Improving SWAT streamflow and nitrate simulations via spatial calibration/validation

preliminary results…

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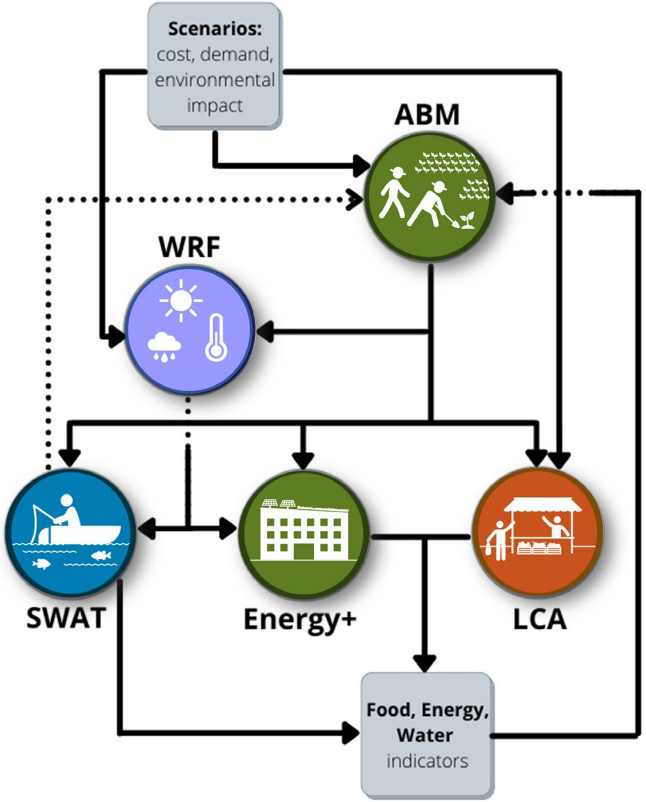
Iowa UrbanFEWS

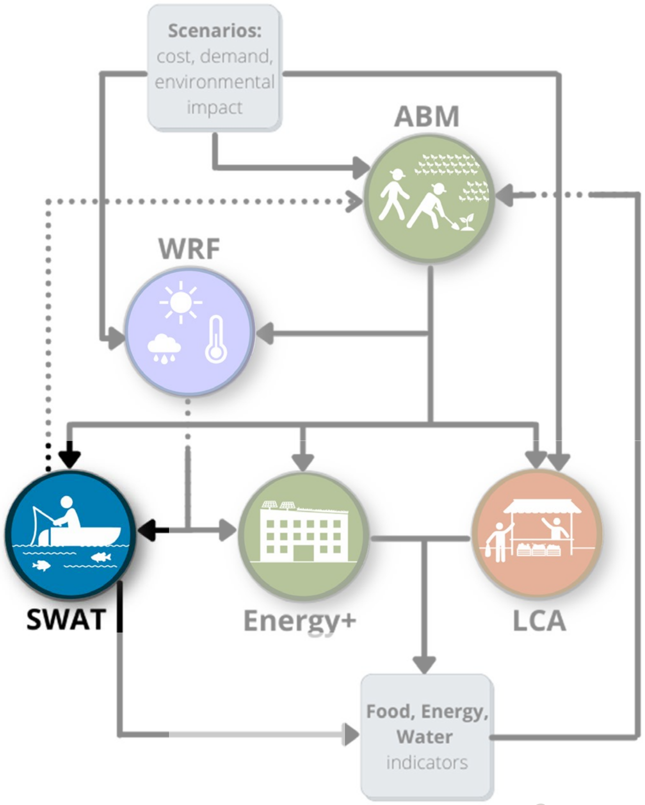
Iowa Urban FEWS – OVERVIEW

The project is focused on **developing sustainable food production systems** in the Des Moines Metropolitan Statistical Area (DMMSA), Iowa, USA. Multiple models are being integrated (co-simulation approach) to evaluate the impact of **converting cropland, peri-urban and/or urban landscapes to table food production**.



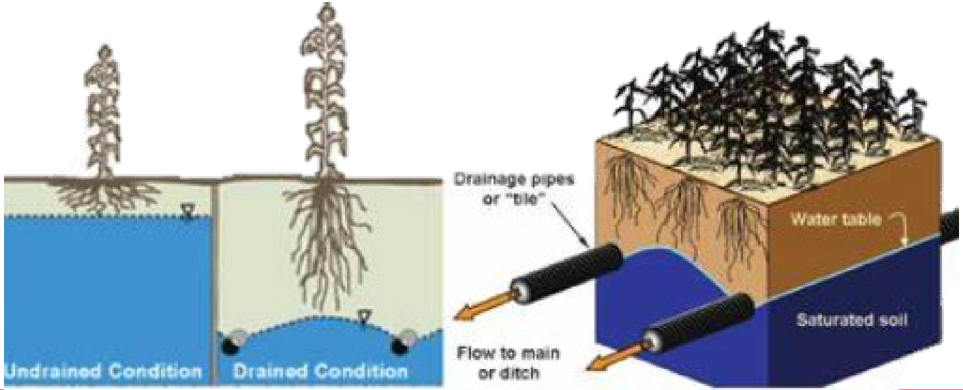
SWAT model within the Iowa **UrbanFEWS**:

- Quantify crop growth.
- **Hydrological cycling.**
- **Nutrient and sediment cycling and transport for cropping systems and associated management practices**.
- Simulate future land use change scenarios to characterize streamflow, nutrient, sediment load conditions, and yields production.



- **Why**? The "Corn Belt" region is an important agricultural area in the central United States, characterized by **dense networks of drainage tile**. Extensive land alterations in this area have generated **natural landscape loss, water pollution, and other environmental problems**. Tile drainage is responsible for the **majority of nitrate load contributions to Iowa rivers** and streams.

- **How**? Ecohydrological models are key tools for accurate system representation and impact measurement, and SWAT can simulate tile drainage implementation in a watershed-scale.



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This study intends to calibrate and validate the SWAT model for streamflow and nitrate loads for the Des Moines River Basin (DMRB), Iowa, U.S., with focus on tile-drain calculations.

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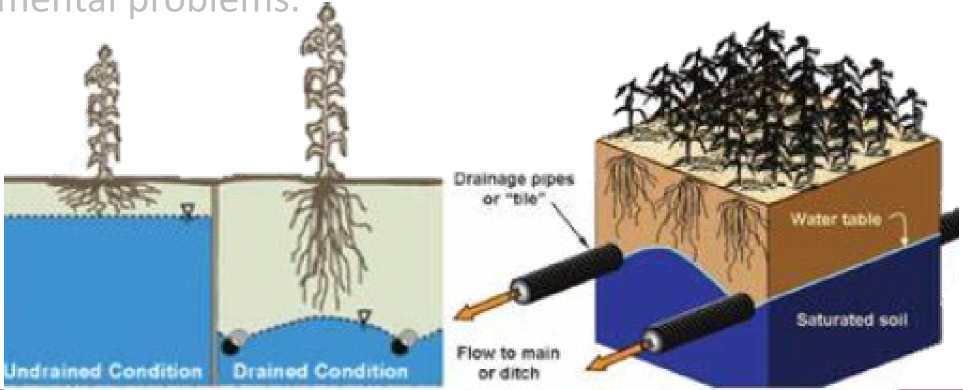
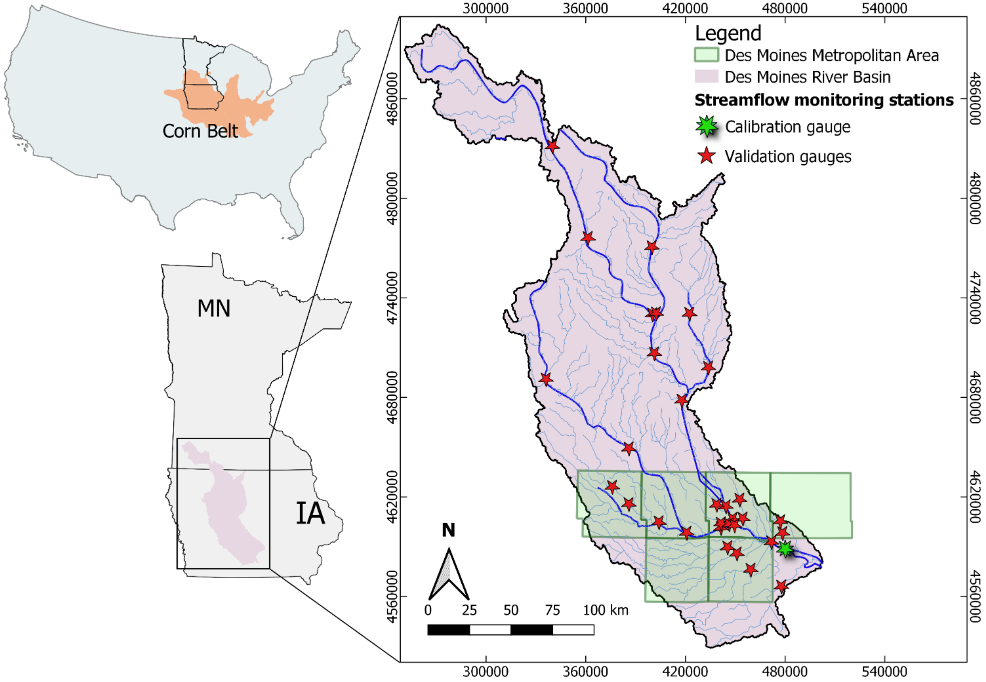


STUDY AREA

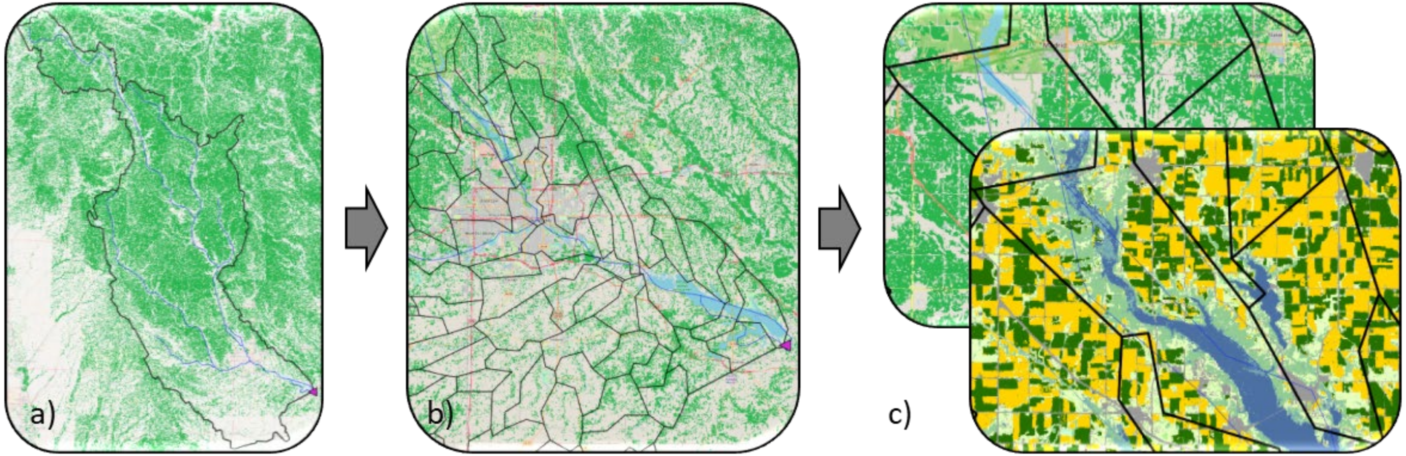
Des Moines River Basin (DMRB) 31,892 km²

- **Land use**: soybean and corn fields representing together 70%.
- **Soil type**: Loamy Wisconsin Glacial Till **(heavy tile drained)**.
- **Precipitation and evapotranspiration**: 873 mm and 670 mm (annual average 1985-2018).



SWAT MODEL SETUP AND TILE-DRAIN CONFIGURATION

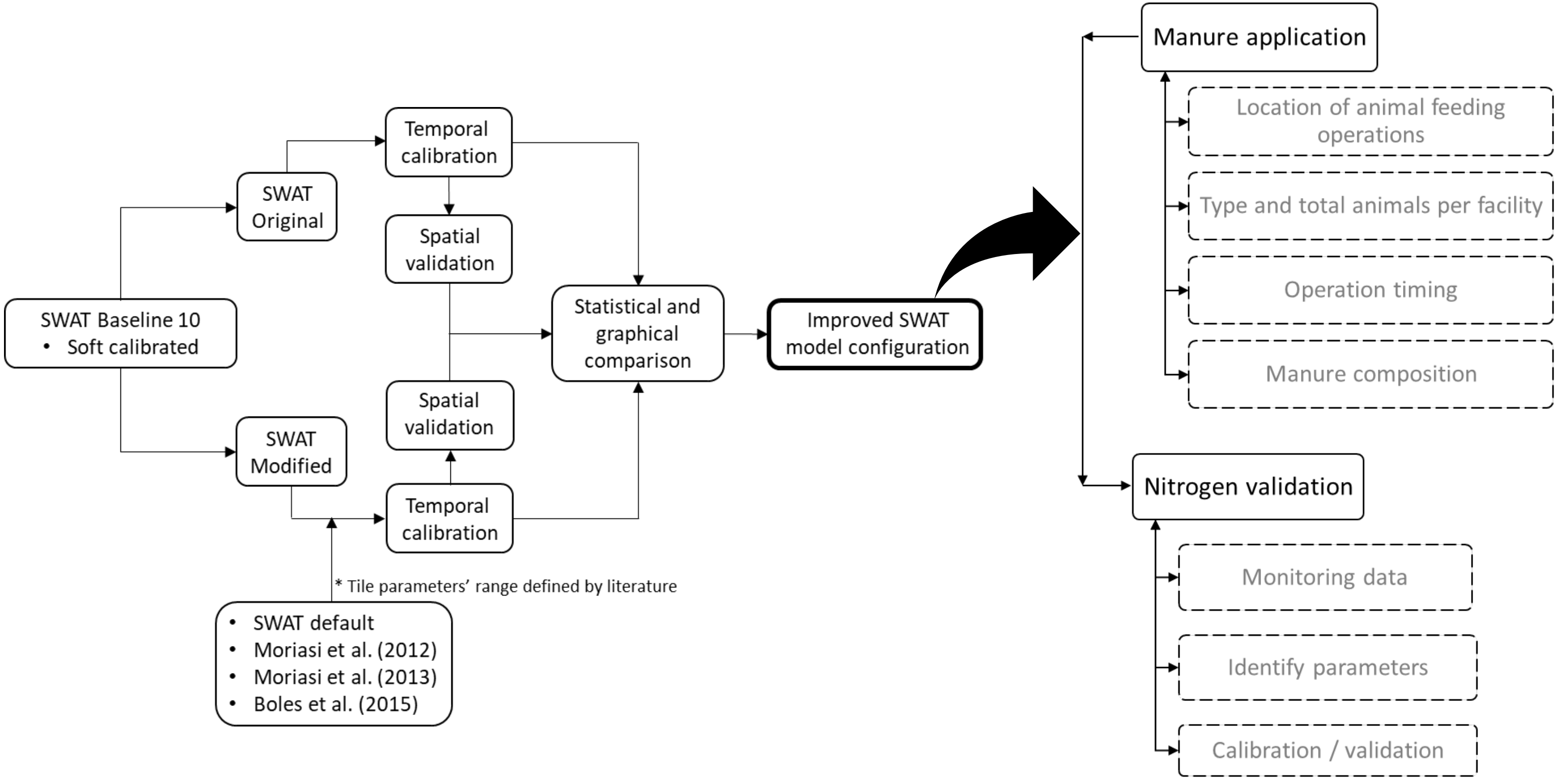
- Initial model setup: previous soft-calibrated model.
- Tile drainage configuration: spatial validated tile-drain map (86% confidence in tile-drain locations); subbasin location.



a) Spatial distribution of tile drainage (shown as green); b) tile-drain zoom-in for the 12-digit subbasin map; and c) representation of the tile drain and land use map overlap.

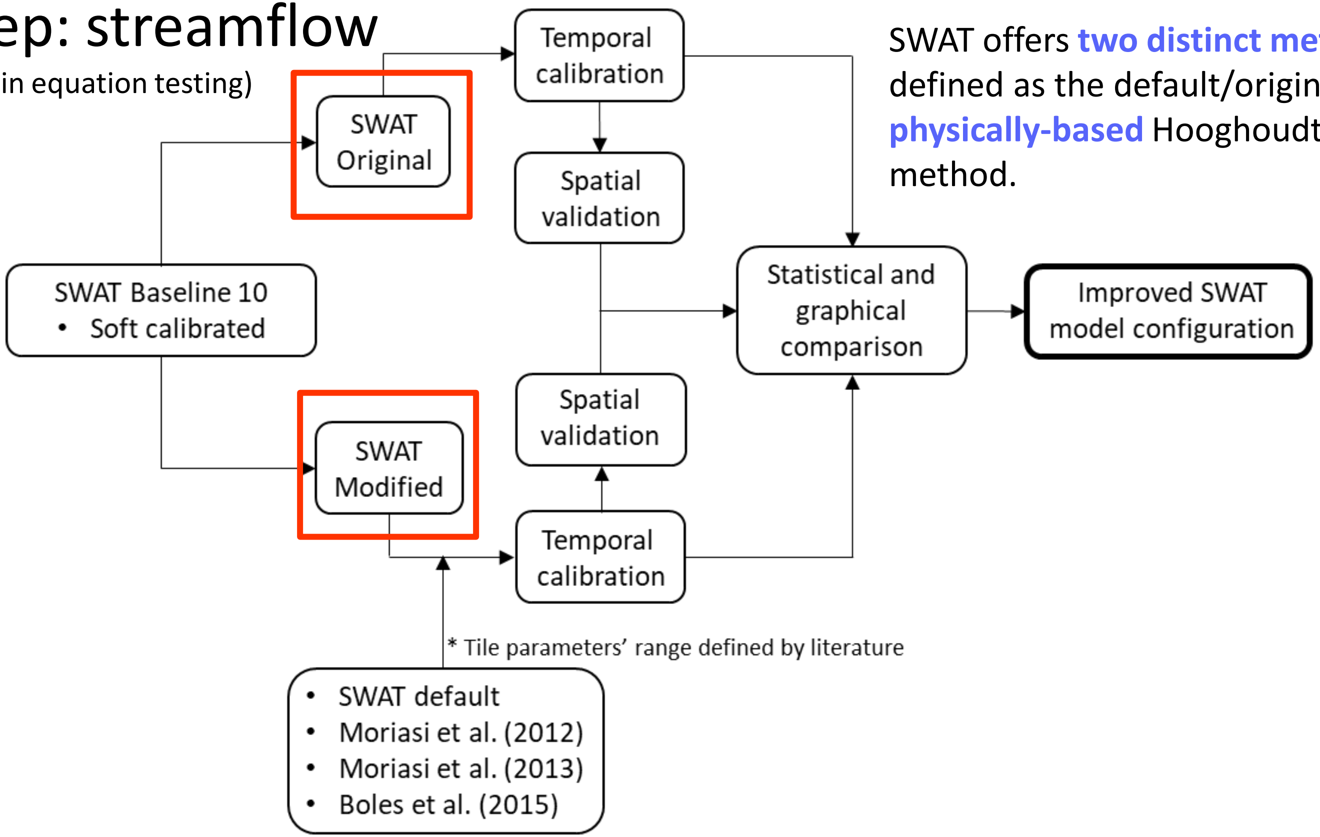
1 step: streamflow

2 step: nitrogen loads



1 step: streamflow

(tile-drain equation testing)



SWAT offers **two distinct methods**: an **empirical** method defined as the default/original option and a modified **physically-based** Hooghoudt and Kirkham equations method.

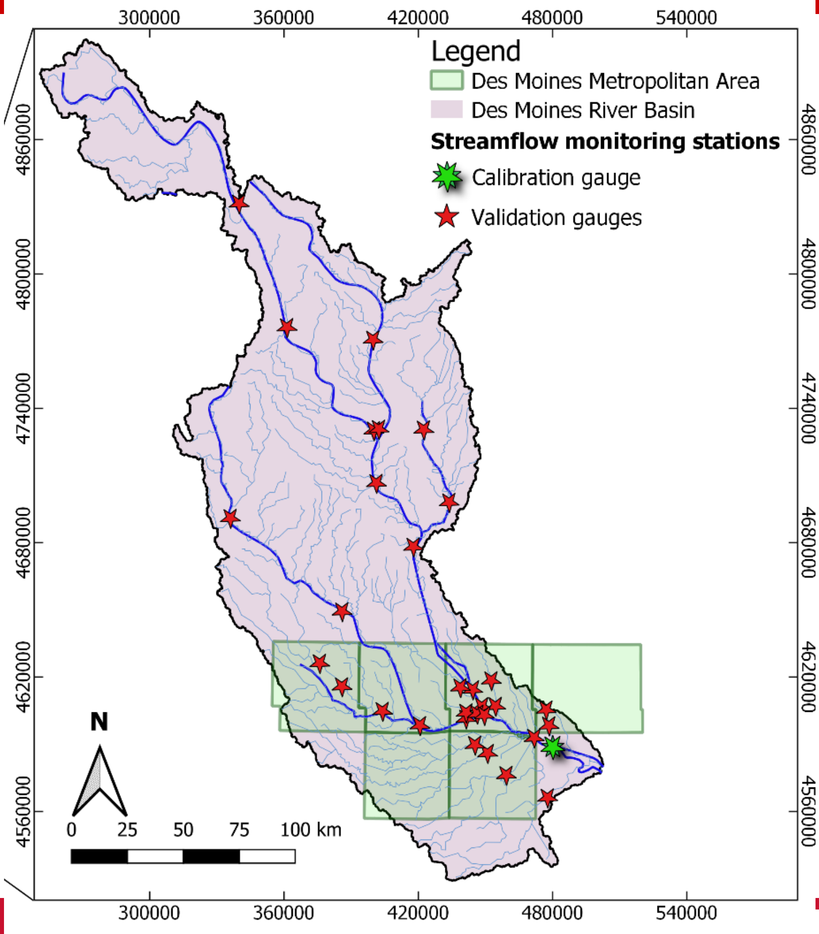
SWAT MODEL CALIBRATION AND STATISTICAL ANALYSIS

Daily

- Temporal calibration: years 2001 to 2009, DMRB outlet.
- Spatial validation: years 2001 to 2010, DMRB 24 subbasins.

The calibration was composed of 1 iteration of 400 runs to develop best parameters, best ranges, and total uncertainty bands. The 10% best parameters obtained during the calibration process were used to carry out the validation.

- Evaluation: NS, KGE, Pbias, FDC, r-factor, p-factor



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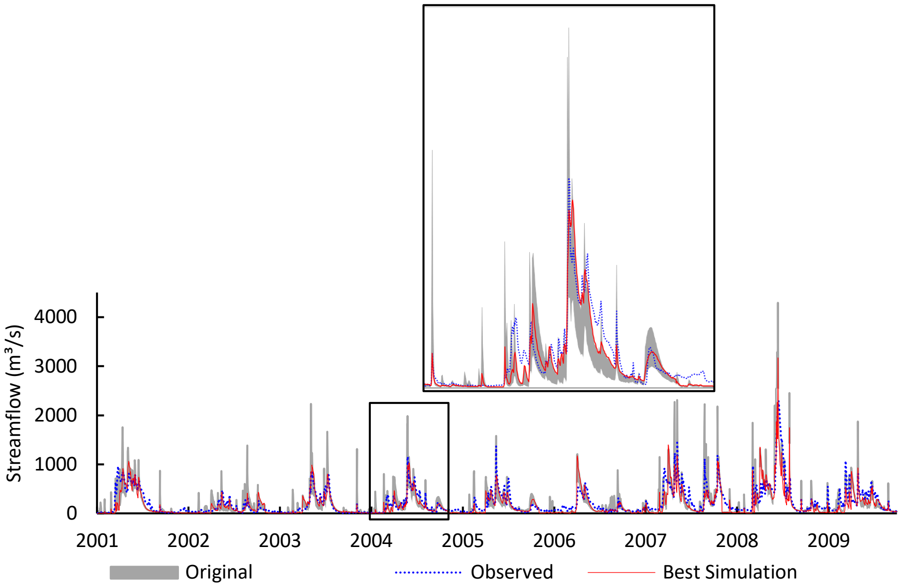
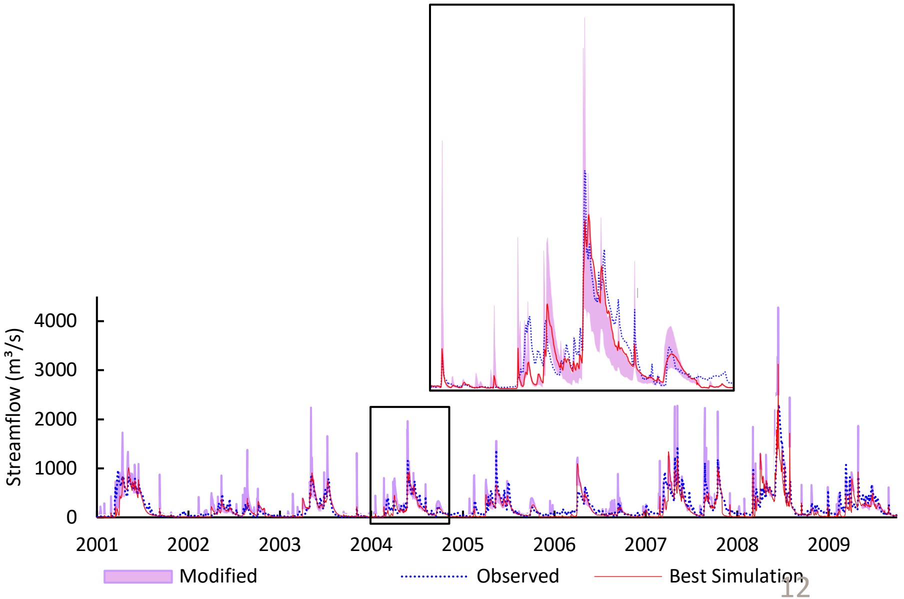
Parameter		Calibration range (original and modified)	
		Min.	Max.
Initial SCS runoff curve number for moisture condition II	r__CN2	-0.2	0.2
Baseflow alpha factor	v__ALPHA_BF	0.001	0.5
Manning's "n" value for the main channel	v__CH_N2	0.01	0.02
Soil evaporation compensation factor	v__ESCO	0.6	1
The delay time	v__GW_DELAY	0	60
Groundwater "revap" coefficient	v__GW_REVAP	0.02	0.2
Threshold depth of water in the shallow aquifer for "revap" or percolation to the deep aquifer to occur	v__REVAPMN	0	1000
Surface runoff lag coefficient	v__SURLAG	0.01	24
Distance between drains	v__SDRAIN	7700	27000
Soil lateral saturated hydraulic conductivity factor	v__LATKSATF	1	3.8
The daily drainage coefficient:	v__DRAIN_CO	13	48
Tile-drain radius	v__RE	25	50
Tile-drain depth	(fix) DDRAIN	1200	1200
Time required to drain the soil to field capacity	(fix) TDRAIN	24	24
Tile-drain lag time	(fix) GDRAIN	48	48
Impervious layer depth	(fix) DEP_IMP	1200	1200*

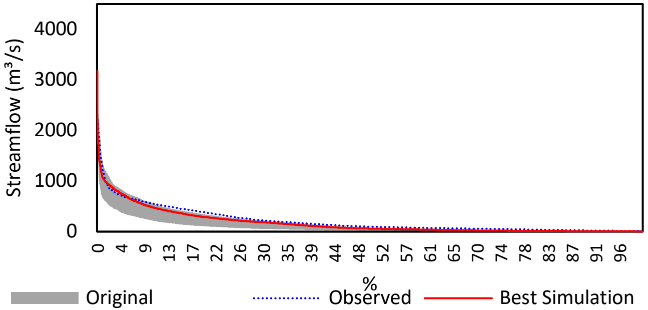
Daily calibration performance - **NSE, KGE, Pbias** - for original and modified tile-drain calculation methods.

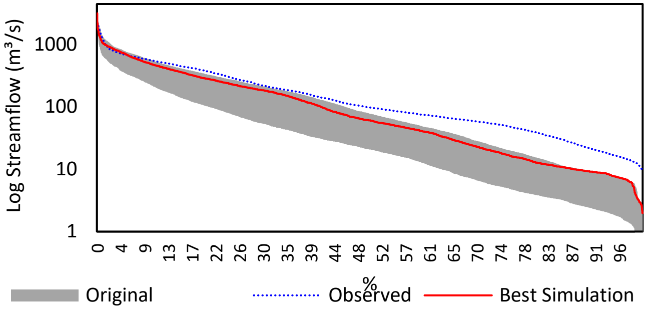
Calibration	NSE	KGE	Pbias	p-factor	r-factor
Original	0.70	0.76	18.5	0.39	0.49
Modified	0.71	0.76	18.3	0.41	0.49

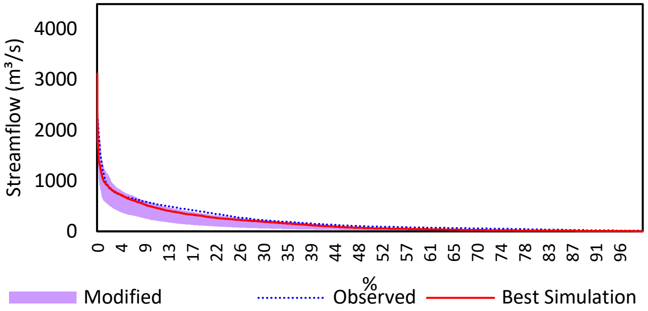


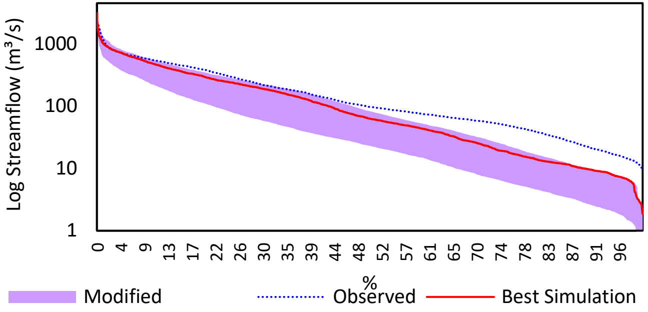


Daily calibration performance - **Flow Duration Curve** - for original and modified tile-drain calculation methods.







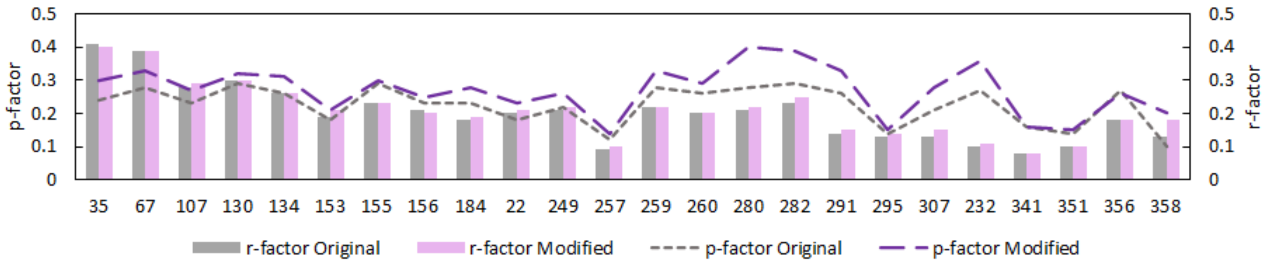


The modified method showed a decrease in the streamflow peaks (below 8% for the best simulation on the FDC).

However, the method resulted in an increase of the streamflow between the 16% and 94% segments on the FDC.

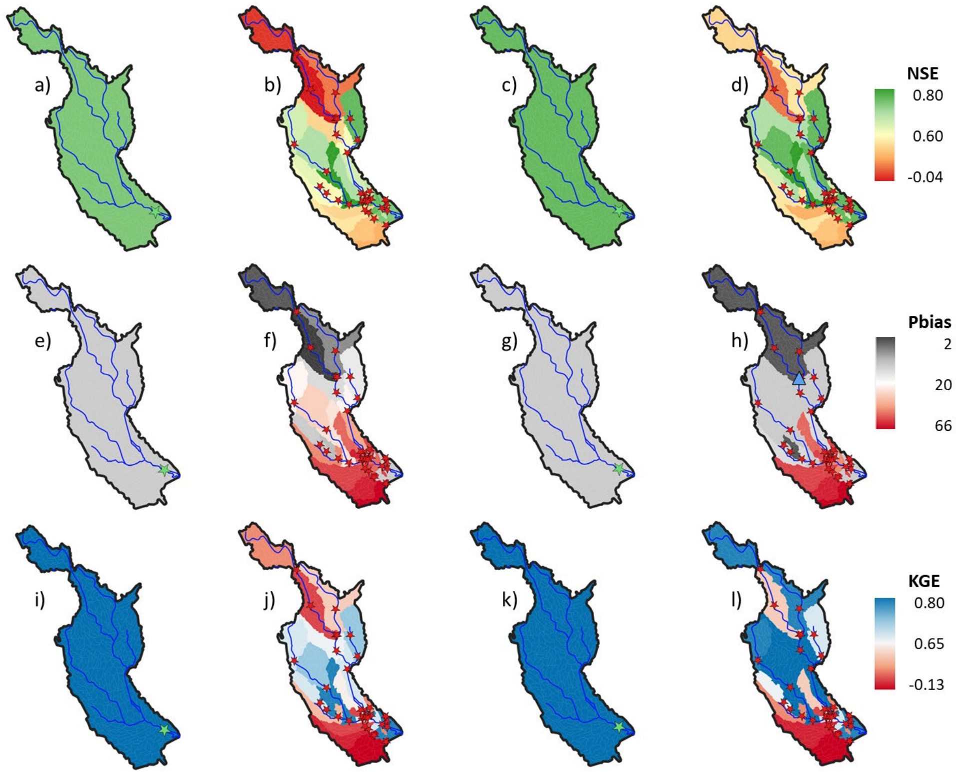
Test (k-s): modified method suggests the equation resulted in a curve with a slightly better fit to the observed data.

Daily validation performance – **p-factor, r-factor** - for original and modified tile-drain calculation methods.



- The p-factor r-factor coefficients showed similar behavior for both methods.
- The modified method had higher p-factor values for all gauges, except for the gauge 341 that resulted in the same values for both methods.
- The r-factor was smaller for the original method at 13 gauges, smaller at 2 gauges for the modified method and the same at 9 gauges

Daily validation performance – **NSE, Pbias, KGE** - for original and modified tile-drain calculation methods.

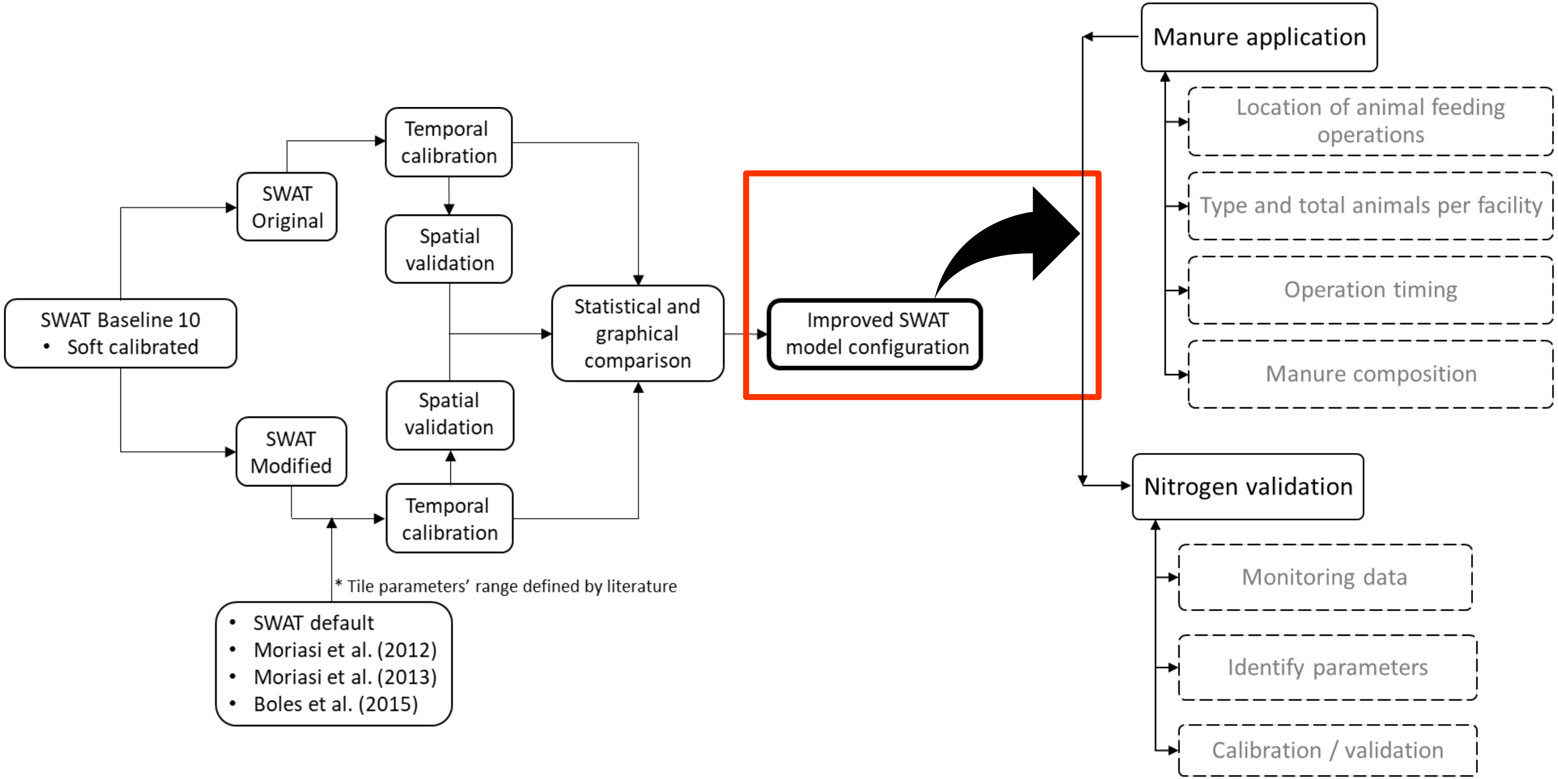


The daily validation process showed improvement when applying the modified tile-drain equation .

	Original			Modified		
	NSE	Pbias	KGE	NSE	Pbias	KGE
Very good	0	1	-	0	2	-
Good	4	1	-	8	2	-
Satisfactory	12	3	14	11	1	16
Not satisfactory	7	21	10	4	19	8

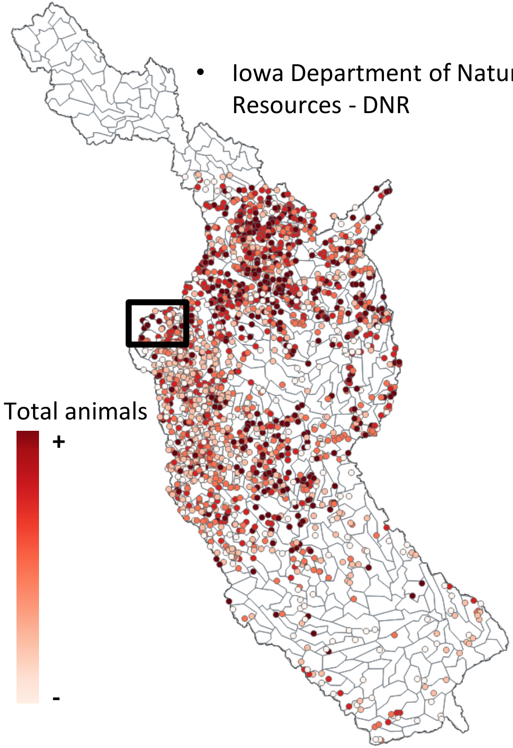
1 step: streamflow

2 step: nutrient loads

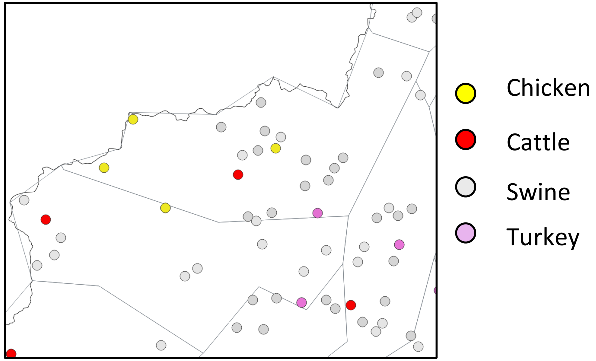


Manure application data

Manure application
- Location of animal feeding operations
- Type and total animals per facility
- Operation timing
- Manure composition

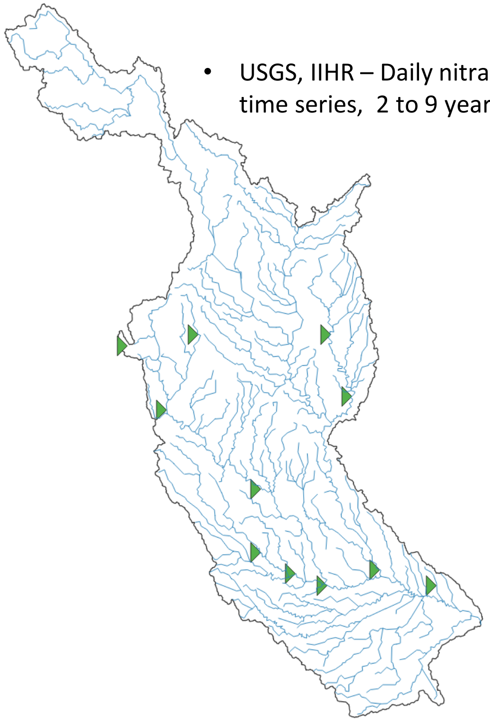


- Iowa Department of Natural Resources - DNR



Nitrogen validation

- Nitrogen validation
  - Monitoring data
  - Identify parameters
  - Calibration / validation



- USGS, IIHR – Daily nitrate time series, 2 to 9 years

Highlights

- The percentages of baseflow comparing to the water yield are 84% for the original and 87% for the modified methods.
- The daily analysis showed the modified method (Hooghoudt and Kirkham equations) has more accurate spatial variability in representing the hydrological processes at the DMRB.
- A common ground between the methods is that both had difficulty in simulating the streamflow at the less drained areas of the watershed.
- These results also underscore the increased challenge for SWAT to replicate the magnitude of the daily streamflow

Thank you!

Methods to calculate flow through subsurface tiles

The SWAT offers **two distinct methods**: an **empirical** method defined as the default/original option and a modified **physically-based** Hooghoudt and Kirkham equations method.

The empirical function composed of four main parameters: 1) tile-drain depth, 2) the time required to drain the soil to field capacity, 3) tile-drain lag time, and 4) impervious layer depth.

The method creates an impermeable layer and simulates the tile flow on days when the height of the water table above the

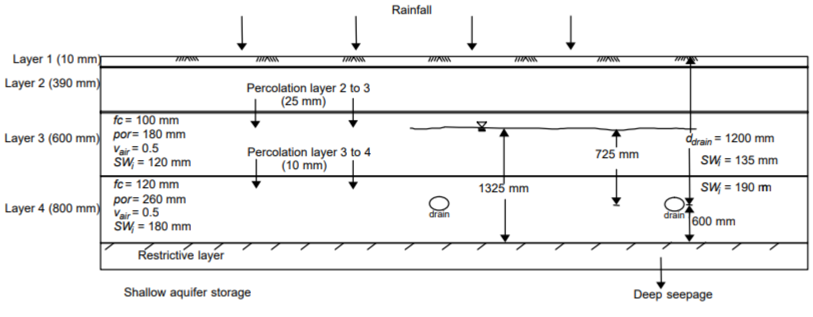
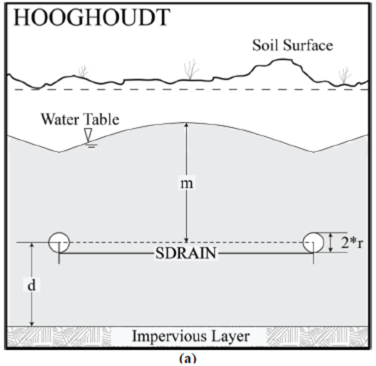


Figure 1. Diagram showing an example water table calculation after a rainfall event.

The physically-based modified version simulates tile flow as a function of lateral saturated hydraulic conductivity of the soil, profile depth, water table elevation, drain spacing, size, and depth.



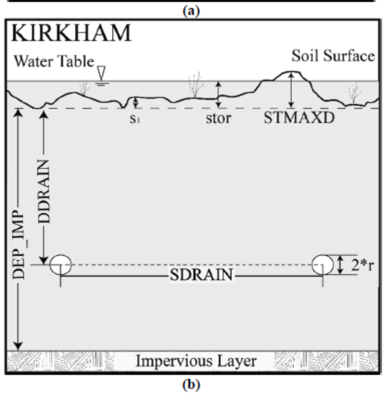


Figure 2. (a) Drainage with the Hooghoudt (1940) steady-state equation and (b) drainage with Kirkham's equation (van Schilfgaarde et al., 1957) for a ponded surface.