EVALUATION OF REVISED SUBSURFACE TILE DRAINAGE ALGORITHMS IN SWAT FOR A COLD CLIMATE

D. N. Moriasi, P.H. Gowda, J. G. Arnold, D.J. Mulla, and S. Ale

Study Goals

- **Modifications made to potential maximum soil moisture retention parameter algorithms to account for the effects of tile drainage on the computation of surface runoff using the CN method in poorly drained agricultural watersheds**

- **Calibration and validation of the SWAT for subsurface tile drain flow for poorly drained soils in a cold climate using long term monitoring data**

Arnold et al. (1998)

Tile Drainage Approaches in SWAT

- **Method 1: Function of water table depth, tile depth, and the time required to drain the soil to field capacity (Arnold et al., 1999)**
- **Method 2: Hooghoudt's (1940) steady-state and Kirkham (1957) tile drain equations; function of water table depth, tile drain depth, size, and spacing (Moriasi et al., 2012)**
- **The water table depth is a function of soil water movement (SW)**
- **The traditional method, which computes the retention parameter in SWAT as a function of soil profile water content, generally over predicts runoff in poorly drained soils equipped with tile drains**

Neitsch et al. (2009)

Surface Runoff Approaches in SWAT

- SCS curve number procedure (SCS, 1972)
  - $$Q_{surf} = \frac{(Rday - 0.2S)^2}{(Rday + 0.8S)}$$
    - $S = 25.4(\frac{1000}{CN} - 10)$
    - Q_{surf} is the accumulated runoff or rainfall excess (mm H_2O),
    - F_{inf} is the cumulative infiltration at time *t* (mm H_2O)
    - *S* is the retention parameter (mm H_2O)
    - *CN* is the curve number for the day
  - $F_{inf,t} = R_{day} - Q_{surf}$
- Green & Ampt infiltration method (1911)
  - $$f_{inf,t} = Ke.\left(1 + \frac{\Psi_{wf}.\Delta\theta_v}{F_{inf,t}}\right)$$
    - f_{inf} is the infiltration rate at time *t* (mm/hr)
    - K_e is the effective hydraulic conductivity (mm/hr)
    - Ψ_{wf} is the wetting front matric potential (mm)
    - $\Delta\theta_v$ is the change in volumetric moisture content across the wetting front (mm/mm)
    - F_{inf} is the cumulative infiltration at time *t* (mm H_2O)
  - $Q_{surf} = R_{day} - F_{inf,t}$

Neitsch et al. (2009)

Retention Parameter Methods in SWAT

- **Function of soil water content (ICN = 0)**
- $$S = Smax * \left(1 - \frac{SW}{SW + exp(w_1 - w_2.SW)}\right)$$
  - S_{max} is the maximum value the retention parameter can achieve on any given day (mm)
  - *SW* is the soil water content of the entire profile excluding the amount of water held in the profile at wilting point (mm H_2O)
  - w_1 and w_2 are shape coefficients
  - The maximum retention parameter value, S_{max}, is calculated by solving

  $S = 25.4(\frac{1000}{CN} - 10)$ using CN_1

- **Function of plant evapotranspiration (ICN = 1)**
- $$S = Sprev + Eo * exp\left(\frac{-cncoef - Sprev}{S_{max}}\right) - Rday - Qsurf$$
  - S_{prev} is the retention parameter for the previous day (mm)
  - E_o is the potential evapotranspiration for the day (mm d^{-1}),
  - *cncoef* is the weighting coefficient used to calculate the retention coefficient for daily curve number calculations dependent on plant evapotranspiration

Neitsch et al. (2009)

CN2

Table 2:1-1: Runoff curve numbers for cultivated agricultural lands (from SCS Engineering Division, 1986; Neitsch et al. (2009)

Cover			Hydrologic Soil Group			
Land Use	**Treatment or practice**	**Hydrologic condition**	**A**	**B**	**C**	**D**
Fallow	Bare soil	- - - -	77	86	91	94
	Crop residue cover*	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	Straight row	Poor	72	81	88	91
		Good	67	78	85	89
	Straight row w/ residue	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured	Poor	70	79	84	88
		Good	65	75	82	86
	Contoured w/ residue	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced	Poor	66	74	80	82
		Good	62	71	78	81
	Contoured & terraced w/ residue	Poor	65	73	79	81
		Good	61	70	77	80
Small grains	Straight row	Poor	65	76	84	88
		Good	63	75	83	87
	Straight row w/ residue	Poor	64	75	83	86

* Crop residue cover applies only if residue is on at least 5% of the surface throughout the year.

- Soil's permeability
- Land use
- Antecedent soil water conditions
- Slope (5%)
- Not a function of tile drainage

Neitsch et al. (2009)

Impact of Tile Drainage on Hydrology

- **(1) increases storage capacity in the soil**
  - **continuous removal of excess water from the soil profile (Skaggs and Broadhead, 1982).**
  - **tile drainage improves soil structure, more porous and hence more storage capacity (Gardner et al., 1994).**

Table 1. The variability of drainable porosity with soil texture and structure (Sands, 2009)

Soil Texture	Field Capacity (% by vol.)	Wilting Point (% by vol.)	Drainable Porosity (% by vol.)
clays, clay loams, silty clays	30-50%	15-24%	3-11%
well structured loams	20-30%	8-17%	10-15%
sandy	10-30%	3-10%	18-35%

- **Example:**
- **2 soils with Pd = 4%; undrained and drained @ 1000 mm below surface. Wtd depth for undrained is 200 mm below surface while drained is 1000 mm below surface on a given day. Undrained soil has (4*200 mm/100) 8 mm of pore space available btn surface and wtd while the drained soil has (4*1000/100) 40 mm of pore space available btn; 32 mm more available (empty) pore space. If low intensity rainfall of 50 mm occurred, you would expect 42 mm of surface runoff from undrained and 10 mm from drained soil ("sponge effect").**

- **(2) increases infiltration, reduces surface runoff (Thomas et al. 1995)**

Neitsch et al. (2009)

Use of CN Method on Tile Drained Watersheds

- **According to Walker et al. (2000) CN method can be used in tile –drained watersheds with possible modifications of:**
  - **(1) CN used to estimate potential maximum soil retention (S)**
    - **In SWAT this is done by calibration**
  - **(2) potential maximum retention (S_{max}) associated with initial abstractions (I_a)**

Neitsch et al. (2009)

Modified Soil H_2O Retention Parameter

- **Modified function of soil water content method (ICN= 2)**
- $$S = 8.0 * Smax * \left(1 - \frac{SW}{SW + exp(w_1 - w_2 . SW)}\right)$$

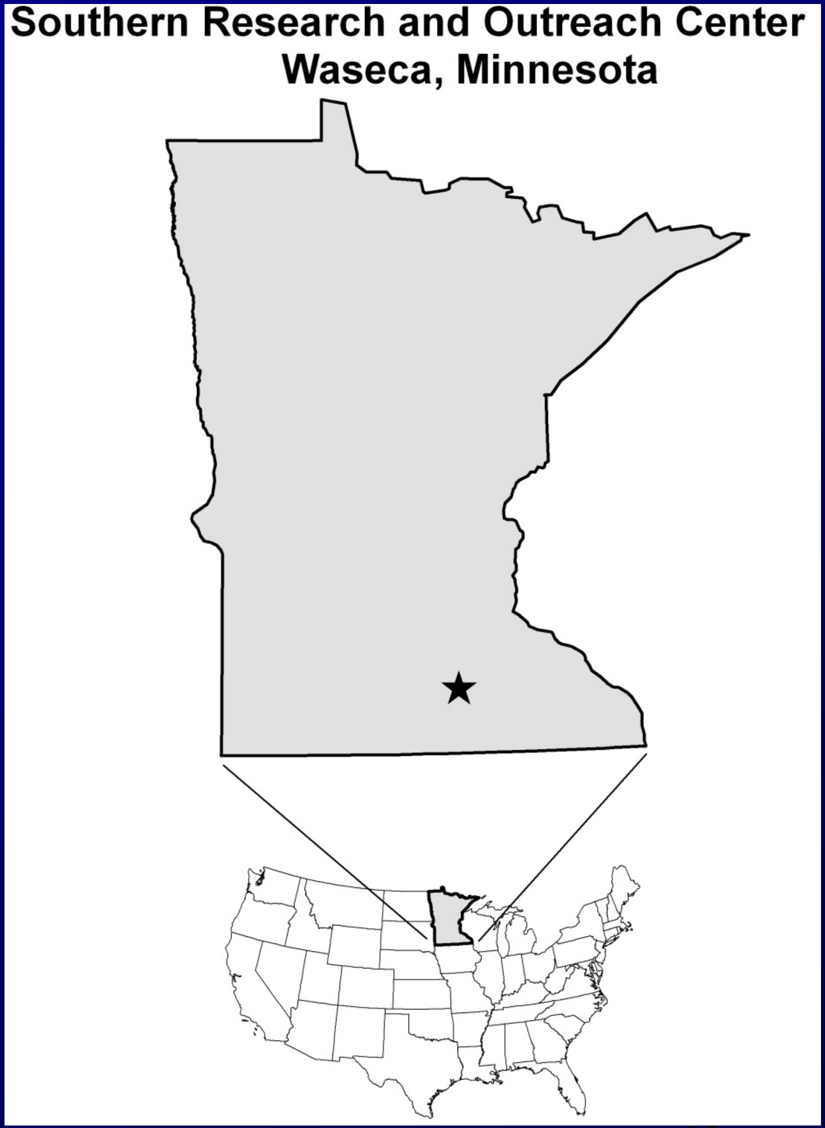
  - S_{max} is the maximum value the retention parameter can achieve on any given day (mm)
  - *SW* is the soil water content of the entire profile excluding the amount of water held in the profile at wilting point (mm H_2O)
  - w_1 and w_2 are shape coefficients
  - The maximum retention parameter value, S_{max}, is calculated by solving

  $S = 25.4(\frac{1000}{CN} - 10)$ using CN_1

Neitsch et al. (2009)

Study Area and Data

- Three continuous corn plots located in the University of Minnesota's Agricultural Experiment Station near Waseca, southern Minnesota
- The size of each plot was 13.5 x 15.0 m. These plots were designed to simulate a tile drain spacing of 27 m. Tile drains were installed at a depth of 1.2 m with a gradient of 0.1%. Diameter of the tile drain was 100 mm.
- Since 1982, these plots were planted with continuous corn under moldboard plow tillage.
- Field measurements of soil and crop properties were made as a part of a tile drainage study
- Tile drain flows were measured daily and summed to calculate monthly and yearly values.
- Weather data recorded at a weather station located 0.5 km from the experimental plots was used in the simulation



Davis et al. (2000)

Tile Drain Parameters

- **Used Hooghoudt's (1940) steady-state and Kirkham (1957) tile drain equations**

Table 1. Values used for subsurface drainage systems in the study plot (Davis et al., 2000).

Parameter	Description	Value
DDRAIN	Depth to subsurface tile (mm)	1200
Size	Diameter of tile drain (mm)	100
SDRAIN	Distance between two drain or tile tubes (mm)	27000

Moriasi et al. (2011)

Results: Water Budget

Table 2. Observed/reported and simulated average annual water budget. ICN = 0 is original method based on soil water content; ICN = 2 is soil water content method, modified for tile drainage. * Moorman et al., 1999; ** Nangia et al., 2009

Component	Obs./Literature		ICN=2, CN2 = 78		ICN=0, CN2=78		ICN=0, CN2=30	
	Depth (cm)	Percent of Precip. (%)	Depth (cm)	Percent of Precip. (%)	Depth (cm)	Percent of Precip. (%)	Depth (cm)	Percent of Precip. (%)
Precipitation	52.8	100	52.8	100	52.8	100	52.8	100
ET		64 – 70*	35.9	68	35.4	67	35.7	68
Tile Drainage	20.7	39	20.3	39	9.1	17	19.7	37
Runoff		5**	0.5	1	13.1	25	0.6	1

Calibrated CN2 Value Implications

Table 2:1-1/2: Runoff curve numbers for cultivated agricultural lands (from SCS Engineering Division, 1986; Neitsch et al. (2009)

Cover			Hydrologic Soil Group			
Land Use	**Treatment or practice**	**Hydrologic condition**	**A**	**B**	**C**	**D**
Fallow	Bare soil	- - - -	77	86	91	94
	Crop residue cover	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	**Straight row**	Poor	72	81	88	91
		Good	**67**	**78**	**85**	**89**
	Straight row w/ residue	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured	Poor	70	79	84	88

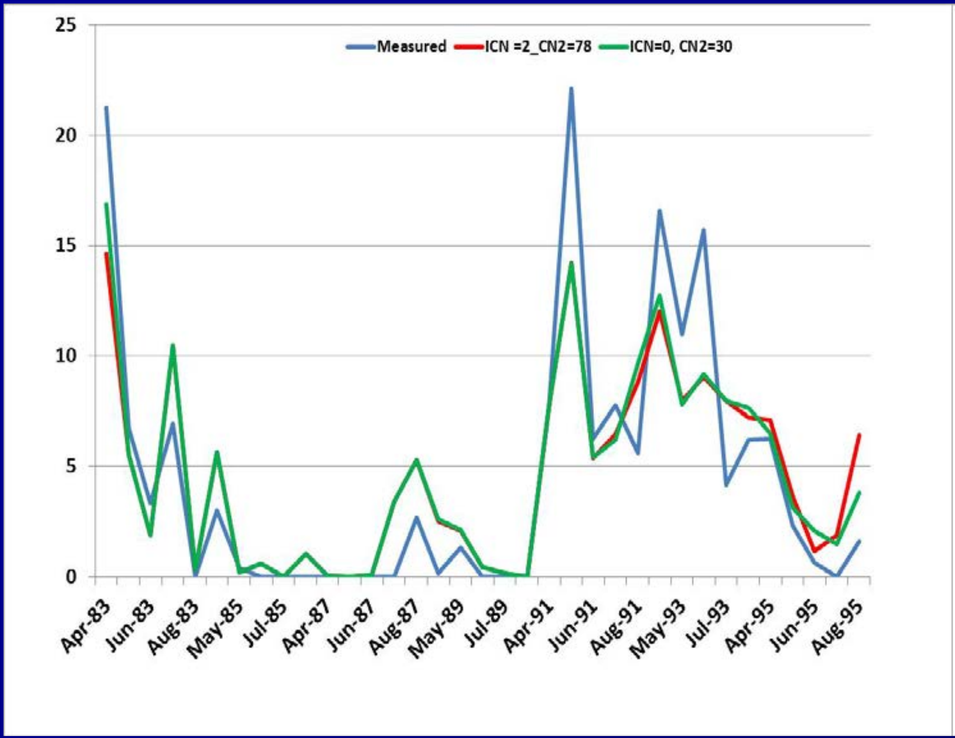
Cover		Hydrologic Soil Group			
Cover Type	**Hydrologic condition**	**A**	**B**	**C**	**D**
Pasture, grassland, or range—continuous forage for grazing	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow—continuous grass, protected from grazing and generally mowed for hay	**- - - -**	**30**	**58**	**71**	**78**
Brush—brush-weed-grass mixture with brush the major element	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	**30**	**48**	**65**	**73**
Woods—grass combination (orchard or tree farm)	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	**30**	**55**	**70**	**77**

Results: Tileflow Simulation Performance

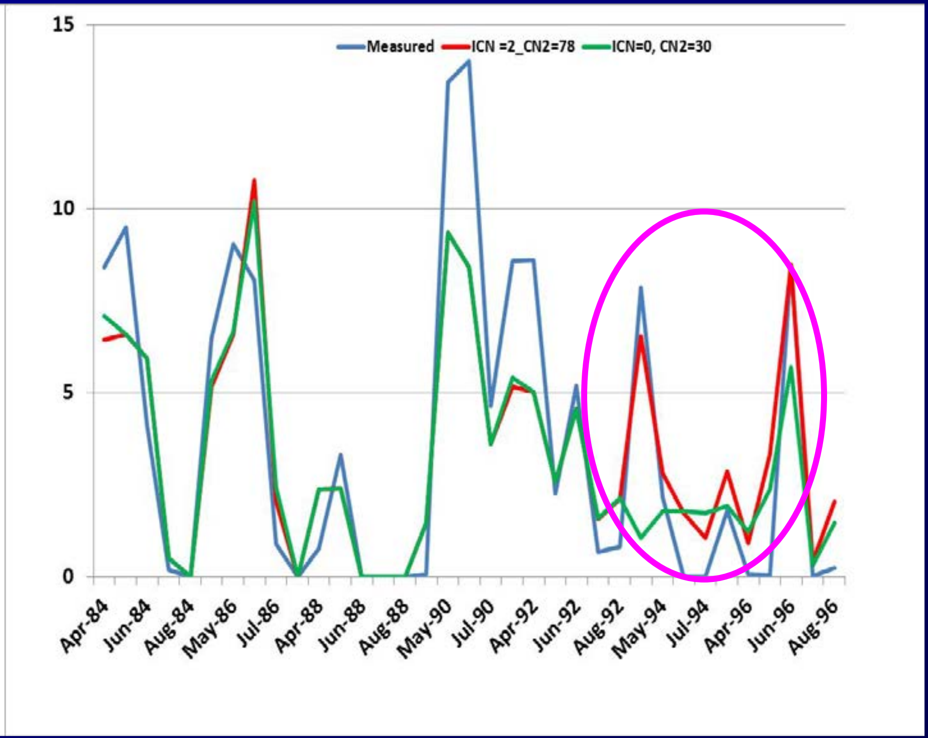
ICN	Calibration		Validation	
	Monthly NSE	**PBIAS (%)**	**Monthly NSE**	**PBIAS (%)**
ICN=2, CN2=78	.77	-1.1	.78	5.4
ICN=0, CN2=78	.39	55.3	.26	57.2
ICN=0, CN2=30	.81	-1.7	.72	12.9

Results: Tileflow Simulation Performance

Calibration



Validation



Thank You!

Questions?