Effect of tile drainage on nitrate load in an agricultural watershed

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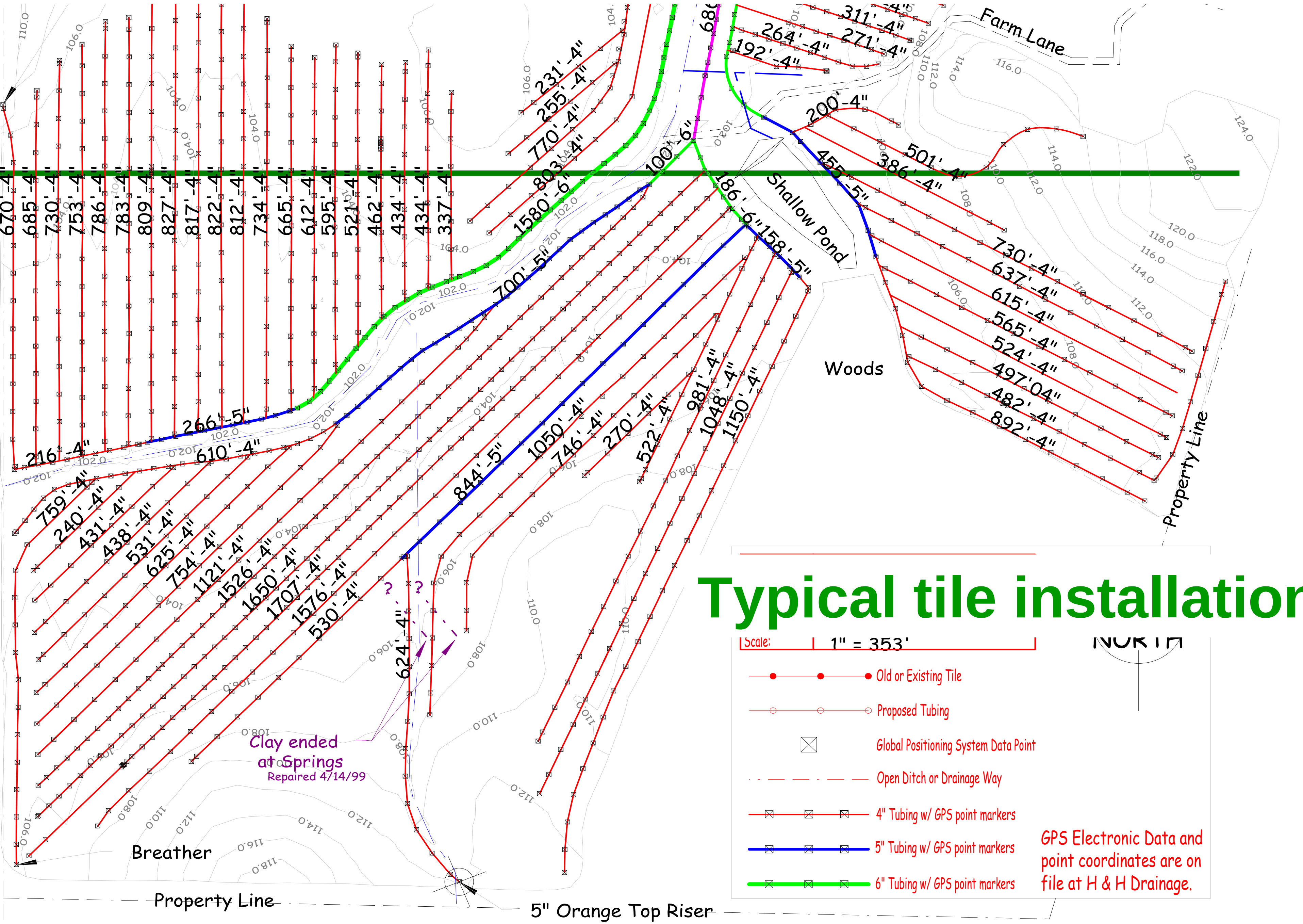
Mostly unseen, tile drains underlay more than half the agricultural land in many areas

Typical tile installation



Installing tile drains

Soil conditions that require artificial drainage

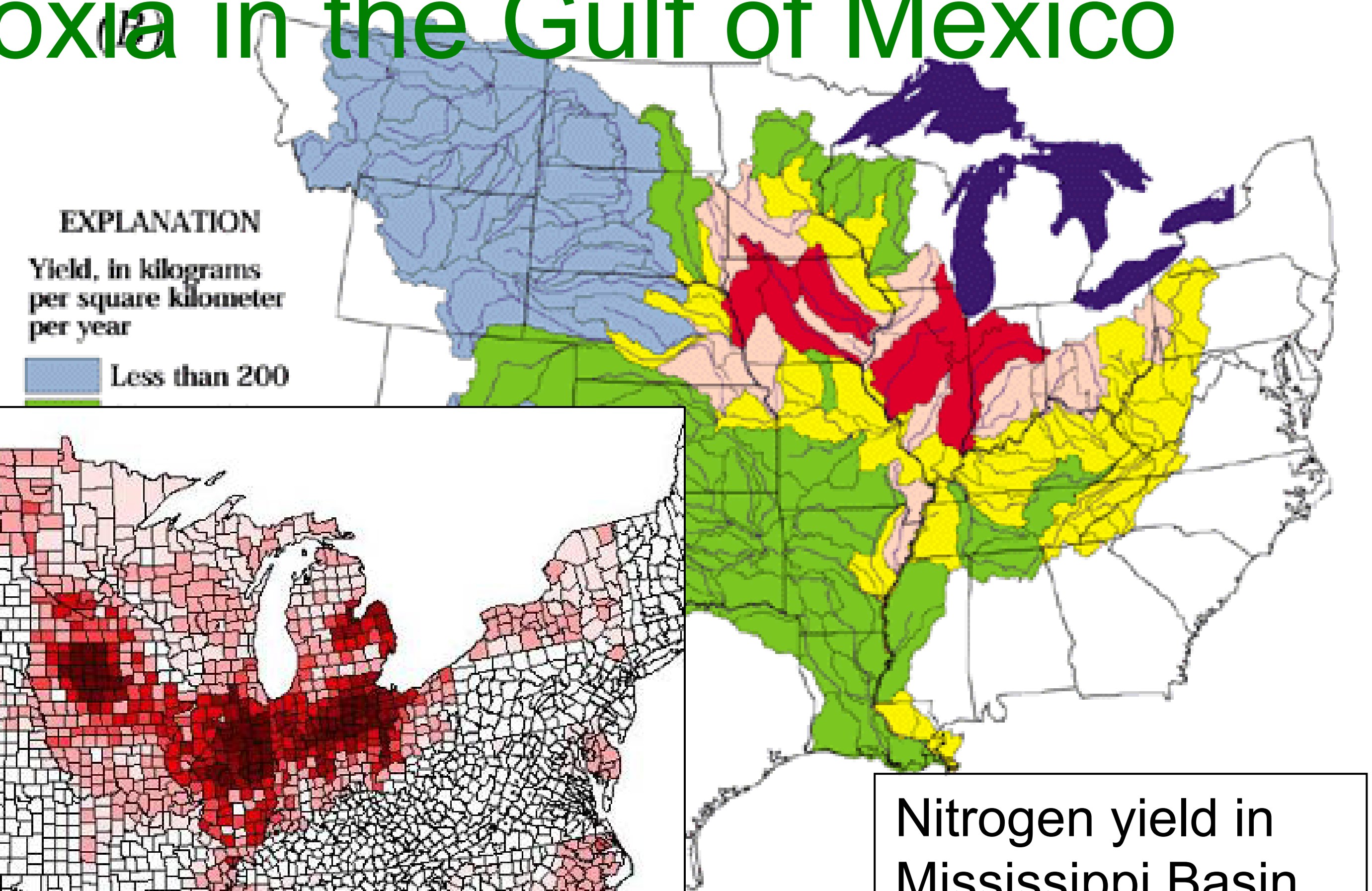
- Shallow restricting soil layers (dense glacial till, fragipan, bedrock)
- Lack of topography and outlet for natural drainage

It is well known that tile drains are an important flow pathway in humid areas

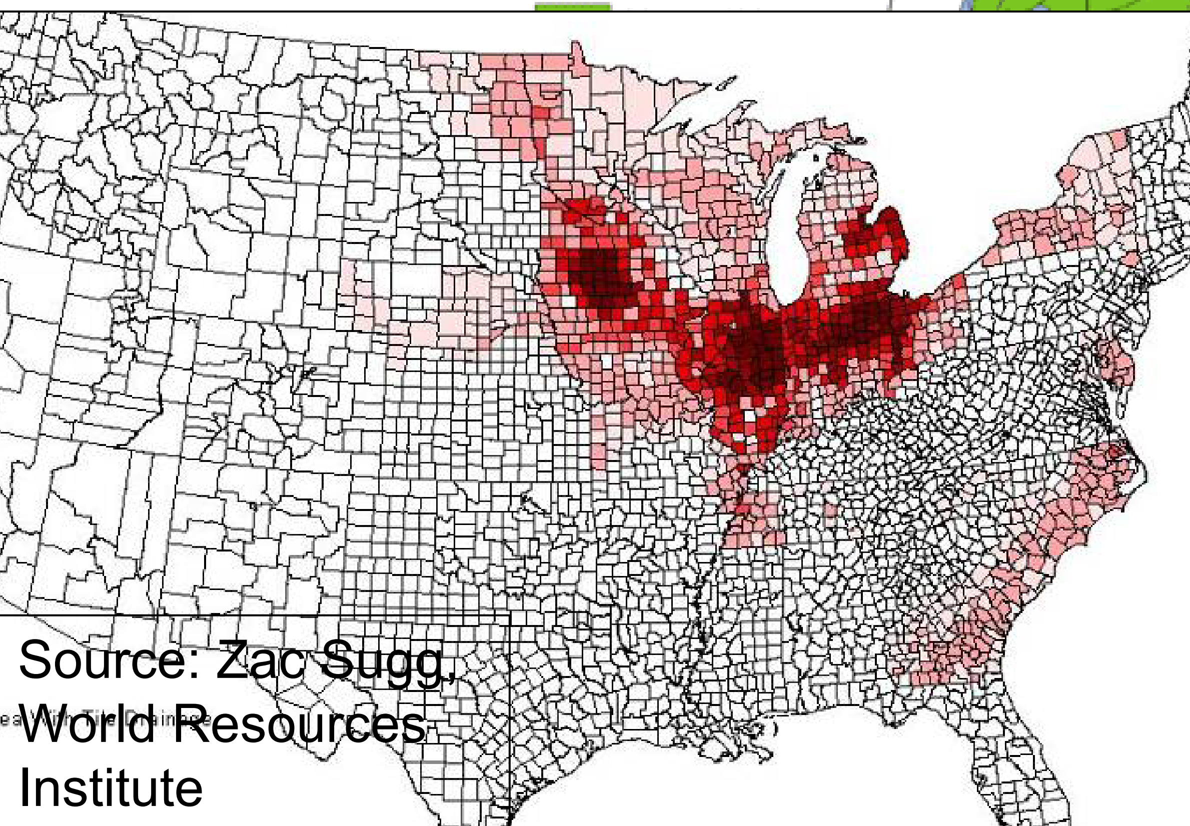
Nitrate from tile drains at the plot or field scale:

- Typical concentrations of 10-40 mg/l nitrate-N in water from tile-drained experimental fields
- Losses from 20-40 kg/ha

Tile drains an important contributor to hypoxia in the Gulf of Mexico



Nitrogen yield in Mississippi Basin (Source: USGS)



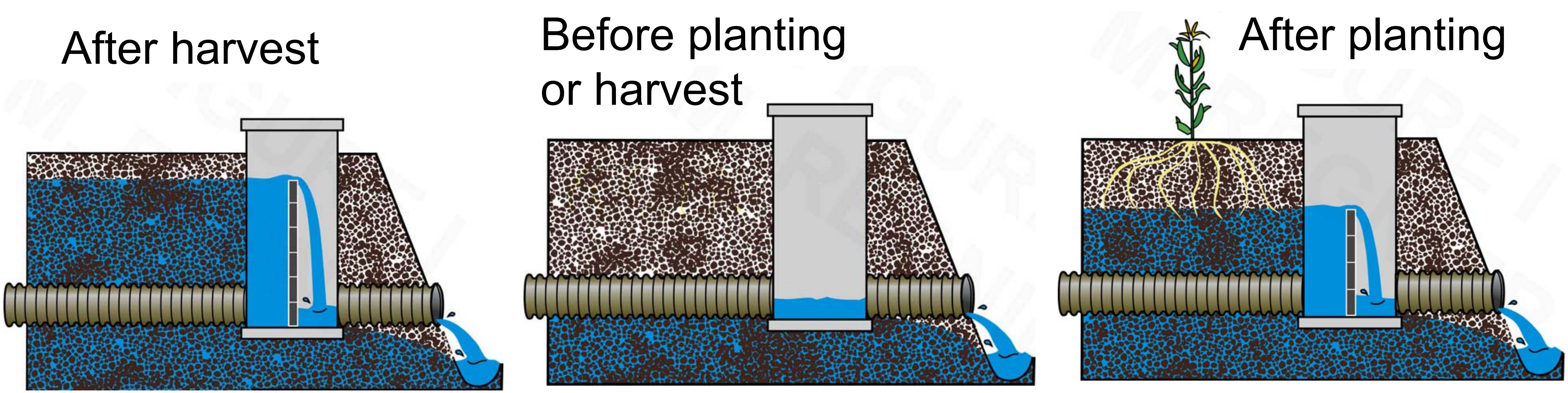
Source: Zac Sugg, World Resources Institute

However, it is not known what proportion of nitrate in the medium to large watersheds comes from tiles

- Knowing proportion of nitrate would be useful for estimating the potential of various technologies to reduce nitrate losses.

Options for managing agricultural drainage systems to reduce nitrate loss

- Shallower drains
- Controlled drainage (drainage water mgmt
- Bioreactor to treat tile flow
- Impact depends on amount of nitrate affected.



Models are the only feasible means of quantifying flowpaths in watersheds

- DRAINMOD-NII (Youssef, Skaggs, et al., 2005) predicts nitrate loss from tiles at the field scale.
- DRAINMOD hydrology has been extended to the watershed scale by linking field-scale simulations with stream routing and water quality models (Amatya et al., 1997; Skaggs et al., 2003; Fernandez et al., 2005).
- Can only predict nitrate in a non-process method

Tile drainage representation in SWAT2005

- Du et al. (2005) modified SWAT to simulate landscapes with tile and potholes drainage systems, by setting a restrictive soil layer at the bottom of the soil profile and predicting the dynamic ground water table.
- Green et al. (2006) found that the new function significantly improved the water balance and runoff simulation. Du. et al., 2006 showed that the model improved monthly nitrate-N load predictions.

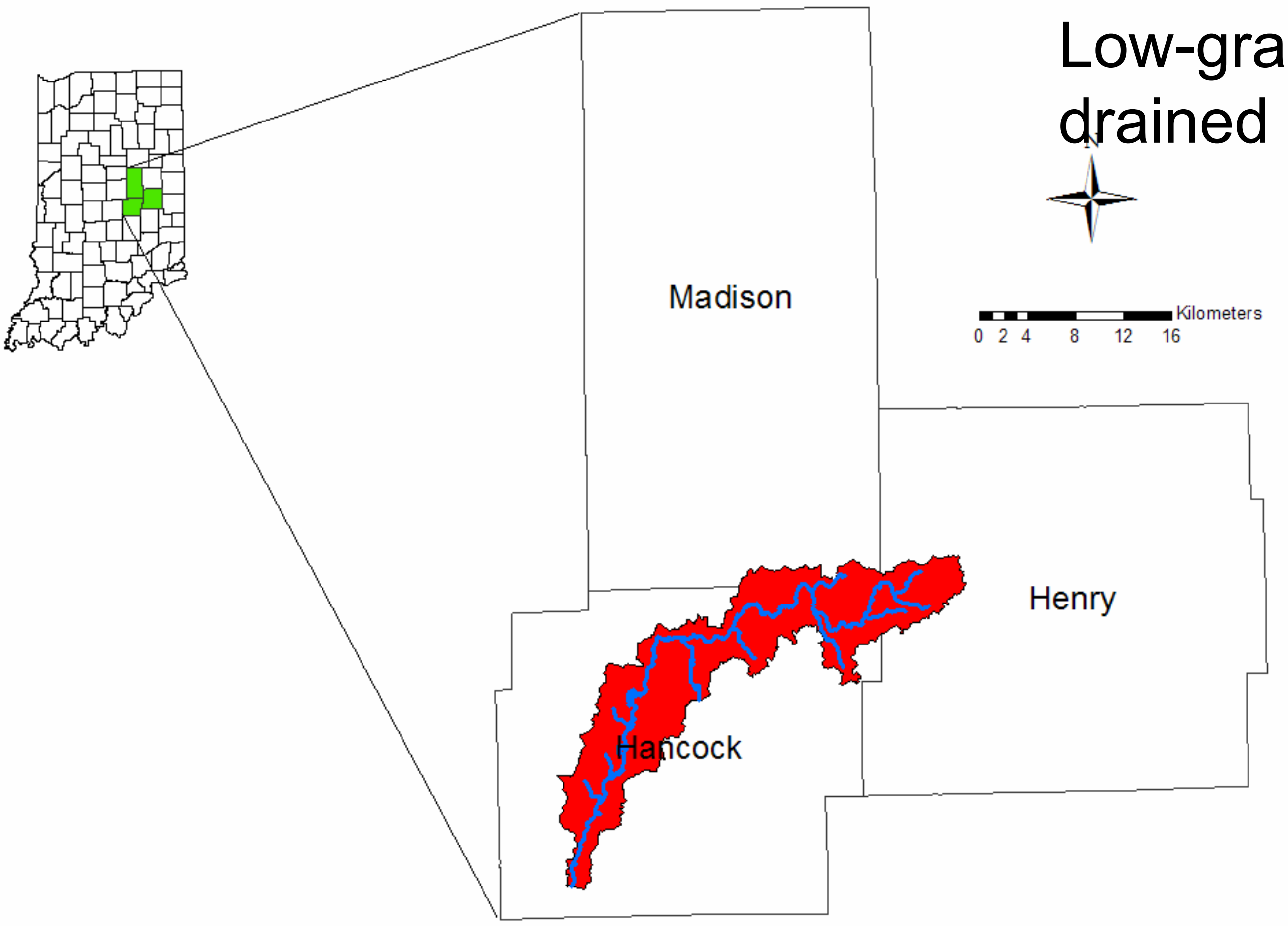
Objective

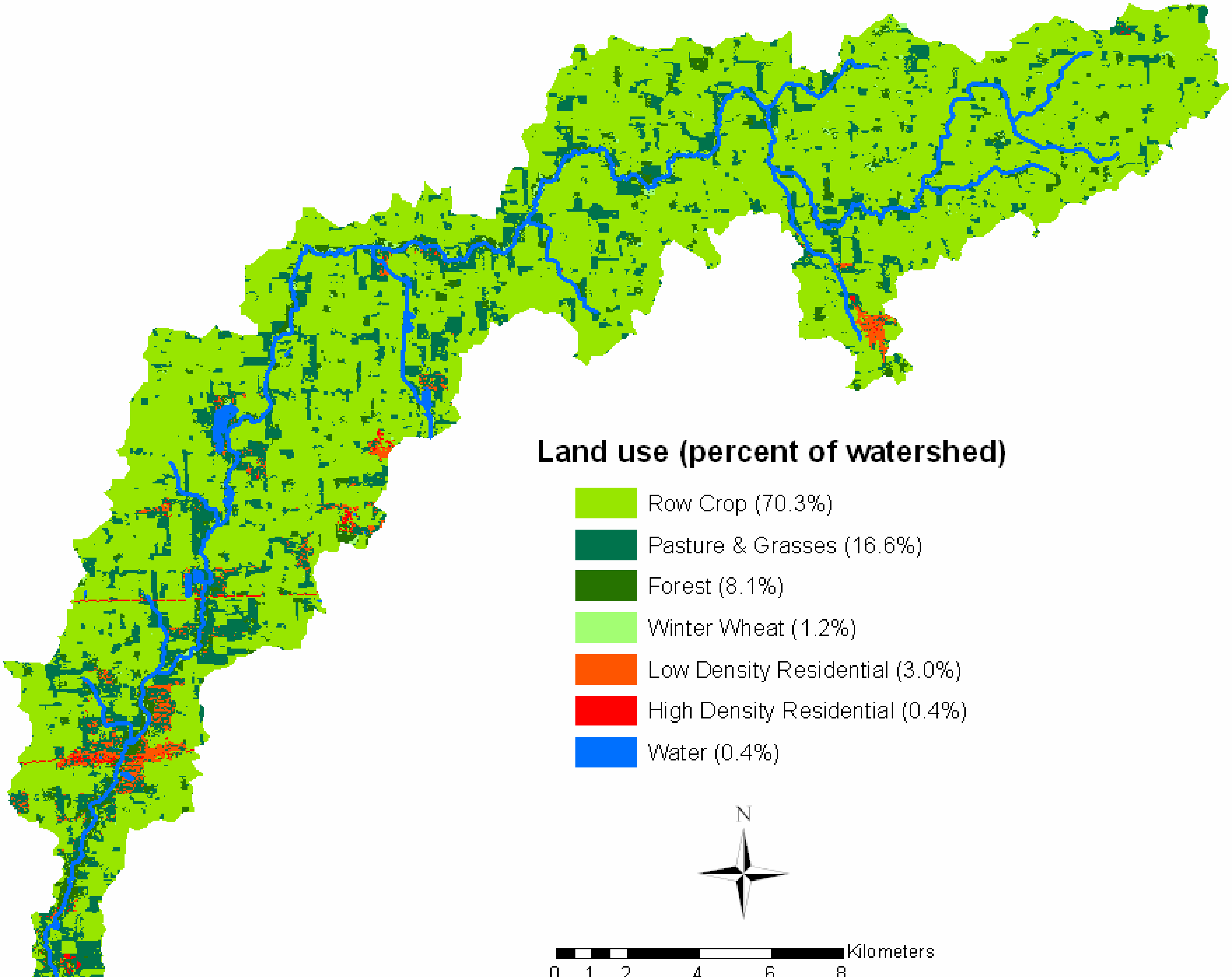
- The objective of this study is to simulate nitrate loads through tile drains in a heavily tile drained watershed, Sugar Creek watershed in Indiana, and compare it with nitrate loads through other flowpaths (surface flow, percolation and lateral flow).

Sugar Creek in Central Indiana

Monitored by USGS for flow, nitrate

242 km2 watershed
Low-gradient, poorly drained

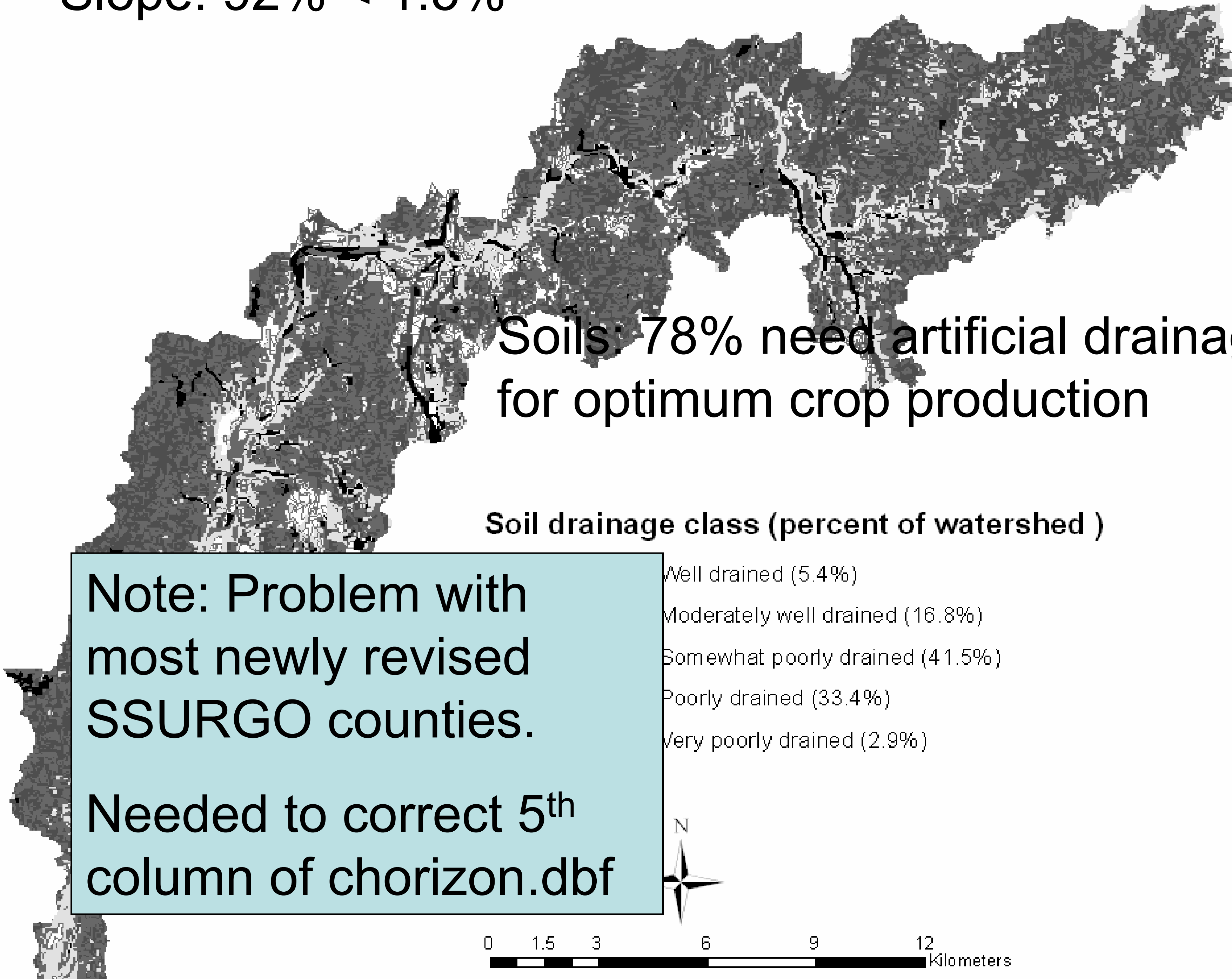




Land use (percent of watershed)
Row Crop (70.3%)
Pasture & Grasses (16.6%)
Forest (8.1%)
Winter Wheat (1.2%)
Low Density Residential (3.0%)
High Density Residential (0.4%)
Water (0.4%)
N
Kilometers
0 1 2 4 6 8

Slope: 92% < 1.5%

Soils: 78% need artificial drainage for optimum crop production

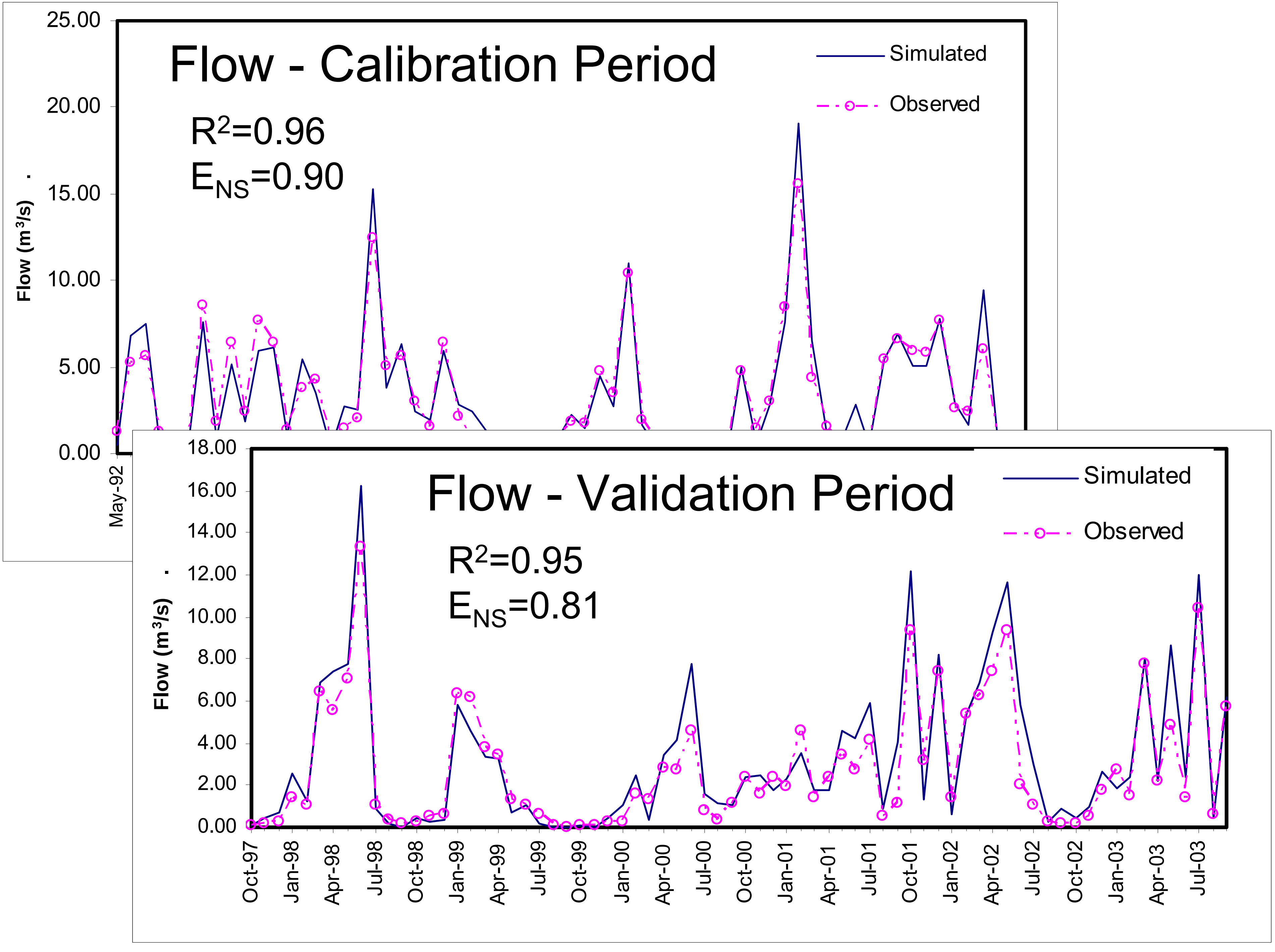


Note: Problem with most newly revised SSURGO counties.

Needed to correct 5th column of chorizon.dbf

Subbasins and Hydrologic Response Units (HRUs)

- 31 subbasins
- Threshold for HRU: 10% soil and 5% land use. Result was 289 HRUs
  - AGRR, FRSD, PAST, HAY, ALFA
  - AGRR rotated between corn and soybeans
- Fertilizer rate and timing from ERS survey



Flow - Calibration Period
Simulated
Observed
R²=0.96
E_NS=0.90
Flow (m³/s)
25.00
20.00
15.00
10.00
5.00
0.00
May-92
Flow - Validation Period
Simulated
Observed
R²=0.95
E_NS=0.81
Flow (m³/s)
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
Oct-97
Jan-98
Apr-98
Jul-98
Oct-98
Jan-99
Apr-99
Jul-99
Oct-99
Jan-00
Apr-00
Jul-00
Oct-00
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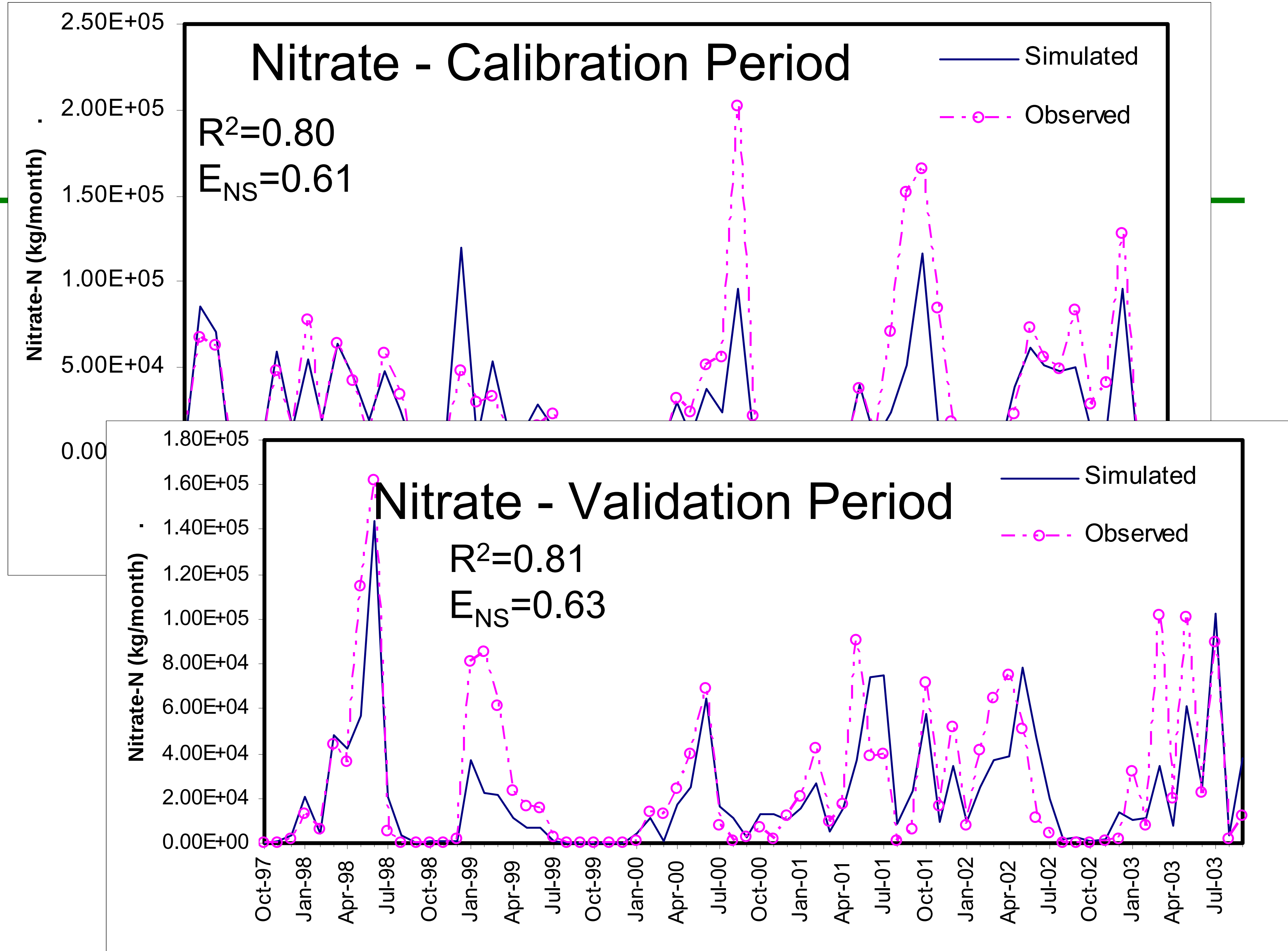
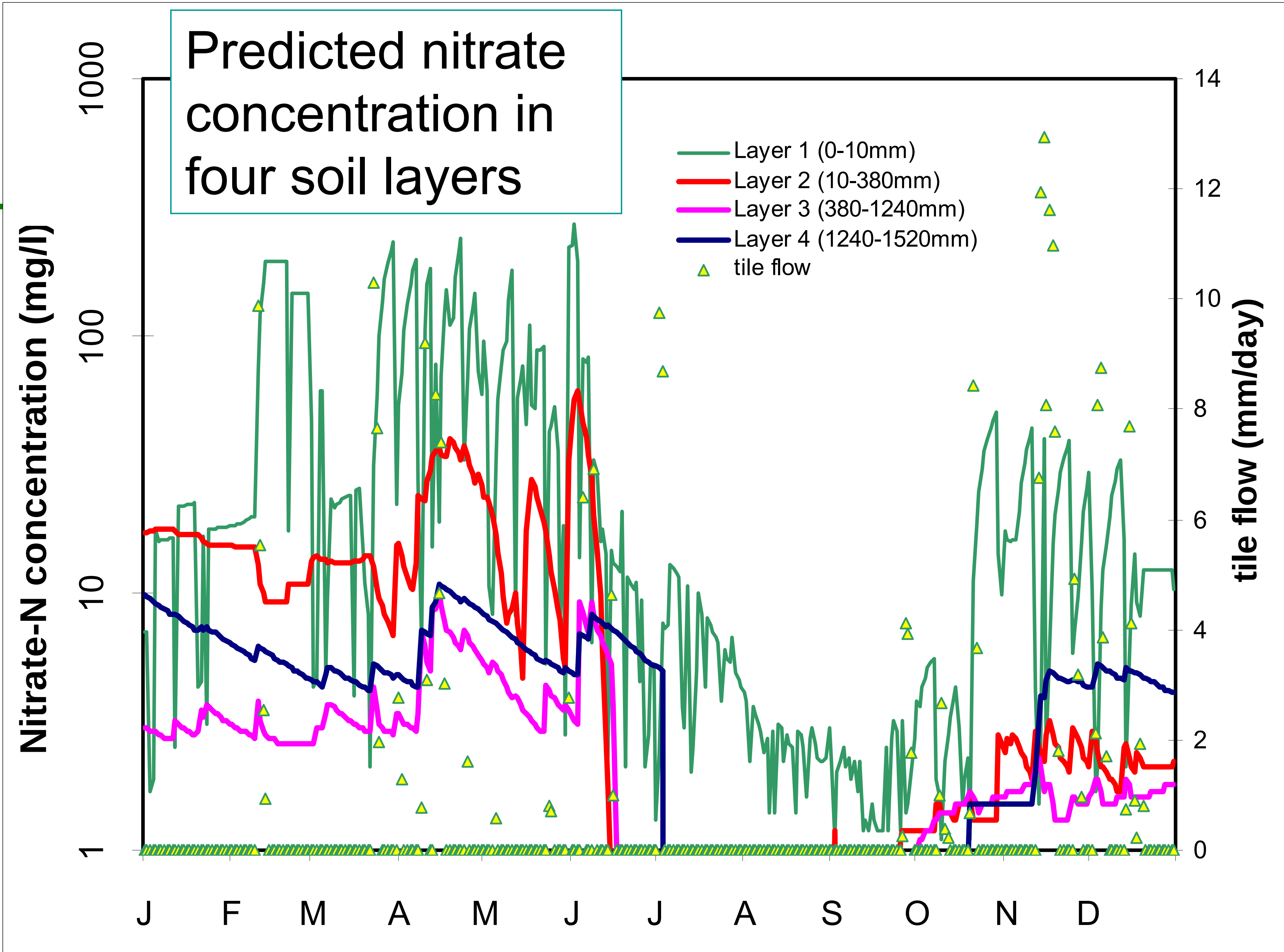
Jan-03
Apr-03
Jul-03



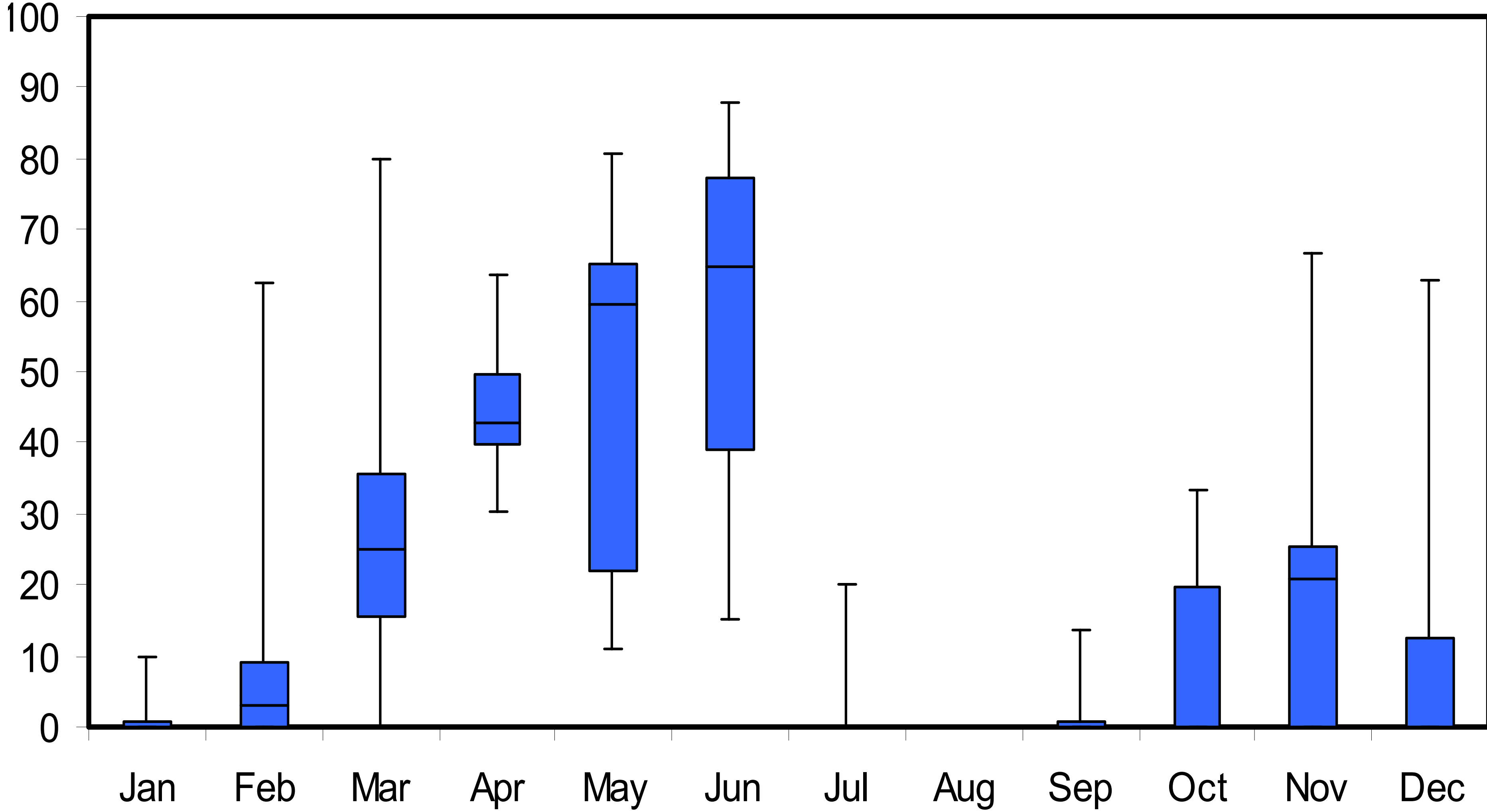
Nitrate - Calibration Period
R^2=0.80
E_{NS}=0.61
Simulated
Observed
Nitrate-N (kg/month)
2.50E+05
2.00E+05
1.50E+05
1.00E+05
5.00E+04
0.00
Nitrate - Validation Period
R^2=0.81
E_{NS}=0.63
Simulated
Observed
Nitrate-N (kg/month)
1.80E+05
1.60E+05
1.40E+05
1.20E+05
1.00E+05
8.00E+04
6.00E+04
4.00E+04
2.00E+04
0.00E+00
Oct-97
Jan-98
Apr-98
Jul-98
Oct-98
Jan-99
Apr-99
Jul-99
Oct-99
Jan-00
Apr-00
Jul-00
Oct-00
Jan-01
Apr-01
Jul-01
Oct-01
Jan-02
Apr-02
Jul-02
Oct-02
Jan-03
Apr-03
Jul-03

Nitrate output from tile drains

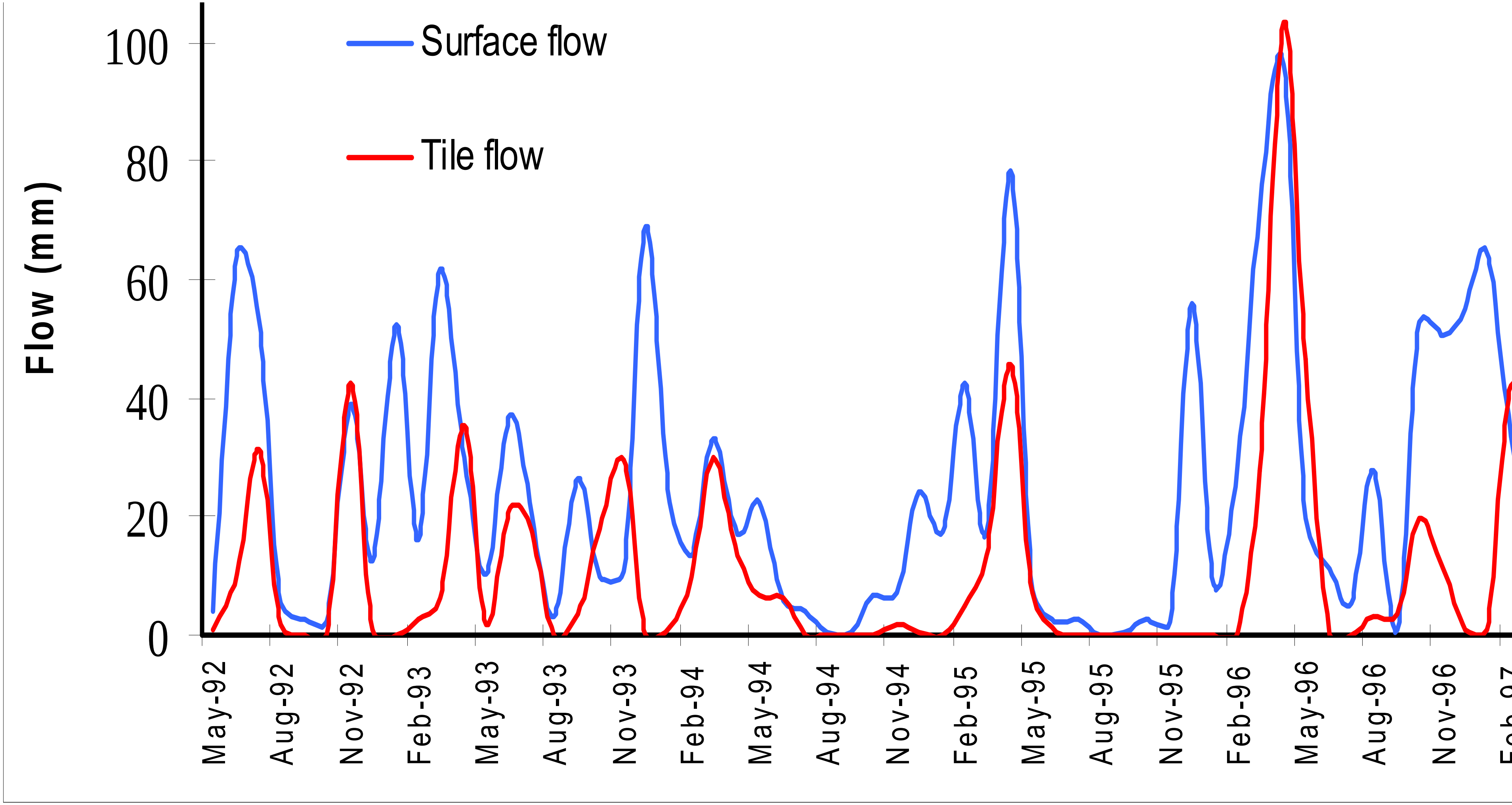
- Modified SWAT source code to output nitrate from tile drains in the watershed along with the other flowpaths in the output.std file.
  - Nitrate concentration in the tile flow assumed to be the same as the nitrate concentration in the soil layer with the tiles
- Nitrate load through tile drains was calculated by multiplying the nitrate concentration in the tile by the tile flow volume for each HRU, and then summarizing across the watershed.


Predicted nitrate concentration in four soil layers
Nitrate-N concentration (mg/l)
tile flow (mm/day)
Layer 1 (0-10mm)
Layer 2 (10-380mm)
Layer 3 (380-1240mm)
Layer 4 (1240-1520mm)
tile flow
1000
100
10
1
14
12
10
8
6
4
2
0
J F M A M J J A S O N D

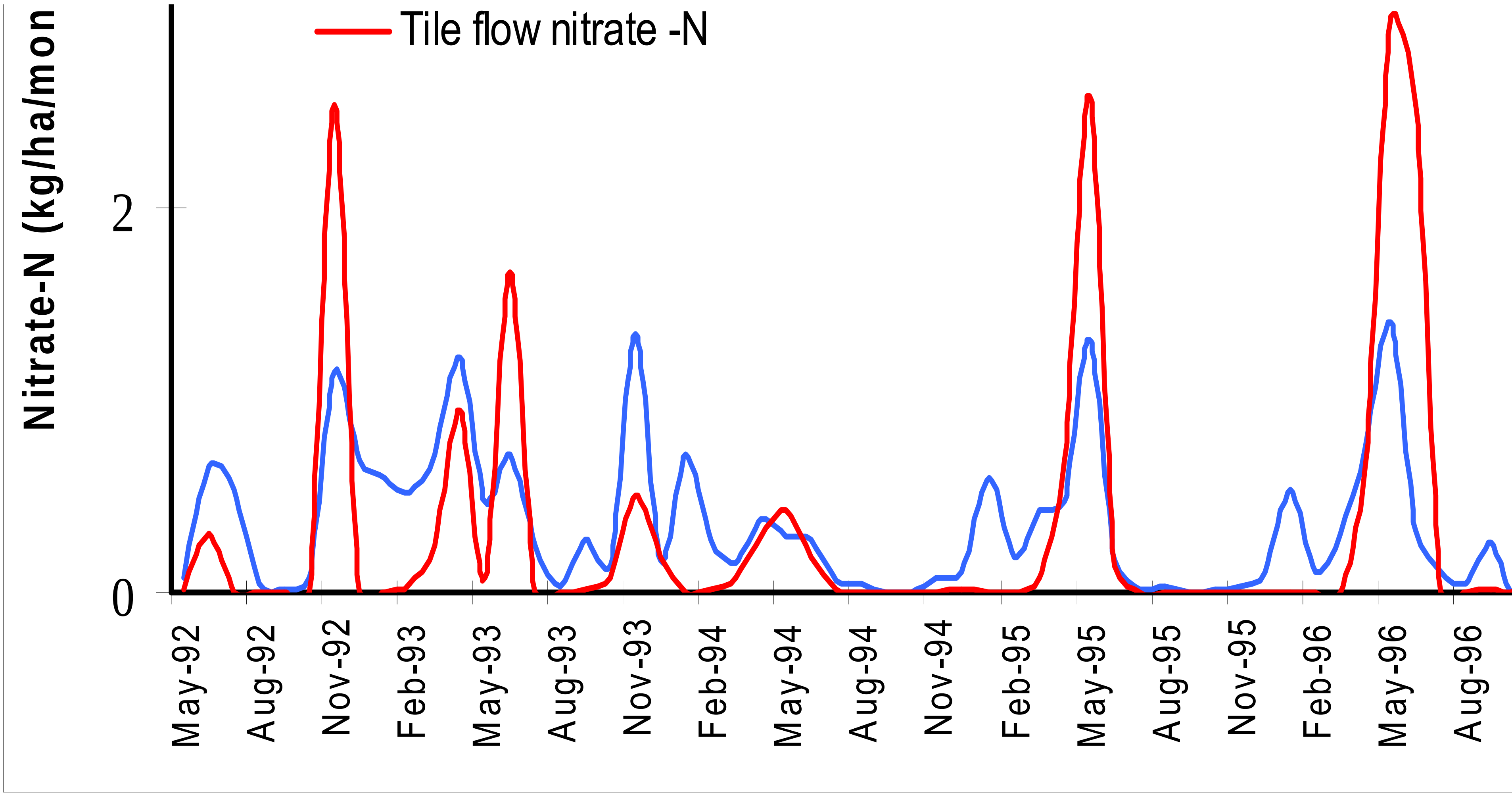
Percent of nitrate predicted to come from tile drains



But due to completely impermeable subsoil, no ground water



Model correctly predicts that percentage of nitrate from tiles greater than percentage of flow from tiles



Problem: "impermeable layer" was completely impermeable

Image from Du et al (2005)

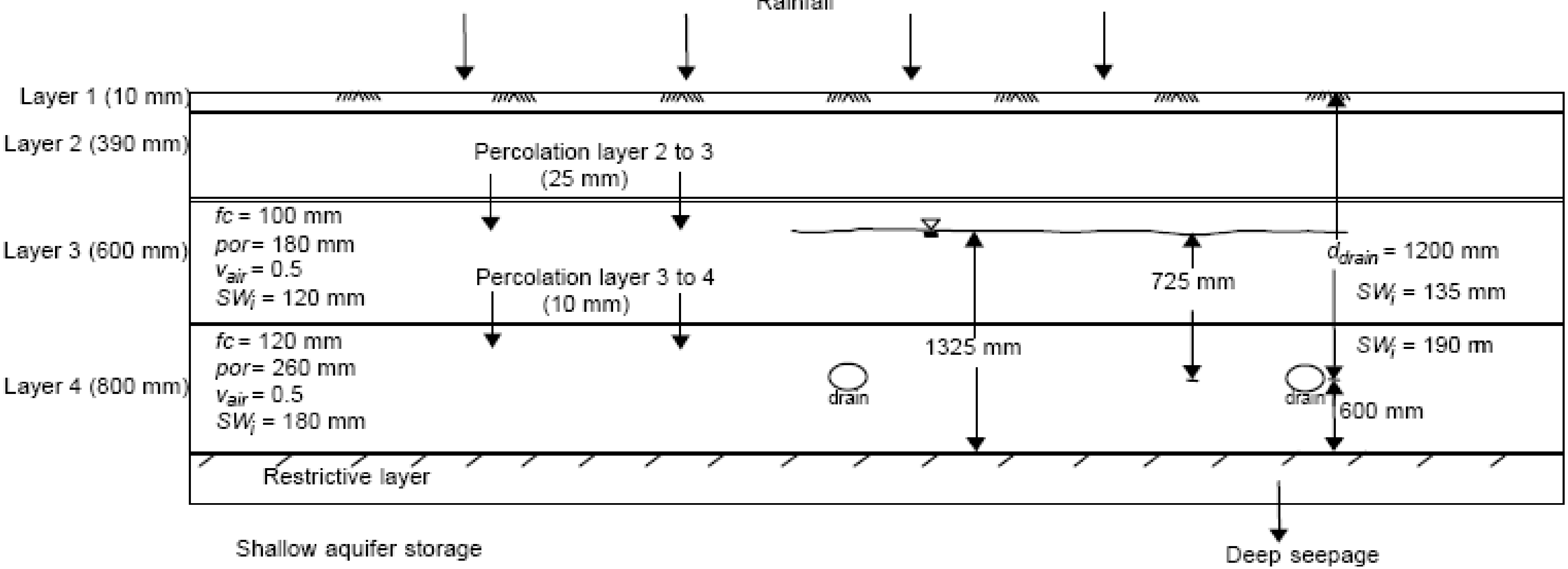


Figure 1. Diagram showing an example water table calculation after a rainfall event.

Based on other studies, permeability should be in the range of 0.00001 cm/h to 0.001 cm/h

Clarification on impermeable layer (from J. Arnold, yesterday)

- The degree of impermeability depends on the depth the user sets.
- If impermeable layer is within the soil profiles, it is completely impermeable.
- If dep_imp is greater, becomes more and more pervious
- If dep_imp=6 m (default) there is no effect

Nitrogen parameters -- transport

- Parameters controlling transport between soil layers
  - fraction of porosity from which anions are excluded (ANION_EX)
  - nitrate percolation coefficient (NPERCO).

Nitrogen processes: mineralization, decomposition, immobilization, nitrification, ammonia volatilization, and denitrification

- Parameters controlling nitrogen transformation
  - rate coefficient for r… active organic nutri…
  - rate coefficient for r… residue fresh organic nutrients (RSDCO),
  - rate coefficient for denitrification (CDN),
  - threshold value of water factor for denitrification to occur (SDNCO).

In our study, no denitrification if SDNCO at its default value, 1.1. Very important process if changed to 0.9

Nitrogen transformations in the stream

- Optional - must be activated by the modeler.
- controlling parameters
- benthic source rate for NH4-N (RS3),
- rate coefficient for organic N settling (RS4),
- rate constant for biological oxidation from NH4 to NO2 (BC1)
- rate constant for biological oxidation from NO2 to NO3 (BC2)

Conclusions – Estimated nitrate from tile drains

- The estimated median percentage of total nitrate loss that occurred through tile drains ranged from 0% to 65% over the 12 months.
- The impermeable layer should not be completely impermeable. We will try adjusting the depth to achieve this.
- These estimates do not take into account the in-stream processes that can modify the nitrate concentrations prior to reaching the watershed outlet.

Conclusion --

Conclusion – SWAT Training

Learning SWAT is a complicated process, with many potential pitfalls

How can the SWAT community help more people learn this valuable tool? ("move from an academic product to the water sector" – R. Price)

- Online video introductory training
- Shared exercises
- More resources for parameterizing
- Other ideas. Let's meet for lunch.