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The Effects of Dosed versus Gravity-Fed Loading Methods on the Performance and Reliability of Contour Trench Disposal Fields Used for Onsite Wastewater Treatment

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In Nova Scotia, Canada, contour trench disposal fields are the most common type of onsite wastewater system. In this study, two identical contour trench disposal fields were monitored for 3 yr to compare performance under gravity-fed versus periodically dosed loading conditions. Influent and effluent from both systems were analyzed for a suite of water quality parameters, and the hydraulics of the systems were assessed using tracer studies and measurements of ponded water depth in the distribution trenches. Ponded water depths in the distribution trench of the gravity-fed disposal field were observed to increase steadily during the monitoring period, indicating progressive clogging. This was not observed in the periodically dosed field. Regarding treatment, both systems performed well, consistently producing effluent with 5-d biochemical oxygen demand and total suspended solids (TSS) concentrations <10 mg L^{-1} and achieving >5 log reductions in *Escherichia coli*. However, the gravity-fed system produced statistically lower average effluent concentrations for total P and TSS. It is speculated that the slightly better treatment performance achieved by the gravity-fed system is due to enhanced biomat formation. This study demonstrated adequate treatment of residential wastewater by contour trench disposal fields regardless of loading method. However, because the hydraulic performance of these systems is heavily dependent on pretreatment and loading methods, it is recommended that a dosing system be used to distribute wastewater to contour trench disposal fields to help prevent hydraulic failure.

In the United States, roughly 23% of residential homes use on-site systems to treat their wastewater (USEPA, 2002). In Canada, this number is approximately 20% (Statistics Canada 2006). Focusing further, roughly 45% of Nova Scotian residents use on-site sewage disposal methods (Nova Scotia Environment, 2011). This coincides with the 45.6% of private homes in Nova Scotia classified as "rural" by Statistics Canada (2006). Nova Scotia Environment also reported that approximately 40% of Nova Scotians use private wells (roughly 90% of rural homes) (Nova Scotia Environment, 2008). It is therefore important to ensure proper functioning on-site wastewater disposal systems to prevent intrusion of contaminants into downgradient potable water supplies.

To degrade, filter, and dilute contaminants, most on-site wastewater disposal systems include a septic/holding tank followed by a disposal field (McCray and Christopherson, 2008). The disposal field provides treatment by physical and biological processes. Although physical filtration occurs, biological growth in the form of a biomat is responsible for an increase in wastewater contact area and improved removal efficiencies (Van Cuyk et al., 2004). Havard et al. (2008) showed that biomat growth in sand filters can result in >5-log removal of microorganisms, >98% removal of 5-d biochemical oxygen demand (BOD_5), and >95% removal of TSS.

The biomat is composed of live and dead microbial biomass, suspended particles filtered from the septic tank effluent (STE), and mineral precipitates and typically forms at the boundary of the distribution trench and adjacent soil (Jones and Taylor, 1965; Thomas et al., 1966; Siegrist and Boyle, 1987). Problems arise when excess biomat growth decreases the soil's hydraulic conductivity to the point of clogging, which can result in system failure if the field is dosed at a greater rate than the biomat throughput (Beal et al., 2006). Failure of the system can lead to reduced water treatment and may lead to contamination of surface or groundwater (Yates, 1985).

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Abbreviations: BOD_5, 5-d biochemical oxygen demand; C2r, Type 2 Raised Contour Trench; STE, septic tank effluent; TKN, total Kjeldahl nitrogen; TN, total nitrogen; TP, total phosphorus; TSS, total suspended solids.

Traditional on-site wastewater systems are gravity fed, providing an inexpensive treatment method (USEPA, 2002). However, this type of system requires some form of clog prevention, such as an STE filter (USEPA, 2002), and periodic draining of clogged material to maintain unsaturated conditions (McGauhey and Winneberger, 1964). In comparison, Nova Scotia Environment (2009) recommends using one to two intermittent does per day to allow the disposal field and biomat to drain between doses. Although there are also operating and minor maintenance requirements for dosing pumps (Barnes and Wilson, 1976), the USEPA (2002) states that virus removal can be enhanced with this method due to better water distribution in the infiltration zone and increased retention time. A daily one-dose application rate was also shown to clog less, thus better maintaining unsaturated hydraulic conditions (Hargett et al., 1982). Leverenz et al. (2009) also showed that dosing frequency in intermittent sand filters significantly influences biomat growth and the likelihood of clogging or hydraulic failure.

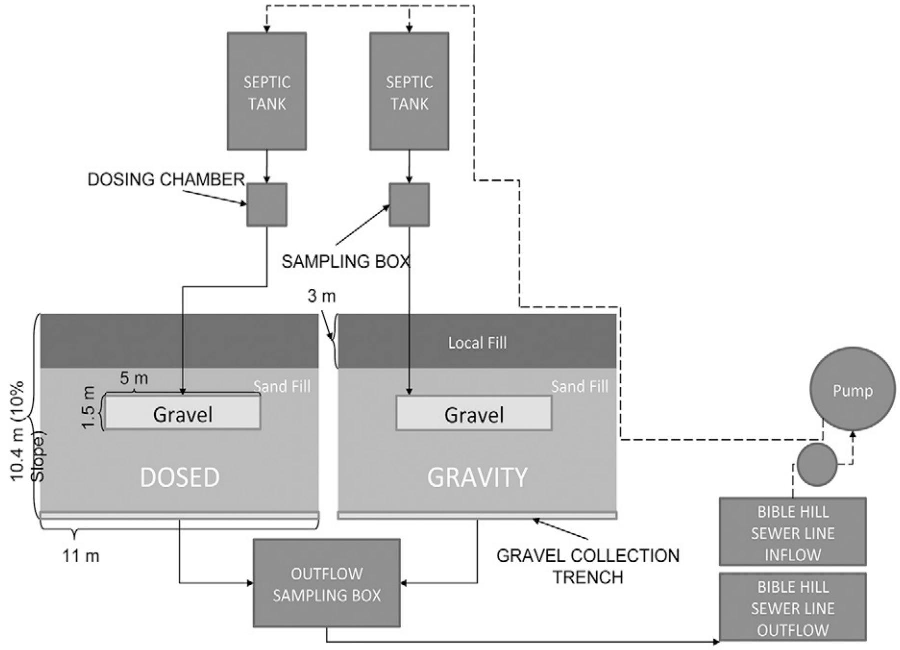

Fig. 1. Plan view illustrating layout of the two experimental contour trench systems.

Biological activity in the biomat is a major contributor to wastewater treatment in sand filters (Van Cuyk et al., 2004; Havard et al., 2008), and its potential reduction under dosed loading (to prevent clogging and hydraulic failure) may result in reduced treatment performance. The objective of this research was to compare gravity-fed and periodically dosed contour disposal fields, evaluating reductions in biomat clogging in periodically dosed systems while identifying the positive or negative effects on treatment performance. A raised contour trench disposal field design was chosen for analysis (Nova Scotia Environment, 2009) because it is one of most common systems installed in Nova Scotia. Identical field-scale contour trench disposal field systems were constructed and monitored for 3 yr. The influence of dosing method on hydraulic and treatment performance was assessed, and the performance of both systems was rated using the Bureau de normalization du Québec (BNQ) guidelines for on-site wastewater system performance (BNQ, 2009).

Materials and Methods

Experimental Facility

In the summer of 2007, two Type 2 Raised Contour Trench (C2r) disposal fields were constructed at the AgriTech Park in Bible Hill, Nova Scotia (45° 23′ N, 63° 14′ W). Plan and profile depictions of this type of disposal field are provided in Fig. 1 and 2, respectively. Both C2rs were constructed as duplicates: the first duplicate acted as a control (gravity fed with end feed without a septic tank effluent [STE] filter), and the other duplicate was loaded using a periodic dosing regimen with a central feed and STE filter. These two loading methods were chosen because they represent the presumed worst- and best-case scenarios for loading effluent into a distribution trench. The constructed systems adhered to the specifications outlined in the On-site Sewage Disposal Technical Guidelines in 2007 (updated version released in 2009) (Nova Scotia Environment, 2009). The

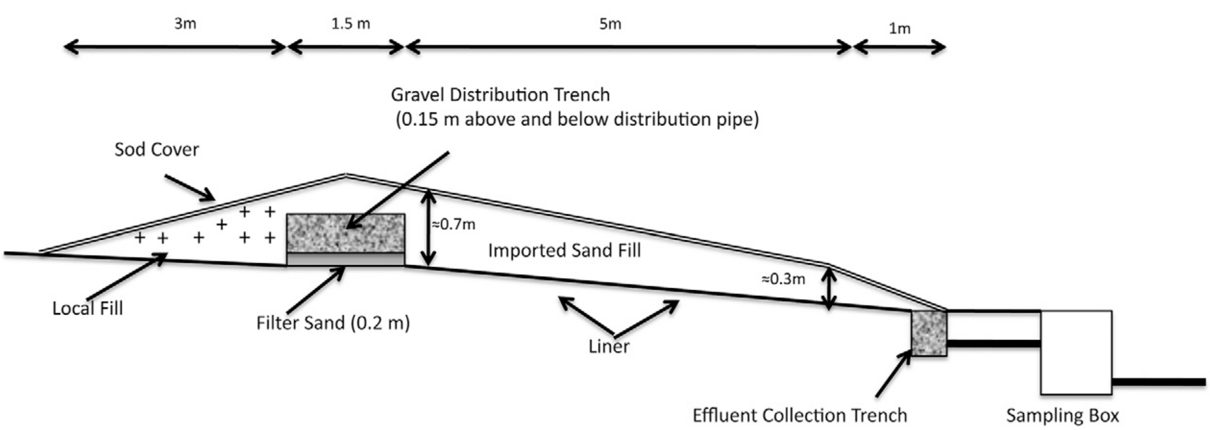

Fig. 2. Cross-sectional view illustrating contour trench design.

C2rs were built on a 10% slope using imported fill with a d_{10} of 0.27 mm, uniformity coefficient of 5.2, and saturated hydraulic conductivity of 4×10^{-2} cm s^{-1}. This slope and fill are consistent with imported sand specifications in the On-site Sewage Disposal Technical Guidelines (Nova Scotia Environment, 2009). Grain size distribution characteristics were determined using ASTM Method C136-01 (ASTM, 2006a), and hydraulic conductivity was determined using ASTM Method D2434 (ASTM, 2006b).

Each C2r was constructed within a 10.5-m-long and 8-m-wide excavation (Fig. 1). A 5-m gravel distribution trench constructed across the upgradient slope served as the point of entry of wastewater into the disposal field. Each gravel trench encased a perforated polyvinyl chloride distribution pipe that connected to one of two septic tanks. For the gravity-fed system, the STE pipe connected to the end of the distribution pipe (end-feed). By contrast, the STE pipe connecting to the dosed C2r was attached to the middle of the distribution pipe (middle-feed).

Each C2r consisted of 3 m of local fill followed by the 1.5-m-long distribution trench and the 6-m long-sand toe, which tapered down to a 0.5-m, gravel-filled collection trench (Fig. 2).

A liner was installed beneath each C2r to collect and direct subsurface flows toward the 60-cm-deep gravel collection trench located at the downslope edge of the C2r (Fig. 2). The two C2rs were hydraulically isolated from each other. The liner installation and an upslope diversion swale were used to prevent upslope drainage from entering the systems. The downgradient effluent collection trench, spanning the full width of the C2r's toe, contained a 10-cm-diameter perforated polyvinyl chloride pipe. From here, all flows were directed to a concrete sampling box below the field elevation. One tipping bucket, wired to a datalogger, was installed in the sampling box associated with each C2r to measure flow rates. A sampling spout was installed before each tipping bucket to ensure unobstructed sample collection. Before wastewater loading, clean water was loaded into each distribution trench to ensure the integrity of the liner system and to verify that both fields were operating in a hydraulically similar manner.

Water was pumped onsite from the municipal sewer system in Bible Hill. The wastewater underwent primary treatment (settling) in two 1000-L septic tanks. Both systems were dosed with 300 L of STE per day, determined using loading rates outlined in the On-site Sewage Disposal Technical Guidelines (Nova Scotia Environment, 2009). An effluent filter was also installed in the discharge pipe of the septic tank feeding the dosed system. Effluent filters are recommended, but not required, in Nova Scotia.

The dosing chamber was configured to distribute the 300 L equally over two 150-L doses per day. The other system received the 300 L slowly over the course of the day by gravity feed. All filter effluent from the sampling boxes was collected in a common conduit and returned to the Bible Hill wastewater system. Wastewater loading and monitoring commenced in June 2008.

Initially, the gravity-fed C2r septic tank did not have an effluent filter, to simulate the worst-case scenario. The dosed system had an effluent filter, which can prevent large particulates from entering the disposal field. After approximately 9 mo of wastewater loading, the gravity-fed C2r system experienced hydraulic failure due to solids accumulation in the distribution trench. The distribution trench was repaired, and an effluent filter was installed in the septic tank feeding the gravity-fed trench. The effluent filter remained in place for the final 2 yr of the study.

Observation wells were installed at three positions along each of the gravel distribution trenches. For both systems, the first well was placed at the point where the STE pipe connected to the distribution pipe. In the gravity-fed C2r, one of the other wells was installed at the far end of the distribution pipe, with the final well installed midway along the trench. For the dosed system, the other two wells were installed at the ends of the distribution pipe. These locations were chosen to monitor ponding of water in the distribution trench to provide an indication of biomat formation and hydraulic performance.

Monitoring

Statistical analysis was based on a sampling program running from 2008 to 2011. Sample collection began in June 2008 at a biweekly frequency to monitor initial biomat development (as evidenced by treatment performance). After the biomat appeared to stabilize in January 2009, the sampling frequency was reduced to monthly.

Wastewater samples were analyzed at the Nova Scotia Agricultural College Environmental Research Laboratory using the procedures found in Standard Methods for the Examination of Water and Wastewater (Clesceri et al., 1998). Biological analysis was performed to quantify *Escherichia coli* (using membrane filtration onto m-ColiBlue24 culture medium [HACH Canada]). Other parameters analyzed included total suspended solids (TSS) (Std. Method 2540D), BOD_5 (Std. Method 5210B), total phosphorus (TP) (Std. Method 4500-P [1999 revision], ascorbic acid method), total Kjeldahl nitrogen (TKN) (Std. Method 4500-N_{org}B), ammonia-nitrogen (NH_3–N) (Std. Method 4500-NH_3), soluble reactive phosphorus (Std. Method 4110 [2000 version]), and nitrate-nitrogen (NO_3–N) (Std. Method 4110 [2000 version]).

Bucket tips were recorded every 30 min by a datalogger and used to calculate flow leaving each C2r. Water depth in the observation wells was initially measured biweekly (starting in November 2008) but was reduced to a monthly frequency in January 2009.

Tracer Study

A bromide (Br) water tracing study was performed on each C2r in March 2011. Bromide was chosen as the tracer chemical due to its nontoxic nature and its relatively low sorption potential, which leads to higher recovery (Gilley et al., 1990). Preparation for each filter included mixing 20 g of sodium bromide in a bucket with 44 L of clean water. The solution was pulse-injected into each system, and 3 L of water was used to rinse the buckets. The outlet of each filter was sampled with autosamplers at intervals ranging from 6 to 36 h depending on the stage of the study and the outlet Br concentrations.

Outlet Br concentrations were determined using ion chromatography. A filtration sample processor (Metrohm 788) was used, followed by injection into a Metrohm 761 Compact Ion Chromatograph. Standard curves were created using 1, 5, 10, 25, and 50 mg L^{-1} Br concentrations in deionized water, with quality control tests run every 10 samples. The method detection limit was 0.105 mg L^{-1}.

Data Analysis

Cumulative flow was tallied daily for each C2r based on the datalogger readings from calibrated tipping buckets. Using these totals, average daily flow statistics were calculated on a monthly basis. Some flow data were lost due to equipment malfunction. Daily data were deemed unsuitable for averages if they did not have 24 h of tipping bucket measurements. Monthly statistics were computed using flow data from months with >14 d of data.

Mean residence times for each C2r were calculated based on the Br effluent concentrations measured in the tracer study. Residence time distribution curves were constructed, and mean residence time was calculated using a moment analysis (Fogler, 1992) with a Quadrature Formula integration technique (even N, with N+1 points) for the moment analysis.

Descriptive statistics were calculated using Microsoft Excel for the gravity-fed system (pre- and postfilter installation) and for the dosed system. Performance comparisons were made between the dosed system and each condition of the gravity-fed system (with and without STE filter). To compare performance between the C2rs, several statistical tests were performed. The first tests were two-sample t tests (unequal variances) performed on the outlet concentrations for each parameter. For these tests, the null hypothesis chosen was that both fields performed similarly, and the alternate hypothesis was that the gravity-fed C2r resulted in lower outlet concentrations. Statistical F-tests were performed on each parameter's outlet concentrations using the null hypothesis that both fields have similar variances and the alternate hypothesis that the gravity-fed system is less variable. For the t tests and the F-tests, 95% statistical confidence was sought.

Results and Discussion

Hydrology

Outflow from the gravity-fed C2r averaged 456 L d^{-1}, whereas the dosed system averaged 441 L d^{-1}. Statistical t tests with 95% confidence were applied to verify that these averages were not significantly different, demonstrating that the two systems received similar water volumes.

Figure 3 displays the effluent Br concentrations from the 2011 tracer study on the gravity-fed and dosed C2rs. Based on these concentrations, the calculated mean residence time (t_m) for the gravity-fed C2r was approximately 288 h, whereas the dosed system had a calculated t_m of approximately 249 h. From inspection of Fig. 2 and the calculated t_m values, bromide concentrations in the dosed system peaked slightly earlier and trailed off faster than within the gravity-fed system.

Although a longer retention time was expected from the dosed system, water in the gravity-fed system was retained for about 10 h longer. This may be due to the fact that the dosed system, which receives large pulses of wastewater as compared with the gravity-fed system, acts more like a plug flow reactor, producing less dispersion of solutes. Van Cuyk et al. (2001) and Beal et al. (2006) concluded that the hydraulic conductivity of the biomat within a sand filter will also affect the overall retention time of the filter. The higher retention time observed in the gravity-fed C2r may therefore be attributed to a higher degree of biomat growth causing a lower hydraulic conductivity. The shorter retention time

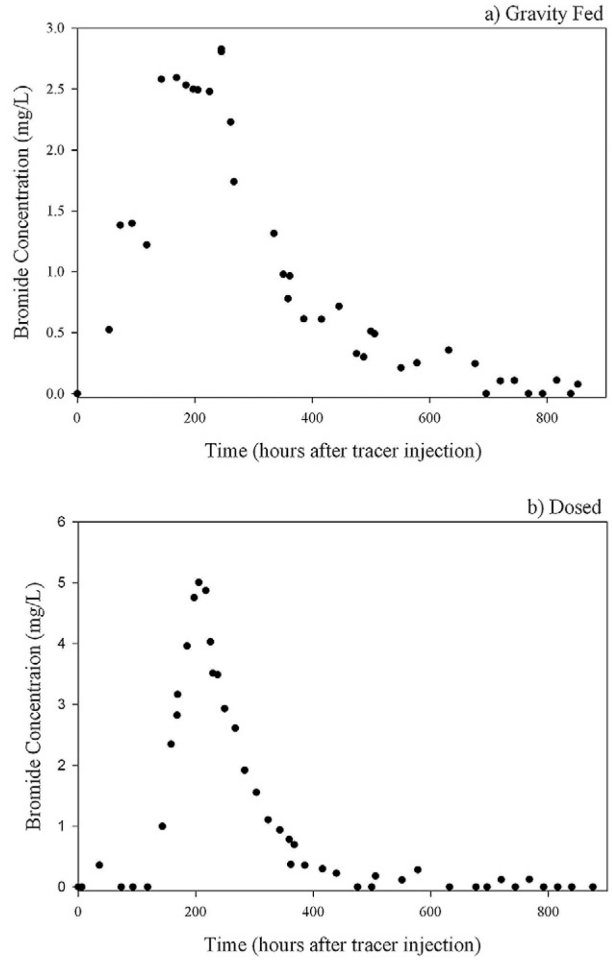

Fig. 3. Bromide tracer study results for the gravity-fed Type 2 Raised Contour Trench (C2r) (a) and the dosed C2r (b).

observed in the dosed C2r could therefore be a result of lesser biomat development. The periodic dosing regime would allow the distribution trench to drain and become aerated, leading to greater degradation of carbonaceous materials.

As biomats within both systems progressively developed, ponding of water was observed in the distribution trench of both systems; however, the presence of ponded water in the distribution trench of the dosed system was only observed sporadically. This is potentially due to sampling strategy; the dosed system was dosed only twice daily, so observations were influenced by the time difference between the sample collection and the last dosing event. When ponding was observed in the dosed system, it was generally exclusive to the central observation well (at the junction with the STE pipe).

The gravity-fed system experienced hydraulic failure within the first year of wastewater loading. After the trench was remediated and an STE filter installed in June 2009, ponded water depths began to increase again (Fig. 4). Generally, the greatest ponding was observed in the well closest to the STE pipe, but ponding in the other two wells was similar. Attempts were made to identify relationships between ponded water depth in the gravity-fed C2r and treatment performance. It was hypothesized that treatment performance would be positively correlated with ponded water depths due to enhanced filtration and biological treatment within the biomat. However, no clear relationships were observed, possibly due to the fact that the system was able to achieve very good pollutant removal throughout the monitoring period.

Treatment Performance

Table 1 summarizes and provides a comparison of treatment performance results from the two gravity-fed system conditions and the dosed C2r. For each system, Table 1 shows the average effluent concentration and the average concentration reduction. Outlet concentrations are also used to rate each system according to the BNQ criteria. Average effluent concentrations for the gravity-fed system (with and without STE filter) were compared with the dosed system based on two-sample *t* tests, and if one system was found to be significantly ($p < 0.05$) lower than the dosed system, it was noted with a superscript.

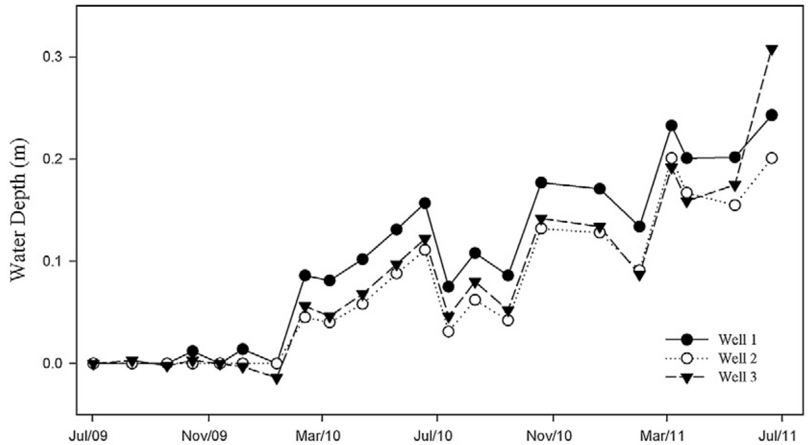

Fig. 4. Water depth in three observation wells located in the distribution trench of the gravity-fed system. The distribution trench was remediated in June 2009 after hydraulic failure was observed in March 2009.

The average STE concentrations entering the C2rs are shown in Table 2. Average concentrations of all parameters entering the gravity-fed systems appear greater after the STE filter was installed, but this difference was not statistically significant. This increase seems counterintuitive because the filter is designed to

Table 1. Average effluent concentrations from three C2r configurations and their tier based on the Bureau de normalization du Québec classification system.

Parameter†	Gravity (n = 9)‡	Gravity w/STE§ filter (n = 17)	Dosed (n = 29)	BNQ¶ Tier	
				Highest class	MAC#
Escherichia coli, CFU per 100 mL					
Outlet	1.6	2.1	2.7	D-II	200
Log reduction	6.0	6.0	5.6		
TSS, mg L^{-1}					
Outlet	2.1††	2.3††	3.3	B-IV	10
% Reduction	98.5	99.3	95.0		
BOD_5, mg L^{-1}					
Outlet	2.4	2.4	2.5	B-IV	10
% Reduction	98.5	99.0	98.0		
TP, mg L^{-1}					
Outlet	0.05††	0.13††	0.31	(dosed) P-I; (gravity) P-II	1.0
% Reduction	98.5	96.8	90.1		0.3
SRP, mg L^{-1}					
Outlet	0.10††	0.12	0.17		
% Reduction	91.2	95.4	91.0		
NH_3–N, mg L^{-1}					
Outlet	0.17	0.40	0.57		
% Reduction	99.1	98.0	97.1		
TKN, mg L^{-1}					
Outlet	0.57††	1.03	1.27		
% Reduction	97.9	97.5	95.5		
NO_3–N, mg L^{-1}					
Outlet	9.89	7.04	8.09		
TN, mg L^{-1}					
Outlet	10.46	8.07	9.36	N-I (post-filter gravity: N-II)	50% reduction
% Reduction	67.0	79.9	69.4		75% reduction

† BOD_5, 5-d biochemical oxygen demand; CFU, colony-forming units; SRP, soluble reactive phosphorus; TKN, total Kjeldahl nitrogen; TN, total nitrogen; TP, total phosphorus; TSS, total suspended solids.

‡ n = number of samples; mean values are arithmetic, except total coliforms and *E. coli* (geometric).

§ Septic tank effluent.

¶ Bureau de normalization du Québec. Data adapted from BNQ (2009).

Maximum allowable concentration.

†† Average values found to be significantly lower ($p < 0.05$) than dosed values.

Table 2. Average concentrations within septic tank effluent entering the disposal fields

Parameter†	Gravity	Gravity w/STE‡ filter	Dosed
Escherichia coli, CFU per 100 mL	1.7×10^6§	1.9×10^6	1.0×10^6
TSS, mg L^{-1}	180.5	440.2	94.5
BOD_5, mg L^{-1}	239.9	332.5	153.7
TP, mg L^{-1}	4.3	5.1	3.8
SRP, mg L^{-1}	1.9	2.9	2.5
TKN, mg L^{-1}	35.8	43.2	34.2
NH_3–N, mg L^{-1}	25.3	26.5	25.8
NO_3–N, mg L^{-1}	0.1	0.1	0.1
TN, mg L^{-1}	35.9	43.3	34.3

† BOD_5, 5-d biochemical oxygen demand; CFU, colony-forming units; SRP, soluble reactive phosphorus; TKN, total Kjeldahl nitrogen; TN, total nitrogen; TP, total phosphorus; TSS, total suspended solids.

‡ Septic tank effluent.

§ Mean values are arithmetic, except total coliforms and *E. coli* (geometric).

prevent the passing of larger particles. However, the increase is primarily attributed to fluctuating sewage quality supplied by the municipal sewer. The average STE concentrations were skewed by a few elevated values. It was also noted that STE concentrations were generally lower in the dosed system, but, again, they were not statistically different from STE values from the gravity-fed system. This difference was not unexpected because septic tank hydraulics within the dosed system would be different from those within the gravity-fed system. The strength of the effluent leaving each the septic tanks was strong: average concentrations of TSS and BOD_5 were close to, or slightly exceeded, the upper ranges typical for STE as presented by Crites and Tchobanoglous (1998).

Statistics on average *E. coli* outlet concentrations are shown in Table 1. The dosed system appeared to have a higher average outlet concentration than both gravity-fed configurations, but this could not be confirmed with 95% confidence. Both gravity-fed configurations achieved greater log removal (6.0 compared with the dosed system at 5.6) of *E. coli*; this was assumed to be due to the greater biomat growth in the gravity-fed system than in the dosed system.

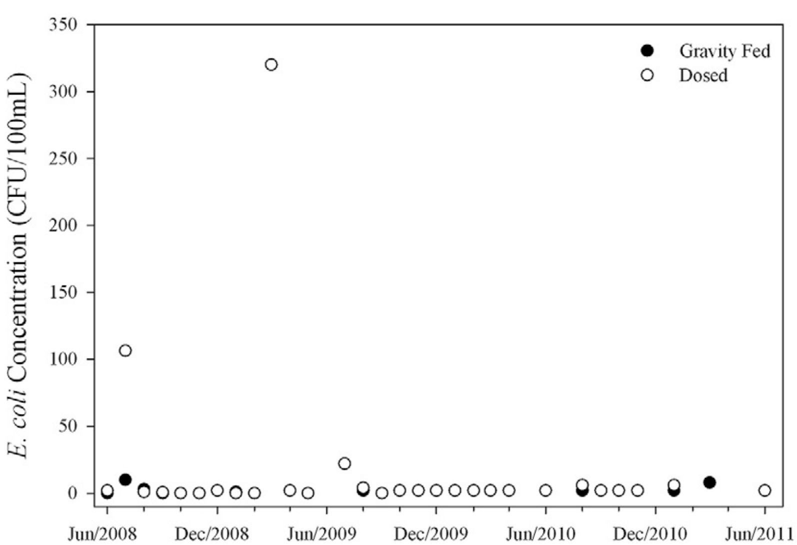

Fig. 5. Average effluent concentrations of *Escherichia coli* during the monitoring period. CFU, colony-forming units.

Effluent *E. coli* concentrations from both systems remained relatively consistent throughout the study. However, significantly less variability was observed in measurements from the gravity-fed C2r than the dosed system. This was due to several outliers observed from the dosed system during the biomat lag growth phase because variability in effluent *E. coli* concentrations was minimal over the final 15 observations (Fig. 5).

Regarding TSS, the gravity-fed system outperformed the dosed system, resulting in significantly lower effluent concentrations under unfiltered (2.1 mg L^{-1}) and filtered (2.3 mg L^{-1}) arrangements (Table 1). The dosed system generated an average effluent concentration of 3.3 mg L^{-1}. Both the gravity-fed C2r configurations also had higher average reductions in TSS. The filtered C2r performed best at 99.3% removal, followed by the unfiltered gravity-fed system at 98.5%. The dosed system, although with a lower removal, still resulted in a 95% reduction. These results provide more evidence that greater biomat formation provides increased contaminant removal.

F-tests showed outlet TSS concentrations from the dosed C2r to be significantly more variable than either of the gravity-fed system configurations (filtered and unfiltered). This can be seen in Fig. 6, where the whisker bars (representing maximum and minimum values) show a larger range of outlet TSS concentrations from the dosed system.

Outlet TSS concentrations for the gravity-fed system were initially low during the first year of the study (without the STE filter) and remained low and relatively consistent after the filter was installed (Fig. 7). By comparison, concentrations from the dosed system were initially high, and it took approximately 5 mo for the dosed system to achieve levels comparable to the gravity-fed C2r. This is likely due to the less favorable conditions for biomat accumulation found in the dosed system. The steady supply of nutrients and organic material and the wet conditions provided by the gravity-fed system resulted in a shorter start-up period.

Both systems produced effluent BOD_5 concentrations that were consistently less than 5 mg L^{-1}, which is consistent with literature on the subject, confirming the suitability of contour trenches for biochemical oxygen demand removal (Jantrania and Gross, 2006). A comparison of the two C2rs could not confirm with 95% confidence that effluent BOD_5 concentrations were different among any of the C2r configurations. Percent removal of BOD_5 was greater than 98% for all three C2r configurations. Variability in the outlet concentrations of the dosed system appeared greater than either gravity-fed C2r configuration (Fig. 6); this was confirmed with the F-test.

It was confirmed with 95% confidence that the dosed system resulted in a significantly higher mean TP concentration (0.31 mg L^{-1}) when compared with the unfiltered gravity-fed C2r (0.05 mg L^{-1}) and the filtered gravity-fed C2r (0.13 mg L^{-1}) configurations (Table 1). Greater treatment performance could be attributed to a number of factors. The gravity-fed system possessed a longer residence time and greater biomat growth. It is also

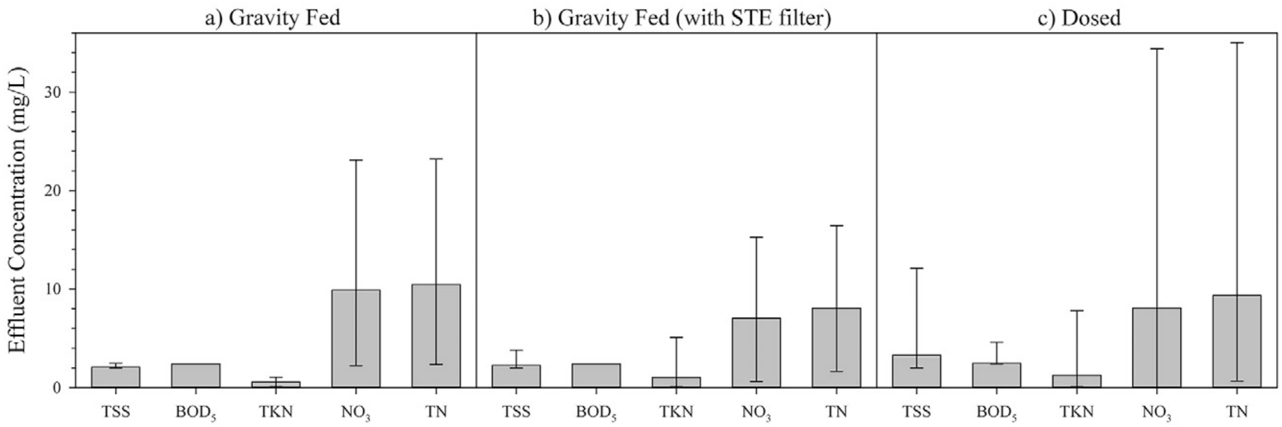

Fig. 6. Average effluent concentrations for select parameters with maximum and minimum observed values for a gravity-fed Type 2 Raised Contour Trench (C2r) (a), a gravity-fed C2r with septic tank effluent (STE) filter (b), and a dosed C2r (c). BOD_5, 5-d biochemical oxygen demand; TKN, total Kjeldahl nitrogen; TN, total nitrogen; TSS, total suspended solids.

possible that preferential flow was more predominant in the dosed system due to the nature of wastewater loading. In addition to possessing higher outlet concentrations, the dosed C2r TP and soluble reactive P concentrations were also significantly more variable than either gravity-fed C2r configuration.

Total P effluent concentrations increased in both systems over the course of the study (Fig. 8). This is consistent with literature reviewed by Cucarella and Renman (2009), which showed that on-site disposal fields have a finite P sorption capacity and that removal efficiencies will progressively decrease with time as sorption sites are depleted. However, TP removal was very good in both systems during this study period, with all system configurations achieving percent reductions of >90%. Based on these monitoring results, the gravity-fed system would achieve a better treatment classification according to the BNQ guidelines (Table 1).

Although mean NH_3–N concentrations from the dosed C2r were higher (Table 1), *t* tests could not show with 95% confidence that the effluent concentrations from the dosed system were significantly greater than that from the gravity-fed C2r. The gravity-fed C2r produced an average 99.1% removal of NH_3–N before the STE filter was installed. Although this fell to a 98% reduction once the filter was installed, it remained slightly higher than the 97.1% reduction produced by the dosed system. The slightly better performance by the gravity-fed system may be due to biomat development, resulting in a larger colony of nitrifying bacteria. It could also be due to longer retention time observed within the gravity-fed C2r. As has been observed with other water quality parameters, F-tests showed that the dosed C2r produced significantly higher variability in outlet concentrations than the unfiltered gravity-fed C2r.

The average TKN outlet concentrations are shown in Table 1. Effluent concentrations from the unfiltered gravity-fed C2r were significantly lower than the dosed system; however, effluent concentrations from the filtered gravity-fed system were not statistically different from the dosed system. Effluent TKN concentrations from the dosed system were also significantly more variable than the unfiltered gravity-fed system but not the filtered gravity-fed system

Nitrate-nitrogen was the only parameter to show an increase in concentration across the disposal fields. In both systems, outlet NO_3–N concentrations exceeded inlet concentrations (Table 1); therefore, removal rates were not calculated. This was expected because nitrification of NH_4–N to NO_3–N by bacteria is associated with aerobic conditions, and raised C2 contour trenches are designed to operate under such conditions (Jantrania and Gross, 2006). The greatest increase in NO_3–N concentration (at 10.8 mg L^{-1}) was observed in the unfiltered gravity-fed C2r. In comparison, the filtered gravity-fed C2r produced the smallest increase (6.9 mg L^{-1}). The mean and variance of effluent NO_3–N concentrations in effluent from all three systems were not statistically different from one another.

As a combination of TKN and NO_3–N, total nitrogen (TN) is affected by the removal and production rates of either component. Even though over 95% removal of TKN was observed from all the C2r configurations, the production of NO_3–N led to a lower TN reduction, ranging from 67 to 80%. No significant differences in mean or variance were observed

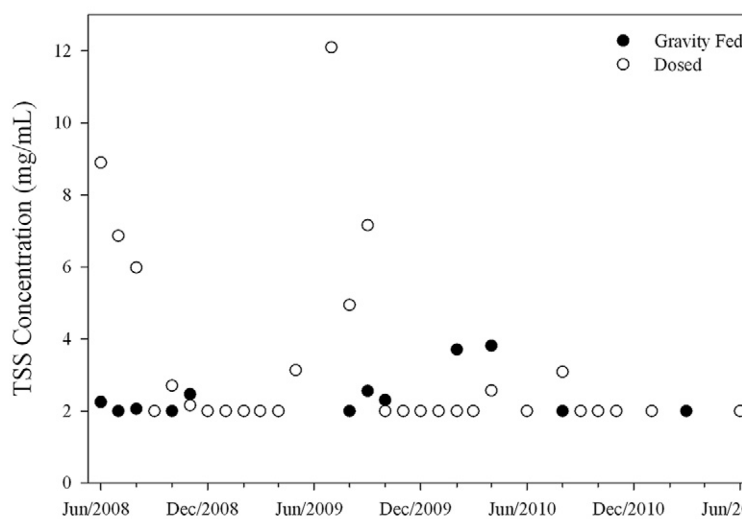

Fig. 7. Average effluent concentrations of total suspended solids (TSS) during the monitoring period. Detection limit is 2 mg L^{-1}.

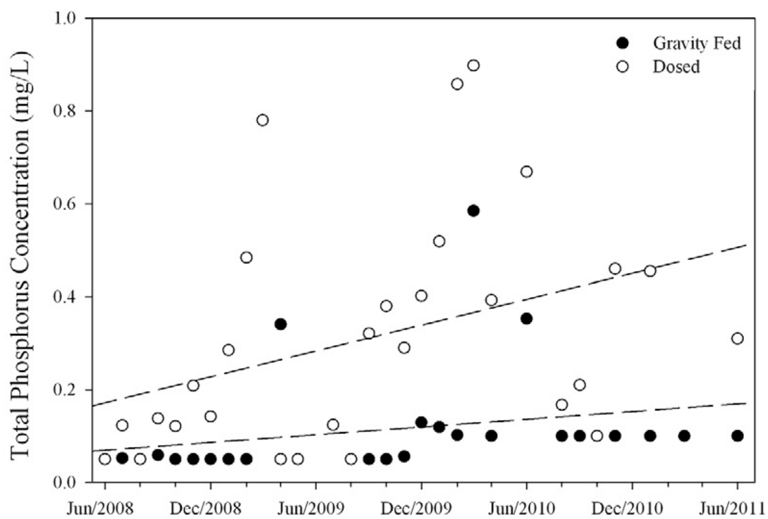

Fig. 8. Average effluent concentrations of total phosphorus during the monitoring period. The dashed lines represent linear regressions (Dosed: $y = 0.00037x - 13.17$ [$r^2 = 0.22$]; Gravity: $y = 0.00011x - 4.09$ [$r^2 = 0.10$]).

between C2rs, although the dosed system produced a larger range of effluent TN levels (Fig. 6).

The increase in NO_3–N concentration suggests that nitrification is a dominant process within the C2r systems. The removal of TN is likely the result of ammonia volatilization and/or denitrification by bacteria (McCray et al., 2005) because the filter sand would not have the clay content to support ammonia sorption through ion exchange (Rožić et al., 2000). Although denitrification is an anaerobic process, nitrogen removals between 30 and 50% can result from intermittent stagnation sites lacking oxygen (Jantrania and Gross, 2006). The >65% removal of TN observed in this study suggests that there are zones of anaerobic conditions promoting denitrification.

Bureau de Normalization du Québec Classification

Nova Scotia Environment's On-site Sewage Disposal Systems Regulations do not include guidelines regarding expected effluent quality from on-site wastewater disposal systems (Nova Scotia Environment, 2007). However, the BNQ has developed a tiered system to classify on-site wastewater technologies based on performance (BNQ, 2009). These tiers fall within four types of treatment: basic, disinfection, phosphorus, and nitrogen. The basic and disinfection treatments (abbreviated B and D, respectively) contain four and three classes, respectively, with higher classes achieving better treatment performance. Phosphorus and nitrogen treatment (abbreviated P and N, respectively) is broken into two classes.

Table 1 shows the BNQ classes into which both C2rs fall. Both C2rs fall into the highest class of basic treatment (B-IV) because both produce effluent concentrations less than the maximum allowable concentration for TSS and BOD_5 (10 mg L^{-1}). Both systems met the requirements for D-II classification for *E. coli* (<200 colony forming units per 100 mL). Only the gravity-fed system achieved P-II classification because it produced to average TP effluent concentrations below 0.3 mg L^{-1}. The dosed system was only slightly above the threshold but still fell into the P-I class. Only the gravity-fed C2r with the STE filter achieved the 75% TN reduction necessary for N-II classification. Without the filter, the same system achieved N-I class. Similarly, the dosed system meets the requirements for N-I classification.

Although effluent quality was relatively consistent over the course of the study, elevated pollutant concentrations were observed in both C2rs in March 2010. Review of daily flow data showed that 12 d before the sample was taken (slightly greater than one residence time period), an 11-mm rainfall event occurred. This rainfall event, combined with snowmelt due to consistent 0 to 5°C temperatures, resulted in outflows from the fields 6 to 8 times higher than baseline levels. It is probable that such high flows dramatically decreased retention times in both systems, leading to poorer treatment.

This observation indicates that climate and hydrological conditions must be concurrently monitored and assessed during treatment performance trials for disposal field–type wastewater systems. This type of monitoring is essential to understand how external hydrologic inputs influence effluent quality. Sampling strategies should be designed to capture a representative number of baseline and hydrological event-based samples.

Conclusions

This study demonstrated that the effluent loading method for a typical contour trench disposal field will influence the hydraulic behavior and treatment performance of the system. From a hydraulic performance perspective, this study provides strong evidence that dosed disposal fields have less biomat accumulation and are therefore less prone to hydraulic failure. Furthermore, both systems performed similarly in terms of effluent water quality.

Due to budgetary and logistical constraints, it was not possible to construct and operate replicates for each type of loading regime, which was a limitation of this study. Additional field-scale studies are needed to further confirm the positive benefits of periodic dosing of disposal fields. In the future, the use of more intensive monitoring during hydrologic events is recommended to better understand how external hydraulic inputs influence contaminant breakthrough. However, the findings of this paper provide scientific support for design and best management practices for on-site wastewater disposal systems. The results from this study have also demonstrated that properly constructed onsite wastewater disposal systems can provide adequate treatment required to prevent contamination of surface and groundwater even when using systems with periodic loading to avoid hydraulic failure.

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