INFILTRATOR®
systems inc.

November 14, 2011

OWTS Policy
State Water Resources Control Board
1001 I Street, 15th Floor
Sacramento, CA 95812

Re: California Assembly Bill 885
Draft Policy for Siting, Design, Operation, and Maintenance of Onsite Wastewater Treatment Systems
Infiltrator Systems Inc. Comments

To Whom It May Concern,

The comments provided herein summarize Infiltrator Systems Inc.'s (Infiltrator's) suggested modifications to *Public Comment Draft Water Quality Control Policy for Siting, Design, Operation, and Maintenance of Onsite Wastewater Treatment Systems* (draft Policy) (September 30, 2011).

Infiltrator's primary comments pertain to the use of proprietary drainfield technologies in the draft Policy. The proposed change is a broadening of the allowable drainfield technologies from gravelless chambers to <u>IAPMO-approved dispersal system technologies</u>. At present, the only IAPMO-certified leachfield technologies that Infiltrator is aware of are gravelless chambers and bundled expanded polystyrene synthetic aggregate systems. Note that at least two companies in the United States manufacture products using both technologies, so the proposed changes do not provide an advantage to a single company or product.

Comments Pertaining to Proprietary Drainfield Technologies

<u>Section 1.0</u>

"NSF" is identified in the definitions section, and referenced in the policy text. IAPMO is referenced in Section 8.2.4, but not referenced in the definitions. Propose the addition of IAPMO to the definitions section:

> *"IAPMO" means the International Association of Plumbing and Mechanical Officials, a not for profit, non-governmental organization that develops health and safety standards and performs product certification.*

<u>Section 8.1.2</u>

The draft Policy currently restricts the use of gravelless technology on Tier 1 systems. The size of a California gravelless leachfield is determined based on the required size of a conventional gravel and pipe leachfield. In other words, if 1,000 square feet of gravel and pipe dispersal system are required based on site conditions (using Table 2 or 3 in the draft Policy to determine required area), the gravelless system would be sized in proportion to the gravel and pipe system. Using the factor of 0.70 identified in Section 9.4.6 of the draft Policy, for a 1,000 square foot gravel and pipe system, 700 square feet of gravelless chamber would be required (1,000 square feet x 0.70 factor = 700 square feet).

Sizing of gravelless chamber and bundled expanded polystyrene synthetic aggregate systems at a factor of 0.70 has been demonstrated through numerous research studies conducted by independent third parties. The third-party studies have demonstrated an increased infiltration efficiency for these technologies. The infiltration rate efficiency for gravelless technologies fully supports the 0.70 factor, which is a conservative value relative to sizing factors in other states. As compared to the efficiency of gravel and pipe, the increased efficiency of gravelless technologies results from:

- the comparatively open bottom area;
- lack of stone fines accumulating on the trench bottom restricting hydraulic function; and
- absence of embedded mineral aggregate stones blocking effluent flow through the trench bottom.

This research has also shown that the purification of effluent by gravelless technologies is equal or superior to gravel and pipe technology, thus maintaining protection of public health and the environment.

This use of a 0.70 multiplier as a sizing methodology is also within the range or more conservative (where sizing is allowed at multipliers of up to 0.6 and 0.5) than sizing allowed under rules and policy in other states, including Oregon, Washington, Nevada, Arizona, New Mexico, Colorado, and Idaho in the western United States. Numerous other states also allow similar sizing of chambers and bundled expanded polystyrene synthetic aggregate leachfield technologies. Allowing for the use of gravelless technologies at a 0.70 multiplier under Tier 1 is protective of public health and the environment. This sizing method is used across California and in the Uniform Plumbing Code (having been added to the UPC in the 1994 edition), as well as by state governments nationwide.

Attachment 1 is a fact sheet with research summaries for key studies supporting IAPMO-approved gravelless technologies. Attachment 2 includes studies supporting the field performance, hydraulics, and treatment for chambers. Attachment 3 includes studies supporting the field performance, hydraulics, and treatment for bundled expanded polystyrene systems.

Infiltrator proposes the allowance of IAPMO-approved dispersal system technologies for Tier 1 systems by replacing Section 8.1.12 text as follows:

> *8.1.12 ~~Increased allowance for gravel-less chamber systems is only allowed under a Tier 2 local management program.~~ Decreased leaching area for IAPMO-approved dispersal system technologies is allowed at a multiplier of no less than 0.70.*

Section 9.4.6

Using the rationale outlined in the discussion under Section 8.1.12 above, Infiltrator proposes the allowance of IAPMO-approved dispersal system technologies for Tier 2 systems as follows:

> *9.4.6 Decreased leaching area for ~~chamber~~ IAPMO-approved dispersal system~~s~~ technologies using a multiplier less than 0.70.*

Section 10.4.6

Using the rationale outlined in the discussion under Section 8.1.12, Infiltrator proposes the allowance of IAPMO-approved dispersal system technologies for Tier 3 systems as follows:

> *9.4.6 Decreased leaching area for ~~chamber~~ IAPMO-approved dispersal system~~s~~ technologies using a multiplier less than 0.70.*

Other Comments on the Draft Policy

Sections 1.0 and 7.5.3

Section 7.5.3 makes reference to a "geotechnical report". This document should be prepared by a "Qualified professional", as defined in Section 1.0 (see such a requirement at the end of Section 7.5.8 for wells). I suggest clarifying this requirement in Section 7.5.3 and expanding the definition of "Qualified professional" in Section 1.0.

Section 7 and 8

This is a global comment for Tier 1 systems. I may have missed this information in the document, but there does not appear to be a stipulated method of effluent flow rate determination from the structure. In order to use Tables 2 or 3, a designer would need a daily flow in gallons per day. Suggestion is to add a value for effluent flow (e.g., 150 gallons per day per bedroom).

Section 7.2

Suggest adding the terms "primary area" and "reserve area" to the definitions in Section 1.0.

Section 7.4

The percolation test report should be prepared by a "Qualified professional", as defined in Section 1.0 (see such a requirement at the end of Section 7.5.8 for wells). I suggest clarifying this requirement in Section 7.4 and expanding the definition of "Qualified professional" in Section 1.0.

Section 8.1.4

Suggest referencing Table 1 in this section.

Table 2

Suggest showing effluent application rate values to the nearest hundredth. Also, suggest adding the work "Maximum" to the title, as follows "Maximum application rates as determined…"

Thank you very much for your consideration of these issues. Please contact me at (860) 577-7198 if you have any questions or would like to discuss any issues.

Sincerely,

David Lentz

David Lentz, P.E.
Regulatory Director
Science & Government Affairs

cc: David Holmes, Infiltrator Systems Inc.

Attachment 1

IAPMO-Approved Gravelless Technologies Fact Sheet

Fact Sheet
Science and Statistics Supporting Gravelless Technology Use in California

The use of a sizing reduction for gravelless products compared to the size of a stone and pipe drainfield is a proven method that is supported by independent research. Numerous statistically valid studies have been conducted on this subject, from the laboratory and full-scale test facility level at major research centers, to the world's largest onsite system field performance study conducted by the North Carolina Department of Environmental and Natural Resources. Taken as a whole, the weight of scientific evidence shows that reduced-size gravelless systems perform consistent with "conventional" stone and pipe. A technical basis for reduced-size gravelless drainfield products is provided below.

Ubiquity of Technology

- Reduced-size gravelless systems have replaced "conventional" stone and pipe as the standard system in many areas of North America.
- Gravelless drainfield products are approved in all 50 states and 10 provinces, with over 2 million systems installed.
- Approximately 50% of the septic systems installed in North America each year are constructed at reduced sizing using gravelless drainfield products
- In the US, proprietary gravelless drainfield products make up over 75% of all systems installed in 9 states. In 16 other states, proprietary products make up between 50 and 75% of all drainfields installed.
- The International Association of Plumbing and Mechanical Officials (IAPMO), allows a 30% sizing efficiency for chambers and bundled expanded polystyrene geosynthetic aggregate products.

Hydraulic Efficiency Multiplier

- The efficiency multiplier measures the ability of a gravelless system to process effluent as compared to a reference.
- Example 1: A 25% reduction equates to an efficiency multiplier of 1.3 (100 ft of stone and pipe trench divided by 75 ft of gravelless system = 1.3 efficiency multiplier).
- Example 2: A 50% sizing reduction (100 ft stone and pipe divided by 50 ft of gravelless), would be a 2.0 multiplier.
- Numerous studies (see Table 1) have compared gravel and gravelless infiltration characteristics.
- The gravelless system infiltration rate efficiency in these studies ranges between 1.3 and 3.2.
- The 1.3 multiplier that equates to a 25% reduction is at the low end of the multiplier range, indicating that scientific evidence supports the concepts behind the proposed 25% sizing.
- The proposed 25% sizing reduction fits within the range of sizing identified by academic researchers.
- Use of gravelless sizing shall not be combined with a reduction for advance treatment (i.e., no double dipping).

Chamber and Bundled Expanded Polystyrene Large-Scale Field Performance Assessments

Large-scale field performance assessments have been conducted to examine the function of installed, real-life gravelless drainfield products. This method of analysis offers the advantage of a large sample population, differing physiographic and climactic conditions, and a wide spectrum of wastewater flows from the dwelling. Table 2 includes a listing of significant field performance studies conducted on chamber and expanded polystyrene systems.

North Carolina: 900-System Gravelless Study at a 25% Reduction

- The North Carolina Department of Environment and Natural Resources conducted a field performance study on 900 systems in total, including chamber and expanded polystyrene drainfields.
- North Carolina is one of the largest on-site wastewater treatment system permit writing jurisdictions in the US.
- Systems ranged in age from 2 to 12 years and were installed at a 25% reduction.
- 303 stone and pipe, 303 chamber, and 306 expanded polystyrene systems were surveyed.
- Over 10,000 of both the chamber and expanded polystyrene drainfields are installed annually in the state.
- Systems were distributed uniformly within the coastal, piedmont, and mountain physiographic regions.
- At a 95% upper confidence level, no statistical difference in malfunction rates was identified between stone and pipe and gravelless systems.
- Based on the study results, the DENR granted chamber and expanded polystyrene products an approval status that, under NC law, designates both products as equal or superior to a stone and pipe system.

Fact Sheet
Science and Statistics Supporting Gravelless Technology Use in California

Oregon: 200-System Chamber Study at a 40% Reduction

- Dr. Larry King and Dr. Michael Hoover at North Carolina State University conducted a 3rd party study of the Infiltrator Equalizer 24 chamber in support of a product approval by the Oregon Department of Environmental Quality.
- A juried article summarizing the study results was published in the Fall 2002 edition of *Small Flows Quarterly.*
- Over 400 chamber and conventional stone and pipe systems were studied.
- Malfunction rates for chamber systems and stone and pipe systems were less than 1.5%.
- There was no statistical difference in surficial failure rates between these two system types.
- Chamber systems in this study were installed with basal area reductions of 40%.
- The Oregon DEQ issued an unrestricted product approval based on the results of the study.

Oregon: 100-System Expanded Polystyrene Study at a 50% Reduction

- An independent third-party study measured the malfunction rate of expanded polystyrene systems. This study report has been submitted for publication in the *Journal of Environmental Health*.
- Expanded polystyrene systems in this study were installed at a 50% reduction.
- Over a 5-year period, 103 systems were evaluated in 434 site visits and evaluations.
- Systems were located within 2 physiographic regions, a wet, and a dry climate, separated by a mountain range.
- The malfunction rate of the systems was determined to be less than 1%.
- The Oregon DEQ issued an unrestricted product approval based on the results of the study.

Maine: 400-System Chamber Study at a 50% Reduction

- The University of Maine's Dr. Chet Rock conducted a study that examined the longevity of gravelless drainfields sized at 50% the length of stone and pipe systems.
- Systems were at least 20, and up to 30 years in age, with 63 chamber and 341 gravel system evaluated.
- All systems were located within a single municipality in the state of Maine.
- The source of information was municipal drainfield repair records, where malfunction was determined based on the record of repair since the time of system construction.
- Repair records showed that, at a 95% upper confidence level, gravelless systems at a 50% sizing reduction outperformed stone and pipe.

Treatment and Hydraulics Studies

Colorado: Chamber Hydraulic and Treatment Study at a 50% Reduction

- Dr. Robert Siegrist of the Colorado School of Mines conducted a 3rd party study of Infiltrator chambers in Colorado.
- 6 operating gravel and 10 operating chamber systems were studied in Colorado.
- Systems were aged up to 11 years.
- Percolate samples analyzed from 30 cm beneath infiltrative surface for treatment performance.
- Effluent ponding was monitored in the chamber and gravel trenches.
- No significant difference in hydraulic or treatment performance between the gravel and 50% reduced length chamber systems.

Massachusetts Alternative Septic System Test Center (MASSTC) Bundled Expanded Polystyrene Study

- A 16-month-long study of expanded polystyrene drainfield media hydraulic and treatment performance was conducted at MASSTC in Buzzards Bay, MA, an NSF-certified and USEPA ETV facility.
- The study included measurement of cBOD, TSS, fecal coliform, total N, ammonia, nitrate, nitrite, TKN, and alkalinity at 600 mm (24 inches) below the infiltrative surface.
- The expanded polystyrene drainfield was installed at a 45% effective bottom area reduction vs. stone and pipe.
- cBOD reduction = 99.48% / average collected effluent concentration = 1.0 mg/l

- TSS reduction = 98.57% / average collected effluent concentration = 3.2 mg/l
- Fecal coliform reduction = 99.99% / average level in collected effluent = 34.8 CFU/100 ml
- No significant difference in the percolate between EZflow and stone and pipe for cBOD and TSS

Other Considerations

<u>Natural Resource Preservation</u>

- California's natural resource reserves can benefit from the proposed addition of gravelless products to the policy document. Gravelless wastewater absorption systems are installed in lieu of crushed rock aggregate. This aggregate is typically mined at a local rock quarry, processed at the quarry to achieve a specific size requirement, and delivered to a construction site for placement in a trench or bed as part of a wastewater absorption system. Gravelless chambers are frequently manufactured using recycled plastics and represent a substitute for the crushed rock aggregate, conserving a valuable, non-renewable natural resource. Other gravelless products are also manufactured using recycled plastics. This product substitution allows natural aggregate reserves to be preserved for use in asphalt, concrete, road bases, etc., where the type of product substitution that is possible for gravelless products in a wastewater absorption system is technically infeasible.

- In addition to preserving aggregate reserves, by eliminating the need to mine, process, and transport aggregate, significant reductions in energy use are realized. This not only reduces the state's energy demand, it also reduces the release of carbon to the atmosphere from electricity generation and internal combustion engine operation. For perspective, one tractor trailer loaded with gravelless chambers contains over 11,000 linear feet of wastewater absorption trench. A single truckload of gravelless chambers is the approximate equivalent of 70 gravel-filled tri-axle dump trucks that would be used to transport aggregate from a quarry to the job site.

<u>Miscellaneous</u>

- Use of an engineered product vs. gravel provides consistent and reliable dimensions for the construction of an onsite system. Gravel trenches may be dimensionally inconsistent, which may lead to system malfunction or reduced wastewater storage capacity.

- Gravelless products can typically be hand-carried, minimizing construction traffic over the area where the onsite wastewater system is to be constructed, thereby preserving and protecting the soil structure. An open soil structure is critical to the effective dispersal of wastewater in the subsurface. If the soil structure collapses from the load of construction vehicle traffic, its ability to absorb wastewater is compromised.

- The number of economical choices available to designers and installers remains high with a gravelless technologies. Maintaining a robust number of cost-effective "tools" that can be installed at reduced sizing allows more flexibility in drainfield design.

Table 1
Research Summary on Infiltration Efficiency of Gravelless Drainfields
Compared to Gravel Aggregate Drainfields

November 2011

Research Study	Description of Study	Difference in Septic Tank Effluent Infiltration Rate Efficiency (Gravelless vs. Gravel Aggregate)
Massachusetts Alternative Septic System Test Center, 2010. Performance Evaluation of the EZflow Geosynthetic Aggregate Leaching System	16-month side-by-side comparison of treatment and hydraulics	2.2
Lowe et al. 2008. Controlled Field Experiment for Performance Evaluation of Septic Tank Effluent Treatment during Soil Evaluation, Journal of Environmental Engineering	Two-year field study of 30 pilot-scale test cells.	1.4 – 1.8
Walsh, R. 2006. Infiltrative Capacity of Receiving Media as Affected by Effluent Quality, Infiltrative Surface Architecture, and Hydraulic Loading Rate, Master Thesis at Colorado School of Mines	One dimensional column study	3.2
Uebler et al. 2006. Performance of Chamber and EZ1203H Systems Compared to Conventional Gravel Septic Tank Systems in North Carolina, Proceedings of NOWRA	Field evaluation of failure rates of approximately 300 of each type system (gravel, chamber, EPS) 2-12 years old	1.4
Radcliffe et al. 2005. Gravel and Sidewall Flow Effects in On-Site System Trenches, Soil Science Society of America Journal	Two dimensional computer model (HYDRUS-2D)	1.5 – 1.93
Siegrist et al.2004. Wastewater Infiltration into Soil and the Effects of Infiltrative Surface Architecture, Small Flows Quarterly	Two one dimensional column studies and pilot-scale field study	1.5 – 2.0
White and West. 2003. In-Ground Dispersal of Wastewater Effluent: The Science of Getting Water into the Ground. Small Flows Quarterly, 2003	Literature Review and One dimensional column study measuring the impact of gravel and fines (clean water)	2.5
King et al. 2002. Surface Failure Rates of Chamber and Traditional Aggregate-Laden Trenches in Oregon, Small Flows Quarterly	Field evaluation of failure rates of 198 chamber systems and 191 gravel systems 2-5 years old	1.6
Burcham, T. 2001. A Review of Literature and Computations for Chamber-Style Onsite Wastewater Distribution Systems, Report commissioned by the Mississippi Department of Health	Literature review and computer model	1.43– 2.0
Joy, Douglas. 2001. Review of Chamber Systems and Their Sizing for Wastewater Treatment Systems, Ontario Rural Wastewater Centre Report, University of Guelph	Literature Review	1.67
Van Cuyk et al, 2001. Hydraulic and Purification Behaviors and their Interactions During Wastewater Treatment in Soil Infiltration Systems", Journal of Water Resources	Three-dimensional lysimeter study of treatment performance	1.67

Table 1
Research Summary on Infiltration Efficiency of Gravelless Drainfields
Compared to Gravel Aggregate Drainfields

November 2011

Research Study	Description of Study	Difference in Septic Tank Effluent Infiltration Rate Efficiency (Gravelless vs. Gravel Aggregate)
Casper, Jay. 1997. Final Report: Infiltrator Side-by-Side Test Site, Killarney Elementary School, Winter Park, Florida. Report to State of Florida, Department of HRS.	Pilot-scale side-by-side study of 15 trenches (gravel and chamber).	1.6 – 2.3
Amerson, RS, Tyler, EJ, Converse, JC. 1991. Infiltration as Affected by Compaction, Fines and Contact Area of Gravel, *in* On-Site Wastewater Treatment: Proceedings of 6th National Symposium On Individual and Small Community Sewage Systems, American Society of Agricultural Engineers, St. Joseph, MI, December 1991	Evaluation of 30 soil cells to assess impact of gravel compaction, contact area and fines. Ratios are the clean water infiltration rate ratios of an open soil surface (control) compared to one with gravel compaction, embedment, and fines.	2.1 – 2.6
Other References		
2006. Uniform Plumbing Code.	International Standard	1.4
Siegrist, Robert. 2006. Evolving a Rational Design Approach for Sizing Soil Treatment Units, Small Flows Quarterly. Summer 2006	Proposed design methodology that takes into account BOD loading, soil type and infiltrative surface architecture.	1.33 – 2.0
2001. U.S. EPA Decentralized Systems Technology Fact Sheet – Septic Tank Leaching Chambers.	Literature Review and Recommended Usage	1.4

Table 2
Summary of Gravelless Drainfield Product Field Performance Studies

State	Regulatory Agency	Lead Investigator	Gravelless Sizing Reduction	System Age (years)	Total Systems Studied	Gravelless Systems Studied	Gravel Systems Studied	Study Conclusion	Resulting Regulatory Action
Chamber Technology									
North Carolina	DENR	Dr. Robert Uebler, DENR	25%	2 to 12	912	303	303	Equivalent performance at the 95% upper confidence level	Approval as gravel equivalent
Oregon	DEQ	Dr. Mike Hoover, NC State University	50%	3 to 5	389	198	191	Equivalent performance at the 95% upper confidence level	Unrestricted product approval
Maine	---	Dr. Chet Rock, University of Maine	50%	20 to 30	404	63	341	Chambers outperformed gravel at 95% upper confidence level	---
Tennessee	TDEC	Andrew England	50%	2 to 9	895	895	0	Less than 1% malfunction rate	Unrestricted product approval
Georgia	DHR	Stephen Dix, Infiltrator Systems	50%	2 to 7	232	98	134	Chamber malfunction rate equivalent to gravel	Continued unrestricted approval
Maine	DHS	Donald Hoxie, Dept. of Human Services	50%	1 to 10	7,677	779	6,898	Chamber malfunction rate lower than gravel	Continued unrestricted approval
Texas	TCEQ	Shawn Ricklefs, Amarillo County Health Dept.	40%	2	42	42	0	Acceptable product performance	Continued unrestricted approval
Washington	DOH	Stephen Dix, Infiltrator Systems	40%	7	28	28	0	No malfunctions attributable to product failure	Continued unrestricted approval
Illinois	IDPH	Stephen Dix, Infiltrator Systems	40%	4	10	10	0	No malfunctions attributable to product failure	Unrestricted product approval
Expanded Polystyrene Technology									
North Carolina	DENR	North Carolina DENR	25%	2 to 12	912	306	303	Equivalent performance at the 95% upper confidence level	Approval as gravel equivalent
Oregon	DEQ	Robert Sweeney, REHS	50%	3 to 5	103	103	0	Less than 1% malfunction rate	Unrestricted product approval
Georgia	DHR	Robertson	60%	2 to 9	~8,000	~8,000	0	Successful function of technology	Continued unrestricted approval
Tennessee	TDEC	Bob Conrad, Mid South Engineering	30% to 60%	2 to 4	80	80	0	No malfunctions attributable to product failure	Unrestricted product approval
Texas	TCEQ	RS Engineering & Construction	40%	5 to 7	38	38	0	1 malfunction due to disconnected pipe of 38 installations	Continued unrestricted approval
Alabama	ADPH	Dr. Kevin White, Univ. of South Alabama	60%	2 to 7	22	22	0	No malfunctions attributable to product failure	Unrestricted product approval
Illinois	IDPH	Chase Environmental Services	40%	2	5	5	0	Performance equal to other drainfield products approved in state	Unrestricted product approval

Note:
1. The North Carolina field performance study was conducted on gravel, chambers, and expanded polystyrene, and results are reported in a single document.

Attachment 2

Third-Party Chamber Research Studies

**Performance of Chamber and EZ1203H Systems Compared to
Conventional Gravel Septic Tank Systems in North Carolina**

R.L. Uebler, S. Berkowitz, P. Beusher, M. Avery, B. Ogle, K. Arrington and B. Grimes

Abstract

The North Carolina On-Site Wastewater Section conducted a statewide survey, which compared the performance of chamber and EZ1203H systems with 25% trench length reduction to conventional gravel systems. A total of 912 systems were randomly chosen in 6 counties across the state. To control evaluation bias, a group of students from Western Carolina University were hired to inspect each system. A system was considered to have failed if there was evidence of sewage at the ground surface or if an owner reported problems with the system. The statewide failure rate of both standard chamber and EZ1203H systems compared to conventional gravel systems was not statistically different at a 95% confidence level.

INTRODUCTION

Recent legislation in North Carolina provides for the designation of approved Innovative on-site wastewater systems as accepted systems. The legislation was supported by Innovative product manufacturers, because of a perceived stigma attached to Innovative designation of their product, and real permitting differences for Innovative products compared to conventional gravel systems, which were required by the state. Systems, which receive accepted system approval, may be permitted in the same manner as conventional septic tank systems. In order to achieve accepted system status, the manufacturer of a system must submit evidence that the system has been in general use in the state for 5 years. In addition, the manufacturer shall provide the Commission for Health Services with information sufficient to enable the Commission to fully evaluate the performance of the system in this State for at least the five-year period immediately preceding the petition. Rule was subsequently developed by the state, which established the requirements for what constituted "sufficient information" for the Commission to make their evaluation. For trench systems, the Rule requires "the field evaluation of at least 250 randomly selected innovative systems compared with 250 comparably-aged randomly selected conventional systems, with at least 100 of each type of surveyed system currently in use and in operation for at least five years. Systems surveyed shall be distributed throughout the three physiographic regions of the state in approximate proportion to their relative usage in the three regions. The survey shall determine comparative system failure rates, with field evaluations completed during a typical wet-weather season (February through early April), with matched innovative and conventional systems sampled during similar time periods in each region" (NCDEHNR. 2006).

Infiltrator, Inc., which manufactures a chamber system, and Ring Industrial Group, which manufactures the EZ1203H polystyrene aggregate system, subsequently applied for accepted

---

*Authors are Dr. Robert Uebler (bob.uebler@ncmail.net), Steven Berkowitz, PE, Kae Arrington, MS, and Dr. Barbara Grimes, NCDENR-On-Site Wastewater Section, 1642 Mail Service Center, Raleigh, NC 27699-1642, Dr. Paul Beusher and Matt Avery, NCDHHS State Center for Health Statistics, Dr. Burton Ogle, Western Carolina University.

system designation. In addition to Infiltrator, three other chamber manufactures, Advanced Drainage Systems, Inc., manufacturer of the Bio-diffuser chamber, Cultec, manufacturer of the Contactor chamber, and Hancor, Inc., manufacturer of the Envirochamber, chose to participate in the survey required for system approval. The objective of the survey was to determine the failure rate of the chamber and EZ1203H systems compared to conventional gravel systems. This paper reports the outcome of the required survey.

Background

Conventional septic tank systems in North Carolina are designed with 3-foot wide trenches, which have a 12-inch gravel depth to provide storage for septic tank effluent. Systems with multiple trenches are spaced with 9-feet of separation between the center of adjacent trenches. A 12 to 18 inch depth of suitable soil is required below the trench to provide treatment of the effluent when it leaves the trench. The amount of trench bottom area required at a site is determined from an evaluation of soil texture. A long-term acceptance rate (LTAR) is chosen for the soil texture found at a site from Table 1.

Table 1**.** Long-term acceptance rates (LTAR) allowed for the soil texture evaluated at a site.

Soil Group	Texture Family (USDA)	Texture Class (USDA)	LTAR (gpd/ft^2)
I	Sands	Sand, Loamy Sand	1.2 to 0.8
II	Coarse Loams	Sandy Loam, Loam	0.8 to 0.6
III	Fine Loams	Sandy Clay Loam, Silt Loam, Clay Loam, Silty Clay Loam, Silt	0.6 to 0.3
IV	Clays	Sandy Clay, Silty Clay, Clay	0.4 to 0.1

The trench bottom area is then calculated by dividing the design flow, 120 gpd per bedroom, by the LTAR. Trench length is then determined by dividing the required trench bottom area by the trench width of 3 feet.

The chamber systems surveyed in this study were the standard design, which had an average open bottom width of about 29 inches and height of about 12 inches. The polystyrene aggregate systems surveyed were the EZ1203H, which is 12 inches high and 36 inches wide. The North Carolina approval for the both the standard chamber and the EZ1203H, allows for a 25% reduction in trench length compared to a conventional gravel trench system. Other trench requirements for chambers and EZ1203H systems are the same as for conventional systems. Trenches are dug with a 3-foot width, and placed on 9-foot centers, if multiple trenches are required.

Methods and Materials

The Rule developed by the state required that a survey be conducted, which was able to detect if the failure rate, for the standard chamber or EZ1203H systems, was 5 or more percentage points higher than the failure rate for conventional systems. Further, if the comparison showed a difference of at least 5 percentage points (e.g. 9% failure rate for innovative system A and a 4%

failure rate for conventional gravel systems), there should only be a 5% chance that the difference between the two samples would occur by chance. This is the “95% confidence level”. If a statistically significant higher failure rate was not detected in the innovative group, than the conclusion would be that the innovative system performs the same as or better than conventional systems. This is a “one sided” test of the difference between proportions.

Preliminary analysis by Dr. Paul Beusher with the NCDHHS State Center for Health Statistics revealed that, a sample size of 300 was needed for each type of system surveyed, in order to conclude with a 95% confidence that a measured failure rate for an innovative system that is 5 percentage points higher than the failure rate for conventional systems is not due to chance. The calculation of required sample size assumed that the samples have an 80% “power” to detect a **true** difference of 5 percentage points. This sample size estimate also assumed an overall septic tank failure rate (across all system types for 5-9 year old systems) in the range of 5%. It was determined that a sample size of 300 for each system would result in valid analysis, regardless of the total number of systems (population) from which the sample was chosen. A slightly larger sample was recommended to be drawn from available records, to allow for sites at which failure status could not be determined, such as inaccessible sites.

It was determined that systems from each of the three physiographic regions must be included in the survey in order for the results to be valid, since soils vary by region of the state. Two counties were chosen in each of North Carolina’s physiographic regions (Mountains, Piedmont, and Coast Plain) for the purpose of conducting the required comparison of system performance. The six counties surveyed were selected on the basis of being representative of the region and the fact that they had a good system of record keeping for septic tank system permits. Further, counties were chosen that were known to have large numbers of each system type, so that it would be likely that a statistically valid sample could be drawn from the records for each system type. Since the total sample size for each system type was required to be at least 300 and there were 6 counties chosen, at least 50 systems were selected from each county for the survey. The counties chosen were Alamance (Piedmont), Buncombe (Mountain), Henderson (Mountain), Lincoln (Piedmont), Onslow (Coast) and Wilson (Coast).

A retired employee formerly with the NC Division of Environmental Health, whose primary responsibilities before retirement involved restaurants, was retained to draw a random sample of the required size from each county. This person was chosen because he was familiar with Health Department records, but had not been involved with the permitting of chamber or EZ1203H systems, in order to avoid a possible source of bias in the sample selection. The available records for each type of system were assigned a number. Records were than drawn on the basis of a random number generator until the required number of systems to be inspected was achieved.

A team of third party inspectors, unaffiliated with the NC On-Site Wastewater Section or the product manufacturers, was hired to visit each system for which a record was randomly drawn. The inspectors were Environmental Health students from Western Carolina University under the supervision of Dr. Burton Ogle from WCU. The students were trained to inspect septic tank systems by a former employee of the NC Wastewater Discharge Elimination program now with WCU, whose primary responsibility had been the identification of failed septic tank systems in need of remediation. Systems were surveyed from March through April of 2005, in an effort to inspect systems during a time when the most failures are normally recorded and control seasonal effects on failure rate. Each system was inspected by two members of the survey team. Only houses, which were known to be occupied, were inspected.

The following questions were answered with a yes or no by the survey team for each system inspected:

1.) Is sewage ponded on the surface?
2.) Does pressure to the soil surface with a shoe result in sewage coming to the surface?
3.) Is there a straight pipe?
4.) Is there evidence of past failure?
5.) Is there evidence of a repair?

In addition, an attempt was made to interview the occupants at each survey site in person or by phone. Answers to the following questions were obtained during the interview:

1.) Has your tank been pumped for other than routine maintenance?
2.) Are you having any of the following problems with your system today: surfacing on the ground; wet over system; odors; back up into the house; other?
3.) Have you had problems with the system in the past: surfacing on the ground; wet over system; odors; back up into the house; other?
4.) How was the problem solved?
5.) Has system been repaired or replaced?

A yes for one or more of the above questions answered by the survey team or the occupant was considered to be a system failure. More information was collected, but was not used to determine system failure.

Results and Discussion

A total of 912 systems were inspected, 303 chamber systems, 306 EZ systems and 303 gravel systems. Interviews were completed with 370 of the occupants. The survey sample contained 290 sites from the Coastal Region, 317 sites from the Piedmont region and 305 sites from the Mountain region. The survey sample had the following age distribution: 307 systems were 2 to 4 years old, 377 systems were 5 to 7 years old, and 228 systems were 8 to 12 years old. No systems older than 12 years were included in the survey because neither the chamber nor EZ1203H were approved in the state at that time.

The following survey results were obtained.

Table 1. System failure rate for conventional gravel, chamber, and EZ1203H systems.

System Type	Systems OK	Systems Failed	Total	Percent Failure
Gravel	281	22	303	7.3
Chamber	277	26	303	8.5
EZ1203H	277	29	306	9.5
Total	835	77	912	8.4

The statewide failure rate was 7.3 % for conventional gravel systems, 8.5% for chamber systems and 9.5% for the EZ1203H systems. The difference in failure rate between the conventional and chamber systems was 1.2%. The difference in failure rate between the conventional and EZ1203H systems was

2.2%. The purpose of this survey was to determine if there was a 5% or greater difference in the failure rate of chamber and EZ1203H systems compared to conventional gravel systems. The difference in failure rate was less than 5% for each system type. Statistical analysis was performed controlling for both physiographic region and age of system. At a 95% confidence level, the null hypothesis of no difference in failure rate could not be rejected for the chamber or EZ1203H system compared to the gravel system, based on the data collected. In laymen's terms, we would say that the chamber and EZ1203H performed the same as gravel when compared on a statewide basis.

Dominant soil texture, upon which LTAR is assigned for system design, varies by physiographic region of the state. In the Coastal region, the two dominant soil groups are sands and fine loams. The most limiting factor to the performance of septic tank systems is often depth to the seasonal high water table. In the Piedmont region, the two most dominant soil groups are fine loams and clays. Soil depth and slowly permeable soils are often the most limiting factors to system performance. In the Mountain region, coarse loams and fine loams are the dominant texture groups. Shallow soil depth and steep slopes are often the most limiting factors to system performance. To see if there was a difference in performance by region, given the differences in dominant site conditions associated with a region, the data was further analyzed by physiographic region of the state (Coastal Plain, Piedmont or Mountains). An insufficient number of sites were surveyed to statistically compare the performance of each system type by region. The data was therefore grouped by region without regard for system type to make the regional comparison, since there was no statistical difference in performance between system types. The results are given in Table 2.

Table 2. System failure rate by physiographic region disregarding differences in system type.

Physiographic Region	Systems OK	Systems Failed	Total	Percent Failure
Coast	256	34	290	11.7
Piedmont	286	31	317	9.8
Mountain	293	12	305	3.9
All Regions	835	77	912	8.4

The failure rate for all systems combined was highest in the Coast, 11.7%, and lowest in the Mountains 3.9%. In the Piedmont area the failure rate was 9.8%, which was similar to the failure rate found in the Coast. The difference in failure rate when the mountains region is compared to both the Piedmont and Coast region was statistically significant at the 95% level. The significant effect of region might be explained as follows. Most systems in the mountains are long and narrower. This factor in conjunction with slope ranging in excess of 25% may promote more efficient movement of sewage away from the drain field, e.g. low linear loading rates, and better system performance.

The data was also analyzed to see if there was a difference in system failure rate as systems aged. System failure rate is summarized in the Table 3 below for three age groups: 1.) 2 to 4 years old, 2) 5 to 7 years old, and 3.) 8 years to 12 years old.

Table 3. System failure rate by age group disregarding differences in system type.

System Age	Systems OK	Systems Failed	Total	Percent Failure
2 to 4 years	283	24	307	7.8
5 to 7 years	351	26	377	6.9
8 to 12 years	201	27	228	11.8
All Ages	835	77	912	8.4

When data for all system types was aggregated within an age group and the aggregated data compared by system age, the failure rate was highest for the 8 to 12 year old systems. The differences between the age groups, while controlling for system type and physiographic region, were not statistically significant at the 95% level. One might expect that the oldest systems should have the highest failure rate as observed, because clogging of the trench can be expected to increase, as more sewage is disposed in the trenches over time. Also, solids will spill over from the septic tank to the absorption field, if settled solids are not periodically removed by the owner as the system ages.

Finally, it is interesting to note that the average failure rate statewide is 8.4% for systems with an age up to 12 years old. There is much speculation in various arenas about the failure rate of ground absorption septic tank systems, with little or no substantive information to support the speculation. Perhaps a side benefit of this survey will be a defensible failure rate upon which to base future discussions.

Summary

The purpose of this survey was to determine if there was a difference in the failure rate of chamber and EZ1203H systems compared to gravel. Based on the data collected, the statewide failure rate of both standard chamber and EZ1203H systems compared to conventional gravel systems was not statistically different at a 95% confidence level. In laymen's terms, we would say that the chamber and EZ1203H systems performed the same as gravel systems.

Acknowledgements

This study could not have been completed without the cooperation of the fine staff from the Alamance, Buncombe , Henderson, Lincoln, Onslow and Wilson County Health Departments, and the hard work of the student surveyors from Western Carolina University. Peter Whitaker from WCU provided training on failure identification to the students. Clay Pennington provided assistance with sample selection. Financial support for this project was provided by Advanced Drainage Systems, Cultec, Hancor, Infiltrator Systems, Ring Industrial Group, and a grant (EW05076) from the USEPA 319 Non-Point Source Pollution Program entitled: In-Field Survey Initiative of Conventional and Innovative Onsite Wastewater Systems Performance In the Mountain, Piedmont and Coastal Physiographic Regions of NC.

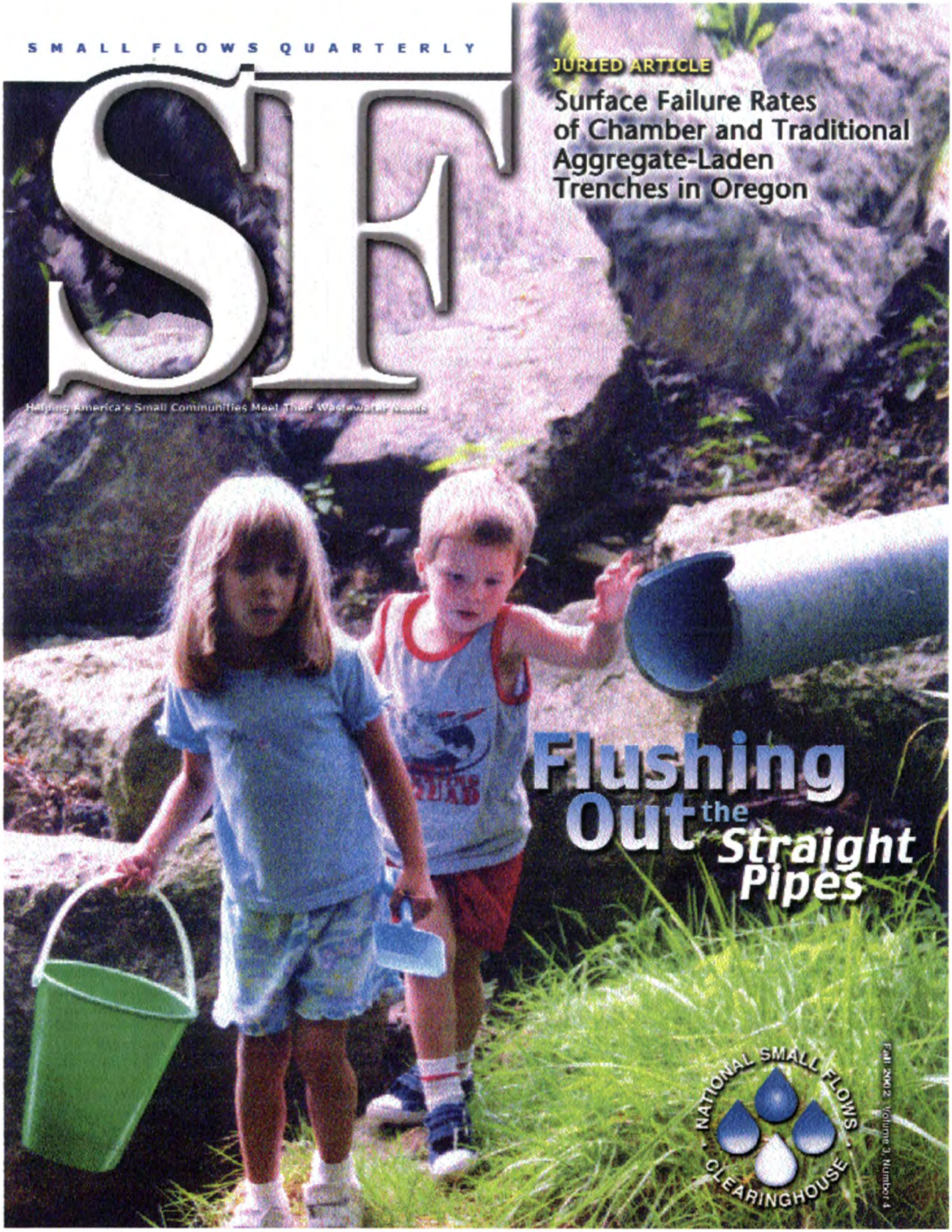
References

NCDENR. 1977. Laws and Rules for Sewage Treatment and Disposal Systems. Department of Environment and Natural Resources, Division of Environmental Health, On-Site Wastewater Section, 1642 Mail Service Center, Raleigh NC 27699-1642
http://www.deh.enr.state.nc.us/osww_new//index.htm

SMALL FLOWS QUARTERLY

SF

Helping America's Small Communities Meet Their Wastewater Needs



JURIED ARTICLE

Surface Failure Rates of Chamber and Traditional Aggregate-Laden Trenches in Oregon

Flushing Out the Straight Pipes

NATIONAL SMALL FLOWS CLEARINGHOUSE

Fall 2002, Volume 3, Number 4

Surface Failure Rates of Chamber and Traditional Aggregate-Laden Trenches in Oregon

CONTRIBUTING WRITERS

Larry D. King, Ph.D., NCLSS, Michael T. Hoover, Ph.D., NCLSS, Thomas H. Hinson, RS, NCLSS, NCPG, Richard L. Polson, CPSS, and Roger W. Everett, RS

Abstract: A methodology for conducting failure rate studies of onsite systems was demonstrated by comparing the field performance of aggregate-free chamber systems (the treatment) with traditional aggregate-laden, rock-filled trench systems (the experimental control) in Oregon. System populations were studied in two counties stratified by physiographic province/climate (i.e., humid temperate climate and high desert climate) and soil permeability (low, moderate, and high permeability). A field assessment of a random, stratified sample of 389 treatment and control systems (average age approximately 4 years old; range from 2.9 to 5 years) was conducted during a two-week time frame to determine failure rates under the same weather conditions for both technologies. Failure was defined as surface discharge of sewage during the field survey. Surface failure rates were low—below five percent for both—and there were no statistically significant differences in failure rates between the technologies or within any of the strata.

Open-bottom concrete chambers have been used as substitutes for gravel aggregate in onsite wastewater trenches for nearly 30 years in New England (EPA, 1980). The state of Maine included chambers in their code at a 50 percent size reduction in 1974 (Dix and Hoxie, 2001). Over the past 15 years, most chambers have been arch-domed plastic chambers rather than the older concrete design. More than 700,000 chamber systems have been installed in the U.S., many with 25 percent to 50 percent reductions in the trench bottom infiltrative area (EPA, 2002).

In November 1995, the Oregon Department of Environmental Quality (ORDEQ) approved the EQ24 chamber technology as equivalent to the traditional stone aggregate trench. In Oregon, both the aggregate trench and chamber trench are 61 cm (24 inches) wide and of the same length. The traditional aggregate-laden trench in Oregon uses a 61-cm wide basal area (trench bottom) filled with 30 cm (12 inches) of aggregate. However, the EQ24 chamber has a 38-cm (15 inches) outside and 30-cm (12 inches) inside width. As a result, the exposed infiltrative basal area inside the EQ24 chamber is only 30 cm (12 inches) wide. Therefore, the exposed infiltrative basal area of the chamber system is only 50 percent of the aggregate system. While the infiltrative basal area for wastewater absorption is reduced by half, the trench length and width are the same size as in the aggregate system.

The design sewage flow rate for a new single family dwelling with between one and four bedrooms in Oregon is 450 gallons per day. This design flow rate was increased by 75 gallons per day for each additional bedroom above four bedrooms. The minimum required trench length in Oregon is determined using a sliding scale based on soil texture, thickness of effective soil depth, and depth to temporary groundwater (Table 1).

The design (bottom area) loading rates for standard systems shown in Table 1 have been calculated from the minimum trench lengths described in the Oregon Administrative Rules. As indicated earlier, the EQ24 chamber was approved as an equivalent to the 61-cm- (24-inch-) wide standard aggregate filled trench. Therefore, the design infiltrative basal area loading rates for the EQ24 chamber are 2.0 times the loading rates given for aggregate systems in Table 1.

While chambers have been used elsewhere for long periods of time, these systems have only been used in Oregon with the reduced infiltrative basal area since 1995. Hence, the state regulatory agency (ORDEQ) desired to determine functional performance of these systems in the state.

Field Side-by-Side Studies

Evaluation of performance of onsite technologies in the past has typically begun with rigorously controlled laboratory experiments and then moved to highly controlled side-by-side field assessments of scaled-down systems. However, for several reasons, side-by-side research assessments of pilot-scale trenches have not, by themselves, provided complete information when evaluating wastewater trench designs. Usually a side-by-side experiment is limited to one or two effluent qualities (wastewater strengths), one soil, one design type, one or two flow rates, one contractor's method for installation, one set of operational parameters, and one climate. By controlling these factors, conclusions may be drawn, yet the results are not easy to extrapolate to other soils, wastewater strengths, installation styles, etc., unless the research is replicated at substantial cost in many different soils, a range of climates, etc.

Side-by-side tests also may be negatively influenced by soil variability within the test site. The limitations of side-by-side studies become more apparent when full-scale systems or full-scale trenches are tested, rather than just studying bench-scale units.

Soils, other than uniform sands, are so naturally variable in their characteristics that it is impossible to control random unexplained error and make direct side-by-side comparisons using side-by-side studies of full-scale trenches or systems. The trenches in such studies must be spaced far enough apart to prevent interactions with each other, thereby introducing significant soil variability.

Loudon et al. (1998) hypothesized that this soil variability introduced significant noise into the data set, such that differences within treatments were greater than differences between treatments. One method to potentially deal with such variability would be to use more replication. However, this approach would expand the research site to additional soil areas and would likely increase the amount of soil variability in the study, confounding the attempt to study treatments.

Since use of side-by-side studies is difficult, there was interest by regulators in Oregon regarding other methods to assess system function and performance. Field performance assessments of large samples of systems using rigorously controlled, random, stratified sampling is another method for assessing technology effectiveness. Such failure rate assessments provide the opportunity to test system function under the real-life range of different soils, climates, wastewater strengths, flow rates, design, installation, and operating conditions. However, such assessments must be designed to include large numbers of randomly selected systems and to utilize other sound research principles.

Purpose and Objectives

One important purpose of this paper is to demonstrate a sound methodology that others can adapt for the design and implementation of comprehensive onsite system failure rate assessments elsewhere. The primary goal of the research was to evaluate the performance of the Infiltrator Systems, Inc., Equalizer 24 (EQ24) chamber trench technology in Oregon using a failure rate assessment. Research objectives were to determine surface failure rates and to determine the factors that influenced the magnitude of failure rates.

The null hypothesis tested was whether the proportion of treatment systems (EQ24 chambers) functioning satisfactorily within the population of chamber trench systems in Oregon was equal to the proportion of control systems (traditional aggregate-laden systems) functioning satisfactorily within the population of gravel aggregate trench systems in Oregon. Satisfactory function was defined for the study as no surface discharge of sewage during the field performance assessment.

Literature Review

Onsite treatment and dispersal of domestic wastewater typically is achieved through primary treatment in a septic tank, followed by subsurface soil infiltration for final treatment and disposal of effluent. The effluent is delivered intermittently to the drainfield trenches by gravity or pressure dosing and moves through the soil into the groundwater (Crites and Tchobanoglous, 1998; EPA, 1978, 1980, and 2002; Kristiansen, 1982; Jenssen and Siegrist, 1990; and Anderson et al., 1985).

As sewage effluent infiltrates the soil at the soil/trench interface in an onsite system, soil pores may be blocked by several mechanisms, including microbiologically produced cells and slimes, chemical precipitates, solids overflow from the septic tank, and mineral fines originating from the aggregate used in rock-filled trenches. These processes collectively form a "biomat" at the soil interface and reduce the hydraulic capacity of the infiltrative surface. Biological, physical and chemical processes all influence biomat development.

In addition to contributing fines, aggregate that becomes embedded in the soil at the soil/trench interface may block soil pores, and thus reduce the area available for effluent infiltration once fines surround the aggregate or a biomat has formed (Tyler and Converse, 1985; Amerson et al., 1991; Siegrist et al.,1999; Jenssen and Siegrist, 1990; and Siegrist, 1986).

Highly controlled laboratory and bench-top scale studies and field assessments of chamber trenches and aggregate-laden trenches were conducted at the Colorado School of Mines from 1997 to 2001 (Siegrist et al., 1999; and Van Cuyk et al., 1999). The authors concluded that the hydraulic and purification performance between the two systems was comparable when a reduced-size infiltrative surface was present in the chamber technology. Theoretically, a distribution system without aggregate will have a larger infiltrative basal area and thus can accept a higher hydraulic loading rate. Joy (2001) and Burcham (2001) reviewed pertinent literature and used Darcy's Law to describe a theoretical basis for reduced infiltrative basal area with aggregate-free systems.

Failure rate studies of conventional and alternative technologies have been conducted over a 25-year period, but rarely have included chamber systems. Past assessments have measured failure rates ranging from less than 5 percent to almost 50 percent (Lindbo et al., 1998; Hoover et al., 1993; Hoover and Amoozegar, 1989; Hoover et al., 1981; and Hoover, 1979).

Failures during wet seasons typically exceeded those during dry seasons, but not always. For instance, dry-season failure rates were very high (even for young systems) when the infiltrative surface area was too small for the soil conditions (Hoover, 1979). Hoover measured failure rates of 30 to 39 percent for sand mound systems three years old and younger during a dry-season summer-time assessment in Pennsylvania.

Also, past failure rate studies have illustrated the impacts of incorporation of a proactive management program and improvement of the soil science expertise of the regulatory agency's field staff on reduction of failure rates. Lindbo et al. (1998) reported very low failure rates (≤ 5 percent) in a survey of sand-lined and traditional aggregate-laden trench systems that were very effectively sited, designed, installed, monitored, and maintained. These systems performed much better than the 12 to 20 percent failure rates measured five years earlier by Hoover et al. (1993) for systems less than five years old in the same four-county area. The major causes for the reduction in failure rates from 12 to 20 percent to ≤ 5 percent in the five-year time frame were the introduction of a public management program and improvement of the field staff's soil science expertise in the local health department.

Materials and Methods

The project was a large-scale, controlled survey of nearly 400 randomly selected onsite systems in Oregon stratified by system type, climate, and soil permeability. This research was conducted by an experienced team of onsite wastewater research scientists from The On-Site Corporation (TOC) and Cpec Environmental, Inc. (Cpec), working in conjunction with regulators from the ORDEQ and from local county onsite regulatory programs.

The first important attribute of the protocol for such a study is to conduct the evaluation independently of the product manufacturers. Therefore, the research was conducted by the third-party scientists and regulators listed above. Manufacturer's representatives were excluded from involvement in the sample selection process and did not participate on survey teams during the system performance evaluation.

Survey Areas and Research Protocol

The state of Oregon comprises three major physiographic regions: the Pacific border, the Pacific Mountain System, and the Columbia-Snake River Plateau. This study focused upon the Pacific border and the Columbia-Snake River Plateau regions, since they encompass much of the area where development has occurred and were of primary importance to the ORDEQ. These two physiographic regions have vastly different climates, ranging from a humid temperate climate with high rainfall in the Pacific border to a semi-arid, high-desert climate in the Columbia-Snake River Plateau, which is in the rain shadow of the Cascade range.

One county in each region was selected for the survey based upon criteria described by Hoover and Hinson (2002). Clackamas County, near Portland, was selected in the Pacific Border region and Deschutes County, near Bend, Oregon, was selected in the Columbia-Snake River Plateau. Hereafter, the survey areas will be referred to as West (Clackamas County, west of the Cascade range) and East (Deschutes County, east of the Cascade range).

Peer-review even of the research protocol is a second important element of properly designed failure rate studies. A peer-review process was used by Siegrist et al. (2000) to develop the Oregon research protocol. The study was designed to assess a broad range of soil conditions representing the range of soil texture groups included in the Oregon rules.

Although permeability within these texture groups can vary substantially with soil structure and other morphological characteristics, for the purposes of this study, the soils were combined into three assumed permeability groupings. Sandy soils were generally assumed to be highly permeable soils; loamy soils were generally assumed to be of intermediate permeability; and clayey, fine textured, soils were generally assumed to be low permeability soils when all other morphological factors were equal. Subsoil textures were therefore grouped into high (sand, loamy sand, and sandy loam), moderate, and low (clay, silty clay, and sandy clay) permeability categories by Hoover and Hinson (2002). This was similar to the three basic soil texture groupings used in the Oregon rules.

Population Database Construction and Sample Selection

Databases were compiled from U.S. Department of Agriculture/Natural Resources Conservation Service (NRCS) soil map databases, county-specific GIS databases, and county septic system permit files with cooperation and support from county staff and the ORDEQ (Hoover and Hinson, 2002).

Another important element in the design of field performance assessments is minimizing bias during the definition of the study population and selection of the sample from the study population. Electronic permit data for chamber systems and aggregate systems in the West and East areas were obtained from the counties and screened to eliminate systems inappropriate for the survey. These included commercial and industrial sites; sites where tanks, but not the drainfield, had been replaced; and systems with missing, incomplete, or contradictory records.

Only systems in use for three to five years were included in the population dataset. Since Oregon did not allow chamber systems until five years prior to the study, older aggregate-

Table 1 Design Loading Rates for Traditional Systems in Oregon.

	Effective Soil Depth or Depth to Temporary Groundwater = 48" or More (gpd/sf)	Effective Soil Depth = 36"– 48" (gpd/sf)	Effective Soil Depth of 24"– 36" or Depth to Temporary Groundwater = 24"– 48" (gpd/sf)	Effective Soil Depth = 18"– 24" (gpd/sf)
Soil Group A*	1.50	1.00	0.75	0.60
Soil Group B*	1.00	0.75	0.60	0.50
Soil Group C*	0.60	0.60	0.50	0.43

**Soil Group A – Sand, Loamy Sand, Sandy Loam.*
**Soil Group B – Sandy Clay Loam, Loam, Silt Loam, Silt, Clay Loam*
**Soil Group C – Silty Clay Loam, Sandy Clay, Silty Clay, Clay.*

laden systems were not included in the study population. Younger, less-mature systems were also excluded from the study population.

Using geographic information system (GIS) technology, tax parcel identification numbers were used to match the county permit records with the parcel location and subsequently correlate permit records with the NRCS soils map data. Using the compiled GIS databases described above, the total population of aggregate systems and chamber systems three to five years old was established. The target size for the survey was 400 systems, with a goal of 100 of each type (chamber and aggregate) per climatic region.

The GIS overlay of systems on NRCS soils maps illustrated an uneven distribution of systems within soil permeability classes. Therefore, all sites in low permeability soils were selected from the West region, and all sites in high permeability soils were selected from the East region. Sites with medium permeability were evenly distributed between the two regions (Table 2).

Every system in each study population strata was assigned a numerically sequential number. Then, sets of random numbers were generated and used to select the study samples for each stratum from these populations. The actual number of sites selected was larger than the target sample size to account for site access problems such as an owner's refusal to participate, dogs, locked gates, "No Trespassing" signs, and uninhabited or incomplete buildings. These randomly selected sites were then assigned a unique identifier number that was used throughout the study to assure quality control during data collection, handling, and analysis.

Performance Survey Procedures

Reconnaissance of randomly selected sites was conducted in the weeks prior to the survey to improve the survey efficiency. Specifically, the reconnaissance

- located and confirmed the identification of the sites,
- determined site access from main roads,
- evaluated access to the site (e.g., uncontrolled dogs, locked gates, etc.), and
- eliminated uninhabited houses or sites where a system was installed but a house had not yet been built (a common occurrence in Oregon).

To avoid skewing data in the subsequent survey, no contact was made with homeowners. If homeowners had been contacted during the reconnaissance phase, they might have refused to allow access in the subsequent survey or in some way tried to hide a failure, thus biasing the sample.

A field survey evaluation instrument was developed with input from the ORDEQ (Hoover and Hinson, 2002). It was designed to serve as a site-specific data collection and compilation guide. Site identification information from the GIS database was electronically included, along with space for recording soils, system, and homeowner interview data. Also, system specifications and soils evaluations listed on the permit were transferred to the instrument prior to the survey. Information packets were also prepared to give to residents during the survey (Hoover and Hinson, 2002).

If the resident was home during the field performance assessment, then he/she was interviewed and the results recorded on the field survey evaluation instrument. On the other hand, if the resident was not at home, the team inserted a questionnaire and self-addressed, stamped envelope into the packet and left this material at the site.

An information packet was prepared and distributed to all the survey team members. It contained the following:

- the purpose and scope of the survey,
- criteria and definition of a failing system,
- drainfield distribution system descriptions,
- interview instructions to use when collecting data from the residents, and
- soil characterization guides (i.e., texture triangle, soil texture, and soil structure flow diagrams, and selected soil profiles from county soil surveys).

Each county was divided into six to eight districts containing approximately equal numbers of sample sites to evenly distribute the workload during the field assessment. Then a survey team was assigned to each district.

Using GIS databases and reconnaissance data, 1:24,000 maps were generated showing roads, the location of each site labeled with its unique identifier number, and routes to the sites. In addition to these hardcopy maps, handheld computers (Compaq-Ipaq) linked to GPS units were used to provide real-time tracking of the team's location relative to the sites while driving. Files were organized in advance for each district with the appropriate maps, permits, and forms for the study sample included within that district.

Data Collection QA/QC Techniques

Another critical element of the study design was to utilize teams for the field performance assessment to minimize the potential for bias during data collection by any one individual. Each survey team consisted of two to three individuals who together provided substantial experience and expertise.

All teams included at least one person from a public regulatory agency (ORDEQ or local county agency) and one of the project scientists. The teams were constructed to assure that each team had experience in onsite wastewater treatment technologies as well as in subsurface investigation. Teams also were used for personal safety purposes and to facilitate quick transport from site to site.

QA/QC during data collection is an additional important element of the research design for field performance assessments. To assure consistency of data collection, the teams were trained together as a large group regarding the field data

Table 2 **Distribution of 440 Randomly Selected Sites by Region, System Type, and Soil Permeability Class.**

	West region		East region	
Permeability	Chamber	Aggregate	Chamber	Aggregate
High	0	0	74	77
Moderate	36	36	39	38
Low	70	70	0	0
Total	**106**	**106**	**113**	**115**

Table 3 Distribution of 389 Viable Sites in the Study Sample.

Region	EQ24	Gravel	Total
West	99	91	190
East	99	100	199
Total	198	191	389
Avg. Age (yrs.)	3.8	4.0	4.0
Age Range (yrs.)	2.9-4.8	2.9-5.0	2.9-5.0

collection protocol (including homeowner interview techniques) in a Monday morning meeting and subsequent field practicum evaluation of a mock site in the early afternoon. Then, teams dispersed and began data collection Monday mid-afternoon, continuing throughout the week until all sites had been properly assessed in their district.

The survey was conducted as a one-pass, single blind study; i.e., the survey teams did not know the type of system at the sites prior to the evaluations. Since a local or state regulatory agency representative was on every team, the one-pass approach (without prior contact of homeowners) was effective at facilitating site access.

If the homeowner was present when the survey team arrived at the site, then soil morphology was evaluated using a soil auger. Site suitability for an onsite system was evaluated and a determination was made as to whether the system had a surface failure. The definition of failure for this study was surface discharge of sewage on the ground surface or via a straight pipe during the field performance assessment.

If the homeowner was not present when the survey team arrived at a site, then only the most critical part of the assessment of hydraulic function (i.e., specifically the surface failure rate determination) was conducted. If the homeowner was not present during the field performance assessment, then the evaluation of the soil properties through soil augering was not conducted.

Substantial data was collected during the field performance survey including information from the following sources:

- county permit records,
- interview or questionnaire survey data from the homeowner, and
- field observations of soil and system conditions by the survey teams.

This data included the following:

- system type;
- water supply source;
- installation date;
- permit number;
- system design;
- system location;
- system inspection data from the final inspection prior to use of the system;
- as-built drawings;
- subsurface texture at the trench bottom depth (from both the permit site evaluation and from the survey team evaluation during the field assessment);
- number of bedrooms;
- number of occupants in the home;
- number of years the system has been in operation;
- problems with the system observed by homeowner;
- septic tank size;
- type of distribution/dispersal system;
- trench length, depth, and, number;
- use of pump system;
- the depth to any unsuitable soil characteristic (from both the permit site evaluation and the field performance assessment during the survey); and
- any observations of possible performance problems that were not surface discharges of sewage effluent.

A statistical approach was used to determine if the probability of observing an event for two binomial processes was the same or different (i.e., surface failure rates of chamber systems vs. surface failure rates of conventional systems). This probability was assessed by comparing the respective sample proportions (e.g., Berthouex and Brown, 1994).

The surveys were conducted in the West region during the week of February 27, 2001, and in the East region during the week of April 23, 2001. They were scheduled in advance to coincide with times of traditionally wet soil conditions and low evapotranspiration in each county, but also to avoid times when the snow pack would be expected to preclude field assessment of hydraulic function.

Results and Discussion

Study Efficiency and Sample Characteristics

Approximately one week had been allocated for each survey. Typically, five to six teams were in the field at the beginning of the week; fewer teams were operational at the end of the week.

The data collection for approximately 200 sites was completed in each region in less than a week. The site reconnaissance enhanced preparation, efficiency, clarity, and speed, which are important for logistical reasons and for quality control in data collection. The site reconnaissance facilitated efficient use of the limited time (one week per region) that the state and county regulatory staff could allocate to participate in the field performance aspect of the study.

Initially, 228 systems were chosen in the East region and 212 in the West region. About 88 percent of these systems (190 in the West area and 199 in the East area) were viable and used in the survey (Table 3).

Sites were nonviable if the residence was recently constructed or vacant and obviously not in use, if uncontrolled dogs were present, if the site was inaccessible during reconnaissance, if there was a locked gate at the driveway, or if the occupant refused to participate. Denial of site access to the survey teams was rare (10 aggregate-laden systems and 5 chamber systems) because the local regulatory authorities were present and involved in the study, and the homeowners were assured that this was a scientific study of system performance and not an enforcement survey.

There was only one site for each system type (of the 15 total sites where access was denied) where the survey teams observed (from afar) such conditions as lush vegetation or possible wet conditions over the drainfield area, indicating the possibility of surface

Table 4 Statistical Analysis of Hydraulic Function of EQ24 Chamber Systems (Treatment) Compared to Aggregate-Laden Systems (Control).

Soil permeability	Treatment (Chambers) HF[1]	p_1	no.	Control (Aggregate) HF	p_2	no.	Total Sample HF	% failed	no.
High	1	0.97a[3]	39	0	1.00a	44	1	1.2	83
Moderate	0	1.00a	71	2	0.97a	74	2	1.4	145
Low	1	0.99a	88	1	0.99a	73	2	1.2	161
Region									
West	1	0.99a	99	2	0.98a	91	3	1.6	190
East	1	0.99a	99	1	0.99a	100	2	1.0	199
All systems	2	0.99a	198	3	0.98a	191	5	1.3	389

1. HF = number of hydraulically failing systems observed in a given class
2. p =sample mean of proportion of systems of a given stratum functioning satisfactorily.
3. Within a row, values followed by the same letter are not significantly different at the 95% level of confidence.

failure. Therefore, there were no indications that the sample was biased by homeowners with failing systems refusing to participate in the study.

The systems in the study sample were comparable in age (Table 3), averaging 4.0 years old.

Based upon the initial NRCS soils map data used for population stratification and sample selection, sites were fairly evenly distributed within permeability classes and system type, with a range of 60 to 70 samples per permeability/system. However, the soil permeability classifications of many sites changed after actual observation of soil texture in the field.

The NRCS soil map data was not as accurate as the field soils data collected during the survey. Therefore, field determination of soil texture (Hoover and Hinson, 2002) showed 36 percent fewer sites in the high permeability category and 30 percent more sites in the low permeability category (data for systems combined). Sites in the medium permeability category increased 7 percent.

Failure Rate Assessment

The null hypothesis tested was whether the proportion of treatment systems (EQ24 chamber systems) functioning satisfactorily (p_1) was equal to the proportion of control systems (aggregate-laden) functioning satisfactorily (p_2). For this null hypothesis, the difference will have a mean of zero and be normally distributed for large sample numbers greater than 20 (e.g., Berthouex and Brown, 1994; Snedecor and Cochran, 1980). For this study "functioning satisfactorily" was defined as no hydraulic failure that resulted in sewage on the ground surface during the field performance survey or no straight pipe discharge of sewage. Hence, "failure" for this study was defined to be "surface failure" only and did not assess any potential "treatment failure" that could result in groundwater contamination.

Survey teams observed five surface failures or 1.3 percent of the total viable sites (Table 4). Three aggregate systems failed and two EQ24 systems failed. When grouped by soil permeability category, one failure occurred in the high category and two each in the moderate and low categories. When grouped by region, three failures occurred in the West region (humid temperate) and two occurred in the East region (semi-arid).

However, differences among failure rates between aggregate and chamber systems were not statistically significant when grouped by soil permeability category or region, nor was the difference significant for the entire sample (1.0 percent for EQ24 chamber and 1.6 percent for aggregate-laden trenches). Therefore, the research results failed to reject the null hypothesis.

The definition of failure used was very specific; that is, surface discharge of sewage on the ground or via a straight pipe at the time of the survey. However, this definition may not have given a full picture of other problems or of system failures repaired prior to the survey. These problems included past repairs to distribution boxes, pump replacement, clogged tanks, crushed lines due to trucks driving over drainfields, homeowners (and dogs) digging into drainfields, backup of sewage into homes due to undefined causes, odor concerns, etc. Eleven to 12 systems in each region exhibited one of these problems, but did not meet the failure definition. These systems were evenly distributed between chamber (11 systems) and gravel aggregate (12 systems) designs.

Factors Influencing the Failure Rates

The extensive datasets collected from the field performance assessment, county permit files, and homeowner interviews/questionnaires by Hoover and Hinson (2002) regarding soils, site characteristics, system function, permitting, and usage indicated that the factors listed below contributed to the low failure rates observed. Our observations indicated

Table 5 Precipitation Prior to and During the Study Period Compared to Previous 38 Years Record.

West Region[1]	Sept-Feb	Dec-Feb	Jan	(survey) Feb	Mar	Apr	May
				mm			
38-yr mean	749	455	165	123	104	75	59
Study period	323	152	39	33	89	62	27
% below mean	57	67	76	74	14	18	55
East Region[2]	**Sept-Feb**	**Dec-Feb**	**Jan**	**Feb**	**Mar**	**(survey) Apr**	**May**
				mm			
38-year mean	187	122	49	25	22	17	21
Study period	103	66	4	37	12	17	0
% below mean	45	46	91	-47	44	1	100
East Region[3]	**Sept-Feb**	**Dec-Feb**	**Jan**	**Feb**	**Mar**	**(survey) Apr**	**May**
				mm			
38-year mean	369	239	94	59	47	31	27
Study period	177	122	39	33	89	62	27
% below mean	52	49	58	44	-89	-99	1

1. Data from North Willamette Experiment Station
2. Data from Bend Experiment Station
3. Data from Wickiup Dam Experiment Station

that each of these factors contributed to the low failure rates and none was singularly responsible for them.

- weather conditions,
- age of the systems,
- accuracy of soil determinations made by county staff at the initial permitting phase,
- effectiveness of regulatory enforcement programs during the system permitting and installation stages, and
- adequate wastewater absorption when the infiltrative basal area was reduced by half for chamber systems.

An important part of the study design was evaluation of both the treatment and control technology under the same weather conditions. The original intent was that the survey would occur under the most challenging weather conditions–the wet spring season.

While the survey was planned in advance and conducted during the spring, rainfall was below normal and this may have impacted the overall failure rates. However, since the comparison did provide an evaluation of the treatment and control technologies under the same weather conditions, weather was a constant, rather than variable, during the comparison of the two technologies.

Precipitation in the West region was 57 to 76 percent below normal prior to the survey (Table 5). However, soil temperature and evapotranspiration were still low in the winter/spring period compared to summer conditions. Significant rainfall did occur in the two-week period before the survey was conducted. Field observations indicated soils were moist, not dry.

Precipitation deficits prior to the survey in the East region were generally less than in the West region (Table 5). However, precipitation at the Bend Station was above normal in February and approximately normal in April prior to the survey, and above normal in March and April at the Wickiup Dam Station.

The young system age (three to five years old) may have also had an influence on the low failure rates observed. But, based upon other studies, the relatively young system age and dry weather conditions during the field assessment do not fully explain the low failure rates observed here.

Other studies of younger systems (one- to three-year-old mound systems) during the dry season in Pennsylvania showed much higher failure rates (e.g., 30 to 39 percent) than observed here when the drainfields in Pennsylvania were too small for the soil conditions (Hoover, 1979; Hoover, et al., 1981). Therefore, based upon past experience, if the chamber systems in the current study had been too small for the soil conditions in Oregon, one would expect to observe higher failure rates than the 1 to 2 percent rates observed here, regardless of the young system ages and dry conditions during the assessment. This is a pertinent issue because of the 50 percent reduction in infiltrative surface basal area sizing used for the chamber trenches in this field study.

The low failure rates observed were unusual but not unprecedented, as seen from earlier results by Lindbo et al. (1998), where failure rates were ≤ 5 percent. This is pertinent to the current study because implementing soil science expertise in the regulatory permitting staff was one primary factor causing the reduction of the 12 to 20 percent failure rates observed earlier by Hoover et al. (1993) to the ≤ 5 percent rates observed by Lindbo et al. (1998) in northeastern North Carolina.

In the current study, soil morphological characteristics and site suitability were observed at many of the study sites during the field performance assessment. These were compared to

Table 6	Minimum Length of EQ24 Chamber Trench Required for Four Bedroom Homes.

State	Length of Equalizer 24 Chambers Required for a 4 Bedroom System (feet)	State Soil Description	Equalizer 24 Approval Description
Oregon	300	Soil Group B	Equivalent to 24" Aggregate Trench
Maine	234	Medium	4.0 square feet/ linear foot
Idaho	333	B-2 (Loam, Silt Loam)	Equivalent to 24" Aggregate Trench
Kentucky	346	Soil Group 2 - Loam	Equivalent to 24" Aggregate Trench
New York	433	30 mpi	Equivalent to 24" Aggregate Trench
Illinois	464	30 mpi	2.5 square feet/ linear foot

the soil/site conditions determined by the county regulatory agency during permitting of the systems studied. Soil morphology and site suitability were evaluated during the field performance assessment at 164 sites–83 in the West region and 81 in the East region. The soil/site suitability decisions made by county regulators during the initial system permitting in Oregon were accurate and matched the survey teams soil assessments determined during the field performance assessment.

Observations indicated that soil/site assessments during permitting in Oregon were superior to soil/site assessments conducted during system permitting in Pennsylvania and North Carolina in earlier studies by Hoover (1979), Hoover and Amoozegar (1989) and Hoover et al. (1993). Therefore, the highly accurate soil/site assessments during system permitting likely also contributed to the low failure rates observed in Oregon.

One reason that may explain the highly accurate permit site assessments in Oregon was the training and expertise required for those conducting site evaluations for onsite systems. County and state personnel in Oregon who conduct site evaluations and issue permits are required to have 10 college credits in soil science, including a soil morphology and genesis course. Many of the county permitting staff in Clackamas and Deschutes Counties were even more highly trained than generally required in Oregon, being soil scientists, some with advanced degrees.

Electronic records and high-quality field procedures and permitting practices contributed to the low failure rates in Oregon. The survey showed that systems were invariably installed in the correct location on the lot; i.e., in the suitable soil that was initially permitted for use. Permitting records showing numerous construction corrections dictated during final inspection indicated that the county staff assured that installation was correct before the system was approved for use.

Also, "as-built" plans were attached to all permits. None of the failures were attributed to unsuitable soils or installation errors. Conducting the surveys in regions with excellent regulatory programs and well-trained site evaluators assured a truer evaluation of the technology by minimizing other sources of variation.

Actual wastewater flows were not measured for the nearly 400 systems that were evaluated for the following reasons. First, a large number of systems (e.g. 389) were randomly selected from the perspective of water use and wastewater loading. Therefore, the water use and wastewater loading tested in this study represented the realities of water use and wastewater loading (from low water use to high, excessive water use) by the suburban and rural population using onsite systems in Oregon. This assured that the study sample evaluated the real-life potential for system failure at the same water use rates that would be expected to occur in the population of onsite systems in Oregon.

Second, because so few systems were failing and water for most houses was obtained from private wells that were unmetered, the collection of actual water use data was not worth the additional effort of installing water meters at all of the homes not already instrumented by the water utility. However, the occupancy of the homes served by both technologies was assessed in the interview/questionnaire process. This data revealed that there was no difference in occupancy or system age between the two technologies. Aggregate-laden systems averaged 2.9 occupants per home (s.d. 1.3), while chamber systems averaged 3 occupants per home (s.d. 1.5). Since occupancy was the same, it is reasonable to assume that water use was likely to be similar for both systems types that were studied.

Finally, it is important to recognize that the random selection process for choosing the sample assured that systems operating at design capacity had equal chance of being included in both the samples for the chamber and aggregate-laden trenches.

Each surface failing system was evaluated with the Failure Analysis Chart for Troubleshooting Septic Systems (FACTSS) method described by Adams et al. (1998) to determine the most likely causes of failure. This analysis determined that the failures observed were primarily due to poor operation and maintenance (O&M) at the sites of failing systems. Excessive water use in the home could not be ruled out as also possibly being a contributing factor to the failures since the systems were served by unmetered private wells.

However, the O&M problems observed were substantial enough to be identified as a primary cause of failure. For example, poor operation and site maintenance included landscaping of a sloping area exposing a trench, construction in a drainfield area disturbing the trenches, driving on a drainfield area causing ruts over and into the trenches, horses digging into a drainfield trench, and animals walking over a drainfield area repeatedly next to a fence in a pasture. Therefore, poor operation and site maintenance by the homeowner (i.e., not following typical O&M procedures, such as those described by Hoover, 1997 and Hoover and Hammet, 1994), even in the short-term for systems five years old and less, were determined to be the principal causes of the failures observed.

All of the failures were a result of poor operation and maintenance and none were related to reduction in infiltrative basal area or to inappropriately assigned loading rates or misevaluation of suitability of the soils by the regulatory authorities during the system siting, design, and permitting process. In Oregon, the EQ24 chamber (effective inside diameter of 30 cm not including the feet of the chamber) is sized with the same trench length as the 61-cm wide aggregate trench. Therefore, if a comparison is made of the infiltrative surface basal areas, the EQ24 chamber basal area is one-half that of aggregate trenches. There was no apparent increase in surface failure rate for the chamber systems in Oregon due to this 50 percent reduction of the infiltrative basal area.

Oregon rules adjusted design loading rates using a sliding scale based upon soil texture, effective soil depth, and depth to temporary groundwater. The deeper the soil and groundwater, the higher the loading rate used for soils of a given texture.

This approach accounted, in part, for differences in the lateral flow capability at the sites. That is, a loamy soil (Group B in Oregon rules) had an effective loading rate that ranged from 2 cm/d (0.50 gpd/ft^2) to 4 cm/d (1.0 gpd/ft^2) with an effective soil depth between 45 and 60 cm and greater than 120 cm, respectively. This sliding scale for system sizing could account for increased lateral flow capability through the soil downslope from the system at sites where limiting conditions are deeper in the soil. Thus, the Oregon rules address linear loading rate issues described earlier by Tyler and Converse (1985) and shown graphically by Hoover and Hinson (2002) and Hoover (2001).

The required EQ24 trench length for a four-bedroom system in various states is shown in Table 6. In each case, the system size in Table 6 was determined for a soil similar to an Oregon Group B soil (sandy clay loam, loam, silt loam, silt, or clay loam) with an effective soil depth of at least 36 inches. The total required trench lengths for EQ24 systems in Oregon was generally smaller than required for four bedroom homes in other states (Table 6). It follows that the results of this study could be extrapolated to other states where sizing of the chamber technology is at least as large as the trench lengths used in Oregon for similarly sized homes, assuming comparable soils are used and high-quality regulatory programs are in place.

Summary and Conclusions

The results of this study showed no significant difference in the surface failure rate of Infiltrator Systems, Inc. EQ24 aggregate-free chamber systems compared to conventional aggregate-laden systems. Failure rates were less than 2 percent for both systems. Of the failures that were observed, none appeared related to the reduction in the infiltrative basal area, but were primarily related to poor site maintenance. No relationship was detected between system failures and climate/physiographic region or soil permeability factors.

By evaluating such a large number of randomly selected systems, the study assured that the results were meaningful in the field and that the sample included a broad range of installation and operation characteristics. The systems were studied in two dramatically different climates, represented three large soil permeability groupings, and included almost 400 mature systems three to five years old. Using a large sample also increased the likelihood that a broad range of wastewater strengths, flow rates, family sizes, landscape positions, and designs were encountered during the field evaluation. Overall, failure rates for both technologies might be greater under wetter conditions, but there was no indication that wetter conditions would influence one technology more than the other.

This study provided an independent, third-party research assessment of whether Infiltrator Systems, Inc.'s EQ24 chamber system in Oregon performed equivalent to the traditional aggregate-laden technology after three to five years of operation. This study provides one building block in a foundation of knowledge regarding real-life performance of chamber technology outside the laboratory. These data should be placed within a foundation of scientific studies that includes other research such as laboratory studies and side-by-side field research, such as that conducted by Siegrist and others.

While the current study has provided important data, further research will be help determine long-term performance. Therefore, in the spirit of the scientific process, we recommend that this study be replicated at the same sample sites periodically over time (perhaps every three to five years) during the next 20 to 30 years and at other locations in the country using similar failure rate research designs. Such a research effort will determine if the data obtained here is reproducible elsewhere under other field conditions and whether failure rates remain low as the systems mature further and are evaluated under wetter weather conditions.

References

Adams, A., M. T. Hoover, B. Arrington, and G. Young. 1998. FACTSS: Failure analysis chart for troubleshooting septic systems. In: D. Sievers (ed.) On-site wastewater treatment: Proceedings of the 8th international symposium on individual and small community sewage systems St. Joseph, Mich.: ASAE. March 8–10. Orlando, Fla.

Amerson, R. S., E. J. Tyler, and J. C. Converse. 1991. Infiltration as affected by compaction, fines, and contact area of gravel. In: Proceedings of the 6th national symposium on individual and small community sewage systems. St. Joseph, Mich.: ASAE. pp 214–222.

Anderson, D. L., R. L. Siegrist, and R.J. Otis. 1985. Technology assessment of intermittent sand filters. Cincinnati, Ohio: U.S. Environmental Protection Agency, Municipal Environmental Res. Lab.

Berthouex, P. M. and L.C. Brown. 1994. Statistics for environmental engineers. Boca Raton, Fla.: CRC Press, Inc.

Burcham, T. N. 2001. A review of literature and computations for chamber-style on-site wastewater distibution systems. Prepared for Ralph Turnbo, Mississippi State Department of Health. Starhadle, Miss.: Innovative Biosystems Engineering, Inc.

Crites, R. C., and G. Tchobanoglous. 1998. Small and decentralized wastewater systems. Boston: McGraw-Hill Publishing Company.

Dix, S. P., and D. C. Hoxie. 2001. Analysis of septic system longevity in Maine. In: D. Sievers (ed.) On-site wastewater treatment: Proceedings of the 9th international symposium on individual and small community sewage systems Fort Worth, Texas. St. Joseph, Mich.: ASAE

Hoover, M. T. 2001. The science and function of on-site wastewater systems (septic systems) using gravel aggregate. Presented to North Carolina General Assembly 605 Working Group. August 31.

Hoover, M. T. 1979. Inventory and evaluation of elevated sand mound sewage disposal systems in Pennsylvania. M.S. Thesis. State College, Penn.: Department of Agronomy. The Pennsylvania State University.

Hoover, M. T. 1994. Soil facts: Septic systems and their maintenance. Raleigh, N.C.: College of Agriculture and Life Sciences. North Carolina State University. AG-439-13.

Hoover, M. T., and W. Hammet. 1997. Soil facts: Septic system owner's guide. Raleigh, N.C.: College of Agriculture and Life Sciences. North Carolina State University. AG-439-22.

Hoover, M. T., G. W. Peterson, and T. T. Fritton. 1981. Utilization of mound systems for sewage disposal in Pennsylvania. In: N. I. McCleland and T. L. Evans (Ed.) Individual on-site wastewater systems. Proceedings of the 7th national conference. Ann Arbor, Mich.: National Sanitation Foundation.

Hoover, M., and A. Amoozegar. 1989. Performance of alternative and conventional septic tank systems. Raleigh, N.C.: North Carolina State University.

Hoover, M. T., R. O. Evans, T. H. Hinson, and R. C. Heath. 1993. Performance of sand-lined trench septic systems on wet, clayey soils in northeastern North Carolina. Raleigh, N.C.: College of Agricultural and Life Sciences. North Carolina State University.

Hoover, M. T., and T. H. Hinson, 2002. Oregon on-site wastewater system field performance assessment. Final Project Report to Infiltrator Systems, Inc. and Oregon Department of Environmental Quality. The On-Site Corporation and Cpec Environmental, Inc.

Jenssen, P. D., and R. L. Siegrist. 1990. Technology assessment of wastewater treatment by soil infiltration systems. Wat. Sci. Tech. 22(3/4): 83–92.

Joy, D. 2001. Review of chamber systems and their potential use in Ontario for on-site wastewater treatment systems. Guelph, Ontario: University of Guelph.

Keys, J. R. 1996. Septic tank effluent infiltration and loading rates for gravel and chamber absorption systems. M.S. thesis. University of Wisconsin-Madison.

Kristiansen, R. 1982. The soil as a renovating medium clogging of infiltrative surfaces. In: A.S. Eikum and R.W. Seabloom (ed.) Alternative wastewater treatment. Boston: D. Reidel Publishing Co. pp. 105–120.

Lindbo, D. L., T. M. Campbell, N. Deal, and R. Hollowell. 1998. Performance of sand lined trench and conventional systems within a management entity. In: D. Sievers (ed.) On-site wastewater treatment: Proceedings of the 8th international symposium on individual and small community sewage systems. March 8–10. Orlando, Fla. St. Joseph, Mich.: ASAE pp. 177–185.

Louden, T. L., G. S. Salthouse, and D. L. Mokma. 1998. Wastewater quality and trench system design effects on soil acceptance rates, In: D. Sievers (ed.) On-site wastewater treatment: Proceedings of the 8th international symposium on individual and small community sewage systems. March 8–10. Orlando, Fla. St. Joseph, Mich.: ASAE. pp. 186–194.

Siegrist, R. L. 1986. Wastewater-induced soil pore clogging development as affected by effluent composition and loading rate. Doctoral dissertation. University of Wisconsin-Madison.

Siegrist, R. L., S. Van Cuyk, A. Logan, S. Masson, and E. Fischer. 1999. Hydraulic and purification behavior in wastewater soil treatment systems as affected by infiltrative surface character and vadose zone soil depth. Proceedings of the annual conference of the National On-Site Wastewater Recycling Association. Nov. 3–6. Jekyll Island, Ga.

Siegrist, R. L., S. Van Cuyk, J. Logan, M. T. Hoover, and T. Hinson. 2000. Field performance survey protocol for determining the equivalency of hydraulic performance of EQ24 chambers and aggregate onsite trenches in Oregon.

Snedecor, G. W., and W. G. Cochran. 1980. Statistical methods. 7th edition. Ames, Iowa: The Iowa State University Press.

Tyler, E. J., and J. C. Converse. 1985. Soil evaluation and design selection for large or cluster wastewater soil absorption systems. Proceedings of the 4th national symposium on small sewage systems. St. Joseph, Mich.: ASAE. pp: 179–190.

Tyler, E. J., M. Milner, and J. C. Converse. 1991. Wastewater infiltration from chamber and gravel systems. Proceedings of the 6th national symposium on small sewage systems. St. Joseph, Mich.: ASAE. pp: 214–222.

U.S. Environmental Protection Agency (EPA). 1978. Management of small waste flows. Report of small scale waste management project. University of Wisconsin-Madison. Cincinnati, Ohio: EPA Municipal Environmental Res. Lab. EPA-600/2-78-173.

——. 1980. Design manual for on-site wastewater treatment and disposal systems. Cincinnati, Ohio: EPA Municipal Environmental Res. Lab.

——. 2002. On-site wastewater treatment systems manual. Washington, D.C.: Office of Water. February. EPA/625/R-00/008.

Van Cuyk, S., R. Siegrist, A. Logan, S. Masson, E. Fischer, and L. Figueroa. 1999. Purification of wastewater in soil treatment systems as affected by infiltrative surface character and unsaturated soil depth. 72nd Water Environment Federation exhibition and technical conference. October 9–13. New Orleans, La.

Acknowledgements

We would like to acknowledge the efforts of Bob Siegrist, Ph.D., and his colleagues at the Colorado School of Mines, who originally developed the research protocol for this study. We appreciate the input and direction provided by Ted Louden, Ph.D., Michigan State University, Doug Joy, Ph.D., University of Guelph, and Larry Nelson, Ph.D., North Carolina State University (Emeritus), who reviewed the protocol, the final project report or statistical design for the study.

We also acknowledge the substantial efforts of those who served on field performance assessment teams or who helped coordinate/assist with its implementation. These individuals included Oregon DEQ staff Ed Woods, Chuck Harman, Mike McNickel, Sherm Olson, Bijan Pour, Bob Baggett, Del Cline, Larry Brown, and Bernie Duffy; Clackamas County soils staff Larry Olander, and Karen Livingston; Deschutes County soils staff Dan Halderman, Jerry Kathan, and Jeff Freund; Clackamas and Deschutes Counties GIS staffs; as well as environmental health specialists, soil scientists, geologists and technicians, including John McKelvey, Stephanie Miscovich, Ryan Davenport, Christine R. Reisz, John Davis, Tony Sacco, Beth Chagaris, and Amy Morgan from North Carolina and Oregon.

We also appreciate the assistance of homeowners who allowed us to evaluate the performance of onsite wastewater systems at their homesites.

Finally, we acknowledge the project funding agencies, Environmental Studies Group and Infiltrator Systems, Inc., for funding such a broad-scale, independent, third-party research study of both chamber and traditional aggregate-laden septic systems across two divergent climatic zones.

Note that while we appreciate the assistance of these individuals, organizations, and funding agencies, the views expressed in this paper are those of the authors and are not those of the collaborators mentioned, their institutions or the funding agencies.

Authors

Larry D. King, Ph.D., NCLSS, is a consultant for The On-Site Corporation and Professor Emeritus of Soil Science at North Carolina State University (NCSU). King has nearly 30 years experience in soils and land application of wastewater to them. He worked for the Tennessee Valley Authority and since 1975 at NCSU until his retirement in 2000. He also has professional experience at the University of Guelph, the New Zealand Government Experiment Station, and in the geography department at the University of Edinburgh in Scotland. King has a broad-based background having obtained engineering and agronomy degrees and has taught university Soil Science courses dealing with land application of wastewaters, including onsite systems, biosolids and spray irrigation of wastewater.

Michael T. Hoover, Ph.D., NCLSS, is professor of soil science at North Carolina State University (NCSU) and president of The On-Site Corporation (under which auspices this project was directed). Hoover obtained his B.S., M.S. and Ph.D. degrees from Pennsylvania State University. He has over 27 years experience in the onsite wastewater field.

Thomas H. Hinson, RS, NCLSS, NCPG, is principal scientist at Cpec Environmental, Inc., in Beaufort, North Carolina. He began his professional career as an environmental health specialist in the Carteret County, North Carolina, Health Department, after which he served as project manager for a NCSU project to investigate failure rates and performance of onsite technologies in northeastern North Carolina. Hinson has a Bachelor's Degree in Geology from the University of North Carolina at Wilmington and a Master's of Science Degree in Soil Science from NCSU.

Richard L. Polson, CPSS, was formerly program manager for soils in the Clackamas County, Oregon, Department of Community Services. He is currently building codes manager for Clackamas County. He has an A.B. degree from Albion College in biology, an M.S. in soil science from Oregon State University, and has been a soil scientist in Clackamas County since 1976.

Roger W. Everett, RS, is director of environmental health for Deschutes County, Oregon. He began his career in 1974 in Douglas County, Oregon, and began working for the environmental health program in Deschutes County in 1979.

LONGEVITY OF CONVENTIONAL GRAVEL AND REDUCED AREA CHAMBER DISTRIBUTION SYSTEMS INSTALLED IN THE TOWN OF CUMBERLAND, MAINE 1975 TO 1988

Chet Rock[1], Larry Nelson[2], Mike Corry[3] and Charles Friedman[4]

Abstract

Over 1100 Maine Subsurface Wastewater Disposal Systems Applications were reviewed and categorized by system type and age. The longevity study was limited to the 404 systems that were at least 20 years old. System failure was established by the application for a replacement system. Fifty-five systems (13.6%) were replaced. The systems were categorized by drainfield location and type (in-ground trench or bed and above-ground trench or bed). Systems were further categorized by drainfield design (chamber vs. conventional gravel). Chambers installed during the timeframe of the study were constructed of concrete. In Maine, chambers are allowed up to a 50% reduction in size, based on the assumption of greater efficiency. While the age at failure and the percent failure were more favorable for reduced area chamber systems, the statistical analysis of the data revealed no significant difference between the two at the 5% level. However, the analysis did reveal that soil conditions have an important effect upon the tendency to fail when systems were designed with the Maine loading rate table in effect at the time. Review of other longevity studies documents the difficulties in the design and interpretation of longevity research.

Introduction

Previous field studies of longevity of chamber and gravel drainfield systems concentrated on young systems (less than 10 years old). The purpose of this paper is to assess longevity of older systems (over 20 years old) by measuring the relative "propensity to fail" (failure rate) and "age at failure" of gravel and reduced area chambers installed in the period of 1975 to 1987 in the Town of Cumberland, Maine under the State of Maine code. Because the quality of the local codes, regulatory practice and the skill of local designers and installers affect longevity performance, the results of this analysis may not necessarily be replicated in other jurisdictions.

Maine, unlike most other states, included sizing criteria for chambers in the body of the code very early in the modern era. The first modern era codes in most other states established drainfield design criteria for gravel filled trenches and beds. Other drainfield technology was considered an alternate to the codified stone filled drainfield and was typically approved under alternate approval processes. When promoters of new technology approached regulators, they were frequently required to support claims that the recommended sizing of the technology would result in equal or greater longevity than the benchmark stone design. Because the technology was new, they were unable to document relative longevity by failure analysis and had to rely on

[1] Chet Rock, Ph.D., P.E. is the Associate Dean, College of Engineering, University of Maine.
[2] Larry Nelson, Ph. D. Emeritus Professor, Department of Statistics, North Carolina State University
[3] Mike Corry, regulatory consultant, former employee of Infiltrator Systems Inc., former Chair of the NOWRA Model Code Framework Committee and former Administrator of the Wisconsin Safety and Building Division
[4] Charles Friedman, undergraduate engineering student, University of Maine

other methods. With over 30 years of history, chamber technology is no longer new and relative gravel and chamber system failure rate and longevity can be measured.

In July 1974 the Maine Subsurface Wastewater Disposal Rules first authorized the use of 50% reduced area chamber systems. “The Rules allows [sic] a reduction in the size of the disposal area when chambers are utilized. The rationale for the allotted reduction in disposal area is that leaching chambers provide an unmasked interface between the effluent and the soil.” (Maine Department of Human Services, 2001)

The chamber design creates a subsurface open-bottom area. Three generations of materials have been used in chamber installations in Maine; wood Vee-plank, concrete and plastic. The primitive Vee-plank (wood planks) design was used extensively beginning in the late 1940’s and was phased out by the beginning of this study period. Concrete chambers were introduced in the mid 1970’s and plastic chambers in the late 1980’s. All chambers installed in Maine during the study period were concrete. The concrete chamber dimensions were commonly 4 feet wide, 8 feet long and 1 foot high with overflow and air exchange ports in the side and end walls. In the late 1980’s the plastic chamber was introduced. (Maine Department of Human Services, 2001)

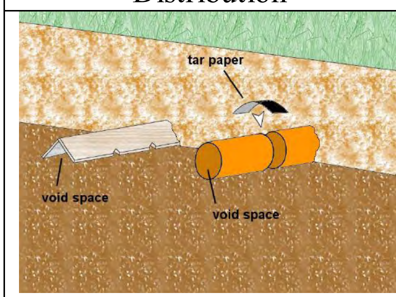
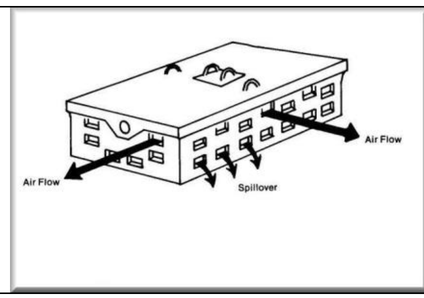
<table>
<tr><td colspan="3"></td></tr>
<tr><td>Vee-Plank Site Constructed Chamber and Tile Distribution</td><td>Concrete Chamber</td><td>Plastic Chamber</td></tr>
<tr><td>
</td><td>
</td><td></td></tr>
</table>

Figure 1- Three generations of Chambers utilized in Maine

Town Dispersal System Design

The 1974 Maine code focused on the bed design because of the difficulty of constructing trenches in areas with shallow bedrock.[5] As a result, ninety-eight percent of the Town of Cumberland installations evaluated were beds. Fill was frequently used because of slopes or shallow soils. The size of the gravel beds was determined by a codified loading rate table. The chamber design simply replaced gravel in a 50% reduced area bed (Martin 2004).

Based on a review of permits, gravel bed design was typically 12 inches of gravel overlying native soil or fill, covered with two inches of straw or hay and 8-14 inches of approved fill. A 4 inch distribution pipe was installed approximately one inch below the top of the gravel. Gravel beds were assigned design area credits based on bottom area.

[5] Based on interview with Russ Martin, Director of Maine’s Subsurface Wastewater Program.

Gravel trench design criteria assigned 3 square feet of area credit per lineal foot of trench. The trenches were typically 2 feet wide with 18 inch sidewalls. No area credit was assigned to the trench bottom. [6]

Based on the review of permits, chamber systems were typically placed on native soil or fill and covered with 6 to 12 inches of approved fill. The 4 x 8 chambers were assigned 32 square feet of area credits for both beds and trenches. All but one of the chamber systems were beds.

Appendix 1 is the Maine loading rate table in effect in 1978. The loading rate tables contained 11 soil conditions based on textural classes, 9 of which were utilized for conventional systems. The 9 textures were grouped into six drainfield sizing categories designated "small" to "extra large." Each group's loading rate was expressed as square feet per gallon of design flow. For example, the loading rate for the classification "Medium" was 2.6 square feet per gallon design flow. The soil condition portion of the table classified site conditions based on vertical separation to a limiting condition and provided design instructions for the various conditions. Design flow was 90 gal/day per bedroom. This was significantly less that than the 120-150 gpd used in many states, resulting in smaller drainfields than in those other states.

Maine loading rate tables evolved over the time period of the study. Appendix 2 contains tables that document the evolution of gravel and chamber distribution system area requirements for various soil groups. Specific comments on the individual tables are:

- The chamber column in the July 1974 table reflects area credits assigned to two specific manufactured products. The values in the gravel trench and bed columns include sizing ranges that allowed the designer to factor in individual household and site characteristics.
- The June 1975 table added more detail relative to sizing for gravel systems and became more generic relative to chambers as multiple manufacturers emerged. The chamber area as a percent of gravel varied from 44.4% to 59%, averaging 50.5%.
- The May 1978 table was more detailed and specified the loading rate requirements as square feet per gallon design flow. The chamber area as a percent of gravel varied from 48.84% to 53.8%, averaging 50.1%.

Efficacy of Longevity Analysis Techniques

System longevity is commonly defined as time from installation to hydraulic failure – usually defined as sewage at the ground surface or backing into the structure. Designers, installers and regulatory policy makers are interested in the longevity of specific designs for both public health and liability reasons.

Gravel drainfields are the benchmark design for the distribution of septic tank effluent in most state codes. State gravel sizing practices have evolved with empirical evaluation over the last half century. Where regulators and designers noticed early system failure in general or in a specific set of site conditions, the regulatory agency normally decreased the loading rate to resolve the problem. While alternate technology is also subject to empirical evaluation, it takes

[6] Ibid, Martin

an extended period to assess the technology. Chambers, in use for over 30 years, are not new technology.

Nationally, almost all state regulatory agencies have accepted some level of area reductions for alternate drainfield designs, from chambers to drip distribution. The agencies are generally interested in the treatment and longevity of the alternate design relative to the conventional gravel design when making approval determinations.

To support claims of chamber infiltrative efficiency, a number of studies have been conducted that were intended to assess the relative longevity of chamber and gravel drainfield designs. The research techniques included field surveys of installed systems, test center studies and studies that attempted to predict longevity based on ponding development in trench systems.

A field longevity evaluation protocol requires trained personnel, appropriate classification of system design, a clear definition of failure, a defined inspection technique, knowledge of changes in design requirements, information on installation and replacement dates and a statistically valid approach. Statistical validity involves determination of adequate sample size for statistical significance, appropriate classification of sites studied (avoiding apples/oranges aggregation), appropriate hypothesis development, consideration of the influence of independent variables and random selection in the case of a sample survey.

Test center studies frequently apply very aggressive loads and flows to induce early biomat formation and ponding to reduce the duration of the evaluation. To the greatest extent possible protocols should mimic common field installation conditions and the results should be calibrated by field surveys of failures.

The primary evaluation methods are listed below along with comments: Individual studies may utilize a mix of these methods. Longevity studies require accurate measurement of installation and the time of failure. Failure rate studies require the date of installation and a method to timely determine system failure occurrence. Periodic physical evaluation of all systems improves the clarity of both evaluations. One-time surveys lack the clarity because they identify failures than may in fact have occurred years earlier.

1. Site evaluation – Physical evaluation of sites for system failure, combined with a record review, is the optimum method of determining both time to failure and failure rate. The evaluation can consist either of evaluation of all systems or of a random sampling.

2. Evaluation by examination of records – While less expensive than field surveys, this method adds error involving bias in reporting system failure and is dependent on the consistency and quality of record keeping. Most jurisdictions have not systematically identified system failures with periodic inspection of all systems. Instead they rely on homeowner initiated repairs and neighbor complaints. This method introduces major reporting bias in that failures are often not reported at all or in a timely manner. This reporting bias explains large gaps in failure detection between this method and field surveys. Nevertheless, this method has merit if the purpose is to determine relative performance of subpopulations such as gravel

and chamber designs, assuming that owners and neighbors are no more or less likely to report failures of gravel systems than chamber systems.

3. Longevity prediction through trench ponding development – This approach is new and in early protocol development stage. The method has been attempted in field and test center studies. It is also complex in critical areas because of the number of variables that affect longevity.

The studies reported below provide information on future protocol designs for both field and test center evaluations.

Review of Longevity Studies

Five examples of previous longevity or protocol evaluation studies are reported here. The focus of the first two studies conducted by NSF International (NSF) at the Massachusetts Alternative Septic System Test Center (MASSTC) and the University of Minnesota (U of M) Water Resources Center was to develop or implement a protocol intended to estimate relative longevity of various drainfield designs by analysis of ponding development in trenches. Ponding development analysis was intended to shorten the 20-30 year period normally needed do a more complete failure analysis. The other three reported studies involve failure rate studies of relatively young installed systems in Oregon, North Carolina and Maine.

NSF/MASSTC Study

This is a Method 3 test center evaluation – evaluation of ponding development. NSF and the Wastewater Treatment Technology Joint Committee (Joint Committee) conducted an evaluation of a possible NSF protocol and standard intended to measure the relative longevity and treatment of gravel and gravelless drainfield technology. The evaluation was conducted over 20 months beginning in February of 2006. The evaluation of the protocol development is the subject of a paper presented at the 2007 ASABE Conference on Small Community Sewage Systems.[7]

The chamber system was utilized as a stand-in for all gravelless systems. Five trench cells each were constructed for the control (gravel) and chamber drainfield technology in ASTM C 33 (Standard Specification for Concrete Aggregate Material) sand. Chamber cells were half the area of gravel cells. Gravel cells were loaded at 1.48gal/ft^2/day. Chambers were loaded with the same volume. All cells were underlain by an impermeable membrane below the sand to allow collection and evaluation of the wastewater for treatment. Two feet of vertical separation were maintained below the drainfield. Ponding heights were measured in each cell at observation ports located at the 1/3 and 2/3 points of the trench length, separated by about 8 feet in gravel and by about 4 feet in chamber cells.

[7] Corry is a member of the NSF Wastewater Technology Joint Committee and a participant in a number of subcommittee discussions regarding the protocol. The progress and circumstances of the MASSTC center evaluation was subject of briefings at the annual Joint Committee meetings in September of each year. The meetings were open to the public.

Heufelder et al 2007 reported ponding height differences in gravel trenches between the two observation ports and speculated that "…biomat material within the gravel in the proximal end of the trenches forms dams or bridges to prevent the equilibrating of liquid level in the entire trench as occurs in the gravelless trenches."

Heufelder (2007) indicated the importance of uniform construction techniques and the necessity of assigning the technologies randomly to the cells. The gravel and chamber cells were installed in blocks of five adjacent cells rather than randomly being assigned to cells. The blocks were constructed during different times of the day using similar techniques and the same source of ASTM C33 sand. The soil report indicated that "Significant differences in the percentage of water drained at different tensions occurred between the longer [gravel] and the shorter cells [chamber]. There were no differences in soil porosity, grain size distribution, particle size distribution and bulk density. Therefore, the observed variation in pore size distributions probably occurred during placement and compaction of the sandy fill material in the test cells." With respect to random placement of the cells, the report indicates "The longer test cells (cells 1-5) were also constructed earlier in the day than the shorter cells (cells 6-10). Hence, the treatments (gravel-laden vs. gravelless trenches) were not randomly applied to the test cells and do not represent completely independent observations." The study report to NSF recommended that the cell assignment be randomized.

The results of the protocol evaluation remain under review by NSF and the NSF Wastewater Technology Joint Committee

University of Minnesota (U of M) Study

This was a combination Method 1 and 3 evaluations – physical site evaluation, record review and measurement of ponding development. The study titled "Field Comparison of Rock-Filled and Chambered Trench Systems**"** was reported at the 2007 NOWRA Annual Conference. The paper described an unsuccessful attempt to estimate longevity of gravel and reduced area chamber drainfields by measuring ponding progression in sequentially loaded trenches in Minnesota. Infiltrator Systems Inc (ISI) co-funded the study with the University of Minnesota and was provided a copy of the database and was allowed to comment on draft reports.[8] The U of M authors controlled the content.

The study initially involved site evaluation of 189 gravel and chamber trench systems age 5-10 years (90 chamber and 99 gravel systems).[9] Similar numbers of sites for each technology were selected in three soil hydraulic permeability classifications (slow, medium and fast) and in 7 geographically dispersed counties. The systems were all drop box sequentially loaded conventional systems serving homes. Ponding data were collected in the spring of 2006 from only the distal observation port on each trench.[10] The average trench length was 68 ft for gravel

[8] Corry, as an ISI employee, and Nelson, as a statistical consultant to ISI, along with other ISI staff, participated in the review of the drafts of U of M study. They were provided U of M draft reports and the databases that were used in the study.

[9] Information from the January 2, 2007 database that was provided by the University of Minnesota..

[10] At the time of the MN protocol development, the MASTC documentation on differential ponding levels between the proximal and distal observation ports was not available. The lack of proximal ponding observation likely affected the calculations of the ponding area utilized in gravel trenches.

and 57 ft for chambers.[11] Ponding development was measured on the basis of ”ponding area utilized”, defined as the percent of total trench volume occupied by ponded wastewater. A trench with 12 inches of gravel and ponded to 6 inches was considered to have used 50% of its area used.

Because site evaluation determines drainfield sizing, a re-evaluation of site soil conditions was conducted by a U of M team member at most sites in order to verify the original loading rate classification. The U of M soil evaluation classification differed from that found on the site permit on 58% of 153 sites where both the original site evaluation and the U of M classification were listed.[12]

A number of circumstances and decisions significantly reduced the utility of the study relative to its intended purpose.

- Christopherson (2007) reported that the systems were too immature to conduct a longevity analysis with "…nearly 60% of the systems visited during the study of the ages 5 -10 years did not have any ponding observed." As a result, "These results should not be used to predict system longevity."
- The design of the gravel systems varied significantly in areas critical to the study: reduced area drainfields, variation in sidewall height and depth of infiltrative surface. In Minnesota, the standard conventional design is a drop-box sequential loaded gravel trench system with the overflow pipe elevated 6 inches above the trench bottom, with the area determined by the number of bedrooms and the loading rate table. The Minnesota code allows gravel drainfield downsizing up to 40% with an elevated overflow pipe that is 24 inches above the trench bottom, with prorated area reductions for shorter pipe elevations (12 inch – 20%, 18 inch - 34%).[13] All but two of the gravel systems had pipe elevations of 6, 12 or 18 inches. Review of the database indicated major differences in ponding development in these three gravel designs. For example, systems with 6, 12, and 18 inch overflow pipes displayed in-trench ponding in 30%, 39% and 90% of the sites, respectively.[14] Instead of disaggregating the unique gravel designs in the report statistics, Christopherson (2007) reported that 27 (64% of 42 ponded systems) gravel systems with ponding heights greater than 6 inches were deleted from the database. The result of the deletions reduced the percent of trench area utilized by ponding from 11.4% [15] to the 4.3% reported in the NOWRA paper. Christopherson (2007) reported chamber percent used at 15.8%.
- Since ponding levels were not measured at the proximal end of the trench, any ponding elevation differences between the proximal and distal ends of the trench were not recorded. A measurement of no ponding at the distal end of the trench was recorded as zero ponding for the trench.

[11] Table 5, Christopherson et al., 2007)
[12] Information from the March 2007 database provided by the University of Minnesota. This information was not reported in the paper but was reported during the presentation of the paper at the January 2008 SW On-Site Wastewater Conference in Laughlin, Nevada.
[13] State of Minnesota Rules, Chapter 7080 Subp2C.(1)b
[14] Calculated from the January 2, 2007 database provided by the university
[15] Ibid

Oregon Study[16]

This is a Method 1 study – visual inspection and review of records. King and Hoover published a paper in 2002 that compared failure rates between gravel and 50% reduced area systems in Oregon. King (2002) reported that "reduced area" was calculated by the chamber open bottom area compared to a 24 inch wide gravel trench. The exposed bottom area of the chamber design was 50% of the basal area of the gravel trenches. The study included a total of 198 chamber and 191 gravel sites in two climates and three soil conditions. The sites were selected through a random, stratified process and were physically inspected by the authors in conjunction with state and county regulatory officials. The systems were 2.9 to 5 years old with an average age of approximately 4 years. Failure was defined as surface discharge of sewage. The study concluded that "…there were no statistically significant differences in failure rates between the technologies…"

North Carolina Study[17]

This is a Method 1 study – physical inspection and record review. R.L. Uebler et al of the North Carolina Department of Environment and Natural Resources published a longevity study of gravel, chamber and expanded polystyrene bundles. Uebler (2006) reported that the size of the installations included 36 inch wide gravel trenches, chambers with an approximate width of 34 inches, and three expanded polystyrene bundles approximately 36 inches in combined width. Chambers and expanded polystyrene were installed with a 25% trench length reduction relative to gravel trenches. Chambers included in the survey were produced by 4 companies. A total of 912 systems, evenly divided between technologies were included in the study. The sites selected were located in three soil groups in 3 counties and three distinct physiographic regions. System ages were from 2 to 12 years old. The conclusion of the paper relative to reduced area chambers was that the failure performance of reduced area chambers relative to gravel trenches was not " … significantly different at a 95% confidence level."

2001 Maine Study[18]

This was a Method 2 study – evaluation of records. Dix and Hoxie published a paper in 2001 of the State of Maine failure rates for two classifications of systems: "all systems" and 50% reduced area "chamber systems." The paper compared failure rates by year of installation (1984 – 1994). The "chamber system" classification included both concrete and plastic chambers. Because 62% of the permits were missing information on the original installation (type of system or date installed), the number of reported failures underestimated total failures. The authors estimated total failure numbers by multiplying the reported failures by the factor of total reports divided by complete reports for each year. The average adjustment factor to estimate actual failures from reported failures was 2.66. The conclusion of the study was: "Comparing systems less than 10 years of age for the two technologies," the authors estimated "… the cumulative

[16] The Oregon protocol design was under the supervision of the Oregon Department of Environmental Quality. The study was made to gain acceptance for Infiltrator Systems Inc reduced area chamber designs.
[17] The North Carolina study was conducted and controlled by the state. The study was funded primarily by the state with various manufacturers funding the remainder.
[18] The study was funded by ISI. Dix was an employee of ISI.

failure of all systems at between 1.56% and 4.13% and for chambers at between 1.92% and 4.99%."

Analysis of Longevity and Failure Rate of Gravel and Reduced Area Chamber Systems in the Town of Cumberland, Maine[19]

Statistical Terms Used

This analysis contains terms and deploys statistical processes new to some members of the onsite industry audience. Definitions and explanations follow:

Type III Sums of Squares and Means Squares are obtained for a test of significance of each factor adjusted for the effects of the other factors in the model. Adjusted means for levels of a significant factor may then be compared to determine where the actual differences exist.

Propensity for failure – Response data are given values of 0 for lack of failure and 1 for failure and an analysis of variance run on this response data. The F-values should not be considered exact due to some distributional problems with the error term. Averages of this response are then obtained for each level of a factor such as Soil Condition. The larger the average, the greater the propensity for failure. Generally the averages will be in the range of 0 to 1.

Odds of an event – number of failures divided by number of lack of failures.

Odds ratio - The ratio of two odds which is calculated by dividing the odds in one group of observations by the odds in another group of observations, e. g. Group 1 = Gravel and Group II = Chamber.

Logit in logistic regression – natural log of an odds ratio. The logit has some desirable properties that the odds ratio doesn't so therefore it is used extensively.

Method

This is a Method 2 study - evaluation of records. Town of Cumberland plumbing permit records were available from 1974 to the present, filed in permit number order, not by address. This required a review of all plumbing permits to determine onsite installation and replacement activity at a site. The target population of installed systems was those age 20 and older. All chambers installed in this period were constructed of concrete.

To verify that designers took advantage of the allowed area reduction, the chamber area reductions were calculated from permit applications using two methods:

- Comparison of gravel and chamber system areas by unique sets of site conditions – Permits contained information on installed system size, the number of bedrooms, the soil profile (texture) and condition (depth to a limiting condition). For each unique combination of factors that controlled sizing (number of bedrooms, soil profile and condition) the size of

[19] This study was funded by ISI. Corry was an employee of ISI during much of the study development.

gravel and chamber systems as listed on the permits was averaged. The average chamber bed area was 53% of the average gravel bed area.
- Calculation of gravel sizing for chamber permits - The gravel design area was calculated for chamber applications based on the information contained on the permits. The resultant gravel area was then divided by the chamber area on the permit. The average chamber area was 55% of the gravel design area.

Permit records were excluded from the study database for the following reasons:
- Only records of conventional gravel drainfields and chambers installed directly on soil were included. Some designers preferred to place chambers on a bed of gravel; however, if this was done, "…the system must be sized as a conventional stone bed." (Maine Department of Human Services, 2001) Because the focus of this study is distribution media installed directly on the trench or bed bottom, chambers installed on stone beds are not included.
- Because evaluation focused on household conventional systems, engineered, cluster and commercial systems were excluded.
- Where the street address of the initial system could not be determined from Town records.
- Where the system was replaced by municipal sewer or was replaced or modified because of an alteration or addition to the home.

The resultant database contained 404 records; 341 gravel and 63 chamber systems. Variables included in the database were: date installed, soil profile, soil condition, area in square feet, system type (gravel or chamber), system design (bed or trench) and (primarily above or below ground), age in years as of January 1, 2008 of existing systems, and date the drainfield was replaced for failed systems. Other variables such as the number of bedrooms, design flows, tank size, and drainfield area were recorded but were not used in the analysis either because data were missing on many permits or because the item was highly correlated with another variable.

Three independent variables were analyzed: soil profile (texture), soil condition (vertical separation to bedrock or groundwater) and drainfield media (rock and reduced area chamber drainfields).

Appendix 1 is the State of Maine loading rate table in effect in 1978. Soil profile consisted of 9 categories of texture which were assigned to five infiltration rate groups (small, medium, medium large, large and extra large) for drainfield sizing calculations. Soil condition categorized sites relative to depth to bedrock (A 1,2,3 = vertical separation to bedrock) and groundwater vertical separation (B = >48 inches, C = 15-48 inches, D = 7-15 inches, E = 0-7 inches)

For purposes of statistical analysis textural group (of which there were five levels) was utilized as a variable. The five soil condition categories were combined into three groups with group 1 = A category, group 2 = B and C categories and group 3 = D category. There were no sites in the E category. Categories B and C were combined as restrictions were the same (see Appendix 1).

Failure rate analysis based on record review of systems installed 20-32 years ago should be closer to reality than a record review of younger systems because of the increased likelihood that the failure would be reported with property turnover and homeowner/neighbor discontent with a persistent failure problem. Further, assuming no failure reporting bias between gravel and chamber systems, it is reasonable to compare statistics of equal age designs.

The results are presented as descriptive statistics and analysis of variance. The dependent variables are "time to failure" and "propensity to fail". Also, related to the propensity to fail, is a logit transformed dependent variable which is used in the logistic regression. Analysis of variance (ANOVA) measures the relationship between multiple independent variables and the dependent variable. Arithmetic and adjusted means can differ because the independent variables are usually correlated to some extent so the effects of one factor need to be adjusted for the effects of others in the model

Results

Caveat - It is likely that these statistics under-report actual failures because of reporting bias inherent in traditional enforcement of regulation of failed systems: homeowner self reporting, neighbor complaints and discovery during voluntary home inspections for real-estate sales.

In Table 1 is presented basic descriptive statistical information on the systems installed during the study period. The arithmetic mean for the percent failure (propensity to fail) and age at failure are presented for the two design options.

Table 1 – Descriptive statistics of gravel and reduced area chamber systems installed from 1975 to 1987

Reduced Area Chamber				Gravel		
Year	Installed	Failed	Age in years at replacement	Installed	Failed	Age in years at replacement
1975	1			12	3	9.9, 18.0, 32.8
1976	1			12	4	18.9, 22.7, 25.1, 27.7
1977	3	1	27.4	28	8	4.0, 6.8, 11.2, 11.3, 13.9, 14.3, 17.1, 18.9
1978	0			36	6	9.8, 10.4, 13.7, 20.2, 21.5, 24.4
1979	5			29	8	8.4, 11.4, 14.4, 15.0, 15.4, 19.4, 22.3, 23.1
1980	10	5	3.7, 11.4, 13.3, 15.5, 20.3	18	4	8.0, 8.7, 17.7, 23.0
1981	0			20	3	3.0, 16.2, 24.6
1982	4			17	2	1.0, 21.7
1983	5	1	16.7	30	0	
1984	6			27	3	1.8, 2.3, 10.0
1985	12			36	3	5.5, 7.5, 19.5
1986	10			39	1	18.9
1987	6			37	3	8.2, 13.9, 17.2
Totals	63	7	Percent failed: 11.1%. Average age at failure: 15.5 years	341	48	Percent failed: 14.1% Average age at failure: 14.8 years

Gravel system failures display the expected effect of age. Systems installed in the five year period of 1975-79 have a 25% failure rate while those installed in the five year period 1983-87 have a 6% failure rate.

Five of the ten chamber systems installed in 1980 failed, accounting for seventy-one percent of chamber system failures (5 of 7). A permit review of the five failures showed that two were adjacent lots and a second pair was in close proximity to each other.

In Table 2 is reported the assignment of soil profile textural classifications in the five Maine drainfield sizing classifications.

Table 2 – Maine loading rate table assignment of soil textural classes to loading rate classifications.

Maine Soil Profile Classification	Drainfield Sizing Classification
6	Small
4, 5	Medium
2, 3, 7	Medium Large
1,8	Large
9	Extra Large

Analysis of variance indicates that "age at failure" is significantly related to the variables soil profile and soil condition at the .05 level. The performance of gravel and reduced area chamber systems was not significantly different at the .05 level. Comparison of ages at failure (data includes only failed systems):

Table 3 – Analysis of variance for "age at failure"

Source	Degrees of freedom	Type III Sum of Squares	Type III Mean Squares	F
Profile Group	4	594.57	148.64	3.27*
Soil Condition	2	260.52	130.26	2.86 NS
Gravel vs. Reduced Area Chamber	1	59.11	59.11	1.30 NS
Error	47	2138.13	45.49	
Contrast Soil Condition 1 and 2 vs. Soil Condition 3		196.08	196.08	4.31*
Significant at .05 * Significant at .01 ** NS = Not significant.				

The adjusted means for age at failure are presented in Table 4. Whereas the chamber mean was higher than that for gravel, the difference was not significant at the .05 level.

Table 4 – Adjusted means for age at failure

Soil Profile group	Adjusted Mean	Soil Condition	Adjusted Mean	Drainfield Media	Adjusted Mean
Small	17.99	1	15.82	Chamber	16.73
Medium	12.69	2	17.00	Gravel	12.85
Medium large	21.26	3	11.56		
Large	9.32				
Extra large	12.70				

ANOVA evaluation of propensity for failure (Table 5) indicates that neither soil condition nor system type was significant relative to propensity for failure. Note that the F value for gravel vs. reduced area chambers is 0.00.

Table 5 - ANOVA for propensity for failure

Source	Degrees of freedom	Type III Sum of Squares	Type III Mean Square	F
Profile Group	4	3.005	.751	6.81**
Soil Condition	2	.345	.173	1. 56NS
Gravel vs. Chamber	1	.000414	.000414	0.00NS
Error	396	43.72	.110	
Significant at .05 * Significant at .01 ** NS = Not significant.				

The following table reports the adjusted means for propensity for failure. Note the large adjusted mean for the Small System category, meaning that failure is more apt to occur in this category than in the others.

Table 6 – Summary table, ANOVA adjusted means for propensity to fail

Soil Profile group	Adjusted Mean	Soil Condition	Adjusted Mean	Drainfield Media	Adjusted Mean
Small	.297	1	.194	Chamber	.128
Medium	.072	2	.147	Rock	.125
Medium Large	.077	3	.0380		
Large	.079				
Extra Large	.104				

The greater propensity for failure of textural class 6 (small system) was recognized by the State of Maine. They have increased the square foot area per gallon design flow from 1.3 to 2 ft^2/gal in more recent codes. (Maine Subsurface Waste Water Disposal Rules, 2005)

Table 7 - Logits and Odds Ratio

Variable	Logit Regression Coefficient Estimate	Odds ratio = e to the logit power
Intercept	-6.3895	0.002
Profile group Small vs. Extra Large	1.0634	2.896
Profile group Medium vs. Extra Large	-0.4677	0.626
Profile group Medium Large 2 vs. Extra Large	-0.4066	0.666
Profile group Large 1 vs. Extra Large	-0.4052	0.667
Soil condition group 1 vs. 3	5.0207	151.606
Soil Condition group 2 vs. 3	4.5647	95.828
Gravel vs. reduced area chamber	.00363	1.004

From Table 7, it is concluded that the Soil Profile group (Small) and one Soil Condition group (3) dominate the failure response of systems Soils in these groups are much more likely to fail than those in other groups with the loading rate tables in place during the period. With an odds ratio of 1.008, both gravel and reduced area chamber systems are equally likely to fail

Conclusion

The Maine study has provided an opportunity to evaluate longevity of systems in a way that previous studies have not. Analysis of data for "age at failure" and "propensity to fail" of gravel and reduced area chamber systems in Maine age 20 years and older indicate that reduced area chambers outperform gravel design in both areas. However, the differences are not statistically significant.   Soil profile and soil condition affected longevity when combined with the loading rate tables in use at the time. Soils in the Small System class are more apt to fail that those in other textural classes. Soil condition groups 1 and 2 are more apt to fail than group 3. The Maine Division of Health Engineering recognized this issue through empirical evidence and adjusted the loading rate tables where disproportionately higher levels of system failure were occurring.

Acknowledgement

The authors would like to acknowledge the assistance of Russell G. Martin, PE, F.NSPE, Director, Subsurface Wastewater Program, Division of Environmental Health, State of Maine, in setting up the research project and his invaluable institutional memory of early state guidelines. The authors would also like to thank the Town of Cumberland, Maine, personnel for their friendly assistance and access to their database.

References

Dix, S., D. Hoxie, 2001. Analysis of Septic System Longevity in Maine. Fort Worth, TX: On-Site Wastewater Treatment Proceedings.: Ninth National Symposium on Individual and Small Community Sewage Systems.

Christopherson, S., D. Wheeler, J. Wittwer, T. Haeg. 2007. Field Comparison of Rock-Filled and Chambered Trench Systems. Baltimore, Maryland: NOWRA 16th Annual Technical Education Conference and Exposition,

Hufelder, G., K. Mroczka, S. Pradhan, M. Hoover, T. Stevens. 2007. Development of a Standard for Gravelless Trench Products - Results of a Pilot Protocol Series. Warwick, Rhode Island: Eleventh Individual and Small Community Sewage Systems Conference Proceedings.

King, L., Ph.D., NCLSS, M. Hoover, Ph. D., NCLSS, T. Hinson, RS, NCLSS, NCPG, R. Polson, CPSS, R. Everett, RS. 2002. Surface Failure Rates of Chamber and Traditional Aggregate-Laden Trenches in Oregon. In: *Small Flows Quarterly, Fall 2002, Volume 3, Number 4*

Maine Department of Human Services, Bureau of Health, Division of Health Engineering, Site Evaluation for Subsurface Wastewater Disposal Design in Maine, Revised April, 2001 Third Edition

Maine Subsurface Waste Water Disposal Rules 10-144 CMR 241, August 1, 2005

Martin, R. G. 2004. The Maine Experience – Subsurface Wastewater Treatment and Dispersal Trends – 1984 to 2003. Albuquerque, NM: National Onsite Wastewater Recycling Association In: *Conference Proceedings, 13th Annual Conference and Exposition, Albuquerque, New Mexico, November 7-11, 2004.*

Uebler, R., P. Beusher, M. Avery, B. Ogel, K Arrington, and B. Grimes. 2006. Performance of Chamber and EZ1203H Systems Compared to Conventional Gravel Septic Tank Systems in North Carolina. Denver CO: National Onsite Wastewater Recycling Association

Appendix 1- Maine 1978 loading rate table, as implemented by the Town of Cumberland

TABLE 6-1

SOIL PROFILE and CONDITION versus DISPOSAL AREA SIZE

PARENT MATERIAL	SOIL PROFILE	TEXTURAL CLASSIFICATION and DESCRIPTIONS	SOIL CONDITIONS: SHALLOW to BEDROCK A BEDROCK I less than 10"	II +10" – −15"	III between [15-40"]	DRAINAGE: B WELL DRAINED Ground Water Table greater than 40"	C MODERATELY WELL DRAINED Ground Water Table between [40" to 15"]	D SOMEWHAT POORLY DRAINED Ground Water Table between [−15" to 6"]	E VERY POORLY DRAINED Ground Water Table less than 6"	DISPOSAL AREA RATING SEC. 12
GLACIAL TILL	1	Silt loam soils which tend to become more more compact with depth and may have a restrictive layer. Angular coarse fragments may be present.		4	2	1	1	3	4	LARGE
GLACIAL TILL	2	Loam to sandy loam soils. Angular coarse fragments may be present.		4	2	1	1	3	4	MEDIUM LARGE
GLACIAL TILL	3	Loam to sandy loam soils with a restrictive layer at depths of (12" - 30"). Angular coarse fragments may be present.		4	2	1	1	3	4	MEDIUM LARGE
GLACIAL TILL	4	Sandy loam to loamy sand. Soils derived from ablation till. Coarse fragments (angular or rounded) may be present.		4	2	1	1	3	4	MEDIUM
STRATIFIED DRIFT	5	Loam to sandy loam soils overlying stratified fine and medium sands. Rounded coarse fragments may be present.		4	2	2	2	3	4	MEDIUM
STRATIFIED DRIFT	6	Loamy sand soils overlying stratified coarse sands and gravel. Round coarse fragments may be present.		4	2	2	2	3	4	SMALL
MIXED ORIGIN	7	Loamy sand to sand overlying a restrictive layer of silt to silty clay which occurs at a depth of 15 inches or greater. Coarse fragments may be present in upper horizons but usually absent in lower horizons.		4	2	1	1	3	4	MEDIUM LARGE
LACUSTRINE MARINE	8	Loam to fine sand overlying firmer silt loam to silt. A restrictive layer may be present. Coarse fragments usually absent. Stratified lenses of very fine sand, silts and clays may be present in the substratum.		4	2	1	1	3	4	LARGE
LACUSTRINE MARINE	9	Silt loam soils overlying firm silt loams to silty clays exhibiting a restrictive layer. Fragments are usually absent.		4	2	1	1	3	4	EXTRA LARGE
ORGANIC	10	Soils are composed of organic materials in various stages of decomposition.								
ALLUVIAL, DUNE, BEACH	11	Variable in texture. Exhibiting very little weathering. Deposited in flood plain, sandy dune or beach environment.				5	5			SEC. 11.F 11.G

ALL SYSTEMS PERMITTED

Note 1 See 11.C.2.a for Separation Distances.

Note 2 See 11.C.2.b for Separation Distances.

Severe Limitations REPLACEMENT SYSTEMS MAY BE PERMITTED (Sec.15)

Note 3 See 15.A for Replacement System Variance by LPI. See 11.C.2.a & 11.C.2.b for Separation Distances.

Very Severe Limitations REPLACEMENT SYSTEMS MAY BE PERMITTED if no alternative. NEW SYSTEMS NOT PERMITTED.

Note 4 See 15 for Replacement System Variance with Department Review. See 11.C.2d for Separation Distances.

Extremely Severe Limitations. SYSTEMS NOT PERMITTED

Note 5 See 11.F for Coastal Sand Dune limitations. See 11.G for Flood Plain limitations.

DIS[POSAL AREA RATING	BED AREA	CHAMBER AREA	TRENCH LENGTH
Small	1.3 sq ft/GPD	0.7 sq ft/GPD	0.4 lin ft/GPD
Medium	2.6 sq ft/GPD	1.3 sq ft/GPD	0.9 lin ft/GPD
Medium Large	3.3 sq ft/GPD	1.7 sq ft/GPD	1.1 lin ft/GPD
Large	4.1 sq ft/GPD	2.0 sq ft/GPD	1.4 lin ft/GPD
Extra Large	5.0 sq ft/GPD	2.5 sq ft/GPD	1.7 lin ft/GPD

Appendix 2 - Letter on History of Gravel and Chamber Sizing in Maine

The following three tables list the early sizing criteria for trenches, beds, and concrete chambers. The so-called Type A was the ameration chamber 45 SF per unit and the Type F was the flowdiffusor 32 SF per unit.

July 1974

Soil Class	Trenches (LF)	Beds (SF)	Chamber A(SF)	Chamber F (SF)
Very Small	84	250	180	160
Small	100-133	300-400	225	192
Medium	166-200	500-600	360	320
Medium Large	233-300	700-900	495	480
Large	Not Permitted	1200-1500	Not Permitted	Not Permitted
Extra Large	Not Permitted	Not permitted	Not permitted	Not permitted

June 1975

Soil Class	Trenches (LF)	Beds (SF)	Chambers (SF)
Very Small	65	300	177
Small	85	400	204
Medium	185	800	355
Medium Large	250	1000	477
Large	Not Permitted	1400	Not Permitted
Extra Large	Not Permitted	Not Permitted	Not Permitted

May 1978

Soil Class	Beds (SF/GPD)	Chambers (SF/GPD)
Small	1.3	0.7
Medium	2.6	1.3
Medium Large	3.3	1.7
Large	4.1	2.0
Extra Large	5.0	2.5

Russell G. Martin, PE, F.NSPE
Director, Subsurface Wastewater Program
Division of Environmental Health
286 Water Street
Augusta, Maine 04333-0011
207 287-4735
207 287-3165 FAX
russell.martin@maine.gov

Field Evaluation of Wastewater Soil Absorption Systems with Aggregate-Free and Aggregate-Laden Infiltrative Surfaces

Final Report

Prepared By

Robert L. Siegrist[1] Sheila Van Cuyk[2] Sarah Masson[2] Elizabeth Fischer[2]

of

Environmental Science & Engineering Division
Colorado School of Mines
112 Coolbaugh Hall
Golden, Colorado 80401

for

Infiltrator Systems, Inc.
Old Saybrook, Connecticut

Draft version, v4.0, prepared on January 28, 2000
Final version, v5.0, published on May 11, 2000

---

[1] Associate Professor, Environmental Science & Engineering, Colorado School of Mines, Golden, CO 80401-1887
Tel. 303.273.3490, Fax. 303.273.3413, email: siegrist@mines.edu http://www.mines.edu/~rsiegris
[2] Graduate Research Assistants, Environmental Science & Engineering, Colorado School of Mines, Golden, CO 80401

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS AND ABBREVIATIONS

$A_{I.S.}$	-	area of the infiltrative surface
BG	-	background
bgs	-	below ground surface
BKGD	-	background
BOD_5	-	biochemical oxygen demand at 5-days
$cBOD_5$	-	carbonaceous biochemical oxygen demand at 5-days
CSM	-	Colorado School of Mines
cha	-	chamber
cfu	-	colony forming unit
CV	-	coefficient of variation
D	-	depth
dw	-	dry weight
ESE	-	Environmental Science & Engineering Division
FC	-	fecal coliforms
gra	-	gravel
HLR	-	hydraulic loading rate
ID	-	identification
I.S.	-	infiltrative surface
ISI	-	Infiltrator Systems, Inc.
MS-2	-	bacteriophage that infects *E. coli.*
nd	-	nondetectable
ND	-	no data
Ne	-	effective porosity
PBS	-	phosphate buffered saline solution
pfu	-	plague forming unit
PRD-1	-	bacteriophage that infects *Salmonella typhimurium*
SCS	-	Soil Conservation Service
STE	-	septic tank effluent
Q	-	flow rate
TBD	-	to be determined
T_r	-	travel time required
TNTC	-	too numerous to count
TOC	-	total organic carbon
USDA	-	U.S. Department of Agriculture
WSAS	-	wastewater soil absorption system

ACKNOWLEDGMENTS

This report describes the methods and results of a field study and ancillary laboratory studies completed in Colorado to evaluate the field performance of wastewater soil absorption systems including both aggregate-free (chamber) and aggregate-laden (gravel) designs. This work was made possible by the contributions and support of several individuals and organizations. The work was sponsored in large part by Infiltrator Systems, Inc. and ISI is acknowledged for their interest and support in advancing the state-of-knowledge regarding onsite wastewater system design and performance. This study would not have been possible without the participation and cooperation of the homeowners at the 16 individual residences studied. In addition, the following individuals are recognized for their contributions and valuable support:

Steve Dix	-	Infiltrator Systems, Inc., Old Saybrook, CT
Jim Bransfield	-	Infiltrator Systems, Inc., Denver, CO
Jim Rada	-	Summit County Environmental Health Dept., Frisco, CO
Ed O'Brien	-	O'Brien & Assoc., Inc., Dillon, CO
Bob Polich	-	Mountain Systems, Inc., Frisco, CO
Warren Brown	-	Tri-County Health Department, Northglenn, CO
Deanne Kelly	-	Tri-County Health Department, Northglenn, CO
Andy Logan	-	Colorado School of Mines, Golden, CO
Rich Harnish	-	Colorado School of Mines, Golden, CO
Brian Bradford	-	Colorado School of Mines, Golden, CO
Tricia Kletke	-	Colorado School of Mines, Golden, CO
Shiloh Kirkland	-	Colorado School of Mines, Golden, CO
Debbie Huntzinger	-	Colorado School of Mines, Golden, CO
Ron Harvey	-	U.S. Geological Survey, Boulder, CO
Dave Metge	-	U.S. Geological Survey, Boulder, CO
John Parsens	-	University of Wisconsin, Madison, WI

1.0 EXECUTIVE SUMMARY

This report discusses a field study completed at the Colorado School of Mines (CSM) that characterizes the hydraulic and purification performance of mature onsite wastewater systems (i.e., systems that have been in operation for more than one year), including systems with aggregate-free (chamber) and aggregate-laden (gravel) infiltrative surfaces. This work included a survey of 16 individual homes located near Silverthorne and Brighton, Colorado from May through December 1999. At 16 of the study sites, septic tank effluent (STE) was characterized, and at 14 of these sites, intact soil cores were successfully acquired and the soil properties were characterized with depth below the soil infiltrative surface. Effluent and soil core samples show constituent levels in the range of previously reported work. As expected, levels of nitrogen species and fecal coliform bacteria decreased with increased depth below the infiltrative surface. A large degree of variation in constituent concentrations was observed between individual systems and among duplicate cores taken within the same system. Analysis of the data revealed no significant differences between aggregate-free and aggregate-laden systems with respect to common measures used to assess hydraulic and treatment performance.

Ancillary testing was also conducted to establish a correlation between fecal coliform data collected from percolate water samples and that extracted from soil solids samples. Results in two different sand media suggest that samples of soil solids yield calculated percolate concentrations of fecal coliforms that are consistently higher than those directly measured in percolating water. This suggests that soil solids analysis can provide a conservative measure of fecal coliform bacteria in percolating soil solution.

This report also describes the methodology and results for evaluating the treatment of virus in an individual WSAS with an aggregate free infiltrative surface. During this test, two bacteriophages (MS-2 and PRD-1) and a conservative tracer (Br^-) were added to the STE before it was applied to the soil absorption system. Weekly samples of the STE were taken and characterized for the surrogate and tracer concentrations. Twenty-five days following the first addition of the surrogates and tracer, soil core samples were taken and analyzed for the added constituents. Removal of the added bacteriophages was estimated to be 3-logs between the infiltrative surface and 60-cm depth. Comparison of the concentrations of fecal coliforms to the bacteriophages measured in the same soil core samples revealed that the presence of fecal coliforms was directly and strongly correlated with the presence of MS-2 and PRD-1 virus.

The results of this study suggest that aggregate-free systems in Colorado that are sized with 50% less infiltration area for a given design flow are performing comparably to the larger aggregate-laden systems. These field results are consistent with the results of intermediate-scale sand lysimeter studies performed previously at CSM (Van Cuyk et al., 1999; Siegrist et al., 1999). The lysimeter studies showed that the treatment performance of aggregate-free systems sized at 8.4 cm/d was comparable to aggregate-laden systems sized at 5.0 cm/d during the most sensitive period, that being startup through the first year of operation, even though the hydraulic loading rate of the former is approximately 67% higher based on gross soil infiltrative surface area.

2.0 INTRODUCTION

2.1. BACKGROUND

Wastewater treatment for onsite and small community applications commonly relies on infiltration and percolation of primary effluent through soil to achieve purification prior to recharge to ground water (U.S. EPA, 1978; 1980; 1997; Jenssen and Siegrist, 1990; Crites and Tchobanoglous, 1998) (Fig. 2.1). These wastewater soil absorption systems (WSAS) can achieve high purification efficiencies due to the complex interactions of hydraulic and purification processes (Fig. 2.2) (Schwagger and Boller, 1997; Ausland, 1998; McCray et al., 2000). Extensive and lengthy contact between wastewater constituents and the soil matrix and associated biofilms occurs during unsaturated flow achieved by daily loadings limited to a small fraction of the soil's saturated hydraulic conductivity (K_{sat}) (e.g., <5 cm/d). In addition, a clogging zone evolves at the soil infiltrative surface (Fig. 2.1 and 2.2) which leads to reduced permeability and more uniform infiltration and a concomitant unsaturated flow almost regardless of hydraulic loading. Wastewater-induced clogging increases the soil biogeochemical activity and can enhance sorption, biotransformation and die-off/inactivation processes within the clogging zone itself or in the underlying unsaturated soil (Siegrist, 1987; Siegrist et al., 1991; Ausland, 1998; Van Cuyk et al., 1999; McCray et al., 2000). Clogging zone genesis has been described as a humification-like process and modeled as a function of the mass loading rates of wastewater suspended matter and bio-oxidizable substances (Siegrist, 1987; Siegrist and Boyle, 1987). In most WSAS, clogging zone genesis must occur to some degree to foster the advanced purification required before ground water recharge, but not to the point where it causes hydraulic problems.

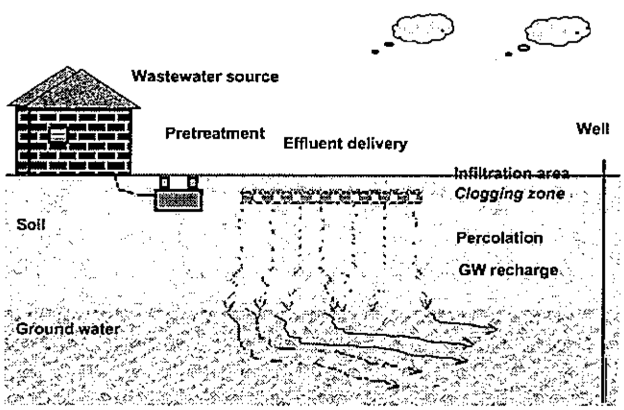


Fig. 2.1. Illustration of an onsite wastewater soil absorption system typical of the 25 million systems in operation in the U.S. today.

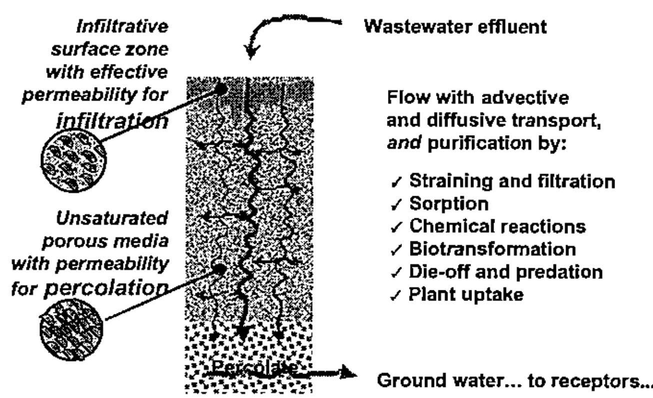


Fig. 2.2. Illustration of hydraulic and purification processes operative in a wastewater soil absorption system.

If clogging zone development is retarded or absent altogether, for example due to the application of highly pretreated effluent (e.g., sand filter effluent), purification of pathogens and other constituents of concern may be less than predicted and desired. Conversely, if soil clogging is too excessive, for example due to application of high strength effluents (e.g., restaurant wastewater), clogging can be detrimental by causing hydraulic dysfunction and soil anaerobiosis and reduced purification (e.g., slower organic matter breakdown and reduced nitrification).

System physical features, operational parameters, and environmental conditions can determine hydraulic and purification behaviors in wastewater infiltration systems. As briefly described below, the infiltrative surface character and the underlying unsaturated soil depth above a ground water table (a.k.a., vadose zone), are two system features that are commonly determined during design. The soil infiltrative surface is normally located below the original ground surface and commonly has a 15- to 30-cm thick layer of 2- to 4-cm diameter gravel placed on it to provide storage for peak wastewater flows and to support the overburden soils (Fig. 2.1). Performance data regarding the rate and extent of soil clogging in systems with gravel on the infiltrative surface (aggregate-laden) led to system designs that avoid the use of gravel aggregate (e.g., open chamber, fabric-wrapped piping, plastic media, fabric bundles). The most common type of system that provides an open or aggregate-free surface involves the use of chambers (Keys, 1996; May, 1996; Tyler et al., 1991).

Gravel on an infiltrative surface can reduce infiltration zone permeability (or infiltrability) by (1) blocking pore entries, (2) becoming embedded in the soil matrix, (3) yielding fines that are deposited in pore entries, or (4) focusing wastewater constituents as a result of the reduced permeability due to the effects of (1)-(3) (Amerson, et al., 1991; Jenssen and Siegrist, 1990; Siegrist, 1987; Siegrist and Boyle, 1987; Siegrist et al., 1991; Tyler and Converse, 1994). Based on an equivalency concept with respect to infiltrability, aggregate-free systems are being utilized with design infiltration areas (i.e., gross total area provided) on the order of 40% less than required with aggregate-laden systems. While keeping the daily loading rate onto the open or effective infiltrative area the same (i.e., that surface not masked or impacted directly by gravel), this strategy does increase the relative hydraulic loading rate on the gross infiltration area by 67%. While previous experience with aggregate-free systems has revealed satisfactory hydraulic performance (May, 1996; England and Dix, 1999), until recently, comparatively less experimental data has existed regarding purification performance (Van Cuyk et al., 1999).

The depth of the soil vadose zone to ground water can affect hydraulic function and in turn purification by influencing the soil water content, aeration status, media surface area, and hydraulic retention time. In the U.S., depths for soil infiltration systems range from 0.6 to 1.2 m and for intermittent sand filters, from 0.6 and 0.9 m (US EPA, 1980; Anderson et al., 1985; Crites and Tchobanoglous, 1998). While a high degree of treatment normally occurs in the infiltration zone as soil clogging develops, at higher hydraulic loading rates and with nonuniform distribution methods, constituents of concern that would normally be treated can be transported through the vadose zone to ground water. For example, many studies have shown that a large percentage of bacteria remain near the infiltrative surface when effluents are applied to porous media (Brown et al., 1979; Kristiansen, 1991; Smith et al., 1985; Huysman and Verstraete, 1993; Emerick et al., 1997; Stevik et al., 1999). However, if hydraulic loading rates are too high or the dosing frequency is too low, some microbes can be transported to lower regions in a soil matrix, posing a purification concern in systems that are too shallow to ground water. Alternatively, while depth is important to hydraulic and purification behavior, at some point there is limited gain in purification by increasing vadose zone depth (Peeples et al., 1991).

In Colorado, wastewater soil absorption systems (WSAS) are designed based on long-term acceptance rates (LTAR) and a design flow estimated at 225 gpd/bedroom (based on 75 gpcd * 2 per/bedroom* 150% peaking factor). The LTAR ranges are typical of those reported in the literature and used in other state codes (e.g., fine to loamy sand w/ 6-10 minute per inch (MPI) percolation test = 1.2 gpd/ft^2, sandy loam to loam w/ 11-20 MPI = 0.72 gpd/ft^2, loam w/21-30 MPI = 0.50 gpd/ft^2, silt loam to sandy clay loam w/ 31-40 MPI = 0.40 gpd/ft^2, etc.). Thus, design application rates in Colorado are mostly in the range of 0.40 to 1.2 gpd/ft^2. The required distance between the bottom of an infiltration trench or bed and high ground water is 4 ft. Regulations allow infiltration area to include sidewall area (below the distribution pipe) and bottom area. The State allows a 50% reduction in the standard infiltration area sizing of WSAS's when Infiltrator chambers are used. As of Fall 1999, there were about 26,000 Infiltrator chamber systems installed in Colorado since the first installations occurred in 1991.

2.2. GOALS, OBJECTIVES AND SCOPE

Research was initiated in the Environmental Science & Engineering Division at the Colorado School of Mines (CSM) to study the hydraulic and purification behavior of wastewater soil infiltration systems from start-up through initial clogging zone development and to quantify the effects of infiltrative surface character and vadose zone soil depth. The entire research effort is comprised of controlled laboratory experimentation with 3-dimensional lysimeters, field monitoring of mature soil infiltration systems, and transport/fate and process modeling. The methods and results of the 3-D lysimeter studies are described in previous publications and forthcoming papers (e.g., Fischer, 1999; Masson, 1999; Van Cuyk et. al., 1999; Siegrist et al., 1999). Results of these 3-D laboratory lysimeter studies completed in 1999 revealed that the performance of aggregate-free systems was comparable to aggregate-laden systems, even though the hydraulic loading rate of the aggregate-free system is 67% higher (i.e., 8.4 vs. 5.0 cm/day, respectively, based on gross horizontal area provided). For both system types, it was shown that a 60- to 90-cm depth to groundwater provided adequate depth of unsaturated media for purification of conventional pollutants (e.g., $cBOD_5$, suspended solids, ammonia nitrogen) as well as bacteria and virus to occur.

Field studies were initiated during late 1998 and intensive sampling and analysis was completed during the fall of 1999. These studies were designed to complement the lysimeter studies by focusing on infiltration of domestic STE in more mature soil absorption systems under field conditions. At each of 14 to 16 onsite WSAS that had been in operation for one year or longer, wastewater effluent quality being applied to the soil and the corresponding constituent concentrations with soil depth below the infiltrative surface were characterized through sampling and analyses. Completion of the field studies was intended to provide insight into the comparative performance of aggregate-free versus aggregate-laden systems after maturity is reached and incipient or continuous ponding is present. The field studies described herein were completed in two parts:

(1) Monitoring of 16 systems of which 10 were Infiltrator chambers and 6 were gravel systems. Data collected included residence characteristics, system design features, STE composition, occurrence and depth of ponding of the infiltration surface, and chemical and bacterial characteristics with depth below the infiltrative surface.

(2) Evaluation of virus treatment in one of the study sites using a conservative tracer (Br^-) and two viral surrogates (MS-2 and PRD-1 bacteriophages).

This report describes the methods and results of this field work. Section 3 contains a description of the monitoring of field WSAS's for physical properties and chemical and bacterial treatment while Section 4 summarizes the virus treatment study. Section 5 presents the conclusions and recommendations derived from the work.

3.0 MONITORING OF HYDRAULIC AND TREATMENT PERFORMANCE

3.1. TECHNICAL APPROACH AND METHODS

3.1.1. Home Identification and Characteristics

Study subdivisions in Colorado were identified based on individual expressions of interest to collaborate with the CSM research team by county environmental health department staff as well as subdivision developers and homeowner's associations. The two study areas identified included the Hamilton Creek subdivision in Summit County, Colorado and the Todd Creek Farms subdivision in Adams County, Colorado. The Hamilton Creek subdivision is located approximately 60 miles west of Denver, near the town of Silverthorne and is at an elevation of ~9,000 feet. Todd Creek Farms subdivision, located 40 miles northeast of Denver, is at an elevation of ~5,000 feet.

Working with the environmental health departments in Summit County and Tri-County, Colorado, individual homes within each of the two study subdivisions were identified by letters of invitation to participate and by support from key subdivision persons (e.g., president of homeowners association). Homeowner questionnaires were used to gather information regarding (1) dwelling occupancy and water using and waste generating fixtures and (2) general soil absorption system design features. General screening criteria were established so the study would include individual wastewater systems that were: designed and installed according to modern practice; between 1 and 10 years old; and loaded at ≥25 to 50% of the design flow capacity. Detailed information regarding the onsite system site evaluation, design, and installation was gathered from county records, as-built construction drawings and interviews with homeowners, as well as field observations.

In the Hamilton Creek subdivision, a pool of systems were identified that had been in operation for periods of 1 to 5 years or longer and included both aggregate-free Infiltrator chamber systems and aggregate-laden gravel systems. A total of 11 systems were sampled in Hamilton Creek, including 7 with chambers and 4 with gravel at the infiltrative surface (Table 3.1). For all of the homes in Hamilton Creek, STE samples were collected and at 9 of these homes, soil cores were taken and analyzed. In the Todd Creek Farms subdivision, a total of 5 homes were monitored, including 3 with chambers and 2 with gravel at the infiltrative surface (Table 3.1). At all of these homes, STE samples and soil cores were collected.

All of the onsite systems included septic tank pretreatment with a dosed (but not uniform, pressure distribution) application of STE to WSAS trenches or narrow beds. Some characteristics of the homes and their onsite systems are summarized in Table 3.1 while a photograph of a Hamilton Creek home is shown in Figure 3.1.

Table 3.1. Selected characteristics of onsite wastewater systems monitored in this study.

Home site[1] ID	Res. size (BR)	Water use (gal/mon)	Date of system installation	Infiltrative surface (I.S.) type	Area of I.S. (ft^2)	Est. HLR[2] (cm/day)	Ponded	STE samples (no.)	Soil core
1	4	6083	1995	Chamber	600	1.4	No	2	Yes
2	3	7785	1991	Chamber	396	2.7	Yes	2	Yes
3	6	5150	1988/97[3]	Gravel	558	1.2	No	2	Yes
4	4	7625	1988	Gravel	1680	0.6	Yes	1	No
5	5	7008	1994	Chamber	528	1.8	No	2	Yes
6	4	4167	1991	Chamber	735	0.8	ND	1	No
7	3	5191	1989	Chamber	930	0.8	Yes	1	Yes
8	2	2058	1989	Gravel	651	0.4	Yes	2	Yes
9	3	2308	1994	Chamber	738	0.4	No	1	Yes
10	4	5350	1992	Gravel	864	0.8	Yes	1	Yes
11	4	8500	1990	Chamber	393	2.9	Yes	1	Yes
12*	3	7550	1997	Chamber	2244	0.4	No	2	Yes
13*	3	-	1996	Gravel	1680	-	Yes	1	Yes
14*	4	-	1997	Chamber	TBD	-	Yes	1	Yes
15*	3	9400	1997	Gravel	1536	0.8	No (wet)	1	Yes
16*	3	9880	1998	Chamber	2208	0.6	Yes	1	Yes

[1] * denotes homes located in Brighton, CO.
[2] HLR = flow (gpd)/area of infiltrative surface (ft^2) where 1 cm/d = 0.24 gpd/ft^2.
[3] After a system hydraulic failure, a new soil infiltration system was installed in 1997.

Fig. 3.1. Study home in Hamilton Creek subdivision in Summit County, Colorado.

3.1.2. Evaluation and Monitoring Methods

Soil Characteristics. General soil characteristics for the two subdivision locations were initially assessed from USDA Soil Conservation Survey (SCS) reports (USDA, 1974; 1977). Soils in the Hamilton Creek subdivision near Silverthorne were reported to consist of Anvik and Frisco soils (mixed Boralfic and mixed Typic Cryoborolls) of deep, well drained material formed in colluvium and glacial drift derived from a variety of rocks (USDA, 1977). These soils are on mountainous uplands that have slopes of 6-35%. The typical soil profile includes a brown loam surface layer (0-15 in., 0-38 cm) with a subsoil of clay loam (15-20 in., 38-51 cm). The depth to bedrock is >5 ft. (1.5 m) and depth to high ground water is > 6 ft. (1.8 m). Rock fragments (10-24 in. (25-60 cm) diameter) make up 30-80% of the solum. Soils in the Todd Creek Farms subdivision near Brighton consist of nearly level to strongly sloping, well drained Platner and Ulm loams (fine, montmorillonitic mesic soils) (USDA, 1974). The typical soil profile includes a heavy loam surface layer (0-7 in., 0-18 cm), with a subsoil of silty clay (7-13 in., 18-33 cm) and a substratum of clay (13-22 in., 33-56 cm). It is listed by SCS as having slow permeability and an average depth to bedrock of 40 to 60 in. (1-1.5 m).

Soil samples collected from the depths of the infiltrative surface in the two subdivisions were analyzed for grain size distribution and these results revealed a coarse-grained soil texture which included considerable pebble and cobble fractions. As shown in Fig. 3.2, the grain size analyses revealed <10 wt.% of the soil was in the silt and clay fraction (i.e., wt.% passing through a no. 200 sieve which is 0.074 mm diameter).

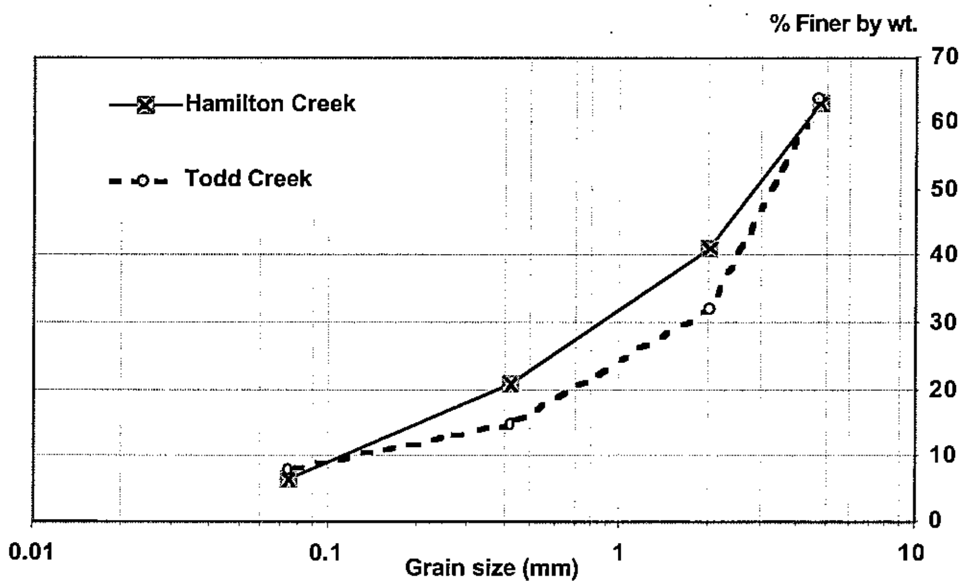


Fig. 3.2. Grain size distributions for soil samples collected from the infiltrative surface depths at study sites in two subdivisions monitored in Colorado.

Wastewater Flow and Hydraulic Loading Rate. Water use data were collected via water use records and/or periodic readings of water meters at each home. The water use data were assumed to be representative of wastewater flow. The flow data were used along with the WSAS area determined from the as-built plans to calculate the estimated hydraulic loading rate (HLR) in gpd/ft^2 that each WSAS was actually receiving (see Table 3.1).

Septic Tank Effluent Sampling and Analysis. Septic tank effluent was collected from the dosing chamber or from within the baffle in the last compartment of the septic tank. Grab samples were taken and placed in sterile polypropylene bottles and stored at 4C until brought to the laboratory for analysis. Two STE samples were collected from most sites at least 7 days apart. All laboratory analysis of the STE was performed within 24 hours of sample collection. The following characteristics of the STE were determined following standard methods (APHA, 1998).

- o pH was measured electrometrically.
- o Alkalinity was measured (total alkalinity) via titration with sulfuric acid according to APHA method 2320B.
- o $cBOD_5$ (carbonaceous biochemical oxygen demand) was measured according to APHA method 5210B.
- o COD analysis was performed using a Hach reactor digestion, colorimetric method (Hach 1992, U.S. EPA-approved).
- o Total solids and total suspended solids were measured according to APHA methods 2540B and 2540D.
- o Total nitrogen (TN) was measured by persulfate digestion, nitrate nitrogen by chromotropic acid method and ammonium by salicylate method (Hach 1992, U.S. EPA-approved).
- o Total phosphorus (TP) was measured according to EPA acid persulfate method (U.S. EPA 365.2).
- o Fecal coliform analysis was performed by membrane filtration according to APHA method 9222D. All dilutions plated in duplicate.

WSAS Soil Coring, Sampling and Analysis. The WSAS was probed at two spatially separate locations using double casing and thin-tube sampling methods. This entailed hand excavation from ground surface to the top of a chamber or gravel trench (see Figs. 3.3 and 3.4). In the case of a chamber, an access hole was cut in the top of the chamber. With a gravel system, hand excavation was completed to the top of the gravel. In either case, when any ponding was present, a steel stove-pipe or PVC plastic pipe was used to case the hand excavation hole. To enable penetration through the gravel, the casing was gradually driven down and aggregate was removed with a post-hole digging tool. The occurrence and magnitude of ponding within the system was manually determined.

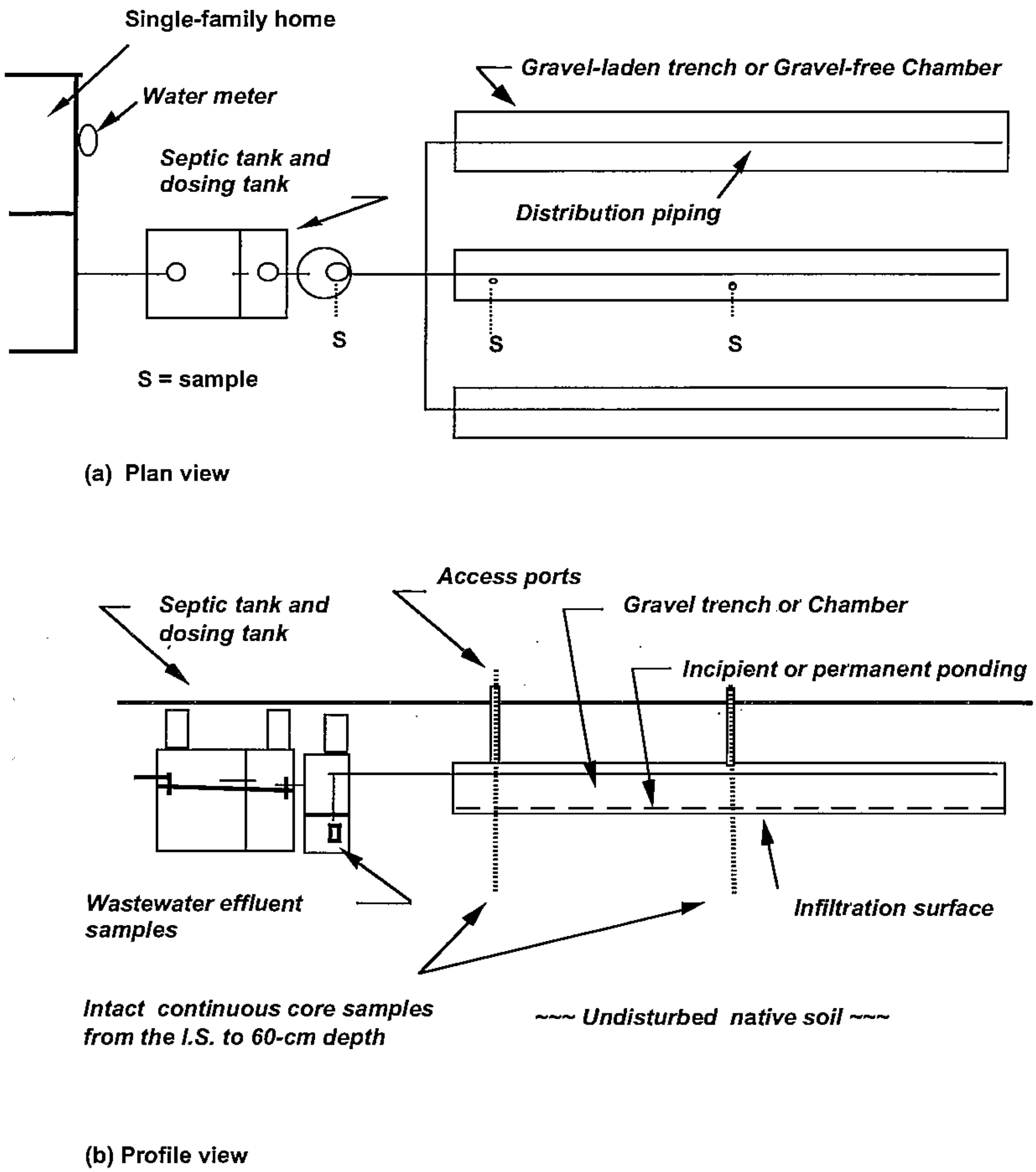


Fig. 3.3. Illustration of the general field site monitoring locations.

Fig. 3.4. Hand excavation from ground surface to the top of a chamber system in Summit County.

Care was taken upon encountering the soil infiltrative surface to avoid unnecessary disruption of the surface soil and any clogging layer. Then, a thin-tube sampling probe with a precleaned stainless steel or acetate liner (2 in. diam. by 6 in. long) was driven into the undisturbed soil and an intact core was retrieved within the sleeve. The core was capped with plastic end caps, labeled, and placed in a cooler containing blue ice. The casing was driven further into the probe hole and then the push probe (after cleaning with 90% v/v ethanol in water followed by a deionized water rinse) was inserted into the probe hole and driven another depth interval (nominally 16 cm or 6 in.). This process was repeated until a depth of 24 to 30 in. (60 to 75 cm) was reached or cobbles and dense soil prevented further penetration.

As just described, relatively intact core samples were aseptically collected from the WSAS infiltrative surface vertically downward to a depth of 60 to 75 cm below it. In addition, a background location outside of the infiltration area was also cored. Samples were then stored at 4C until laboratory analysis was performed at CSM. In the lab, the cores were carefully opened and the outer-most soil media was removed and wasted. Then, subsamples of the interior of the core were taken with sterile utensils at up to 4 intervals that corresponded approximately to those used in the CSM laboratory lysimeter study (Van Cuyk et al., 1999) (e.g., 0-5 cm, 10-15 cm, 25-30 cm, and 55-60 cm below the infiltrative surface). All laboratory analyses for water content and fecal coliform bacteria were performed within 24 hours of sample collection. After drying, soil samples were stored at 4C until analyses were made for organic matter and nutrients.

Analyses of field core subsamples were made for the following characteristics:

- o Soil color was recorded using the Munsell Color Chart.
- o Soil pH was measured on a 1:1 (solids:solution) extract using a calibrated pH electrode.
- o Water content was measured gravimetrically and recorded as percent dry weight.
- o Dried soil samples were also analyzed for organic matter, total nitrogen, ammonium, nitrate, available phosphorus. Results were expressed on a dry weight basis.
- o Fecal coliform analysis on soil core samples was performed aseptically in duplicate by taking a known weight (~4 grams) of moist soil and adding 40 mL of 1.5% beef extract solution to a yield a final dilution of ~1:10 (sand:beef extract). APHA method 9221A suggests extraction for coliform bacteria in sediments and sludges using 10% phosphate buffered saline (PBS). However, a comparison of extraction methods conducted at the bench scale at the CSM microbiology laboratory using 6 different extractants (including PBS) proved beef extract to be the most efficient method for removing the coliform bacteria (Masson, 1999). Following the addition of beef extract, samples were shaken for 2 minutes at 350 rpm and then allowed to settle for 1 minute at which time the liquid sample was analyzed. Early in the study, an aliquot of liquid (typically 1 mL) was withdrawn from mid-depth of a sterile 50 ml conical (Masson, 1999) and analyzed directly (for low levels) or diluted as needed (for high levels). Analyses for fecal coliform bacteria were made according to the membrane filtration method (APHA method 9222D). To reduce the method quantitation limit, all 40 mL of the extraction broth were filtered and analyzed for homes 8 to 16. All sample dilutions were plated in duplicate. Results are expressed as org./g soil, based on the dry weight of the soil.

3.1.3. Ancillary Study of Soil Solid vs. Soil Percolate Fecal Coliform Measurements

Controlled laboratory experiments were conducted using known concentrations of *E.coli* bacteria applied to sand or silty sand to determine the relationship between microbial densities estimated in percolating soil water based on analysis of soil solids (e.g., from a soil core) as compared to those measured directly in collected percolate water (e.g., as measured in a pan lysimeter). This information was deemed necessary for an understanding of how results obtained from soil cores correlate to levels of bacteria being transported in soil water. It was hypothesized that solids samples should yield calculated percolate concentrations of fecal coliforms that are always equal to or higher than those measured directly in percolating water. Tyler and Converse (1998) acknowledged that there were no criteria established for soil systems and no current method for equating soil water values (org/mL) with soil-solids extracted values.

Experiments were conducted in mini-columns (50-mL polypropylene syringe barrels) filled with low organic content (TOC= 0.017% dry weight) clean medium sand (d_{10} =0.22 mm, d_{60} =0.60 mm) with *E.coli* added at 10^5 cfu/ml in sterile phosphate buffered saline (PBS) solution. The columns were dosed four times daily (every 6 hours) in an automated fashion at total hydraulic loadings of approximately 5 cm/day. A second column experiment was run under the same conditions using a different sand media that contained a higher organic carbon content (TOC= 0.225% dry weight).

3.2. RESULTS

3.2.1. WSAS Characteristics and Performance

WSAS Age and HLR. The chamber systems varied in age from 1 to 10 yr. while the gravel systems were 2 to 11 yr. old (Fig. 3.5). The estimated hydraulic loading rates averaged 1.31 cm/d for the chamber systems compared to 0.76 cm/d for the gravel systems (Fig. 3.6). For the chamber systems, 5 of the 10 exhibited some degree of effluent ponding while for the gravel 4 of 6 exhibited ponding. These data suggest comparable hydraulic performance with the chamber systems receiving a higher loading rate on average that was 70% higher (1.31 vs. 0.76 cm/d based on gross horizontal infiltrative surface area).

Septic Tank Effluent Composition. A total of 16 individual onsite systems were monitored including 10 with chambers and 6 with gravel. Descriptive statistics for each subdivision are presented in Tables 3.2 and 3.3 while results for individual homes may be found in the Appendix (see Table A.1). The STE composition at the individual study homes was typical of residential STE containing appreciable concentrations of pollutants. In the Hamilton Creek development, the average concentrations were: BOD_5 = 175 mg/L, TSS = 258 mg/L, total N = 62 mg-N/L, total P = 7.7 mg-P/L, and fecal coliform bacteria = 4×10^6 to 6.3×10^6 cfu/100mL. Table 3.4 presents a synopsis of some literature values, allowing a comparison of the STE composition determined in this study to previously reported values.

WSAS Soil Coring and Analyses. A total of 14 WSAS (9 chamber and 5 gravel systems) were successfully sampled wherein a set of soil cores were taken at each site. Some of the systems were continuously ponded while others were not. In general, coring was difficult and time consuming due to common problems with field monitoring (e.g., locating subsurface system boundaries, system depth, rocky soil). Detailed results for each WSAS may be found in the Appendix (Tables A.2 and A.3) while a summary of the results follow.

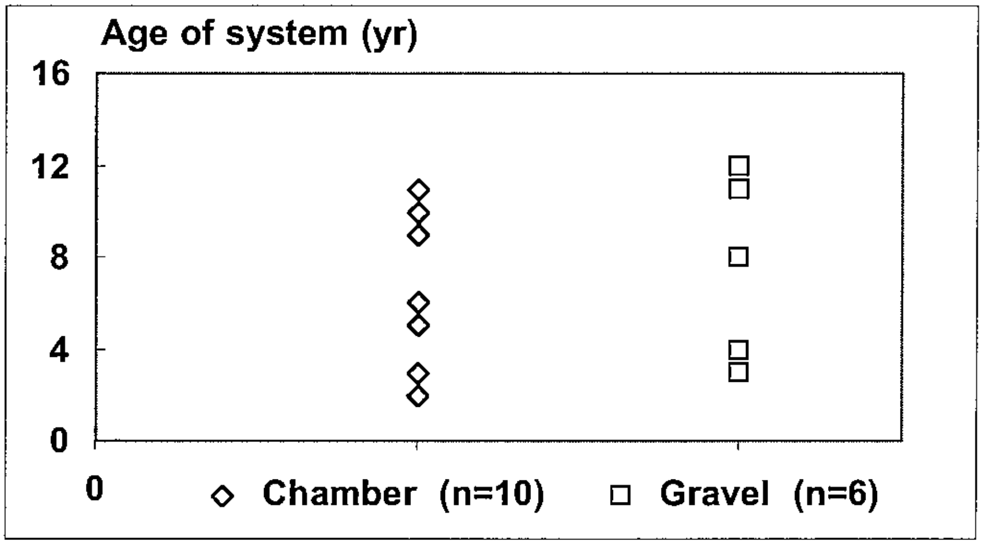


Fig. 3.5. Comparison of system age (yr.) for the wastewater systems studied.
Note that each symbol may represent more than one sample result.

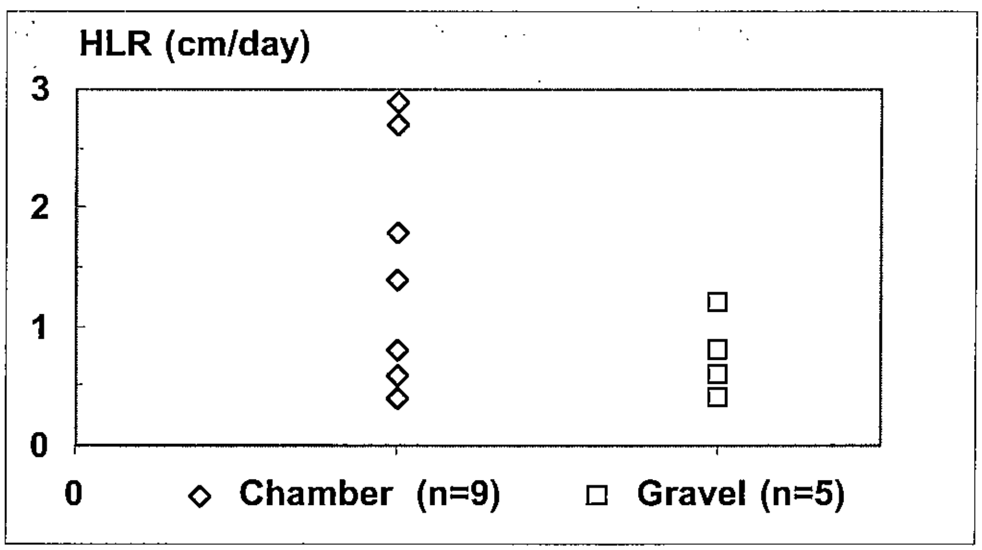


Fig. 3.6. Comparison of hydraulic loading rates for the WSAS's studied (1 cm/d = 0.24 gpd/ft^2).
Note that each symbol may represent more than one sample result.

Table 3.2. Descriptive statistics for septic tank effluent composition in Hamilton Creek.[1]

Parameter	Units	Average	Std. dev.	CV	No.	Minimum	Maximum
pH	-	-	-	-	16	6.95	7.94
Alkalinity	mg-$CaCO_3$/L	528	142	0.27	16	288	860
BOD_5	mg/L	175	52	0.30	14	98	358
COD	mg/L	260	165	0.63	16	109	990
TSS	mg/L	251	246	0.98	16	20	958
TN	mg-N/L	62	23	0.37	16	41	102
NH_3-N	mg-N/L	43	17	0.40	16	3	64
NO_3-N	mg-N/L	1.3	0.7	0.54	16	0.5	2.4
Total P	mg-P/L	7.7	2.0	0.26	9	5.7	11.1
Fecal coli.	cfu/100mL				16	4.00E+06	6.30E+06

[1] See Appendix Table A.1 for detailed results for each WSAS.

Table 3.3. Descriptive statistics for septic tank effluent composition in Todd Creek Farms.[1]

Parameter	Units	Average	Std.dev.	CV	No.	Minimum	Maximum
pH	-	-	-	-	5	7.05	8.04
Alkalinity	mg-$CaCO_3$/L	676	25	0.37	5	658	726
BOD_5	mg/L	332	46	0.14	3	385	301
COD	mg/L	496	303	0.61	5	170	825
TSS	mg/L	102	58	0.67	5	0	143
TN	mg-N/L	69	10	0.14	5	56	84
NH_3-N	mg-N/L	66	9.8	0.15	5	54	75
NO_3-N	mg-N/L	2	0.7	0.35	5	0.9	2.6
Total P	mg-P/L	10	2.4	0.24	5	6.25	11.95
Fecal Coli.	cfu/100mL				5	2.5E+05	1.3E+07

[1] See Appendix Table A.1 for detailed results for each WSAS.

Table 3.4. Comparison of STE composition in Hamilton Creek with literature values.[1]

Parameter (units)	Average	Std. dev.	Range	Reference
BOD_5 (mg/L)	175	52	98 to 358	This CSM study
	81	31	29 to 140	Tyler et al., 1991
			150 to 250	Crites & Tchobanoglous, 1998
	132			Harkin et al., 1979
COD (mg/L)	260	164	109 to 990	This CSM study
	157	46	49 to 244	Tyler et al., 1991
			250 to 500	Crites & Tchobanoglous, 1998
	445			Harkin et al., 1979
TSS (mg/L)	251	245	20 to 958	This CSM study
			40 to 140	Crites & Tchobanoglous, 1998
	87			Harkin et al., 1979
NH_4-N (mg-N/L)	43	17	3 to 64	This CSM study
	50	11	10 to 69	Tyler et al., 1991
	41		30 to 50	Crites & Tchobanoglous, 1998
NO_3-N (mg-N/L)	1.3	0.74	0.5 to 2.4	This CSM study
	0	0	0 to 2	Tyler et al., 1991
Total P (mg-P/L)	7.7	2.0	5.7 to 11.1	This CSM study
	17.3		12 to 20	Crites & Tchobanoglous, 1998
	7.3			Harkin et al., 1979
Fecal coli. (org/100mL)	2.14E+06		4.0E+04 to 5.1E+06	This CSM study
			1.0E+06 to 1.0E+08	Crites & Tchobanoglous, 1998
	1.00E+06			Harkin et al., 1979

[1] A blank cell indicates information not available.

Water content versus depth for the soil cores collected from all of the study homes is shown in Fig. 3.7. Water content is generally highest near the infiltrative surface and declines with increasing depth below it. Figure 3.8 presents ammonium-nitrogen and Fig. 3.9 presents nitrate-nitrogen data from soil cores samples by interval and by type of infiltrative surface (see Appendix Fig. A.1 for detailed nitrogen data for homes 2, 3 and 7). Fig. 3.10 presents available phosphorus data for the soil core samples. Ammonium-nitrogen and nitrate-nitrogen appear to be present throughout the sampling depths at each site, with highest levels at depths closest to the infiltrative surface. Tables 3.5 and 3.6 illustrate that the nitrogen data collected in this study are generally similar to the results reported in recent work of Tyler and Converse (1998).

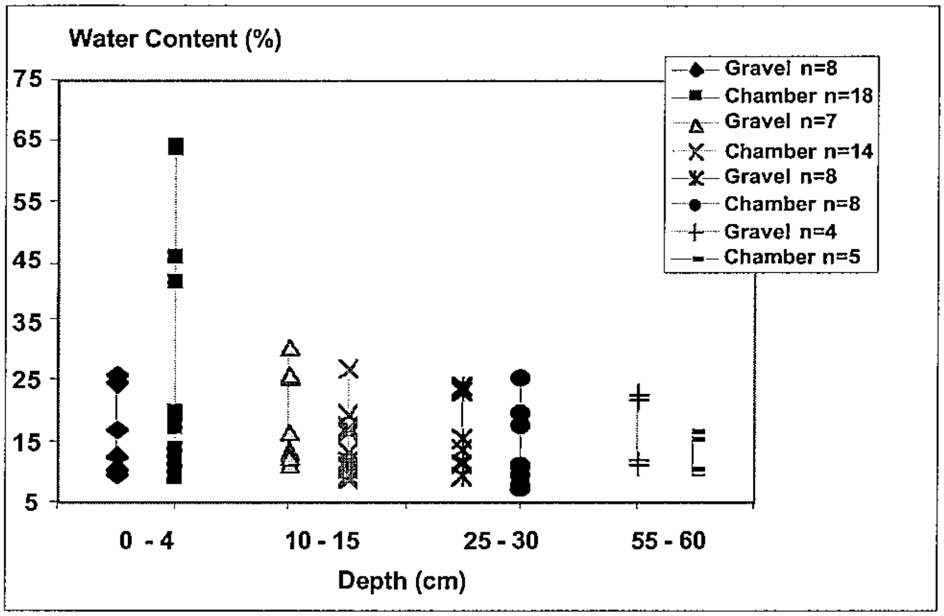


Fig. 3.7. Water content in soil core samples by depth below the infiltrative surface. Note that each symbol may represent more than one sample result and background soil core data are excluded.

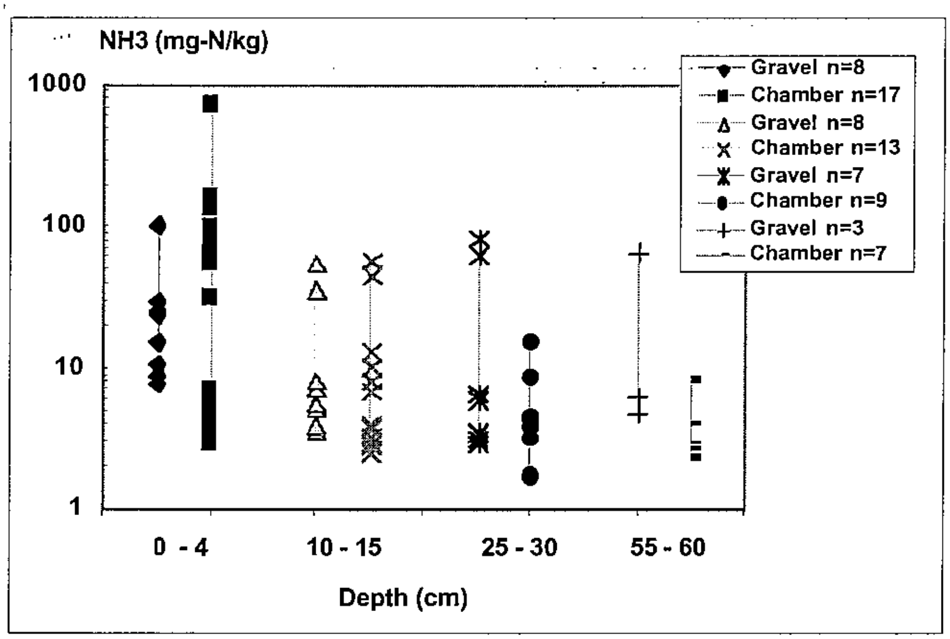


Fig. 3.8. Ammonium-nitrogen in soil core samples by depth below the infiltrative surface. Note that each symbol may represent more than one sample result and background soil core data are excluded.

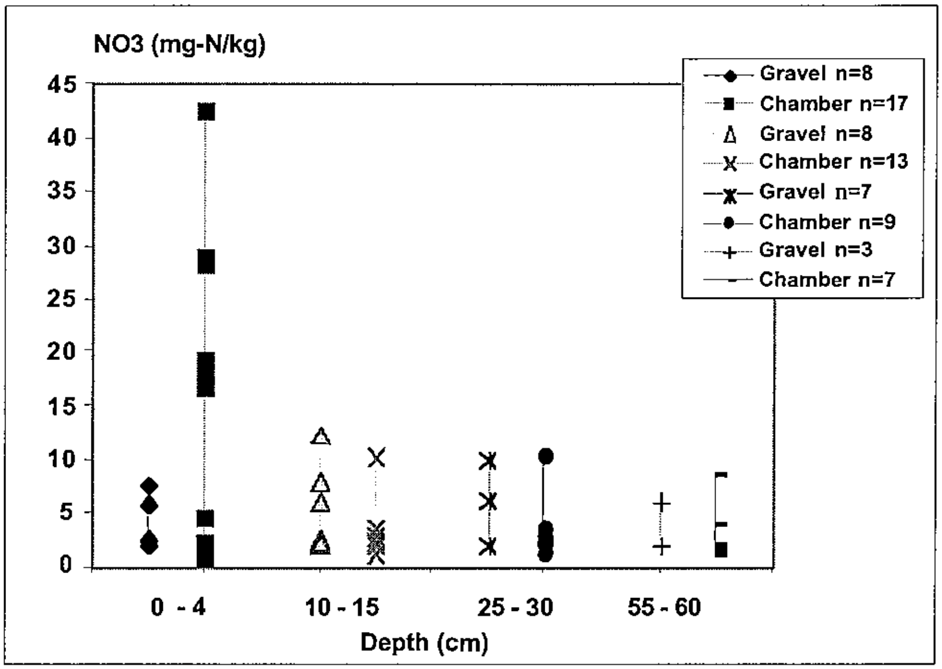


Fig. 3.9. Nitrate-nitrogen in soil core samples by depth below the infiltrative surface. Note that each symbol may represent more than one sample result and background soil core data are excluded.

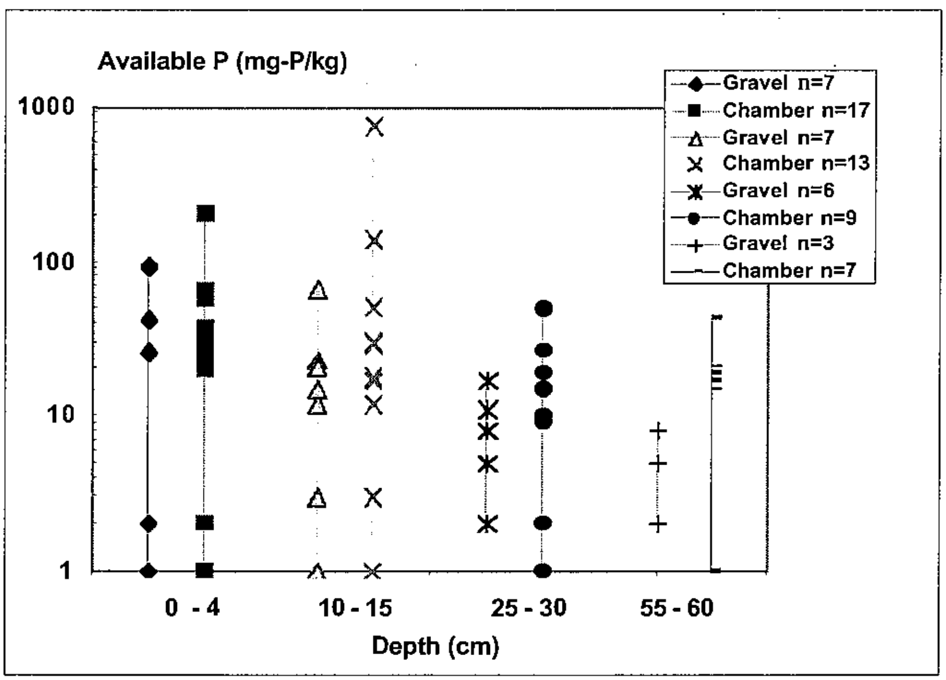


Fig. 3.10. Available phosphorus in soil core samples by depth below the infiltrative surface. Note that each symbol may represent more than one sample result and background soil core data are excluded.

Table 3.5. Summary of water content and nutrient concentrations with depth below soil infiltration systems receiving effluent during this study.

Soil depth (cm)	Ammonia (mg-N/kg dw) Average (range)	Nitrate (mg-N/kg dw) Average (range)	Water content (dry wt.%) Average (range)
0 – 5	64 (3 to 721)	8 (1 to 42)	18.4 (10 to 26)
10 – 15	14 (2 to 57)	5 (1 to 17)	16 (9 to 31)
25 – 30	13.5 (2 to 82)	3.3 (1 to 10)	15 (7 to 25)
55 - 60	11 (2 to 66)	3 (1 to 8)	15 (9 to 22)
BKGD 0 - 4	13.8	1 (0 to 2)	13 (8 to 18)
BKGD 10 - 15	8.4 (6 to 14)	0.8 (0.6 to 0.9)	10 (5 to 14)
BKGD Batch[1]	5.6 (3 to 9)	3 (2 to 8)	8 (2 to 21)

[1] Batch samples were collected at same depth as infiltrative surface and a 0-10 cm interval was mixed for sampling.

Table 3.6. Water content and nutrient concentrations with depth below soil infiltration systems receiving aerobically treated effluent (Converse and Tyler, 1998).

Soil depth (cm)	Ammonia (mg-N/kg dw) Average (range)	Nitrate (mg-N/kg dw) Average (range)	Water content (dry wt.%) Average (range)
0 – 15	4 (0 to 35)	7 (0 to 33)	12 (4 to 45)
15 – 30	13 (0 to 96)	9 (1 to 29)	22 (4 to 40)
30 – 45	11 (1 to 112)	8 (1 to 23)	22 (4 to 48)
45 – 60	7 (1 to 38)	8 (0 to 22)	21 (7 to 33)

The results for fecal coliform bacteria levels with depth are summarized in Table 3.7. Figure 3.11 provides a graphical summary of fecal coliform levels at soil coring depths for chamber versus gravel systems. As shown, the results for the chamber systems are comparable to those for the gravel systems. At most sites, fecal coliform concentrations declined with depth and by 30 to 60 cm depth, fecal coliform bacteria were very low or not detected (detection level of 1 org. per g soil) (see Table 3.7). A statistical comparison of the fecal coliform bacteria levels at 30-cm and 60-cm below the infiltrative surface in chamber systems versus gravel systems was made following a Mann-Whitney nonparametric test procedure (Minitab, Inc., 1995). This analysis revealed that the fecal coliform levels at both depths were not significantly different at 95% confidence (p=0.05).

Table 3.8 presents literature comparison values for soil core fecal coliform levels with depth below an infiltrative surface. Compared to the results of Converse and Tyler (1998) as summarized in Table 3.8, the fecal coliform results observed in this study are similar (see Tables 3.7 and 3.8). It is noted that the STE concentrations applied to the soil absorption systems in the CSM study were considerably higher, ranging from 250,000 to 1,300,000 org./100 mL compared to a maximum of 150,000 org./100 mL reported by Converse and Tyler (1998).

Table 3.7. Summary of fecal coliform concentrations with soil depth during this study.

Source	Units	Median	Min.	Max.	Samples
Wastewater	org/100 mL	-	250000	1300000	21
Soil @ depth (cm)					
0-4	org/g dw	53	4582	15000	22
10-15	org/g dw	27	1261	4028	19
25-30	org/g dw	< 1	3377	14029	17
55-60	org/g dw	19	925	2853	10
BKGD 0-4	org/g dw	< 1	< 1	< 1	4
BKGD 10-15	org/g dw	< 1	< 1	< 1	3
BKGD 25-30	org/g dw	< 1	< 1	< 1	1
BKGD 55-60	org/g dw	< 1	< 1	< 1	0
BKGD Batch [1]	org/g dw	< 1	< 1	< 1	17

[1] Batch samples were collected at same depth as infiltrative surface and a 0-10 cm interval was mixed for analysis.

Table 3.8. Fecal coliform concentrations with soil depth in sands/sandy loam soils reported by Converse and Tyler (1998).

Source	Units	Median	Average	Max.	Samples
Wastewater	org/100mL	1850	33778	150000	14
Soil @ depth (cm)					
0 – 2	org/g dw	2	83	798	20
2 – 15	org/g dw	5	40	482	28
15 – 30	org/g dw	2	22	216	28
30 – 45	org/g dw	<1	6	70	28
45 – 60	org/g dw	1	19	318	27
60 – 75	org/g dw	<1	7	120	25
75 – 90	org/g dw	<1	1	9	23
90 – 105	org/g dw	<1	1	5	22

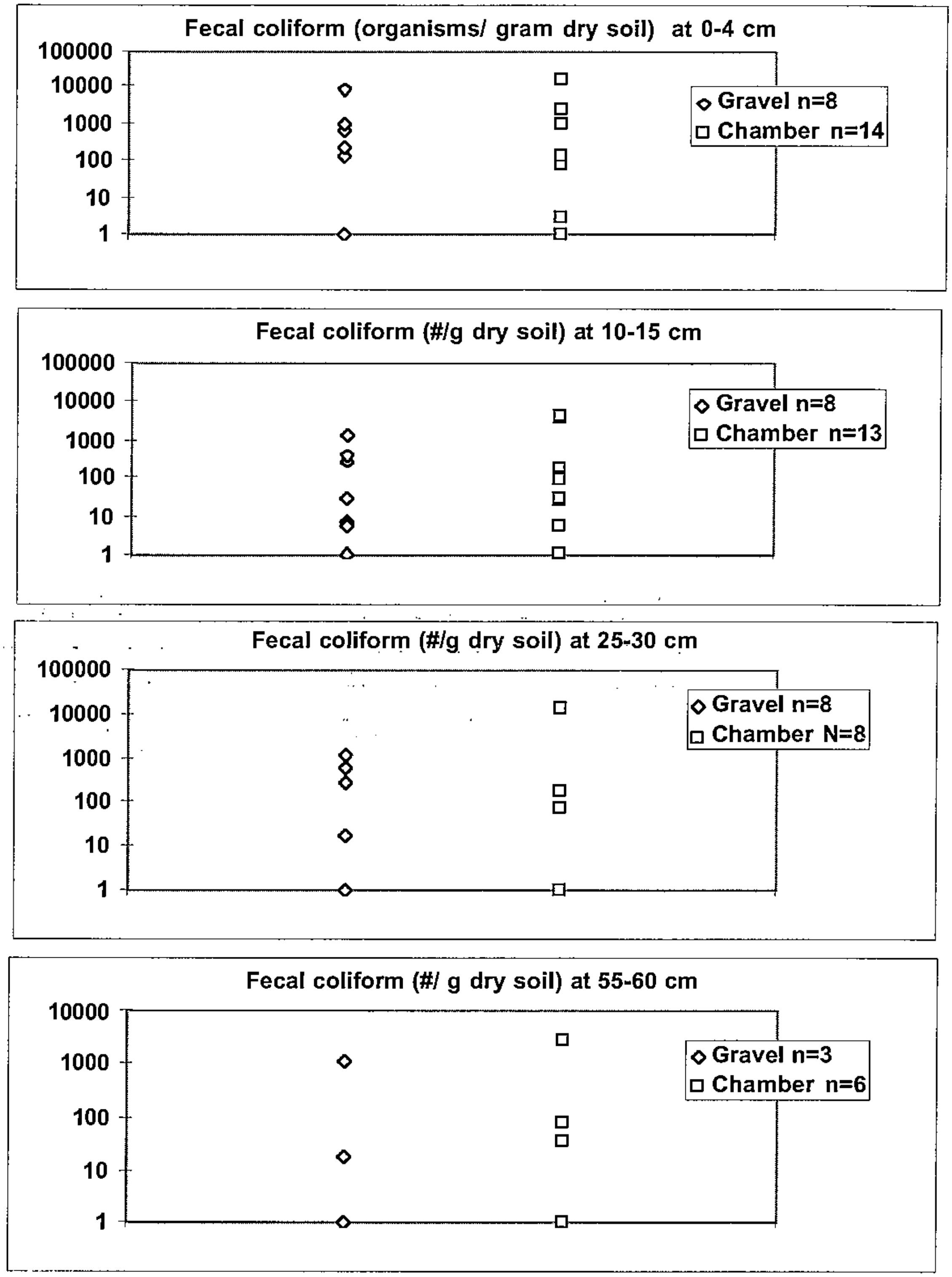


Fig. 3.11. Fecal coliform data in soil samples from all sampled sites.
Note that each symbol may represent more than one sample result and background soil core data are excluded.

3.2.2. Comparison of Fecal Coliforms in Soil Solid vs. Percolate Samples

The results for medium sand with 0.017 wt.% total organic carbon (TOC) and a silty sand with 0.225 wt.% TOC, are presented in Fig. 3.12 and 3.13, respectively. These data suggest that in both types of sand media, at the dose of bacteria used, values for *E.coli* obtained from soil core extracts would be higher (therefore a more conservative measure) compared to the concentrations actually contained in the percolate/soil water. This relationship is reasonable and likely due to the retention of bacteria on soil solids. These bacteria may not be mobile in the soil water, but they are measured in the extract made from the bulk solids. Further testing on various laboratory and field soil samples at different levels of influent bacteria, as well as virus, will enable correlations to be developed between soil core and pore water concentrations at different environmental conditions.

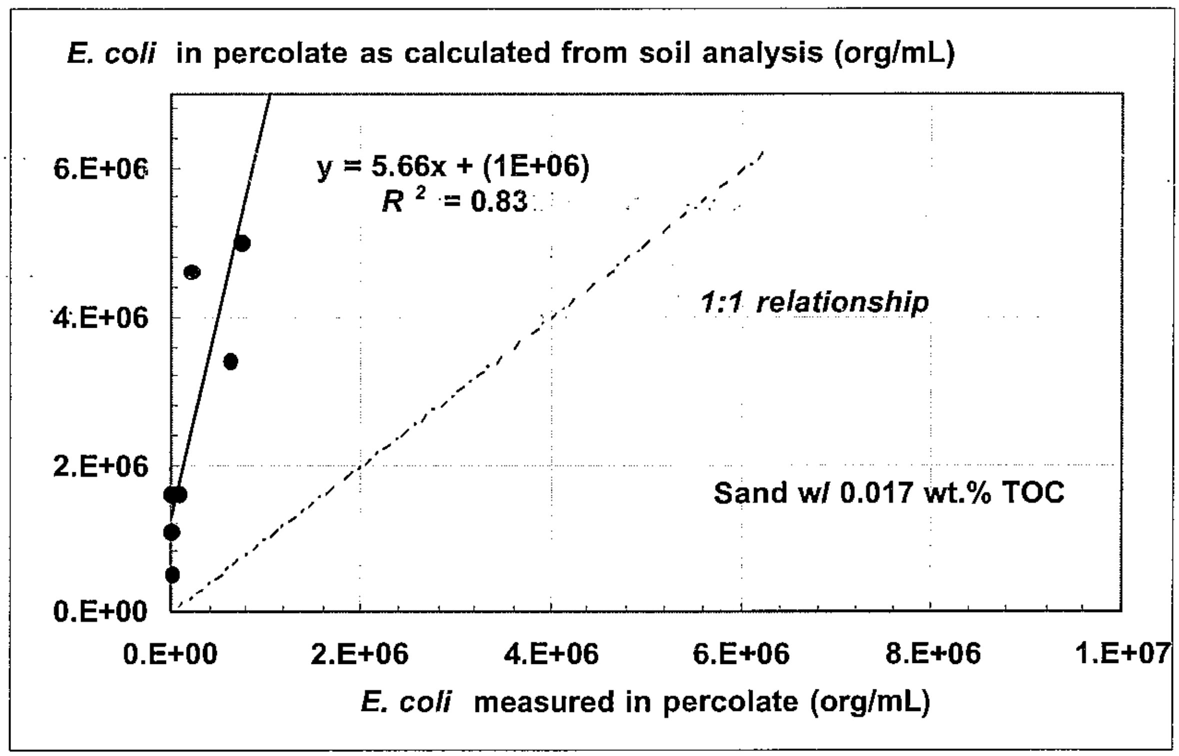


Fig. 3.12. Relationship of *E. coli* determined by analyses of extracts from sand versus direct analysis of percolate water.
Note: Each point represents the average of duplicate columns.

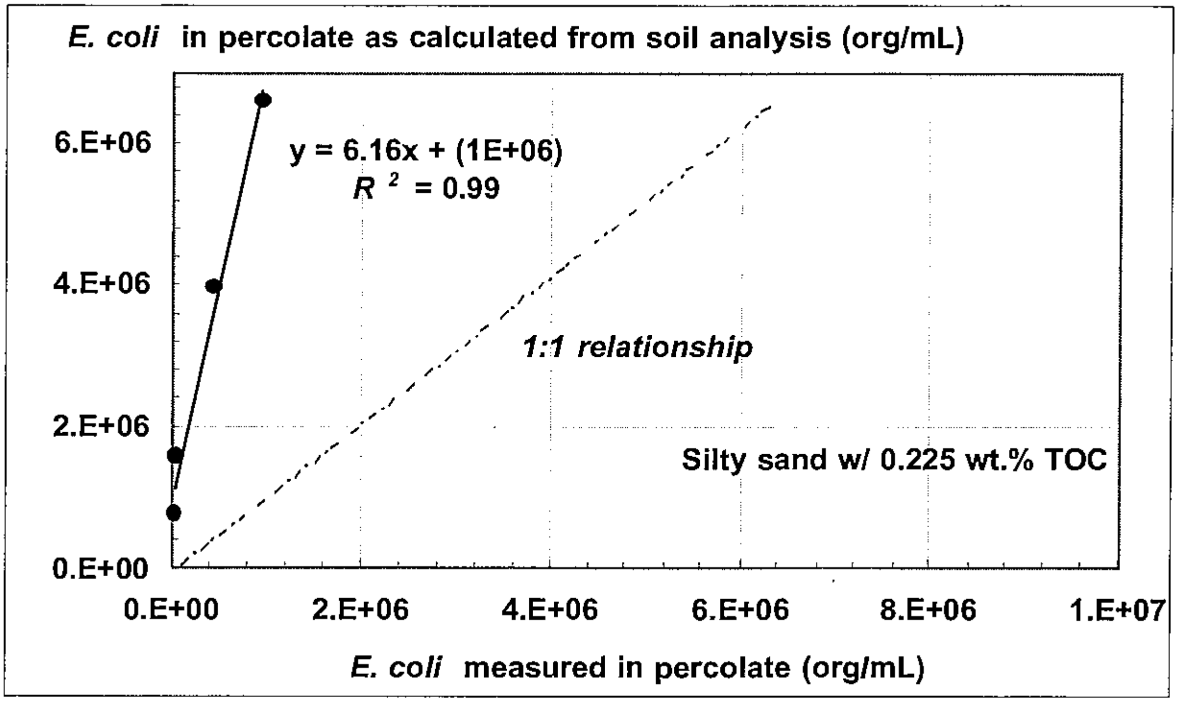


Fig. 3.13. Relationship of *E. coli* determined by analyses of extracts from silty sand versus direct analysis of percolate water.
Note: Each point represents the average of duplicate columns.

3.3. DISCUSSION

The interpretation of soil purification efficiency requires determination that wastewater did in fact reach the infiltrative surface location at which soil cores have been collected. Such an assessment can be made by integrated consideration of several factors, including: ponding (or wetness), soil color, water content and nutrient levels in the soil core profile, as well as the presence of fecal coliform bacteria near the infiltrative surface. Based on these parameters, most soil cores were collected at locations where STE had infiltrated.

Ammonium-nitrogen and nitrate-nitrogen appear to be present throughout the sampling depths and in background samples collected at each site, with the highest levels at depths closest to the infiltrative surface. These data are consistent with results found in laboratory lysimeters, where ammonium-nitrogen and nitrate-nitrogen levels were highest from 0 to 8 cm below the infiltrative surface (Van Cuyk 1999; Fischer, 1999) and with recent published field research (e.g., Tyler and Converse, 1998). In the CSM lysimeters, nitrification rate measurements indicated that nitrification was greatest at 3 cm, was less at 8 cm, and essentially did not occur at the 30 cm depth (Fischer, 1999). Values for nitrogen species (Figs. 3.8 and 3.9) and fecal coliform (Fig. 3.11) at soil coring depths for the chamber versus gravel systems show these systems to be performing comparably.

Tables 3.7 and 3.8 enable literature comparisons for nitrogen and fecal coliform and demonstrate that the data collected in this study is generally consistent with previously reported results. While a large degree of variation in constituent concentrations was observed between individual systems, and even among duplicate cores taken within the same system, the values measured for both system types were for all practical purposes, comparable.

4.0 MONITORING OF VIRUS TREATMENT EFFICIENCY

4.1. TECHNICAL APPROACH AND METHODS

4.1.1. Evaluation of a WSAS under Field Conditions

From the pool of 16 WSAS monitored for chemical and bacterial characteristics (as described in Section 3), one system was chosen for a field-scale evaluation of virus treatment efficiency using a multicomponent surrogate and tracer methodology. This effort was viewed as experimental and a means to refine a methodology employed during controlled laboratory experiments (Van Cuyk et al., 1999) and apply it under field conditions to a mature operating WSAS. Conservative tracers and viral surrogates had been used previously in studying flow and transport in ground water systems (both native bacteriophage and spiked phage) (Harvey, 1997a; 1997b) and appeared quite suitable for evaluation of WSAS under field conditions. However, multicomponent surrogates and tracers had received relatively limited use for evaluation of WSAS under field conditions. Field studies reported in the literature included studies in Florida with virus surrogate spiking of a research site near Tampa by Anderson et al. (1991, 1994) and spiking of cesspools near the Florida Keys by Rose et al. (1999). Field studies completed in California by Oakely et al. (1999) and in Massachusetts by Higgins et al. (1999) relied on indigenous bacteriophage. Most of these studies (all but the study by Anderson et al. (1994)) did not employ multicomponent mixtures containing a conservative tracer plus two contrasting viral surrogates. Thus the field testing completed in this study was viewed as a methods development and evaluation effort.

In this study, a multicomponent surrogate and tracer mixture was used to confirm that a mature WSAS, designed with Infiltrator chambers and a typical reduced infiltrative surface area, can remove virus such that the concentrations are reduced by ≥ 3 logs between the infiltrative surface and 60 to 90 cm depth below it. For this evaluation, two viral surrogates and a conservative tracer were to be added to the STE being applied to a soil absorption system (Fig. 4.1). Then after a period of time, during which application of STE and the surrogates/tracer continued, duplicate soil cores were collected from the infiltrative surface vertically downward to 60 to 75 cm depth below it. From each core, duplicate soil samples were aseptically collected and analyzed to quantify the concentrations of the viral surrogates and the tracer as well as the soil water content and fecal coliform concentrations.

For this test, a mature onsite system was selected for study. This system had been in operation for approximately eight years, was estimated to have a current HLR of ~ 0.7 gpd/ft^2 (~2.7 cm/d), and exhibited some STE ponding of the infiltrative surface (Table 3.1, home site 2). In addition, this site provided easy access to the septic tank and chamber soil absorption system which facilitated the required sampling activities.

The multicomponent mixture was comprised of two viral surrogates, MS-2 and PRD-1 bacteriophages (not infectious to humans)(Van Duin, 1988), in addition to the conservative tracer, bromide. MS-2 and PRD-1 had been previously used as viral surrogates in ground water transport studies (Harvey, 1997a,b). MS-2 is an icosahedral phage with a diameter of 26 nm (VanDuin, 1988) and a pH_{icp} of 3.9 (Bales et al., 1991) while PRD-1 is an icosahedral lipid phage with a diameter of 62 nm (Olsen et al., 1974). MS-2 and PRD-1 bacteriophage assays were made following the plaque-forming-unit technique (*Escherichia coli* and *Salmonella typhimurium* host, respectively) described by Adams (1959).

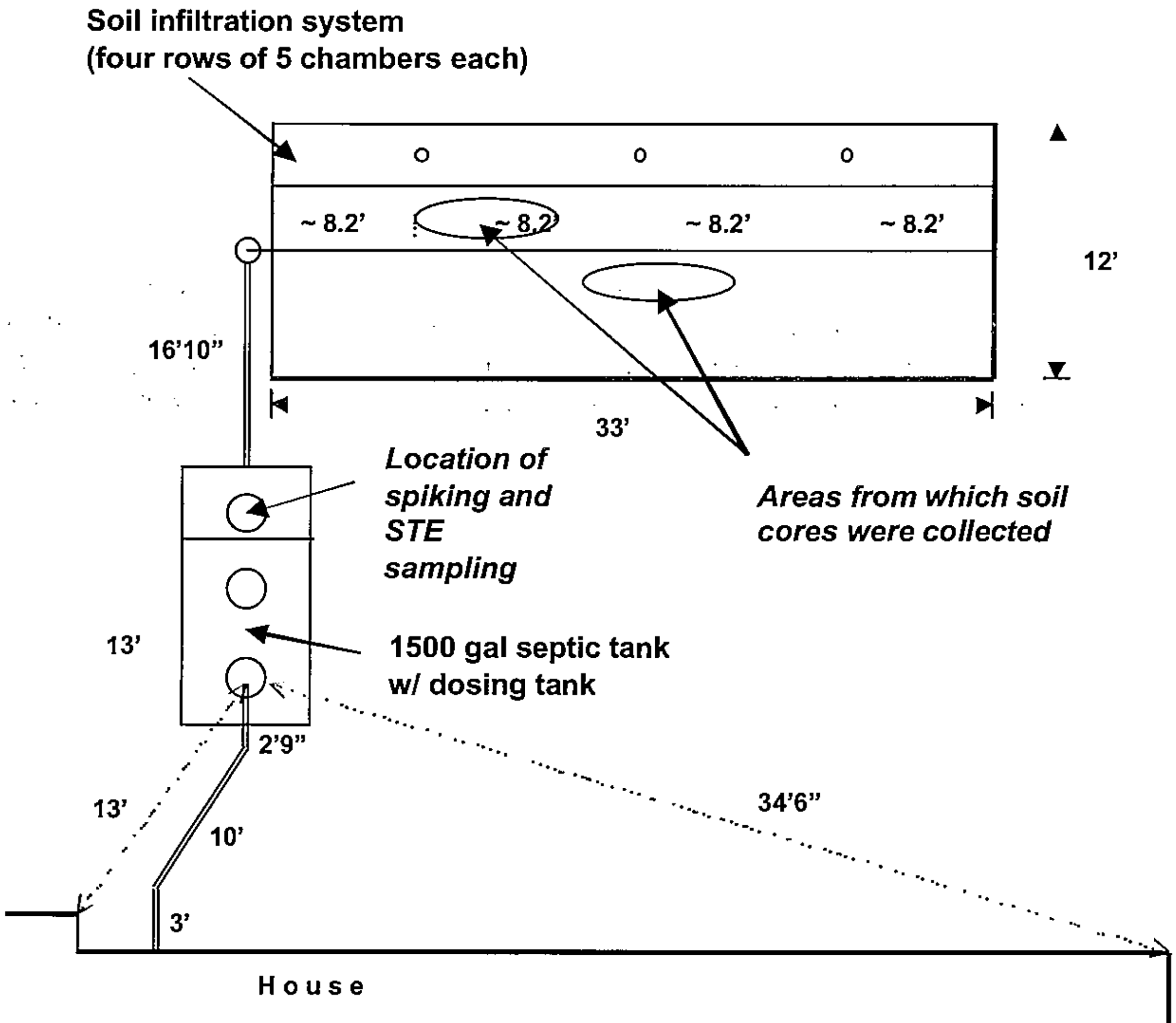


Fig. 4.1. Site layout for the onsite wastewater system studied during the virus treatment test at Site 2.

The volume of wastewater in the STE dosing tank at the study site was estimated to be approximately 250 gallons. Prior to the addition of the surrogates and tracer mixture, STE samples were collected to quantify pretreatment levels of bromide, MS-2 and PRD-1. There was no detection of any of these surrogates or tracers in the untreated STE. Stock solutions of bromide (added as KBr), MS-2 and PRD-1 were added to the STE dosing tank to obtain final concentrations targeted at 500 mg-Br/L of bromide tracer and 100,000 pfu/mL of both MS-2 and PRD-1. The bacteriophage concentrations were selected to be representative of those in a home STE during or soon after a viral infection within the household.

Following surrogate/tracer addition to the STE in the dosing tank, it was mixed using a submersible pump which recirculated STE within the tank for approximately 10 minutes. After this period of mixing, five (5) grab samples of the STE, amended with the surrogates and tracer, were collected to characterize the time zero conditions. Subsequently, STE samples were collected from the dosing tank weekly in order to characterize the concentrations of surrogates and tracers being dosed into the soil infiltration system over time.

An estimate of the time required for effluent to infiltrate and percolate to a depth of 60 cm was made based on the daily flow, area of infiltrative surface, and an effective porosity for the soil based on the following relationship:

$$T_r = \frac{(A_{I.S.})\,(D)\,(Ne)}{Q} \qquad [4.1]$$

where, T_r = travel time required for effluent to reach the depth of interest (days), D = depth of interest (m), $A_{I.S.}$ = infiltrative surface area (m^2), Q = daily flow (m^3/day), and Ne = effective porosity (v/v). This relationship assumes uniform application and infiltration into the absorption system and is thus a first approximation of travel times. For the study site, the $A_{I.S.}$ was determined from the as-built drawings to be 36.8 m^2, the depth of interest to evaluate was 0.60 m, the average daily flow was 1.0 m^3/d, and the effective porosity was estimated at Ne=0.20 v/v. For these conditions, the time required for applied effluent to percolate to 60 cm depth below the infiltrative surface was 4.4 days. To ensure that adequate time was allowed for the surrogates/tracers to be distributed in the system and infiltrate/percolate into the soil, soil core sampling was not commenced for a few weeks after the initial addition of the surrogates/tracers to the STE. During this time, samples were collected from the STE being applied to the WSAS to identify changes in concentrations over time.

Twenty-five days after introduction of the viral surrogates and tracer, coring of the subsurface beneath the infiltrative surface commenced. Soil cores were taken at two spatially separate locations and at each location, soil subsamples were collected in duplicate at depths of 0-5, 10-15, 25-30 and 55-60 cm below the infiltrative surface. Extraction and analysis were conducted for Br-, MS-2, PRD-1 concentrations, in addition to fecal coliform concentrations and water content.

4.1.2. Ancillary Study of Bacteriophage Inactivation in STE

An ancillary study was completed to determine the rate and extent of inactivation of the bacteriophages (MS-2 and PRD-1) in the STE over time. In this bench-scale test, two of the samples collected from the dosing tank following addition of the multicomponent mixture were saved and stored in the dark at either 4C or 20C for a period of 26 days. At five timepoints (time 0 corresponds to the initial dosing concentration in the chamber) during this 26-day period, the concentrations of MS-2 and PRD-1 remaining in the samples were measured.

4.2. RESULTS

The concentrations of conservative tracer (Br-) and viral surrogates (MS-2 and PRD-1) measured in the STE at Site 2 over time are presented in Table 4.1 and Figure 4.2. These results show a decline in the bromide concentration in the dosing tank that is consistent with the decline in concentration expected based on dilution due to incoming STE with no tracer in it. After five days, the Br- concentration had declined by 99%. Similarly, the levels of MS-2 and PRD-1 declined during the initial 5-day period (Figure 4.3). However, between 12 and 20 days, the bromide concentration continued to drop toward zero (nondetectable at < 1 mg/L), but the MS-2 and PRD-1 levels remained relatively unchanged. These apparently unchanging virus levels are not due to analytical error since the variability between duplicate analyses was only 11% compared to the variability in concentrations from time-point to time-point which was nearly 1 log. Rather, these data suggest the potential for growth of the bacteriophages in the STE. If this in fact did occur, then the applied dose of viral surrogates to the soil absorption system could have been higher than that anticipated based on the bacteriophage concentrations that were spiked into the STE.

Table 4.1. Br-, MS-2, and PRD-1 concentrations in the STE dosing tank at Site 2 with time.

Elapsed time after spiking (days)	Bromide			MS-2			PRD-1		
	Average (mg/L)	Std. dev. (mg/L)	CV	Average (pfu/mL)	Std. dev. (pfu/mL)	CV	Average (pfu/mL)	Std. dev. (pfu/mL)	CV
0	570.00	9.54	0.02	75000	35355	0.47	153333	128582	0.83
5	8.58	7.03	0.82	1125	760	0.68	2250	957	0.43
12	<1	-	-	275	50	0.18	463	250	0.54
19	<1	-	-	225	87	0.38	1113	595	0.52
25	<1	-	-	72	10	0.15	8	10	1.25

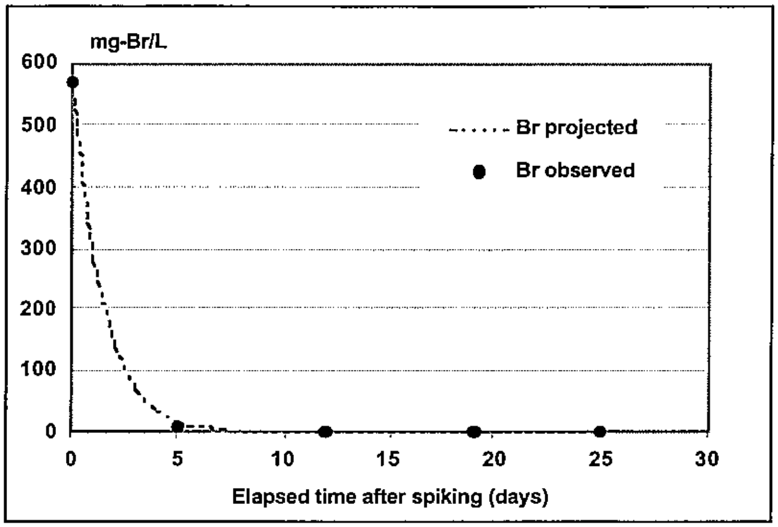


Fig. 4.2. Observed and predicted concentrations of Br^- tracer in the STE at Site 2 over time. Note the dashed line represents the projected Br^- concentration change due to dilution alone.

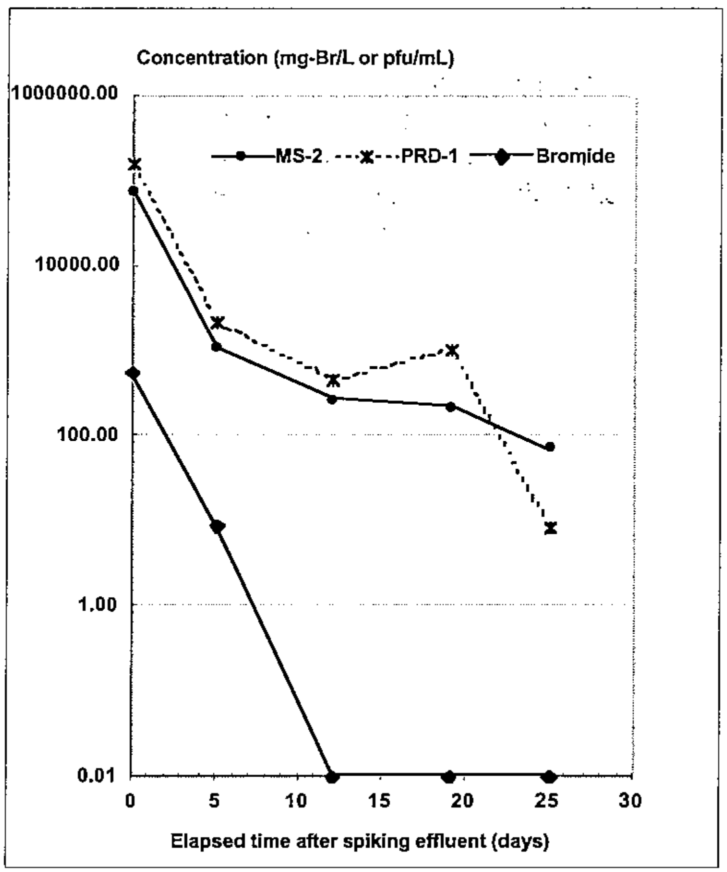


Fig. 4.3. Concentrations of MS-2 and PRD-1 bacteriophages and the conservative tracer, Br-, in the STE dosing tank at Site 2 over time.

Results of the bench-scale inactivation test are shown in Fig. 4.4. These data indicate that there can indeed be some apparent growth of bacteriophage in the STE at 4C and 20C. In the same sample over time, the PRD-1 levels increase at both temperatures while those of MS-2 increased at 4C but not at 20C. After approximately 20 days, all samples began to show signs of inactivation. The results of the dosing tank measurements and the bench-scale test with STE from the study site strongly suggest that there is growth of the added MS-2 and PRD-1 occurring in the STE dosing chamber at Site 2 (temperature of the chamber was measured at ~8C). These results show the need for more intensive monitoring of the temporal changes in surrogate/tracer concentrations where unexpected growth could be occurring.

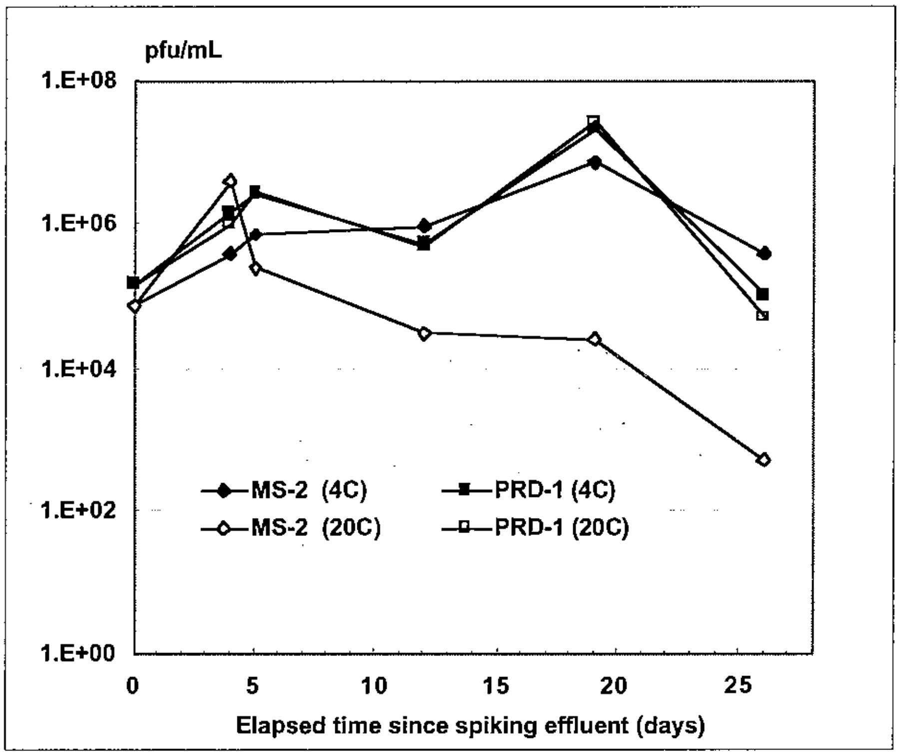


Fig. 4.4. Inactivation of MS-2 and PRD-1 in STE during incubation at 20C and 4C.
Note that all samples were run in duplicate and the average percent difference was 11%.

Results of soil coring showed no bromide in any of the extracted soil cores. This is likely the result of the bromide concentrations decline with time due to dilution in the dosing tank (Fig. 4.2, 4.3). In addition, the fast travel time in the soil infiltration system may have resulted in the added bromide migrating into and through the depth interval of interest prior to collection of the soil cores.

Soil core values for MS-2 and PRD-1 are graphically depicted in Figure 4.5 along with fecal coliform densities at each coring interval. Detailed results may be found in Appendix Table A.4. An overall trend of lower levels of virus and bacteria with increasing depth below the infiltrative surface was observed, although, one core at 25-30 cm depth did show the highest number of fecal coliform bacteria.

The relationship of MS-2 and PRD-1 to fecal coliform concentrations is of interest, since fecal coliforms are often used as indicators of microbial contamination. As shown in Fig. 4.6, the concentrations of fecal coliforms (cfu/g) measured in soil core samples exceeded that of the MS-2 all of the time (26 of 26 pairs or 100%) and was higher than that of the PRD-1 most of the time (23 of 26 pairs or 88%) (see Appendix Table A.5 for detailed results). These data suggest that, under the conditions examined, fecal coliforms in soil extracts may be a reasonable indicator for the presence virus at the same location.

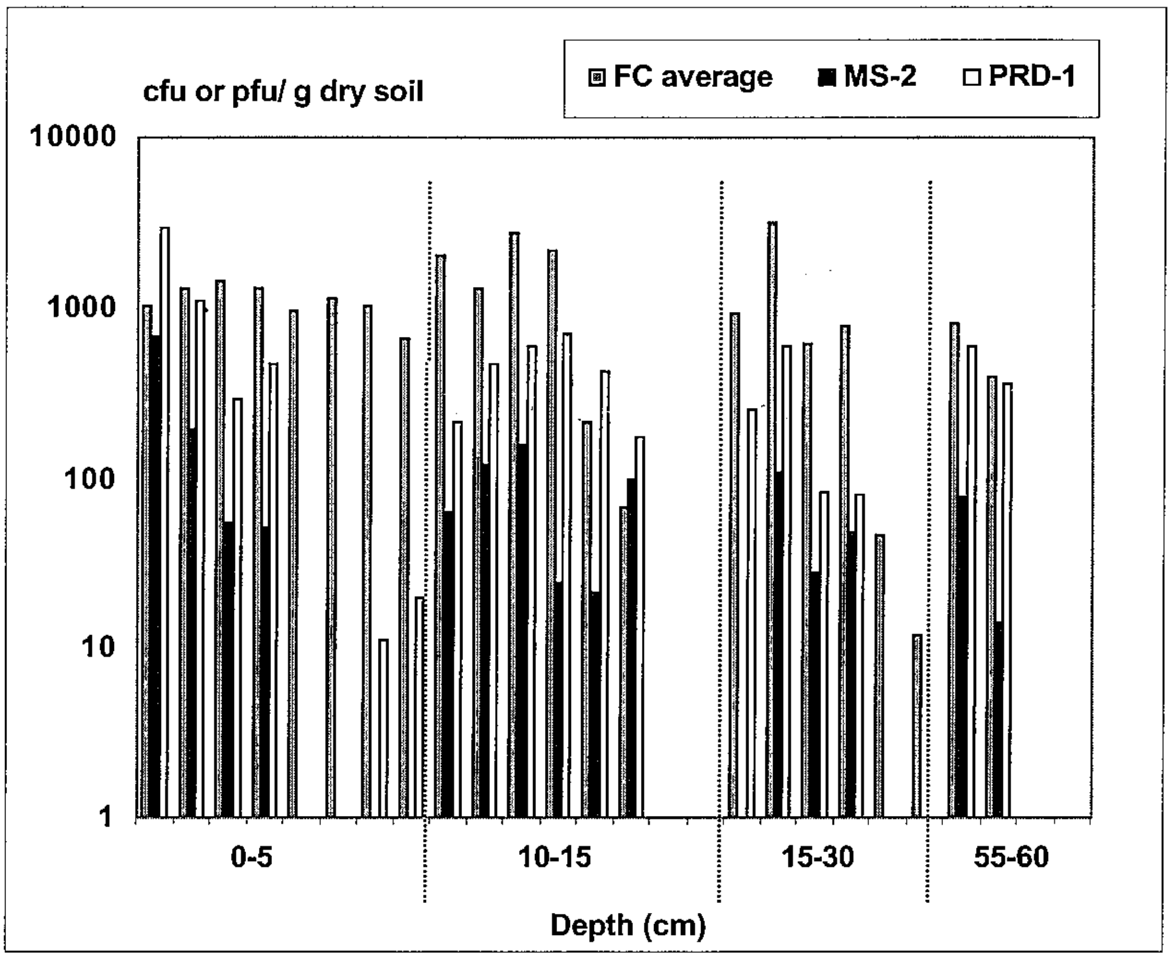


Fig. 4.5. Fecal coliform, MS-2 and PRD-1 levels in soil core extracts collected from Site 2, 25 days following addition of surrogates and tracer to the STE being applied. Note: Initial influent levels were 570 mg/L of bromide, 75,000 pfu/mL of MS-2 and 153,000 pfu/mL of PRD-1. Zero values (blank bars) represent non-detects.

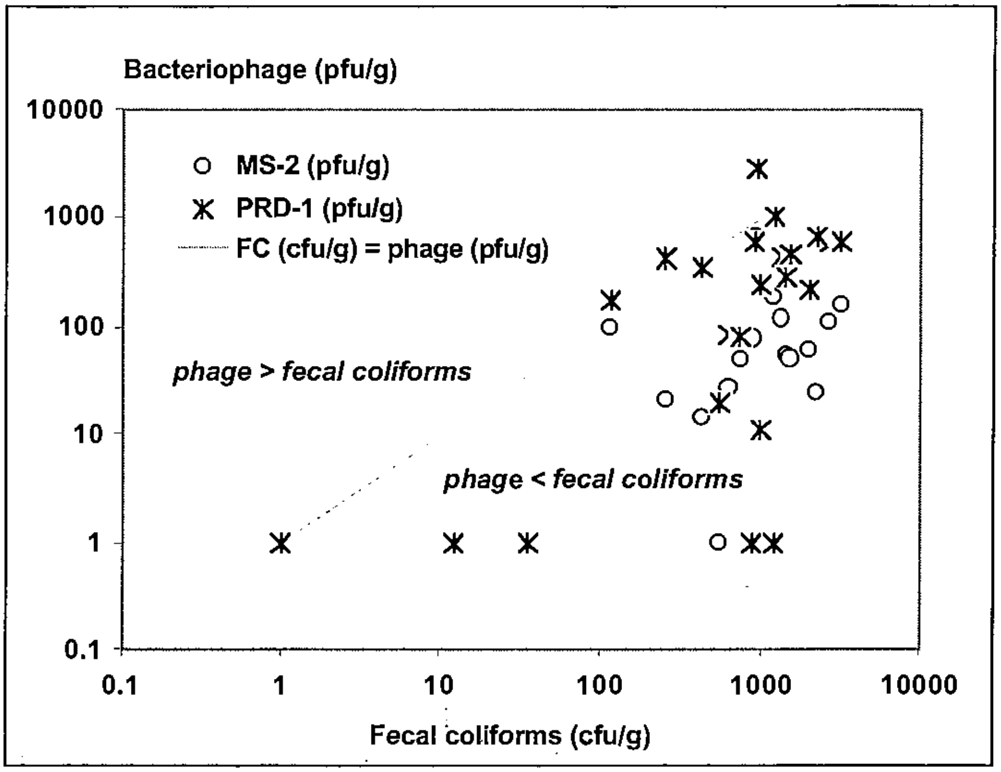


Fig. 4.6. Relationship of bacteriophages to fecal coliforms as determined in the same soil samples at depths of 0 to 60 cm below the infiltrative surface of a WSAS.
Note: 26 samples were analyzed for all three constituents (see Table A.5 for details).

The removal of bacteriophages was conservatively estimated based on the assumption that all bacteriophage detected in the extraction of soil solids were mobile in the soil pore water. Based on a 15 dry wt.% water content, the pfu/g dry soil values were converted to pfu/mL of pore water. These estimated pore water values were then compared to the dose concentration of MS-2 or PRD-1. As presented in Table A.4, at a depth of 30 cm below the WSAS infiltrative surface, the concentrations of MS-2 detected were <1, <1, <1, 28, 48 and 108 pfu/g for the various core samples. The concentrations of PRD-1 were <1, <1, 80, 84, 250, and 594 pfu/g. Using the median value detected for each bacteriophage (14 pfu/g for MS-2 and 82 pfu/g for PRD-1), the pore water concentrations were estimated to be 97 pfu/mL for MS-2 and 547 pfu/mL for PRD-1. Compared to the dose concentrations of 75,000 pfu/mL for MS-2 and 153,300 pfu/mL for PRD-1, these estimated pore water concentrations correspond to a removal efficiency of 99.9% for MS-2 and 99.6% for PRD-1. Considering that the extracted bacteriophages may not have all been mobile in the pore water (as noted for the fecal coliforms, see Figs. 3.12 and 3.13) and some growth of the spiked bacteriophage may have occurred, it is reasonable to conclude that a 3-log removal of the applied viral surrogates was achieved. Achievement of 3-log removal of virus after

STE infiltration at 1 to 3 cm/d and percolation through 60 to 90 cm of natural soil is reasonable to achieve as shown in this and previous field studies (see Table 4.2).

Table 4.2. Results of field studies of virus treatment in wastewater soil absorption systems.

Investigator	Study characteristics/ *location*	Virus and concentrations applied	Method of assessment	Findings
This CSM study, 2000	2.7 cm/d HLR of STE to a mature chamber soil absorption system *Colorado*	Spiking of STE with MS-2 at 7.5×10^4 and PRD-1 at 1.5×10^5 pfu/mL	Soil core collection and extraction	99.9% removal after 60 cm
Higgins et al., 1999	3cm/day HLR of STE to a buried sand filter constructed of medium sand *Massachusetts*	Indigenous MS-2 at 3×10^4 pfu/mL in raw wastewater and 7.8×10^3 in STE applied to sand	Pressure-free pan lysimeters placed during sand placement in buried lined cells	74.44% removal in septic tank 99.17% removal in 30cm[1] 98.45% removal in 60 cm[1] 99.79% removal in 152cm[1]
Oakley et al., 1999	Variable loading (0.81-6.5 cm/day) of STE to a soil absorption system in clay loam *California*	Indigenous ϕX174 at 1×10^0 to 1×10^4 pfu/mL in STE	Suction-lysimeters augured and driven into intact natural soil	1-log removal in recirculating gravel filter 100% removal in 60 cm soil
Anderson et al., 1991	Onsite soil absorption systems and subdivisions on fine sandy soils *Florida*	Indigenous virus present in STE at 0.06 to 43.7 MPN of infectious units per L	Soil cores and extraction plus ground water samples	No Enterovirus were detected in soil samples below the soil infiltration area at four homes At one home, virus was detected in shallow ground water at 0.6 to 0.9 m depth right under the system but not 3 m downgradient from it
Gilbert et al., 1976	Secondary effluent land applied at 100 m/year with cyclic flooding onto fine loamy sand *Arizona*	Indigenous Enterovirus at 1×10^3 to 7×10^3 pfu/100L in municipal effluent	Ground water sampling and analysis	99.99% removal in 3 to 9 m soil

[1] %removals shown in soil are based on the STE levels applied to the soil.

4.3. DISCUSSION

The results of the evaluation completed revealed that under the conditions examined, a 3-log treatment efficiency for virus was achieved by 60-cm depth below the STE soil infiltratve surface. Removal of $\geq$ 3 logs of virus during soil absorption of STE through 60-cm depth is consistent with the results of the CSM laboratory studies (Van Cuyk et al., 1999) as well as the results of previous field studies reported by other investigators (see Table 4.2).

In this study, a strong correlation was observed between the concentrations of fecal coliforms in soil samples and the concentrations of the MS-2 and PRD-1 virus. These data suggest that under the conditions examined, fecal coliform bacteria in soil extracts may be an indicator of the presence of virus at the same location. This is in contrast to previous work conducted where indigenous bacteria and virus were isolated in ground water below municipal wastewater rapid infiltration basins. In these ground water systems, virus occurrence could not be correlated to the occurrence of total or fecal coliforms, indicating the limitation of microbial water quality indicators for predicting their virological quality (Vaughn et al., 1983; Keswick and Gerba, 1980). However, the correlation in the ground water beneath and away from systems receiving higher rate application of more highly pretreated wastewater may be different than that in the vadose zone immediately under a WSAS. In the ground water at a given point in time and space where comparative analyses were made, the processes controlling the transport/fate of the wastewater effluent fecal coliforms versus the virus might have either affected them differently and/or had sufficient time to yield differences that caused the poor correlation. Such differences might not arise in the vadose zone immediately beneath a WSAS, either due to the absence of the same transport/fate processes or lack of adequate time for the processes to yield erratic differences in concentrations. If a strong correlation between fecal coliforms and virus does exist immediately below a WSAS, this could provide an indicator of virus treatment. For example, given that fecal coliforms were very low or not detected in soil samples collected at 30 to 60 cm depth below the infiltrative surface in the pool of 16 systems examined (see Section 3), it might be plausible to assume that if virus surrogates had been added in the STE at those sites, the virus might not have been present at or past the 30 to 60 cm depths.

The virus testing completed in this study was viewed as a methods development and evaluation effort. We had originally envisioned testing up to five soil absorption systems for virus treatment efficiency, but we were unable to accomplish this due to the extensive effort required to conduct this type of field testing *in situ*. From the experience gained through this test, a few changes would be recommended. The first suggestion would be to monitor bromide concentrations in the STE dosing chamber and add necessary stock solution of bromide in order to ensure continued high dosing of the tracer. This would help sustain conservative tracer addition during the entire period of study and aid in the assessment of virus treatment, especially in cores where no virus surrogates are detected. In this experiment we were fortunate to have high levels of the virus detected in some of the surface (0-4 cm) cores collected, ensuring that some virus-amended STE had indeed reached the location from which soil cores were collected and analyzed. Since STE samples collected just prior to addition of the multicomponent mixture showed no MS-2 or PRD-1 in the system it was assumed that surrogates detected in soil cores were those intentionally added. The possibility that measured virus surrogates could be "native" to the STE should be tested for in any system prior to initiating such a test. In addition, the possibility that growth of the added virus surrogates could be occurring should be taken into consideration when deciding on sampling times and locations.

5.0 CONCLUSIONS

A field study was completed to monitor the performance of mature wastewater soil absorption systems in Colorado to gain insight into the comparative performance of aggregate-free (chamber) and aggregate-laden (gravel) infiltration systems. A total of 16 individual onsite wastewater systems were monitored including both aggregate-free (10 chamber systems) and aggregate-laden systems (6 gravel systems). Data collected at each site included residence characteristics, system design features, STE composition, occurrence and depth of ponding of the soil infiltrative surface, and pollutant concentrations with depth below the infiltrative surface for parameters such as nutrients and fecal coliform bacteria. A laboratory study was completed to determine the relationship between fecal coliform bacteria concentrations measured directly in percolating water versus analyses of bulk soil samples. Finally, virus treatment efficiency was evaluated using a multicomponent mixture of MS-2 and PRD-1 bacteriophages and a conservative bromide tracer.

Based on the work completed and with due consideration of the related 3-D lysimeter research and previously reported findings (Van Cuyk et al., 1999; Siegrist et al., 1999), the following conclusions have been drawn and several recommendations can be made.

1. The STE composition at the individual study homes was typical of residential STE containing appreciable concentrations of pollutants. In the Hamilton Creek subdivision where 11 homes were monitored, the average concentrations were: BOD_5 = 175 mg/L, TSS = 258 mg/L, total N = 62 mg-N/L, total P = 7.7 mg-P/L, and fecal coliform bacteria = 4 x 10^6 to 6.3 x 10^6 cfu/100mL.

2. A total of 16 individual onsite systems were monitored including 10 with chambers and 6 with gravel. The chamber systems varied in age from 1 to 10 yr. while the gravel systems were 2 to 11 yr. old. The estimated hydraulic loading rates averaged 0.32 gpd/ft^2 (1.31 cm/d) for the chamber systems compared to 0.18 gpd/ft^2 (0.76 cm/d) for the gravel systems. For the chamber systems, 5 of the 10 exhibited some degree of effluent ponding while for the gravel, 4 of 6 exhibited ponding. These data suggest comparable hydraulic performance with the chamber systems receiving a higher loading rate as compared to the gravel systems (based on the normal 50% reduction allowed in the gross infiltration area for a chamber system).

3. Monitoring of soil properties and pollutant concentrations with depth beneath the infiltrative surfaces of 14 homes revealed spatially variable concentrations. At most sites, pollutant concentrations declined with depth and by 60 cm depth, fecal coliform bacteria were not detected. A Mann-Whitney nonparametric analysis revealed that the fecal coliform levels at both 30- and 60-cm depths were not significantly different between chamber and gravel systems at 95% confidence (p=0.05).

4. Based on bench-scale analyses completed with mini-columns and two soil media (clean sand with low TOC and silty sand with higher TOC), the estimated concentrations of fecal coliforms in percolating water can be conservatively estimated based on analysis of bulk soil solids. Further experimentation is warranted under a wider range of environmental and process conditions and for other constituents of interest such as nutrients and virus.

5. A methodology for using a multicomponent mixture of virus surrogates and a conservative tracer to assess virus purification in a wastewater soil absorption system was successfully applied under field conditions. In this study, 3-log reductions in the applied MS-2 and PRD-1 viral surrogate concentrations were achieve at 30 cm below the infiltration surface. The results of this effort also revealed a strong correlation between fecal coliform concentrations measured in soil core samples to MS-2 and PRD-1 virus concentrations. It was observed that the bacteriophage may exhibit apparent growth in residential STE and this must be accounted for in test design and execution.

6. Under the conditions examined in this study, the performance measurements made for the chamber systems were comparable to those determined for gravel systems, even though the chambers were estimated to be receiving a hydraulic loading rate of 0.32 gpd/ft^2 (1.31 cm/d) as compared to 0.18 gpd/ft^2 (0.76 cm/d) for the gravel systems. The performance observations made under field conditions are consistent with the findings derived from 3-D lysimeter studies carried out under controlled laboratory conditions at CSM (see Van Cuyk et al., 1999; Siegrist et al., 1999).

6.0 REFERENCES

Adams, M.H. 1959. Bacteriophages. Interscience Publishers: New York.

American Public Health Association (APHA). 1992. Standard Methods for the Examination of Water and Wastewater. 18th ed. Am. Public Health Assoc., Am. Water Works Assoc., and Water Pollut. Control Fed., Washington, DC.

American Public Health Association (APHA). 1998. Standard Methods for the Examination of Water and Wastewater. 20th ed. Clesceri, L.S., A.E. Greenberg and A.D. Eaton, eds. APHA-AWWA-WPCF, Washington, DC.

Amerson, R.S., E.J. Tyler and J.C. Converse. 1991. Infiltration as Affected by Compaction, Fines and Contact Area of Gravel. In: Proc. 6th National Symposium on Individual and Small Community Sewage Systems. ASAE, St. Joseph, MI. pp: 214-222.

Anderson, D.L., R.L. Siegrist and R.J. Otis. 1985. Technology Assessment of Intermittent Sand Filters. U.S. Environmental Protection Agency, Municipal Environmental Res. Lab., Cincinnati, Ohio.

Anderson, D.L., A.L. Lewis, and K.M. Sherman. 1991. Human Enterovirus Monitoring at Onsite Sewage Disposal Systems in Florida. In: Proc. 6th National Symposium on Individual and Small Community Sewage Systems. ASAE, St. Joseph, MI. pp: 94-104.

Anderson, D.L., R.J. Otis, J.I. McNeille, and R.A. Apfel. 1994. In-Situ Lysimeter Investigation of Pollutant Attenuation in the Vadose Zone of a Fine Sand. Proc. 7th International Symposium on Individual and Small Community Sewage Systems. December 1994, Atlanta, GA. pp. 209-218.

Ausland, G.A. 1998. Hydraulics and Purification in Wastewater Filters. Ph.D. dissertation. Agricultural University of Norway. As, Norway.

Bales, R.C., S.R. Hinkie, T.W. Kroeger, and K. Stocking. 1991. Bacteriophage Adsorption During Transport Through Porous Media: Chemical Perturbations and Reversibility. *Environ. Sci. Technol.* 25(12):2088-2095.

Brown, K.W., H.W. Wolf, K.C. Donnelly, and J.F. Slowey. 1979. The Movement of Fecal Coliforms and Coliphages below Septic Lines. *J. Environmental Quality.* 8(1):121-125.

Crites, R.C. and G. Tchobanoglous. 1998. Small and Decentralized Wastewater Systems. McGraw-Hill Publishing Company, Boston.

Converse, J.C., and Tyler, E.J. 1998. Soil Treatment of Aerobically Treated Domestic Wastewater with Emphasis on Modified Mounds. Eighth national Symposium on Individual and Small Community Sewage Systems.

Emerick, R.W., R.M. Test, G. Tchobanoglous, and J. Darby. 1997. Shallow intermittent sand filtration: Microorganism removal. *The Small Flows Journal.* 3(1):12-22.

England, A. and S. Dix. 1999. Performance of the Infiltrator Chamber System in Hamilton County, Tennessee. Proc. National Onsite Wastewater Recycling Association 8th Annual Conf. and Exhibition, Jekyll Island, GA, November 1999. pp. 99-106.

Fischer, E.A. 1999. Nutrient Transformation and Fate During Intermittent Sand Filtration of Wastewater. M.S. Thesis. Colorado School of Mines, Golden, Colorado.

Gilbert, R.G., R.C. Rice, H. Bouwer, C.P. Gerba, C. Wallis, and J.L. Melnick. 1976. *Science* 192:1004-1005.

HACH. 1992. Water Analysis Handbook. 2nd ed. HACH Chemical Co., Loveland, CO. USA.

Harkin, J.M., C.J. Fitzgerald, C.P. Duffy, and D.G. Kroll. 1979. Evaluation of Mound Systems for Purification of Septic Tank Effluent. Technical Report. WIS WRI 79-05. University of Wisconsin Water Resources Center, Madison, Wisconsin.

Harvey, R.W. 1997a. Microorganisms as Tracers in Groundwater Injection and Recovery Experiments: A Review. *FEMS Microbiology Reviews*. 20:461-472.

Harvey, R.W. 1997b. In Situ and Laboratory Methods to Study Subsurface Microbial Transport. In: Manual of Environmental Microbiology. Hurst, C.J., G.R. Knudsen, M.J. McInerney, L.D. Stetzenback, and M.V. Walter (eds.). ASM Press, Washington, D.C. pp. 586-599.

Higgins, J.J., G. Heufelder, and Sean Foss. 1999. Removal Efficiency of Standard Septic Tank and Leach Trench Septic Systems for MS2 Coliphage. Proc. 10th Northwest On-Site Wastewater Treatment Shortcourse. September 20-21, 1999, Univ. of Washington, Seattle, WA. pp. 81-88.

Huysman, F. and W. Verstraete. 1993. Water Facilitated Transport of Bacteria in Unsaturated Soil Columns: Influence of Inoculation and Irrigation Methods. *Soil Biol. Biochem.* 25(1):91-97.

Jenssen, P.D. and R.L. Siegrist. 1990. Technology Assessment of Wastewater Treatment by Soil Infiltration Systems. *Water Science & Tech.* 22(3/4):83-92.

Keswick, B.H. and C.P. Gerba. 1980. Viruses in Groundwater. *Environ. Sci. Technol.* 14(11):1290-1297.

Keys, J.R. 1996. Septic Tank Effluent Infiltration and Loading Rates for Gravel and Chamber Absorption Systems. M.S. thesis. University of Wisconsin-Madison.

Kristiansen, R. 1991. Sand-filter Trenches for Purification of Septic Tank Effluent: III, The Microflora. *Journal of Environmental Quality,* 10(3):361-364

Masson, S.K. 1999. Fate of Microorganisms in a Soil Infiltration System as Affected by Infiltrative Surface Character and Depth. M.S. Thesis. Colorado School of Mines, Golden, CO.

May, R. 1996. Problems Associated with the Use of Gravel in Septic-Tank Leachfield Systems. *Journal Environmental Health.* September 1996. pp. 6-11.

McCray, J.E., D. Huntzinger, S. Van Cuyk, and R.L. Siegrist. 2000. Mathematical Modeling of Unsaturated Flow and Transport in Soil-Based Wastewater Treatment Systems. WEFTEC 2000, Water Environment Federation, October, Anaheim, CA.

Minitab, Inc. 1995. Minitab Release 10Xtra. State College, PA. 16801-3008.

Oakley, S., W.P. Greenwood, and M. Lee. 1999. Monitoring Nitrogen and Virus Removal in the Vadose Zone with Suction Lysimeters. Proc. 10th Northwest On-Site Wastewater Treatment Shortcourse. September 20-21, 1999, Univ. of Washington, Seattle, WA. pp. 211-232.

Olsen, R.H., J. Siak, and R. Gray. 1974. Characterization of PRD1, A Plasmid-Dependent Broad Host Range DNA Bacteriophage. *J Virol.,* (14): 689-699.

Peeples, J.A., K.M. Mancl, and D.L. Widrig. 1991. An Examination of the Role of Sand Depth on the Treatment Efficiency of Pilot Scale Intermittent Sand Filters. Proc. 6th Nat. Symp. on Individual and Small Community Sewage Systems. ASAE, St. Joseph, MI.

Rose, J.B., D.W. Griffin, and L.W. Nicosia. 1999. Virus Transport from Septic Tanks to Coastal Waters. Proc. 10th Northwest On-Site Wastewater Treatment Shortcourse. Sept. 20-21, Univ. of Washington, Seattle, WA. pp. 71-80.

Schwagger, A and M. Boller. 1997. Transport Phenomena in Intermittent Filters. *Wat. Sci. Tech.* 35(6): 13-20.

Siegrist, R.L. and W.C. Boyle. 1987. Wastewater Induced Soil Clogging Development. *J. Environmental Engineering*. 113(3):550-566.

Siegrist, R.L. 1987. Soil Clogging During Subsurface Wastewater Infiltration as Affected by Effluent Composition and Loading Rate. *J. Environmental Quality*. 16, pp. 181-187.

Siegrist, R.L. and P.D. Jenssen. 1989. Nitrogen Removal During Wastewater Infiltration as Affected by Design and Environmental Factors. Proc. 6th On-site Wastewater Treatment Short Course. Sept. 1989. University of Washington, Seattle.

Siegrist, R.L., R. Smed-Hildmann, Z. Filip, and P.D. Jenssen. 1991. Humic Substance Formation During Wastewater Infiltration. ASAE Publ. 10-91. ASAE, St. Joseph, MI. pp. 182-191.

Siegrist, R.L., S. Van Cuyk, A. Logan, S. Masson, and E. Fischer. 1999. Hydraulic and Purification Behavior in Wastewater Soil Treatment Systems as Affected by Infiltrative Surface Character and Vadose Zone Soil Depth. Proc. Annual Conf. of the National Onsite Wastewater Recycling Association. Jekyll Island, GA. Nov. 3-6, 1999.

Stevik, T.K.. G.A. Ausland, P.D. Jenssen, P.D., and R.L Siegrist. 1999. Purification of *E. coli* Bacteria During Intermittent Filtration of Wastewater Effluent as Affected by Dosing Rate and Media Type. *Water Research*. 33(9):2088-2098.

Tyler, E.J., M. Milner, and J.C. Converse. 1991. Wastewater Infiltration from Chamber and Gravel Systems. Proceedings of Sixth National Symposium on Individual and Small Community Sewage Systems.

Tyler, E.J. and J.C. Converse, 1994. Soil Acceptance of On-site Wastewater as Affected by Soil Morphology and Wastewater Quality. In: Proc. 7th International Symposium on Individual and Small Community Sewage Systems, ASAE, St. Joseph, MI. pp. 185-194.

USDA. 1974. Soil Survey of Adams County, Colorado. United States Department of Agriculture, Soil Conservation Service, Washington, D.C. 20402.

USDA. 1977. Soil Survey of Summit County Area, Colorado. United States Department of Agriculture, Soil Conservation Service, Washington, D.C. 20402.

U.S. EPA. 1978. Management of Small Waste Flows. Report of Small Scale Waste Management Project, University of Wisconsin, Madison, WI. U.S. Environmental Protection Agency, Municipal Environmental Res. Lab., EPA-600/2-78-173. Cincinnati, Ohio.

U.S. EPA. 1980. Design Manual for Onsite Wastewater Treatment and Disposal Systems. U.S. Environmental Protection Agency Municipal Environmental Res. Lab., Cincinnati, Ohio.

U.S. EPA. 1997. Response to Congress on Use of Decentralized Wastewater Treatment Systems. U.S. Environmental Protection Agency, Office of Water, Washington, D.C.

Van Cuyk, S., R.L. Siegrist, A. Logan, S. Masson, E. Fischer, and L. Figueroa. 1999. Purification of Wastewater in Soil Treatment Systems as affected by Infiltrative Surface Character and Unsaturated Soil Depth. Water Environment Federation, WEFTEC '99. New Orleans, Louisiana.

Van Duin. J. 1988. In: The Bacteriophages. 1st ed.; Calender, R. (ed.). Plenum Press, New York. Vol. 1, pp. 117-167.

Vaughn, J.M., E.F. Landry and M.Z. Thomas. 1983. Entrainment of Viruses from Septic Tank Leach Fields Through a Shallow, Sandy Soil Aquifer. *Appl. Environ. Micro.* 45(5):1474-1480.

7.0 APPENDIX

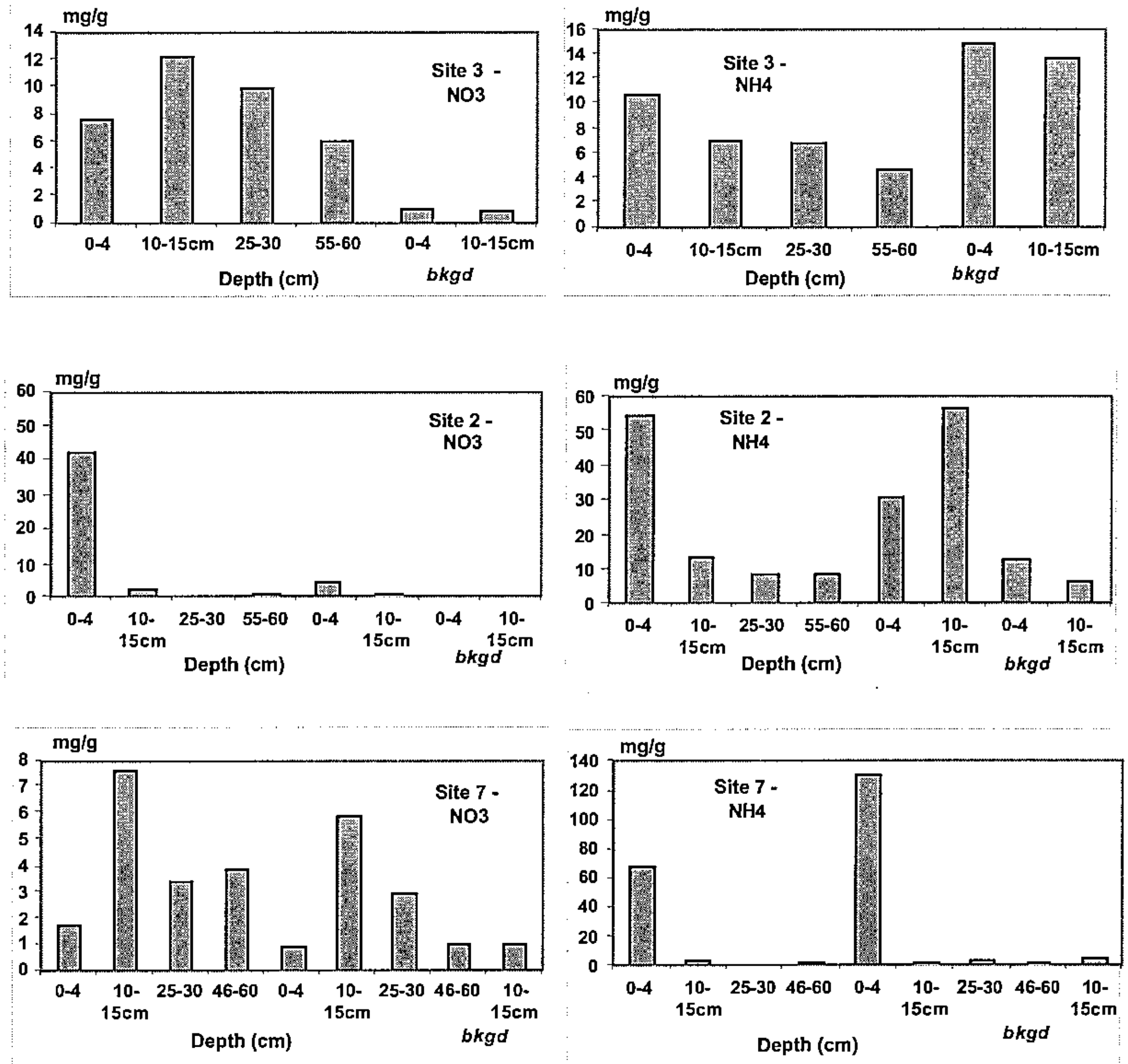


Fig. A.1. Nitrate- and ammonium-nitrogen in soil cores from homes 2, 3 and 7.

Table A.1. Characteristics of septic tank effluent samples collected from homes in the Hamilton Creek subdivision near Silverthorne, Colorado and the Todd Creek Farms subdivision near Brighton, Colorado.

Site ID	Type	pH	Alk. (mg/L)	$cBOD_5$ (mg/L)	COD (mg/L)	TSS (mg/L)	TN (mg/L)	NH_3 (mg/L)	NO_3 (mg/L)	TP (mg/L)	FC (cfu/100mL)
1	Cha[1]	7.83 7.58	460 452	113 128	109 110	55 98	41 44	25 35	1.2 0.6	6.83 6.9	5.10E+06 3.30E+06
2	Cha	7.10 7.74	420 390	173 143	124 134	20 80	47 44	37 31	0.7 0.5	5.68 6.15	4.00E+04 1.30E+05
3	Gra[1]	7.41 7.53	510 480	171 149	244 260	72 125	46 68	54 62	0.6 1.5	7.33 8.8	1.50E+06 6.20E+06
4	Gra	7.26	486	134	325	185	64	47	1.2	11.1	3.00E+06
5	Cha	7.94 7.8	524 416	112 98	162 207	118 270	68 64	50 56	0.7 0.8	10.6 ND	2.80E+05 2.40E+05
6	Cha	7.5	288	250	330	512	18	3	1.8	ND	6.30E+06
7	Cha	7.5	860	250	675	958	96	42	2.4	ND	3.00E+06
8	Gra	7.3 7.6	634 620	170 ND[2]	137 120	275 305	102 102	63 57	1.8 1.2	ND ND	3.20E+05 1.80E+05
9	Cha	6.95	594	358	990	370	74	27	3.2	ND	6.00E+06
10	Gra	7.53	616	205	425	515	58	32	1.3	ND	4.70E+05
11	Cha	7.5	692	ND	540	60	64	64	0.8	6.23	6.00E+05
12*[3]	Cha	8.04 7.95	726 658	ND ND	350 320	128 0	84 70	74.6 70.2	1.5 0.9	11.95 11.85	6.30E+05 ND
13*	Gra	7.29	678	300	815	143	56	54.4	1.7	9.25	6.30E+05
14*	Cha	7.05	674	310	825	125	72	73.4	1.1	6.25	1.30E+07
15*	Gra	8.17	320	184	270	ND	ND	ND	ND	ND	ND
16*	Cha	7.32	692	385	170	115	64	55.6	2.6	8.90	2.50E+05

[1] For Type, Cha = chamber system and Gra = gravel system.

[2] ND = no data.

[3] Denotes homes located in Brighton, CO.

Table A.2. Summary of soil core data for onsite wastewater systems in Hamilton Creek.[1]

Site ID[2]	Soil core loc.	Depth below I.S. (cm)	Soil color	Water content (wt.%)	Fecal coli. (org./g)	NH_3 (mg-N/kg)	NO_3 (mg-N/kg)	P (mg-P/kg)	Org. matter (mg/kg)
1 *cha No*	A	0-4	10YR4/6	13.2	2548	7.02	18.04	65	1.2
		10-15	10YR3/6	10.6	3801	8.15	8.35	51	1.6
	BG[3]	0-4	10YR2/2	18.6	<1	12.47	1.84	38	5.1
		25-30	7.5YR5/2	13.0	<1	6.39	1.84	25	2.1
2 *cha Yes*	A	0-4	10YR3/4	64.2	126	54.6	42.2	200	3.2
		10-15	10YR3/4	16.6	85	13.1	2.9	75	1
		25-30	10YR4/6	13.7	83	8.54	1.1	50	0.9
		55-60	10YR4/4	17.0	79	8.45	1.3	44	0.8
	B	0-4	10YR4/4	42.0	79	31.14	4.4	200	1.6
		10-15	10YR4/3	10.6	30	56.8	1.3	140	.06
	BG	0-4	10YR3/4	8.7	<1	12.47	0.5	42	1.2
		10-15	10YR4/4	5.1	<1	6.12	0.6	37	1
3 *gra No*	A	0-4	10YR2/1	9.7	<1	10.7	7.5	26	1.7
		10-15	10YR2/1	16.7	7	7.0	12.2	23	1.3
		25-30	10YR2/2	15.6	17	6.7	9.9	17	1.4
		55-60	10YR3/2	11.3	19	4.7	6.0	8	0.6
	BG	0-4	10YR2/1	13.6	<1	14.9	1.1	27	2
		10-15	10YR2/1	12.4	<1	13.6	0.8	28	2
5 *cha No*	A	0-4	10YR3/2	12.7	<1	4.75	28.2	38	2.3
		10-15	10YR4/4	9.6	<1	2.56	17.37	29	1.3
	B	0–12	10YR3/4	11.5	<1	3.84	16.48	28	1.2
		dupe.	10YR3/4	10.7	<1	4.54	29.02	34	2.3
		trip.	10YR3/4	10.1	<1	5.69	19.08	30	1.6
7 *cha Yes*	A	0-4	10YR4/4	19.8	<1	69.3	1.7	58	0.7
		10-15	10YR5/6	19.8	<1	3.3	7.5	12	0.9
		25-30	10YR4/4	17.5	<1	1.7	3.4	9	0.7
		46-60	10YR4/4	16.9	<1	2.3	3.8	15	0.8
	B	0-4	10YR4/2	19.6	3	130.4	0.8	61	0.7
		10-15	10YR4/6	17.8	<1	2.5	5.9	12	1
		25-30	10YR5/6	19.6	<1	3.1	2.9	10	0.7
		46-60	10YR3/3	15.4	<1	2.7	0.9	21	0.4
	BG	0-4	10YR2/1	-	<1				
		10-15	10YR3/2	14.3	<1	5.7	0.9	36	0.7

[1] Results expressed on dry weight basis.

[2] Site ID *cha* = chamber and *gra* = gravel. *No* = no ponding and *Yes* = ponding.

[3] BG = background cores taken at stated distance below ground surface (bgs) and analyzed in duplicate (dupl.).

Table A.2 cont. Summary of soil core data for onsite wastewater systems in Hamilton Creek. [1]

Site ID [2]	Soil core loc.	Depth below I.S. (cm)	Soil color	Water content (wt.%)	Fecal coli. (org./g)	NH_3 (mg-N/kg)	NO_3 (mg-N/kg)	P (mg-P/kg)	Org. matter (mg/kg)
8 *gra* *Yes*	A	0-4	10YR2/1	12.7	<1	15.75	1.91	90	0.8
		10-15	10YR2/1	11.4	31	3.63	2.01	67	0.5
		25-30	10YR3/2	11.5	<1	3.45	1.94	11	0.8
	B	0-4	10YR3/1	10.5	131	8.86	1.85	90	0.6
		10-15	10YR3/1	13.6	6	3.95	2.57	21	0.7
		25-30	10YR3/1	9.5	<1	3.18	1.89	8	0.7
	BG[3]	105 cm bgs	10YR4/3	4.6	<1	5.16	1.84	25	1.3
		Dupl.	10YR4/3	4.7	<1	4.76	1.89	24	1.3
9 *cha* *No*	A	0-4	10YR3/6	9.8	<1	3.29	2.10	23	0.9
		10-15	10YR4/6	8.7	<1	2.87	2.00	17	0.8
		25-30	10YR4/6	7.2	<1	4.32	1.93	15	0.7
		55-60	10YR4/6	9.3	<1	2.40	2.08	17	0.6
	B	0-4	10YR4/6	9.6	<1	2.91	2.09	20	0.9
		10-15	10YR4/6	9.2	<1	2.92	1.96	18	0.8
		25-30	10YR4/6	7.8	<1	4.32	1.94	19	0.8
		55-60	10YR5/6	16.2	<1	2.94	1.82	19	1.1
	BG	60 cm bgs	10YR4/3	4.2	<1	4.39	2.08	51	1.5
		Dupl.	10YR4/3	4.4	<1	4.17	2.06	50	1.6
10 *gra* *Yes*	A	0-4	10YR3/1	16.9	8730	102.77	1.92	93	1.3
		10-15	10YR4/4	12.4	293	5.3	7.89	12	0.8
		25-30	10YR4/3	11.7	245	2.9	6.18	11	1.0
	B	0-4	10YR3/2	16.9	661	29.29	5.74	42	1.0
		25-30	10YR4/3	13.8	639	8.11	6.08	15	0.9
	BG	75 cm bgs	10YR5/3	3.2	<1	5.53	1.98	30	0.8
		Dupl.	10YR5/3	3.1	<1	3.69	1.92	30	0.6
11 *cha* *Yes*	A	0-4	10YR3/1	17.3	918	99.03	1.97	59	1.1
		10-15	10YR3/2	12.3	27	6.75	2.00	30	1.4
		25-30	10YR3/1	10.8	191	4.48	2.03	27	1.1
		55-60	10YR3/1	10.4	34	4.04	1.97	15	0.9
	BG	75 cm bgs	10YR3/2	2.7	<1	8.44	2.09	22	3.9
		Dupl.	10YR3/2	(18.6)	<1	8.48	2.01	23	3.6

[1] Results expressed on dry weight basis.

[2] Site ID *cha* = chamber and *gra* = gravel. *No* = no ponding and *Yes* = ponding.

[3] BG = background cores taken at stated distance below ground surface (bgs) and analyzed in duplicate (dupl.).

Table A.3. Summary of soil core data for onsite wastewater systems in Todd Creek Farms. [1]

Site ID [2]	Soil core loc.	Depth below I.S. (cm)	Soil color	Water content (wt.%)	Fecal coli. (org./g)	NH_3 (mg-N/kg)	NO_3 (mg-N/kg)	P (mg-P/kg)	Org. matter (mg/kg)
12 *cha* *No*	A	0-4	10YR2/1	12.7	<1	4.26	1.92	2	1.4
		10-15	10YR2/1	11.4	31	3.96	1.99	1	1.3
		25-30	10YR3/2	11.5	<1	3.73	2.00	1	1.1
	B	0-4	10YR3/1	10.5	131	3.36	2.13	1	0.9
		10-15	10YR3/1	13.6	6	3.76	2.00	1	0.9
		25-30	10YR3/1	9.5	<1	3.15	2.34	2	0.3
	BG[3]	105 cm bg	10YR4/3	4.6	<1	4.11	2.12	1	1.4
		Dupl.	10YR4/3	4.7	<1	4.23	1.85	2	0.3
13 *gra* *Yes*	A	0-4	10YR5/4	26.3	227	7.78	2.52	2	0.5
		10-15	10YR5/4	31.1	<1	5.59	1.89	1	0.5
		25-30	10YR5/4	23.3	<1	5.99	1.90	5	0.6
		55-60	10YR5/4	21.6	<1	6.26	1.85	2	0.6
	BG	50 cm bgs	10YR4/3	19.2	<1	6.19	3.27	6	0.7
		Dupl.	10YR4/3	18.7	<1	5.82	1.97	5	0.8
14 *Cha* *Yes*	A	0-4	10YR3/1	46.0	TNTC[4]	721.99	1.97	27	1.7
		10-15	10YR4/3	27.1	4208	10.13	10.49	1	1.1
		25-30	10YR4/3	25.4	14029	15.21	10.19	1	0.8
		55-60	10YR5/4	ND	2853	8.19	8.44	1	0.8
	BG	70 cm bgs	10YR4/4	5.4	<1	3.17	7.97	8	0.1
		Dupl.	10YR4/4	5.8	<1	3.27	1.55	8	0.1
15 *Gra* *No*	A	0-4	10YR5/4	24.9	1465	24.06	2.05	1	0.7
		10-15	10YR5/4	25.9	1428	55.16	1.89	3	0.6
		25-30	10YR4/4	23.9	1277	62.62	2.01	2	0.6
		55-60	10YR4/3	23.0	1108	65.75	1.95	5	0.6
	B	0-4	10YR4/3	25.2	TNTC	25.68	1.96	6	1.0
		10-15	10YR5/4	26.1	424	35.63	2.21	2	1.1
		25-30	10YR5/4	24.4	310	82.52	1.92	6	1.1
	BG	60cm bgs	10YR5/4	12.1	<1	9.2	5.17	4	1.8
16 *cha* *Yes*	A	0-4	10YR3/1	17.3	918	159.85	1.92	2	1.2
	B	0-4	10YR3/2	12.3	27	80.44	2.18	2	1.1
		10-15	10YR3/1	10.8	191	45.20	2.50	2	1.1
	BG	45 cm bgs	10YR3/2	21.5	<1	8.76	1..85	3	2.0
		Dupl.	10YR3/2	21.5	<1				

[1] Results expressed on dry weight basis.
[2] Site ID *cha* = chamber and *gra* = gravel. *No* = no ponding and *Yes* = ponding.
[3] BG = background cores taken at stated distance below ground surface (bgs) and analyzed in duplicate (dupl.).
[4] TNTC = too numerous to count (>15,000/g). Results are express on a dry weight basis.

Table A.4. Fecal coliforms and MS-2 and PRD-1 bacteriophages with soil depth at Site 2.

Soil core sample	Depth (cm)	Fecal coliforms (cfu/g dry soil)	MS-2 (pfu/g dry soil)	PRD-1 (pfu/g dry soil)
1a(1)	5	928	673	2922
1a(2)	5	1091		
1b(1)	5	1181	194	1084
1b(2)	5	1394		
2a(1)	15	1994	62	218
2a(2)	15	2088		
2b(1)	15	1287	120	464
2b(2)	15	1347		
3a(1)	30	966	<1	250
3a(2)	30	858		
3b(1)	30	2646	108	594
3b(2)	30	3564		
4a(1)	60	895	77	602
4a(2)	60	741		
4b(1)	60	418	14	360
4b(2)	60	367		
5a(1)	5	1387	55	292
5a(2)	5	1533		
5b(1)	5	1487	52	471
5b(2)	5	1152		
6a(1)	15	3073	158	591
6a(2)	15	2364		
6b(1)	15	2161	25	712
6b(2)	15	2112		
7a(1)	30	625	28	84
7a(2)	30	616		
7b(1)	30	717	48	80
7b(2)	30	845		
9a(1)	5	864	<1	<1
9a(2)	5	1030		
9b(1)	5	1175	<1	<1
9b(2)	5	1125		
10a(1)	15	254	21	423
10a(2)	15	169		
10b(1)	15	117	98	176
10b(2)	15	20		
11a(1)	30	35	<1	<1
11a(2)	30	58		
11b(1)	30	12	<1	<1
11b(2)	30	12		
12a(1)	60	<1	<1	<1
12a(2)	60	<1		
12b(1)	60	<1	<1	<1
12b(2)	60	<1		

Table A.4. cont. Fecal coliforms and MS-2 and PRD-1 bacteriophages with soil depth at Site 2.

Soil core sample[1]	Depth (cm)	Fecal coliforms (cfu/g dry soil)	MS-2 (pfu/g dry soil)	PRD-1 (pfu/g dry soil)
13a(1)	5	969	<1	11
13a(2)	5	1079		
13b(1)	5	540	<1	20
13b(2)	5	761		
14a(1)	15	<1	<1	<1
14a(2)	15	<1		
14b(1)	15	<1	<1	<1
14b(2)	15	<1		

[1] Core segment code conveys the following: the number gives the segment number, the letter gives the duplicate subsample, and the (number) gives the duplicate analysis. For example, 1a(1) = segment 1 (location 1 at 5 cm depth), core subsample (a), and duplicate analysis (1) versus 14b(2) = segment 14 (location 4 at 15 cm depth), core subsample (b), and duplicate analysis (2).

Table A.5. Relationship of fecal coliforms and bacteriophage in soil core samples collected below the infiltrative surface of a mature WSAS.

Depth (cm)	Fecal coliforms (cfu/g dry soil)	MS-2 (pfu/g dry soil)	PRD-1 (pfu/g dry soil)	Ratios FC/MS-2	Ratios FC/PRD-1
5	928	673	2922	1.4	0.3
5	1091				
5	1181	194	1084	6.1	1.1
5	1394				
15	1994	62	218	32.2	9.1
15	2088				
15	1287	120	464	10.7	2.8
15	1347				
30	966	1	250	966.0	3.9
30	858				
30	2646	108	594	24.5	4.5
30	3564				
60	895	77	602	11.6	1.5
60	741				
60	418	14	360	29.9	1.2
60	367				
5	1387	55	292	25.2	4.8
5	1533				
5	1487	52	471	28.6	3.2
5	1152				
15	3073	158	591	19.4	5.2
15	2364				
15	2161	25	712	86.4	3.0
15	2112				
30	625	28	84	22.3	7.4
30	616				
30	717	48	80	14.9	9.0
30	845				
5	864	1	1	864.0	864.0
5	1030				
5	1175	1	1	1175.0	1175.0
5	1125				
15	254	21	423	12.1	0.6
15	169				
15	117	98	176	1.2	0.7
15	20				
30	35	1	1	35.0	35.0
30	58				
30	12	1	1	12.0	12.0
30	12				
60	1	1	1	1.0	1.0
60	1				
60	1	1	1	1.0	1.0
60	1				
5	969	1	11	969.0	88.1
5	1079				
5	540	1	20	540.0	27.0
5	761				
15	1	1	1	1.0	1.0
15	1				
15	1	1	1	1.0	1.0
15	1				
Count =	52	26	26	26	26
Min =	1	1	1	1	0.32
Max =	3564	673	2922	1175	1175
Median =	861	23	197	20.9	3.51

Note: values of 1 = nondetect at <1

Attachment 3

Third-Party Bundled Expanded Polystyrene Research Studies

Performance of Chamber and EZ1203H Systems Compared to
Conventional Gravel Septic Tank Systems in North Carolina

R.L. Uebler, S. Berkowitz, P. Beusher, M. Avery, B. Ogle, K. Arrington and B. Grimes

Abstract

The North Carolina On-Site Wastewater Section conducted a statewide survey, which compared the performance of chamber and EZ1203H systems with 25% trench length reduction to conventional gravel systems. A total of 912 systems were randomly chosen in 6 counties across the state. To control evaluation bias, a group of students from Western Carolina University were hired to inspect each system. A system was considered to have failed if there was evidence of sewage at the ground surface or if an owner reported problems with the system. The statewide failure rate of both standard chamber and EZ1203H systems compared to conventional gravel systems was not statistically different at a 95% confidence level.

INTRODUCTION

Recent legislation in North Carolina provides for the designation of approved Innovative on-site wastewater systems as accepted systems. The legislation was supported by Innovative product manufacturers, because of a perceived stigma attached to Innovative designation of their product, and real permitting differences for Innovative products compared to conventional gravel systems, which were required by the state. Systems, which receive accepted system approval, may be permitted in the same manner as conventional septic tank systems. In order to achieve accepted system status, the manufacturer of a system must submit evidence that the system has been in general use in the state for 5 years. In addition, the manufacturer shall provide the Commission for Health Services with information sufficient to enable the Commission to fully evaluate the performance of the system in this State for at least the five-year period immediately preceding the petition. Rule was subsequently developed by the state, which established the requirements for what constituted "sufficient information" for the Commission to make their evaluation. For trench systems, the Rule requires "the field evaluation of at least 250 randomly selected innovative systems compared with 250 comparably-aged randomly selected conventional systems, with at least 100 of each type of surveyed system currently in use and in operation for at least five years. Systems surveyed shall be distributed throughout the three physiographic regions of the state in approximate proportion to their relative usage in the three regions. The survey shall determine comparative system failure rates, with field evaluations completed during a typical wet-weather season (February through early April), with matched innovative and conventional systems sampled during similar time periods in each region" (NCDEHNR. 2006).

Infiltrator, Inc., which manufactures a chamber system, and Ring Industrial Group, which manufactures the EZ1203H polystyrene aggregate system, subsequently applied for accepted

*Authors are Dr. Robert Uebler (bob.uebler@ncmail.net), Steven Berkowitz, PE, Kae Arrington, MS, and Dr. Barbara Grimes, NCDENR-On-Site Wastewater Section, 1642 Mail Service Center, Raleigh, NC 27699-1642, Dr. Paul Beusher and Matt Avery, NCDHHS State Center for Health Statistics, Dr. Burton Ogle, Western Carolina University.

system designation. In addition to Infiltrator, three other chamber manufactures, Advanced Drainage Systems, Inc., manufacturer of the Bio-diffuser chamber, Cultec, manufacturer of the Contactor chamber, and Hancor, Inc., manufacturer of the Envirochamber, chose to participate in the survey required for system approval. The objective of the survey was to determine the failure rate of the chamber and EZ1203H systems compared to conventional gravel systems. This paper reports the outcome of the required survey.

Background

Conventional septic tank systems in North Carolina are designed with 3-foot wide trenches, which have a 12-inch gravel depth to provide storage for septic tank effluent. Systems with multiple trenches are spaced with 9-feet of separation between the center of adjacent trenches. A 12 to 18 inch depth of suitable soil is required below the trench to provide treatment of the effluent when it leaves the trench. The amount of trench bottom area required at a site is determined from an evaluation of soil texture. A long-term acceptance rate (LTAR) is chosen for the soil texture found at a site from Table 1.

Table 1**.** Long-term acceptance rates (LTAR) allowed for the soil texture evaluated at a site.

Soil Group	Texture Family (USDA)	Texture Class (USDA)	LTAR (gpd/ft^2)
I	Sands	Sand, Loamy Sand	1.2 to 0.8
II	Coarse Loams	Sandy Loam, Loam	0.8 to 0.6
III	Fine Loams	Sandy Clay Loam, Silt Loam, Clay Loam, Silty Clay Loam, Silt	0.6 to 0.3
IV	Clays	Sandy Clay, Silty Clay, Clay	0.4 to 0.1

The trench bottom area is then calculated by dividing the design flow, 120 gpd per bedroom, by the LTAR. Trench length is then determined by dividing the required trench bottom area by the trench width of 3 feet.

The chamber systems surveyed in this study were the standard design, which had an average open bottom width of about 29 inches and height of about 12 inches. The polystyrene aggregate systems surveyed were the EZ1203H, which is 12 inches high and 36 inches wide. The North Carolina approval for the both the standard chamber and the EZ1203H, allows for a 25% reduction in trench length compared to a conventional gravel trench system. Other trench requirements for chambers and EZ1203H systems are the same as for conventional systems. Trenches are dug with a 3-foot width, and placed on 9-foot centers, if multiple trenches are required.

Methods and Materials

The Rule developed by the state required that a survey be conducted, which was able to detect if the failure rate, for the standard chamber or EZ1203H systems, was 5 or more percentage points higher than the failure rate for conventional systems. Further, if the comparison showed a difference of at least 5 percentage points (e.g. 9% failure rate for innovative system A and a 4%

failure rate for conventional gravel systems), there should only be a 5% chance that the difference between the two samples would occur by chance. This is the “95% confidence level”. If a statistically significant higher failure rate was not detected in the innovative group, than the conclusion would be that the innovative system performs the same as or better than conventional systems. This is a “one sided” test of the difference between proportions.

Preliminary analysis by Dr. Paul Beusher with the NCDHHS State Center for Health Statistics revealed that, a sample size of 300 was needed for each type of system surveyed, in order to conclude with a 95% confidence that a measured failure rate for an innovative system that is 5 percentage points higher than the failure rate for conventional systems is not due to chance. The calculation of required sample size assumed that the samples have an 80% “power” to detect a **true** difference of 5 percentage points. This sample size estimate also assumed an overall septic tank failure rate (across all system types for 5-9 year old systems) in the range of 5%. It was determined that a sample size of 300 for each system would result in valid analysis, regardless of the total number of systems (population) from which the sample was chosen. A slightly larger sample was recommended to be drawn from available records, to allow for sites at which failure status could not be determined, such as inaccessible sites.

It was determined that systems from each of the three physiographic regions must be included in the survey in order for the results to be valid, since soils vary by region of the state. Two counties were chosen in each of North Carolina’s physiographic regions (Mountains, Piedmont, and Coast Plain) for the purpose of conducting the required comparison of system performance. The six counties surveyed were selected on the basis of being representative of the region and the fact that they had a good system of record keeping for septic tank system permits. Further, counties were chosen that were known to have large numbers of each system type, so that it would be likely that a statistically valid sample could be drawn from the records for each system type. Since the total sample size for each system type was required to be at least 300 and there were 6 counties chosen, at least 50 systems were selected from each county for the survey. The counties chosen were Alamance (Piedmont), Buncombe (Mountain), Henderson (Mountain), Lincoln (Piedmont), Onslow (Coast) and Wilson (Coast).

A retired employee formerly with the NC Division of Environmental Health, whose primary responsibilities before retirement involved restaurants, was retained to draw a random sample of the required size from each county. This person was chosen because he was familiar with Health Department records, but had not been involved with the permitting of chamber or EZ1203H systems, in order to avoid a possible source of bias in the sample selection. The available records for each type of system were assigned a number. Records were than drawn on the basis of a random number generator until the required number of systems to be inspected was achieved.

A team of third party inspectors, unaffiliated with the NC On-Site Wastewater Section or the product manufacturers, was hired to visit each system for which a record was randomly drawn. The inspectors were Environmental Health students from Western Carolina University under the supervision of Dr. Burton Ogle from WCU. The students were trained to inspect septic tank systems by a former employee of the NC Wastewater Discharge Elimination program now with WCU, whose primary responsibility had been the identification of failed septic tank systems in need of remediation. Systems were surveyed from March through April of 2005, in an effort to inspect systems during a time when the most failures are normally recorded and control seasonal effects on failure rate. Each system was inspected by two members of the survey team. Only houses, which were known to be occupied, were inspected.

The following questions were answered with a yes or no by the survey team for each system inspected:

1.) Is sewage ponded on the surface?
2.) Does pressure to the soil surface with a shoe result in sewage coming to the surface?
3.) Is there a straight pipe?
4.) Is there evidence of past failure?
5.) Is there evidence of a repair?

In addition, an attempt was made to interview the occupants at each survey site in person or by phone. Answers to the following questions were obtained during the interview:

1.) Has your tank been pumped for other than routine maintenance?
2.) Are you having any of the following problems with your system today: surfacing on the ground; wet over system; odors; back up into the house; other?
3.) Have you had problems with the system in the past: surfacing on the ground; wet over system; odors; back up into the house; other?
4.) How was the problem solved?
5.) Has system been repaired or replaced?

A yes for one or more of the above questions answered by the survey team or the occupant was considered to be a system failure. More information was collected, but was not used to determine system failure.

Results and Discussion

A total of 912 systems were inspected, 303 chamber systems, 306 EZ systems and 303 gravel systems. Interviews were completed with 370 of the occupants. The survey sample contained 290 sites from the Coastal Region, 317 sites from the Piedmont region and 305 sites from the Mountain region. The survey sample had the following age distribution: 307 systems were 2 to 4 years old, 377 systems were 5 to 7 years old, and 228 systems were 8 to 12 years old. No systems older than 12 years were included in the survey because neither the chamber nor EZ1203H were approved in the state at that time.

The following survey results were obtained.

Table 1. System failure rate for conventional gravel, chamber, and EZ1203H systems.

System Type	Systems OK	Systems Failed	Total	Percent Failure
Gravel	281	22	303	7.3
Chamber	277	26	303	8.5
EZ1203H	277	29	306	9.5
Total	835	77	912	8.4

The statewide failure rate was 7.3 % for conventional gravel systems, 8.5% for chamber systems and 9.5% for the EZ1203H systems. The difference in failure rate between the conventional and chamber systems was 1.2%. The difference in failure rate between the conventional and EZ1203H systems was

2.2%. The purpose of this survey was to determine if there was a 5% or greater difference in the failure rate of chamber and EZ1203H systems compared to conventional gravel systems. The difference in failure rate was less than 5% for each system type. Statistical analysis was performed controlling for both physiographic region and age of system. At a 95% confidence level, the null hypothesis of no difference in failure rate could not be rejected for the chamber or EZ1203H system compared to the gravel system, based on the data collected. In laymen's terms, we would say that the chamber and EZ1203H performed the same as gravel when compared on a statewide basis.

Dominant soil texture, upon which LTAR is assigned for system design, varies by physiographic region of the state. In the Coastal region, the two dominant soil groups are sands and fine loams. The most limiting factor to the performance of septic tank systems is often depth to the seasonal high water table. In the Piedmont region, the two most dominant soil groups are fine loams and clays. Soil depth and slowly permeable soils are often the most limiting factors to system performance. In the Mountain region, coarse loams and fine loams are the dominant texture groups. Shallow soil depth and steep slopes are often the most limiting factors to system performance. To see if there was a difference in performance by region, given the differences in dominant site conditions associated with a region, the data was further analyzed by physiographic region of the state (Coastal Plain, Piedmont or Mountains). An insufficient number of sites were surveyed to statistically compare the performance of each system type by region. The data was therefore grouped by region without regard for system type to make the regional comparison, since there was no statistical difference in performance between system types. The results are given in Table 2.

Table 2. System failure rate by physiographic region disregarding differences in system type.

Physiographic Region	Systems OK	Systems Failed	Total	Percent Failure
Coast	256	34	290	11.7
Piedmont	286	31	317	9.8
Mountain	293	12	305	3.9
All Regions	835	77	912	8.4

The failure rate for all systems combined was highest in the Coast, 11.7%, and lowest in the Mountains 3.9%. In the Piedmont area the failure rate was 9.8%, which was similar to the failure rate found in the Coast. The difference in failure rate when the mountains region is compared to both the Piedmont and Coast region was statistically significant at the 95% level. The significant effect of region might be explained as follows. Most systems in the mountains are long and narrower. This factor in conjunction with slope ranging in excess of 25% may promote more efficient movement of sewage away from the drain field, e.g. low linear loading rates, and better system performance.

The data was also analyzed to see if there was a difference in system failure rate as systems aged. System failure rate is summarized in the Table 3 below for three age groups: 1.) 2 to 4 years old, 2) 5 to 7 years old, and 3.) 8 years to 12 years old.

Table 3. System failure rate by age group disregarding differences in system type.

System Age	Systems OK	Systems Failed	Total	Percent Failure
2 to 4 years	283	24	307	7.8
5 to 7 years	351	26	377	6.9
8 to 12 years	201	27	228	11.8
All Ages	835	77	912	8.4

When data for all system types was aggregated within an age group and the aggregated data compared by system age, the failure rate was highest for the 8 to 12 year old systems. The differences between the age groups, while controlling for system type and physiographic region, were not statistically significant at the 95% level. One might expect that the oldest systems should have the highest failure rate as observed, because clogging of the trench can be expected to increase, as more sewage is disposed in the trenches over time. Also, solids will spill over from the septic tank to the absorption field, if settled solids are not periodically removed by the owner as the system ages.

Finally, it is interesting to note that the average failure rate statewide is 8.4% for systems with an age up to 12 years old. There is much speculation in various arenas about the failure rate of ground absorption septic tank systems, with little or no substantive information to support the speculation. Perhaps a side benefit of this survey will be a defensible failure rate upon which to base future discussions.

Summary

The purpose of this survey was to determine if there was a difference in the failure rate of chamber and EZ1203H systems compared to gravel. Based on the data collected, the statewide failure rate of both standard chamber and EZ1203H systems compared to conventional gravel systems was not statistically different at a 95% confidence level. In laymen's terms, we would say that the chamber and EZ1203H systems performed the same as gravel systems.

Acknowledgements

This study could not have been completed without the cooperation of the fine staff from the Alamance, Buncombe , Henderson, Lincoln, Onslow and Wilson County Health Departments, and the hard work of the student surveyors from Western Carolina University. Peter Whitaker from WCU provided training on failure identification to the students. Clay Pennington provided assistance with sample selection. Financial support for this project was provided by Advanced Drainage Systems, Cultec, Hancor, Infiltrator Systems, Ring Industrial Group, and a grant (EW05076) from the USEPA 319 Non-Point Source Pollution Program entitled: In-Field Survey Initiative of Conventional and Innovative Onsite Wastewater Systems Performance In the Mountain, Piedmont and Coastal Physiographic Regions of NC.

References

NCDENR. 1977. Laws and Rules for Sewage Treatment and Disposal Systems. Department of Environment and Natural Resources, Division of Environmental Health, On-Site Wastewater Section, 1642 Mail Service Center, Raleigh NC 27699-1642
http://www.deh.enr.state.nc.us/osww_new//index.htm

FIELD INSPECTIONS AND EVALUATION
OF THE HYDRAULIC PERFORMANCE OF
EZ FLOW 1201P
GRAVEL SUBSTITUTE DRAINFIELD SYSTEMS
IN
CLACKAMAS, MARION, CROOK, MULTNOMAH AND
DESCHUTES COUNTIES, OREGON

Prepared by:

Robert Sweeney, MS, REHS

Steve Greenslate, AAS

Justin Hartmann, MS

Environmental Management Systems, Inc.

4080 SE International Way

Suite B-112

Milwaukie, OR 97222

Phone: 503-353-9691

Fax: 503-353-9695

envmgtsys.com

TABLE OF CONTENTS

INTRODUCTION

Purpose and Scope

This report reflects a third party performance evaluation of EZflow 1201P brand drain product, conducted by Environmental Management Systems, Inc (EMS). The evaluation, contracted by the RING Industrial Group (RING), was conducted in accordance with the letter of approval, issued by the Oregon Department of Environmental Quality (DEQ), to evaluate the performance of the EZflow 1201P product (dated February 7th, 2003, and signed by the DEQ Water Quality Program Administrator, Michael Llewelyn). This letter is attached to this report as Appendix A. Additional discussions with DEQ staff were continued through April of 2004, to clarify study expectations.

Prior to the letter of approval, the EZflow 1201P product was reviewed by Oregon's Technical Review Committee (TRC), which recommended that the 1201P product be approved for installation and evaluation. Pass-fail determinations were to be documented annually for a minimum of 25 systems or 10% of installations up to a maximum of 100 systems installed from the date of approval. These systems were revisited and evaluated spanning a five year period (2003-2007), starting from the letter of approval to the performance evaluation.

In accordance with the aforementioned letter of approval, Environmental Management Systems, Inc. was hired by RING Corporation to perform a neutral, third party evaluation for its EZflow 1201P drainfield product. EMS staff is familiar with the product, having specified, designed and inspected systems with EZflow 1201P, gravel and other drainfield products. EMS does not have any financial interest in the RING Corporation, its employees nor its subsidiaries.

This study began, following approval in February 2003, when RING started selling its 1201P product line in Oregon. The product has been stocked and distributed by several plumbing and related materials companies and has been installed by DEQ licensed installers. At present, potentially 3000 of the EZflow 1201P aggregate trench systems could have been installed in Oregon as per the DEQ approval letter (Appendix A). However, based on information from the RING Corporation, DEQ, various product distributors, and our survey of installed systems, it is suspected by EMS staff that far fewer (~1300) have actually been installed as components of septic systems. The EZflow 1201P system represents a new or innovative technology in Oregon and thus requires a performance evaluation prior to its unregulated sale (Oregon Administrative Rule (OAR) 340-071-0135, Appendix B). The EZflow systems are designed to be alternatives to traditional washed gravel septic leach fields. Expanded Polystyrene Systems (EPS) were developed in North Carolina and patented in the mid-1980s as the Houck drainage system® (Robertson 2000). The EZflow systems are now widely used throughout North America and are approved for use in 35 States and 4 Canadian provinces (RING Industrial 2008). The manufacturer claims that the EPS Aggregate trench systems outperform the traditional systems due to ease of handling, the absence of fine particles, consistent sizing in aggregate material, and an increased surface area (Robertson 2000).

The EPS aggregate systems examined in this study are composed of 1 inch grooved cubes of expanded polystyrene aggregate, loosely packed into polyethylene netting. These particles have been determined to be structurally sound, durable, and inert in the environment in which they are placed (Sonnenberg 2001). The bundle diameter for this study was 12 inches with a single bundle installed per 12 inch wide trench. The center tubing consists of a 4 inch perforated flexible tube in compliance with ASTM F 405 (American Society for Testing and Materials). While this study investigated installations using a single bundle, other installation regimes have been composed of up to six bundles installed in a variety of configurations ranging from triangular to vertical or horizontal (Robertson 2000).

EMS obtained records from several sources to determine the number and location of actual installations of the product. Investigations of installed systems which were conducted over the study period polled residents for waste strength, hydraulic loading, and problems with the systems. Site visits with physical inspections were performed with prior notice to property owners and the Oregon DEQ.

Background

The function of an onsite wastewater system relies on its ability to both treat septic inflow and in its ability discharge treated wastewater effectively. In typical residential onsite systems, wastewater, generated within a house, is first drained or pumped to a septic tank. A properly functioning septic tank will provide the initial primary treatment step in the remediation of residential wastewater. Here it allows for a sufficient residence time (≥2 days) for pretreatment and for the separation of the inflow to three major components. These layers, in vertical order, are the oils and fats which comprise the top layer, the clear effluent layer which is in the middle, and a dense bottom layer where solids settle out (Crites and Tchobanoglous 1998).

Effluent, the clear middle layer, is passed from the septic tank to the leach field for dispersion and disposal. Traditionally, wastewater treatment systems utilize a leach field which is filled with washed gravel. Here effluent entering the system slowly flows into the washed gravel area and into native soil where remaining nutrients, bacteria and viruses are removed naturally before the treated water has the potential to mix with groundwater. Five factors are relevant to the successful operation of such systems (Appendix C):

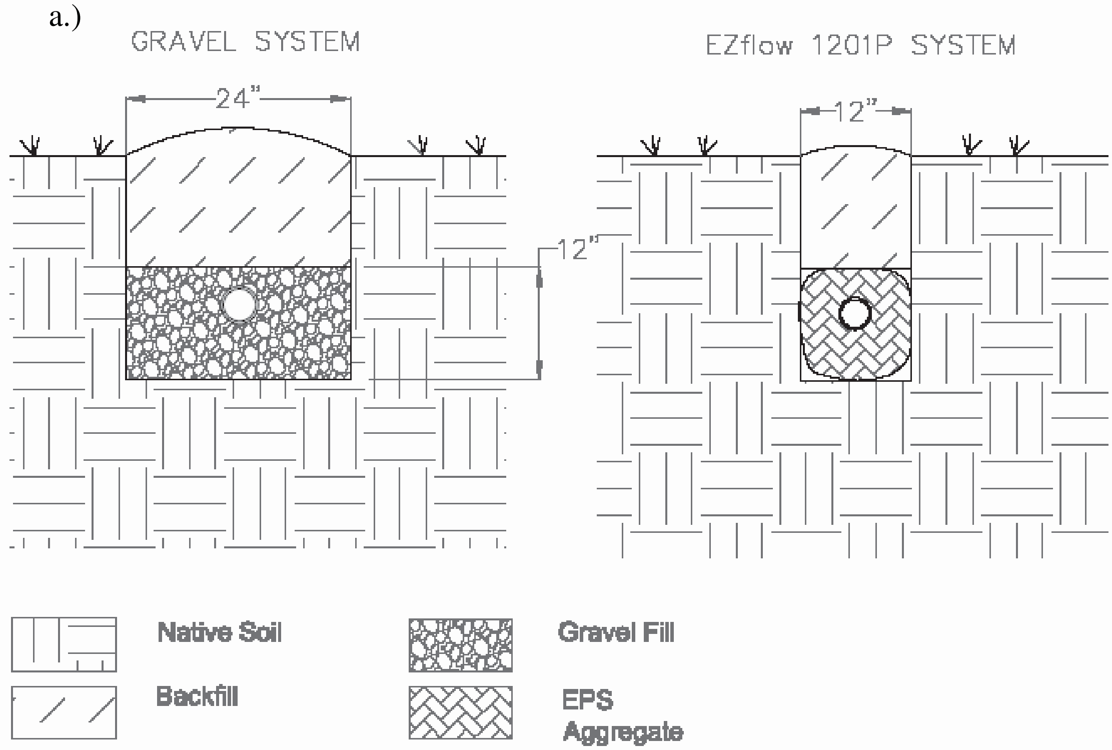
1. Siting
2. Design
3. Construction
4. Operation
5. Maintenance

If any of these five factors are overlooked in the use of an onsite or decentralized wastewater treatment systems, failures are possible. Given the appropriate installation, siting, design, operation, and maintenance of onsite septic systems, a lifetime of 20 years or longer can be expected (appendix C).

The Oregon DEQ approval letter (Appendix A) requires failure rates of 3% to be the standard for comparison between new technologies and conventional gravel systems. In addition, a recent study, looking at over 400 septic systems, estimates the failure rates in Oregon to be roughly 2% (Hallahan 2002). Problems leading to system failure may begin within the septic tank or be caused by compromises in the infiltration system. For example, overuse of a system will result in a low residence time in the septic tank for effluent and subsequent poorly treated effluent being discharged into the leach field. This may cause low permeability in the leach field due to a high suspended solid load or as a result of the large biomat that will grow in the presence of excessive nutrients from the untreated wastewater. Problems may also reside in the infiltrative part of the septic system where fine inorganic particles clog soil pores and 'back up' filtrate. Fine particles, once built up in a single layer, may result in the reduced function of a septic leach field. This has been demonstrated by White (2002), where the total permeability of the leaching system is controlled by the layer with the lowest saturated hydraulic conductivity (K_{sat}).

The saturated hydraulic conductivity of the receiving soil and neighboring soil is a central concept in quantifying a leach field's ability to treat and infiltrate wastewater. Filtrate movement within the soil is a function of the hydraulic gradient of the system (fill, soil, etc.) and the saturated hydraulic conductivity, which encapsulates physical properties of the fluid, over a given area. Designs for soil absorption systems are based on the anticipated daily flow and hydraulic loading rates which are traditionally <5% of the K_{sat} of the resident soil. Therefore, in theory, ponding above installed systems should be unlikely. However, as previously mentioned, biomats form within the leach fields and may control the infiltrative rates there providing it has the lowest K_{sat}. Percolation rates should largely be based on mature soils where the potential for a biomat to reduce the hydraulic conductively has been taken into account. Typical hydraulic loading rates range from 0.2 gal/ft^2/d for fine grained soils to around 1 gal/ft^2/d for coarse grained soils (Burks and Minnis 1994). However, Oregon has devised a slightly different system which is a function of linear feet per 150 gallons of design flow. The standard Oregon trench system is 2 feet wide, whereas the approved EZlflow 1201P system installed in 1 foot wide trenches (Fig. 1). In comparing the infiltrative surface contact area of gravel and EZflow systems, it is relevant to discuss the criterion used. Calculated infiltrative rates depend on whether the trench sidewall, bottom, or both parts of the trench are taken into account. For example, if just the sidewall is used, both systems are 12 inches deep and therefore have equivalent infiltrative rates. If the bottom is used, the EZflow system has half the infiltrative rate compared to gravel systems because the trench is half as wide. Lastly, if both are taken into account, the EZflow 1201P systems have 75% of the infiltrative rates compared to gravel systems.

a.)



b.)

Figure 1a.) Cross sections of gravel filled systems compared to EZflow 1201P installations in Oregon. b.) Picture of Expanded Polystyrene (EPS) Aggregate.

RING Industrial, the maker of EZflow 1201P, claims that the use of bundles containing Expanded Polystyrene (EPS) facilitates lower rates of failure over gravel systems (Robertson 2000). This is based on the absence of fine particles associated with gravel systems that may clog soil pores and thereby reduce the system hydraulic conductivity. In addition, the EPS facilitates a more tortuous path allowing more contact of wastewater with the treatment system before being released into the surrounding soil. Moreover, K_{sat} values have been determined to be higher in EPS systems such as EZflow rather than washed gravel (White 2002). Thus, by coupling the greater surface area and the increased K_{sat} values, the EZflow systems have the potential to remediate more wastewater in less time than conventional gravel systems. Furthermore, the manufacturer claims that the EZflow 1201P systems have less volume than conventional trenches and therefore promote a more rapid rise of effluent height within the trench and a more rapid fall due to subsequent changes in hydraulic head. This can result in a more efficient use of the entire trench surface, allow more wetting and drying within the trench, and allow greater oxygen exchange and management of the biomat layer.

Project objectives

The goal of this study is to observe whether the EZflow 1201P aggregate disposal systems are equivalent to that of gravel systems. In Oregon this means that an equivalent length of trench is required by the test product as with a gravel disposal trench. As a third party performance evaluator, Environmental Management Systems, Inc. began a performance evaluation of the EZflow 1201P brand drain product with these project objectives:

1. **Protocol, RING Industrial (Appendix C) Phase 1**
    - **a. Establishment of total population of EZflow 1201P systems comprised of:**
        - **1) Two physiographic areas of Oregon**
            - **-Pacific border**
            - **-Columbia-Snake River Plateau**
        - **2) 3 soil types ranging from high permeability to low**
        - **3) Sites should be 1-3 years old**

2. **Protocol, RING Industrial (Appendix C) Phase 2**
    - **a. Random subsample population drawn from 15 categories (5 Counties and 3 soil types)**
    - **b. Physical Site Inspections of sample population**
    - **c. Interviews and Mailers to home owners**

d. In case of failing systems: An investigation was conducted to ensure failure was caused by EZflow 1201P product

3. **Determine failure rates in the EZflow 1201P systems.**

   Record pass/fail rates for EZflow1201P systems/ The definition of a failing septic system is found in OAR 340-071-0100(66):

   "Failing system" means any system which discharges untreated or incompletely treated sewage or septic tank effluent directly or indirectly onto the ground surface or into public waters.

4. **Determine if EZflow 1201P meets DEQ requirements for unlimited installations of the aggregate systems in Oregon. (DEQ letter of Approval, DEQ OAR 340-071-0135) based on:**
   - **a. Whether or not the product is structurally sound, durable, and inert in the environment they are placed**
   - **b. Whether or not the product is capable of passing wastewater toward the infiltrative surface at a rate equal to or greater than gravel drain media**
   - **c. Site, soil and design requirements for investigated systems should be the same as the standard stone filled disposal system**
   - **d. Whether or not the product is based on theory or applied research that supports its intended use**

5. Investigation of 25 systems or 10% (whichever is larger) of the total 1201P installations (in the 5 Counties chosen) up to roughly 100 sites

a. Mailers and/or personal interviews

b. Site Inspections by a qualified technician

6. Follow evaluation protocol that has been peer reviewed, approved by DEQ, and accounts for variations in:

a. SOIL

b. CLIMATE

c. WASTE CHARACTERISTICS

d. TOPOGRAPHY

7. Whether or not the study had controls that represent performance standards to be achieved

8. In the event annual reports indicate a failure rate greater than 3%, RING will evaluate an equivalent number of gravel aggregate systems in similar soils and climactic conditions.

* DEQ was notified before and was provided the opportunity to observe all field inspections

STUDY PROCEDURES

Climate and Soils

As described in the Testing Protocol (Appendix C) two of Oregon's three major physiographic regions were selected for this study. The first, the Pacific border, was chosen because of its high rainfall and temperate climate. In contrast the second, the Columbia-Snake River Plateau, was chosen because it has a semi-arid climate and is slightly cooler throughout the year. Marion, Clackamas, and Multnomah Counties were selected for study in the Pacific border region because of their availability of electronic permit file records, number and variety of on-site wastewater treatment systems, and due to the variety of soil types in a relatively small geographic area. For the semi-arid climate region, Deschutes and Crook Counties were selected for their higher frequency of coarser (Group A) soils to facilitate a larger array of climactic and soil textures for the evaluation of the EZflow 1201P product. Differences between the areas are highlighted by Figure 2 in terms of one representative eastern area, Crook County (representative of Deschutes and Crook Counties) and one representative western area, Multnomah County (representative of Marion, Clackamas, and Multnomah Counties). Here, precipitation amounts and temperatures between the two Counties throughout the year are compared. Multnomah County, during most of the year, has greater than twice the rainfall in Crook County. The exception is found during the summer months when both are relatively dry. In addition, temperatures over the year in Multnomah County are roughly 10 degrees higher than Crook County.

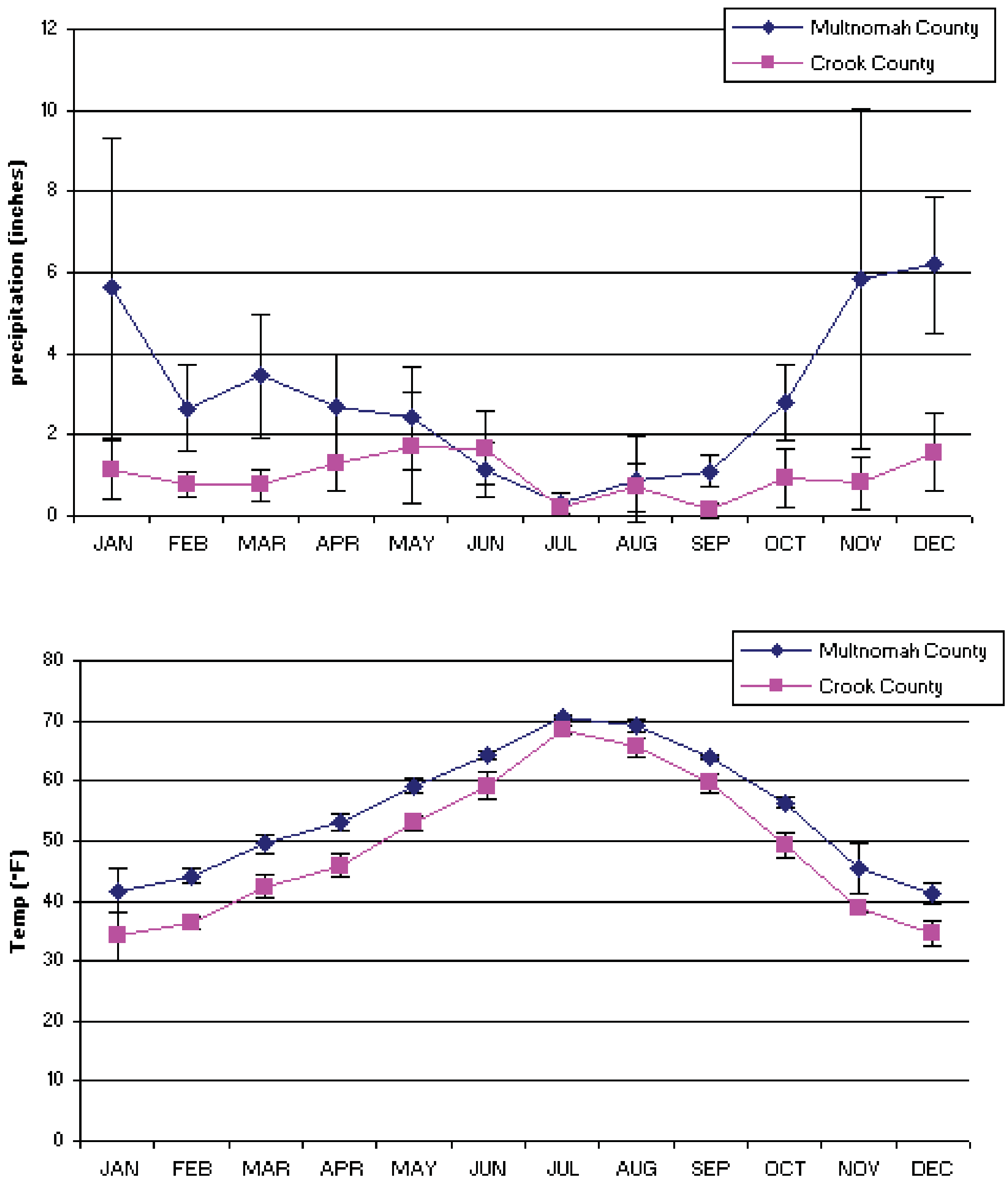


Figure 2. Monthly precipitation and temperature values averaged over the years of study (2003-2007) taken from Multnomah County (station number 356883) and Crook County (station number 356749) (Oregon Climate Service 2008)

Although testing was performed over a number of different soil classes (see Appendix D), the final reporting of soils can be divided into three simplified types. These Soil types range from those being highly permeable (Type A) to having low permeability (Type C, Table 1). Great effort was made to sample EZflow systems installed in all three soil types in all Counties when possible. However, type B was sampled predominantly followed by type C and the type A (Fig. 3).

Soil Type	Soil Texture	permeability
A	gravel, sand, loamy sand	High permeability
B	silt loam, sandy lay loam	Medium permeability
C	silty loam, silty clay, clay, sandy clay	Low permeability

Table 1. Soil texture and soil types used in study

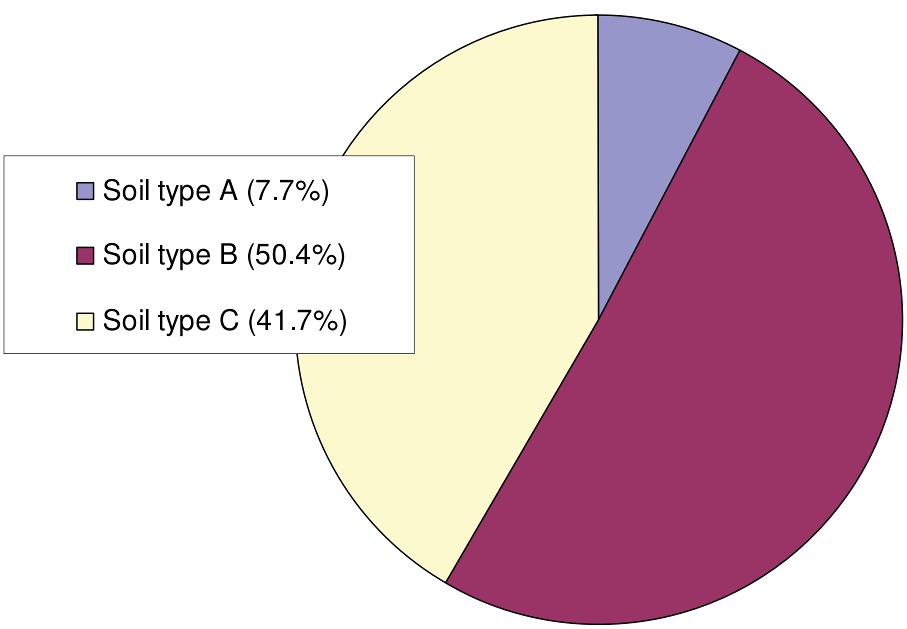


Figure 3. Breakdown of Soil types investigated throughout study period (2001-2008)

Site Selection

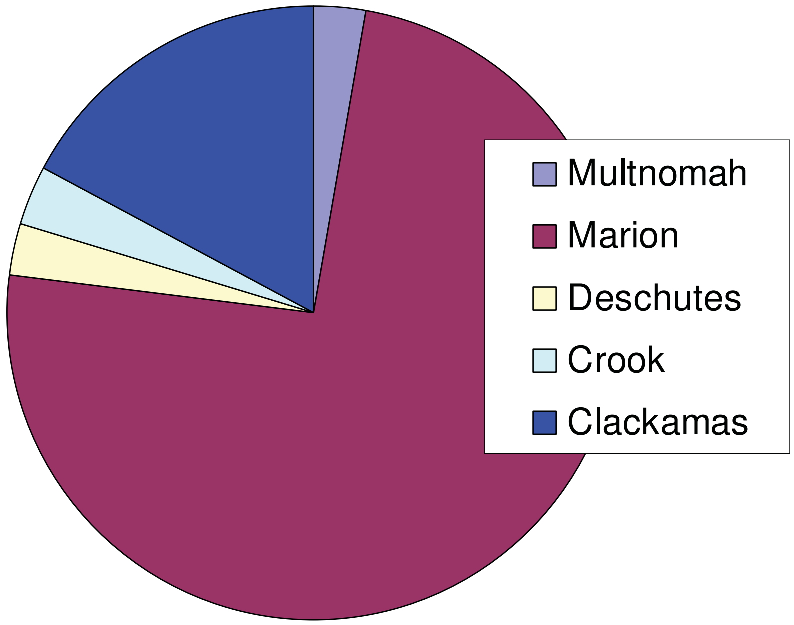


Figure 4. Breakdown of Counties investigated throughout study period (2001-2008)

Using County septic permit record database search engines, information from installers, regulators, and the manufacturer, 103 installed EZ Flow systems throughout Oregon were identified between the years 2002 and 2007. Once located, any available construction permits, soil notes, site evaluations, inspection reports, tax lot numbers, addresses, and "as-built diagrams" were collected for each of sites which were then assigned a site I.D. number (appendix D). With the addresses from the permit records, large-scale overview maps of all site locations to be visited were created. In Clackamas County, the tax lot number from the permit record was used on the County GIS website (Clackamas County 2008) to identify the USDA soil type for each of the sites. The NRCS website (Natural Resource Conservation Service 2008) was used to identify all other Counties soil types used over the study. Site selection was based on a minimum of two sites per soil grouping, age of system, treatment system, drainfield distribution type, and diversity of geographic location to minimize duplication of soil type within a soil group

In the first year, 2003, 50 sites were chosen based on the number of suspected (estimated by EMS) EZflow 1201P systems installed as roughly 500. This covered three Counties in the western part of Oregon (Multnomah, Clackamas, Marion). The next year, 2004, the site count was increased to 77 over 5 Counties (Multnomah, Clackamas, Marion, Crook, and Deschutes Counties, Figs. 4 & 5). Then in 2005 the site count was again increased to its maximum over the study of 103 where it remained until the conclusion in 2007. Figures 5 (a & b) compare suspected EZlow 1201P installations to the percent investigated in any given year over the study period. From 2003 to 2005, EZflow 1201P systems were estimated by EMS to have increased from 500 to 900 installations. This was the result of counted systems by EMS staff, discussions with regulation agencies (DEQ), and interviews of installers of the product. Beyond 2005, our maximum sample site population of roughly 100 was reached (Oregon DEQ approval letter, appendix A) and detailed investigations into the total number of installed systems were no longer required. Therefore, the site counts in 2006 and 2007 represent a projection based on trends in installations from 2003 to 2005 (Fig. 5a).

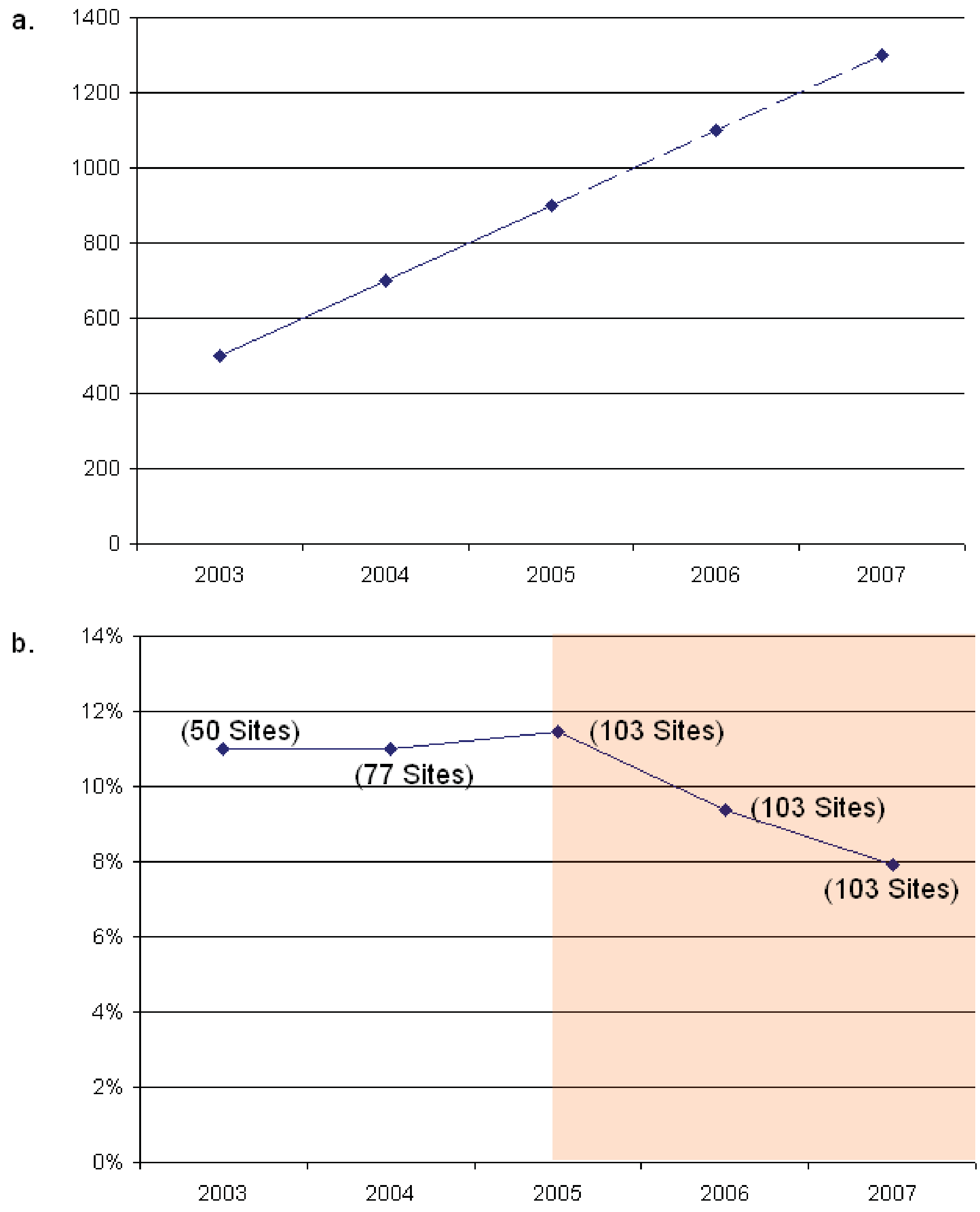


Figure 5. (a) EZflow 1201P installations over the five year study estimated by EMS (dashed line represents projected installations; EMS was limited to roughly 100 sites by the DEQ approval letter). (b) Percentage of EZflow 1201P installations investigated by EMS in the equivalent year. In addition, the site count in any given year is reported in parentheses (the darker area corresponds to a sample site population of roughly 100).

A database was created and maintained that contains system features such as number of bedrooms, estimated wastewater flow, site topography, soil conditions, wastewater pretreatment method, loading rates, onsite construction methods, and repairs to any of the systems (Appendix D). As sites were incorporated into the study population, all were re-visited annually until the study was completed in 2007. During the inspections, EMS verified the location and determined a “Pass” or “Fail” status for each site.

There were 5 sites investigated in the eastern Counties while 99 sites in the western Counties of Oregon were examined. Specifically, in the western region of the State, Marion County has the most sites sampled as a result of the records of the installed EZflow systems being well organized and readily available to EMS. Therefore, Marion County was sampled over each of the soil types 1 – 3, Deschutes and Crook Counties were only sampled for type A soils, Multnomah was sampled for only type B soils, and Clackamas County was sampled in terms of type B and C soils (Table 2).

Soil	**County**	**Site**
TYPE A	Marion	3
	Deschutes	3
	Crook	2
TYPE B	Marion	36
	Clackamas	13
	Multnomah	3
TYPE C	Marion	38
	Clackamas	5

Table 2. Soil types and Counties represented.

Interviews, Mailers, and Site Inspections

Interviews were performed based on availability of residents at the time of the evaluation. 134 site interviews were conducted in the five participating Counties of study between the dates of May 2003 and May 2007**.** Evaluations were unannounced, thus residents were often not available for comment. Attempts to contact residents via phone and postage paid survey response card were also used over the entire 5 year study. If residents could not be interviewed or would not allow photographs or entry into the leach field area a questionnaire form was given where residents were asked:

- How many residents/bedrooms
- Years residence at location
- Use of disposal, dishwasher, and laundry
- Pumping of septic tank
- Any problems/failures with system

During these interviews, if the resident was home, a request to physically inspect the EZflow 1201P system was made. If the homeowner agreed to the inspection, a site inspection was performed and a certified technician or Registered Environmental Health Specialist would observe and record any signs of failure in accordance with OAR 340-071-0100(66). The EZflow systems were found using the “as-builts,” the location of vent pipes and cleanouts, or the occupant's knowledge of system components. The site visits included the following facets:

- General site evaluation of the soil absorption system to verify site/soil suitability, Soil absorption system size assessment
- Determination of the surfacing of wastewater effluent by seepage to the ground surface or direct discharge via a straight-pipe
- Digital photographs taken
- GPS coordinates taken
- Occurrences of overgrowth of vegetation documented
- Livestock intrusion documented
- Vehicular traffic documented

In addition, for cases where the home owner gave permission, auger holes were dug to verify soil data collected prior to sampling. Of the 30 holes created, all corresponded correctly to soil profile information pulled from the individual counties (Clackamas County 2008; Natural Resource Conservation Service 2008), site evaluations, or permit records. No attempt has been made to excavate or probe into the leach fields, as that would risk damaging otherwise functional components and was not required by the DEQ letter of approval (Appendix A). Observations were therefore limited to visual and olfactory indicators, photographs taken at site, and interviews with occupants, where possible.

RESULTS

SURVEY RESULTS	Site Count
Number of bedrooms	
2 bedrooms	5
3 bedrooms	46
4 bedrooms	36
5 bedrooms	4
6 bedrooms	1
Other	5
NR	6
years residence	
0-1 years	3
1-2 years	16
2-3 years	22
3-4 years	13
4-5 years	5
5+ years	12
NR	32
Pumped Septic tank	
Yes	5
No	85
NR	13
problems	
Yes	3
No	100
NR	0

Table 3. Results from interviews with residents and Mailers over study period. NR denotes 'no response' as a result of the homeowner not knowing or not responding to the question asked.

Survey results indicate a sample set comprised mostly of 3 to 4 bedroom houses (Table 3). The number of bedrooms termed 'Other' encompasses two manufactured homes on one EZflow system, a barn, a shop, and an office building. Occupancy ranged from 6 to 2 people per house where the time of occupancy is on average 1-4 years. Thus, the sample population represents a diverse group in terms of both users and the amount of users of the EZflow 1201P product.

There were 3 reports of problems by concerned residents over the study period in our sample population (Table 3). However, when physical investigations were performed by EMS none were determined to be failures. All were complaints of a foul odor on the residence property, most likely from the vent pipe and not the leach field.

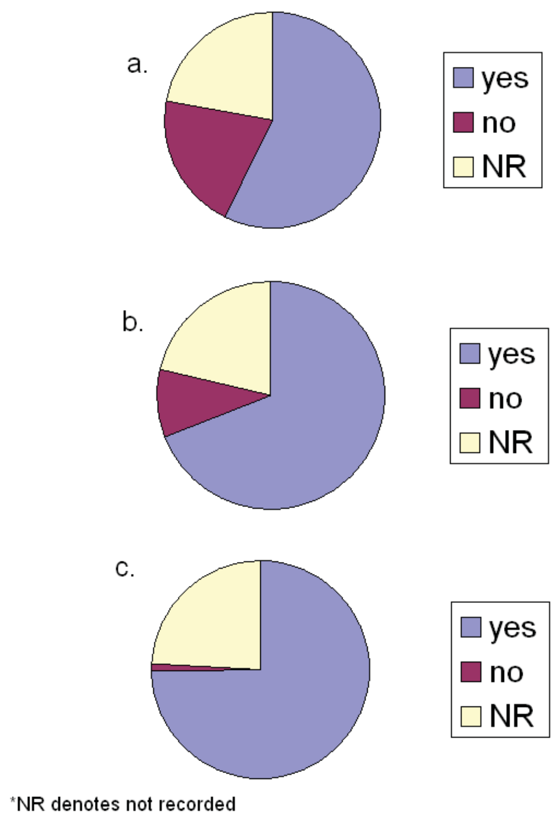
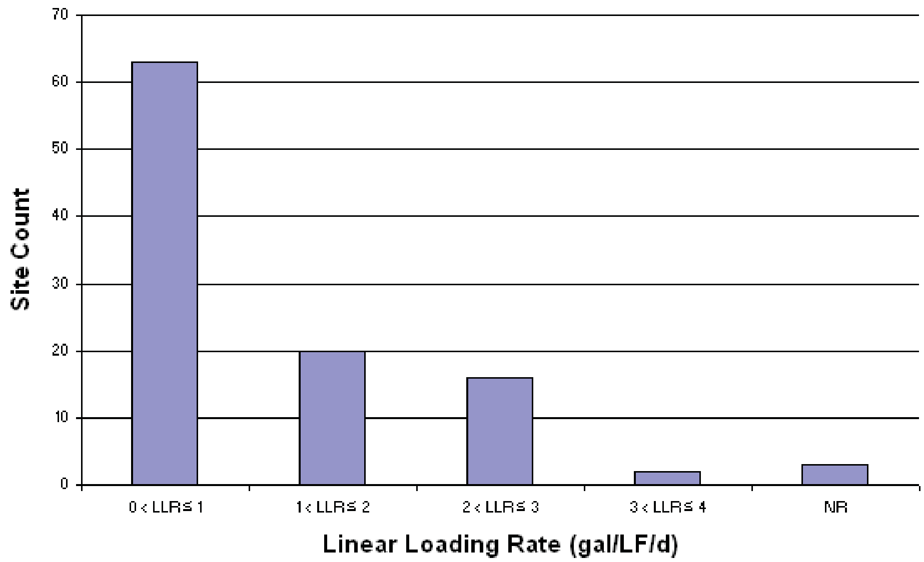


Figure 6. Responses from survey about whether or not there is a (a.) Garbage Disposal (b.) Dishwasher (c.) Laundry machine

The houses measured typically used a washer and dryer, a dishwasher and garbage disposal (Figure 6, a,b,c). However, the study incorporated sites with these appliances and without. As stated above, some of the EZflow systems were not connected to residences and thus had no need for laundry machines, dishwashers, or garbage disposals.

a.



b.

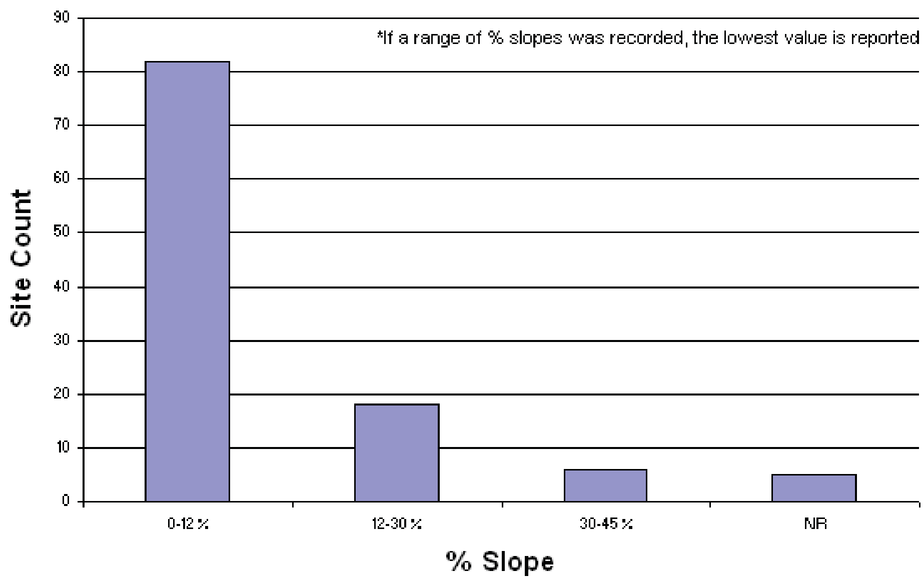


Figure 7. (a.) Number of sites plotted against the linear loading rate at each site (b.) Number of sites plotted against the % slope

As requested by the DEQ (appendix A and B), all investigated sites incorporated those of variable waste load and strength, topography/grades, and climatology. Figure 7b demonstrates that the % slope used ranged from 2 to 45%.

The loading rates varied from 0.81 to 3.60 gal/LF/d (gal/ft^2/d) (Fig.7a). The median loading value was 1 gal/LF/d, consistent with suggested loading rates outlined and recommended in the introduction for coarse grained soils.

All sites where found to be passing throughout the 5 year study (436 visits) with one exception. In accordance with the letter of approval and the cited Oregon Administrative Rule OAR 340-071-0100 (66), on November 4, 2004, 1 EZflow 1201P system was found to be failing. This leads to a total failure rate in Oregon for the EZflow systems of 0.97 %.

Soil	County	Number of Sites	Passing Systems	% Passing
TYPE A	Marion	3	3	100%
	Deschutes	3	2	66.6%
	Crook	2	2	100%
TYPE B	Marion	36	36	100%
	Clackamas	13	13	100%
	Multnomah	3	3	100%
TYPE C	Marion	38	38	100%
	Clackamas	5	5	100%
	Total	**103**	**102**	**99.03%**

Table 4. Soil types and Counties with the number of sites, passing systems and the passing percentage for each category

In the event that the failure criteria was exceeded (failures>3%) for all sites, EMS was required to test an equivalent amount of gravel disposal systems under similar environmental conditions and test for a null hypothesis (DEQ approval letter, Appendix A). However, because the failure rate was not met, an equivalent amount of gravel disposal systems was not investigated. Therefore, the null hypothesis statistical test could not be run.

Representative Site Evaluation

Due to the large population size (103) of investigated sites, an individual Site was chosen from each County for a detailed review. These sites are meant to be representative of each County chosen for EZlow 1201P installation observations. However, the Oregon Counties included in this study consist of a wide range of environmental settings under a variety hydrologic loading conditions. Therefore, individual results should be used for detailed analysis (Appendix D) rather than the single site reviews presented here. In addition, approximate site locations are used rather than specific site locations to ensure anonymity of the residents participating in the study.

Multnomah County

The septic system at Site #1, Multnomah County (Figs. 8 & 9), was first constructed on November 21, 2003. This installation was repaired from a failed leach field prior to the EZflow 1201P installation. The site has semi-permeable drainage (Soil type B) with a silt loam soil texture. At present, there are no signs of leach field failure and no complaints from the owner with regard to the leach field or the EZflow 1201P installation.

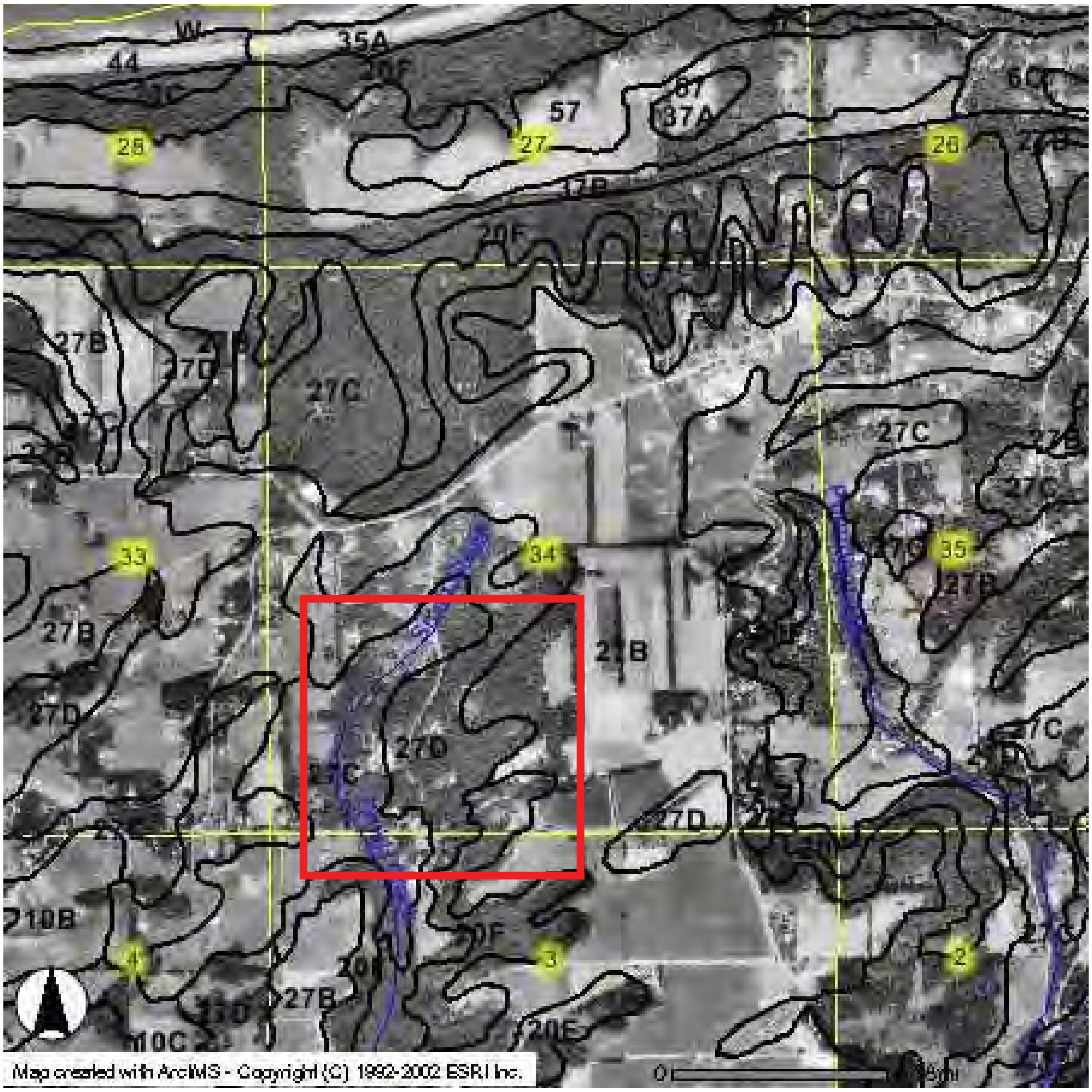


Figure 8. Soil Map for sample site (Mershon silt loam) in the area of Multnomah County Site #1 (Natural Resource Conservation Service 2008). Approximate site location shown by red box.


Figure 9. Picture of the leach field at Site #1 in Multnomah County.

Marion County

The Marion County Site #1 (Figs. 10 & 11) was a newly constructed leach field built on March 12, 2004. Like the Multnomah County site, this site has a semi-permeable soil type (type B) with a silt clay loam structure. This design was constructed for a 3 bedroom house with an estimated 450 gallon per day effluent flow and a linear loading rate of 1 gal/LF/day. To date there is no evidence of a leach field failure.

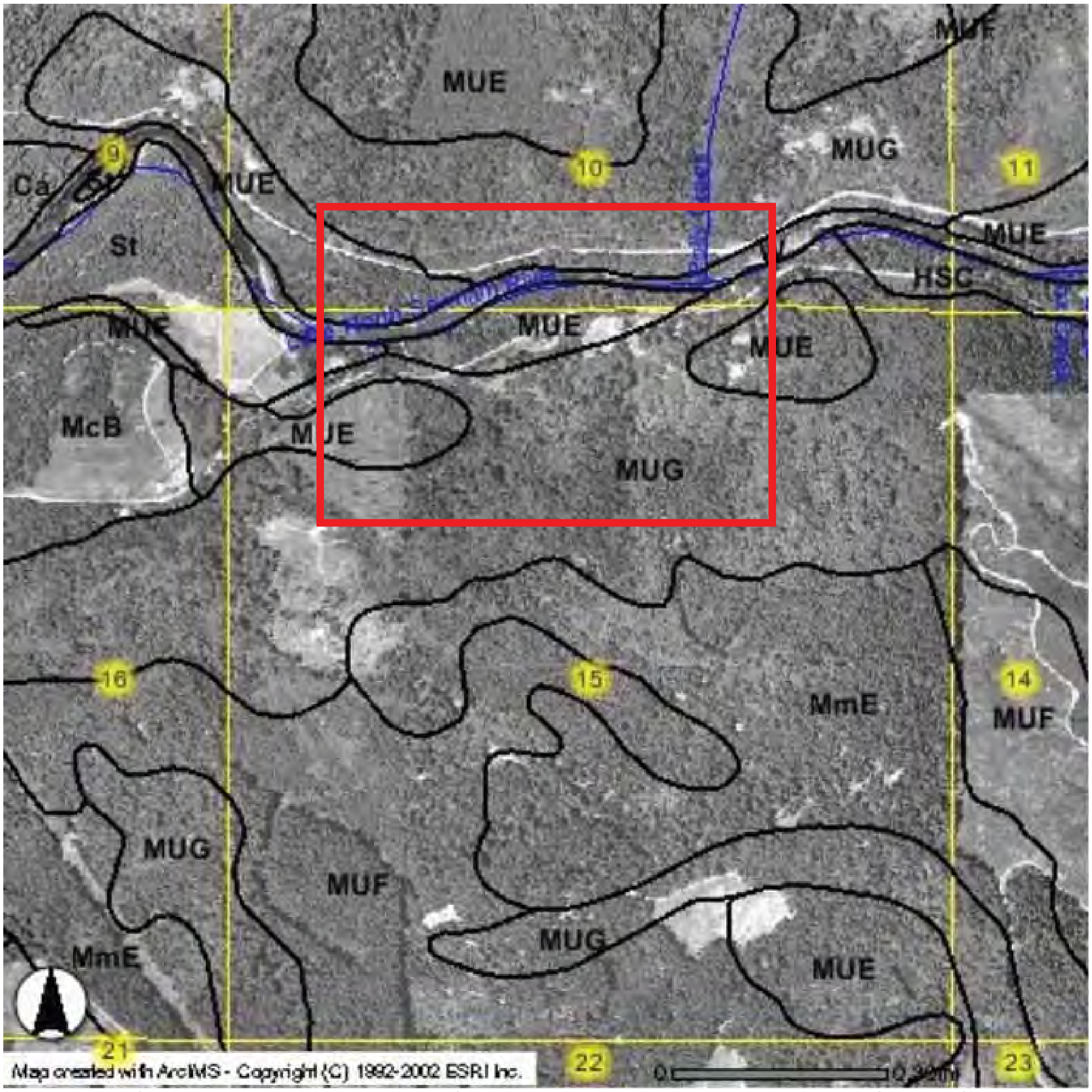


Figure 10. Soil Map for sample site (McCully clay loam) in the area of Marion County Site #1 (Natural Resource Conservation Service 2008). Approximate site location shown by red box.

Figure 11. Site #1, Marion County, where the leach field area is marked by stakes.

Clackamas County

The site in Clackamas County (#1, Figs. 12 & 13) was built on March 4, 2003. The leach field was built into type C soils, meaning the least permeable of the study population. The septic system is connected to a three bedroom house with an estimated wastewater flow of 450 gallons per day with 5 residents. The loading rate for Clackamas County Site#1 was calculated to be 1.07 gal/LF/day on a pressure distribution system. Currently, there is no evidence of failure in the leach field at this site.

Figure 12. Soil Map for sample site (Bornstedt Silt Loam) in the area of Clackamas County Site #1 (Clackamas County 2008). Site location highlighted in green.


Figure 13. Picture of the leach field at Site #1 in Clackamas County.

Crook County

NRCS maps were not available in Crook County; therefore the soil type was determined as a sandy loam (type A) from hand texturing. Crook County Site #1 (Fig. 14) was constructed on March, 3, 2003 as a new system. The septic system was connected to a 2 bedroom house with 2 residents with a design wastewater flow rate of 450 gallons per day and a linear loading rate of 1.8 gal/LF/day. Presently, there is no evidence of a leach field failure.


Figure 14. Picture of the leach field at Site #1 in Crook County.

Deschutes County

Deschutes County Site #2 (Figs. 15 & 16) was built in March 1, 2003 as repair to an older system. This system is built into type A soils with a sandy loam texture. The EZflow 1201P disposal system here is connected to a three bedroom house with two residents and a design daily wastewater flow of 450 gallons and a linear loading rate of 2.81 gal/LF/day.

Figure 15. Picture of the leach field at Site #2 in Deschutes County.

Figure 16. Soil Map for sample site (Laidlaw Sandy Loam) in the area of Deschutes County Site #2 (Natural Resource Conservation Service 2008). Approximate site location shown by red box.

Failures

Year	sites	interviews	pass	fail	installations	Counties
2003	50	28	50	0	~ 500	Marion, Clackamas, Multnomah
2004	77	14	77	1	>700	Marion, Clackamas, Multnomah, Crook, Deschutes
2005	103	56	102	0	>900	Marion, Clackamas, Multnomah, Crook, Deschutes
2006	103	36	103	0	>1100	Marion, Clackamas, Multnomah, Crook, Deschutes
2007	103	36	103	0	>1300	Marion, Clackamas, Multnomah, Crook, Deschutes

Table 5. Results for each year and the corresponding annual report

In 2004, Site #3, in Deschutes County, showed signs of system stress including ground surface saturation which was discovered by an EMS staff member, Brannon Lamp REHS, during an inspection of the property on November 4, 2004. The causes of failure were found to be insufficient soil cap depth and taper. Findings included:

1.) The even, settled depth of 12” above the EZ Flow bundles was not met according to the provisions of OAR 340-071-0265.

2.) The cap needed to be extended to a minimum of 10’ beyond any portion of the absorption facility.

3.) Lack of grass cover on the leach field area may have reduced evapotranspiration in the bare soil conditions.

4.) Drainage may have been impeded by underlying bedrock. OAR 340-071-0265 (1) (g) requires a minimum of 6” of undisturbed soil between the bottom of the disposal trench and a layer limiting effective soil depth (bedrock). Probing conducted indicated that there may have been as little as 2” of undisturbed soil in some areas of this installation.

5.) EZflow aggregate was not degraded as observed visual and microscopic inspections.

6.) The EZflow pipe had not collapsed.

7.) The EZflow leach field was not deformed.

8.) The EZflow trench sites were not deformed.

Therefore, it was determined by EMS staff that the failure was caused by siting and construction errors, outlined in the introduction, and not the EZflow product itself.

DISCUSSION

The performance objectives for this study were to count failures in installed EZflow 1201P systems throughout Oregon in variable environmental settings. The study spanned both the wet and dry regions of the State in addition to covering the three basic soil types listed previously. The EZflow product was also installed in a large array of slopes (0-45%) with varying linear hydraulic loading rates (1-4 gal/LF/d). The total failure rate of EZflow systems measured in this study was < 1% out of 103 sites.

The one failure over this study was in the eastern portion of the State where there were fewer sites installed. Given that the total State failure rate of < 1% is less than 'traditional' stone filled systems (2%) (Hallahan, 2002) previously measured in Oregon, this total failure rate suggests that the failures in eastern Oregon fall within the failure rate of the entire State rather than the product being unsuited to the eastern Oregon environment. In addition, as was discussed above, the EZflow systems failure was deemed by EMS to be siting and installation errors rather than the inability of the EZflow systems to operate analogous to that of a stone filled disposal systems in the eastern portion of the State.

As the failure rate associated with the EZflow systems was below 3%, no direct study was done to compare the EZflow success/failure rate with that of gravel systems by Environmental Management Systems, Inc. However, the two have been compared in numerous other studies (RING Industrial 2008). With regard to loading and hydraulic conductivity, researchers and engineers have verified that the EZflow systems are competitive in loading capacity and hydraulic conductivity. With respect to loading capacity two independent studies have been performed where the first was under “extreme conditions” and the second was under an AASHTO (American Association of State Highway and Transportation Officials) H-10 load rating. This former study (Beam and Associates Engineering 2002), shows that the EZflow system deforms only 3.3% in height under their maximum test load which was 12 feet of soil. Moreover, loads of only four feet, still deeper than is usually allowed for a septic disposal system, showed no deformation at all. The latter study (Crabtree Engineering 2002) was performed to demonstrate that the EZflow systems maintain their integrity underneath active work sites. There, twenty trench feet of EZflow 1203H was laid out in a 36 inch wide trench under 12 inches of compacted soil. A cement truck with a load of 48,000 lbs was then driven twice over the center of the system (the weakest point and a connector line). On each of the passes the truck stopped with a load bearing axle (16,000 lbs) atop the center line of the EZflow product. At the end of the experiment, the EZflow system was excavated and analyzed for structural failures, no failures were reported.

In addition, a study was performed to test the hydraulic conductivity of the EZflow systems vs. a standard gravel system (White 2002). This study found that the resistance to flow was controlled by the layer with the lowest saturated hydraulic conductivity. Since the EZflow systems have no fine grain particles like gravel systems, it was found that the EZflow material fill is more permeable than gravel.

Based on the investigations by EMS into the EZflow product, no failures in installed septic systems could be contributed to the product. In addition to the failure found within this study, EMS investigated all failures brought to our attention within the states of Washington and Oregon over the years of 2003-2008(the time period of this study). This led to two additional sites where failures in leach fields were found concurrent with the EZflow 1201P product. The first was recently developed neighborhood in Wenatchee, Washington (Douglas County) where it was found:

1.) Developers had improperly characterized the soil permeability as "Type 3" when inspections by EMS and laboratory analysis confirmed the resident soil was a less permeable "Type 4." This led to improper application rates for treated wastewater.
2.) The soil had been compacted during development.
3.) Preliminary subdivision profiles appear to have been used by the designer to size all systems, rather than conducting individual site & soil studies-Seepage Beds were designed, approved and installed with 40% reductions in bottom area allowed and reductions of up to 56% of total drainfield area. Seepage Beds were allowed in Type 4 soils, in conflict with WAC 246-272 requirements

The second failure, found outside of the study, was brought to the attention of EMS in 2008 and located in Prineville, OR. On 23 January, Robert Sweeney, REHS, visited the site and met with the regulator, installer, RING representative and the home-owner. The leach field was observed to be surfacing in the northwest corner of the looped leach field. A review of records, interviews and field observations were performed and samples of the septic tank effluent were tested by a qualified laboratory. The conclusions of EMS were that the EZFlow product was not degraded or otherwise implicated in the failure, and that the system failed because of a combination of factors, including:

1.) Inadequate soil depth.

2.) Inadequate Tank Size.

3.) Inadequate leach field length.

4.) Rodent activity.

5.) High strength wastewater.

At the conclusion of the study local regulators were polled within the 5 Counties investigated and asked if they had any additional knowledge of failures associated with the EZflow 1201P systems.

- **Clackamas County, Oregon**
  - Jim Fisher – No knowledge of failures
  - **Soils Program Supervisor**
- **Marion County, Oregon**
  - Jessica Joye (Southern half)– No knowledge of failures
  - Matt Knudsen (Northern half) – No failures as of the conclusion of the study
  - **Onsite Wastewater Specialists**
- **Multnomah County, Oregon**
  - Mike Ebeling – “Not aware of any failures”
  - **City of Portland Sanitarian**

- **Deschutes County, Oregon**
  - Dan Haldeman – No failures as of the conclusion of the study
  - **Director, Environmental Health Department**
- **Crook County, Oregon**
  - Russ Hanson – 1 failure (Prineville); no knowledge of any other failures
  - **Environmental Health Director, Food/Sanitation**

SUMMARY AND CONCLUSION

Throughout the phase one portion of this study the two physiographic areas of Oregon were identified and sites were chosen in five counties based on soil types, age (1-3 yrs old), and access to records. These soil types were chosen to represent the variety of native soils encompassing the State of Oregon. After the overall picture was drawn up, phase two began. In phase two, random sites were chosen from the 15 chosen categories (five Counties, 3 soil types) which were equal to, or more than, 10% the number of installed EZflow 1201P systems in Oregon. Although all three soil types were not investigated in each county, each of the three soil types was represented and each of the counties was sampled. These samples consisted of interviews and mailers along with site inspections (when permitted). Subsequently, if it was found that there was a failure according to DEQ OAR 340-071-0135, the failure was recorded and investigated by EMS for this report. In addition, all failures reported to EMS were investigated throughout the Northwest United States. While this study did not require absolute controls whereby gravel systems were directly compared to the EZflow systems, indirect controls were used and did represent the performance standards to be achieved. Specifically, if there was a failure rate in any given year over 3%, a similar number of gravel systems were to be analyzed and tested against the null hypothesis. Since the failure rate of the EZflow 1201P product was less than 1% there was no need for such a comparison. Thus, the findings of EMS are the EZflow 1201P product fits the requirements in Oregon for

‘Approval of New Innovative Technologies, Materials, or Designs for Onsite Systems’ which are summarized in table 6.

Requirement	met	not met
Failure rate in any given year under 3% (study control that represents performance standards)	X	
Structurally sound, durable, and inert in the environment in which it is placed	X	
Capable of passing wastewater toward the infiltrative surface at a rate equal to or greater than gravel drain media	X	
Soil and design requirements are the same as the standard stone filled disposal system under various environmental conditions	X	
Based on theory or applied research that supports its intended use	X	
Variations accounted for in soil, climate, waste characteristics and topography	X	
Soil	X	
Climate	X	
Waste characteristics	X	
Topography	X	

Table 6. Summary of DEQ requirements for ‘Approval of New Innovative Technologies, Materials, or Designs for Onsite Systems.’

In keeping with Oregon requirements, the product is structurally sound, durable, and inert in the environment in which it is placed (Sonnenberg 2001). In addition, White (2002) found it capable of passing wastewater toward the infiltrative surface at a rate equal to or greater than gravel drain media.

The scope of this project was to count failures associated with the EZflow product and in doing so provide the Oregon DEQ and RING Industrial Group a more holistic view of its use in Oregon. This was demonstrated, in this study, for installed systems where the site, soil and design requirements are the same as the standard stone filled disposal system under various environmental conditions. These environmental conditions, according to the DEQ, must account for variations in soil, climate, waste characteristics and topography. Sites chosen for this study were over variable grade, loading rates, soils, and climactic regimes and demonstrated failure rates (<1%) less than those estimated for gravel filled disposal systems (2 or 3%).

All DEQ criteria were met for approval of the EZ Flow 1201P product.

Disclosure statement: In accordance with the DEQ letter of approval, Environmental Management Systems, Inc. was hired by RING Corporation to perform a neutral, third party evaluation for its EZflow 1201P drainfield product. EMS staff is familiar with the product, having specified, designed and inspected systems with EZflow 1201P, gravel and other drainfield products. Neither EMS, its employees nor the undersigned have any financial interest in the RING Corporation, its employees nor its subsidiaries.

REGISTERED ENVIRONMENTAL HEALTH SPECIALIST
STATE OF OREGON
Robert F. Sweeney
EH-S-202513
Expires 30 SEP 08

Robert F. Sweeney, MS, REHS
President
ENVIRONMENTAL MANAGEMENT SYSTEMS, Inc.

WORK CITED

Beam and Associates Engineering (2002). Determination of Soil Interface Area for EZflow 1201 Product Under Extreme Load Conditions. Memphis, TN.

Burks, B. and M. M. Minnis (1994). Onsite Wastewater Treatment Systems. Madison, Hogarth House.

Clackamas County. (2008). "Clackamas County Geographical Information Systems." 2002-2008, from http://www.co.clackamas.or.us/gis/.

Crabtree Engineering (2002). Evauation of EZflow Brand Drainage Products Under as AASHTO H-10 Load Rating. J. Crabtree.

Crites and Tchobanoglous (1998). Small Decentralized Wastewater Management Systems. New York, McGraw-Hill.

Hallahan, D. F. (2002). "The Standard Septic System: Still an Effective Choice for Onsite Wastewater Treatment " Water Engineering & Management **149**(10).

Natural Resource Conservation Service (2008). "Natural Resource Conservation Service: Soils <http://soils.usda.gov/>."

Oregon Climate Service. (2008). "Oregon Climate Service: Climate Data." Retrieved april 23, 2008, from http://www.ocs.oregonstate.edu/index.html.

RING Industrial (2008). Technical Information: State Approvals <http://www.ezflowlp.com/tech_info_st_app.htm>.

Robertson, S. (2000). Survey and Study of Installed Expanded Polystyrene (EPS) Aggregate Onsite Sewage Treatment and Disposal Systems in Georgia: 1989 thru 1998. NOWRA Proceedings.

Sonnenberg, F. (2001). performance of expandable polystyrene. D. Koerner. Oakland, TN, Styrochem.

White, K. (2002). Evaluation of the Hydraulic Conductivity of EZflow Brand Hardened Expanded Polystyrene Aggregate as Compared to Gravel Systems, University of South Alabama.

FINAL

Onsite Wastewater Technology Testing Report

Massachusetts Alternative Septic System Test Center
Air Station Cape Cod, Massachusetts 02542
Telephone: 508-563-6757
MASSTC@barnstablecounty.org

Massachusetts
Alternative
Septic
System
Test
Center

-- September 2010 --

Performance Evaluation of the EZflow Geosynthetic Aggregate Leaching System

Technology Vendor

Infiltrator Systems Inc.

I certify that I represent the Massachusetts Alternative Septic System Test Center, a project of the Barnstable County Department of Health and Environment, Barnstable County Massachusetts. I further certify that I am authorized to report the testing results for this proprietary treatment product. I attest that the details described in this report to include details regarding the test protocol and results are true and accurate to the best of my knowledge.

George Heufelder

George Heufelder, M.S., R.S.
Director, Barnstable County Department of Health and Environment
Massachusetts Alternative Septic System Test Center

Glossary of Terms

Alkalinity – A measure of the ability of a solution to neutralize acid. Although alkalinity is comprised of the effect of all bases in the solution, it is expressed as the equivalent of all bases to calcium carbonate (mg/L $CaCO_3$).

Biochemical Oxygen Demand ($BOD_{5\text{-day}}$) – Alternately known as 5-day BOD. The concentration of oxygen (expressed in mg/L) utilized by microorganisms in the oxidation of organic matter during a five-day period at a temperature of 20 °C.

Carbonaceous Biochemical Oxygen Demand ($cBOD_{5\text{-day}}$) – Alternately known as 5-day cBOD. The concentration of oxygen (expressed in mg/L) utilized by microorganisms in the non-nitrogenous oxidation of organic matter during a 5-day period at a temperature of 20 °C.

Colony Forming Units (CFU) – This is a measure based on the ability of a bacterium in a sample to form a colony on poured plate media. The colony is visible to the human eye after 24 hours. The visible colony represents one bacterium in the original sample. Thus, a count of colonies after the incubation period is an indication of the number of bacteria originally present. All fecal coliform counts are expressed as CFU per 100 ml of sample by convention despite the volume actually filtered.

Effluent/percolate – The liquid collected at a point following its percolation through the sand substrate.

Fecal Coliform – A group of bacteria used to indicate the possible presence of human pathogens of fecal origin and defined by their ability to ferment lactose and produce gas at temperatures of approximating 44^{o}C. They are a subset of the total coliform bacteria.

Nitrogen – An element that exists in various forms in wastewater and in some of these forms is considered a nutrient. Important measures of nitrogen in wastewater include Total Kjeldahl Nitrogen (TKN), nitrate, nitrite and ammonium.

Total Kjeldahl Nitrogen (TKN) – The combination of organically bound nitrogen and ammonium in a matrix. In water, it is usually expressed as a concentration in milligrams per liter.

Total Nitrogen (TN) –The total of inorganic and organically bound nitrogen in a matrix. In water, it is usually expressed as a concentration in milligrams per liter.

Total Suspended Solids (TSS) – Those solids (expressed in mg/L) which are retained by a glass fiber filter and dried to constant weight at 103–105 ^{o}C.

Executive Summary

The Massachusetts Alternative Septic System Test Center conducted tests comparing the EZflow™ leaching system with a conventional pipe-in-stone leaching trench. The hydraulic loading rate of the pipe-in-stone trench was 0.74 gal/ft^2/day. The loading rate to the EZflow system reflected a 40% reduction in sizing of the leaching trench when using the bottom and sidewall area as the design infiltrative area. A direct comparison of bottom area excluding the sidewall area reflects a 45% reduction for EZflow.

Three replicate trenches of each treatment were constructed in individually lined cells. Percolate was sampled monthly for sixteen months at a depth of 24 inches below the soil interface and was assayed for $cBOD_{5\text{-}Day}$, TSS, nitrate-nitrite, Total Kjeldahl Nitrogen (TKN), ammonium and alkalinity. During this period, weekly assays for fecal coliform, pH, dissolved oxygen and temperature were also conducted. Liquid-level elevations (or ponding measurements) above the soil interface were conducted five days per week for twenty-two months. Influent wastewater used for the tests originated in residential housing and a correctional facility.

Data revealed no significant difference in the percolate between the conventional pipe-in-stone and EZflow system for $cBOD_{5\text{-}Day}$ and TSS, standard indicators of wastewater treatment. During the colder months of October through February, EZflow percolate exhibited significantly lower TKN to total nitrogen ratios compared with pipe-in-stone replicates ($p=.01$) suggesting better ability to oxidize nitrogen compounds in the colder months. These findings are corroborated by the observation of significantly higher dissolved oxygen levels in EZflow percolate compared with pipe-in-stone percolate ($p=.5$). The removal of fecal coliform, a standard indicator of human wastewater, was significantly greater in the EZflow system ($p=.0016$) than the pipe-in-stone system. Alkalinity and pH exhibited predicable trends based on the expected influence of changes in nitrogen chemistry.

Observations of ponding revealed a seasonal trend in the accumulation or restrictive quality of the biomat. During the fall and winter months, the ponding levels increased and then subsided to negligible levels during the drier summer months. An examination of long-term ponding of the pipe-in-stone system (2006–2010 with one year discontinuous) indicated that after the initial summer, ponding during the winter months advanced to approximately the same maximum height as subsequent winters, and then subsided again during the summer. As a point of interest, the fines (particles passing a #200 sieve) measured in the stone used in this test equaled 0.2% expressed as a percentage of weight.

Since only data from two annual warm cycles is available for EZflow, it is unknown whether ponding in years subsequent to year two would follow this same trend. The hydraulic loads applied to EZflow during this study period resulted in an average ponding height in cold/wet months (January 1 through May 31) equaling 1.55 inches and an average peak ponding height of 4.21 inches in year two as indicated by all three EZflow replicates. This exceeded the ponding elevations of the pipe-in-stone system in year two of its initial operation (2007), when the average ponding height in the cold/wet months was 0.75 inches with an average peak ponding elevation of 2.75 inches, and year two during the present study (2010), when the average ponding height in the cold/wet months equaled 0.81 inches with an average peak ponding elevation of 2.88 inches. The lower ponding elevations observed in the stone-in-pipe trenches could be attributed to the near absence of fines, the lower loading rate, or a combination of the two. The implications of this difference in ponding are not known.

Section 1.0 Introduction

The Massachusetts Alternative Septic System Test Center (MASSTC) is located at the Otis Air National Guard military base in Falmouth, Massachusetts. The test center, also known as the Buzzards Bay Test Facility, is operated by the Barnstable County Department of Health and Environment under the direction of a Steering Committee with members from the Massachusetts Department of Environmental Protection, the United States Environmental Protection Agency (USEPA), Barnstable County, Massachusetts Coastal Zone Management and the University of Massachusetts School of Marine Science and Technology.

The mission of MASSTC is to provide a location for the verification and testing of onsite wastewater treatment technologies and components. The facility conducts testing under various protocols, some of which are widely recognized. Of note, the National Sanitation Foundation International (NSF) has employed MASSTC to conduct its standard protocol NSF-40 on a number of onsite septic system technologies. In addition, several verification tests were performed in accordance with a nutrient testing protocol jointly developed with industry, NSF and USEPA known as the Environmental Technology Verification Program (ETV). Finally, MASSTC has been used to conduct the more recently developed nitrogen reduction standard NSF/ANSI 245.

In 2006, MASSTC conducted a 14-month-long pilot protocol for the testing of leaching-product technologies as a part of NSF's efforts to develop a standard protocol for such. Following the completion of this series of tests, representatives from the EZflow product line requested testing of their product using a modified version of the pilot protocol.

This report describes the testing of EZflow, a geosynthetic aggregate and pipe system used in wastewater soil absorption systems.

Section 2.0 Dimensions and Description of the Test Units

2.1 Test Cell Construction

The tests reported herein were conducted using pre-existing test cells. Each test cell was comprised of a volume of ASTM C-33 sand within an impervious liner and individually drained toward a sampling location. Calibrated dosing buckets supplied each test cell individually, and the underdrain of each cell directed percolate to a tipping tray equipped with a data logger/recorder intended to verify the approximate flow through the cell and provide a consistent location for water quality sampling.

The EZflow product configuration used for this test (referred to as 1202H) was two side-by-side 10-foot-long bundles having an effective bottom area infiltration of 24 inches and effective sidewall of 6 inches (Figure 1). This configuration resulted in an infiltrative area of 3.0 ft^2/ftof trench. Three replicates of this configuration were placed centrally in three adjacent sand test cells each measuring 12 ft x 9 ft x ~ 5 ft.

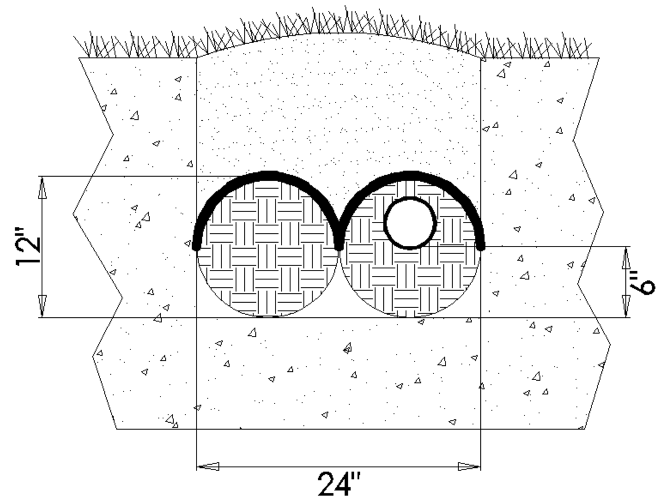


Figure 1. EZflow configuration 1202H used in test cells.

For comparison, three 24-ft stone aggregate control trenches were constructed centrally in three test cells (28 ft x 9 ft x ~ 5 ft). These trenches had an exposed basal width of 32 inches and were constructed such that 6 inches of the 3/4 inch to 2-1/2 inch gravel aggregate was below the 4-inch distribution pipe. The stone aggregate was washed prior to delivery to the test site. A sieve analysis was performed on two samples yielding less than 0.2% material passing the #200 sieve (0.07 mm). The total aggregate depth was 1 ft. The distribution pipe was placed on a level grade with end plates installed approximately 6 inches from each end of the trench to reduce end effects. A woven filter fabric was placed on top of the aggregate to prevent intrusion of fine materials.

Observation ports were installed to facilitate the measurement of ponding levels within the trench. Ports for the pipe-in-stone system were comprised of 4-inch slotted pipes extending to the elevation of the soil interface at the bottom of the stone (Figure 2). Due to the nature and configuration of the EZflow system and in order to minimize the potential for disrupting the integrity of the bundles or the cover material, two sets of observation ports were installed (Figure 2B). The first observation ports were comprised of 0.5-inch pipes placed through the middle of the bundle containing the distribution pipe. Slotted lateral extensions were placed on these pipes for stability and to allow equilibration of the effluent level. The pipes extended to the soil interface at the bottom round surface of the EZflow bundle. Throughout the study, these ports were found to clog and present erratic effluent level readings, hence, data from the 0.5-inch pipes were not included in graphical presentations.

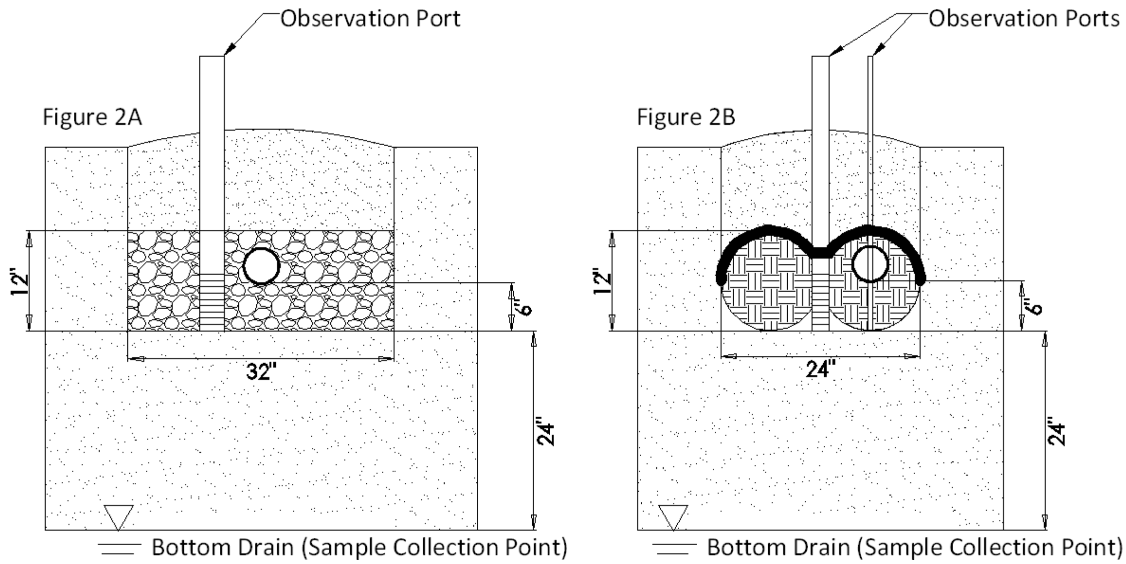


Figure 2. Placement of observation ports in (A) pipe-in-stone and (B) EZflow systems (end view).

The second set of observation ports incorporated 2-inch slotted pipes positioned along the length of the bundle pair and between the bundles at distances of 2.5, 5.0 and 7.5 ft from the proximal end of the bundle (Figure 2B). These ports were not subject to clogging, and data collected at these locations were used in graphical presentations.

2.2 Hydraulic Loading Calculations

North American regulatory jurisdictions employ varying policies on the manner of determining sizing for gravelless drainfield products such as EZflow. In general, the two predominant methods include sizing based on either a combination of the trench basal area plus sidewall, or the trench basal area only. The hydraulic loading rates resulting from both of these methods are addressed in this section.

When a reduction in square footage is utilized for gravelless drainfield products, the calculation may implement the reduction by multiplying or dividing the design infiltrative area of the gravelless product by an efficiency factor. Alternatively, the reduction may be incorporated by increasing the long term acceptance rate. The calculations provided below utilize the former approach.

2.2.1 Hydraulic Loading Calculation Using Trench Bottom Area and Sidewall Area

The hydraulic loading rates of the control and test product are calculated below using trench bottom area plus sidewall area beneath the invert of the distribution pipe.

The pipe-in-stone trench was hydraulically loaded at a rate of 0.74 gallons per day per square foot of bottom and sidewall area. The effluent volume supplied per trench was calculated in the following manner:

- Effective infiltrative area per linear ft = 6-inch sidewall + 6-inch sidewall + 32-inch basal width = **3.67 ft^2/ft of trench**
- 24-ft trench length x 3.67 ft^2/ft of trench = 88 ft^2/trench
- 88 ft^2 x 0.74 gal/ft^2/day = 65 gal/trench/day

The EZflow product was installed to test the performance of a 40% reduction in sizing compared to the pipe-in-stone control trenches. The hydraulic loading rate and effluent volume supplied per trench was calculated as follows to simulate a 40% sizing reduction in bottom and sidewall area:

- Effective infiltrative area per linear ft = 6-inches below the bottom elevation of one side of the distribution pipe + 6-inches below the bottom elevation of distribution pipe alternate side + 24-inches shadow area of bottom = 3.00 ft^2/ft of trench
- 3.00 ft^2/ft of trench / (1 - 0.40) (to reflect 40% reduction) = **5.00 ft^2/ft of trench**
- 10-ft trench length x 5.00 ft^2/ft of trench = 50 ft^2/trench
- 50 ft^2 x 0.74 gal/ft^2/day = 37 gal/trench/day

2.2.2 Hydraulic Loading Calculation Using Trench Bottom Area

In contrast with the method employed in Section 2.2.1, the hydraulic loading rates of the control and test product are calculated below using only the trench bottom area.

The pipe-in-stone trench was hydraulically loaded at a rate of 1.01 gallons per day per square foot of bottom area, calculated as follows:

- 65 gal/trench/day / 24 ft long x 2.67 ft wide = 1.01 gal/ft^2/day

Without consideration of sidewall area, the volume supplied per trench can be calculated in the following manner:

- Effective infiltrative area per linear foot = 32-inches basal width = **2.67 ft^2/ft of trench**
- 24-ft trench length x 2.67 ft^2/ft of trench = 64 ft^2/trench
- 64 ft^2 x 1.01 gal/ft^2/day = 65 gal/trench/day

When the sizing reduction is incorporated into the EZflow design calculation without considering sidewall area, the bottom area reduction is 46% compared to the pipe-in-stone control. The hydraulic loading rate and effluent volume supplied per trench was calculated as follows to simulate a 46% sizing reduction in bottom area:

- Effective infiltrative area per linear foot = 24-inch shadow area of bottom = 2.00 ft^2/ft of trench
- 2.00 ft^2/ft of trench / (1 - 0.46) (to reflect 46% reduction) = **3.70 ft^2/ft of trench**
- 10-ft trench length x 3.70 ft^2/ft of trench = 37 ft^2/trench

- 37 ft^2 x 1.01 gal/ft^2/day = 37 gal/trench/day

2.3 Influent Wastewater Source

Wastewater used in this study primarily originates from residential housing and a county house of corrections. Wastewater was dosed to a 1,500-gallon septic tank that drained by gravity to a pump chamber. The septic tank allowed a wastewater residence time of approximately two days. Wastewater from the pump chamber was then conveyed to dosing buckets capable of a precision of approximately one percent. Design loading was apportioned during the day with 35% of the flow administered between 0600h and 0900h, 25% between 1100h and 1400h, and 40% between 1700h and 2000h. Wastewater characteristics are described in section 4.1.

Section 3.0 Test Description

3.1 Testing Protocol

The testing protocol herein is comprised of the following:

- Weekly grab-sample testing of influent and percolate for fecal coliform, pH, dissolved oxygen, and temperature;
- Measurements of effluent depth (five days per week) at the system/soil interface (commonly referred to as ponding);
- Daily verification of wastewater influent supply volume; and
- Monthly composite sampling of influent and percolate for $BOD_{5\text{-Day}}$, TSS, pH, alkalinity, nitrate-nitrite and ammonium-TKN.

All samples with the exception of fecal coliform were taken with composite samplers and assayed using the appropriate methods in the American Public Health Association's *Standard Methods for the Examination of Water and Wastewater*. Fecal coliform assays were performed on grab samples. For purpose of this report, the terms effluent and percolate are used interchangeably. For purposes of data analyses, all samples having results below the minimum reportable detection limit were reported as one-half of the detection limit. Parameters where this strategy was exercised are noted in the respective sections below.

Ponding measurements were completed each day between 1040h and1100h which corresponds to a period immediately before the second dosing period of the day. Ponding measurements were taken at the two-inch and four-inch observation wells by lowering a tape measure into the port and noting the distance from the effluent surface to a standardized section on the port rim. This number was then subtracted from the observation port depth measured from this same point on the port ring immediately after its installation. Liquid depth measurements in ½-inch observation ports were taken by lowering a clear tube to the bottom of the observation port, capping the top of the clear tube, withdrawing the tube and measuring the liquid depth.

3.2 Data Inclusion

All data collected from the test are included in this report. No data were excluded due to field or laboratory quality assurance issues.

Section 4.0 Results

4.1 Influent Characteristics

Sixteen (n=16) septic tank effluent observations for $BOD_{5\text{-day}}$ and TSS were made between October 15, 2008 and February 18, 2010 (481 days or ~16 months), concurrent with percolate sampling, to confirm that the wastewater was of adequate strength. The overall mean TSS was 201 mg/L with a median TSS of 66 mg/L. The overall mean $BOD_{5\text{-day}}$ was 190 mg/L with a median $BOD_{5\text{-day}}$ of 155 mg/L. The measurement of $BOD_{5\text{-day}}$ in the influent and Carbonaceous Biochemical Oxygen Demand or $cBOD_{5\text{-Day}}$ in the effluent is consistent with methodology employed by NSF to determine the treatment efficiency for secondary treatment units.

Dissolved oxygen levels in septic tank effluent ranged between 0.05 and 4.17 mg/L (n=89) with a mean and median of 0.42 and 0.30 mg/L, respectively. The pH of the septic tank effluent ranged from 5.47 to 7.08 pH units with a mean and median of 6.55 and 6.68 pH units, respectively (n=88). The geometric mean of fecal coliform in the septic tank effluent was 2×10^6 cfu/100 mL (n=91).

Volume of influent was confirmed within 1% of the design volume for the test period through daily calibration checks. All influent and effluent raw data are presented in Appendix 1.

4.2 Performance Data (percolate characteristics)

4.2.1 Carbonaceous Biochemical Oxygen Demand - $cBOD_{5\text{-day}}$

The $cBOD_{5\text{-Day}}$ parameter is used here as a surrogate measure of the ability of the leaching structure (pipe-in-stone or EZflow product) and the underlying soil system to stabilize the wastewater and remove oxygen-demanding characteristics. This classical measure of wastewater strength is used widely to evaluate wastewater treatment.

Both conventional pipe-in-stone and EZflow performed similarly in their ability to reduce $cBOD_{5\text{-Day}}$ in conjunction with the underlying soil system. No $cBOD_{5\text{-Day}}$ value in excess of 5.0 mg/L was observed and >80% of the levels observed in both cases were at or below the lower detection limit of the methodology (Appendix 1). Note that those $cBOD_{5\text{-Day}}$ results below the minimum reportable detection limit were noted as 1 mg/L in Appendix 1. The author concludes that, relative to the stabilization of wastewater as indicated by reduction in $cBOD_{5\text{-Day}}$ demand in percolate, the EZflow system performed as well as the pipe-in-stone system during the testing period.

4.2.2 Total Suspended Solids - TSS

Similar to $cBOD_{5\text{-}Day}$, TSS is often used as a general indicator of effluent quality. In the present test, the pipe-in-stone system was never higher than the lower reportable limit of the method used (5 mg/L). In 5 of 39 observations, the percolate beneath the EZflow system exceeded 5.0 mg/L, however none of these exceeded 15 mg/L (Appendix 1). Note that those sample results below the minimum reportable detection limit were noted as 2.5 mg/L in Appendix 1. The occurrences of higher TSS levels appeared clustered within two successive sampling dates in July and August 2009. The TSS levels before and after this period were lower and comparable with the pipe-in-stone system. The significance of these is unknown. The author concludes that, relative to the treatment of wastewater as indicated by reduction in TSS percolate, the EZflow system performed as well as the pipe-in-stone system during the testing period.

4.2.3 Nitrogen Species

Another common indicator of wastewater stabilization is the ability of a treatment system to oxidize the nitrogen-containing portion of wastewater. In general, nitrogen in wastewater enters the septic tank as an organic compound, such as protein, and is mineralized during anaerobic digestion of ammonium. Some of the organic nitrogen remains in bound organic form, and can be later oxidized in the aerobic portion of the septic system. Ideally, a soil absorption system promotes the oxidation of the ammonium and the bound organic nitrogen to oxidized forms of nitrogen such as nitrate. This is desirable for two reasons: ammonium is toxic to many aquatic life forms that might be in the discharge area of septic system plumes; and the ammonium itself may exert an undesirable demand for oxygen in ground or surface waters. Accordingly, performance of the septic system leachfield can be gauged by the ability to promote the complete oxidation of nitrogen species.

In this series of tests, the ability of each technology to oxidize the nitrogen-containing compounds were compared by determining the percentage of total nitrogen comprised of Total Kjeldahl Nitrogen or TKN (the most reduced organic form in wastewater). The ability of a system to successfully oxidize/stabilize nitrogen waste in this comparison would be indicated by *lower* percentages of TKN (Figure 3).

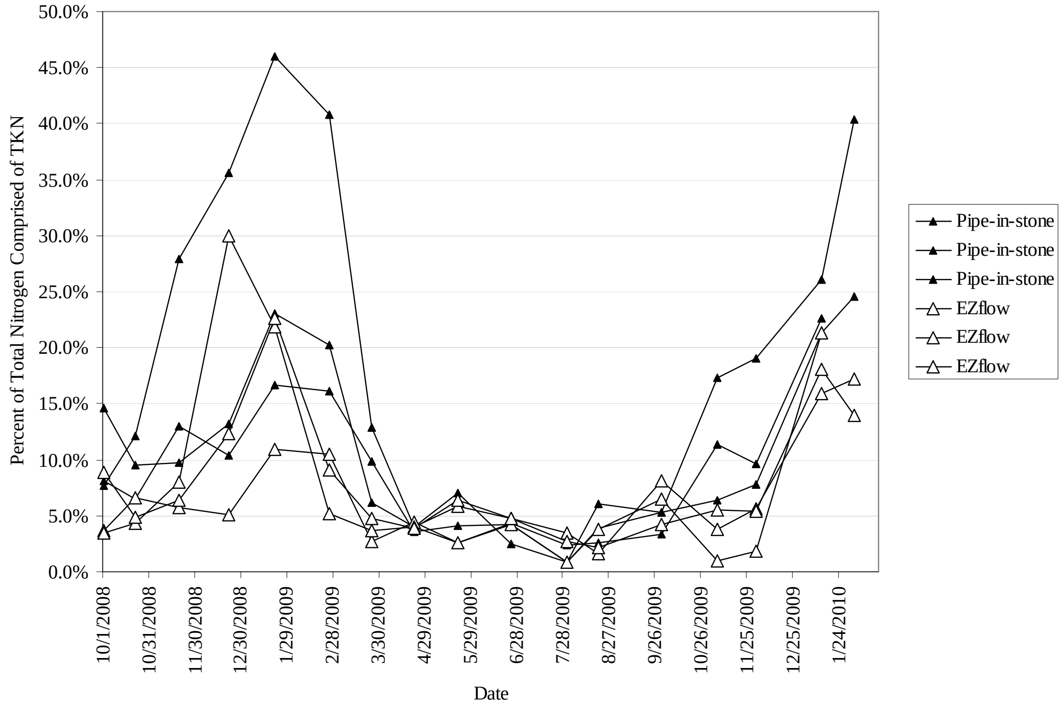
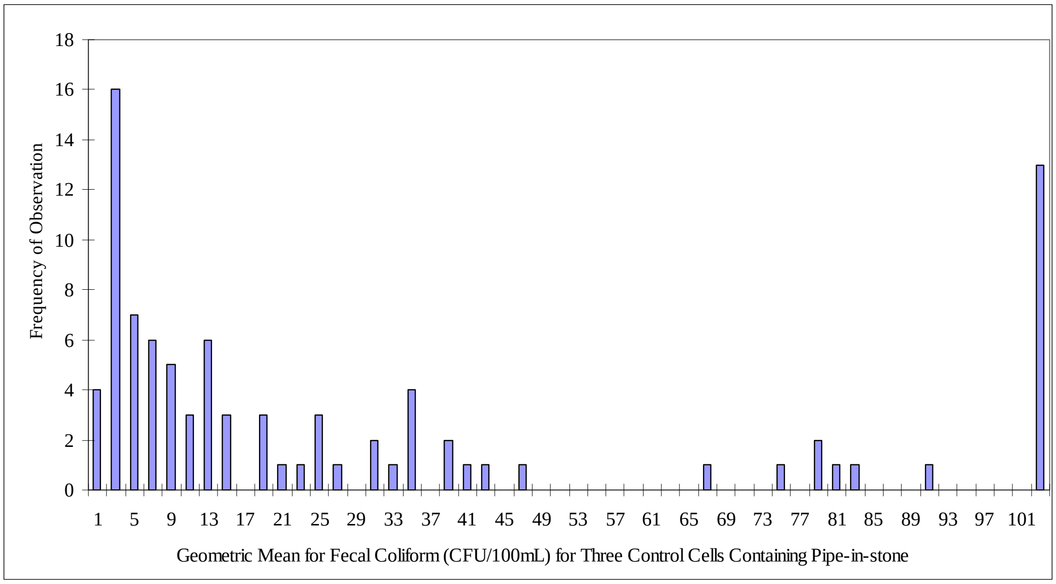


Figure 3. Comparison of TKN to Total Nitrogen ratios in percolate of pipe-in-stone and EZflow test cell replicates.

The data clearly show a seasonal pattern for all replicates, with less nitrogen waste oxidation occurring during the colder months (October–February) of both years. This would be expected due to metabolic reductions of nitrifying bacteria at colder temperatures. Accordingly, two statistical comparisons were conducted, one for colder months and one for warmer months (March–September). During the colder months of October through February, EZflow percolate exhibited significantly lower TKN to total nitrogen ratios compared with pipe-in-stone replicates (*p=.01)*, suggesting better treatment during colder months. A comparison of data from warmer months revealed no significant difference (*p=.01)* in performance between pipe-in-stone and EZflow.

4.2.4 Fecal Coliform

Fecal coliform grab samples were taken weekly from mid-October 2008 through mid-July 2010 at each of six lined cells: three control cells containing pipe-in-stone replicates and three test cells containing EZflow system replicates. For each sampling event, a geometric mean was calculated for each of the three replicates in each of the control and EZflow group that allowed for a comparison of 91 paired observations. These data were first plotted on a histogram to determine whether data approximate a normal distribution (Figure 4), a prerequisite for parametric statistical analyses. Both datasets provide clear evidence that geometric means are skewed to the right (toward lower values), precluding the use of standard parametric statistical tests such as the Student's T or ANOVA.



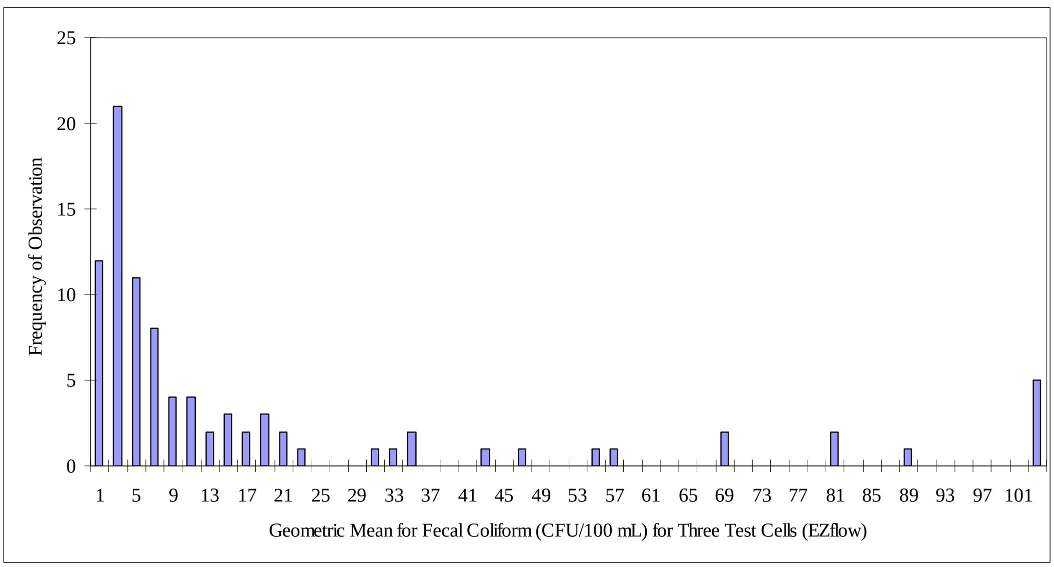


Figure 4. Frequency of geometric mean observations calculated for replicate test cells for pipe-in-stone and EZflow.

4.2.4.1 Time-series Analyses

The first analyses performed were to answer the question of whether either test condition exhibited changes in fecal coliform densities in relation to time. During the startup of a system, it is theorized that septic tank influent is distributed unevenly across the infiltrative surface due to an inherent inability to achieve identical elevations at all discharge holes. The result of this condition is localized areas of saturated flow beneath the soil absorption system at the lowest discharge-hole elevation. This condition would change as a restrictive layer of material forms across the infiltrative surface, commonly referred to as biomat, thereby dispersing effluent over a greater soil surface area and resulting in decreasing breakthrough of fecal coliform over time.

To investigate the possible occurrence of this phenomenon, the following analyses were performed. First, a graphical representation of a time series for each individual cell was compiled (Figure 5). The figures indicate no discernable pattern of fecal coliform densities in the percolate over time. Second, a Spearman's Rank Correlation test was performed using WINKS SDA Software (Texasoft, Cedar Hill, TX) to determine whether there was a relationship between the date of sampling and the fecal coliform values observed. In each case, the relationship between time and fecal coliform was weak (Spearman's rho = 0.03 (p=0.76) and 0.05 (p= 0.62) for the control cells and the EZflow cells, respectively).

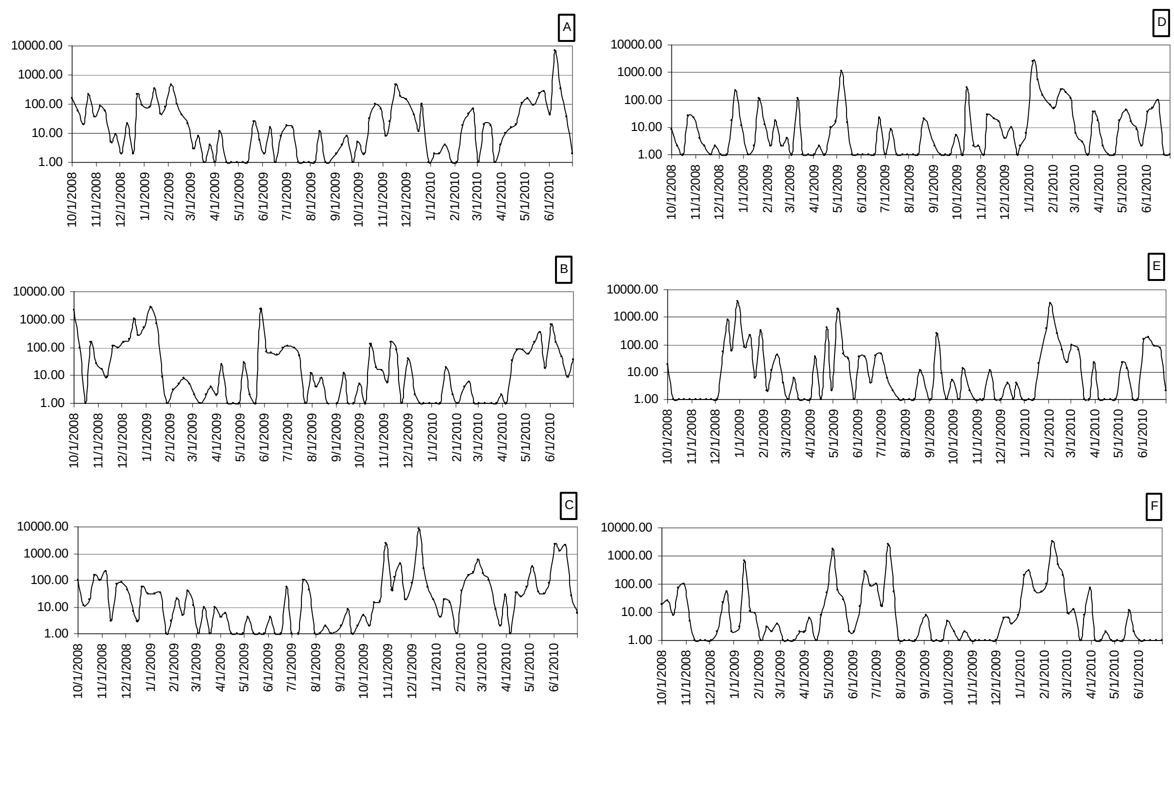


Figure 5. Time series representation of fecal coliform densities in percolate from test cells. Cells A, B and C derive from pipe-in-stone systems. Cells D, E and F derive from EZflow test cells. Vertical axis denotes fecal coliform/100 mL of sample.

4.2.4.2 Comparative Analyses

Following the determination of a weak association between treatment and time of operation, a direct comparison of test conditions (pipe-in-stone vs. EZflow) was conducted using the geometric means for each set of replicates (91 paired observations) using a Wilcoxon's Signed Rank Test (WINKS SDA Software, Texasoft, Cedar Hill, TX). This analysis indicates a significantly higher removal capability of EZflow (geometric mean median value = 6.1 CFU/100 mL) compared with the pipe-in-stone trench (geometric mean median value = 12.6 CFU/100 mL) ($p=.0016$). In order to examine the differences more closely by quartile, each replicate was plotted on a cumulative frequency graph (Figure 6), which allows for the comparison of ranked values. Figure 6 indicates that all interquartile values (middle 50%) of fecal coliform from the EZflow system are below those of the pipe-in-stone systems.

The author concludes that during the test period, the EZflow synthetic aggregate system yielded significantly higher levels of fecal coliform removal than the conventional pipe-in-stone absorption system as observed at an elevation of two feet below the soil interface and at the specified hydraulic loading rates.

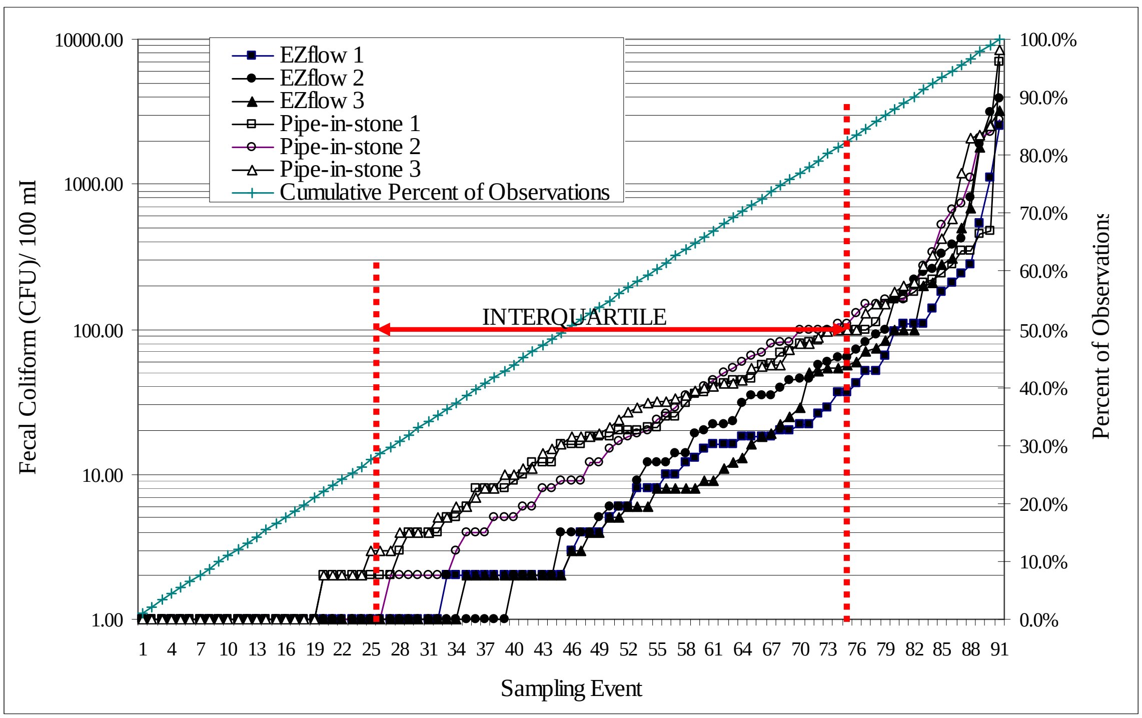


Figure 6. Cumulative frequency representation of fecal coliform levels (CFU/100 mL) beneath lined cells of EZflow and pipe-in-stone soil absorption systems.

4.2.5 Other Physical and Chemical Parameters Measured

4.2.5.1 Alkalinity and pH

Alkalinity and pH are useful diagnostic parameters that help interpret water chemistry data. For instance, when interpreting nitrogen transformations, it is understood that there are two possible reasons for a system's inability to oxidize ammonium: inadequate oxygen (which might be considered a deficiency in the design of the soil absorption system), or inadequate alkalinity (which depends on wastewater characteristics). It is generally understood that in order to oxidize all of the ammonium in a wastewater stream, the alkalinity (in mg/L $CaCO_3$) must be five to seven times the numerical concentration of total nitrogen (mg/L), assuming no return of alkalinity during any denitrification that might occur. During the test period, the author concluded that the alkalinity present in the influent (mean value 176 mg/L, median 170 mg/L) was marginally supportive of complete oxidation (nitrification) of the influent nitrogen levels (mean value 42 mg/L, median 39 mg/L). Although this situation did not preclude a direct comparison of the pipe-in-stone and EZflow systems as described above, these data may explain the residual ammonium levels on any particular date. The pH levels observed (Appendix 2) demonstrate an expected trend of lower pH values coincident with low alkalinity values (Figure 7) due to the limited buffering ability of lower alkalinity water and the simultaneous production of acidic conditions resulting from the nitrification process.

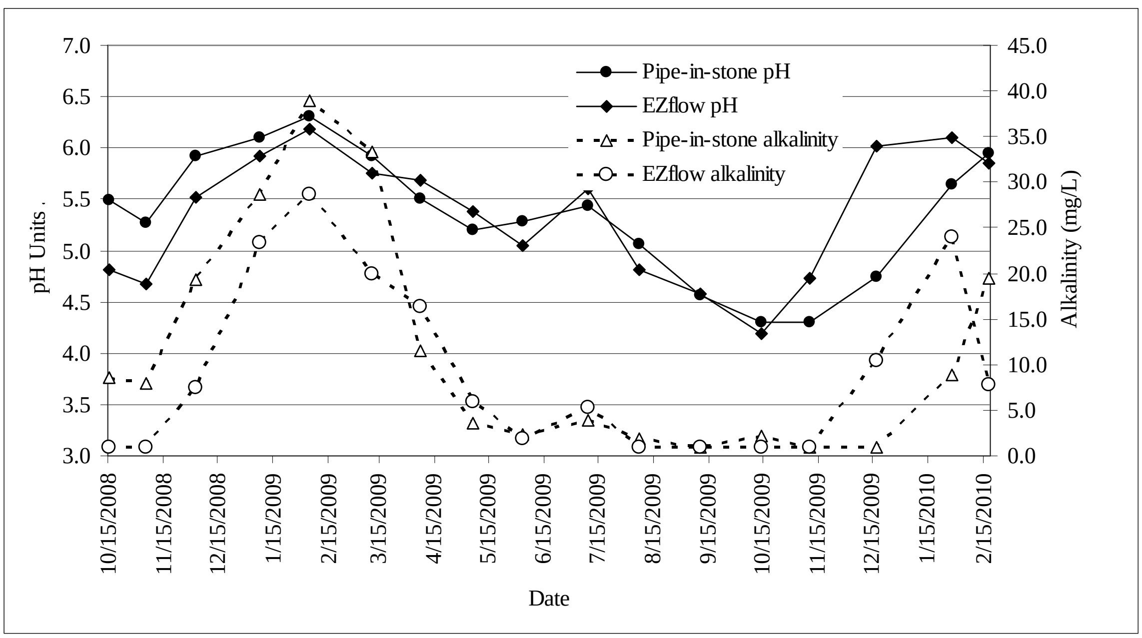


Figure 7. pH and alkalinity levels in percolate of pipe-in-stone and EZflow soil absorption systems during the period October 2008–February 2010.

Temperature and Dissolved Oxygen

Examination of dissolved oxygen data and temperature shows an expected general seasonal pattern of both dissolved oxygen and temperature (Figure 8).

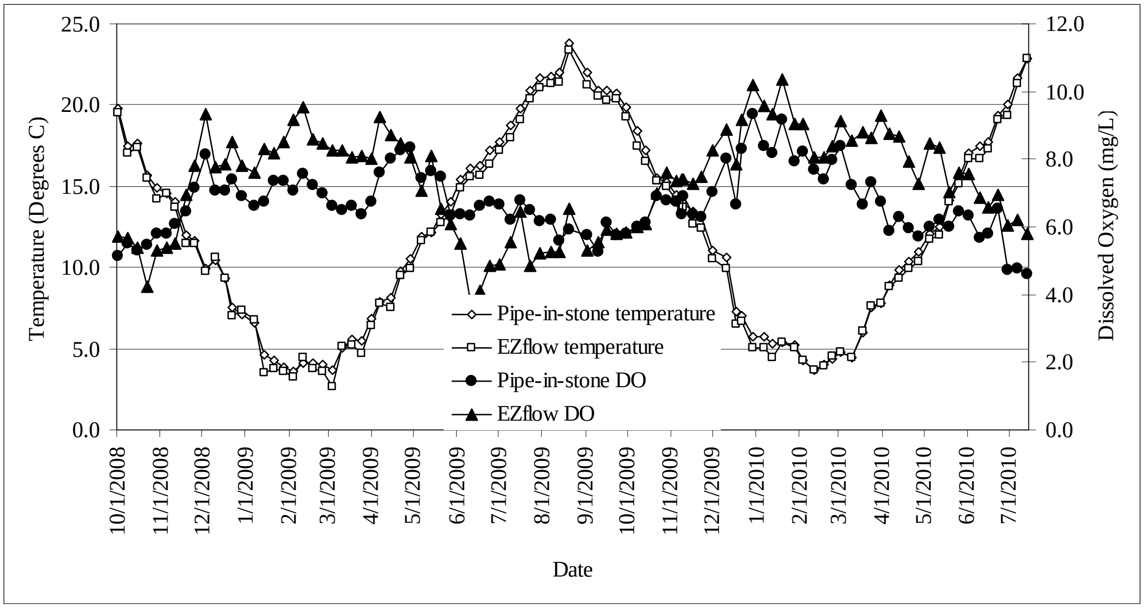


Figure 8. Dissolved oxygen and temperature levels in percolate of pipe-in-stone and EZflow soil absorption systems during the period October 2008 – July 2010.

As would be expected, dissolved oxygen levels are higher at the lower effluent temperatures due to the changes in oxygen solubility in effluent with temperature. The data suggest that the EZflow percolate contained higher concentrations of dissolved oxygen in general (significant at $p=.05$) than the pipe-in-stone system, suggesting that the system facilitated oxygen transfer to the percolate in a more efficient manner than did the pipe-in-stone. The higher concentrations of dissolved oxygen could be the result of a lesser resistance to gas transfer in the EZflow system. Located at the bottom of the EZflow trench is a void channel between the two EZflow bundles that spans the length of the trench providing an unobstructed channel for liquid and gas movement.

4.3 Hydraulic characteristics

Soil absorption system conveyance components (such as pipe-in-stone or pipe-in-synthetic media) perform two important functions. The first function is to facilitate the movement of septic tank effluent to the soil in such a manner as to allow for soil treatment. This has been assessed in the preceding sections that describe the chemistry of the percolate. The second function is to maintain the hydraulic capacity so that the soil absorption system can disperse effluent in the subsurface. A surrogate measure of this function is referred to as ponding. Ponding is the height of the effluent within the drainfield media remaining above the soil interface.

In the present study, the ponding levels of three pipe-in-stone and three EZflow systems are compared. Observations were made immediately before the second dosing period of each day. Figure 9 shows the ponding in the pipe-in-stone systems from October 2008 through July 2010, while Figures 11 and 12 show observations at the EZflow systems during the same period. The pipe-in-stone data are consistent with previous observations that showed significant differences between the proximal and distal areas of the trench. It is presumed that these differences are due to bridging and damming of effluent along the soil interface that allows for a higher ponding elevation behind the proximal "dams". In the EZflow structure, there is a void extending along the length of the paired bundles (refer to Figure 1) that apparently prevents any significant differences between sections of the trench and equalizes the ponding level in the trench. The significance of these differences in effluent distribution along the trench is unknown.

Observations made during the present study and during previous studies of the same pipe-in-stone trenches during 2006 through 2007 (Figure 13), confirm that there is a seasonal pattern to ponding, with higher ponding levels observed during the colder months, followed by diminishing ponding as warmer months ensue. These data also suggest that at some point the annual seasonal rise in ponding level reaches a comparable annual maximum level that recurs each year during the fall and winter months and subsides to negligible ponding levels during mid to late summer. In the present study, the cold/wet months average ponding level in the pipe-in-stone trenches recorded in year two was 0.81 inches, while the average peak ponding level was 2.88 inches. The limited duration of the present test precludes concluding that this cycle is similar for the EZflow system, however during year two of the present study, the cold/wet season average ponding level was 1.55 inches, while the average peak ponding level was 4.21 inches for all EZflow replicates.

The manufacturer of EZflow claims an improved hydraulic efficiency primarily due to the absence of fine materials (effective size of 0.07 mm and passing a #200 sieve) commonly found in natural stone aggregate. The lower ponding elevations observed in the stone-in-pipe trenches could be attributed to the near absence of fines, the lower loading rate, or a combination of the two. The implications of the average 0.74-inch difference in the cold/wet seasonal ponding levels and the average 1.33-inch difference in peak ponding levels are unknown. There is also a difference in the timing of this ponding subsidence between the two types of systems with the pipe-in-stone system ponding subsiding approximately one month earlier than the EZflow. Again the significance of this difference is not known.

The cold/wet season and peak ponding elevations for both stone-in-pipe and EZflow systems are illustrated in Figure 9.

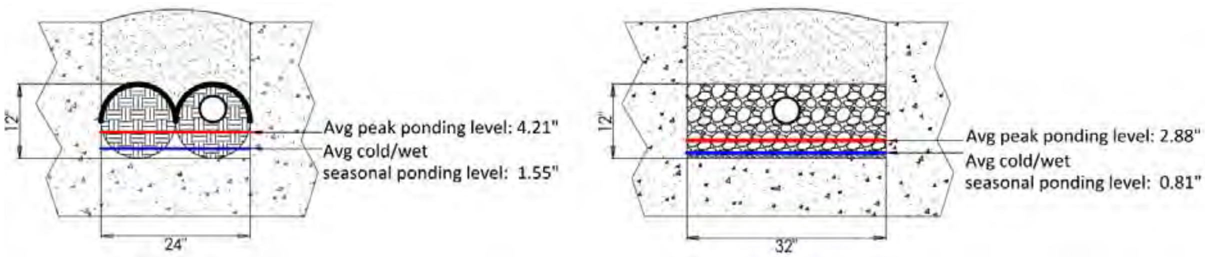
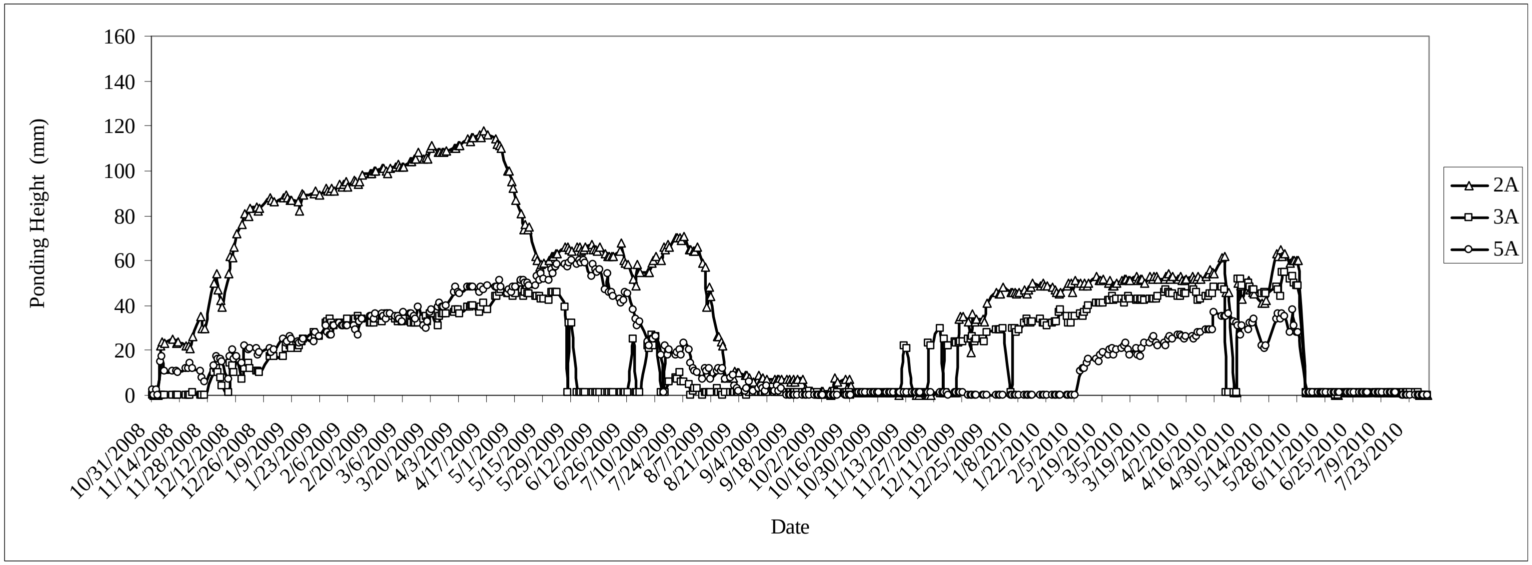


Figure 9. Cold/wet season average ponding levels from January 1 through May 31 and average peak ponding levels in pipe-in-stone and EZflow trenches recorded in final year.



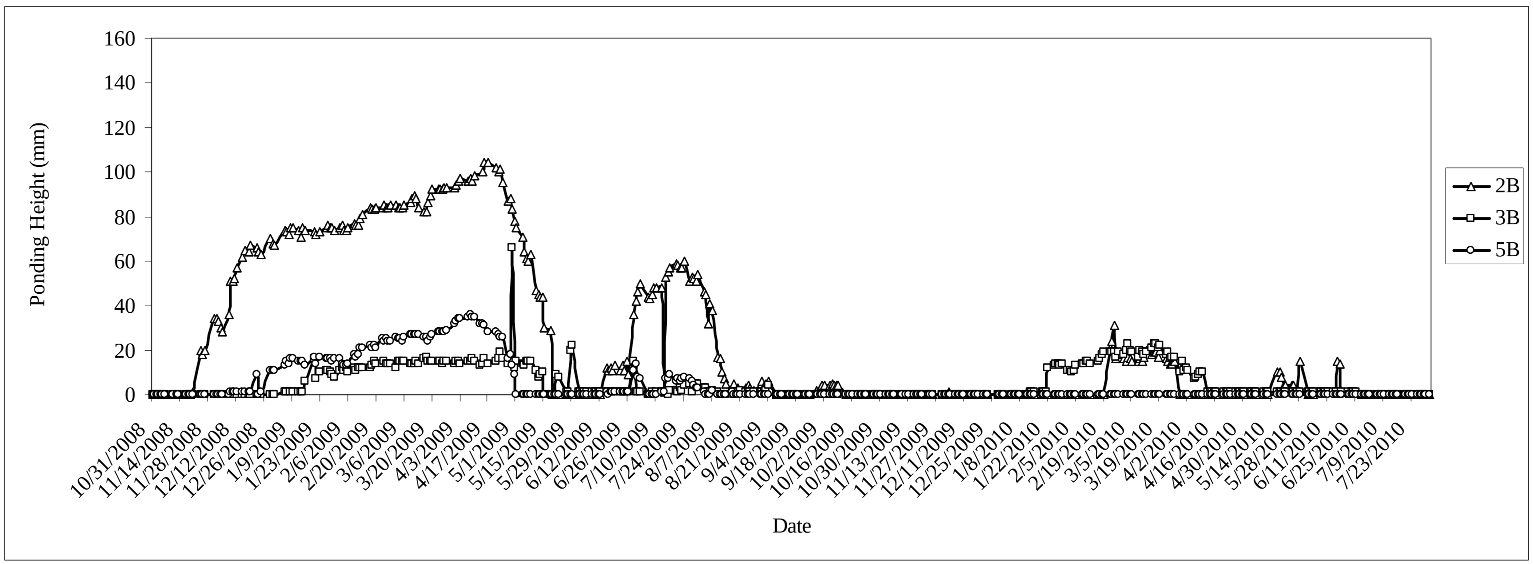


Figure 10. Ponding levels in pipe-in-stone leaching trenches, October 2008 – July 2010. Measurement of 2A, 3A and 5A taken at 33% of the length of system from the proximal end. Measurements of 2B, 3B and 5B taken at 66% of the distance from the proximal end.

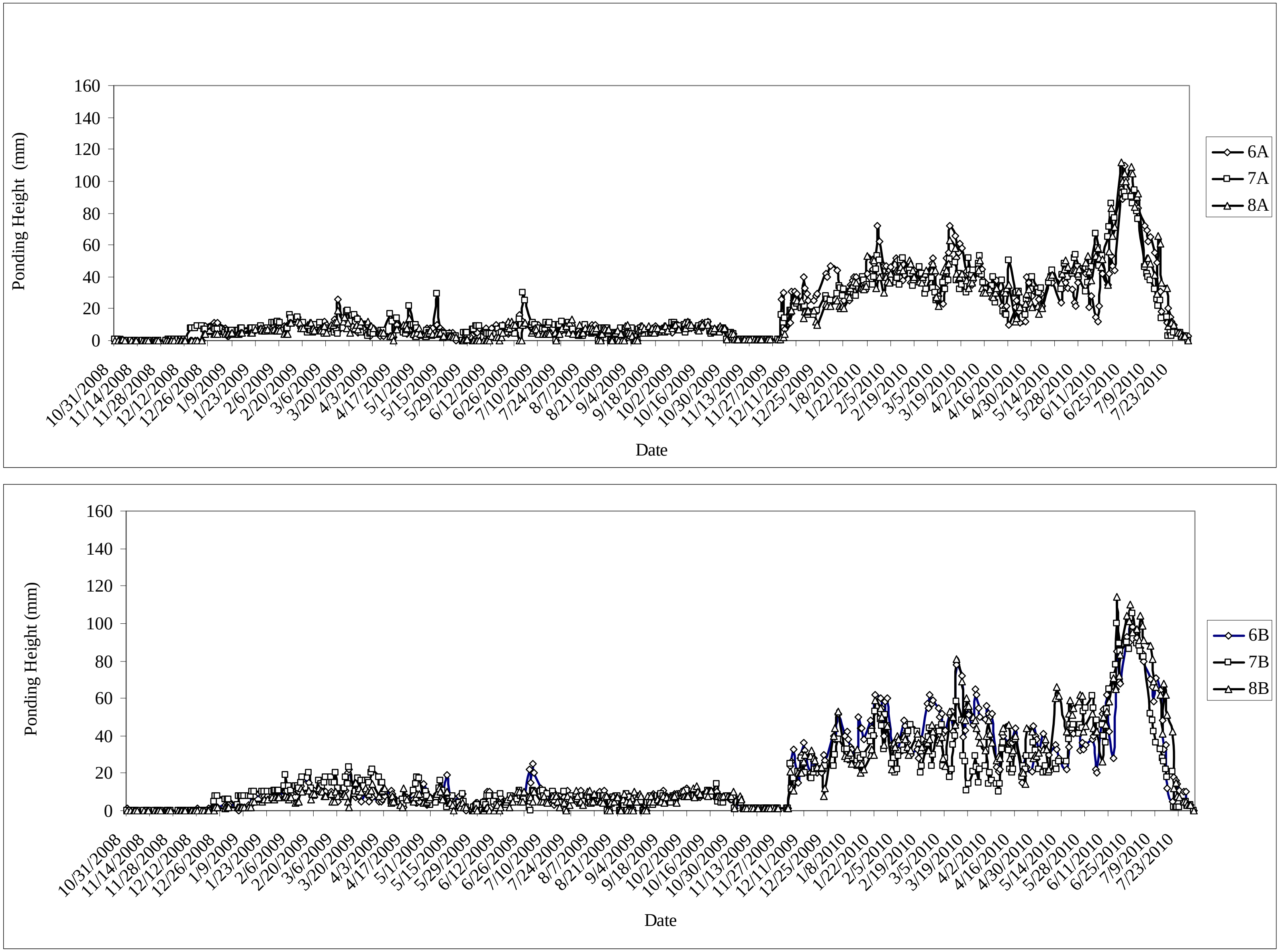


Figure 11. Ponding levels in EZflow leaching trenches, October 2008 – July 2010. Measurements of 6A, 7A and 8A taken at 25% of system length from the proximal end. Measurements of 6B, 7B and 8B taken at 50% of the system length.

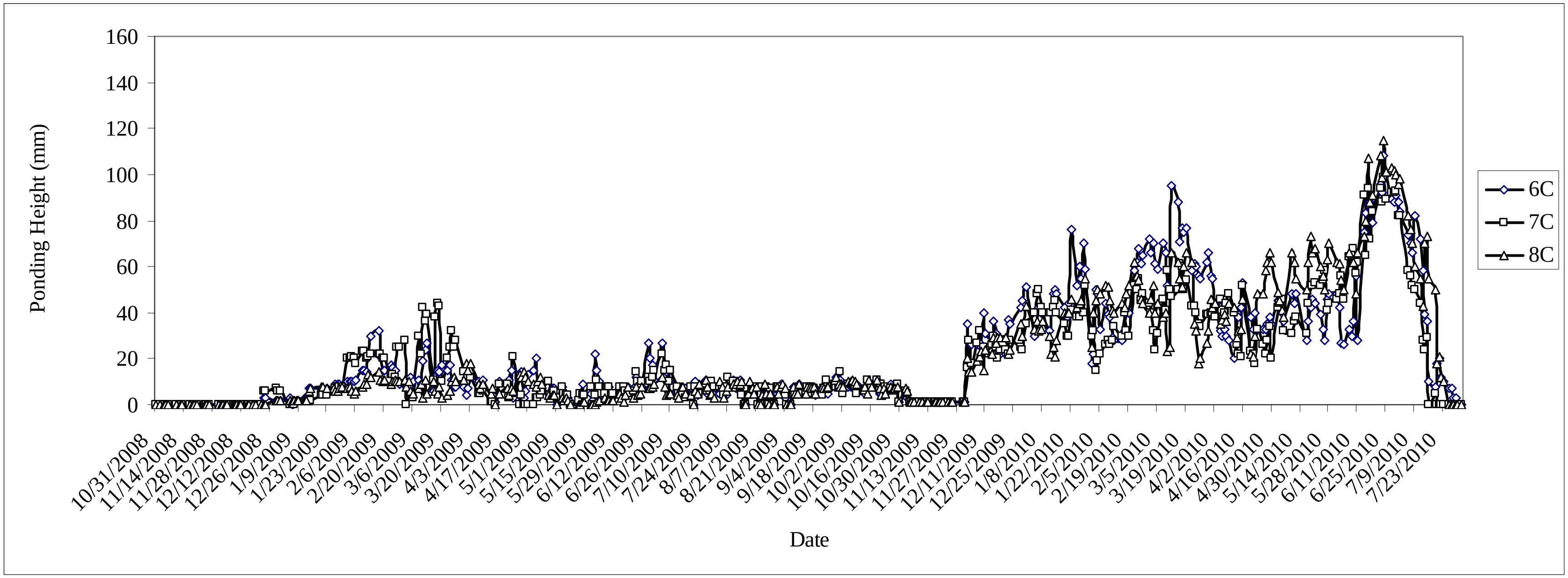
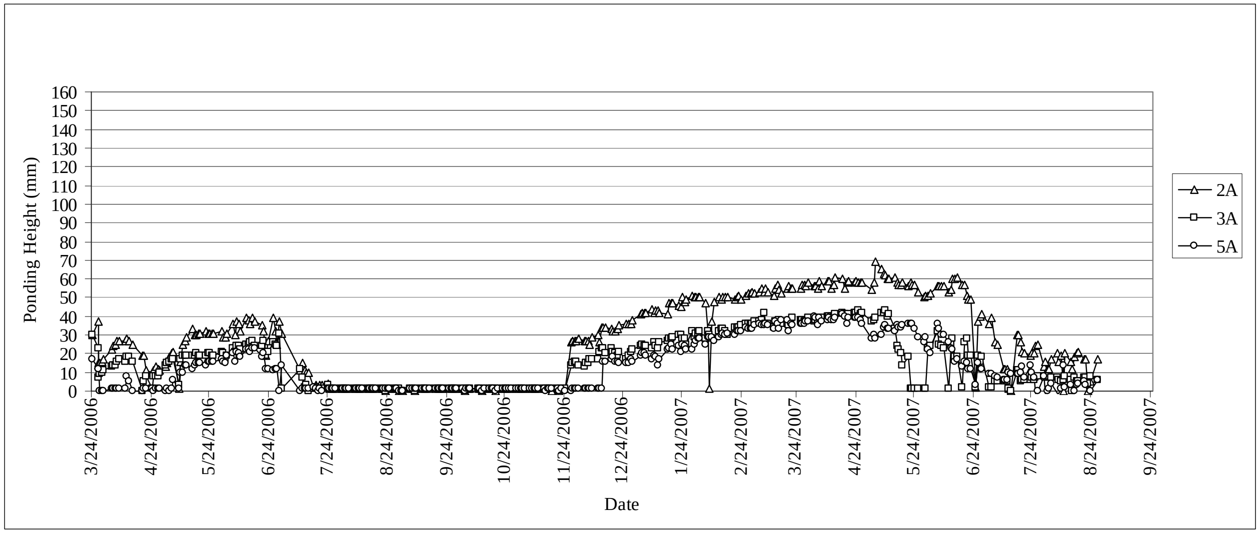


Figure 12. Ponding levels in EZflow leaching trenches, October 2008 – July 2010. Measurements of 6C, 7C and 8C taken at 75% of the system length.



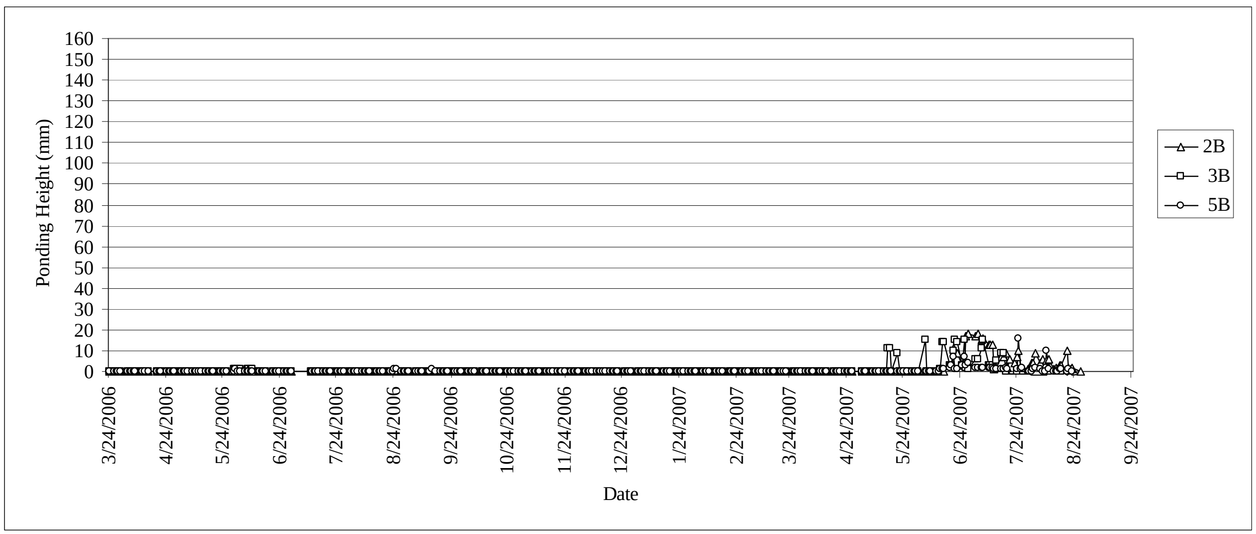


Figure 13. Ponding levels in pipe-in-stone leaching trenches, March 2006 – August 2007. Measurements of 2A, 3A, and 5A taken at 33% of the length of system from the proximal end. Measurements of 2B, 3B, and 5B taken at 66% of the distance from the proximal end.

Appendix 1

Laboratory Data From
Percolate of Pipe-in-Stone and EZflow
Soil Absorption System

Key

Control 2, Control 3 and Control 5 – pipe in-stone replicates

Ring 6, Ring 7, Ring 8 – EZflow replicates

Trailer East Influent – Septic tank effluent used as source for leaching facilities.

	BOD5 (mg/L)	CBOD (mg/L)					
Date	Trailer East Influent	Control 2	Control 3	Control 5	Ring 6	Ring 7	Ring 8
Min	92.00	1.00	1.00	1.00	1.00	1.00	1.00
Median	155.00	1.00	1.00	1.00	1.00	1.00	1.00
Max	590.00	2.20	3.40	3.00	1.00	2.30	1.00
Average	190.13	1.08	1.41	1.12	1.00	1.08	1.00
Geometric Mean	168.19	1.05	1.26	1.07	1.00	1.05	1.00
Standard Deviation	123.02	0.30	0.79	0.49	0.00	0.32	0.00
Count	16.00	16.00	17.00	17.00	15.00	17.00	17.00
	BOD5 (mg/L)	**CBOD (mg/L)**					
Date	**Trailer East Influent**	**Control 2**	**Control 3**	**Control 5**	**Ring 6**	**Ring 7**	**Ring 8**
10/15/08	100.00	1.00	1.00	1.00	1.00	1.00	1.00
11/05/08	92.00	1.00	1.00	1.00	1.00	1.00	1.00
12/03/08	130.00	1.00	2.30	1.00	1.00	1.00	1.00
01/07/09	150.00	1.00	3.40	1.00	1.00	1.00	1.00
02/04/09	120.00	1.00	2.20	1.00	1.00	1.00	1.00
03/11/09	150.00	1.00	1.00	1.00	1.00	1.00	1.00
04/07/09	210.00	1.00	1.00	1.00		1.00	1.00
05/06/09	360.00	1.00	1.00	1.00	1.00	1.00	1.00
06/03/09	180.00	1.00	1.00	1.00	1.00	1.00	1.00
07/09/09	590.00	1.00	1.00	1.00	1.00	1.00	1.00
08/07/09	150.00	1.00	1.00	1.00	1.00	1.00	1.00
09/10/09		1.00	1.00	1.00	1.00	1.00	1.00
10/14/09	120.00	1.00	1.00	1.00	1.00	1.00	1.00
11/10/09	170.00	1.00	1.00	1.00	1.00	1.00	1.00
12/17/09	190.00	1.00	3.00	1.00	1.00	1.00	1.00
01/28/10	160.00	2.20	1.00	1.00	1.00	1.00	1.00
02/18/10	170.00		1.00	3.00		2.30	1.00

	TSS (mg/L)						
Date	Trailer East Influent	Control 2	Control 3	Control 5	Ring 6	Ring 7	Ring 8
Min	40.00	2.50	2.50	2.50	2.50	2.50	2.50
Median	65.50	2.50	2.50	2.50	2.50	2.50	2.50
Max	1200.00	2.50	2.50	2.50	9.00	11.00	14.00
Average	201.13	2.50	2.50	2.50	3.32	3.34	3.18
Geometric Mean	95.24	2.50	2.50	2.50	2.95	2.93	2.77
Standard Deviation	342.29	0.00	0.00	0.00	2.17	2.42	2.79
Count	16.00	16.00	17.00	17.00	15.00	17.00	17.00
	TSS (mg/L)						
Date	Trailer East Influent	Control 2	Control 3	Control 5	Ring 6	Ring 7	Ring 8
10/15/08	100.00	2.50	2.50	2.50	2.50	2.50	2.50
11/05/08	44.00	2.50	2.50	2.50	2.50	2.50	2.50
12/03/08	63.00	2.50	2.50	2.50	2.50	2.50	2.50
01/07/09	54.00	2.50	2.50	2.50	2.50	2.50	2.50
02/04/09	88.00	2.50	2.50	2.50	2.50	2.50	2.50
03/11/09	40.00	2.50	2.50	2.50	2.50	2.50	2.50
04/07/09	280.00	2.50	2.50	2.50		2.50	2.50
05/06/09	910.00	2.50	2.50	2.50	2.50	2.50	2.50
06/03/09	80.00	2.50	2.50	2.50	2.50	2.50	2.50
07/09/09	1200.00	2.50	2.50	2.50	8.30	8.30	2.50
08/07/09	97.00	2.50	2.50	2.50	2.50	11.00	14.00
09/10/09		2.50	2.50	2.50	2.50	2.50	2.50
10/14/09	52.00	2.50	2.50	2.50	2.50	2.50	2.50
11/10/09	48.00	2.50	2.50	2.50	2.50	2.50	2.50
12/17/09	40.00	2.50	2.50	2.50	9.00	2.50	2.50
01/28/10	54.00	2.50	2.50	2.50	2.50	2.50	2.50
02/18/10	68.00		2.50	2.50		2.50	2.50

	Nitrate as Nitrogen (mg/L)					
Date	Control 2	Control 3	Control 5	Ring 6	Ring 7	Ring 8
Min	13.00	9.80	8.90	13.00	14.00	14.00
Median	21.00	21.00	20.00	26.00	23.00	24.00
Max	33.00	33.00	35.00	33.00	34.00	34.00
Average	22.25	20.87	21.64	24.25	23.53	24.06
Geometric Mean	21.20	19.42	20.00	23.33	22.63	23.40
Standard Deviation	6.99	7.80	8.28	6.63	6.63	5.71
Count	16.00	17.00	17.00	16.00	17.00	17.00

	Nitrate as Nitrogen (mg/L)					
Date	Control 2	Control 3	Control 5	Ring 6	Ring 7	Ring 8
10/15/08	21.00	24.00	27.00	26.00	23.00	22.00
11/05/08	20.00	21.00	20.00	24.00	24.00	21.00
12/03/08	13.00	9.80	12.00	16.00	15.00	16.00
01/07/09	21.00	15.00	24.00	26.00	18.00	22.00
02/04/09	14.00	11.00	14.00	18.00	15.00	14.00
03/11/09	16.00	11.00	15.00	17.00	18.00	18.00
04/07/09	23.00	19.00	20.00	20.00	22.00	22.00
05/06/09	31.00	31.00	30.00	32.00	34.00	30.00
06/03/09	31.00	33.00	30.00	32.00	32.00	31.00
07/09/09	33.00	32.00	32.00	32.00	30.00	34.00
08/07/09	29.00	29.00	29.00	30.00	31.00	30.00
09/10/09	31.00	28.00	35.00	33.00	33.00	31.00
10/14/09	24.00	23.00	27.00	26.00	25.00	25.00
11/10/09	21.00	22.00	20.00	26.00	25.00	24.00
12/17/09	14.00	13.00	8.90	13.00	14.00	26.00
01/28/10	14.00	14.00	11.00	17.00	18.00	19.00
02/18/10		19.00	13.00		23.00	24.00

	Nitrite as Nitrogen (mg/L)					
Date	Control 2	Control 3	Control 5	Ring 6	Ring 7	Ring 8
Min	0.03	0.03	0.03	0.03	0.03	0.03
Median	0.03	0.03	0.03	0.03	0.03	0.03
Max	0.19	0.30	0.03	0.03	0.10	0.55
Average	0.04	0.06	0.03	0.03	0.03	0.08
Geometric Mean	0.03	0.03	0.03	0.03	0.03	0.04
Standard Deviation	0.04	0.08	0.00	0.00	0.02	0.15
Count	16.00	17.00	17.00	16.00	17.00	17.00

	Nitrite as Nitrogen (mg/L)					
Date	Control 2	Control 3	Control 5	Ring 6	Ring 7	Ring 8
10/15/08	0.03	0.03	0.03	0.03	0.10	0.55
11/05/08	0.03	0.03	0.03	0.03	0.03	0.38
12/03/08	0.03	0.03	0.03	0.03	0.03	0.03
01/07/09	0.03	0.03	0.03	0.03	0.03	0.03
02/04/09	0.03	0.03	0.03	0.03	0.03	0.03
03/11/09	0.19	0.30	0.03	0.03	0.03	0.03
04/07/09	0.03	0.03	0.03	0.03	0.03	0.03
05/06/09	0.03	0.03	0.03	0.03	0.03	0.03
06/03/09	0.03	0.03	0.03	0.03	0.03	0.03
07/09/09	0.03	0.25	0.03	0.03	0.03	0.03
08/07/09	0.03	0.03	0.03	0.03	0.03	0.03
09/10/09	0.03	0.03	0.03	0.03	0.03	0.03
10/14/09	0.03	0.03	0.03	0.03	0.03	0.03
11/10/09	0.03	0.03	0.03	0.03	0.03	0.03
12/17/09	0.03	0.03	0.03	0.03	0.03	0.03
01/28/10	0.03	0.03	0.03	0.03	0.03	0.03
02/18/10		0.06	0.03		0.03	0.03

	Alkalinity (mg/L)						
Date	Trailer East Influent	Control 2	Control 3	Control 5	Ring 6	Ring 7	Ring 8
Min	150.00	1.00	1.00	1.00	1.00	1.00	1.00
Median	170.00	5.05	7.50	6.00	4.80	5.50	5.40
Max	210.00	37.00	56.00	29.00	31.00	47.00	32.00
Average	175.63	9.56	15.11	8.94	8.29	11.50	7.95
Geometric Mean	174.75	4.73	5.79	5.23	3.94	5.03	4.23
Standard Deviation	18.25	11.24	19.17	8.57	9.40	13.64	8.49
Count	16.00	16.00	17.00	17.00	16.00	17.00	17.00

	Alkalinity (mg/L)						
Date	Trailer East Influent	Control 2	Control 3	Control 5	Ring 6	Ring 7	Ring 8
10/15/08	190.00	10.00	7.50	8.30	1.00	1.00	1.00
11/05/08	200.00	2.80	15.00	6.00	1.00	1.00	1.00
12/03/08	180.00	12.00	31.00	15.00	8.80	8.20	5.40
01/07/09	190.00	27.00	47.00	12.00	8.90	47.00	14.00
02/04/09	170.00	37.00	56.00	24.00	21.00	33.00	32.00
03/11/09	200.00	28.00	52.00	20.00	23.00	24.00	13.00
04/07/09		9.40	16.00	9.30	14.00	24.00	11.00
05/06/09	150.00	5.50	1.00	4.20	3.90	9.30	4.70
06/03/09	160.00	1.00	4.10	2.00	1.00	2.30	2.10
07/09/09	160.00	3.50	3.40	4.80	5.70	4.20	5.90
08/07/09	170.00	1.00	1.00	3.60	1.00	1.00	1.00
09/10/09	170.00	1.00	1.00	1.00	1.00	1.00	1.00
10/14/09	170.00	4.60	1.00	1.00	1.00	1.00	1.00
11/10/09	210.00	1.00	1.00	1.00	1.00	1.00	1.00
12/17/09	150.00	1.00	1.00	1.00	9.40	11.00	11.00
01/28/10	160.00	8.10	8.80	9.80	31.00	21.00	20.00
02/18/10	180.00		10.00	29.00		5.50	10.00

	Ammonia as Nitrogen (mg/L)						
Date	**Trailer East Influent**	**Control 2**	**Control 3**	**Control 5**	**Ring 6**	**Ring 7**	**Ring 8**
Min	24.00	0.25	0.25	0.25	0.25	0.25	0.25
Median	26.50	1.14	1.30	1.30	0.25	0.25	0.25
Max	35.00	4.10	7.60	7.30	4.30	7.00	3.60
Average	27.00	1.57	2.38	1.61	0.63	1.22	1.01
Geometric Mean	26.85	1.08	1.04	0.98	0.37	0.52	0.54
Standard Deviation	2.99	1.27	2.66	1.75	1.04	1.89	1.24
Count	16.00	16.00	17.00	17.00	16.00	17.00	17.00

	Ammonia as Nitrogen (mg/L)						
Date	**Trailer East Influent**	**Control 2**	**Control 3**	**Control 5**	**Ring 6**	**Ring 7**	**Ring 8**
10/15/08	30.00	2.80	0.25	2.10	0.25	0.25	1.10
11/05/08	28.00	1.30	2.40	1.30	0.25	0.25	0.56
12/03/08	24.00	0.98	2.90	1.50	0.25	0.25	0.25
01/07/09	28.00	2.50	6.90	1.40	0.25	7.00	2.90
02/04/09	24.00	3.40	7.60	1.70	1.30	3.40	3.60
03/11/09	28.00	4.10	7.00	2.40	1.30	0.98	0.56
04/07/09	24.00	1.40	2.70	0.98	0.25	0.25	0.25
05/06/09	28.00	0.25	0.25	0.25	0.25	0.25	0.25
06/03/09	26.00	0.56	1.30	0.25	0.25	0.25	0.25
07/09/09	30.00	0.98	0.25	0.25	0.25	0.25	0.25
08/07/09	27.00	0.25	0.25	0.25	0.25	0.25	0.25
09/10/09		0.25	0.25	0.25	0.25	0.25	0.25
10/14/09	26.00	0.56	0.25	0.56	0.25	0.25	0.25
11/10/09	35.00	1.50	0.25	2.70	0.25	0.25	0.25
12/17/09	24.00	0.84	0.25	0.84	0.25	0.25	0.25
01/28/10	24.00	3.40	2.90	3.40	4.30	2.80	2.90
02/18/10	26.00		4.80	7.30		3.50	3.10

	TKN (mg/L)						
Date	Trailer East Influent	Control 2	Control 3	Control 5	Ring 6	Ring 7	Ring 8
Min	28.00	0.70	0.25	0.25	0.25	0.56	0.70
Median	39.00	1.50	2.50	2.10	1.35	1.30	1.50
Max	74.00	4.20	9.40	8.80	4.60	7.70	4.20
Average	42.44	2.15	3.39	2.49	1.38	2.10	1.95
Geometric Mean	41.36	1.80	2.37	1.96	1.03	1.58	1.67
Standard Deviation	10.76	1.29	2.82	1.92	1.06	1.90	1.17
Count	16.00	16.00	17.00	17.00	16.00	17.00	17.00

	TKN (mg/L)						
Date	Trailer East Influent	Control 2	Control 3	Control 5	Ring 6	Ring 7	Ring 8
10/15/08	42.00	3.60	2.00	2.40	0.98	0.84	2.20
11/05/08	38.00	2.10	2.90	1.40	1.70	1.10	1.10
12/03/08	28.00	1.40	3.80	1.80	0.98	1.30	1.10
01/07/09	37.00	3.20	8.30	2.80	1.40	7.70	3.10
02/04/09	35.00	4.20	9.40	2.80	2.20	4.20	4.10
03/11/09	43.00	4.10	7.80	2.90	2.00	0.98	1.80
04/07/09	50.00	1.50	2.80	2.20	0.56	0.84	1.10
05/06/09	54.00	1.30	1.30	1.10	1.50	1.40	1.20
06/03/09	39.00	0.84	2.50	1.30	0.84	2.00	2.10
07/09/09	74.00	1.50	0.84	1.40	1.40	1.50	1.70
08/07/09	44.00	0.70	0.25	0.25	0.25	1.10	0.84
09/10/09		0.84	1.80	1.40	1.30	0.56	0.70
10/14/09	36.00	0.84	1.30	1.50	1.80	2.20	1.10
11/10/09	50.00	2.70	1.50	4.20	0.25	0.98	1.40
12/17/09	34.00	1.50	1.10	2.10	0.25	0.84	1.50
01/28/10	36.00	4.10	3.80	3.90	4.60	3.40	4.20
02/18/10	39.00		6.20	8.80		4.80	3.90

	Total Nitrogen (mg/L)					
Date	**Control 2**	**Control 3**	**Control 5**	**Ring 6**	**Ring 7**	**Ring 8**
Min	14.43	13.63	11.03	13.28	14.87	17.13
Median	24.38	23.93	24.23	26.64	25.73	25.43
Max	34.53	35.53	36.43	34.33	35.43	35.73
Average	24.44	24.31	24.15	25.65	25.66	26.09
Geometric Mean	23.66	23.50	22.94	24.81	24.90	25.57
Standard Deviation	6.24	6.31	7.46	6.45	6.27	5.27
Count	16.00	17.00	17.00	16.00	17.00	17.00
	Total Nitrogen (mg/L)					
Date	**Control 2**	**Control 3**	**Control 5**	**Ring 6**	**Ring 7**	**Ring 8**
10/15/08	24.63	26.03	29.43	27.01	23.94	24.75
11/05/08	22.13	23.93	21.43	25.73	25.13	22.48
12/03/08	14.43	13.63	13.83	17.01	16.33	17.13
01/07/09	24.23	23.33	26.83	27.43	25.73	25.13
02/04/09	18.23	20.43	16.83	20.23	19.23	18.13
03/11/09	20.29	19.10	17.93	19.03	19.01	19.83
04/07/09	24.53	21.83	22.23	20.59	22.87	23.13
05/06/09	32.33	32.33	31.13	33.53	35.43	31.23
06/03/09	31.87	35.53	31.33	32.87	34.03	33.13
07/09/09	34.53	33.09	33.43	33.43	31.53	35.73
08/07/09	29.73	29.28	29.28	30.28	32.13	30.87
09/10/09	31.87	29.83	36.43	34.33	33.59	31.73
10/14/09	24.87	24.33	28.53	27.83	27.23	26.13
11/10/09	23.73	23.53	24.23	26.28	26.01	25.43
12/17/09	15.53	14.13	11.03	13.28	14.87	27.53
01/28/10	18.13	17.83	14.93	21.63	21.43	23.23
02/18/10		25.26	21.83		27.83	27.93

Appendix 2

Field Data From
Percolate of Pipe-in-Stone and EZflow
Soil Absorption System

Key

Control 2, Control 3 and Control 5 – pipe in-stone replicates

Ring 6, Ring 7, Ring 8 – EZflow replicates

Trailer East Influent – Septic tank effluent used as source for leaching facilities.

pH

pH	Trailer East Influent	Control 2	Control 3	Control 5	Ring 6	Ring 7	Ring 8
Min	5.5	3.5	3.5	3.7	3.4	3.5	3.6
Median	6.7	5.2	5.3	5.3	5.3	5.4	5.4
Max	7.0	6.5	6.7	6.1	6.3	6.3	6.3
Average							
Standard Deviation							
Count	92	98	97	98	96	96	96
pH							
Date	Trailer East Influent	Control 2	Control 3	Control 5	Ring 6	Ring 7	Ring 8
10/1/08		5.9	5.7	6.1	5.5	5.5	5.8
10/8/08		5.8	5.2	5.8	4.8	4.8	4.7
10/15/08		5.7	5.3	5.6	4.9	4.8	4.7
10/22/08	6.7	5.4	5.4	5.5	4.9	4.8	4.6
10/29/08	6.7	5.2	5.5	5.4	4.9	4.9	4.8
11/5/08	6.6	5.1	5.3	5.3	4.8	4.6	4.6
11/11/08	6.8	5.7	5.5	5.7	5.1	5.0	5.0
11/19/08	6.8	5.8	6.0	5.9	5.5	5.3	5.2
11/25/08		5.6	6.0	5.6	5.3	5.3	5.0
12/3/08	6.6	5.9	5.9	5.9	5.6	5.5	5.5
12/10/08	6.9	6.0	6.1	5.9	5.6	5.9	5.9
12/17/08	6.9	5.8	5.8	5.9	5.9	6.0	6.2
12/22/08	6.8	6.1	6.1	6.0	6.0	6.3	6.1
12/29/08	6.7	5.9	6.2	5.8	5.8	6.1	6.1
1/7/09	6.8	6.1	6.2	6.0	5.7	6.1	5.9
1/14/09	6.9	6.1	6.4	6.0	6.2	6.2	6.2
1/21/09	6.7	6.3	6.3	5.8	5.8	5.9	6.0
1/28/09	6.9	6.3	6.7	6.0	6.0	6.1	6.2
2/4/09	6.7	6.3	6.6	6.1	6.1	6.2	6.3
2/11/09	6.9	6.5	6.7	6.1	6.1	6.2	6.2
2/18/09	6.8	6.3	6.5	6.1	5.9	5.9	5.9
2/25/09	6.8	6.3	6.6	6.1	5.7	5.9	5.8
3/4/09	6.8	6.0	6.4	5.8	5.6	5.7	5.7
3/11/09	6.4	5.9	6.2	5.7	5.8	5.8	5.7
3/18/09	6.8	6.0	6.3	5.8	5.8	5.8	5.7
3/25/09	6.6	5.8	6.0	5.7	5.4	5.4	5.4
4/1/09	6.7	5.8	6.0	5.8	5.6	5.7	5.7
4/7/09	6.5	5.4	5.6	5.5	5.6	5.8	5.7
4/15/09	6.4	5.2	5.2	5.3	5.3	5.5	5.6
4/22/09	6.2	5.7	5.6	5.7	5.8	5.7	5.7
4/29/09	6.4	5.7	5.4	5.6	5.7	5.8	5.8
5/6/09	6.2	5.3	5.2	5.1	5.3	5.4	5.4
5/13/09	6.6	4.3		4.5	4.2	4.2	4.2
5/20/09	6.2	5.4	5.1	5.2	5.0	5.7	5.3
5/27/09	6.2	5.1	5.7	5.2	4.8	5.4	5.1
6/3/09	6.3	5.2	5.4	5.3	4.9	5.3	5.0
6/10/09	6.2	5.1	4.9	4.9	4.5	4.7	4.4
6/17/09	6.4	5.0	5.1	5.2	4.4	4.7	5.0
6/24/09	6.5	5.4	5.5	5.4	5.3	5.4	5.5
7/1/09	6.6	5.4	5.5	5.6	5.4	5.4	5.6
7/9/09	6.7	5.3	5.5	5.6	5.6	5.6	5.6
7/16/09	6.5	5.3	5.3	5.6	5.4	5.4	5.7
7/23/09	6.7	5.2	4.8	5.5	4.9	4.6	5.1
7/30/09	6.4	5.0	4.3	4.4	4.6	4.6	5.0
8/7/09	6.9	5.3	4.3	5.6	4.8	4.6	5.0
8/13/09	7.0	5.0	4.2	5.1	4.2	4.2	4.6
8/20/09	7.0	4.9	4.3	4.8	4.2	4.2	4.3

Dissolved Oxygen (mg/L)

Dissolved Oxygen (mg/L)	Trailer East Influent	Control 2	Control 3	Control 5	Ring 6	Ring 7	Ring 8
Min	0.1	5.0	4.0	3.5	4.2	3.6	2.9
Median	1.0	6.5	6.8	6.4	7.8	7.3	7.2
Max	4.2	9.3	10.2	9.0	10.8	10.3	10.7
Average	1.1	6.7	6.8	6.4	7.8	7.0	7.0
Standard Deviation	0.8	1.0	1.3	1.2	1.6	1.6	1.7
Count	93	98	98	98	96	96	96
Dissolved Oxygen (mg/L)							
Date	Trailer East Influent	Control 2	Control 3	Control 5	Ring 6	Ring 7	Ring 8
10/1/08		5.4	4.0	6.0	6.0	5.3	5.8
10/8/08		6.4	5.2	4.9	6.1	5.1	5.9
10/15/08	0.9	5.6	5.8	4.6	7.1	4.1	5.0
10/22/08	1.0	5.4	5.4	5.6	4.2	3.6	4.9
10/29/08	1.1	5.3	5.8	6.3	6.5	3.6	5.8
11/5/08	2.4	6.1	5.6	5.7	6.5	4.0	5.8
11/11/08	1.4	6.0	5.7	6.5	7.1	4.1	5.4
11/19/08	1.6	7.1	5.4	6.9	8.4	5.5	6.9
11/25/08		8.1	6.1	7.3	8.9	7.2	7.3
12/3/08	2.3	9.3	6.7	8.4	10.4	8.1	9.5
12/10/08	3.1	7.7	6.6	6.9	8.6	6.9	7.8
12/17/08	3.1	7.8	6.3	7.2	8.8	7.0	7.8
12/22/08	1.5	7.7	7.3	7.2	8.6	8.2	8.8
12/29/08	1.2	7.8	6.1	6.8	9.4	5.9	8.1
1/7/09	1.1	6.8	6.1	6.9	8.8	5.9	8.1
1/14/09	1.2	7.1	6.1	7.0	8.9	6.5	9.5
1/21/09	2.4	7.4	7.8	7.0	10.3	6.4	7.8
1/28/09	4.2	7.1	6.8	8.2	10.1	6.4	8.9
2/4/09	2.3	6.8	7.0	7.4	10.1	7.9	9.5
2/11/09	1.4	7.2	7.2	8.2	10.8	8.5	9.3
2/18/09	1.5	6.6	7.2	7.8	9.9	7.6	8.2
2/25/09	2.4	7.1	6.6	7.2	9.5	7.8	8.1
3/4/09	2.4	6.4	6.2	7.3	9.1	7.8	8.0
3/11/09	2.2	6.4	6.5	6.6	9.1	8.3	7.4
3/18/09	1.0	6.3	6.4	7.1	9.0	8.3	6.9
3/25/09	1.3	6.2	6.2	6.8	9.4	8.3	6.7
4/1/09	1.4	6.8	6.3	7.1	9.4	8.1	6.6
4/7/09	2.3	7.6	7.3	7.9	9.3	9.5	9.0
4/15/09	2.6	8.6	7.2	8.2	9.3	8.4	8.4
4/22/09	1.8	9.0	7.4	8.5	9.7	7.9	7.9
4/29/09	2.1	8.5	7.6	9.0	9.6	7.4	7.2
5/6/09	1.8	8.1	6.8	7.5	7.8	7.0	6.4
5/13/09	0.8	7.3	7.6	8.1	8.3	8.0	8.1
5/20/09	1.1	6.9	7.4	8.2	7.6	7.6	4.4
5/27/09	1.1	6.2	5.2	7.6	6.7	7.4	4.1
6/3/09	2.6	6.4	5.6	7.1	6.6	6.0	4.0
6/10/09	1.3	6.3	6.4	6.4	4.4	4.1	2.9
6/17/09	1.2	6.8	6.2	6.9	5.0	4.3	3.0
6/24/09	0.2	7.1	6.5	6.7	5.3	4.6	4.7
7/1/09	1.0	6.8	6.7	6.5	5.0	5.1	4.6
7/9/09	0.2	5.4	6.5	6.8	6.2	5.5	4.9
7/16/09	1.0	6.4	6.2	7.8	7.7	5.8	5.9
7/23/09	0.4	6.3	6.9	6.3	5.5	4.9	4.1
7/30/09	0.9	6.1	6.2	6.1	6.1	4.9	4.7
8/7/09	1.2	6.5	6.5	5.6	5.5	5.6	4.8
8/13/09	1.6	5.7	6.1	4.9	5.8	4.9	5.1
8/20/09	0.4	5.9	6.0	5.9	6.7	6.2	6.7

Discharge Temperature (ºC)

Discharge Temperature (ºC)	Trailer East Influent	Control 2	Control 3	Control 5	Ring 6	Ring 7	Ring 8
Min	4.9	3.5	3.7	3.4	3.0	2.4	2.7
Median	13.3	12.5	12.6	12.2	12.1	11.8	11.9
Max	25.7	23.9	23.8	23.9	23.2	23.4	23.5
Average	13.3	12.7	12.6	12.5	12.1	12.0	12.0
Standard Deviation	5.6	6.3	6.3	6.2	6.0	6.1	6.1
Count	93	98	98	98	95	96	96
Discharge Temperature (ºC)							
Date	Trailer East Influent	Control 2	Control 3	Control 5	Ring 6	Ring 7	Ring 8
10/1/08		20.1	19.8	19.4	19.3	19.6	19.8
10/8/08		17.1	18.1	17.1	16.9	16.9	17.3
10/15/08	18.6	17.7	17.9	17.4	17.2	17.5	17.5
10/22/08	17.4	15.6	15.7	15.7	15.4	15.3	15.7
10/29/08	16.6	15.1	15.0	14.8	14.2	14.4	14.1
11/5/08	14.8	14.5	14.6	14.5	14.5	14.6	14.6
11/11/08	14.9	13.7	14.3	14.0	13.9	13.7	13.5
11/19/08	14.1	11.5	12.6	11.8	11.2	11.4	11.8
11/25/08		11.4	11.9	11.7	11.6	11.4	11.6
12/3/08	11.6	9.9	10.0	10.0	9.8	9.7	9.8
12/10/08	10.4	10.3	10.7	10.5	10.7	10.7	10.5
12/17/08	10.6	9.3	9.3	9.3	9.5	9.3	9.3
12/22/08	9.5	7.6	7.4	7.6	7.7	7.1	6.4
12/29/08	9.5	7.1	7.1	7.2	7.5	7.4	7.3
1/7/09	7.8	6.6	6.7	6.6	6.9	6.7	6.6
1/14/09	6.1	4.5	4.6	4.7	3.7	3.4	3.5
1/21/09	6.2	4.3	4.2	4.5	3.8	3.5	4.0
1/28/09	4.9	3.8	4.0	3.7	3.4	3.4	3.9
2/4/09	5.7	3.5	3.7	3.7	3.5	3.2	3.1
2/11/09	5.8	4.0	4.1	4.3	4.6	4.5	4.3
2/18/09	6.1	4.1	4.0	4.2	4.0	3.4	3.8
2/25/09	5.9	4.0	4.0	4.1	3.8	3.3	3.7
3/4/09	6.0	3.9	3.7	3.4	3.0	2.4	2.7
3/11/09	6.9	5.1	5.1	5.0	5.3	5.1	5.0
3/18/09	7.4	5.7	5.6	5.3	5.4	5.1	5.2
3/25/09	7.1	5.8	5.4	5.3	4.8	4.6	4.6
4/1/09	8.3	7.0	6.8	6.6		6.4	6.4
4/7/09	9.4	8.0	7.9	7.7	7.9	7.8	7.7
4/15/09	9.5	8.4	8.1	7.9	7.7	7.5	7.5
4/22/09	10.2	10.0	9.8	9.6	9.6	9.7	9.3
4/29/09	12.3	10.7	10.6	10.4	9.9	10.0	9.8
5/6/09	12.6	12.1	11.9	11.7	11.7	11.6	11.7
5/13/09	12.8	12.1	12.2	12.2	12.1	12.2	12.2
5/20/09	13.7	13.5	13.2	13.0	12.8	12.6	12.8
5/27/09	14.6	14.2	14.3	13.8	13.2	13.0	13.6
6/3/09	15.5	15.6	15.5	15.1	14.8	14.8	14.9
6/10/09	16.3	16.4	16.2	15.7	15.5	15.7	15.7
6/17/09	16.4	16.6	16.3	16.0	15.6	15.7	15.8
6/24/09	17.1	17.2	16.9	17.6	16.3	16.4	16.4
7/1/09	19.0	18.1	17.9	17.3	17.2	17.2	17.3
7/9/09	18.6	19.1	18.9	18.4	17.8	18.0	18.2
7/16/09	19.7	20.0	19.9	19.4	19.1	19.1	19.1
7/23/09	20.1	21.2	20.8	20.6	20.2	20.3	20.5
7/30/09	21.2	21.9	21.5	21.7	21.1	21.0	21.2
8/7/09	21.7	22.1	21.8	21.4	21.2	21.3	21.4
8/13/09	21.9	22.4	22.0	21.7	21.4	21.7	21.2
8/20/09	22.5	23.6	23.8	23.9	23.2	23.4	23.5

pH							
Date	Trailer East Influent	Control 2	Control 3	Control 5	Ring 6	Ring 7	Ring 8
9/2/09	6.8	5.1	4.5	4.7	5.4	4.5	5.4
9/10/09	6.8	4.7	4.3	4.7	4.6	4.3	4.8
9/16/09	6.9	5.0	4.6	4.8	5.6	5.1	5.7
9/23/09	6.8	4.6	4.3	4.5	4.8	4.3	4.8
9/30/09		4.5	4.4	4.4	4.5	4.1	4.7
10/8/09	6.8	4.3	4.4	4.1	4.5	4.1	5.0
10/14/09	6.4	4.4	4.4	4.1	4.1	4.0	4.4
10/22/09	6.9	4.4	4.6	4.3	4.7	4.8	5.1
10/29/09	6.9	4.7	5.0	4.5	5.1	5.6	5.1
11/5/09	6.9	4.4	4.3	4.1	4.4	4.6	4.9
11/9/09		4.6	4.3	4.6	4.3	4.6	4.9
11/10/09	7.0	4.3	4.2	4.4	4.2	4.7	5.3
11/17/09	6.8	4.1	4.1	4.6	4.0	4.3	4.6
11/23/09	6.8	4.2	4.2	4.8	4.1	4.3	4.9
12/1/09	6.6	4.9	4.8	4.8	4.7	5.1	5.4
12/10/09	6.7	5.1	5.4	5.3	5.8	6.1	5.9
12/17/09	6.8	4.4	4.9	4.9	5.9	6.0	6.2
12/21/09	6.8	4.6	5.0	4.7	5.6	5.7	6.1
12/29/09	6.7	5.7	5.6	5.3	5.8	6.0	6.0
1/6/10	6.8	4.6	5.1	5.7	5.8	5.4	5.8
1/12/10	6.9	5.4	5.7	5.8	6.0	5.6	5.9
1/19/10	6.8	5.9	5.9	5.9	6.3	6.3	6.3
1/28/10	6.9	5.7	5.7	5.6	6.2	6.0	6.1
2/3/10	6.8	5.8	5.6	5.7	6.1	6.1	6.1
2/11/10	6.9	6.0	5.7	5.7	5.8	6.0	6.1
2/18/10	7.0	6.0	5.8	6.1	6.0	5.6	5.9
2/24/10	6.8	6.3	5.6	6.1	6.0	5.9	5.9
3/2/10	6.6	6.2	5.8	6.0	5.9	6.0	6.0
3/10/10	6.7	6.3	5.5	6.1	5.9	6.0	6.0
3/18/10	6.9	6.3	5.4	6.1	5.9	6.0	6.3
3/24/10	6.4	5.9	5.4	5.6	5.7	5.9	5.9
3/31/10	6.5	5.4	5.3	5.4	5.8	5.9	5.9
4/6/10	6.6	4.5	4.4	5.3	5.5	5.5	5.8
4/13/10	6.6	4.2	4.2	4.7	5.2	5.2	5.8
4/20/10	6.8	4.2	4.3	4.5	4.9	5.0	5.5
4/27/10	6.7	4.1	4.2	4.3	4.6	4.9	5.3
5/5/10	6.4	3.9	4.1	4.1	4.3	4.5	5.0
5/12/10	6.6	4.0	4.2	4.1	4.2	4.5	5.0
5/19/10	6.4	4.2	4.6	4.2	4.5	4.8	4.4
5/26/10	6.4	3.8	4.3	4.5	4.8	5.0	5.7
6/2/10	5.5	3.8	3.9	4.3	4.1	4.1	4.9
6/10/10	6.6	4.2	4.2	4.5	4.0	4.1	4.7
6/16/10	6.6	4.1	4.0	4.4	4.2	4.1	4.7
6/23/10	6.7	3.8	3.6	3.9	3.7	3.7	4.1
6/30/10	6.6	3.7	3.5	4.0	3.5	3.5	3.6
7/7/10	6.5	3.7	3.8	4.0	3.8	3.8	3.9
7/14/10	6.3	3.5	3.5	3.7	3.4	3.5	3.8
7/20/10	6.5	3.7	3.8	3.8	3.8	3.7	3.8
7/27/10	6.5	3.8	3.8	3.9	3.9	3.8	4.0
8/3/10	6.9	3.9	4.1	3.8			
8/10/10	6.7	3.7	4.0	3.9			

Dissolved Oxygen (mg/L)							
Date	Trailer East Influent	Control 2	Control 3	Control 5	Ring 6	Ring 7	Ring 8
9/2/09	1.1	5.5	6.4	5.3	5.6	4.9	5.5
9/10/09	0.3	5.4	5.6	4.8	5.8	5.1	5.8
9/16/09	0.2	5.8	6.8	5.8	6.1	5.5	6.3
9/23/09	1.3	5.5	6.8	4.9	6.3	5.3	5.8
9/30/09		5.0	6.8	5.6	5.8	5.7	6.1
10/8/09	1.2	5.5	6.3	6.2	6.3	5.8	5.9
10/14/09	0.3	5.8	6.5	6.1	6.0	6.0	6.2
10/22/09	0.2	6.4	7.7	6.7	7.2	6.9	6.8
10/29/09	0.6	6.4	7.3	6.7	7.9	7.2	7.7
11/5/09	0.5	6.9	7.1	6.2	7.2	7.5	7.3
11/9/09		6.4	6.9	5.8	7.2	7.6	7.3
11/10/09	0.6	6.7	7.7	6.3	7.6	7.6	7.0
11/17/09	0.2	6.3	7.3	5.5	7.5	7.2	7.2
11/23/09	0.6	5.9	7.8	5.2	7.8	7.5	7.2
12/1/09	0.5	7.2	7.9	6.1	8.4	8.3	8.0
12/10/09	0.5	7.6	8.7	7.7	8.9	9.1	8.6
12/17/09	2.9	6.1	6.8	7.1	7.9	7.6	8.0
12/21/09	0.6	7.9	9.8	7.2	9.0	9.0	9.4
12/29/09	0.6	9.1	9.8	9.0	10.6	10.0	10.0
1/6/10	0.2	8.0	10.2	7.0	9.3	9.8	9.6
1/12/10	0.8	7.7	10.1	6.8	9.5	9.4	9.1
1/19/10	0.4	9.0	10.1	8.4	10.1	10.3	10.7
1/28/10	0.5	7.6	9.3	6.9	9.6	8.8	8.7
2/3/10	0.2	7.9	9.4	7.4	8.8	9.1	9.3
2/11/10	0.2	7.7	9.2	6.1	7.2	9.2	7.9
2/18/10	0.3	7.5	8.5	6.2	6.8	9.1	8.3
2/24/10	0.6	7.8	8.9	7.2	7.5	9.3	8.5
3/2/10	1.0	8.5	9.2	7.5	9.2	9.2	8.9
3/10/10	1.3	8.0	8.0	5.7	8.5	8.8	8.3
3/18/10	0.2	7.6	7.6	4.8	9.0	8.7	8.7
3/24/10	1.6	7.5	7.7	6.7	8.9	8.8	8.2
3/31/10	0.7	6.9	7.8	5.6	9.8	8.9	9.2
4/6/10	0.1	6.3	7.1	4.2	8.8	8.5	8.9
4/13/10	1.7	7.3	7.2	4.3	8.7	9.0	8.3
4/20/10	0.5	5.8	7.1	5.0	8.2	7.9	7.8
4/27/10	0.4	6.0	7.0	4.0	7.5	7.7	6.7
5/5/10	1.4	6.3	6.8	5.0	8.9	8.4	8.2
5/12/10	0.2	6.4	7.2	5.1	9.0	8.2	7.8
5/19/10	0.9	5.5	6.7	5.7	7.6	6.9	6.6
5/26/10	1.1	5.9	7.1	6.3	8.4	7.6	6.8
6/2/10	0.6	6.5	6.4	6.1	8.1	7.8	6.9
6/10/10	0.2	5.9	5.5	5.6	7.4	6.8	6.5
6/16/10	0.6	6.2	5.6	5.5	7.0	6.6	6.1
6/23/10	0.7	7.2	7.0	5.4	7.3	6.9	6.6
6/30/10	0.1	5.8	4.7	3.7	6.3	6.3	5.6
7/7/10	0.1	5.5	5.2	3.6	6.9	6.4	5.3
7/14/10	0.1	5.5	4.8	3.5	6.3	6.0	5.1
7/20/10	0.7	5.4	5.1	5.0	6.3	5.6	6.0
7/27/10	0.1	5.4	4.6	5.1	6.0	4.7	5.1
8/3/10	0.1	6.1	4.3	5.3			
8/10/10	0.1	5.0	4.1	5.0			

Discharge Temperature (ºC)							
Date	Trailer East Influent	Control 2	Control 3	Control 5	Ring 6	Ring 7	Ring 8
9/2/09	21.5	22.3	22.0	21.8	21.0	21.2	21.4
9/10/09	20.5	21.1	20.9	20.9	20.5	20.5	20.7
9/16/09	20.8	21.0	21.0	20.7	20.2	20.3	20.5
9/23/09	19.9	20.9	20.7	20.5	20.4	20.3	20.4
9/30/09		20.1	19.9	19.5	19.2	19.2	19.3
10/8/09	18.9	18.7	18.5	18.1	17.6	17.5	17.2
10/14/09	17.7	17.4	17.1	17.1	16.5	16.5	16.6
10/22/09	15.8	15.6	15.5	15.5	15.3	15.3	15.3
10/29/09	15.8	15.3	15.3	15.2	15.0	15.0	14.9
11/5/09	15.0	14.5	14.3	14.5	14.2	13.9	14.1
11/9/09		13.8	13.8	14.0	13.8	13.6	13.6
11/10/09	14.8	14.0	13.9	14.1	13.9	13.7	13.6
11/17/09	14.8	13.5	13.2	13.6	12.9	12.4	12.9
11/23/09	14.0	13.1	12.9	13.2	12.4	12.4	12.5
12/1/09	12.8	10.8	11.1	11.2	10.6	10.4	10.5
12/10/09	11.1	10.6	10.5	10.7	9.8	10.0	10.0
12/17/09	9.5	8.1	7.9	6.0	5.8	6.1	7.6
12/21/09	8.7	7.2	6.5	7.4	7.4	6.3	6.3
12/29/09	8.0	5.5	6.0	5.6	5.2	4.8	5.2
1/6/10	7.3	5.9	5.4	5.9	5.3	4.9	4.9
1/12/10	7.3	5.5	5.0	5.4	4.7	4.4	4.4
1/19/10	6.0	5.2	5.3	5.7	5.6	5.5	5.2
1/28/10	6.9	5.3	5.1	5.3	5.2	5.0	5.0
2/3/10	6.2	4.3	4.2	4.3	4.3	4.5	3.9
2/11/10	5.5	3.5	3.8	3.9	3.9	3.6	3.6
2/18/10	5.6	4.0	4.1	4.0	4.3	3.7	3.7
2/24/10	5.7	4.4	4.6	4.2	4.7	4.5	4.4
3/2/10	6.0	4.8	4.7	4.8	4.9	4.8	4.8
3/10/10	6.6	4.5	4.5	4.3	4.5	4.4	4.4
3/18/10	7.4	6.0	6.0	5.9	6.2	6.0	6.0
3/24/10	8.9	7.7	7.5	7.5	7.7	7.6	7.5
3/31/10	9.0	7.9	7.8	7.7	7.9	7.8	7.8
4/6/10	10.2	9.2	8.9	8.7	8.9	8.8	8.7
4/13/10	11.0	10.0	9.9	9.7	9.4	9.2	9.5
4/20/10	10.9	10.5	10.4	10.1	10.1	9.9	9.8
4/27/10	11.9	11.0	11.1	10.7	10.5	10.3	10.4
5/5/10	13.3	12.3	12.1	11.8	11.8	11.7	11.7
5/12/10	13.4	12.7	12.5	12.2	12.1	11.9	12.0
5/19/10	14.2	14.4	14.1	13.9	14.0	14.0	14.0
5/26/10	15.3	15.7	15.6	15.2	15.2	15.1	15.0
6/2/10	16.9	17.4	17.1	16.7	16.7	16.7	16.6
6/10/10	18.1	17.8	17.5	17.2	16.8	16.7	16.7
6/16/10	18.4	17.9	17.7	17.4	17.3	17.3	17.3
6/23/10	19.9	19.7	19.4	19.0	19.2	19.0	19.1
6/30/10	20.3	20.5	20.1	19.6	19.2	19.2	19.5
7/7/10	20.9	21.9	21.7	21.3	21.4	21.4	21.3
7/14/10	22.1	23.1	22.9	22.7	22.8	22.8	22.9
7/20/10	22.3	23.2	23.0	22.9	22.8	22.9	23.1
7/27/10	22.3	23.1	22.9	22.6	22.3	22.5	22.4
8/3/10	25.7	23.2	23.3	22.7			
8/10/10	23.0	23.9	23.6	23.4			