Simulation of Tile Drainage in Two Midwestern Watersheds Using SWAT2012

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Tile drains are installed about 1 meter below the surface in poorly drained soils throughout the U.S. Midwest and other regions such as northern Europe

Drainage is critical for productive agriculture in poorly-drained soils

But nutrient losses are significant concerns:

- It has been known for decades that tile drains greatly increase loss of **nitrate** to streams.
- Recent research is showing more clearly that phosphorus also moves through tiles.

Photo from Dan Jaynes

Critical national issues are linked to nutrient losses from subsurface tile drainage

- Hypoxia in the Gulf of Mexico

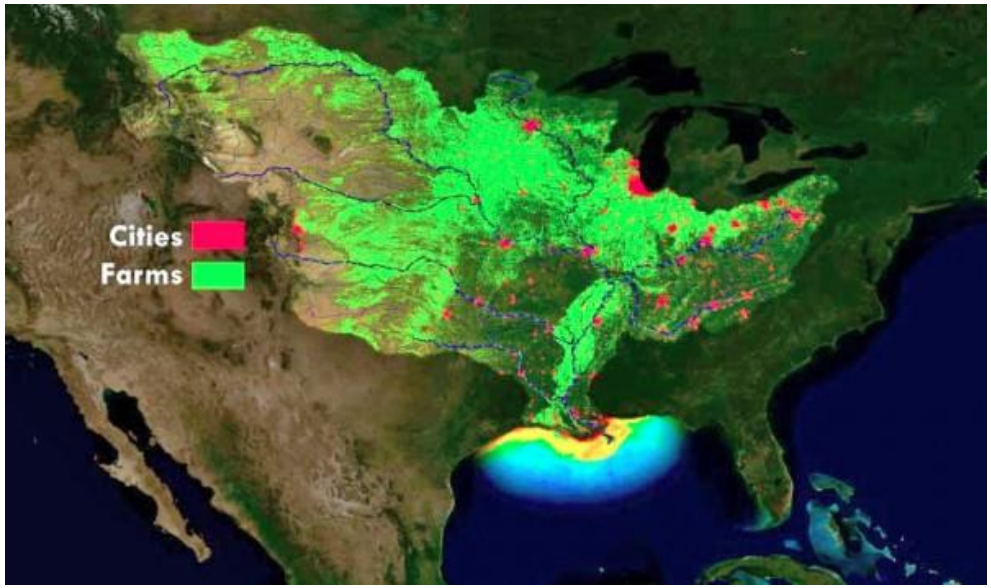


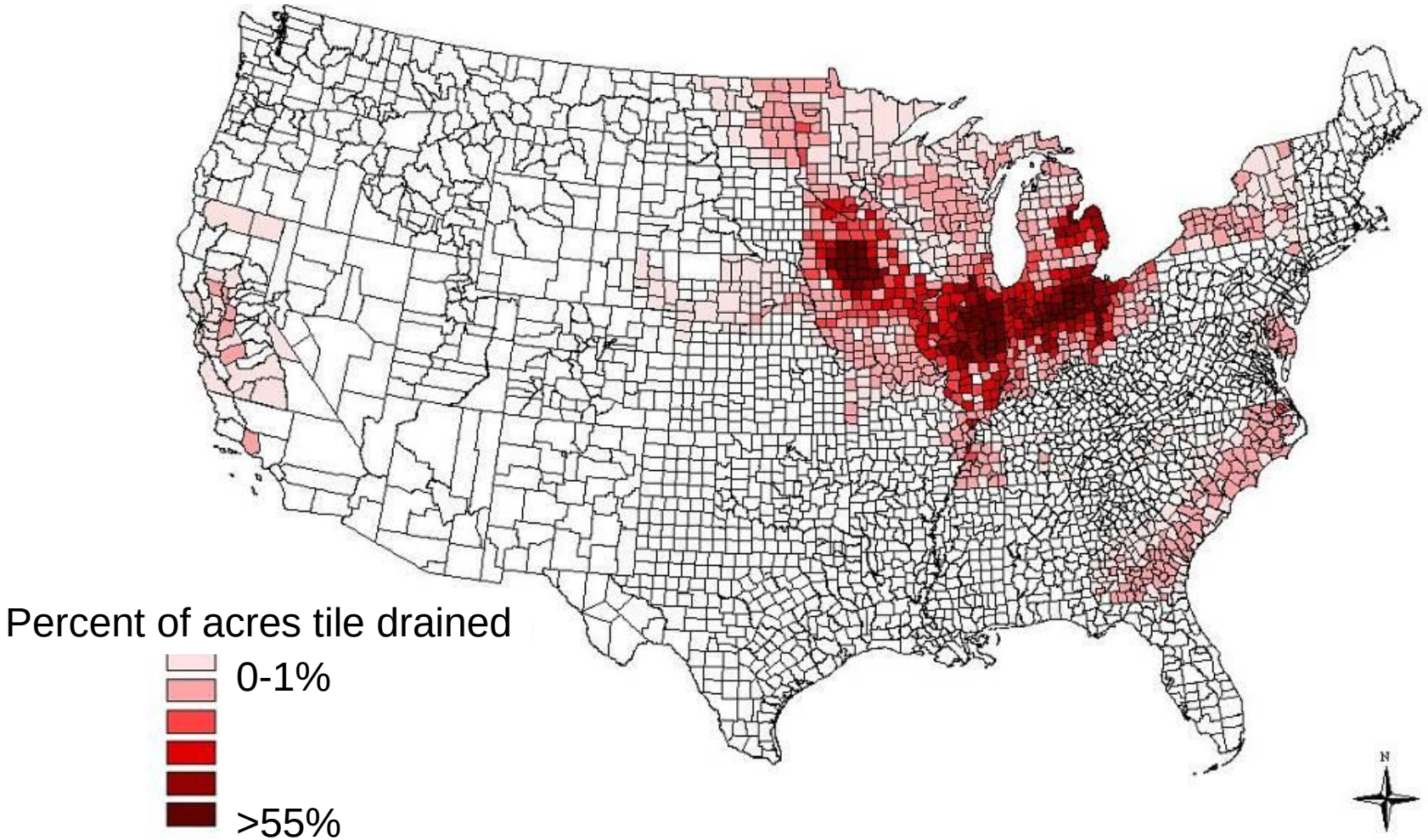
Image from NOAA

- Toxic algae in Lake Erie

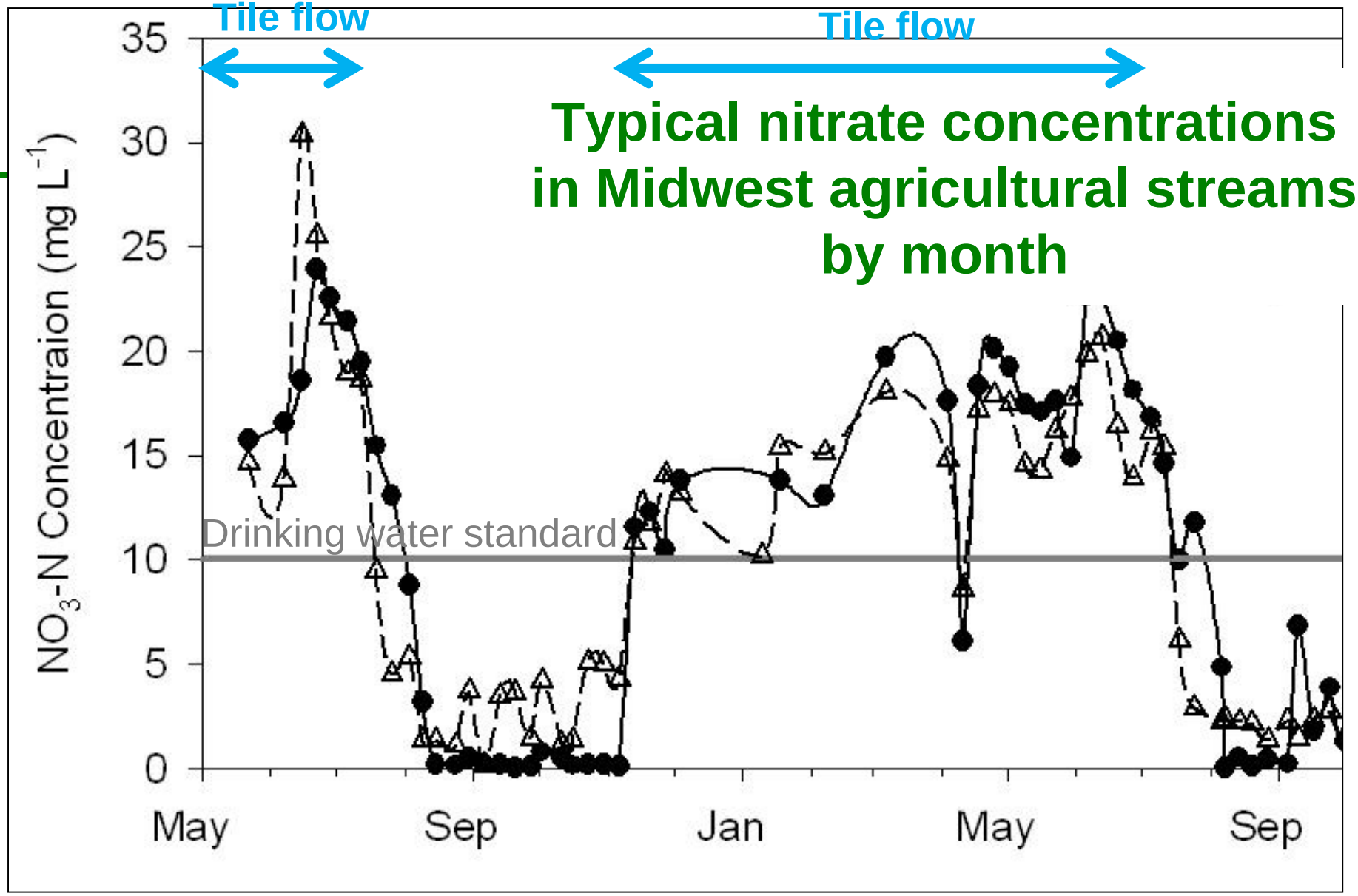
August 2015 Headline:
“Toxin leaves 500,000 in northwest Ohio without drinking water”

Image from Tom Bridgemen

Tile drainage: Estimated extent



Source: Zachary Sugg, World Resources Institute



Graph courtesy Sylvie. Brouder

SWAT tile drainage routines

- Du et al (2005) developed a routine implemented in SWAT 2005
  - TDRAIN = time to drain soils to field capacity, set by the user as a static parameter.
  - Large storm or small, the time of drainage is the same.
  - GDRAIN= a lag coefficient

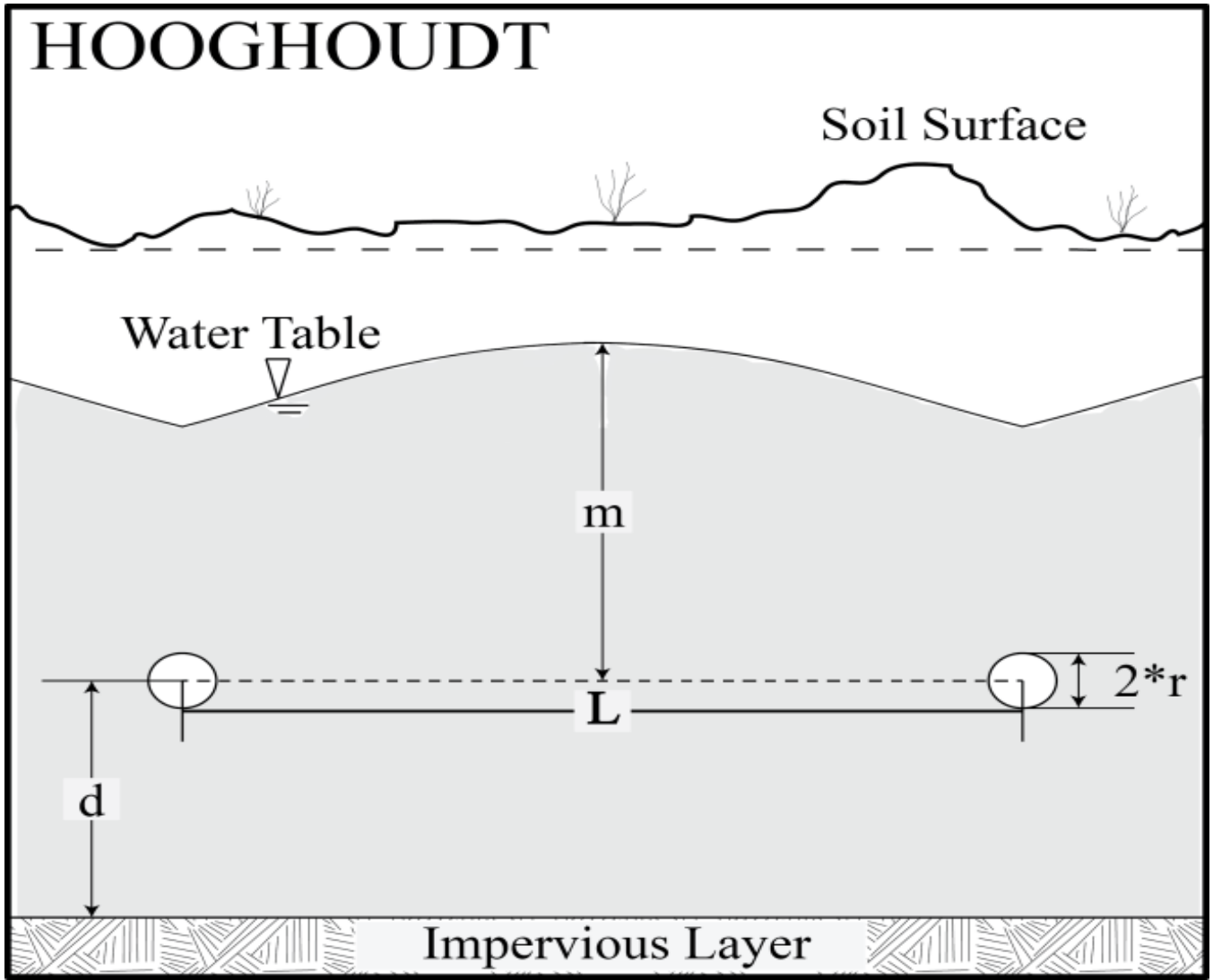
$$tile\_ttime(j) = 1 - e^{\left(\frac{-24}{\mathrm{GDRAIN}(j)}\right)}$$

SWAT tile drainage routines

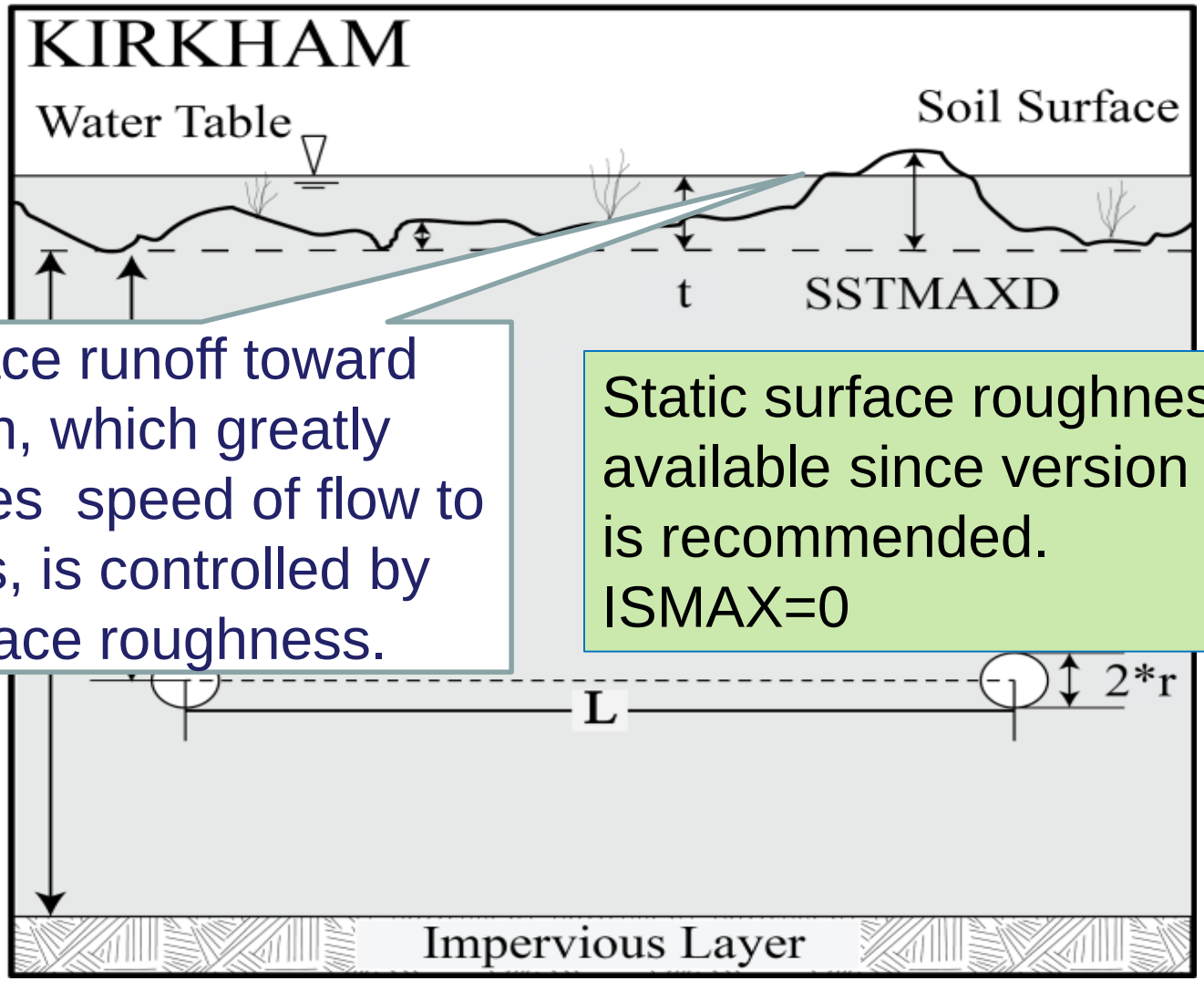
- Moriasi et al. (2007a) developed a new drainage simulation method available starting in SWAT 2012
- Uses Houghoudt and Kirkham drainage equations and a drainage coefficient to replace the drawdown time-based algorithm.
  - Some call this the “DRAINMOD routines”
  - Boles et al (in press) called it “HKdc”

Boles, C., J. Frankenberger, D. Moriasi, in press. Tile Drainage Simulation in SWAT2012:Parameterization and Evaluation in an Indiana Watershed. Transactions of ASABE.

Hooghoudt Equation - when water table below the surface (no surface flow)



Kirkham Equation – when water table above the surface, runoff can flow toward drain.



Surface runoff toward drain, which greatly increases speed of flow to drains, is controlled by surface roughness.

Static surface roughness available since version 537 is recommended.
ISMAX=0

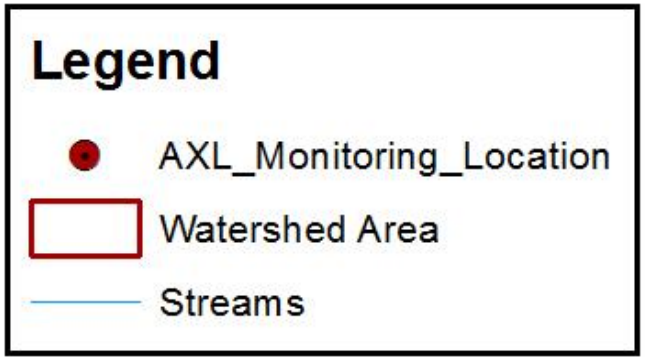
Drainage coefficient – based on the size of the pipes.

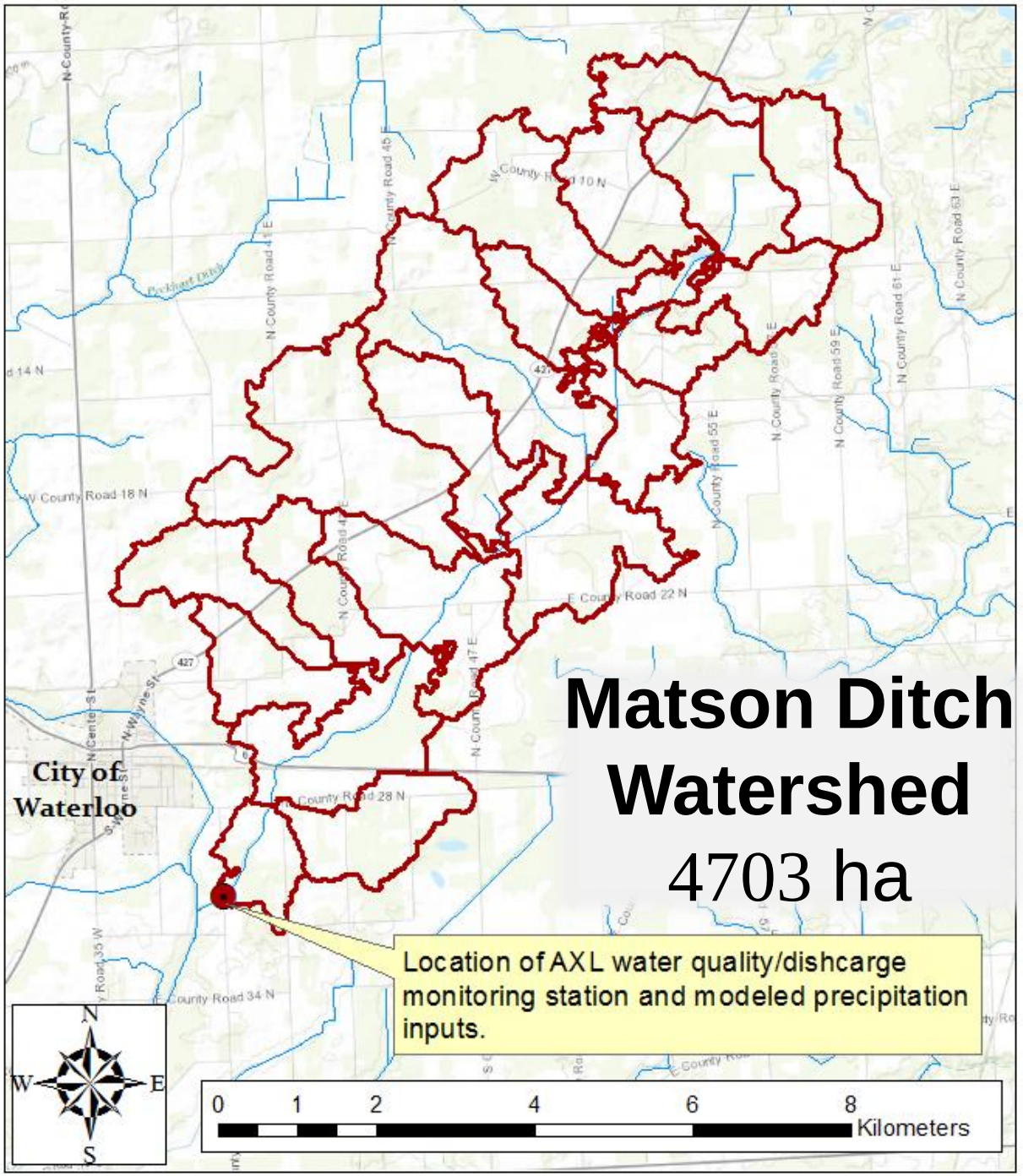
This can limit tile flow in a very intense storm.

Photo: Dan jaynes

Application in Midwestern Watersheds


IN

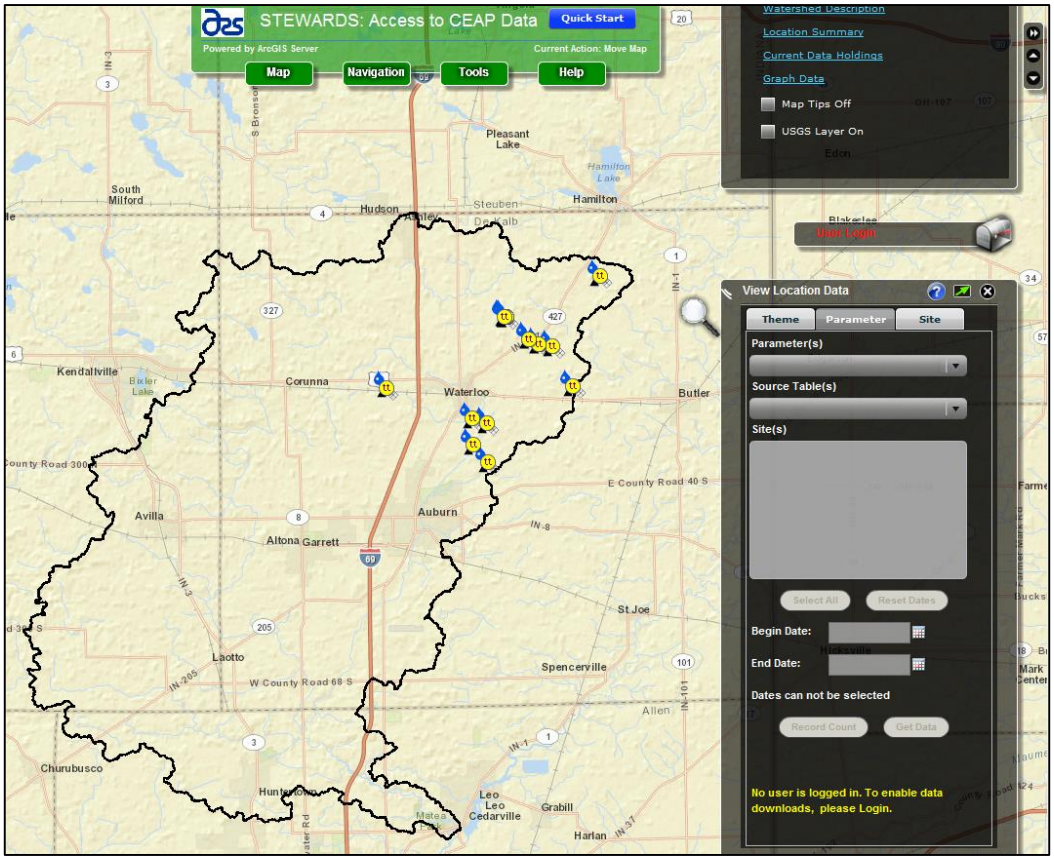

Legend
AXL_Monitoring_Location
Watershed Area
Streams


Matson Ditch Watershed
4703 ha
City of Waterloo
Location of AXL water quality/dishcarge monitoring station and modeled precipitation inputs.
N
W
E
S
0
1
2
4
6
8
Kilometers

Flow & Nutrient Data from ARS STEWARDS database

- Collected by USDA-ARS National Soil Erosion Research Laboratory

Station: St. Joseph River, Indiana
Publisher: USDA/ARS National Soil Erosion Research Laboratory, West Lafayette, Indiana



Data – Flow & Nutrients

Very high temporal resolution

Flow: 10-minute resolution, averaged to daily

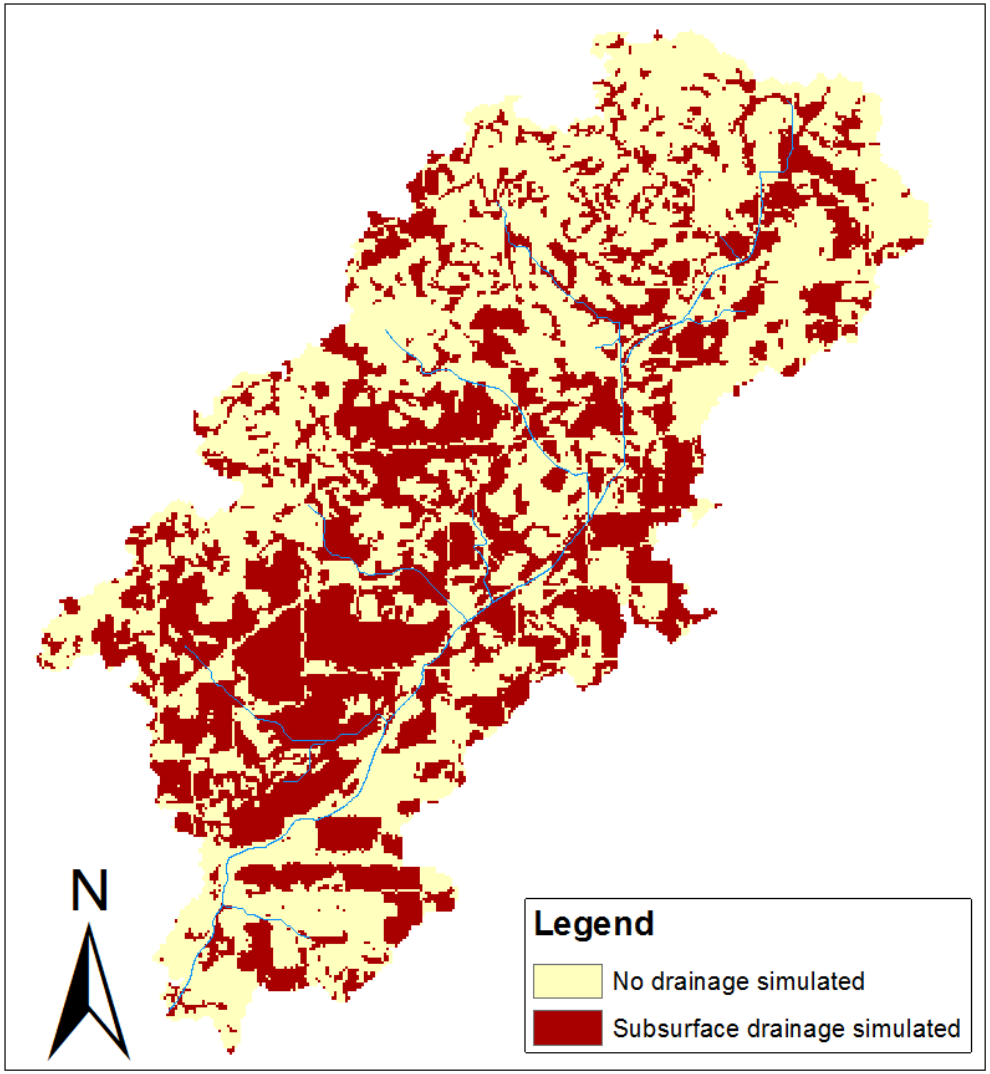
Nutrient Concentration: daily, with higher frequency, storm-based sampling occurring during large events

But, unfortunately, only collected from **April to November.** Flow meters removed during winter to prevent freezing

Data available on STEWARDS from 2004-2009

Tile Drainage 51% of watershed, based on…

- SSURGO drainage class of
  - poorly drained,
  - somewhat poorly drained, or
  - very poorly drained.
- Current crop of soybeans, corn, or wheat

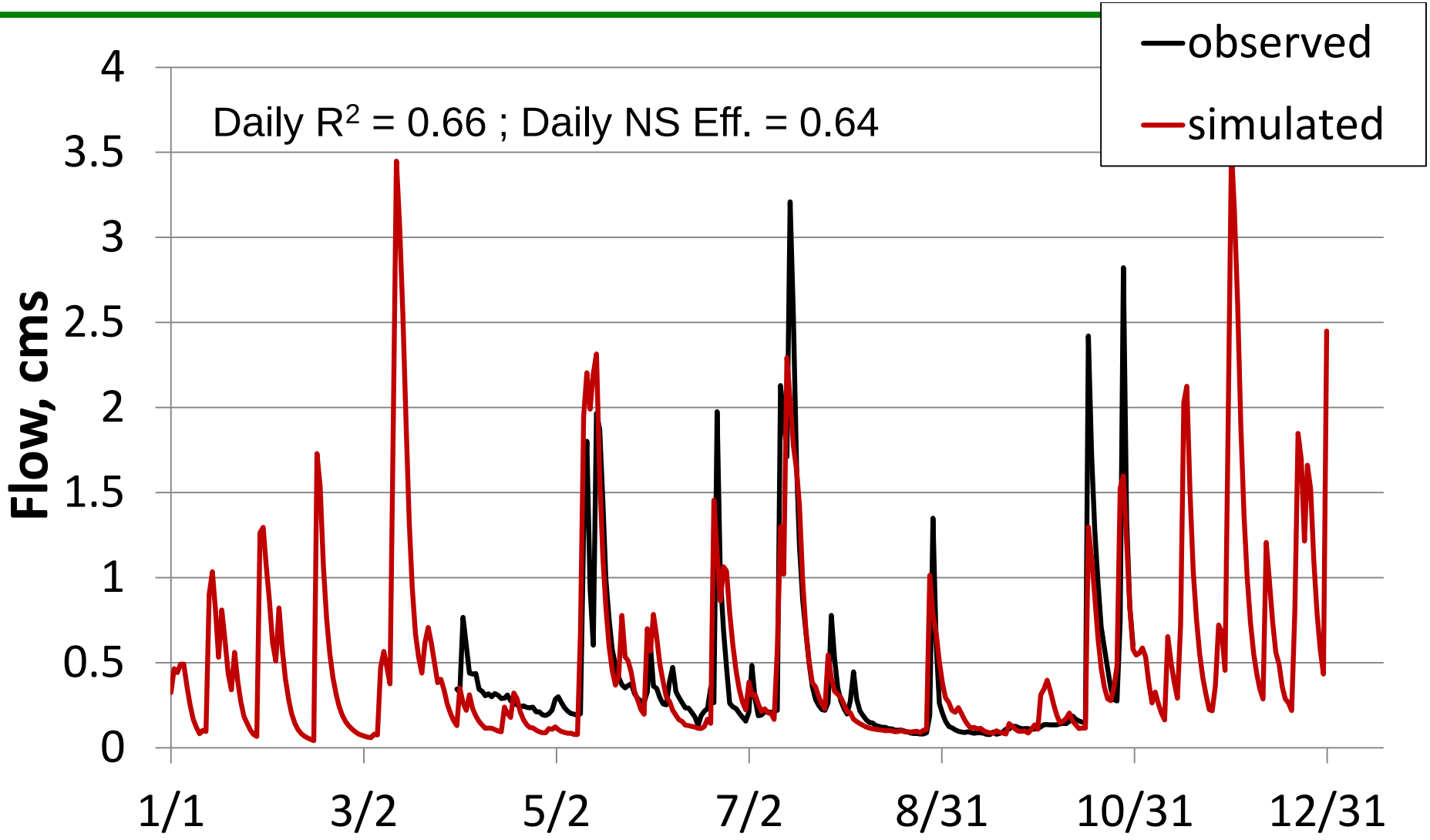


Model Setup

- 23 total sub-basins with 275 hydrologic response units (HRUs)
- Modeled corn and soybean lands in two year rotation
- Also developed realistic tillage and fertilization for **wheat** (not shown)

Current Crop	Date	Operation
Corn Year	22-Apr	N Application
	22-Apr	P Application
	6-May	Tillage, Field Cultivator
	6-May	Planting
	14-Oct	Harvesting
Soybean Year	10-May	N Application
	10-May	P Application
	24-May	Planting with no till
	7-Oct	Harvesting
	1-Nov	Tillage, Chisel plow

Results: Stream flow



How to evaluate tile drainage simulation?

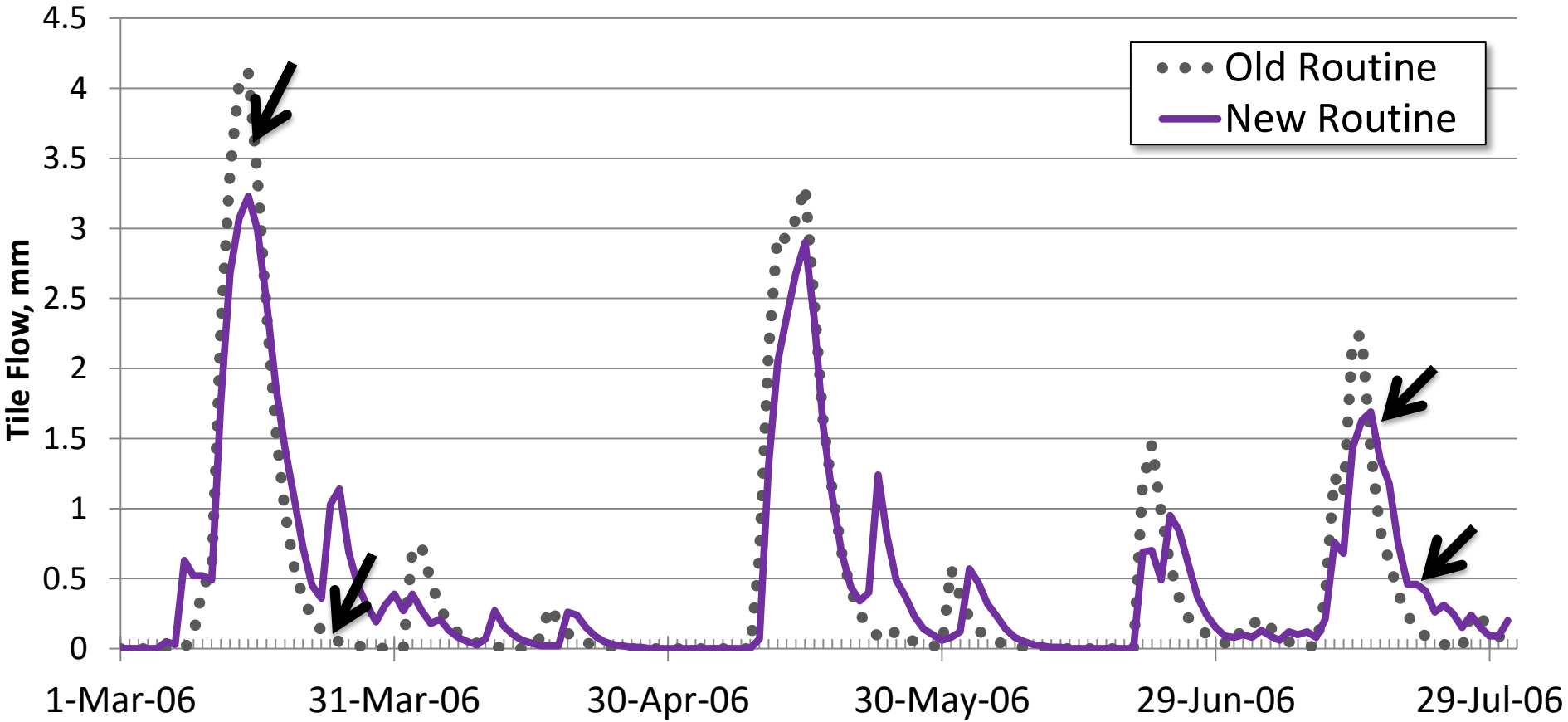
Tile Flow – Comparison to "soft data"

Year	Precipitation (mm)	Tile Flow (mm)	% of Precip as Tile Flow
2006	1058	172	16.2
2007	839	110	13.1
2008	1001	85	8.5
2009	1144	166	14.5

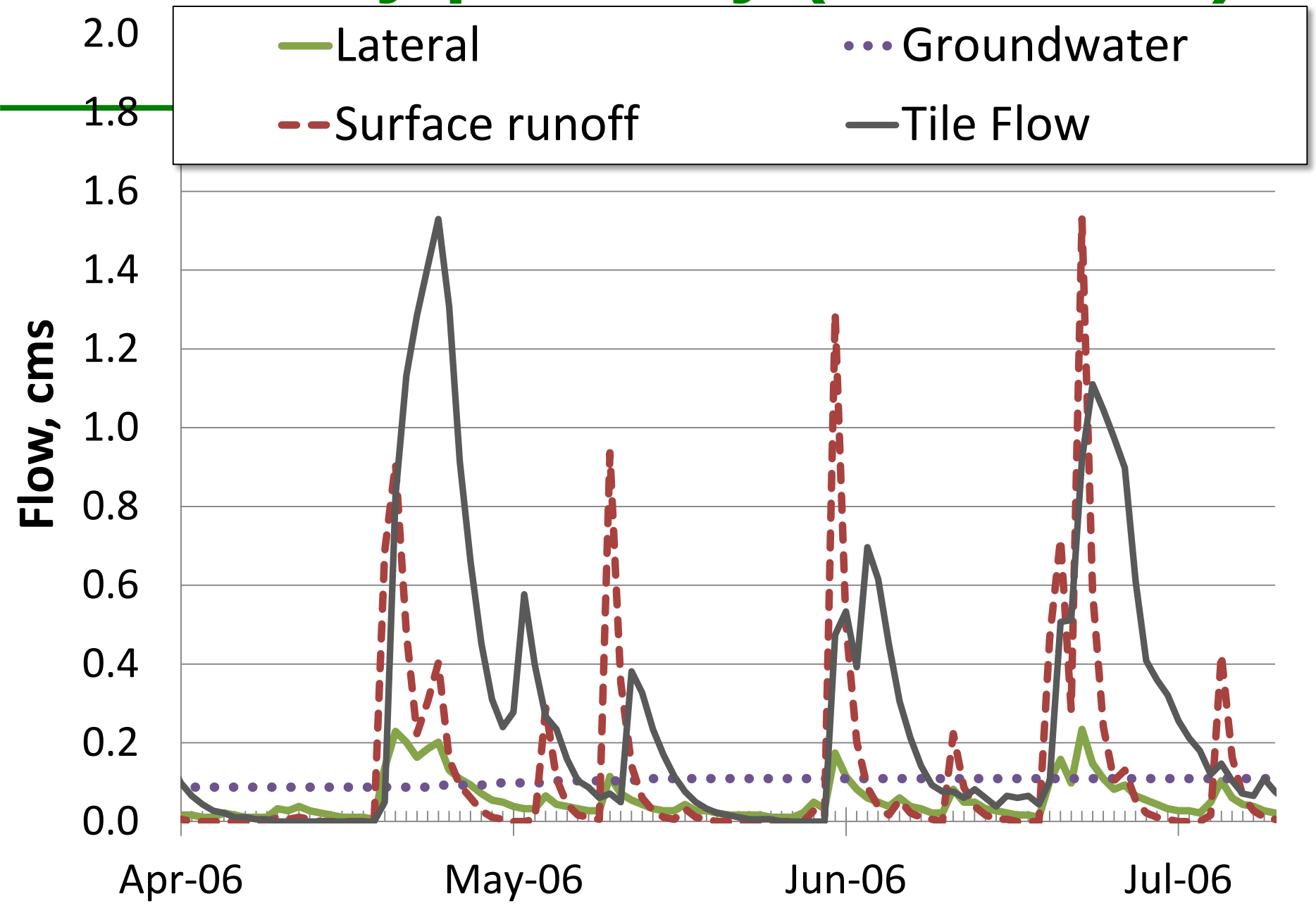
- Literature: Tile drain flow 9% to 37% of precipitation on tile drained lands.
- As only 50% of the watershed is drained, 5% to 19% was expected from Matson Ditch.

Comparison of old “drawdown time” to new “HKdc”

- Hooghoudt-Kirkham-drainage coefficient (new version) reduced peaks in drain flow.



Flow by pathway (simulated)

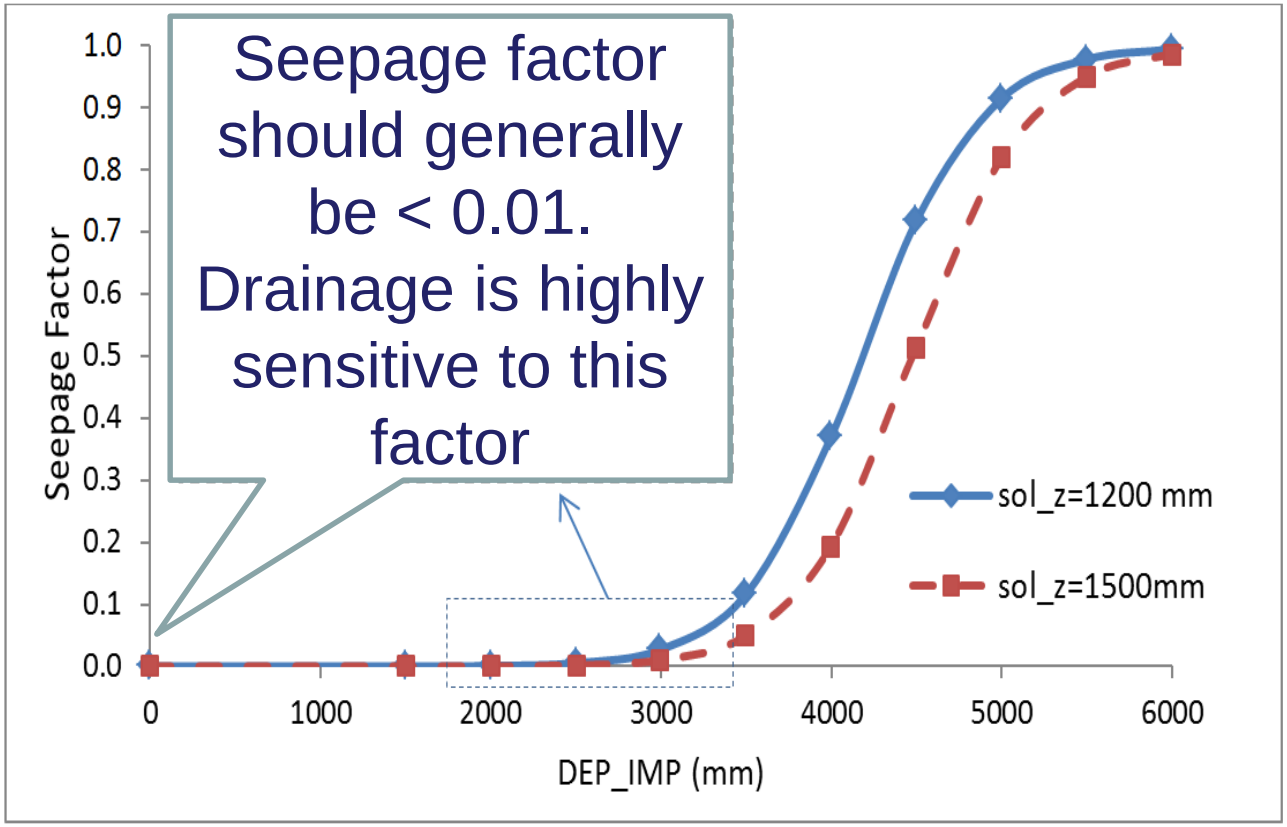


Contribution: Reasonable values for new tile drainage parameters

Parameter	Description	Value	Basis for Parameter Value
DRAIN_CO	Drainage coefficient	10 mm/day	Recommended by Extension for drainage systems
R_E	Effective radius	15 mm for 6-in tile	Based on a 4-inch tile, typical for system
SDRAIN	Tile spacing	20,000 mm	Typical spacing in northeastern Indiana
LATKSATF	Conductivity multiplier	1? 5?	1 is reasonable, but higher number improves simulation
SSTMAXD	Static surface roughness	12 mm	From published DRAINMOD simulations

Remaining issue: The impermeable layer – Depth and permeability should be separated

- "DEP_IMP" described as a depth, but actually controls permeability (seepage through the layer)



Scaling DOWN: Application to a smaller watershed

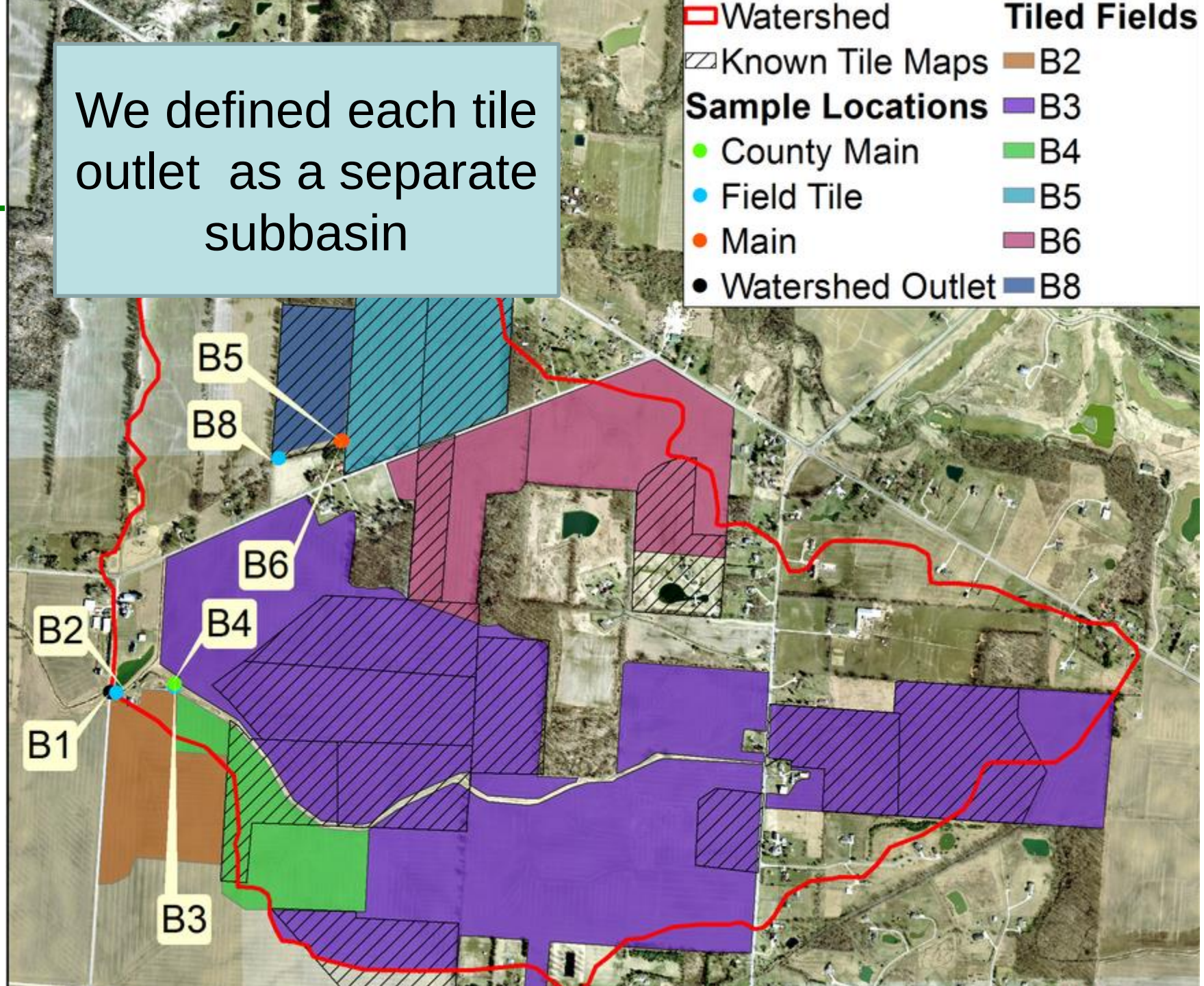
Journal of Environmental Quality SPECIAL SEC

PHOSPHORUS FATE, MANAGEMENT, AND MODELING IN ARTIFICIALLY DRAINED SY

Contributions of Systematic Tile Drainage to Watershed-Scale Phosphorus Transport

Kevin W. King,* Mark R. Williams, and Norman R. Fausey

We defined each tile outlet as a separate subbasin



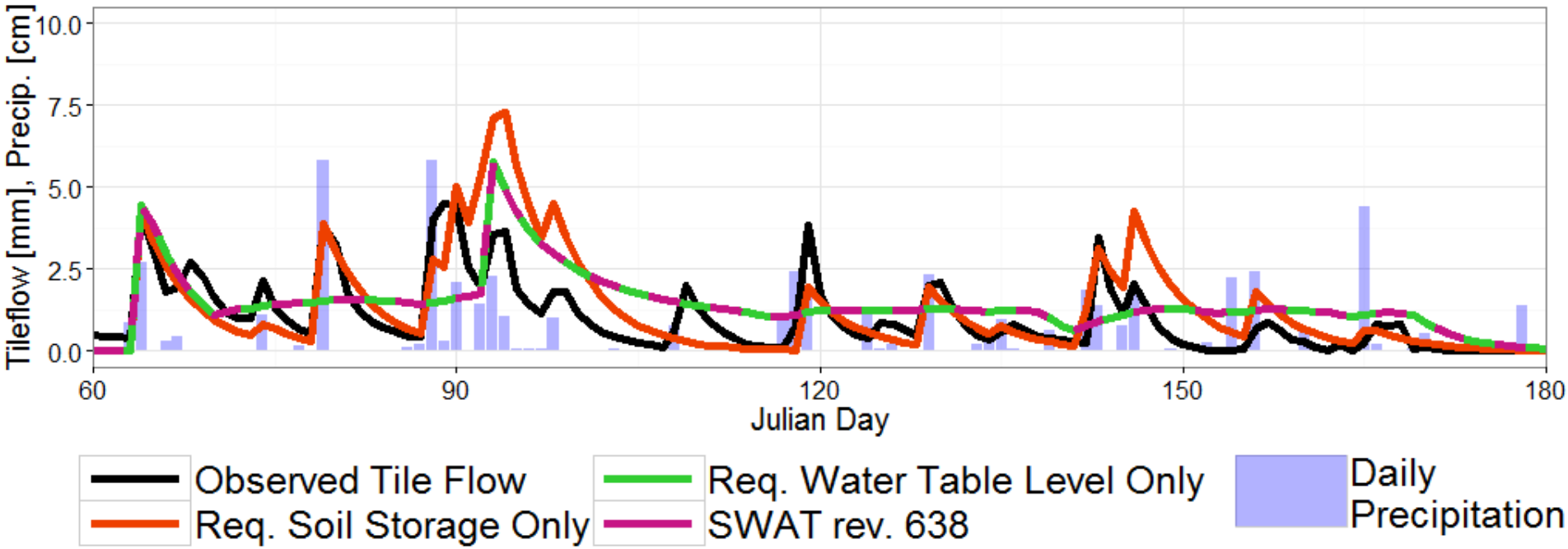
SWAT can now output tile drain values in the .sub file

- Thanks SWAT team!
- This allows the use of SWAT-CUP with tile drain outputs


Next step: Scaling DOWN even further, to better understand and improve tile drain processes for a single HRU
(Presentation by Colleen Moloney, Session C3)

Simulating Single HRUs shows that implementation of the Kirkham Equation in SWAT may need to be changed

- Rev. 638 has two conditions to trigger Kirkham: Water table < 5 mm from the surface and soil storage full



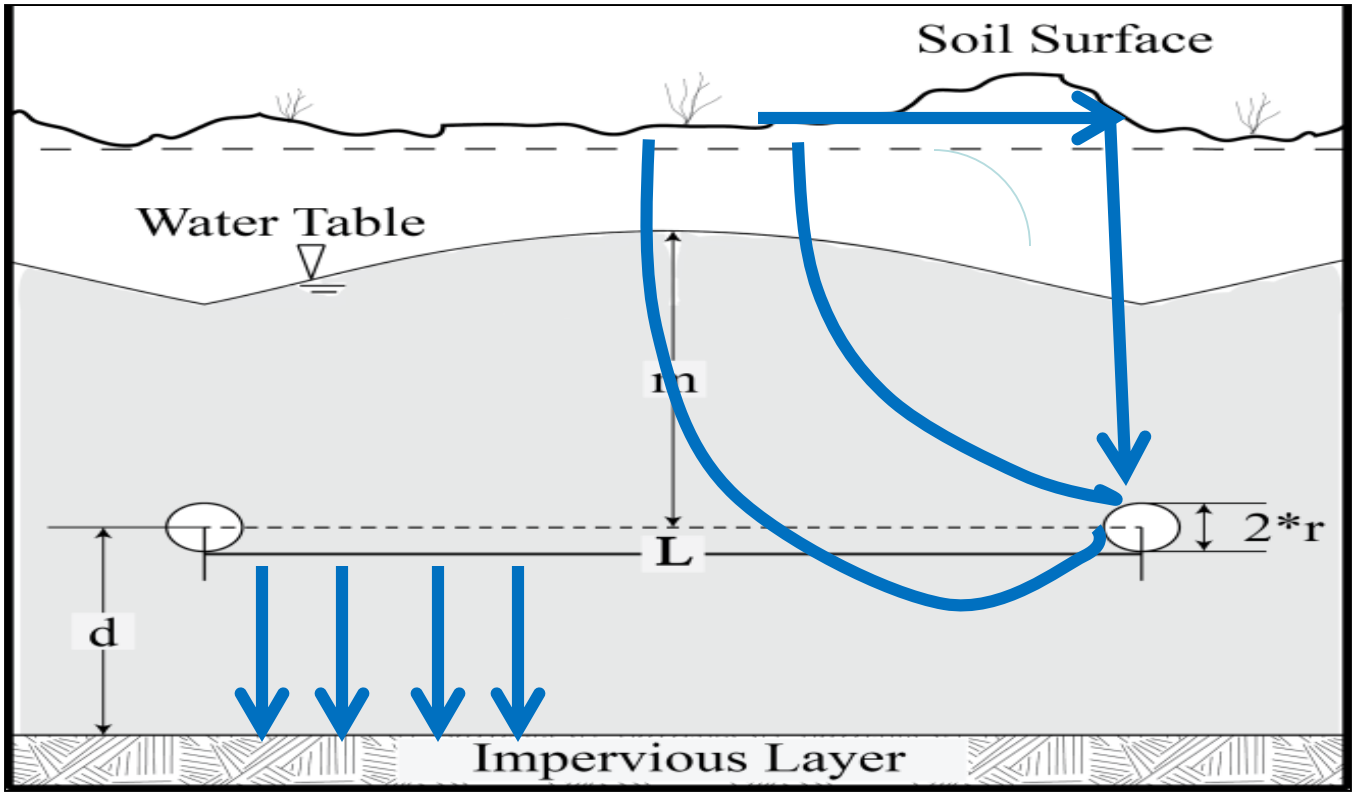
Conclusions

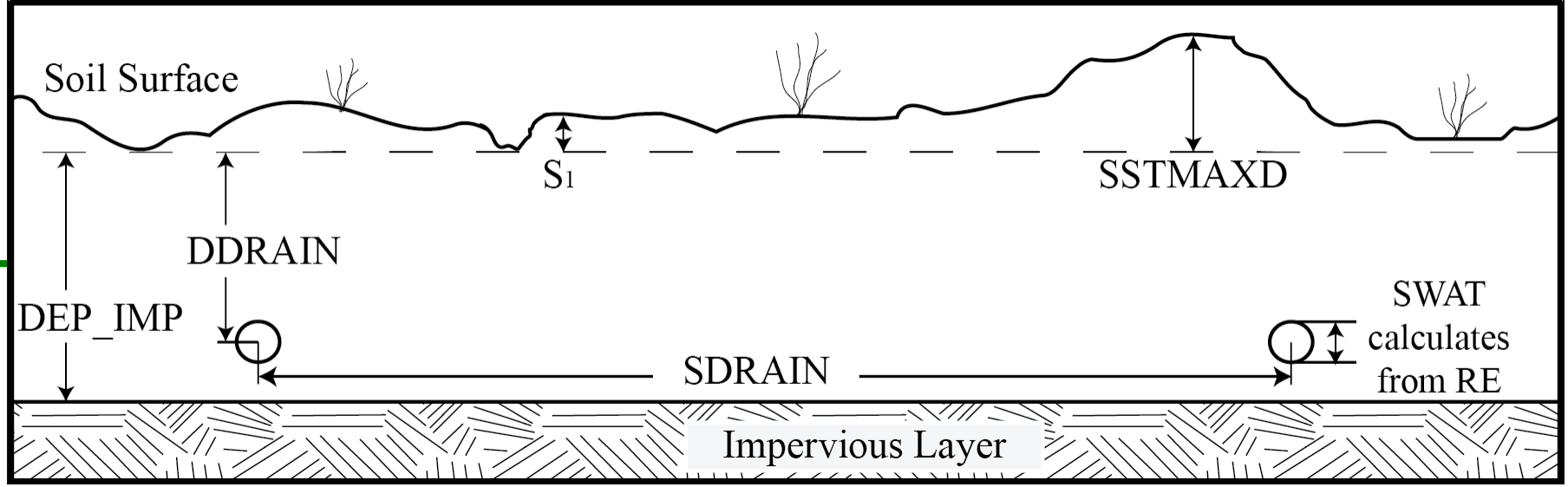
- Simulating tile drains is critical for understanding hydrology and water quality in the Midwest.
- The new tile drainage routine based on Hooghoudt and Kirkham Equations, with a drainage coefficient provides a realistic simulation of tile outputs but some processes could be improved.
- More simulations of (1) small watersheds, and (2) individual tile drains, are needed to fully test these routines.

Tile flow is water that has infiltrated; Curve number needs to reflect that.

- SCS Curve number was developed to reproduce the hydrograph
- It is empirical with no physical basis
- Logically, if it is used to separate surface runoff and infiltration, it needs to be greatly reduced in tile-drained landscapes, often by **30%** or more

4. Impermeable layer – depth but especially permeability





Drainage parameters in the .sdr file

15.00 | **re:** effective radius of drains (mm)

20000.00 | **sdrain**: distance between two drain tiles (mm)

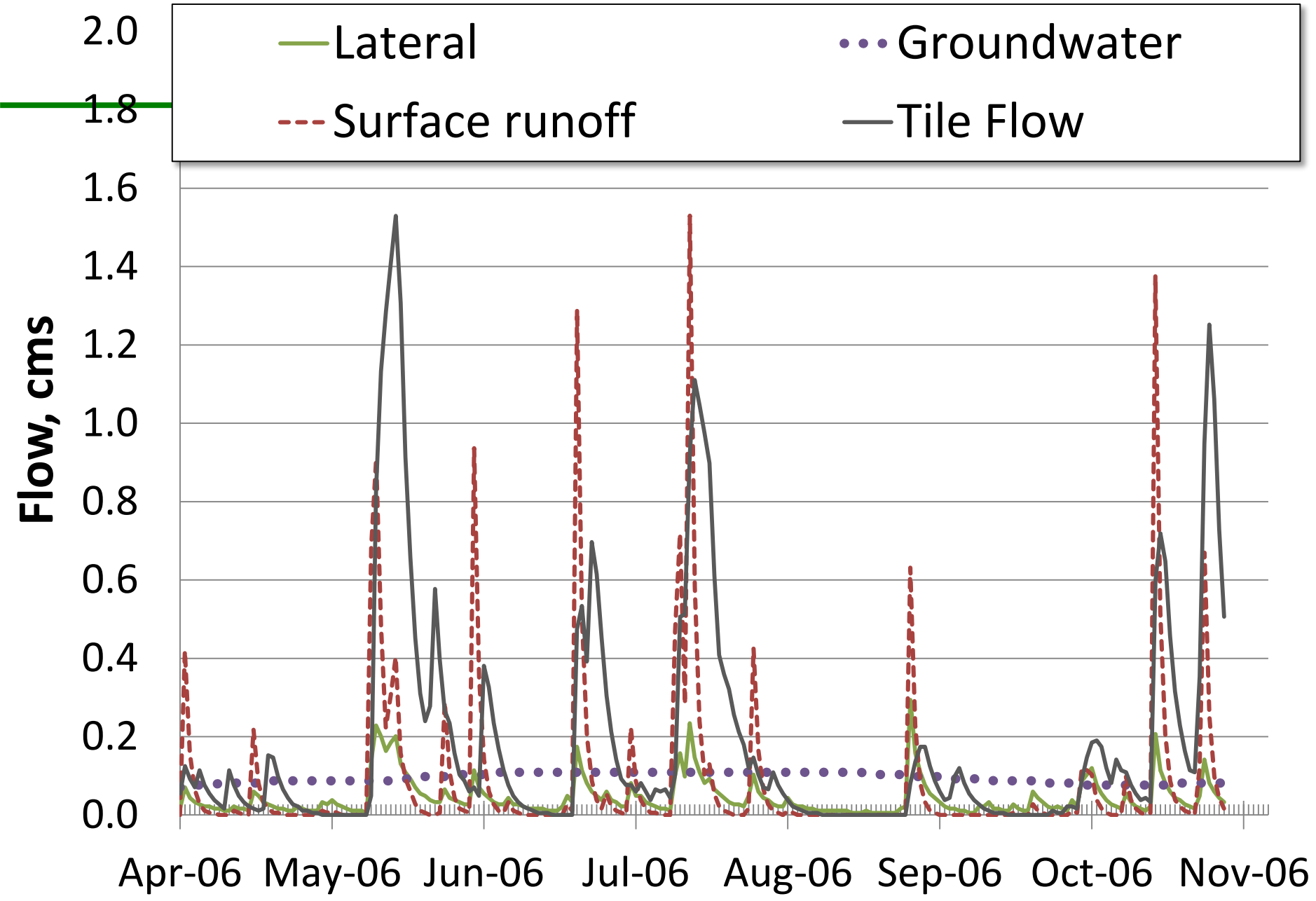
10.00 | **drain_co**: drainage coefficient (mm/day)

0.00 | **pc:** pump capacity (mm/hr)

1.00 | **latksatf:** multi factor for later conductivity

12.50 | **sstmaxd**: Static maximum depressional

Resulting partition of flow pathways



Remaining Needs

Despite excess water in spring, crops often suffer from lack of water in late summer.