

Rational Design of a Soil Treatment Unit within an Onsite Wastewater System

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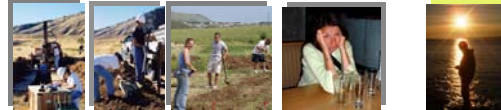


CPOW Education Conference - January 29, 2010 in Denver, CO

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Opening Remarks

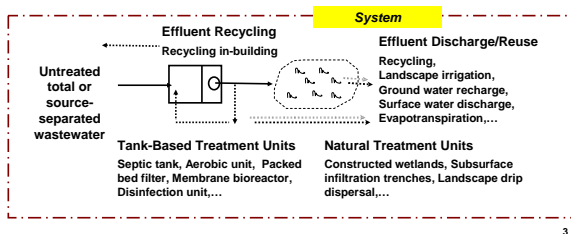
- Presentation overview
 - Context and motivation
 - Moving from "Drainfields" to "Soil Treatment Units" as a unit operation in an onsite or decentralized system
 - Rational design of a Soil Treatment Unit
 - Illustration of an approach and criteria for a network of infiltration trenches
- Acknowledgements...



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Context & Motivation

- Onsite and decentralized systems (DWS)
 - DWS are made up of different components and operations
 - Through a *design process*, these can be combined to yield a DWS to achieve different performance goals and enable different discharge and reuse options



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Soil Treatment Units

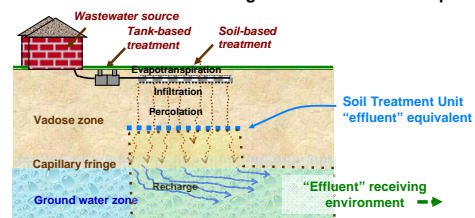
- The vast majority of DWS have included, and will continue to include, a unit operation involving a soil profile within a landscape
 - In contrast to years ago when soil was used as a simple means of waste disposal, the modern view encompasses treatment and hydrologic functions
 - Terminology has evolved to reflect this view
 - Historical = Drainfield, Leachfield, Seepage pit
 - Contemporary = Soil Treatment Unit (Siegrist *et al.* 2004)
 - Soil Treatment Units = *In Situ* Porous Media Biofilters (PMBs)
 - Capable of achieving tertiary treatment with natural disinfection
 - While enabling resource recovery and reuse
 - And doing so in a reliable, affordable, and sustainable manner

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- Basic features of a "Soil Treatment Unit" (STU)
 - Raw wastewater is first treated in a tank-based unit (s)
 - Septic tank effluent (STE) (or a higher quality effluent) is discharged into a distribution network placed in subsurface soil (i.e., below the original or final ground surface)
 - Effluent is intermittently dosed under pressure into the distribution network (or it can flow by gravity and more continuously trickle into the distribution network)
 - Effluent exits the distribution network and infiltrates into the soil where it migrates in 3D, the relative magnitude of which, depends on site conditions and the system design
 - In the soil, the effluent is treated by a dynamic, interacting set of hydraulic and purification processes
 - Beneficial reuse/recovery of water, organic matter, nutrients... can be achieved

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- Soil Treatment Unit "effluent"
 - There is no "effluent" per se from a soil treatment unit
 - For most systems, the "effluent equivalent" is the soil solution at some depth (e.g., at 3 ft. below infiltration pt.)
 - From a "system design" perspective, the treatment capacity of the subsurface receiving environment can be important



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- **Performance capabilities**
 - Overall performance of a system using a STU can include:
 - Tertiary treatment with natural disinfection
 - Low O&M, affordable cost over a long service life
 - Depending on system type and site conditions, resource recovery can be realized
 - It is important to recognize that STU performance can depend on:
 - Hydraulic function
 - Purification function
 - Assimilation function - Landscape and hydrologic systems

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- **Representative treatment performance**
 - Domestic STE percolation through 2 to 3 ft. of unsaturated, aerobic soil at daily HLR's in the range of 0.2 to 1.2 gpd/ft²
 - Soil solution ≈ "Soil treatment unit effluent"

Parameter	Units	Septic tank effluent	Soil solution	% Removal
D.O.	mg/L	<2	3 - 5	-
BOD ₅	mg/L	150 - 250	5 - 15	>95
TSS	mg/L	50 - 150	5 - 10	>95
Total N	mg/L	40 - 80	20 - 70	10 - 50
Total P	mg/L	5 - 15	0 - 15	100 - 0
Fecal coli.	#/100mL	10 ⁵ - 10 ⁷	0 - 10 ²	>99.99
Virus	pfu/100mL	0 - 10 ⁵	0 - 10	99.9 to >99.99%
OWCs	ng/L	Variable	Variable	>90%

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Rational Design of a STU

- **Background**
 - Engineering design relies on scientific principles to apply methods and technologies to provide a sound solution
 - Key design elements typically include
 - Wastewater source and site characteristics
 - Wastewater treatment prior to infiltration
 - Site suitability for an in-ground infiltration or other soil dispersal unit design approach
 - Loading rates for design of the infiltration area
 - Architecture of the infiltrative surface
 - Effluent delivery and distribution
 - O&M, monitoring and controls

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- **Design requirements for these elements as conveyed in codes do not necessarily yield, or even allow for, good engineering design practices**
 - Why...???



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- **But, STU's can be engineered as a unit operation**
 - Major research findings during the past 10 years provide new scientific understanding and tools
 - Enhanced understanding can be used to appropriately facilitate the design process and assure reliable performance
 - Design guidance can recognize the variability and uncertainty differences in applications
 - "Presumptive designs" for ...
 - Isolated systems treating domestic wastewater in areas where receiving environments have high assimilative capacity
 - "Site-specific designs" for ...
 - Isolated systems in sensitive settings
 - Commercial and non-residential systems
 - Clusters of sources and small communities
 - Some excerpts of evolving guidance follow ~ primarily focused on STU's comprised of trench networks

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- **Setting design wastewater flows**
 - Current practice is ultraconservative and yields larger systems, but not necessarily better systems
 - For a single dwelling unit, design flows are ~200% larger than they need to be even for a high flow situation

Daily Q = (Bedrooms x 2) x 75
 - For all onsite systems collectively, we expend resources to build and operate infrastructure for 500% more flow than actually occurs
 - Redirecting resources from simply larger systems to better systems is warranted

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- **Setting design hydraulic loading rates**
 - Selecting a hydraulic loading rate for design (HLR_D) can be one of the most difficult steps in the design process
 - A simplified approach is needed
 - Classify soils into three major groups based on saturated hydraulic conductivity (K_{sat})
 - Approach is based on research that reveals long-term acceptance rates for wastewater effluents are relatively insensitive to native soil properties for soils with K_{sat} 's ranging from ~5 to 2500 cm/d
 - Soil morphology may be sufficient to classify soil profiles for this purpose
 - Even a crude percolation test may be of some value for the course discrimination needed for this classification scheme

- **Setting a maximum HLR_D**
 - Three (3) soil classes based on morphology (Table 1)
 - HLR_D are used for sizing an open horizontal infiltrative surface based on year-round, normal usage, over ~20 yr
 - Limit the HLR_D for near-clean water quality effluent applied to an open soil infiltrative surface so loading rates will not exceed 5% to 10% of the soil's K_{sat} in the infiltration zone

Table 1

Soil class	Representative soil textures	Representative cleanwater hydraulic conductivity (gpd/ft ²)	Maximum daily hydraulic loading rate (gpd/ft ²)
Class I	Sand, loamy sand	250 (1000 cm/d)	12.5 (50 cm/d)
Class II	Sandy loam, loam, silt loam	25 (100 cm/d)	2.5 (10 cm/d)
Class III	Silty clay loam, clay loam	2.5 (10 cm/d)	0.25 (1 cm/d)

- **Setting a base HLR_D for different effluents**
 - Effluents are classified into three major types reflecting the effects of quality components on performance
 - Soil clogging and permeability loss (cBOD, TKN, TSS)
 - Aeration status (cBOD, TKN)
 - HLR_D 's are established for each of the primary soil classes
 - The HLR_D for a given site must not exceed the hydraulic and treatment capacity of the entire soil profile and site
 - Recognize potential low K_{sat} zones and shallow groundwater so HLR_D does not cause excessive groundwater mounding
 - For treatment, maintain HLR_D to provide adequate travel time, aeration, and soil contact volume
 - Conventional pollutants and pathogens
 - OWCs and emerging contaminants



- Effluent classification and base HLR_D 's based on key pollutants that control infiltration rate loss
 - HLR_D 's for an open horizontal infiltrative surface
 - HLR_D 's for continuous, normal usage, with a 20-year life

Table 2

Effluent type	Effluent composition (mg/L)	Example treatment to achieve an effluent type	Daily HLR_D		
			Class I (Sand, loamy sand)	Class II (Sandy loam, silt loam)	Class III (Silty clay loam, clay loam)
Type I	cBOD ₅ = 150 TKN = 60 TSS = 75	Anaerobic bioreactor with effluent screen	1.0 gpd/ft ² (4 cm/d)	0.50 gpd/ft ² (2 cm/d)	0.12 gpd/ft ² (0.5 cm/d)
Type II	cBOD ₅ = 30 TKN = 5 TSS = 30	Fixed film aerobic treatment unit	2.0 gpd/ft ² (10 cm/d)	1.0 gpd/ft ² (4 cm/d)	0.12 gpd/ft ² (0.5 cm/d)
Type III	cBOD ₅ = 5 TKN = 5 TSS = 5	Packed bed biofilter and effluent filter	4.0 gpd/ft ² (20 cm/d)	1.0 gpd/ft ² (4 cm/d)	0.25 gpd/ft ² (1 cm/d)

- **Adjustments to the base HLR_D 's for design or operational features such as shown in Table 3**
 - HLR_D 's in Table 2 are multiplied by a factor shown below in Table 3 to increase or decrease the base HLR_D (...+FOS)

Table 3

Design or operation feature	Factor	Rationale
Construction impacts	0.1x or less	Account for the loss in clean-water K_{sat} due to compaction and smearing during installation
Infiltrative surface architecture	0.50x to 0.75x	Account for loss in long-term capacity due to solid objects including effects of fines and embedment and greater difficulty for monitoring and rehabilitation
Discontinuous operation during normal 20-yr life	1.5x to 2.0x	Account for cyclic operation with extended rest periods; e.g., 1 year online and 3 years offline
Relatively shorter design service life	2.0x to 4.0x	Account for lessened loss in infiltration rate during 1- to 5-year design life

- **Other key design elements and parameter values that need to be specified**
 - STU layout and installation attributes
 - Landscape position
 - Geometry
 - Minimum separation
 - Design service life
 - Method of effluent application within the STU
 - Delivery method
 - Equalized application needs
 - Effluent application rates during dosing
 - Uniformity of distribution to online components
 - Cyclic loading of a segment of a STU

- Design guidance for STU layout and installation attributes
 - Landscape placement, geometry, and profile placement
 - Well-drained, upslope settings, minimize linear loading rates
 - Infiltration trenches preferred over beds
 - Width = ≤ 3 ft. and Height = ≤ 2 ft.
 - Avoid large beds, especially for Type I effluents
 - Shallow placement in the soil profile
 - Horizontal infiltrative surface = ≤ 3 ft. bgs
 - Vadose zone depth to limiting condition (e.g., ground water, bedrock)
 - Type I to III effluents in Class I soil = ≥ 2 ft.
 - Type I to III effluents in Class II and III soil = ≥ 3 ft.
 - Design for long-term service and rejuvenation needs

- Distribution to an infiltration unit (e.g., trench network)
 - Dosed application, such as provided by a pump
 - Class I soil = ≥ 4 doses per day
 - Class II and III soil = ≤ 2 to 4 doses per day
 - Equalize application by dosing all infiltration segments that are 'on-line' (e.g., operating trenches)
 - Type I effluent - soil clogging will enable more uniform infiltration via bottom infiltrative surfaces
 - Type II and III effluents - engineering (e.g., pressurized dosing) should attempt "uniform distribution" at startup and where clogging may be retarded or limited
 - Uniformity of application can be achieved by design
 - The instantaneous dosing rate can be set \geq the soil's Ksat for clean water
 - e.g., 1 gpm from an orifice to infiltrate 10 ft² provides a dosing rate of 144 gpd/ft² or 0.007 cm/s (similar to a Class I soil Ksat)

- Alternative distribution and operation approaches
 - Cyclic loading of portions of the infiltration unit
 - Use dosing and sequential application of effluent to portions of the soil treatment unit
 - Loading cycles should be on the order of 3 to 12 mon with resting cycles of ≥ 12 mon
 - For sites with treatment limitations (e.g., limited unsaturated soil depth, shallow ground water with nearby drinking water wells), consider engineering-enhanced distribution
 - e.g., pressurized distribution networks with spray nozzles within a chamber-outfitted trench network

- Modeling as an aid to planning and design
 - Models can be valuable for a variety of purposes, e.g.
 - Production of design and environment vs. performance relationships to support performance-based codes
 - Development of site-specific designs
 - Assessment of cumulative effects of systems and watershed-scale impacts
 - Models can range from very simple to highly complex
 - Empirical models, based on experimental observation
 - Index-based models (often GIS)
 - Analytical physical-based models
 - Numerical physical-based models
 - Practitioners and regulators can benefit from models but they do not need to become modelers themselves

Predicting infiltration rate loss during effluent infiltration in a STU

Evaluating water table mounding under larger systems

Predicting treatment within a STU

Assessing onsite system impacts and benefits in a multi-use watershed

- Design for monitoring is needed
 - All onsite systems should have:
 - A method to reliably measure and record daily wastewater flow (e.g., indoor water meter, pump counter)
 - A means for inspection (and maintenance) of the infiltrative surface of the soil infiltration unit (e.g., observation ports)
 - What may or may not be required and/or feasible
 - Sampling and analysis of the effluent to be treated is costly if done properly, and it is normally not needed, except for:
 - Some commercial or institutional units
 - Cluster systems, notably those with surface discharge
 - Field studies to verify performance potential of new infiltration unit designs
 - Sampling and analysis of soil and ground water is difficult and costly and should only be considered for special cases

Summary



- **Soil Treatment Units are a valuable unit operation within onsite and decentralized systems**
 - They can be designed to provide robust, reliable, cost-effective, and sustainable wastewater reclamation
- **System design can follow a rational process underpinned by scientific understanding with recognition of application variability and uncertainty and practical constraints**
 - We have, or will have, the knowledge and decision-support tools to enable this to happen
 - Guidance continues to evolve
- **Thank you for listening...questions...?**



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Further Information



- **Research publications**
 - Conn KE, Siegrist RL, Barber LB, Meyer MT. 2010. Fate of Trace Organic Compounds during Vadose Zone Soil Treatment in an Onsite Wastewater System. *J. Environmental Toxicology and Chemistry*. 29(2):285-293. Published online 8 October 2009. DOI:10.1002/etc.40
 - Lowe KS, VanCuyk SM, Siegrist RL, Drewes JE. 2008. Field Evaluation of the Performance of Engineered Onsite Wastewater Treatment Units. *ASCE J. Hydrologic Eng.*, 13(8):735-743.
 - Lowe KS, Siegrist RL. 2008. Controlled Field Experiment for Performance Evaluation of Septic Tank Effluent Treatment during Soil Infiltration. *ASCE J. Environmental Engineering*, 134(2):93-101.
 - Siegrist RL. 2007. Engineering Soil Treatment Units as a Unit Operation in Onsite Wastewater Reclamation Systems. Proc. 11th National Symposium on Individual and Small Community Sewage Systems, Warwick, RI, October 21-24, 2007, ASABE, St. Joseph, MI.
 - Siegrist RL. 2006. Evolving a Rational Design Approach for Sizing Soil Treatment Units. *Small Flows Journal*. 7(3):16-24.
- <http://smallflows.mines.edu/>



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