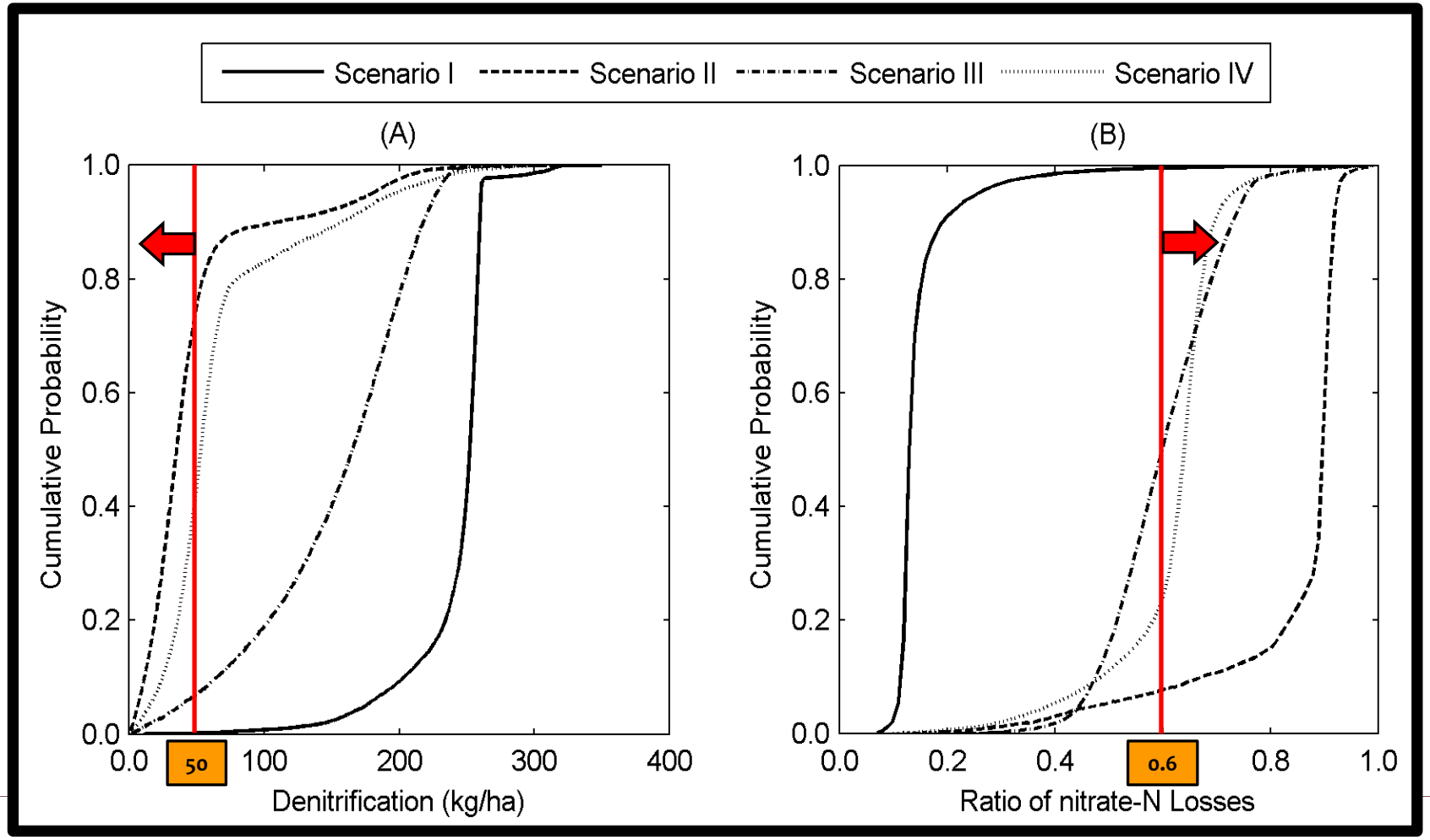
- Percentage of parameter samples penalized for each scenario (%)

Case Scenarios	Rate of Penalty	DENI Constraint	SSQ Ratio Constraint	At least one constraint violated	Both constraints violated
Scenario I	0.00	99.83	99.59	99.96	99.46
Scenario II	24.50	24.50	7.60	26.71	5.39
Scenario III	48.48	92.99	48.48	93.11	48.34
Scenario IV	59.24	56.08	22.69	59.24	19.55

- You don't want to use results from Scenario I at all!
- DENI constraint has influence on SSQ Ratio constraint.

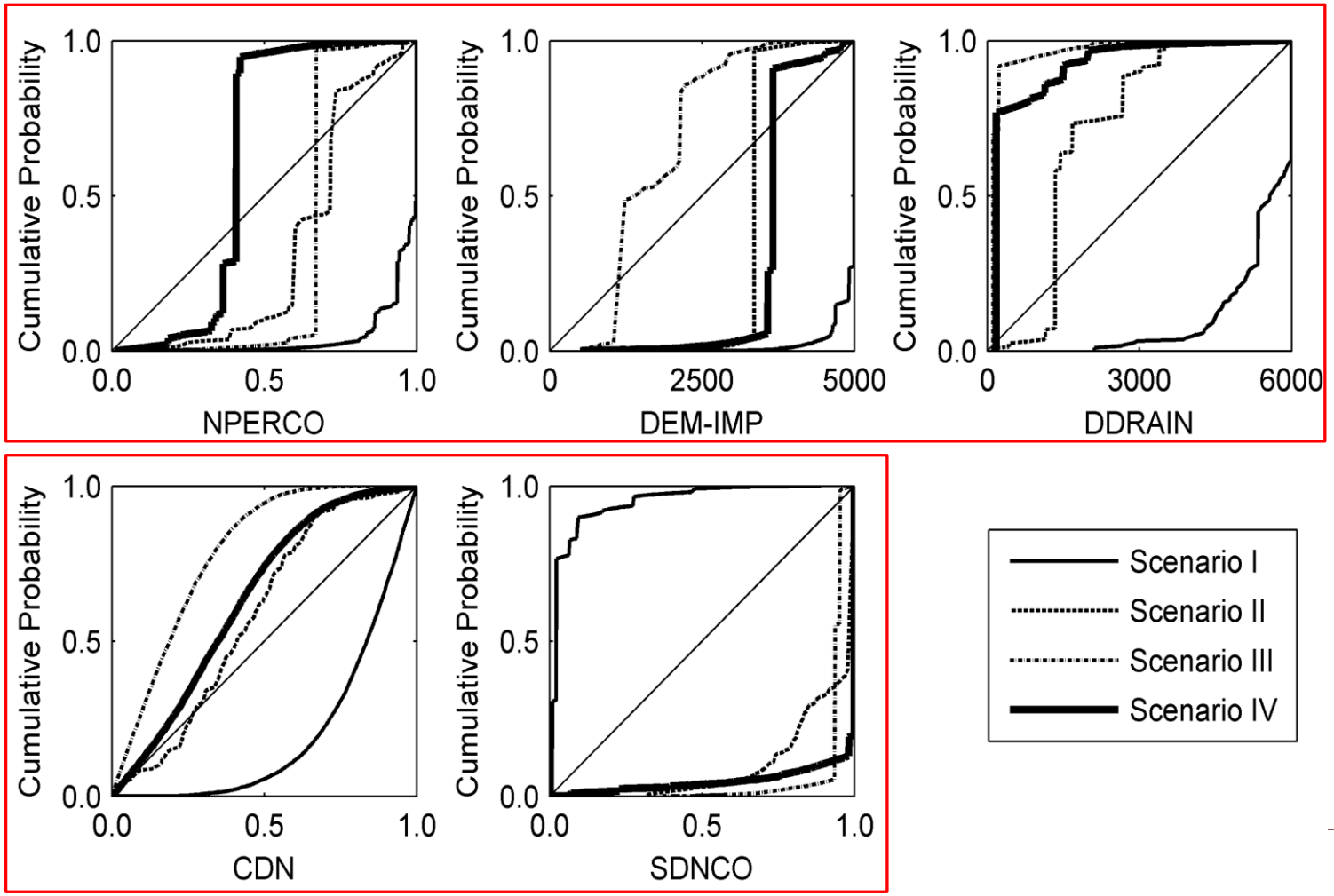
Results (5/6)

- Cumulative distribution functions of constraints



Results (6/6)

- Cumulative distribution functions of sensitive parameters



Sensitive to SSQ ratio

Sensitive to denitrification

Discussion and Conclusion

- It is important to include additional constraints that represent intra-watershed responses
  - Statistically well performed parameter samples are giving wrong outputs in real world applications
  - Watershed characteristics could be violated
  - Especially for watershed which little knowledge is available on parameter ranges

- Interactions between constraints
  - Denitrification constraint has shown great influence over results
  - Automatically regulates SSQ Ratio

Thanks for your attention!

Haw Yen, Ph.D.
hyen@brc.tamus.edu

Texas A&M AgriLife Research