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Effluent Dispersal into Soil for Onsite Treatment and Discharge/Reuse

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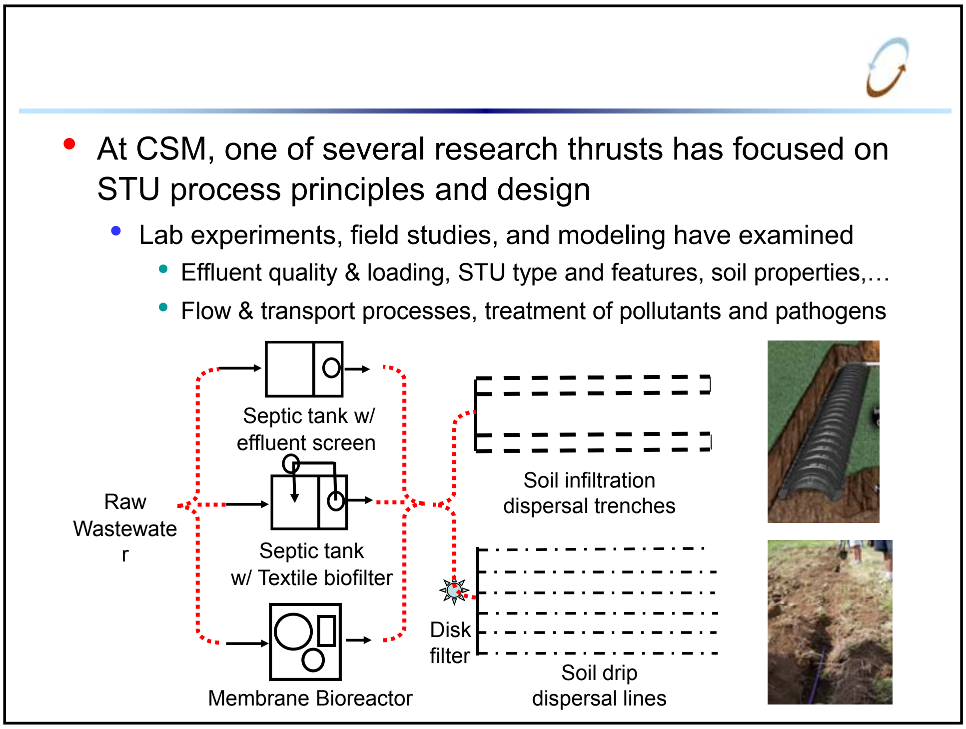
Nordic Conference on the State of the Art concerning Soil Treatment Systems
Malmo, Sweden 8-9 Feb 2011

Introduction

- Most onsite wastewater systems in rural and suburban areas of the U.S. have include a unit operation involving a soil profile within a landscape
  - In contrast to years ago when soil was used as a simple means of short-term waste *disposal*, the modern view encompasses long-term *treatment* and *hydrologic functions*
    - Terminology has evolved to reflect this view
      - Historical = Cesspool, Seepage Pit, Leachfield, Drainfield
      - Contemporary = Effluent Dispersal, Soil Treatment Unit (STU)
    - We now have the knowledge and tools to design and implement a STU within an onsite system that is:
      - Capable of achieving tertiary treatment with natural disinfection
      - While enabling resource recovery and reuse
      - And doing so in a reliable, affordable, and sustainable manner



- At CSM, one of several research thrusts has focused on STU process principles and design
  - Lab experiments, field studies, and modeling have examined
    - Effluent quality & loading, STU type and features, soil properties,…
    - Flow & transport processes, treatment of pollutants and pathogens

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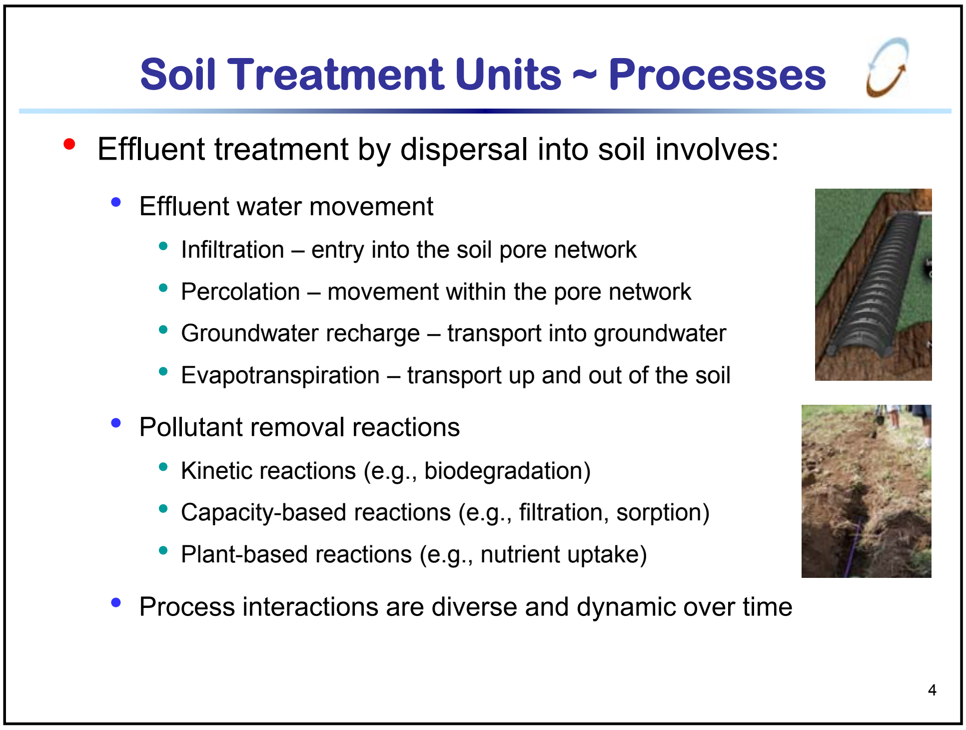

Soil Treatment Units ~ Processes

- Effluent treatment by dispersal into soil involves:
  - Effluent water movement
    - Infiltration – entry into the soil pore network
    - Percolation – movement within the pore network
    - Groundwater recharge – transport into groundwater
    - Evapotranspiration – transport up and out of the soil
  - Pollutant removal reactions
    - Kinetic reactions (e.g., biodegradation)
    - Capacity-based reactions (e.g., filtration, sorption)
    - Plant-based reactions (e.g., nutrient uptake)
  - Process interactions are diverse and dynamic over time

- Key factors that control effluent water movement include:
  - Soil properties and site conditions
    - Soil texture and structure
    - Soil profile depth, layering, hydrology
  - Design and operation
    - Dispersal unit type and infiltrative surface architecture
      - Landscape placement, geometry, depth
      - Infiltrative surface features
    - Effluent application rate and method
      - Hydraulic loading rate
      - Frequency, uniformity, and continuity of application
    - Effluent composition
      - Concentrations of organic matter, nutrients, and microbes

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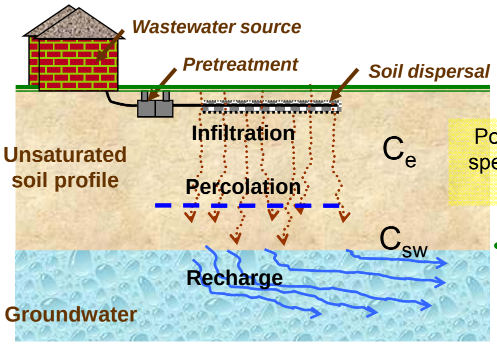
- Key factors that affect pollutant removal
  - Primary factors are related to the types and rates of reactions plus the hydraulic retention time (HRT)
  - Hydraulic loading rate (HLR) and effluent quality
    - HLR and effluent quality can affect infiltration capacity, uniformity of infiltration and HRT in the soil profile
  - Method of effluent delivery and application
    - The application method can affect uniformity of infiltration, unsaturated flow conditions, and HRT
  - Infiltration depth and unsaturated zone properties
    - Depth affects aeration and plant-based processes
    - Unsaturated zone thickness affects aeration and HRT
    - Soil properties (e.g., NOM, mineralogy, pH, °C) can affect reactions and rates

- Assessing pollutant removal in a STU?
  - Unlike a tank-based unit, with effluent dispersal in soil there is not an outlet pipe discharging a treated effluent
    - Treatment is often based on concentrations in soil pore water at a specified depth (C_{sw}) compared to the effluent applied (C_e)



$$\%\text{Removal} = \left[\frac{C_e - C_{sw}}{C_e}\right] x\,100\%$$

Pollutant removals by a specified depth in the soil profile (e.g., 60 cm)

- Treatment also occurs by dilution and natural attenuation during groundwater recharge and flow away from the site

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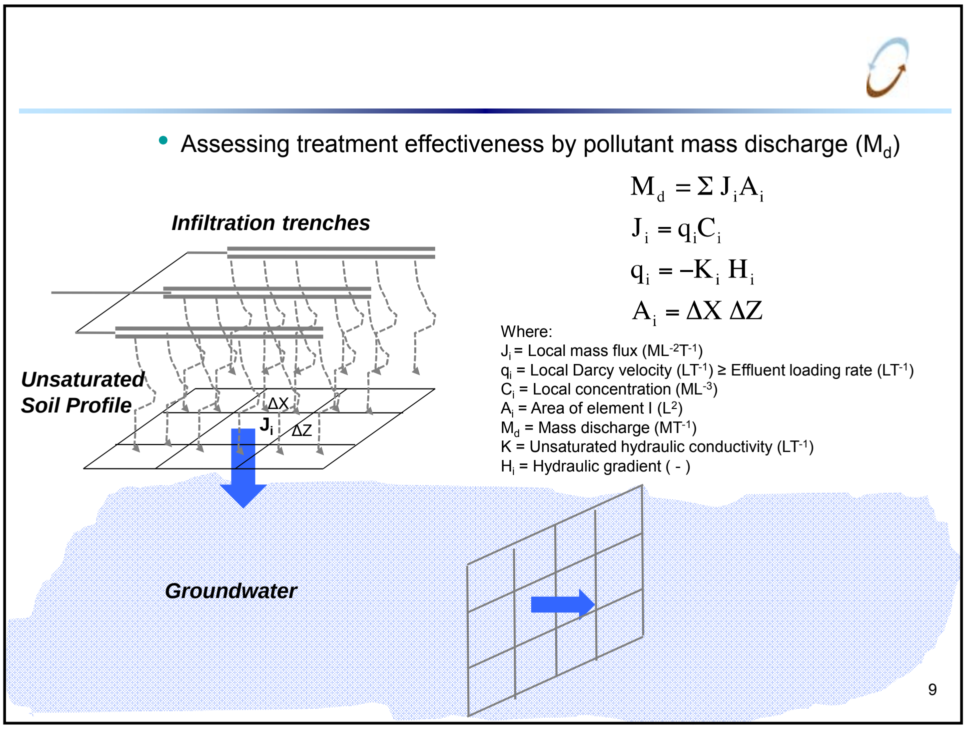
- Example pollutant removals in a STU
  - Based on effluent dispersed by infiltration at 10 to 40 L/m^2/d
  - Concentrations in soil pore water at approx. 90-cm depth

Pollutant	Units	Influent = Septic tank effluent	Concentration in soil water by 90 cm depth	% Removal by infiltration & percolation
Organic matter	mg-DOC/L	35	2	94%
Susp. solids	mg/L	75	5	93%
Nitrogen	mg-N/L	60	48	20%
Phosphorus	mg-P/L	10	<0.1	99%
Fecal coliforms	#/100mL	1 x 10^5	<10	99.99%
Virus	pfu/100mL	<1 to 10^5	<10	99.99%
Trace organics	µg/L	<1 to 100	<1 to <10	up to >99%



- Assessing treatment effectiveness by pollutant mass discharge (M_d)

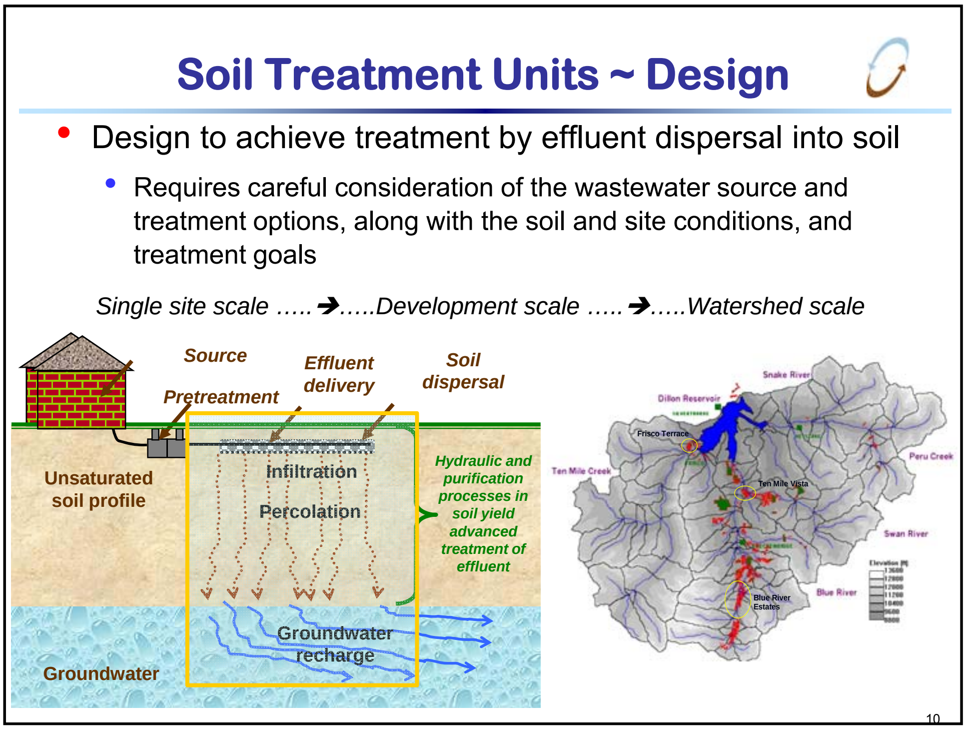
$$M_d = \Sigma J_i A_i$$

$$J_i = q_i C_i$$

$$q_i = -K_i\ H_i$$

$$A_i = \Delta X\ \Delta Z$$

Where:
J_i = Local mass flux ($ML^{-2}T^{-1}$)
q_i = Local Darcy velocity (LT^{-1}) ≥ Effluent loading rate (LT^{-1})
C_i = Local concentration (ML^{-3})
A_i = Area of element I (L^2)
M_d = Mass discharge (MT^{-1})
K = Unsaturated hydraulic conductivity (LT^{-1})
H_i = Hydraulic gradient (-)

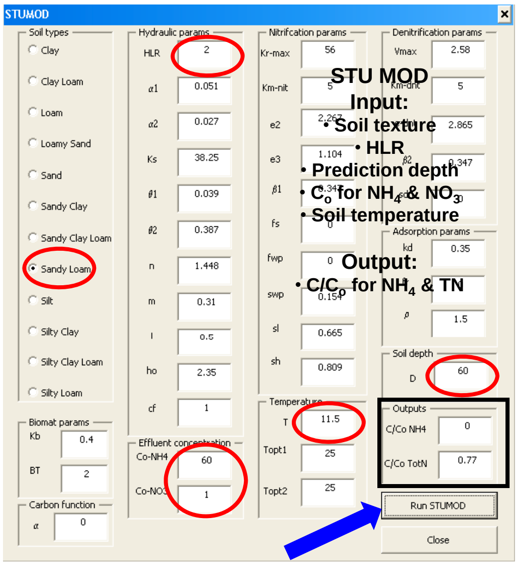


Soil Treatment Units ~ Design

- Design to achieve treatment by effluent dispersal into soil
  - Requires careful consideration of the wastewater source and treatment options, along with the soil and site conditions, and treatment goals

Single site scale …..➔…..Development scale …..➔…..Watershed scale

- Design can be aided by decision-support tools
  - Site-scale modeling, e.g.:
    - STUMOD – A CSM spreadsheet model based on complex eqn.
    - Tables & statistical distributions (CFDs)
    - Nomographs & probability distributions (STUMOD output)
  - Used to estimate pollutant removal with depth & to determine the uncertainty in the predicted value



STUMOD

Soil types
○ Clay
○ Clay Loam
○ Loam
○ Loamy Sand
○ Sand
○ Sandy Clay
○ Sandy Clay Loam
● Sandy Loam
○ Silt
○ Silty Clay
○ Silty Clay Loam
○ Silty Loam

Biomat params
Kb 0.4
BT 2

Carbon function
α 0

Hydraulic params
HLR 2
α1 0.051
α2 0.027
Ks 38.25
θ1 0.039
θ2 0.387
n 1.448
m 0.31
l 0.5
ho 2.35
cf 1

Effluent concentration
Co-NH4 60
Co-NO3 1

Nitrifcation params
Kr-max 56
Km-nit 5
e2 2.267
e3 1.104
β1 0.347
fs 0
fwp 0
swp 0.154
sl 0.665
sh 0.809

Temperature
T 11.5
Topt1 25
Topt2 25

Denitrification params
Vmax 2.58
Km-dnt 5
2.865
β2 0.347
0

Adsorption params
kd 0.35
ρ 1.5

Soil depth
D 60

Outputs
C/Co NH4 0
C/Co TotN 0.77

STU MOD

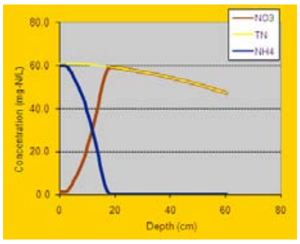
Input:
- **Soil texture**
- **HLR**
- **Prediction depth**
- **C_o for NH_4 & NO_3**
- **Soil temperature**

Output:
- **C/C_o for NH_4 & TN**

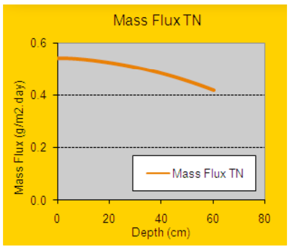
McCray *et al.* 2010

- Example output from a STUMOD simulation

Concentration of N species with depth (mg-N/L)

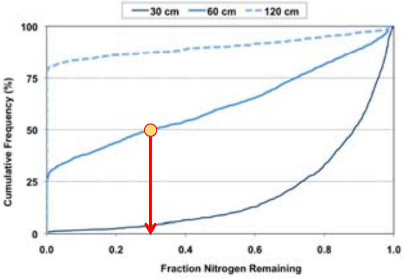


Mass per time per footprint area (g-N/m^2/day)

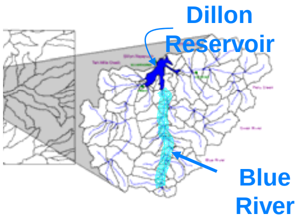


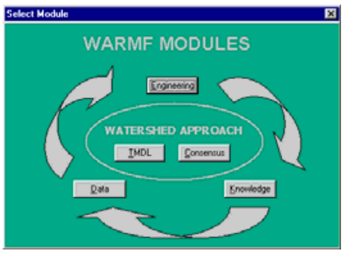
Probability distribution that a given removal will occur under specified conditions

e.g., there is a 50% probability of 70% nitrogen removal at 60-cm depth



- Watershed-scale modeling
  - Can link onsite systems serving single sites or development areas with the environment and other sources of pollutants
  - WARMF GIS-based watershed model and decision support system
  - Five linked modules including Consensus and TMDL modules
  - Physically based, dynamic model
    - Driven by meteorology, land use, point sources, fertilizer, air quality data,...
    - Simulates temperature, DO, TSS, N, P, fecal coli., Chl-a, etc.





Siegrist *et al*. 2005, McCray *et al*. 2009

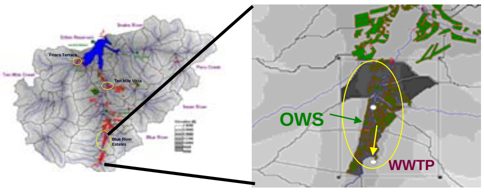
- Example decision that watershed modeling can help inform
  - Benefits to water quality by converting 906 residents from onsite (362 onsite systems) to an existing centralized plant?
  - Results of model simulations revealed that there would be little or no benefit to water quality in the Blue River by centralization
  - But there would be known and potential costs

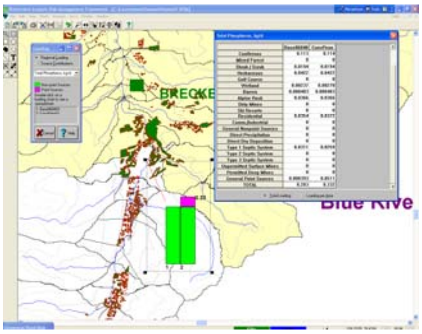
:Changes in P loading to the River:

Nonpoint P ⇓

Point P ⇑

Total P load ⇑

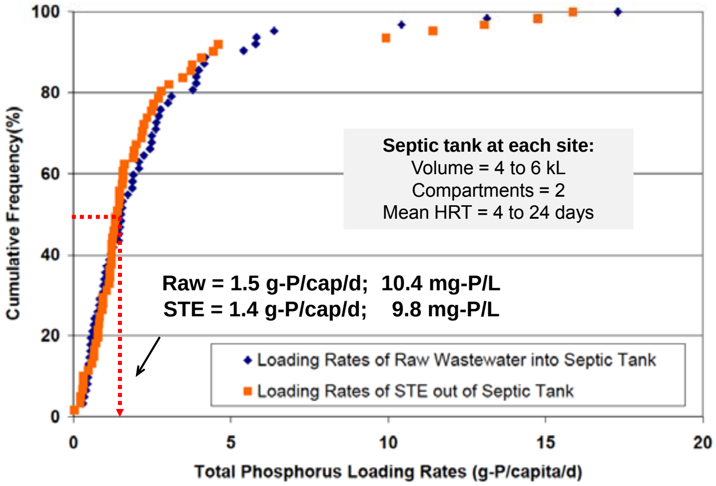




What about Phosphorus?

- Phosphorus - generation and removal in a septic tank
  - Cumulative frequency diagram (CFD)

Recent data for 17 homes in Colorado, Florida, Minnesota; 24-hr flow-weighted composite sampling during each season (2008-2009)



Septic tank at each site:
Volume = 4 to 6 kL
Compartments = 2
Mean HRT = 4 to 24 days

Raw = 1.5 g-P/cap/d; 10.4 mg-P/L
STE = 1.4 g-P/cap/d; 9.8 mg-P/L

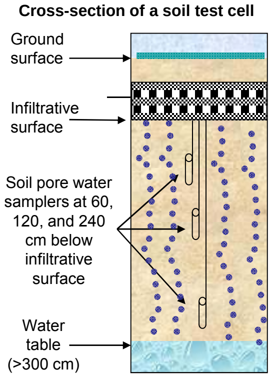
Lowe *et al.* 2009

- Phosphorus – removal in a soil treatment unit
  - Long-term field studies at the Mines Park Test Site
    - STU employing infiltration trenches
      - Septic tank effluent, textile biofilter effluent, or membrane bioreactor effluent
      - 20, 40, or 80 L/m^2/day (bottom area basis)
      - Infiltration chambers, gravel filled trenches, or plastic bead filled trenches
      - 3 to 5 replicates of each condition plus controls
    - STU employing drip emitter lines
      - Septic tank effluent
      - 5 or 10 L/m^2/day (footprint area basis)
      - Natural turf or grass sod

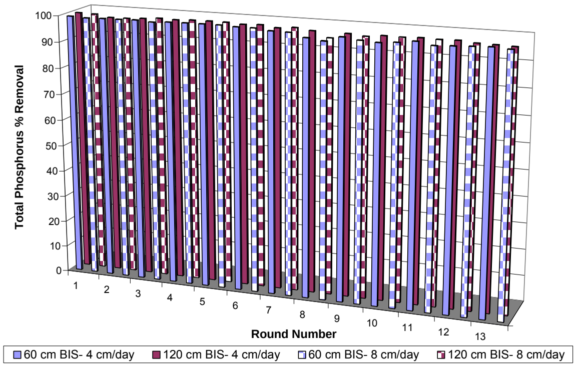
Tackett *et al.* 2004, Dimick 2005, VanCuyk *et al.* 2005, Parzen *et al.* 2007, Lowe and Siegrist 2008, Lowe *et al.* 2008

- Soil and site conditions
  - Ascalon sandy loam
  - Landscape features
    - Open field, easterly aspect, 5 to 7% slope
    - Elevation = 1820 to 1823 m above msl
  - Soil properties (trend from 0.6 to 2.4 m bgs)
    - Sand; silt; clay % = 70; 09; 21 ➔ 77; 11; 12
    - Water content = 4.6 ➔ 5.8 dry wt. %
    - pH = 7.3
    - Organic matter = 1.1 ➔ 0.3 dry wt. %
    - CEC = 8.9 ➔ 2.5 meq/100 g dry soil
  - Hydrology
    - Ground water table depth = ~ 2.9 to 5.0 m bgs
    - Percolation rates = 10, 16, 16, 20 min/in
- Typical HLR for this soil (e.g., Jefferson County, CO)
  - STE at 20 L/m^2/day (2 cm/day)

- Monitoring of effluent applied and soil pore water at depth, *et al.*
  - With effluent dispersal for during 3 to 5 years of operation
  - P removal by 60-cm depth = 97.9% (± 0.1) to 99.5% (± 0.2)
  - P concentrations in pore water = 0.2 mg-P/L



Tillotson 2009



- Why was P effectively removed in the STU?

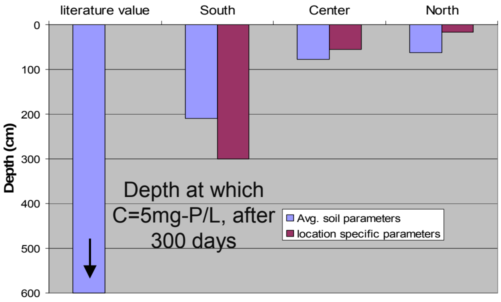
- Hydrus 1-D numerical model
  - Simulated 300 days of 20 L/m²/day effluent infiltration
  - Average of 10 mg-P/L
  - Unsaturated hydraulic conductivity

    Based on silt-sand-clay data at the site using the Rosetta statistical method
  - Sorption parameters

    Measured values; median literature value (15 L/kg)
  - Initial conditions

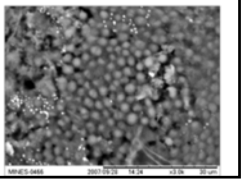
    -100 cm pressure head
  - Boundary conditions

    2 cm effluent ponding



- Sorption alone does not explain P removal
- PHREEQC modeling suggested potential for P precipitation
- Biological effects?

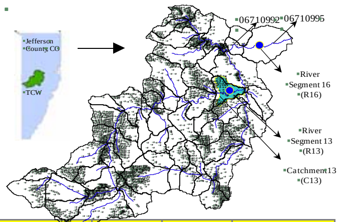
  Cyclic aerobic-anaerobic conditions



Doyle 2006, McKinley and Siegrist 2010

- What about P from onsite systems in a watershed setting?

- A WARMF watershed model was set up to simulate P transport in the Turkey Creek Watershed, Colorado and to evaluate the impact of scenarios related to:
  - Population growth, STE concentration levels, conversion of OWS to sewers, and soil adsorption capacity



- Result: Contributions of OWS to total P concentrations in the stream estimated to be minimal in this watershed, indicating that soil provides sufficient treatment

Location	Growth scenario	Pop. (no.)	Total P (mg/L)	Scenario to base case (-)
Stream segment 61	Base case	11,000	0.0210	
	No. I	22,000	0.0219	1.04
	No. II - no OWS	None	0.0199	0.95
Stream segment 13	Base case	11,000	0.0288	-
	No. I	22,000	0.0303	1.05
	No. II - no OWS	None	0.0271	0.94
Bottom soil layer (Ctmt. 13)	Base case	11,000	0.0524	-
	No. I	22,000	0.0529	1.01
	No. II - no OWS	None	0.0517	0.99

Geza *et al.* 2010, McCray *et al.* 2010

Summary

- Today, soil treatment units can be engineered to:
  - Achieve tertiary treatment of primary or secondary effluents and accomplish natural disinfection
    - Effluent water movement and pollutant removal processes are increasingly better understood
    - Decision-support tools enable a more rational design process
  - They also provide a receiving environment for reclaimed water and can enable beneficial reclamation of resources
- They can be designed as a unit operation in an onsite system to provide robust, reliable, cost-effective, and sustainable effluent treatment

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Further Information

- Associated Research Publications

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