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Performance Expectations of Ontario Sand Filters & Proprietary Absorbent Filter 'Area Bed' Systems

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Introduction

Sand 'Filter Beds' have been treating septic tank effluent in Ontario since their introduction by the MOE in the early 1980s, and have been transferred to the Ontario Building Code ('OBC') in Subsection 8.7.5. as an acceptable benchmark that is presumed safe. Sand Filter Beds installed under the OBC are not routinely sampled and there is no requirement for maintenance contracts. Therefore, there has been no opportunity to determine their performance under installed conditions or their impact on the groundwater resource.

In contrast, the performance of proprietary absorbent filter systems that use sphagnum peat or open-cell foam (Jowett and McMaster, 1995; Talbot *et al.*, 1998), which are maintained through on-going management contracts (*e.g.*, Ouellet *et al.*, 2000) is better known.

The validity of 'presumptive compliance' implicit in prescriptive codes like the OBC can be examined, however, first by summarizing the quality of effluent obtained during original testing of the under-drained sand filters by Chowdhry (1974), and second, by comparing the tested configuration with actual installed OBC Filter Bed systems. This way, 'performance expectations' can be estimated for OBC Filter Bed systems and compared to performance-based proprietary systems, with a view to evaluating relative health and safety risks and to minimizing those risks.

This paper describes the scientific development and thorough testing of Filter Beds by the Ministry of the Environment ('MOE') and their subsequent adoption in prescriptive building codes. The under-drained Filter Beds tested provide the benchmark for presumed treatment effectiveness, especially for fecal coliform bacteria used as an indicator of human pathogens. In this paper, the tested configurations are compared to field installations of OBC Filter Beds, and to similar proprietary biological filters tested by third-party agencies. Levels of pathogens exiting the OBC Filter Beds may be predicted, and using OBC vertical separation distances, what is entering the groundwater resource may be estimated. Finally, we comment on whether expectations of presumed compliance are being met, and how fecal removal might be optimized.

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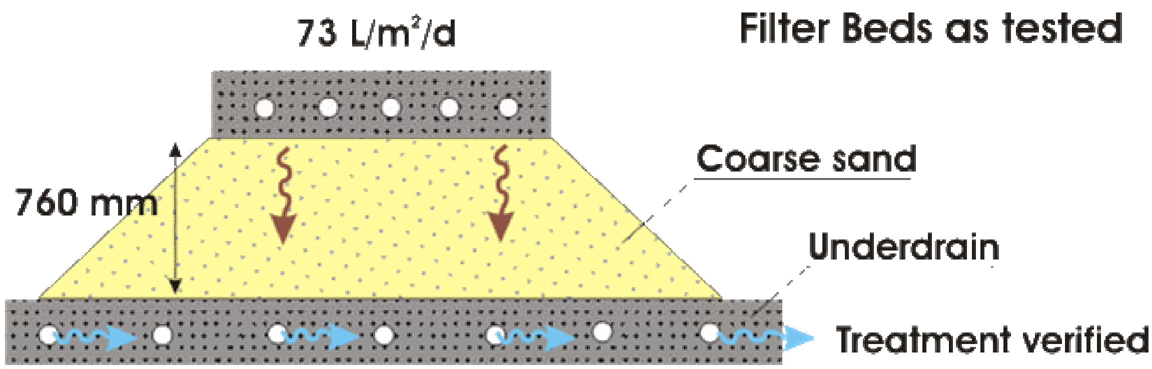
Development of 'Whitby' Sand Filter

The MOE tested Filter Beds using six different types of sand from 1969 to 1973 using sewage from the Whitby psychiatric hospital. Hence, this testing is referred to as the 'Whitby' sand Filter Bed testing (Chowdhry, 1974). This research was well ahead of its time in North America, perhaps by 15-20 years. One of the sands was mixed with 'red mud' for phosphorus removal. Only the other five clear sands tested at Whitby are of interest here, as they form the basis for the filter sands prescribed in OBC Sentence 8.7.5.3.(3).

The Whitby sand Filter Beds were constructed in boxes 3.05 m by 3.66 m in plan view and 0.76 m in depth. They were fed at rates of 24, 49, and 73 L/m^2/day by 'trickle' and 'time-dosed' flush flow through three 2.4-m lengths of 100 mm perforated pipes set 1.2 m apart within crushed stone. Under-drain pipes at the base of the 760-mm thick sand kept the filters free-draining, and collected the effluent for sampling before being discharged to a tile bed (Figure 1).

Figure 1. Schematic of Whitby Filter Beds as tested by Chowdhry (1974), with under-drain to keep the sand filter free-draining to ensure treatment.



Test Results of Free-Draining Whitby Filter Beds

Chowdhry (1974) details the extensive MOE biochemical study which shows that the sewage was filtered to a very high degree. Median BOD and SS values (carried out at MOE Laboratory and assumed standard MOE cBOD & TSS) were <10 mg/L with all sand grades, and usually <5 mg/L. Septic tank effluent was fairly weak, in part due to infiltration into the septic tank, with average medians of only 97 mg/L BOD, 61 mg/L SS, and 19 mg/L total nitrogen. No total nitrogen was removed, despite the high rate of nitrification typically evident after 11-19 months operation.

Removal of fecal coliforms is an indication of basic health and safety (Table 1). The results obtained at the Whitby sand Filter Bed study (carried out at Public Health Laboratory) clarify the fundamental controls necessary for lower fecal content, being: (a) lower loading rates (*e.g.*, 49 L/m^2/d rather than 73 L/m^2/d), especially when the sand is coarse, (b) finer grained sand, (c) biological aging or maturing of the filter, and (d) gravity trickling rather than timed (pump) dosing, especially when the sand is coarse. The finer Sands 2 and 4 were shown to be capable of accepting both increased loading rate and pump-dosing with little effect on fecal removal. However, coarser Sands 5 and 6 were shown to be negatively affected by increased loading rate and especially by time-dosing. Effluent fecal content does not appear to be affected by septic tank content.

Table 1. Characteristics of sands treating septic tank effluent, and fecal coliform values (cfu/100mL) exiting the Whitby sand Filter Beds (Chowdhry, 1974). During Period I (and Period II in part), the sand Filter Beds were loaded at 49 L/m^2/day and in later periods, at 73 L/m^2/day. During Period IV, the sand Filter Beds were time-dosed to simulate siphon or pump dosing. Each sand filter was sampled ~185 times over the four Periods, and the values reported here are the medians of samples taken in each Period.

Effluent Source	Sand 'k' conductivity cm/s	Sand 'T' time min/cm	Period I *49 L/m^2*	Period II **73 L/m^2** *49 L/m^2*	Period III **73 L/m^2**	Period IV **73 L/m^2** time-dosed
Sand 4	2.6e^{-2}	3	*1500*	*290*	**430**	**1700**
Sand 2*	9.0e^{-2}	2	*10,000**	**3500***	**1850***	**2050***
Sand 3	3.4e^{-1}	1	*4400*	**6200**	**4400**	**27,100**
Sand 5	9.6e^{-1}	0.5	*7000*	*3000*	**6500**	**73,000**
Sand 6	4.8e^{0}	0.1	*38,000*	*31,000*	**36,000**	**241,000**
Septic tank	-	-	800,000	2,200,000	2,600,000	1,047,000

* Note: Sands 2 and 4 are similar in grain size, so Sand 2 is omitted from calculations.

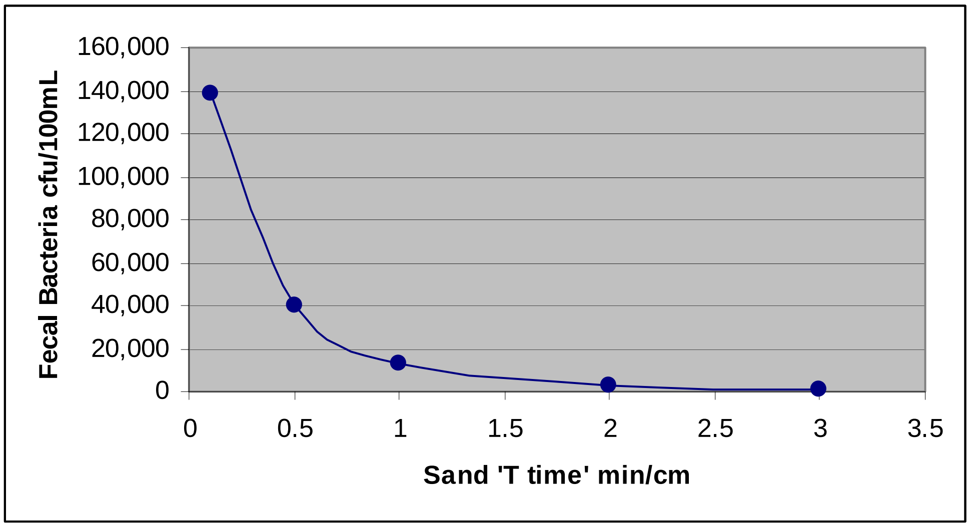
OBC Filter Bed Performance Expectations

A 'best guess' fecal value exiting the typical OBC Filter Bed can be estimated by averaging the median values from filter Sands 4, 3, 5 and 6 as tested at the Whitby test facility. Sand 2 plots very close to Sand 4 on the grain size distribution graph described in OBC Sentence 8.7.5.3.(3), and because this duplication would bias a 'best guess' of actual installed systems, Sand 2 is excluded from these calculations.

Calculated values from the four Whitby sand Filter Beds are ~12,000 cfu/100mL for the seven values at 49 L/m^2 daily loading and ~44,000 cfu/100mL for the nine values at the higher 73 L/m^2 rate. An alternative method is to include all five sand types from Periods III and IV dosed at 73 L/m^2 to give a 'best guess' of ~40,000 cfu/100mL. These values are the fecals that can be expected at 750 mm depth with an underdrain installed; the OBC requires an additional 150 mm of vertical separation between this level and water table.

Figure 2 shows expected values for each of the different grain sizes tested. The finer the sand, the better the fecal removal, but the risk of hydraulic failure by anoxic biomat clogging by septic tank effluent is greater. Extrapolating the line out to T = 6-10 min/cm sand predicts the thorough removal of fecals when dosing proprietary filter-treated effluent onto finer 'Area Bed' sand, described below.

Figure 2. Average of fecal coliform median values expected at the 760 mm level of under-drained Filter Beds 6, 5, 3, 2, and 4 loaded at 73 L/m^2/day (excluding all 49 L/m^2/day results) with respect to percolation rates allowed in OBC Sentence 8.7.5.3.(3) (from Chowdhry, 1974). The average of Sands 6, 5, 3, and 4 that better represent the range of sands allowed in the OBC is about 44,000 cfu/100mL or ~40,000 for all five samples dosed at 73 L/m^2/day in Periods III and IV (see text).

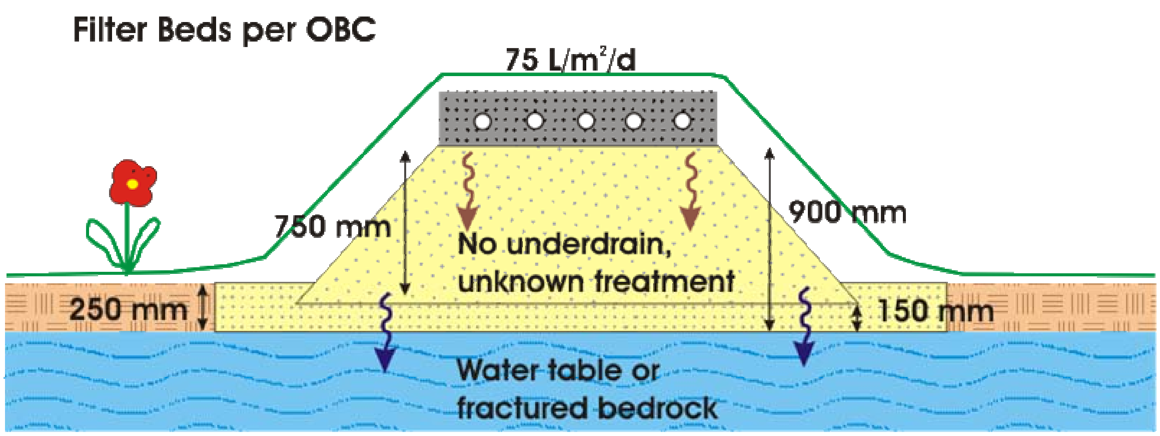


With most design flows in Ontario being ≤3000 L/d and therefore loaded at 75 L/m^2/d, the expected fecals at 750 mm depth in an under-drained Filter Bed is ~40,000-44,000 cfu/100mL (or 96% removal). If the installer chooses a fine sand like Sand 4, the fecal content might fall to ~1000 cfu/100mL (Figure 2). However, as noted above, a Filter Bed that is 750 mm thick and comprised of finer sand carries a greater risk of premature clogging by anoxic biomat from untreated septic tank effluent. If the installer chooses the coarser Sand 6 to avoid premature clogging from septic tank effluent, the 'best guess' can range up to 241,000 cfu/100mL when dosed by siphon or pump (Table 1), but again, only if there is an under-drain.

Chowdhry (1974) concluded that "under-drained filters … are considered effective in treating septic tank effluent" (p. 40). Nothing is said about filters without under-drains, because these were not tested. Under-drains have been the hallmark of intermittent (single-pass) sand filters for more than 100 years, and typically the effluent is collected and sent to an in-ground disposal means (Crites and Tchobanoglous, 1998; Ch. 11). OBC Sentence 8.7.5.3.(4) requires that the "filter medium shall be unsaturated for its entire depth", but does not require under-drains to be installed (Figure 3).

To comply with this OBC requirement and with Chowdhry's conclusion with respect to 'under-drained filters', a natural under-drain would only be established if the sand Filter Bed were installed on coarse soil of perhaps T<10 min/cm (or on fractured bedrock). If ‘unsaturated’ and ‘under-drains’ are mentioned for a purpose, then it is reasonable to assume that the Filter Bed would best perform its treatment function when installed only in or on soils that are highly permeable.

Figure 3. Raised Filter Beds are installed in high-risk areas such as high water table and fractured bedrock without under-drains. Under the OBC, only 150 mm of fast, coarse sand may separate the bottom of the sand Filter Bed (which yields 40,000-44,000 fecals or more) from the groundwater resource.



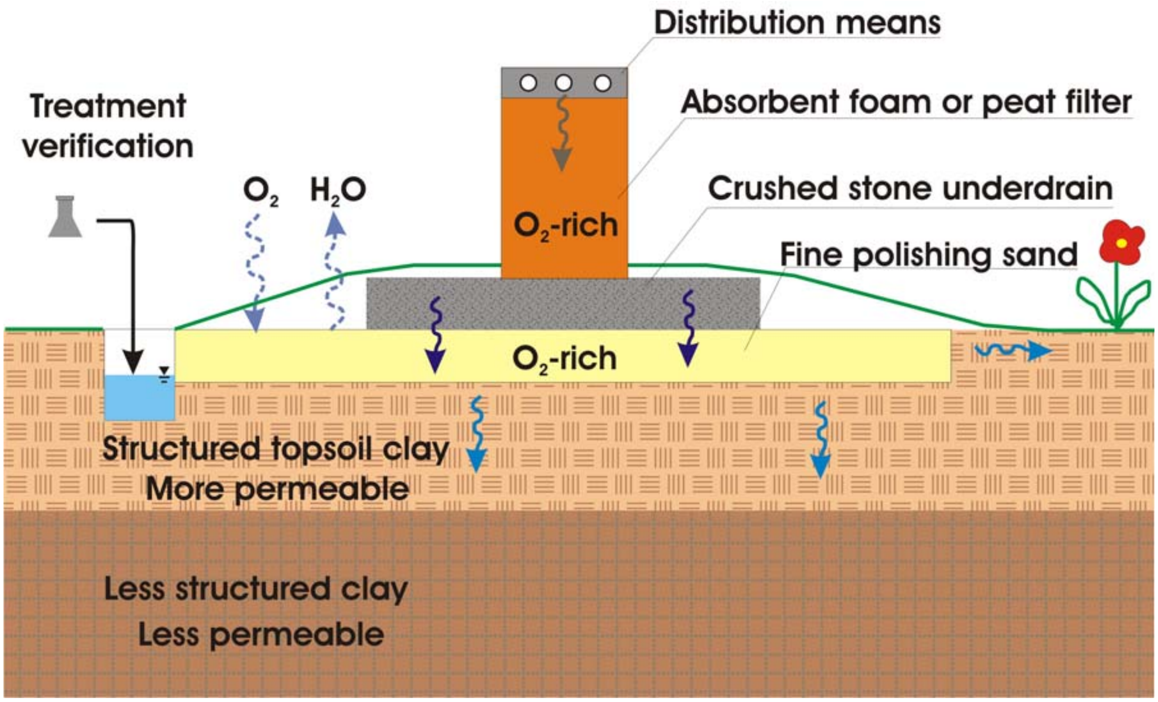
How do we predict the fecal contamination of the groundwater supply from Filter Beds as installed in Ontario? Two years of pan lysimeter sampling at the EPA-sponsored Buzzards Bay test facility shows that 300 mm of coarse sand (T = 0.8 min/cm) reduces 14,600 cfu/100mL fecals in foam-filtered effluent to 265 cfu/100mL at a loading rate of 80 L/m^2/day (Heufelder, 2003). OBC sand Filter Beds as installed in Ontario have three times the fecals (40,000-44,000 cfu/100mL) below the Filter Bed when loaded at 75 L/m^2/day (Figure 3) with only half that vertical separation (150 mm) between the bottom of the OBC Filter Bed and groundwater. Therefore, in the case of OBC sand Filter Beds, the groundwater would likely receive 1500 cfu/100mL fecals or more. Without an under-drain, or with coarser sand, or with pump-dosing, all of which are allowed under the OBC, the water contamination would likely be much higher.

Proprietary Absorbent Filter Systems – Separate Filtration and Shallow Disposal

In the early to mid-1990s, shallow Area Beds were field tested in Ontario and Quebec for disposal of filtered effluent from Ecoflo (peat) and Waterloo (foam) proprietary absorbent filters (Figure 4). (The rationale for physically detaching the filter-treatment function from the disposal-polishing function by inserting a gravel underdrain is detailed in Jowett and Masuy (2006).) These proprietary absorbent filters, loaded at higher rates than sand, were shown to be capable of maintaining performance without clogging from the anoxic biomat of septic tank effluent (Jowett and McMaster, 1995;

Talbot *et al.*, 1998). The filters in question are dosed by uniform distribution means, and, very importantly, installed with a gravel under-drain to maintain free-draining conditions.

Figure 4. In this type of system, proprietary filter technology and specifically engineered, sized and oriented Area Beds work together to perform distinct treatment and disposal functions. The filter-treatment component is under-drained and contains sampling points to confirm filter-treatment. The disposal component of the system is comprised of a thin layer of specifically engineered fine sand for dispersal and near-complete fecal removal (from Jowett and Masuy, 2006).



Independent third-party testing of the foam filters show consistent 99.3% removal of fecals to 14,600 cfu/100mL (Costa, 2001; www.buzzardsbay.org/etistuff/results/waterlooresults.pdf). Field results in the 1990s from 12 Waterloo residential and office sites (n = 210 samples) show that fecal removal improves with age from ~10,000 cfu/100mL at 6-12 months of operation to ~6,000 fecals at 12-24 months of operation. Similar Ecoflo >99% fecal removal is reported in Talbot *et al.* (1998).

In heavy clays, the original design of the shallow Area Beds consisted of 250 mm of gravel embedded in the upper 30-50 cm of topsoil, where permeability of the native soil is greatest (*e.g.*, Mokma *et al.*, 2001). The design of the shallow Area Beds was subsequently standardized to include 250-300 mm of finer polishing sand (T = 6-10 min/cm) loaded at 17 L/m^2/day below the gravel (Figure 4). Typically, these systems or others are installed over water table, heavy clay, and fractured bedrock, high risk or difficult areas where raised beds are otherwise required. Additional infiltration area is provided by adjacent permeable topsoil.

Independent testing agencies have found that vertical movement of filtered effluent emanating from the Waterloo and Ecoflo filters through gravel and then 250 mm of the finer sand removes fecals to below detectable even at the much higher loading rates of 106 and 212 L/m^2/day (Heufelder, 2003; Jowett and Masuy, 2006). These tested loaded rates are much higher than the 75 L/m^2/day under the gravel in Area Beds and in OBC sand Filter Beds. Essentially non-detectable (<30 cfu/100mL) levels were also found after 10 m lateral movement through the finer sand at linear loading rates of ≥180 L/m/day (Alfred, 2005), again, similar to Area Beds and OBC Filter Beds when all treated water is directed one way. So these tests equal or exceed actual field conditions in Ontario for the proprietary absorbent filter systems as installed with shallow Area Beds.

Table 2 summarizes fecal fates in high-risk installations where vertical movement predominates, indicating that proprietary Area Beds can be expected to provide a more predictable and safer method of sewage treatment and disposal than the presently implemented OBC Filter Beds.

Table 2. Comparison of filter treatment technologies in Ontario, with most probable number of fecals at the base, the vertical separation to groundwater, sand or soil type below filter, and the estimated fecals entering the natural environment such as groundwater table (‘GW’).

Filter Technology	**Fecals at base of filter (cfu/100mL)**	**Minimum separation to GW (mm)**	**Polishing sand type (min/cm)**	**Estimated fecals in GW (cfu/100mL)**
Tested MOE Filter Bed with underdrain	~44,000 (760 mm depth)	150 (+ 0 mm gravel)	Coarse sand T=0.1-3	~1500
Installed OBC Filter Bed; no underdrain	>>44,000	150 (+ 0 mm gravel)	Coarse sand T=0.1-3	>>1500
Waterloo Area Bed	~10,000	250-600 (+ 250 mm gravel)	Fine sand T=6-10	~0
Ecoflo Area Bed	~10,000	300-600 (+ 200 mm gravel)	Fine sand T=6-10	~0

With OBC sand Filter Beds installed with no gravel under-drain as tested by Chowdhry, no treatment verification, no maintenance, higher fecal content at filter base, very small 150-mm vertical separation of coarse sand to groundwater (Table 2) they are most likely contaminating groundwater far more than proprietary absorbent filter and shallow Area Bed systems. The greater fecal removal ability of the proprietary filters, the presence of a substantial gravel under-drain, as tested, and greater vertical separation with fine sand with proven ability to remove pathogens far better than coarse sand, all improve the quality of effluent entering the natural environment.

After 12 years of experience in Ontario and elsewhere, there are many thousands of Area Beds installed on difficult sites, where sewage is first treated by underdrained absorbent media filtration, and then by fine sand filtration before it enters the natural environment. On-going management is in place, and treatment can be verified before problems from excessive disinfectant use, for instance, become irreversible.

With verifiable filter treatment of sewage, shallow disposal and on-going management, the Ecoflo and Waterloo systems constitute 'sustainable infrastructure' (Rubin *et al.*, 2004) equivalent to managed municipal sewage treatment plants. In comparison, OBC Filter Beds are often installed differently than tested, and have no management. They are presumed compliant by prescription, but as yet cannot be considered sustainable infrastructure.

Conclusions

The performance of installed OBC sand Filter Beds can be estimated from the original MOE test results and provides a minimum standard of safety against which other filter systems may be measured. This analysis demonstrates that fecal removal in the OBC sand Filter Beds is very good overall, but is optimum when; (a) using the finer-grained sands 2, 3, & 4 (percolation of 1-3 min/cm), (b) using a loading rate of 50 L/m^2/day, and (c) installed in free-draining sandy soils (*e.g.*, T<10 min/cm). It is reasonable to suggest that these construction criteria be used when installing Filter Beds.

Independent field testing shows that proprietary Ecoflo and Waterloo Area Bed systems go beyond what is expected in fecal removal, exceeding the performance of OBC sand Filter Beds, and improving on the quality of effluent entering the natural environment. With robust, low-energy filter treatment and on-going management, these systems exemplify a new 'on-site sustainable infrastructure' that is equivalent to centralized municipal sewage treatment plants.

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