Modelling Onsite Wastewater Systems in SWAT

J. Jeong, C. Santhi, J. G. Arnold, R. Srinivasan

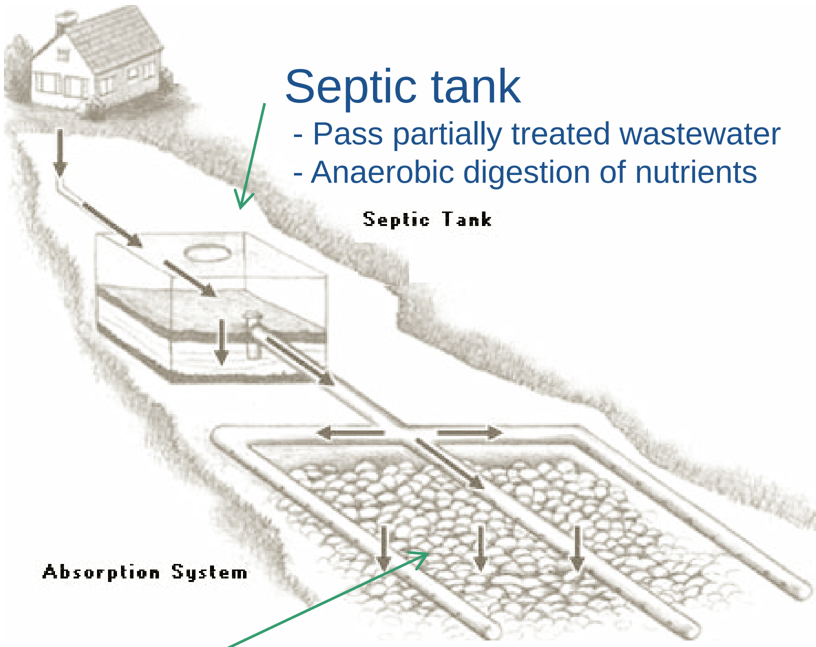
Texas AgriLife Research

Contents

Onsite Wastewater Systems (OWSs)

- **Definition: Decentralized wastewater treatment systems for treating domestic wastewater in rural areas**
- **More than 20% (26.1 million) of total U.S. housing units are served by OWSs**
- **OWSs are a cause of significant non-point source pollution**
- **SWAT2005 does not have algorithms that directly simulate OWSs**

Conventional septic system, (Swann, 2001)



Septic tank
- Pass partially treated wastewater
- Anaerobic digestion of nutrients

Soil absorption system
- Drain field
- Dispose/treat wastewater by filtering through soil profile below drain field

Types of OWS

Conventional Systems

- Most common type of OWSs with septic tank and drain field
- No pretreatment other than a septic tank

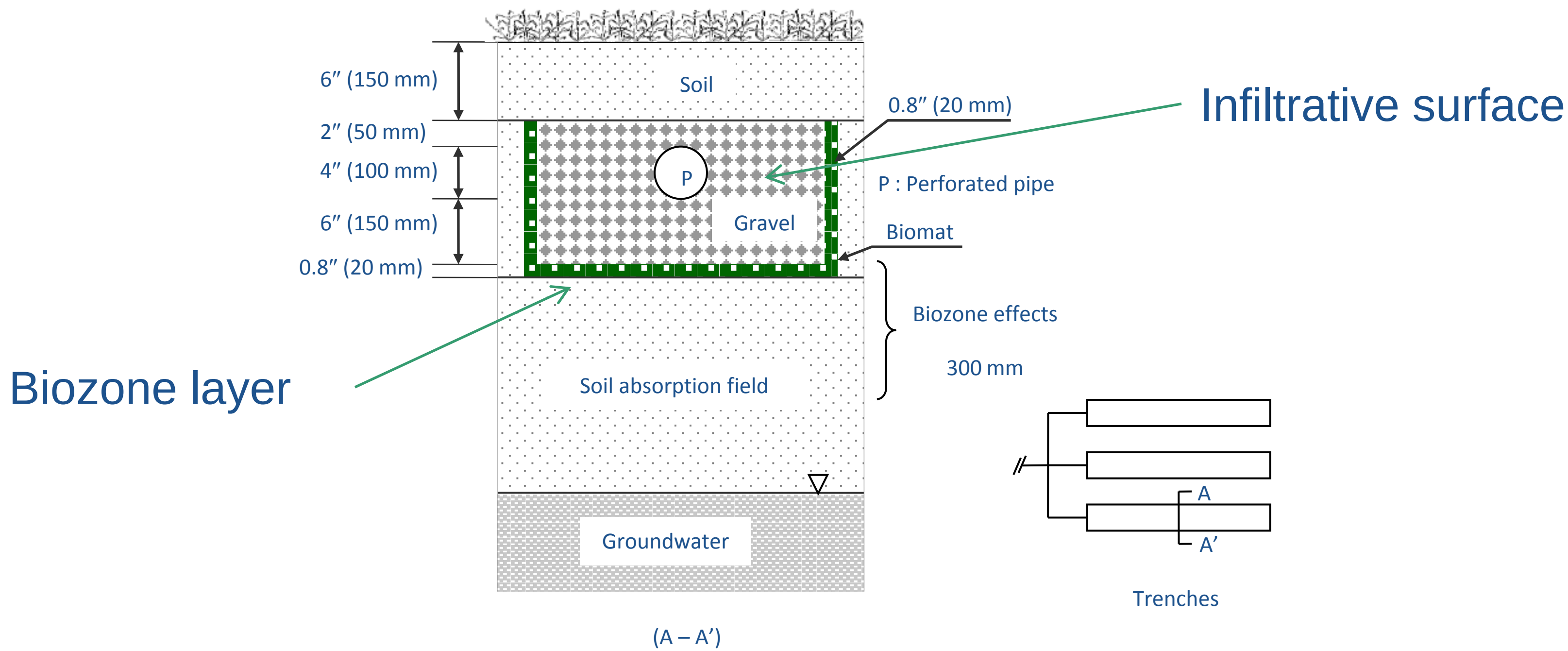
Advanced Systems

- Systems with specially designed pretreatment process (e.g. sand filter, wet lands, biofilter, UV disinfection)
- Database collected for 24 different types advance system

Failing Systems

- Aged systems that do not work as designed due to clogging after 15~25 years of service
- System failure rate increases > 70% after 25 years operation
- Hydraulic failure - backup of STE to the sink or ground surface
- Pollutants can be released to the reach via surface runoff or groundwater flow

Development of biozone in soil



- Biozone is a zone of biologically active treatment layer in the soil matrix
- Biozone is developed due to delivery of septic tank effluent
- Biozone impacts hydrologic properties and the transport and discharge of pollutants to receiving watersheds
- Biozone is conceptualized as soil layer in a HRU for configuration in SWAT

Biozone Algorithm

- Adapted from Siegrist et al. (2005)
- Basin scale, continuous simulation model
- Validated at watershed scale
- Currently used in US EPA's WARMF model
- Simulates system's aging effect by estimating the amount of live bacteria biomass and plaque
- Estimates fate of nutrients, BOD, and Fecal Coliform in the biozone layer

Biozone Algorithm

❖ Mass balance for live bacteria biomass

$$\frac{d\left(M_{bio}\right)}{dt} = \alpha\left[Q_{STE}BOD_{STE} - Q_{perc}BOD_{bz}\right] - R_{resp} - R_{mort} - R_{slough}$$

- M_{bio}= Live bacteria biomass in biozone, kg/ha
- BOD_{STE}= BOD concentration in STE, mg/L
- BOD_{bz}= BOD concentration in biozone, mg/L
- Q_{STE}= Flow rate of STE, m^3/day
- Q_{perc}= Percolation to subsoil layer, m^3/day
- α= Biomass/BOD conversion factor
- R_{resp}, R_{mort}, R_{slough} = Respiration, mortality, sloughing rate, kg/ha

Biozone Algorithm

First order kinetics for domestic pollutants

$$\ln\left(C_{i,f} / C_{i,0}\right) = -\frac{K_i \cdot M_{bio}}{\theta_s \cdot Z \cdot A} \cdot \Delta t$$

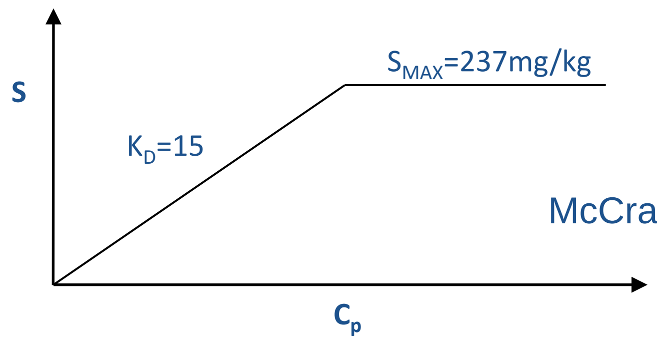
- i = pollutant (NH_4^+, NO_3^-, BOD, F.Coli)
- $C_{i,f}$ = Final concentration of pollutant i in biozone
- $C_{i,o}$ = Initial concentration of pollutant i in biozone
- K_i = First order reaction rate for pollutant i, 1/day
- M_{bio} = Live bacteria biomass in biozone
- θ_s = Saturated moisture content
- Z= Thickness of biozone layer
- A= Biozone area

Biozone Algorithm

❖ Linear isotherm for Phosphorus sorption

$$S = K_D \cdot C_p \qquad (S \le S_{\max})$$

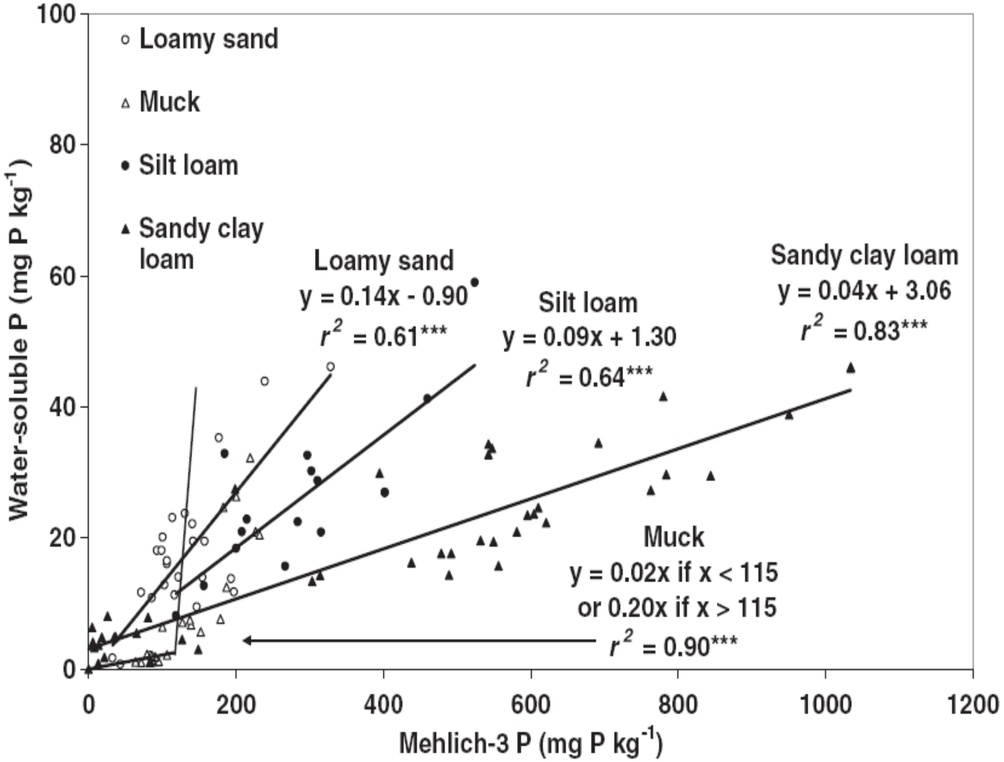
- S = Potential amount of P sorbed per unit weight of soil (mg/kg)
- K_D = Linear distribution coefficient (L/kg)
- C_p = Concentration of P in solution (mg/L)
- S_{max} = Maximum sorption capacity (mg/Kg)



McCray et al. (2005)

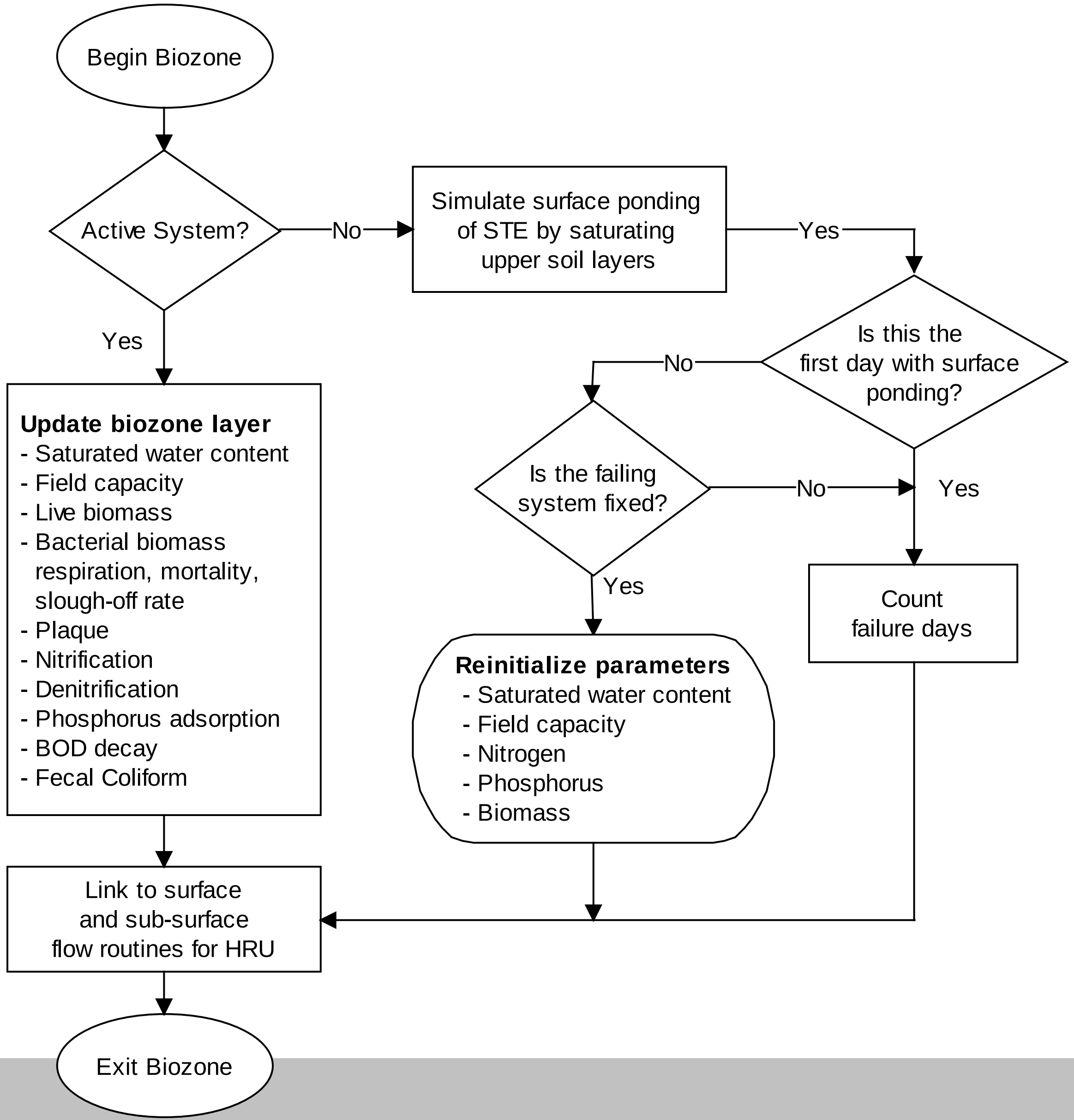
Biozone Algorithm

- P sorption isotherm assumes zero effluent P concentration if soil is not fully saturated with P
- Effluent P concentration at equilibrium is estimated by linear equations developed by Bond et al. (2006)



Water-soluble P as a function ofMehlich-3 P for native Autryville loamy sand, Wasda muck, Georgeville silt loam, and Pacolet sandy clay loam soils (Bond et al., 2006)

Schematic diagram for biozone procedures



Water quality database for OWSs

Database includes 26 types of OWSs and 2 generic type systems

Type*	Q $m^3/d/c$	BOD mg/l	TSS mg/l	TN mg/l	NH4 mg/l	NO3 mg/l	NO2 mg/l	OrgN mg/l	TP mg/l	PO4 mg/l	OrgP mg/l	F.Coli cfu/100ml	Description
GCON	0.227	170	75	65	54.8	0.2	0	10	10	9	1	10000000	*Generic type conventional system*
GADV	0.227	22	14	31.5	18.9	9.6	0	3	6	5.1	0.9	543	*Generic type advanced system*
COND	0.227	170	75	60	58	0.2	0	14	10	9	1	10000000	*Conventional Drainfield*
SAS1	0.227	170	75	70	60	0	0	10	10	8.5	1.5	10000000	*Septic w/SAS*
SAS2	0.227	170	75	70	0	0	0	0	10	9	1	10000000	*Septic w/SAS*
SAS3	0.227	170	80	20	0	20	0	0	10	8.5	1.5	1000000	*Septic w/in-tank N removal and SAS*
SAS4	0.227	100	65	20	0	0	0	0	10	8.5	1.5	10000000	*Septic tank w/effluent N removal and recycle*
SAS5	0.227	20	10	7.7	2.4	7.1	0	0	0	0	0	0	*Septic w/corrugated plastic trickling filter*
SAS6	0.227	18	17	11	5.6	4.1	0	1.3	0	0	0	0	*Septic w/open-cell form tricklig filter*
SPF1	0.227	3.5	2	38	0	0	0	0	0	0	0	360	*Single pass sand filter*
SPF2	0.227	3.2	9	30	0	0	0	0	0	0	0	407	*Single pass sand filter*
SPF3	0.227	4	17	37.5	0	0	0	0	14.1	12	2.1	862	*Single pass sand filter*
SPF4	0.227	75.1	29.1	15.5	10.6	0.3	0	4.6	0	0	0	0	*Single pass sand filter*
RCF1	0.227	3.5	3.5	13.5	0	0	0	0	0	0	0	2920	*At grade recirculating sand filter*

*13 other types not shown here

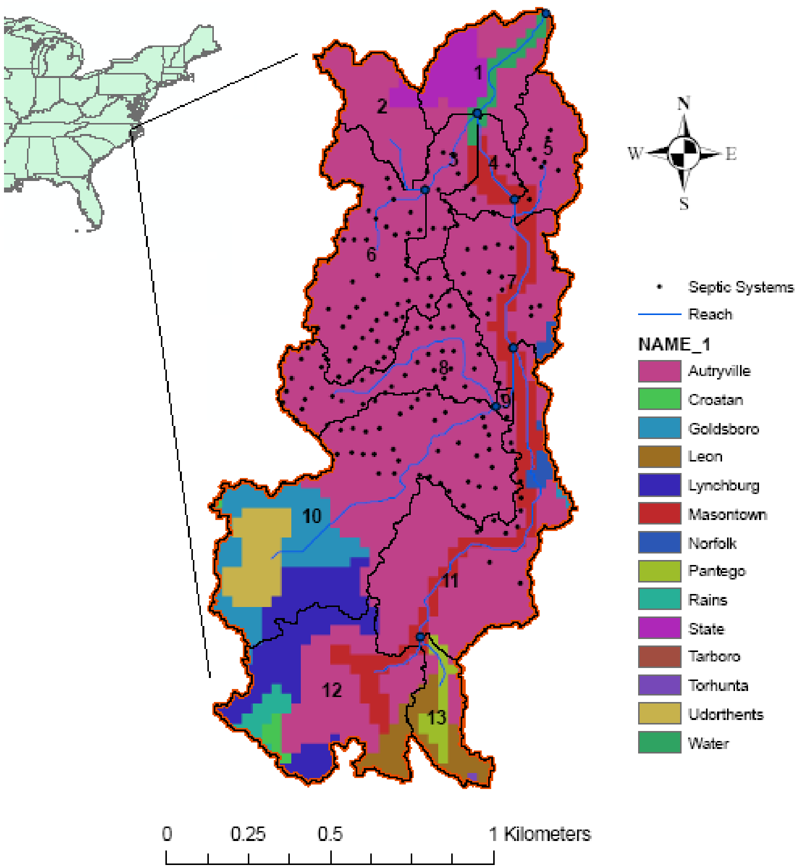
Septic HRU input file

Septic variables are defined in *.sep files

```
Septic HRU data file: 000020006.sep

                1 !isep_typ: septic system type
                1 !isep_opt: 1=active, 0=failing
              2.5 !isep_cap: number of permanent residents in the house
               60 !isep_tfail: time until failing system gets fixed, days
              500 !bz_z: Depth of biozone layer,mm
               50 !bz_thk: Thickness of biozone layer,mm
             1000 !bio_bd: Density of biomass,kg/m3
              0.5 !coeff_bod_dc: BOD decay rate coefficient,m3/d
             0.32 !coeff_bod_conv: Gram of bacterial growth/gram of BOD
               30 !coeff_fc1: Field capacity coefficient 1, unitless
              0.8 !coeff_fc2: Field capacity coefficient 2, unitless
              1.3 !coeff_fecal: F. coli bacteria decay rate coefficient,m3/d
              0.1 !coeff_plq: Conversion factor for plaque from TDS
              0.5 !coeff_mrt: Mortality rate coefficient,m3/d
            0.156 !coeff_rsp: Respiration rate coefficient,m3/d
             0.31 !coeff_slg1: Sloughing coefficient 1,kg/m
              0.5 !coeff_slg2: Sloughing coefficient 2
          149.320 !coeff_nitr: Nitrification rate coefficient, m3/d
           42.040 !coeff_denitr: Denitrification rate coefficient, m3/d
              128 !coeff_pdistrb: Linear P sorption distribution coefficient,L/kg
              850 !coeff_psorpmax : Maximum P sorption capacity, mg P/kg Soil
            0.056 !coeff_solpslp: slope in the effluent soluble P equation
            2.304 !coeff_solpintc: intercept in the effluent soluble P equation
```

Study area



Hood's Creek Watershed, North Carolina

- **The Hood's Creek watershed has 227 housing units with active OWSs in operation over the area of 172 ha**
- **No point sources and very small area of crop land in terms of nutrient sources other than OWSs**
- **Field data from several locations of OWSs is available thanks to NCSU**
- **GIS map layers**
  - 1meter resolution LIDAR
  - 1:24000 hydrograph map
  - SSURGO 2.0
  - 1:24000 land use map

Field data

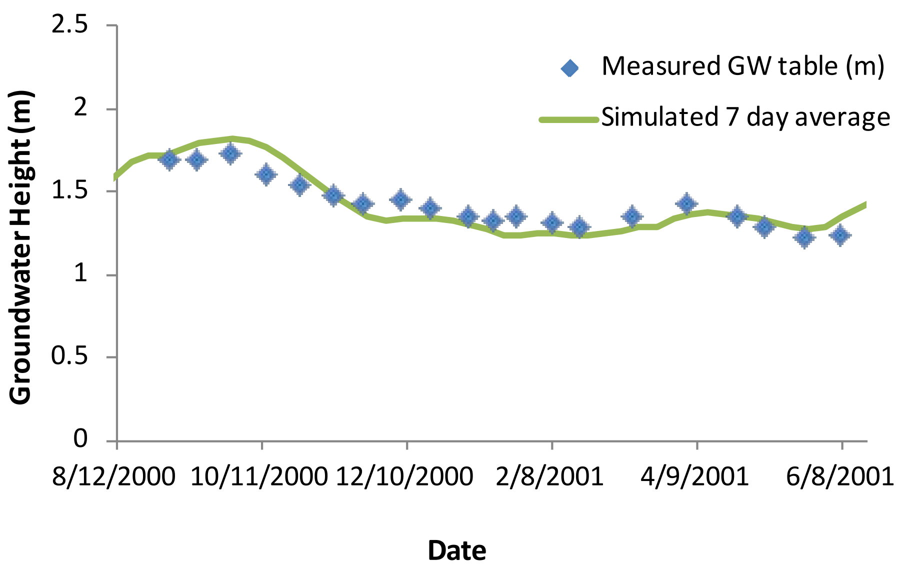
Site (#)	Septic System Type	Number of Bedrooms	Number of Occupants	Slope (%)	Age[1] (years)	QSTE (Liters/day)
1	Conventional	3	3	2	13	930
2	Conventional	3	6	3	13	1385
3-1	Conventional	3	2	4	11	590
3-2	Conventional	3	2	6	10	545
3-3	Advanced	3	3	4	2	798

[1] Age of septic system at year 2000 since installed

- **Field data was collected from monitoring wells around and near drainfields for 1 year period by NCSU**
- **Groundwater level, nutrients including nitrate and phosphate, ph, and metal concentration**
- **10-20 samples collected during the study period**

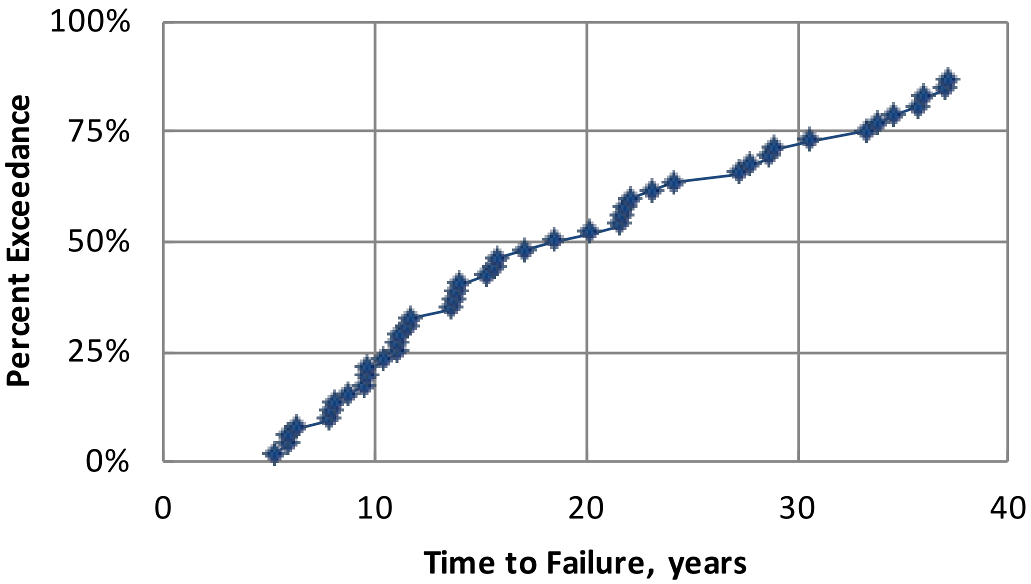
Calibration – Hydrologic processes

- Groundwater height was calibrated instead of stream flow as the biozone processes are more related to subsurface flow
- Predicted 7-day average GW height was calibrated to observation for 1 year period
- Due to the insufficient number of observed data, calibration was conducted based on visual inspection



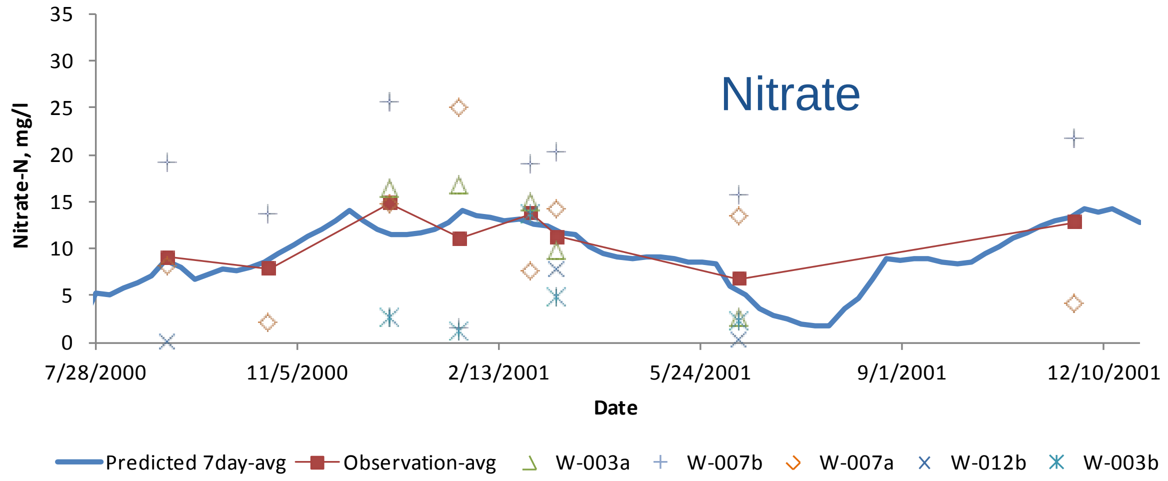
Calibration – Service life span

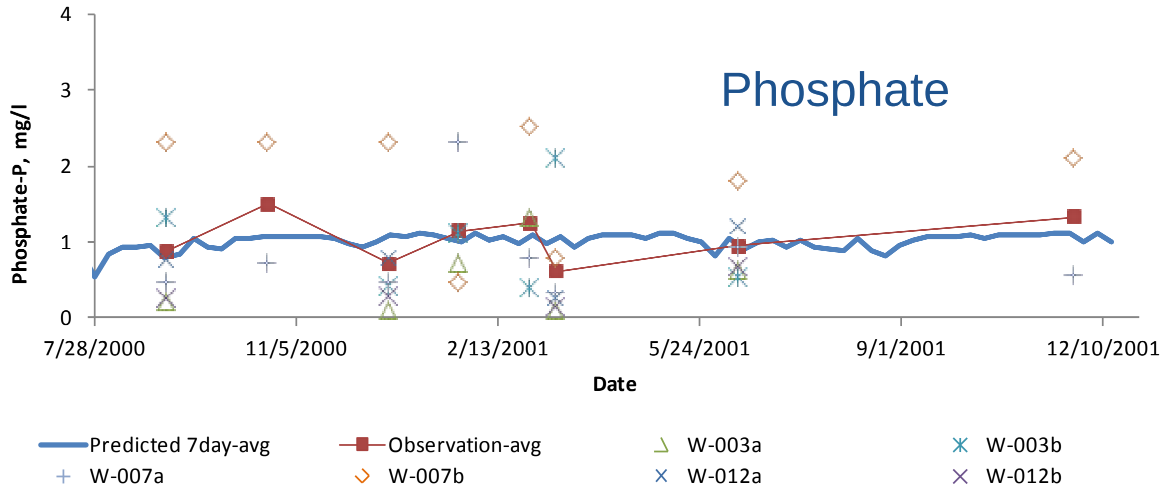
- Service life span of OWSs typically ranges from 11 years to longer than 30 years
- No direct field data is available for calibration
- 52 septic HRUs were tested for 50 years with different scenarios with a Monte Carlo simulation
- Biozone parameters were calibrated such that the failure occurs within the recommended range (75% fails less than 35 years)



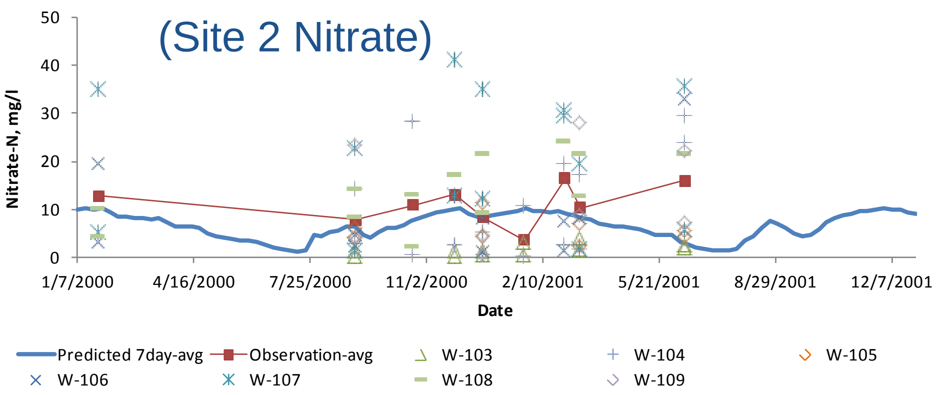
Calibration – nitrate, phosphate

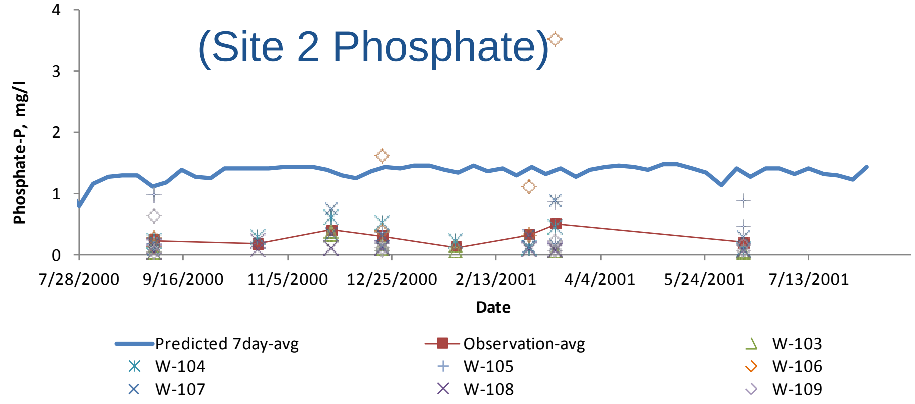
- **Site 1 conventional system**
- **7-day average prediction was calibrated to the mean observation**

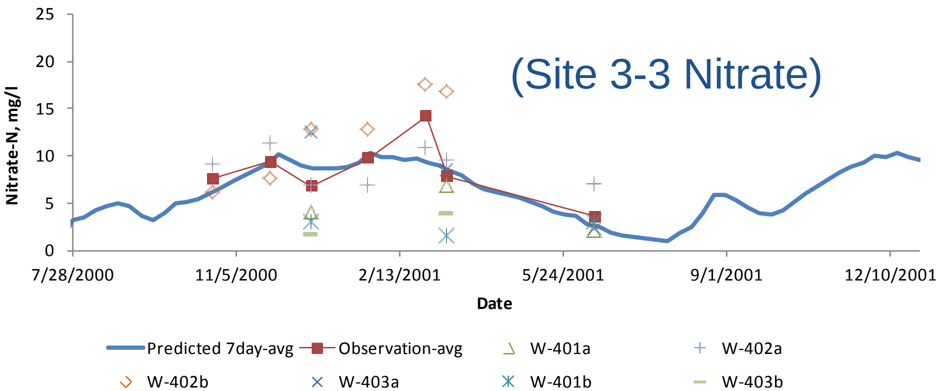


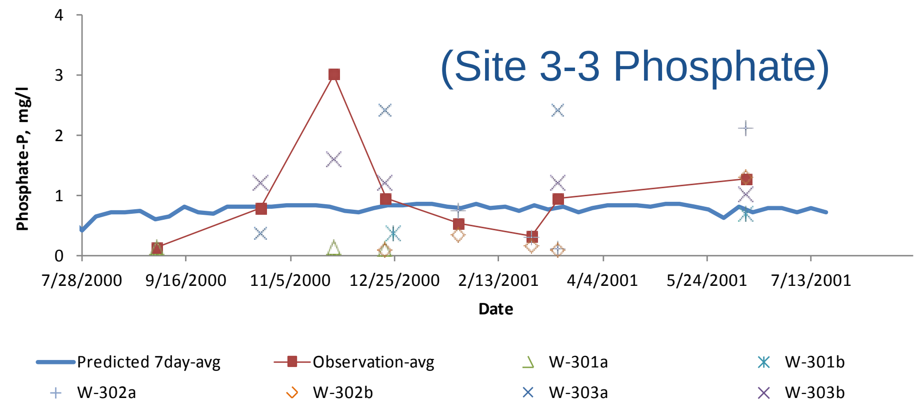


Validation – nitrate, phosphate









Summary

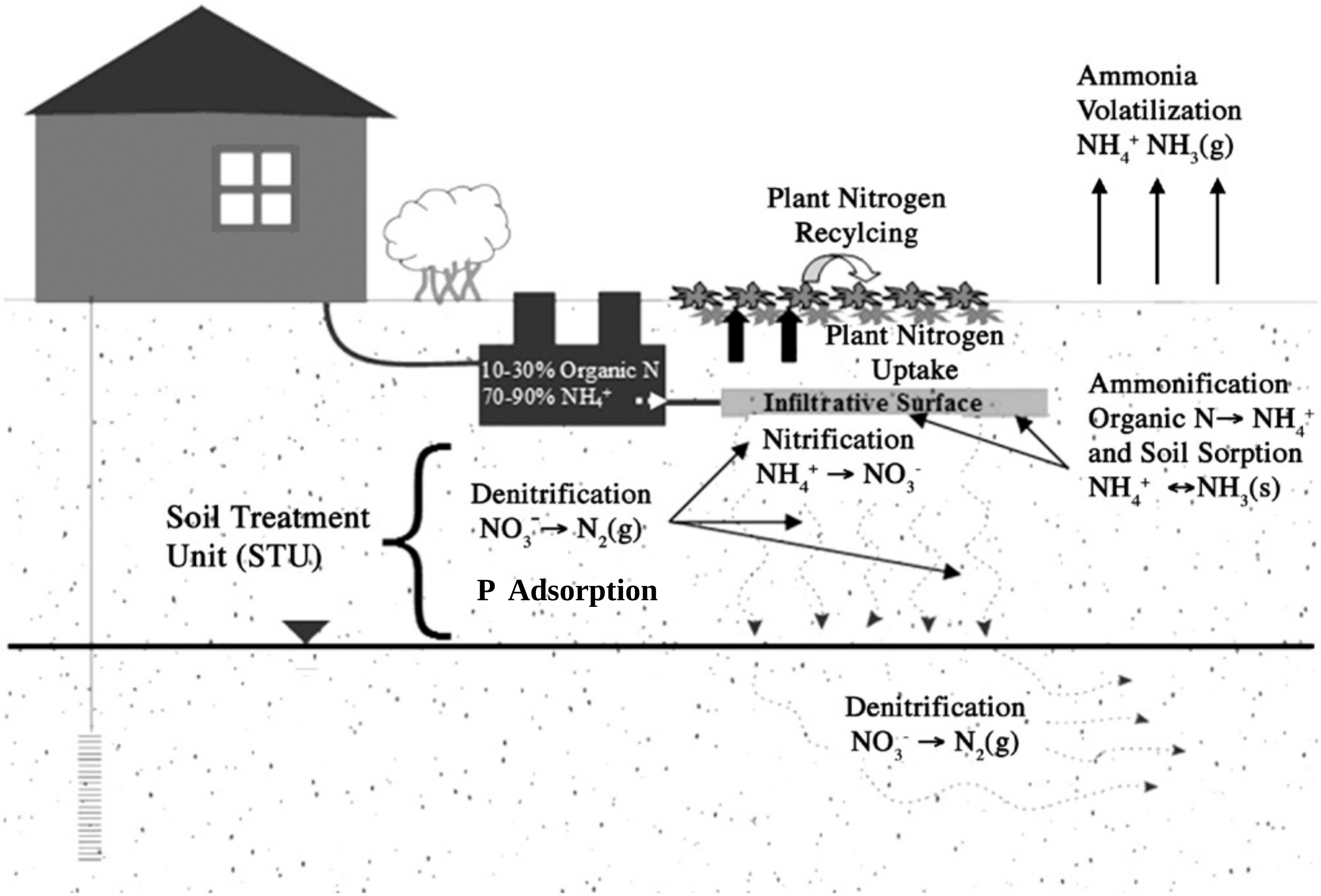
- Effects on receiving waters due to the combined effect of all point and nonpoint source loads, including different types of septic tank systems
- Strength of the SWAT model is increased with the addition of the biozone algorithm
- Total Daily Maximum Loads (TMDL) analysis and cost/benefit analyses of onsite-systems versus centralized treatment systems.

Characteristics of septic tank effluent

Conventional system

Pollutants/Rate	Unit	Median	Range
Septic Tank Flow Rate	m^3/person/day	0.227	
BOD	mg/L	170	
TSS	mg/L	70	
TN	mg/L	60	12~453
Ammonium	mg-N/L	58	17~78
Nitrate	mg-N/L	0.2	0~1.94
Nitrite	mg-N/L	0	
Organic N	mg-N/L	14	9.4~15
TP	mg-P/L	10	
Phosphate	mg-P/L	9	1.2~21.8
Organic P	mg-P/L	1	
Fecal Coliform	cfu/100mL	1.0 E7	

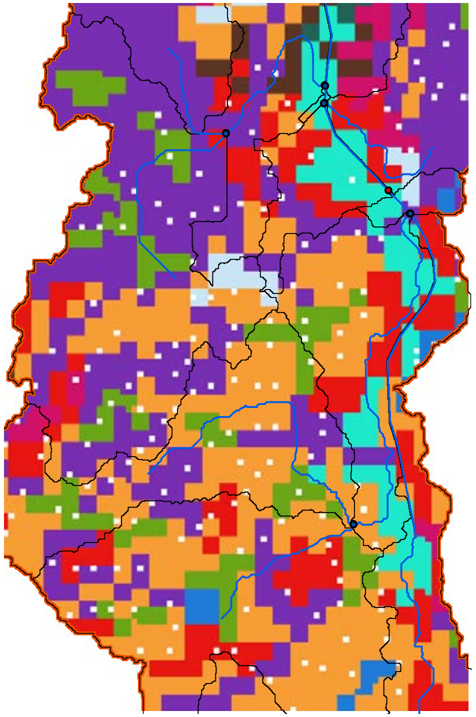
Nutrient transformation processes



(Picture from Heatwole and McCray, 2007)

GIS Preprocessing for septic layer

Individual OWSs must be defined in land use map
LU type for OWSs: SEPT
Each SEPT grid cell has ~ 10m x 10m area



(Land use map overlaid with OSTs shape file) (Final land use map with "SEPT")

Assumptions/Limitations

Assumptions

- Typical thickness of the biozone layer is 2-5cm
- A continuous daily STE inflow occurs.
- No intermittent dosing of STE is allowed
- Zero STE if soil temperature gets below freezing point

Limitations

- Not all the septic pollutants are routed through soil profile and lateral flow/groundwater flow
- Requires (x,y) coordinates of onsite septic systems and a pre-processing of the land use map layer
- Hydraulic failure is the only cause of system failure