

Field Comparison of Rock-Filled and Chambered Trench Systems

University of Minnesota Onsite Sewage Treatment Program

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ABSTRACT

Due to actions of the Minnesota State Legislature, systems utilizing chambers and synthetic drainfield distribution media are allowed to be designed and installed up to 40% smaller than the standard or conventional trench system area, under provisions of a special “Warrantied System” category. If approved for “Warrantied System” sizing, manufacturers can receive reduced sizing guidelines in exchange for offering a five-year performance warranty and technical information. There has been debate among regulators, professionals and manufacturers about the long-term hydraulic longevity of systems that use the reduced-area trenches for final treatment and dispersal. A project was designed to identify whether there is a statistical difference in performance between chambered and rock-filled trench systems. This was achieved by a large-scale survey of over 100 selected onsite systems of both rock-filled trenches and chambered trenches across seven Minnesota counties. Each system type was studied within three major soil permeability categories (fast, medium and slow) utilizing soil texture classes. In addition to a general evaluation of the system and homeowner survey including questions on usage and maintenance frequency, the percentage of the system in use at the time of the site visit was determined. This was possible because a majority of trench systems in Minnesota utilize drop box or sequential distribution which loads the trenches in a particular order so that one trench is loaded to a specific level before the subsequent trenches are utilized. Adjusting both types of systems to a standard size datum, the ponding levels were compared. Surprisingly nearly 60% of the systems visited during the study of the ages 5 -10 years did not have any ponding observed at the end of the first trench segment. When the amount of ponding was compared between rock-filled and chambered systems the data was not able to prove the hypothesis that chambered systems of a similar age as rock-filled systems utilize 25% less area than the rock systems at 10% significance level. To the contrary, the results indicate that rock-filled trench systems were utilizing less soil treatment area than the chambered systems due in part to the smaller area per trench of the chamber systems. More mature trench systems of both types need further investigation and analysis to more fully evaluate this issue.

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INTRODUCTION

Trench-type drainfields are a simple method of treating wastewater in settings when proper soil and site conditions exist. In gravity dispersal systems, septic tank effluent flows or is dosed to a drop box or a distribution box. Only systems utilizing drop boxes were evaluated in this study, where effluent flows from an outlet pipe in the lowest position in the box to the first trench in a series. In Minnesota, individual sewage treatment systems (ISTS) can utilize various media for temporary storage of sewage prior to absorption by soil, including drainfield rock, chambers, and other approved products. All of these medias have the same objective: to apply wastewater to the soil in a manner that allows movement into or through the soil, resulting in treatment and dispersal of the wastewater. The media also maintains the excavation to expose the infiltrative surfaces and provides storage. Absorption of effluent by the soil is dependent on a complex series of processes. The factors involved include the initial soil characteristics, hydraulic and organic loading, dosing regime, aeration status of the infiltrative surface and soil biogeochemical properties (Kropf et al., 1977).

When septic tank effluent is delivered to a gravity dispersed trench system, the wastewater will initially seep directly into the soil. However, as more and more organic material and solids enter the trench, a biomat of organic material and bacteria gradually covers the bottom of the trench. This biomat collect some materials at the surface and biomass fills the soil pores in a zone at and below the infiltrative surface. In most instances, this biomat is less permeable than the bare soil, and as a result, wastewater will begin to pool in the trench. Once the biomat has covered the entire trench floor, the biomat will begin to develop on the sidewalls (Kropf et al., 1977, Dix, 2001). Eventually, the first trench will be completely full of wastewater to the level set by the outlet elevation of the drop box. At this stage, wastewater begins flowing to the second trench, and the process begins anew.

In a rock-filled trench, the effluent flows out through the holes in the first length of distribution pipe and moves through the rock layer and into the exposed soil which act as a surface for the infiltration of the septic tank effluent. According to MN Rules Chapter 7080, drainfield rock is igneous rock, or similar insoluble, durable, and decay-resistant material between 1.9 and 6.4 centimeters in size, with no more than five percent by weight passing a 1.9 centimeter sieve and no more than one percent by weight passing a No. 200 sieve. In Minnesota, rock trenches are typically 0.92 meters in width and sized with at least 15.3 centimeters of rock below the distribution pipe, with reduction credit given for rock beyond 15.3 centimeters, up to 61.0 centimeters below the distribution pipe. The distribution pipe is then covered with 5 more centimeters of rock. Geotextile material is then placed over the rock to allow water and air to pass while preventing soil from migrating into the rock voids.

Chambered trench systems consist of a plastic dome-shaped structure buried in a trench to create an enclosed open space, with the exposed soil acting as a surface for the infiltration of septic tank effluent. When sewage effluent is applied by gravity, the effluent is directly introduced to the soil surface at the bottom of the trench. The width of open bottom area is 0.74 meters, while the outside foot print is 0.86 meters. Holes or slots are located on the sides of the chamber to allow for sidewall application of effluent in addition to trench bottom absorption.

In Minnesota, drainfields sized according to Minnesota State Rule (Table 1) are considered “standard”. Alternatively, drainfields can be installed at a reduced size, using a special classification created by the Minnesota State Legislature at the request of chamber manufacturers. Under this “warrantied system” classification, drainfield trenches built using chambers and expanded polystyrene can be sized with up to a 40% reduction in soil treatment trench bottom area. In order for a technology to be classified as a warrantied system the system manufacturers are required to submit technical performance and design information, financial assurance documentation to ensure performance on warranties, information showing that at least 50 of its systems were operating successfully for at least three years across all major Minnesota soil classifications and a \$1,000 application fee.

The standard system length required is calculated by taking the estimated flow based on bedrooms multiplied by the soil sizing factor divided by the width of the rock trench or chamber. The warrantied sizing is simply 60% of the calculated length or bottom area. When drop boxes are used, the actual loading rate to the first trench in sequence, regardless of distribution media, is often much higher than the design loading rate. This increased loading encourages the formation of a biomat which assists in the treatment process. It was expected that most of the systems visited with ages from 5 -10 years would have an established biomat with some measurable ponding.

Table 1. Soil sizing factors used to design trench systems in Minnesota (MPCA, 2002)

Soil Texture	Loading Rate (lpd/m²)	Warrantied/ 40% Downsized Loading Rate(lpd/m²)	Permeability Class for this Evaluation
Course, medium or loamy sand	48.9	29.4	Fast
Sandy loam	32.6	32.6	Medium
Fine Sand and Loam	24.5	14.7	Medium
Silt loam and silt	20.4	12.2	Slow
Clay loam, sandy clay or silty clay	18.3	11.0	Slow
Clay, sand or silty clay	9.8	5.9	Slow

According to the 2005 annual reports supplied to the Minnesota Pollution Control Agency (MPCA) by local units of government, approximately 40% of the systems installed that year were of the trench-type. The vast majority of these were full sized “standard” trench systems, although a growing number of chambered systems are being sized as reduced sized “warrantied systems”. There has been debate among regulators, professionals and manufacturers about the

hydraulic longevity of systems that use reduced-area trenches versus “standard” trenches (Hall, 2002).

Generally, the argument on the part of proponents of the installation of chamber systems at reduced area has been that the infiltration rate in rock-filled trenches compared to chambered systems is reduced due to an embedment layer composed of rocks impressed with the soil at the infiltrative surface. It is argued that the more open nature of chambers, including its larger volume of storage capacity, more open infiltrative soil surface, lower compaction from installation, and the absence of fines are justification for the downsizing (Siegrist, 1997). Regardless of distribution media, the soil has a limited hydraulic capacity which cannot be exceeded regardless of distribution media. In most cases, the most hydraulically restrictive layer will be the biomat at the soil infiltrative surface and not the underlying soil although is heavy textured soil this many not be the case.

Over the years, research has been conducted evaluating drainfield rock and reduced sized chambers. Amerson et al., (1991) evaluated the impact of compaction by falling gravel, fines and the contact area of gravel (masking) in both a silt loam and a sandy soil. When evaluated individually the study found no effect from masking or compaction on infiltration rates. The study did find reduced infiltration rates in the silt loam when fines where included. When all three variables where combined reduced infiltration rates were found in both soil types and the authors conclude that the fines were the greatest contributor to reduced infiltration rates in rock-filled trenches.

In an evaluation using Hydrus 2D by Radcliffe et al. (2005), results evaluating masking and embedment where mixed depending on the position of the gravel, the difference in the hydraulic conductivity of the biomat and the underlying soil and the degree of sidewall flow. The results generally showed that infiltration rates for chambered systems were 1.33 to 1.93 times that of rock-filled systems depending upon whether sidewall flow was included and assumptions on biomat conductivity relative to soil hydraulic conductivity. The conditions with lower ratios of infiltration are thought to be due to lateral gradients pulling water into the areas beneath gravel particles and lack of embedment in sidewalls.

Beach et al. (2005) and Walsh et al. (2006) used sand filled columns with both and open and rock-filled infiltrative surfaces to study hydraulic conductivities and acceptance rates when higher then typical design loading rates were applied. After a period of 140 -144 days of application of septic tank effluent, conductivities and infiltration rates in the columns with rock were significantly lower than in the open columns. Several studies utilizing a field site and computer modeling conducted at the Colorado School of Mines have consistently indicated that trenches utilizing gravel compared to chambers have a reduction in the long term acceptance rate (Siegrist et al., 2004 and Lowe et al., 2006).

Field studies have been completed in several states attempting to determine if chambered systems can be sized smaller than rock-filled systems while yielding similar performance. In Colorado, an evaluation of 16 systems, including 10 Infiltrator chambered systems sized at a 50% reduction and 6 gravel systems showed that the chambered systems performed similarly to rock-filled trenches (Siegrist et al., 2000). The systems in this study ranged from 1 -11 years in

age and the estimated hydraulic loading rate averaged 13.0 liters per day (lpd)/m² for the chambers and 7.3 lpd/m² for rock-filled trenches while about half of the systems of each type exhibited some degree of ponding. While the chambers received a higher loading rate due to the downsizing, the removal of fecal coliform was comparable indicated that the higher loading rate was not creating a treatment problem. The authors state that further testing under a wider range of conditions is warranted.

In another study performed in Oregon by Hoover and Hinson (2002), Infiltrator Equalizer[®] 24 chambers installed with a 50% reduction in trench bottom area were compared to rock-filled trenches. In this study, system failure was defined as seepage of effluent to the ground surface or a straight-pipe discharge to the ground surface. The systems ranged from 3-5 years in age. After evaluating nearly 400 systems, the findings indicated there was no significant difference in system failure between rock-filled trenches and the downsized chambered trenches. Three failures occurred in the rock-filled trenches (1.6%) and two failures occurred in the chambered trenches (1%). Due to the young age of these systems and with failure used as the criterion to assess performance, there are questions about the meaningfulness of this study. The authors recommend that further research to determine if failure rates will maintain low.

In North Carolina (Uebler et al., 2006), 303 chambers installed with a 25% reduction in trench length were compared to 303 rock trench systems. The age of the systems ranged from 2-12 years. These systems were also evaluated on the failure surfacing criteria. Once again, no statistical difference was found between failures with the chambered trenches (8.5%) and the rock-filled systems (7.3%). This study also evaluated differences in failures rates depending on region within the state, which was broken down into: Coastal, Piedmont and Mountain. The Mountain region was found to have a significantly lower failure rate (3.9%), compared to 11.7% in the Coastal region and 9.8% in the Piedmont region. The lower failure rate in the Mountain region was attributed to the typically long, narrow systems that are installed on the steep 25% slopes, which may be promoting more efficient movement of effluent away from the drainfield. These relatively high levels of failure for both rock and chambered systems ranging in age from 2-12 years suggests design or use related problems that make the usefulness of these results limited.

Dix and Hoxie (2001) studied the longevity of septic systems in Maine. They found that chambered systems, installed at a 50% reduction are following the same patterns as rock-filled trench systems, with over 80% of both types providing more than 20 years of service. Data analysis was done on 145,000 permits to define the frequency of repairs or replacement, therefore no field verification was completed. When systems less than 10 years of age were compared for the two technologies, the cumulative failure of all systems ranged from 1.6% and 4.1%, and for chambers between 1.9% and 5.0%. According the authors this difference is likely due to poorly drained soils and commercial applications where chambers are more common due to the 50% sizing of this technology.

In general, due to system age and lack of field data collection, the results of these studies are limited in their application. Several of these studies indicate that more time is needed to truly answer the question of whether the long term system performance of downsized chambered systems is comparable with that of larger-sized rock-filled trenches.

METHODS AND MATERIALS

Project Design

This research was coordinated by the University of Minnesota Onsite Sewage Treatment Program working in conjunction with regulators from local county onsite programs. This study attempted to evaluate the issue of system hydraulic performances between the two distribution medias.

System hydraulic performance was evaluated by:

- (i.) determining if the system was sized according to state standards and also met a 0.61 meter vertical separation requirement,
- (ii.) investigating whether sewage was coming or has come to the surface, and
- (iii.) the percentage of system in use as indicated by ponding of effluent. Use was determined in this study by verifying ponding occurrence and ponding depth in order to calculate the percentage of system in use. Systems experiencing no ponding at the end of the first trench segment will have a percentage use of zero.

This project was designed as a large-scale survey of onsite systems across Minnesota. Systems sampled were selected based on system type (rock-filled or chamber) and major soil types utilizing three general soil texture classes as the authors expect there may be differences in system hydraulic performance based on the nature of the soil material(s) encountered. Chambered systems that were designed with both standard and warrantied sizing were included because they would be evaluated for comparison by the percentage of system in use compared to standard sizing.

The evaluation was performed independently of the product manufacturers. The month of May was chosen as a target time period to visit the systems, as this period generally coincides wetter soils and with higher seasonal water tables in Minnesota (Minnesota Climatology Working Group, 2006). This period was chosen to test the systems as it presents the worse case scenario when ponding of systems would be at a peak level. The study was designed to be conducted in its entirety during a 1-month period in the spring of 2006 to minimize climatic variation among the study sites.

Statistical Approach

The hypothesis for this project is that chambered systems of a similar age (5-10 years since installation) as rock-filled systems will utilize 25% less area than the rock-filled systems at a 10% significance level. Thus, for similar soils, we anticipate that a chambered system will accept more wastewater per unit area of trench before ponding, and that chambered systems should take more wastewater per unit area of trench.

This project was designed as a large-scale survey of 220 onsite systems across Minnesota. Our minimum sample sizes were determined to minimize the effect of flow variability in our percent usage data. By utilizing flow per capita and standard deviation data (Mayer et al., 1999), we desired to detect a 25% difference in system area used with a probability of 0.90 at a significance

level of 0.10. Factoring in this flow variability along with other key variables of system type and major soil category, we determined that for each system type a minimum of 33 systems must be evaluated stratified by 1/3 of the systems in each major soil category to minimize flow uncertainties.

Basic statistics were computed for all data collected to develop an understanding of data. Comparison of percentage in use data between system types and stratified by major textural category within each system type (Systat 10, 2000). Significance levels utilized for all analyses is 0.01. Assumptions common to the paired t-test analysis include random equal variance and approximately normal distribution. Non-normally distributed data is common in uncontrolled experiments and may result in the skewing of risk levels, which are chosen arbitrarily (Koch and Link, 1980).

The survey areas were chosen based on three conditions:

1. The systems were spread across Minnesota. This was important to limit the data being biased by a particular region, county or professional.
2. The systems were located in counties with a sufficient number of chambered and rock-filled systems ranging in age from five to ten years which utilize drop boxes as the distribution method.
3. The systems were spread across the soil textural classes. For the purpose of this study all soils were placed into categories of slow, medium, and fast. With “fast” representing coarse sand, medium sand or loamy sand; “medium” representing fine sand, sandy loam, and loam; and “slow” representing silt, silty clay loam and sandy or silty clay with approximately a third of both the chambered and the rock-filled systems in each of the three categories.

Based on historical sales data and known soil conditions, counties with the highest probability of a match to the categories studied were contacted. Working with county staff, approximately 1000 systems were identified that met the criteria. After the systems were identified, permission was obtained from homeowners prior to the evaluation period. Homeowners were provided with a clear outline of the project with assurance that enforcement would not occur as a result of the field evaluation of their system. A short homeowner questionnaire was required to be completed prior to the visit provided including the question from Table 3. The data gained from this questionnaire eliminated some systems from the study and provided information on operational and management issues which may affect the amount of ponding in a system. In general, because a large number of systems were surveyed, one would not expect operation and maintenance to vary by system type, so this factor should not affect the survey results. The questions regarding bedrooms and people living in the home were used to determine estimated and calculated flow values.

Estimated daily flow values, used to design all systems in Minnesota were strictly based on the number of bedrooms (568 liters/bedroom). Actual flows were estimated from the number of persons in each residence. The AWWA Research Foundation’s report on Residential Water Use reports a median flow per capita of 229 lpd was used with a standard deviation 150 lpd (Mayer et al., 1999). The use of this median value is justified by the large number of systems evaluated in this study so the daily flow variability from site to site is averaged out and not considered to be an explanatory variable between the two types of media studied. The number of persons in each

residence was multiplied by the reported median flow per capita to obtain the estimated actual daily flow for each residence.

Table 3. Homeowner questionnaire.

Question	Rationale
Is the home used on a seasonal basis?	Used to eliminate seasonal residences
How many bedrooms are in the home?	Used to calculate design flow
How many people live in the house?	Used to calculate estimated actual usage
When was the last time your septic tank was pumped?	Used to determine if a relationship exists between recently pumped tanks and usage.
Do you have a garbage disposal?	Used to determine if a relationship exists between presence of garbage disposal and usage.

There was a concern that with this method of system selection, property owners with surfacing systems would be less likely to allow access to their sites. There are two reasons this is of less concern. First, these systems are relatively young in age, all designed and installed by licensed professionals and inspected by county inspectors, so the number of surfacing systems should be very minimal. Second, surfacing hydraulic failure was not our only parameter to indicate system performance. Instead we focused on determining the percentage of system in use. Additional parameters collected were possible explanations for differences in usage and may be used to add additional insight into our analyses and outcomes.

Field Survey Protocol

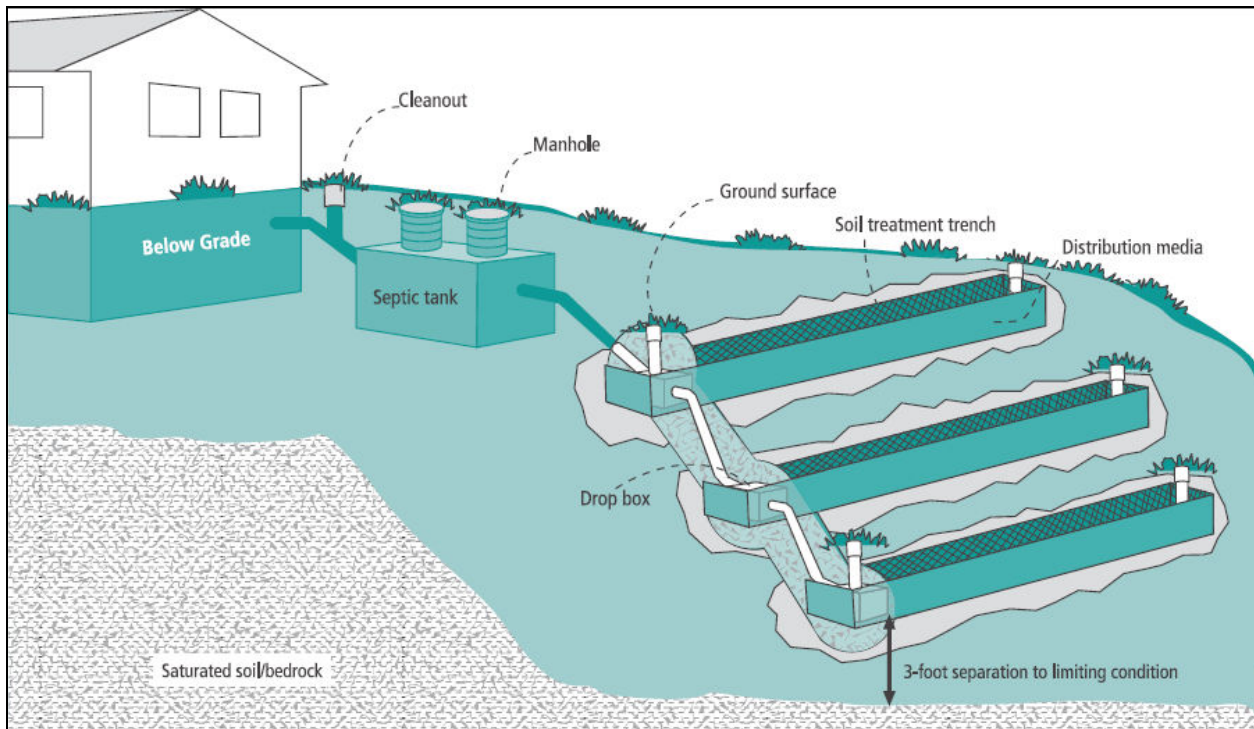
A field survey evaluation form, including the protocol, was designed to serve as a site-specific data collection and compilation guide (See Appendix A). County permit data was used, as available, as a starting point for field evaluation. Typical county permit data available in Minnesota includes the system type, installation date/age, system design, well location, number of bedrooms, design flow, septic tank sizing, use of a pump, type of distribution method, depth to limiting condition, soil sizing factor, system length, depth, and location of trenches, system construction inspection data and as-built drawings. If a subsequent compliance inspection was part of the permit file, it would also be evaluated.

A licensed private inspector visited each site chosen for the survey. A member of the University of Minnesota research team participated in approximately 30% of the site visits to both establish the initial protocol and provide quality assurance throughout the study. The following parameters were evaluated by the inspector:

- a. The size of the system installed was confirmed.
- b. Surfacing of septic tank effluent or evidence that the system surfaced in the past was investigated.
- c. The number, length and depth of trenches was confirmed.

- d. The soil texture and vertical separation was identified with in a soil boring performed outside the area of influence along the mid-point contour of the soil treatment system was performed.
- e. The width for rock trenches was assumed to be 0.91m (typical design variable and bucket width in Minnesota and 0.74m for chambers (inside foot print of chambers). For design purposes most designers use the excavation width of 0.91m when sizing chambered systems. The actual infiltration area was considered to more accurate for the purposes of this study.
- f. The amount of ponding was recorded for each trench. The drop boxes and inspection wells on the ends of the trenches provide a location for monitoring the use and amount of ponding, height above the trench bottom (see Figure 1). This was done by inserting a probe into the inspection port until the bottom was reach, removing the probe and recording the amount of effluent visible on the probe. If inspection ports were absent, the trench media was manually exposed for ponding measurement. If the trench had no measurable ponding it was recorded as having zero meters of ponding even though portions of that trench were accepting the effluent, but had yet to reach the point of building a biomat resulting in ponding. Due to the use of drop boxes, the subsequent trenches will not receive effluent until the first trench is ponding to its maximum potential.

Figure 1. Trench system layout utilizing drop boxes for distribution.



The acceptable sites were organized by area and scheduled for site inspection. The time of day which the site was visited was not considered to be a variable which would affect the amount of ponding recorded at the end of each trench. The septic tank serves as damping device to control the typical morning and evening surges in most homes. Most property owners requested that they be notified via a phone call before the inspector would visit their site, and many were home

at the time of inspection, which provided the benefit of active use of the system. Upon arrival at the site, the inspector again reviewed the permit data to identify the location of the components of the system. In some cases, conspicuous inspection pipes on the septic tank, drop boxes, and trench ends were present. More often, the inspection pipes had been cut off at or below grade, or removed altogether. In these cases, the site was manually probed to identify the location of components.

Once the drainfield had been identified, the inspection pipes were located and exposed. By examining the drop boxes, it was possible to identify which of the trenches were in use, by the presence or absence of effluent in the boxes. Trench ponding was measured in the inspection pipes at the ends of the trenches with an error of up to 2.54 centimeters. To increase accuracy measurement, the inspector probed the trench, noting the amount of soil covering the trench media and the depth to the bottom of the media. This was compared to the permit data and to the depth of the inspection pipe on the trench end. In cases where the inspection pipe did not extend to the bottom of the trench media, or if the inspection pipe was absent, ponding was measured by either probing the media or by manually digging through the media to measure the ponding.

After establishing the location, size, and type of the drainfield, the inspector then conducted a soil boring adjacent to the drainfield. The location was selected based on its proximity to the system: it needed to be close enough to be representative of the soils in the drainfield area, but far enough to be outside the area of influence of the effluent. Borings were typically along the contour of the mid-point of the drainfield, 3 to 6 meters from the end of the trenches. Other factors affecting the selection of the boring location included proximity from trees, surface water drainage, landscaping, and utilities. Soil borings were completed to a depth 0.91m below the drainfield media, or to a point of refusal (rocks or other restrictive layer). Often, multiple attempts were necessary to achieve the necessary depth of soil observation.

Data about ponding was recorded on the field inspection form, as well as a site sketch and any other relevant notations. Upon completion of the inspection, property owners were given a Septic System Owner's Guide (University of Minnesota, 2005), contact information for any questions they may have regarding their system or the study, and either \$25 cash or gift card in appreciation for their participation.

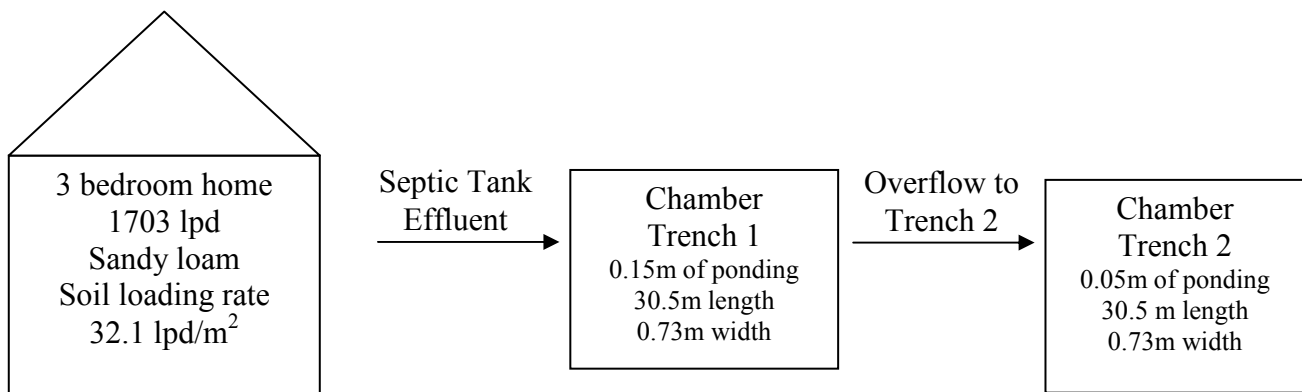
Determining Percentage of System in Use

Based on the data collected in the field, the percentage of system in use was calculated and compared to the datum of a "standard/conventional" sized system so both full and downsized systems were able to be included in the study. This measurement does not indicate life expectancy as the development of biomat is dynamic and is not likely to be a linear process. The calculation allows for a comparison between the two types of media to test the project hypothesis that a smaller percentage of use will exist in chambers compared to rock-filled trenches.

The percentage of the system in use was calculated using the following procedure

1. The amount of ponding recorded was compared to the potential amount of ponding for each trench. For chambered systems in this study, 0.15m was the maximum amount of potential ponding. For rock systems, the depth of rock beneath the pipe varied from 0.15m to 0.61m but only rock trenches with less than 0.15m of ponding were included to provide an equal comparison between the two media types. The amount of ponding in the rock trenches was not adjusted for the space occupied by the rock which can account for up to 60% of the volume. This was done to simplify the calculation as it was not thought to be significant variable. See Figure 2 below for example. *Example calculation: If in a chambered system, in the first trench, 0.15m of ponding was recorded, the percentage of use for that trench is 0.15m divided by 0.15m or 100%. If in the second trench, 0.05m of ponding was recorded the percentage of trench is use is 0.05 divided by 0.15 or 33%.*

Figure 2. Example site for percentage of use calculations.



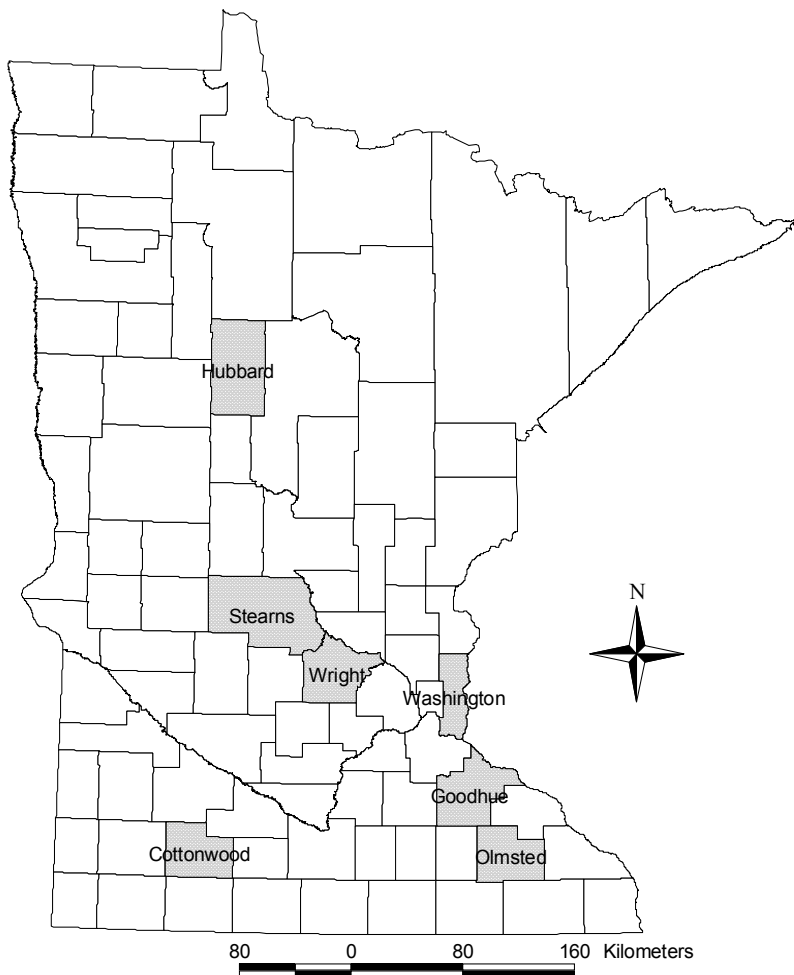
2. This percentage was then converted to an equivalent area (EA). The percentages calculated in the step 1 were then multiplied by the length and width of for each trench. *Example calculation: For trench 1 the EA is 30.5m multiplied by 0.73m multiplied by 100% or 22.3 m². For the second trench the equivalent area is 30.5m multiplied by 0.73 multiplied by 33% or 7.4 m². Adding the two trenches together the total EA is 29.6 m².*
3. Calculated the standard/conventional sized area (SA) based on the number of bedrooms and loading rate or soil sizing factor based on soil texture. *Example calculations: flow based on bedrooms, 1703 liters per day, divided by the soil loading rate of 32.1 lpd/m² results in a SA of 53.2 m².*
4. Calculated the percentage of system in use by comparing the EA to the SA. *Example calculation: 29.6 m² divided by 53.2 m² equal 56% in use.*

RESULTS AND DISCUSSION

Survey Area

To meet the conditions of geographic spread, sufficient numbers of each system type and soil textural class, seven Minnesota counties were selected for the study: Hubbard, Goodhue, Cottonwood, Olmsted, Wright, Stearns, and Washington (Figure 3). Other factors that influenced the selection of target counties included the level of interest by local government units to participate and the return of the consent form and questionnaire by homeowners. Once a county was identified as having chambered or rock-filled systems that could qualify for the study, that county's offices were visited for research and duplication of records. At that time, a letter explaining the study, a consent form, and a questionnaire were mailed to owners of potential study sites.

Figure 3. Location of studied counties within Minnesota.



Climate

Climatic patterns can play an integral role when inspecting septic system performance and usage. We attempted to keep climate variation to a minimum by selecting a roughly 30-day window for conducting our analyses. In order to better understand our data, we need to understand the climatic trends. The field evaluation was conducted between April 26 and June 24, 2006. To determine if the study period was seeing a below normal, normal, or above normal precipitation, the 30 year average (1975-2005) was determined for each county for the given study period (weather station information in (Appendix B, Table 1). Also considered was the precipitation 30 days prior to the study, and how that compared to the 30-year average for the study period (Appendix B, Tables 2 - 8).

Our analysis of the climate data for all of the study locations suggests that precipitation averages over the study period plus the 30 days prior for all but one location are within 30% of the 30-year averages (Table 4). This indicates that precipitation patterns are roughly similar to what would be expected. The exception was Cottonwood County. Since there were only 2 systems utilized from this county in this study, this is not expected to influence the results.

Table 4. Average daily precipitation for study period plus 30 days previous comparing 2006 and 30 year average, where n equals the number of observations.

County	Precipitation (centimeters) Study Period Plus 30 Days Previous	
	2006	30 yr Avg
Cottonwood (n=36)	0.48	0.28
Goodhue (n=37)	0.23	0.30
Hubbard (n=32)	0.36	0.28
Olmsted (n=81)	0.23	0.30
Wright (n=68)	0.23	0.15
Stearns (n=82)	0.28	0.30
Washington (n=68)	0.28	0.33

Systems Characteristics

In this study, 116 chambered and 104 rock-filled systems were inspected across seven different Minnesota counties, stratified by 3 major soil textural categories. Each system included in the study had to be occupied year round and have at least 0.61 meters of vertical separation to the seasonally high water table or bedrock. Over the study period, 31 systems were inspected that did not meet this 0.61 meter separation requirement and were not included in these results. We also removed rock-trench systems (27 systems) from the database that included more than 0.15m of ponding (where rock-filled trench depths were greater than 0.15m) in order to compare similar systems to chambers. Surfacing during the field visit or indications of past surface discharge were not observed in any of the systems inspected during the survey. Only one system was fully ponded with very limited additional storage capacity.

All systems meeting study criteria (162 systems total) for this study were between 5 and 10 years of age, with 82% of the systems operating for 6 to 7 years. Seventy percent of the systems had been pumped within the last 5 years and 20% had garbage disposals. A trench with 0.15m of rock beneath the pipe serves as our datum when determining if a system was downsized. The flow for the home multiplied by our soil sizing factor then serves as a “standard” sized system. If the system was greater than or equal to a 20% reduction, the system was classified as downsized. Twenty seven percent of the rock-filled systems were classified as downsized. This was due to the most part by allowed reductions due to increased media depth (i.e. a 20% reduction is allowed with a 0.15m increase in rock depth compared to a standard gravel trench). Forty-six percent of the chambered systems were considered downsized. In the vast majority of sites this was due to the allowance of up to a 40% reduction when chambers are utilized. Occasional systems in both categories where the incorrect soils interpretations were made that resulted in a downsized system. Downsizing was not an important variable the way the study was conducted because the systems are sequentially loaded. Downsizing would have an effect only when a number of the systems surveyed are fully loaded to the end of the final trench of the drop box or sequentially loaded system and this only occurred in one chambered system.

The field evaluation was conducted between April 26 and June 24, 2006. The time period of evaluation was lengthened due to problems gaining consent from property owners. 30 systems per category was the goal, but due to study requirements and sample time limitations the number was slightly less for several categories as shown in Table 5. The sample set is statistically valid in size.

Table 5. Number of system per soil type and average age and trench length.

System Type	Soil Type and Number of Systems ()	Avg. Age in years & Standard Deviation ()	Avg. Trench Length (m) & Standard Deviation ()
Chamber	Fast (33)	6.0 (0.5)	14 (6)
	Medium (28)	6.0 (0.8)	16 (5)
	Slow (31)	7.0 (1.5)	20 (7)
Total/Averages	90	6.3 (1.1)	17 (7)
Rock	Fast (22)	6.4 (0.7)	17 (5)
	Medium (22)	6.5 (0.8)	21 (7)
	Slow (28)	6.7 (0.9)	24 (6)
Total/Averages	72	6.7 (0.9)	21 (7)

System Comparison Evaluation

There were a large number of systems where no ponding was recorded (96 total, 57 rock and 39 chamber) indicating the biomat had not yet matured to the point of causing ponding. Generally speaking a biomat is a positive attribute of gravity trenches receiving septic tank effluent as it

assists in unsaturated flow through the soil profile. One likely explanation for less rock systems experiencing measurable ponding is due to the fact that it takes longer for the mature biomat to develop in rock-filled trenches because they are generally longer in length as shown in Table 5. Chambered systems are about 30% shorter (SE 5.1%).

T-test comparisons utilizing the entire database demonstrate a higher usage in systems without garbage disposals (12.9% use versus 3.5%, respectively, $p = 0.002$), while there was no difference in usage between recently pumped systems and those less recently pumped (10.4% use versus 11.8%, respectively, $p = 0.688$). To further investigate these differences, we compared within system types. Analyzing the presence or absence of garbage disposals shows the same trends, at significant levels ($p < 0.10$), within both rock and chambered systems. For the pumping frequency, the statistically insignificant results continued.

T-test results indicate no significant differences between systems (chambered and rock) studied comparing overall system size (assuming Minnesota state standard sizing was utilized) or system age. These findings are important when comparing system types in terms of usage. Since there were no significant differences regarding size or age, these properties are not considered influential variables if differences between system types are observed.

Estimated daily flows were determined by multiplying the number of residents from the homeowner survey by 229 liters per day. The mean estimated flows between chambered and rock trench systems did not vary significantly at the 0.10 level (655 and 700 liters per day, respectively).

T-test comparisons of all rock-filled trenches versus all chambered systems found chambered systems have a higher percent usage ($p = 0.000$). Investigating the system types by major soil category shows that for each soil textural category, chambered systems use more system area when compared to rock systems (Table 6). The significant differences between system types even when stratified by soil type may be partially explained by trench length.

Table 6. Comparison of percent use by system type and general soil texture class.

Soil Category	Percent Use (%)		p value
	Rock	Chambers	
Fast	8.7	20.8	0.041
Medium	3.1	16.5	0.003
Slow	1.6	9.6	0.001

To investigate the role of trench length as an explanatory variable in this study, we first needed to develop a metric of comparison between systems. Since length of the systems is not comparing the same area per unit length, we chose area as our metric. All systems have varying lengths of trenches so we averaged the trench lengths in order to derive our final variable, which is average area per trench. We found average area per trench (square meters) to vary significantly between system types when data is aggregated and between fast, medium and slow soils (Table 7). Chambered systems have shorter trench segments and therefore are more likely to pond sooner. Since our study evaluated system usage by determining ponding, chambers are

likely to have a higher use because of their shorter trench segments. It can also be seen in Table 7 that the actual soil sizing factors based on the estimated flows and average area per trench the loading rates to both systems are quite high since all the wastewater is flowing into the first sequential trench. The data indicated that chambered systems are receiving a higher loading rate which encouraged the formation of a biomat and measurable ponding. These results should not be used to predict system longevity.

Table 7. Comparison of average area per trench by system type and general soil texture class.

Soil Category	Avg. Area Per Trench (m ²)			Loading Rate(lpd/m ²)	
	Rock	Chambers	p value	Rock	Chambers
Fast	16.8	12.9	0.008	45.2	50.9
Medium	20.3	15.1	0.006	33.8	45.2
Slow	21.9	19.1	0.093	31.4	33.8

To further investigate how much of the variability in percent use to attribute to average area per trench, a linear regression was completed of the percent of soil treatment system use by average area per trench stratified by soil textural class. This data found average area per trench to explain 29, 38 and 46% for slow, medium and fast soils respectively of the variation in percentage of system used. So while trench area plays a role in explaining why this study found chambers using a greater amount of a soil treatment area, it is not a complete explanation. Numerous possible explanations exist to potentially further explain the differences including chamber settling, surface compaction due to foot traffic in the trenches and wastewater application methods, quality of sites and installers on sites utilizing downsized chambers and treatment/biomat development which may occur initially in rock trenches before ponding occurs as effluent travels over the rock similar to a trickling filter. Evidence of these occurrences was not identified in this study as the chambers and trench bottoms were not exposed.

To determine which attributes of the systems measured significantly impacted the percent in use SYSTAT was used to perform a multiple linear regression of all the systems included in the study. Evaluating the percent in use type of system ($p = 0.001$), people in the home/usage ($p = 0.000$) and average area per trench ($p = 0.000$) are all important variables which explain approximately 30% of the variability. Within each system type, number of people (chambers $p = 0.007$, and rock $p = 0.000$) and average area per trench (chambers $p = 0.000$ and rock $p = 0.003$) are statistically significant and garbage disposal use is significant only for chambered systems ($p = 0.061$).

Systems were then divided into three size categories based on average area per trench: small (1), medium (2), large (3). Analysis of percent in use was performed with all the systems and number of people ($p = 0.008$) and size category ($p = 0.000$) are explanatory variables. When the data is grouped into rock-filled and chambered the number of people and the size category were significant in both rock filled ($p = 0.001$ and 0.006) and chambered ($p = 0.008$ and 0.000), respectively.

Summarizing percent in use by area categories was determined for each system type as shown in Table 8. The size categories were chosen based on sample size and natural breaks in system areas. As systems increase in average area per trench the percent in use decreases across the two system types. This holds true for each system type with systems with smaller area having higher percent use than medium, and medium higher than large. Even within the same size category rock-filled systems have a smaller percentage of system in use than chambered systems. These differences are significant with the exception of category 3 due to the large area of the trenches and the sampling methods.

Table 8. Percent in Use Results with Systems Categorized by Square Meter Categories.

Size Category - Range in m ²	Number of Systems	Percent in Use			
		All	Rock	Chambers	p value
1 - (0 – 13.9)	60	19.6	9.5	24.3	0.011
2 - (13.9 – 23.2)	66	7.8	3.9	10.9	0.020
3 - (> 23.2)	36	1.2	0.6	2.4	0.353

The data collected in this study was unable to prove the hypothesis that chambered systems of a similar age as rock-filled systems will use 25% less area than rock-filled systems at 10% significance level. The data shows the opposite with less ponding in rock-filled systems. Based on the age of systems used in this study this phenomenon may occur because many systems have not yet reached the point of building a mature biomat, which causes ponding. Statistically significant differences were detected by a t-test at the 0.10 level between chamber and rock-filled trench systems when mean percent of system area in use was compared (Table 9). However, it is the rock-filled trenches that are experiencing a lower mean percentage of system use, not chambered systems as stated in our hypothesis. While statistically valid differences do exist, they appear to be small differences and our conclusion from this analysis is that rock-filled trenches and chambered systems act similarly in terms of area used for the age of systems in this study (5-10 years). Therefore, there was no observed advantage of chambered systems over rock-filled systems at this age range in terms of system usage discovered in this study.

Table 9. Results of unpaired t-tests comparing system types. P-values were evaluated at a significance level of $p < 0.10$.

System Type	Age (years)		System Size (m ²)		Estimated Flow (lpd)		Percent Use (%)	
	Mean	p-value	Mean	p-value	Mean	p-value	Mean	p-value
Chamber	6.3	0.120	79.2	0.770	655	0.359	15.8	0.000
Rock	6.5		76.8		700		4.3	

CONCLUSIONS

While direct flow measurements and actual biomat cannot be quantified, our sampling provided non-intrusive methods for collecting data suitable for comparison. Surprisingly, 59.3% of systems included in our study of the ages 5- 10 years did not have any ponding observed during a typical wet time of year for Minnesota climatic conditions. This finding is cause for additional analyses in order to ascertain a suitable explanation, as establishment of a biomat at the bottom

of a soil treatment system ensures proper treatment of effluent. Additional data may be required in order to fully understand this unexpected outcome.

Rock-filled trench septic systems between 5-10 years in age were found in our study to be utilizing less soil treatment area than chambered systems. While total area between the two system types did not vary, it is estimated that part of the explanation for why rock systems were found to use less of the soil treatment area is because of the smaller area per trench utilized in many chambered systems (29-46%). Analyses of additional data collected in this study failed to provide further insight into the differences determined. These results should not be used to predict system longevity.

Based on the results of this study, the design parameter used in Minnesota (loading rates and 0.91 meters of separation), proper installation and maintenance along with the licensing, permitting and inspection program are resulting in excellent system performance of gravity sequentially loaded trenches. The authors believe the requirements in Minnesota generally result in successful system at relatively low cost due to their proper design and installation. Another large benefit of the trenches in Minnesota is the inspection at both the drop box and end of the trench which allowed us to investigate the amount of ponding and provide a system management component.

FUTHER RESEARCH

This study provides a more detailed protocol to investigate the performance of trench systems. It would be advantageous and informative to either complete this study in a different location with older systems or to rerun this study in 5-10 years to determine if a longer term difference between the system types will exist. This would testing systems for allow longevity and system performance with a higher proportion of systems experiencing measurable ponding.

The development of ponding in gravity trenches needs further investigation. It was assumed when this project was under development that more then 75% of systems with sequential loading would have some measurable ponding at the end of the first trench aGer five years or more of operation. This lack of biomat development questions our general understanding of biomat formation time lines, identifies our conservative design approach and highlights that shorter trench installation maybe be helpful in the performance of systems.

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REFERENCES

- 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*, ASAE, St. Joseph, MI, Pp. 243-247.
- Beach, D.N.H., J.E. McCray, K.S. Lowe, and R.L. Siegrist. 2005. Temporal changes in hydraulic conductivity of sand porous media biofilters during wastewater infiltration due to biomat formation. *Journal of Hydrology*, 31: 230–243.
- Dix, S. Affects of Sand Texture on Sidewall Absorption of Septic Tank Effluent, in *On-Site Wastewater Treatment: Proc. 9th Nat. Symp. Individual and Small Community Sewage Systems*, ASAE, St. Joseph, Michigan, Pp. 159-170
- Dix, S. and D. Hoxie. 2001. Analysis of Septic System Longevity in Maine in *On-Site Wastewater Treatment: Proc. 9th Nat. Symp. Individual and Small Community Sewage Systems*, ASAE, St. Joseph, Michigan, Pp. 340-348.
- Hall, Selden. 2001. Special Features and Applications of Drainfield Products. Washington State Department of Health, Rule Development Committee Issue Research Report WAC 246-272-11501(2)(k)(l).
- Hoover, M.T. and T.H. Hinson. 2002. Oregon On-Site Wastewater System Field Performance Assessment. The On-Site Corporation and Cpec Environmental, Inc. Final Project Report to Infiltrator Systems, Inc. and Oregon Department of Environmental Quality.
- Kropf, F.W., Laak, R., Healy, K.A. 1977. Equilibrium Operation of Subsurface Absorption Systems. *J. Water Pollut. Control Fed.* 49 (9), 2007–2016.
- Lowe, K., Siegrist, R. and K. Tacket. 2006. Hydraulic Loading Rate and Infiltrative Surface Architecture Effects on Septic Tank Treatment During Soil Infiltration in the 2006 NOWRA Technical Education Conference Proceedings - #PE-06-38, August 28-31, 2006 Denver Co.
- Mayer, P.W., W.B. DeOreo, E.M. Opitz, J.C Kiefer, WY. Davis and B Dziegielewski. 1999. Residential End Uses of Water. *AWWA Research Foundation and the American Water Works Association*. Denver, CO.
- Minnesota Pollution Control Agency. 2002. Individual Sewage Treatment System Standards: Chapter 7080 MN Rules. *Minnesota Pollution Control Agency*, Water Quality Div., St. Paul, MN 55155.
- Minnesota Climatology Working Group, 2006. Soil Moisture Data. Accessed on line at <http://climate.umn.edu/doc/agwx.htm>.

- Radcliffe, D., West, L. and J. Singer. 2005. Gravel Effect on Wastewater Infiltration from Septic System Trenches. *Soil Sci. Soc. Am. J.*, (69)1217-1224.
- Siegrist, R.L. 1987. Soil Clogging During Subsurface Wastewater Infiltration as Affected by Effluent Composition and Loading Rate, *J. Environmental Quality*, 16(2):181-187.
- Siegrist, R.L., S. Van Cuyk, S. Masson, and E. Fischer. 2000. Field Evaluation of Wastewater Soil Absorption Systems with Aggregate-Free and Aggregate-Laden Infiltrative Surfaces. Final project report for Infiltrator Systems, Inc. Colorado School of Mines, Golden, CO, 80401-1887. 50 pg.
- Siegrist, R.L., J.E. McCray, and K.S. Lowe. 2004. Wastewater infiltration into soil and the effects of infiltrative surface architecture. *Small Flows Journal*. 5(1): 29–39.
- Systat Software, Inc. 2000. SYSTAT Version 9.01. Systat Software, Inc., San Jose, CA.
- Uebler, R.L., Berkowitz, S., Beusher, P., Avery, M., Ogle, B., Arrington, K., and B. Grimes. Performance of Chamber and EZ1203H Systems Compared to Conventional Gravel Septic Tank Systems in North Carolina. 2006 NOWRA Technical Education Conference Proceedings - #PE-06-38, August 28-31, 2006 Denver Co.
- Olson, K., D. Gustafson, S. Christopherson and Barbara Luikkonen. 2005. Septic System's Owners Guide. University of Minnesota Extension Service. 405 Coffey Hall, St. Paul, MN 55108.

APPENDIX A – Field Inspection Form

PONDING STUDY INSPECTION REPORT

Observation #

Landscape:

Method of Observation:

Depth to Restrictive Soil:

FROM MUNSELL SOIL COLOR CHART

DEPTH (meters)	MUNSELL COLOR	SUBSTRATE H / V / C	MOTTLE H / V / C	SOIL TEXTURE	WATER (Y / N)	BEDROCK (Y / N)

TRENCH MEDIA:

TRENCH #	DEPTH TO BOTTOM	PONDING @ D-BOX	PONDING @ END	MEDIA THICKNESS	TRENCH WIDTH	TRENCH LENGTH	TRENCH AREA
1							
2							
3							
4							
5							
6							
SEEPAGE?				TOTAL AREA:			
SURFACE DISCHARGE?				% IN USE:			

OWNER:	COUNTY:
ADDRESS:	PERMIT #:
CITY, ZIP:	
REVIEWED BY:	OWNER HOME?
REVIEW DATE:	OWNER PAID?

APPENDIX B – Additional Climate Data

Table 1.

County	Township/range/section	station #/ID
Cottonwood	106 37 32	219033 Windom
Goodhue	111 18 23	215987 Northfield
Hubbard	140 35 25	216360 Park Rapids
Olmsted	107 14 14	211485 Chester
Wright	121 24 31	21107 Buffalo
Stearns	124 30 20	211691 Collegeville - St. John's
Washington	30 20 35	218037 Stillwater 1SE

Table 2.

Cottonwood County				
	study period 5/3-5/9/06	30 year average (1975- 2005)	month prior 4/2-5/2/06	30 year average month prior (1975-2005)
Total	0.00	0.91	6.79	3.15
Average	0.00	0.13	0.22	0.10
Median	0.00	0.00		

Table 3.

Goodhue County				
	study period 5/20-5/27/06	30 year average (1975-2005)	month prior 4/19- 5/19/06	30 year average month prior (1975- 2005)
Total	0.22	0.47	3.15	3.96
Average	0.03	0.07	0.10	0.13
Median	0.00	0.00		

Table 4.

Hubbard County				
	study period 5/21-5/23/06	30 year average (1975-2005)	month prior 4/20- 5/20/06	30 year average month prior (1975- 2005)
Total	0.20	0.85	4.25	2.57
Average	0.03	0.12	0.14	0.09
Median	0.00	0.00		

Table 5.

Olmsted		County		
	study period	30 year average	month	30 year
	5/4-6/24/06	(1975-2005)	prior 4/20- 5/20/06	average month prior (1975- 2005)
Total	3.24	6.78	4.31	3.26
Average	0.06	0.14	0.14	0.11
Median	0.00	0.04		

Table 6.

Wright		County		
	study period	30 year average	month	30 year
	5/17-5/24/06	(1975-2005)	prior 4/16- 5/16/06	average month prior (1975- 2005)
Total	0.00	0.83	6.26	3.27
Average	0.00	0.12	0.20	0.11
Median	0.00	0.28		

Table 7.

Stearns		County		
	study period	30 year average	month	30 year
	5/2-6/23/06	(1975-2005)	prior 4/1- 5/1/06	average month prior (1975- 2005)
Total	4.04	7.22	5.12	2.54
Average	0.08	0.14	0.17	0.08
Median	0.00	0.00		

Table 8.

Washington		County		
	study period	30 year average	month	30 year
	5/8-6/15/06	(1975-2005)	prior 4/7- 5/7/06	average month prior (1975- 2005)
Total	3.13	5.56	4.23	3.37
Average	0.08	0.14	0.14	0.11
Median	0.00	0.00		