## Development of Quantitative Tools to Determine the Expected Performance of Unit Processes in Wastewater Soil Treatment Units

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# Acknowledgements

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A multi-university team was necessary:

- to provide the needed expertise in contaminant transformations
- for mathematical modeling
- to incorporate information from OWTS field sites in different soil and climate settings

# Goal

To provide a toolkit and protocol to assess Soil Treatment Unit (STU) performance for important wastewater constituents over a relevant range of Onsite Wastewater Treatment System (OWTS) operating conditions to aid system designers and decision-makers assess the expected STU performance

# Key Results

No single model exists that is appropriate for modeling all wastewater contaminants!

A simple approach is provided for estimation of OWC attenuation

Laboratory experiments showed complete virus removal, and $\log_4$ removal of *E.coli*

Field experiments provided information on nitrogen removal for numerical modeling

Two spreadsheet models were developed for nitrogen attenuation:
N-calc & STUMOD

# Approach

1. Develop an approach to model Organic Wastewater Contaminant (OWC) attenuation
2. Conduct column studies to evaluate microbial and virus attenuation, and couple the results with numerical modeling
3. Evaluate nitrogen removal through field studies, and couple the results with numerical modeling
4. Provide examples of scenarios that illustrate how different factors impact nitrogen removal
5. Develop a tool-kit for making nitrogen attenuation predictions
   a. Visual-graphic tools – Nomographs
   b. Spreadsheet models – STUMOD & N-calc

# OWC

- OWCs include:
  - Personal Care Products
  - Household chemicals
  - Pharmaceutical compounds
- Five OWCs were selected
  - persistence in environmental
  - likely to be regulated due to toxicity
  - appearance in wastewater

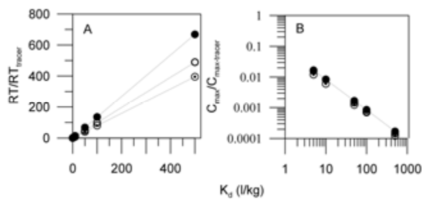
| Compound | Class | Toxicity/Risk | Persistence in Environment | Appearance in Onsite Wastewater |
|---|---|---|---|---|
| Diclofenac | analgesic | high | high | moderate |
| Triclosan | antimicrobial | high | moderate | very high |
| 1,4-dichlorobenzene | deodorant | high | moderate | high |
| 17-β estradiol | hormone | high | high | moderate |
| Estrone | hormone | high | moderate | moderate |

# OWC Attenuation

OWC attenuation estimation in the STU

Method

- characterize a tracer in terms of maximum concentration & retention time
- characterize OWC in terms of $K_d$ & half-life
- estimate $RT/RT_{tracer}$ and $C_{max}/C_{max\text{-}tracer}$ from relationship established below






# OWC Attenuation

Use simple spreadsheet tool

| Parameter | Units | Input | Parameter | Output |
|---|---|---|---|---|
| Half-life | days | 2 | $RT/RT_{tracer}$ | 9.79 |
| $K_d$ | L/kg | 10 | $C_{max}/C_{max\text{-}tracer}$ | 0.008 |

- The retention time of the tracer can be multiplied by the $RT/RT_{tracer}$ to estimate the retention time of the OWC
- The concentration of the tracer can be multiplied by $C_{max}/C_{max\text{-}tracer}$ to estimate the concentration of the OWC



# Microbes & Virus

Goal

To provide the practitioner with guidelines to estimate bacteria and virus removal efficiencies

Method

1.Column experiments using a model bacterium (*E.coli*) and virus (*MS-2* coliphage)
2.Three types of soils - sand, sandy loam, and clay loam

Key Findings

•Virus concentrations in all three soils were below detection limit at 25 cm depth level, while *E.coli* saw $\log_4$ reduction
•Virus and *E.Coli* removal rate:

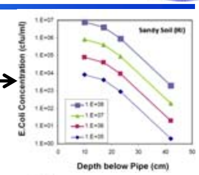
- clay loam > sandy loam > sand
- Increased with mature biofilm



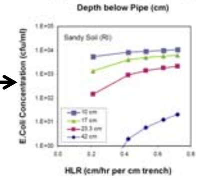
# Modeling Microbial Transport

Method

Incorporating results from column experiments into HYDRUS




The following scenarios were simulated:
•Variable hydraulic conductivity
•Variable initial *E.coli* concentration
•Variable hydraulic loading rate
•Variable precipitation or irrigation from the surface




Key Findings

The removal effectiveness varied only slightly under high stress conditions



# Field Studies

coupled with numerical modeling

Goals

1.Install and instrument an experimental OWTS and measure hydraulic performance and $NH_4$ & $NO_3$ movement
2.Develop a 2-Dimensional model of water and N movement using the numerical model HYDRUS
3.Compare the model predictions to the data obtained at the experimental site

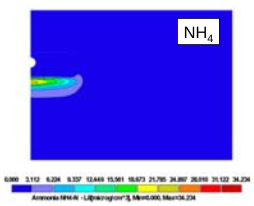


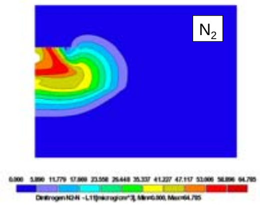
# Key Findings – Field Work

- Little to no $NH_4$ was detected in the lysimeters suggesting:
  - complete nitrification in or very near the trench, and/or
  - adsorption near the trench
- Low concentrations of $NO_3$ (1-2 mg-N/L) below trench where soil moisture was high, suggesting optimal conditions for denitrification
- Higher concentrations of $NO_3$ (~10 mg-N/L) between trenches where soil moisture was low, thus suggesting less optimal conditions for denitrification

# Numerical Modeling

Geometry
- Half of the trench area was modeled
- Top of domain - soil surface
- Bottom boundary – "free drainage" appropriate for a deep water table
- Model was run for 100 days
- STE was dosed 3 times/day and assumed to be 60 mg-N/L as ammonium






# Key Findings – Modeling

- The model accurately predicted water movement and pressure heads
- Soil and moisture conditions appear to be critical when modeling denitrification
- The model appears to accurately predict nitrification
- The model slightly overestimated denitrification



# Select Scenarios

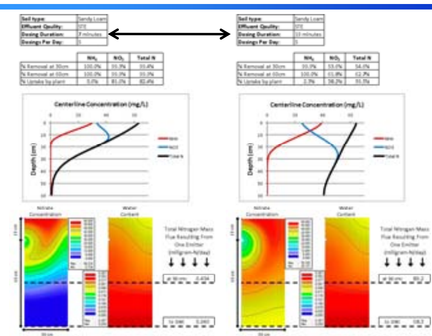
**HYDRUS was used to simulate select scenarios**

**Drip Dispersal Systems**
- Influence of dosing duration
  - 7 min/dose
  - 19 min/dose
- Influence of soil texture
  - Sand
  - Sandy loam
  - Silty clay
- Influence of effluent quality
  - Standard effluent 60 mg-N/L
  - Nitrified effluent 15 mg-N/L

**Trench Systems**
- Influence of HLR
  - 2 cm/day
  - 10% Ksat
- Influence of soil texture
  - Sand
  - Sandy loam
  - Silty clay
- Influence of effluent quality
  - Standard effluent 60 mg-N/L
  - Nitrified effluent 15 mg-N/L

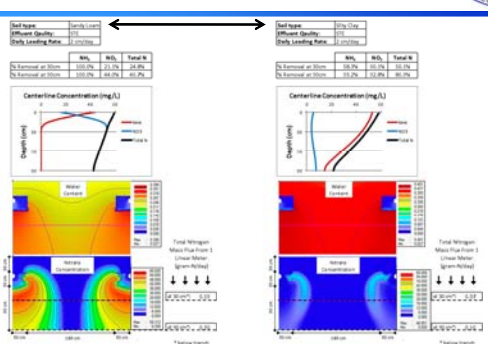


# Key Findings – Drip Dispersal
## Dosing Duration





# Key Findings – Trench
## Soil Texture





# Tools

Type of Tools:
- Look-up tables
- Cumulative Frequency Distributions (CFD)
  - Expected contaminant concentration
  - Nitrogen transformation parameters
- Nomographs
  - Removal of N with depth under specific conditions
  - Uncertainty associated with prediction
- Spreadsheet tools
  - N-calc
  - STUMOD

# Look-Up Tables

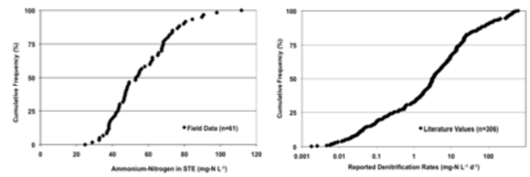
| | Expected Daily Flow (L/capita/day) | | | | |
|---|---|---|---|---|---|
| | Mean | Standard Deviation | 25[th] Percentile | Median | 75[th] Percentile |
| **All Sites** | 207 | 143 | 116 | 171 | 252 |
| **Variations due to Age** | | | | | |
| Occupants < 65 | 148 | 78 | 87 | 137 | 196 |
| Occupants > 65 | 297 | 177 | 169 | 248 | 381 |
| **Variations due to Region** | | | | | |
| Mid-West | 207 | 98 | 137 | 173 | 235 |
| South | 184 | 103 | 109 | 171 | 226 |
| West | 234 | 207 | 98 | 154 | 254 |

| | | Typical Concentrations in STE | | |
|---|---|---|---|---|
| | Units | 25[th] Percentile | Median | 75[th] Percentile |
| **Total Nitrogen** | mg-N/L | 47 | 63 | 78 |
| **Ammonium-Nitrogen** | mg-N/L | 43 | 53 | 68 |
| **Nitrate-Nitrogen** | mg-N/L | 0.50 | 0.65 | 0.90 |
| **COD** | mg/L | 318 | 377 | 542 |
| **cBOD5** | mg/L | 152 | 204 | 268 |
| **Alkalinity** | mg $CaCO_3$/L | 292 | 407 | 493 |
| **pH** | - | 7.1 | 7.3 | 7.7 |

Data from Lowe et al. 2009



# CFD

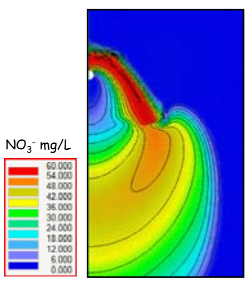


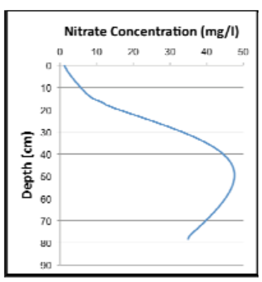
Cumulative Frequency Distributions are used for making risk-based decisions on appropriate input parameters used in the spreadsheet tools



# Nomographs

Complex tools were used to develop simple tools






# Nomograph Development

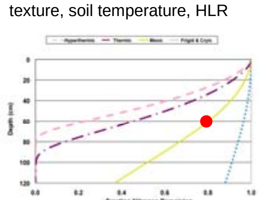
Method & Assumptions

- Nitrogen transformation parameters were obtained from the literature
- Nitrogen transformations were assumed to follow Monod kinetics
- Sorption, nitrification and denitrification were the only transformation processes accounted for
- Nitrogen in STE was assumed to be in the form of $NH_4$
- Sufficient carbon was assumed to exist for denitrification
- Alkalinity and pH were assumed to be optimal
- Regional average annual soil temperatures were obtained from USDA
- Soil properties were obtained from the Rosetta database



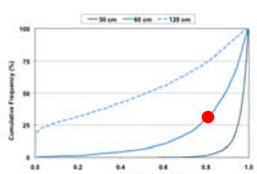
# Type of Nomographs

Fraction nitrogen remaining in the soil with depth based on soil texture, soil temperature, HLR



Example: Sandy loam, with a HLR of 2 cm/day in a mesic temperature region

Probability distribution that a given removal will occur at different depths at a set soil temperature



Example: at 60 cm depth, the uncertainty associated with the prediction is ~30%



# Spreadsheet Tools

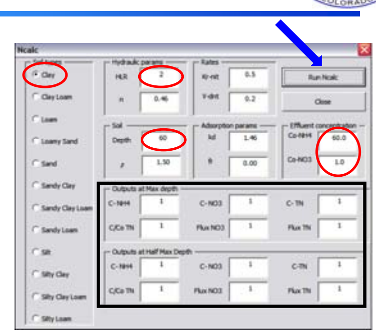
## N-calc

Simple spreadsheet tool based on first order reaction rates

Input:
- Soil texture
- HLR
- Prediction depth
- $NH_4$ & $NO_3$

Run N-calc

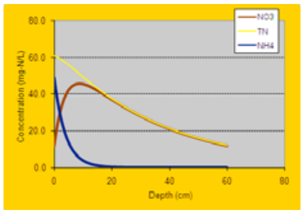
Output:
- Concentrations of $NH_4$ & $NO_3$
- Fraction N remaining in soil
- Mass flux at depth



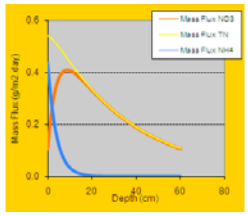
# N-calc Output Graphs

Example output from previous example

Concentration of nitrogen species with depth
mg-N/L




Mass nitrogen/area with depth
g-N/m²/day





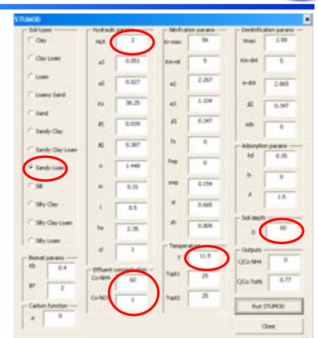

# Spreadsheet Tools

## STUMOD

- Complex spreadsheet tool, where the reaction rates are a function of soil moisture and temperature
- Requires more technical expertise to use
- The user can modify input parameters as needed based on site conditions
- Model can be calibrated to field data

Minimum Input:

- Soil texture
- HLR
- Prediction depth
- $NH_4$ & $NO_3$
- Soil temperature





# STUMOD Output Graphs

Example output from previous example

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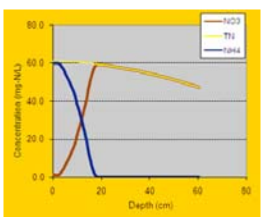


Mass nitrogen/area with depth
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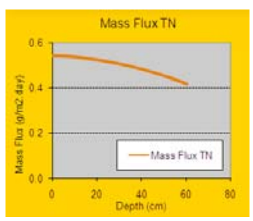




# Conclusions

- A simple approach is provided for estimation of OWC attenuation
- Laboratory experiments showed complete virus removal, and 4-log removal of *E.coli*
- Field experiments provided information for the development of a 2D numerical model
- Look-up tables and CFDs allow the user to choose relevant input parameters
- N-calc
  - Intended as a screening level tool when input data is limited
- STUMOD
  - More complex tool including operational and hydraulic parameters, and nitrogen-transformation processes

# Implications

- **Quantitative Assessments of Nitrogen Attenuation**
  - User can obtain predictions on the fraction of ammonium, nitrate or total nitrogen removed versus depth below trench
- **Scenario Evaluation**
  - Practitioners can perform rapid evaluations of scenarios that may influence nitrogen treatment such as the influence of nitrogen concentrations in septic tank effluent, pretreatment, soil properties, loading rates, and temperature
- **System Design**
  - Hydraulic loading rates, effluent quality, trench size, or loading area can be evaluated in light of nitrogen-treatment performance goals
- **Rigorous Assessment**
  - STUMOD can be calibrated to actual site and subsequently used to optimize operation of OWTS or to design new OWTS in a similar soil setting