ASSESSMENT AND MANAGEMENT OF ENVIRONMENTAL RISKS
ASSOCIATED WITH DECENTRALIZED RURAL WASTEWATER MANAGEMENT SYSTEMS

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CANADIAN WATER NETWORK
RÉSEAU CANADIEN DE L'EAU

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WHY DID WE DO THIS RESEARCH?

In Canada, approximately 20% of the human population rely on on-site wastewater systems (OWSs) to treat their domestic wastewater. Some provinces and regions have even higher percentages of their populations using OWSs, such as Nova Scotia at ~50%. Untreated domestic wastewater, which is a source of pathogens, nutrients and pharmaceuticals, can present a serious environmental and human health risk if it enters surface and groundwater resources. To minimize the potential risks from untreated domestic wastewater entering freshwater resources, most provinces have detailed technical guidelines for the design and installation of OWS to ensure proper treatment. An OWS design typically consists of domestic wastewater leaving the household and entering a septic tank where solids are allowed to settle out. The liquid effluent from the septic tank then enters a disposal field that is constructed using native soils or imported filter media before the treated wastewater is discharged into the surrounding soil profile or to the ground surface. When OWSs are not adequately maintained or are improperly designed and installed this can cause poor treatment performance or surface hydraulic failure (the OWS becomes clogged with solids from the domestic wastewater and untreated effluent then percolates upward to the ground surface).

Leah Boutilier with Nova Scotia Environment stated that "...research findings evaluating treatment performance of OWS that are designed and installed in NS provides confirmation of adequate treatment and robust design, while on-going long-term performance evaluation equals confidence in system design."

One question of interest to the OWS management community relates to the long-term treatment performance of OWS. Leah Boutilier with Nova Scotia Environment stated that "...research findings evaluating treatment performance of OWS that are designed and installed in NS provides confirmation of adequate treatment and robust design, while on-going long-term performance evaluation equals confidence in system design." Examination of the long-term treatment performance of OWSs and when these technologies should be replaced to minimize their environmental and human health risks is required.

The Nova Scotia OWS industry group, Waste Water Nova Scotia Society, is similarly concerned with OWSs, with a

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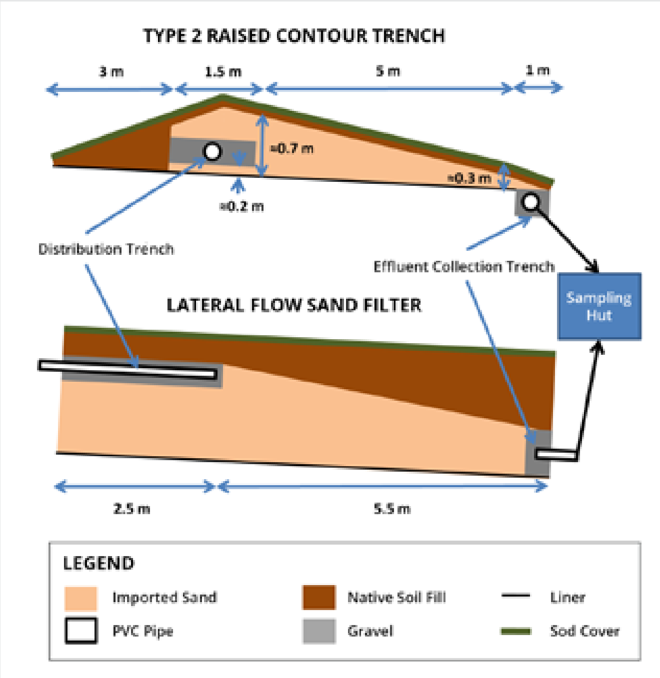
Gary Cameron, Waste Water Nova Scotia Society

particular interest in new and potentially cheaper OWS technologies to be approved for use in the province. The local soil and geologic conditions in Nova Scotia of shallow groundwater tables, bedrock outcroppings, and impermeable soils restrict the types of OWS that can be installed. The majority of approved OWS disposal field designs are constructed using imported disposal field filter media (e.g. sand) and are designed to promote horizontal/ lateral flow through the filter, instead of the more common downward vertical flow direction. The executive director of the Waste Water Nova Scotia Society, Gary Cameron, said that "in Nova Scotia, some of the older developments are very cramped and there is not a lot of space to do anything." Identifying OWS technologies, through field scale research studies, that would provide adequate long-term treatment with smaller footprints and lower installation costs than existing approved technologies would be mutually beneficial to both regulatory bodies and industry.

The issues of OWS design types, maintenance and long-term treatment performance identified by provincial government regulatory bodies and the OWS industry led to the development of the following research questions addressed by this Canadian Water Network (CWN)-funded project:

- What is the long-term treatment performance of various, unique OWS designs used in adverse soil and geologic conditions in eastern Canada?
- Using the results of these treatment performance studies, can we develop and test watershed scale computer modeling tools to assist in evaluating the environmental and human health risks of OWSs and producing appropriate management strategies to minimize those risks?

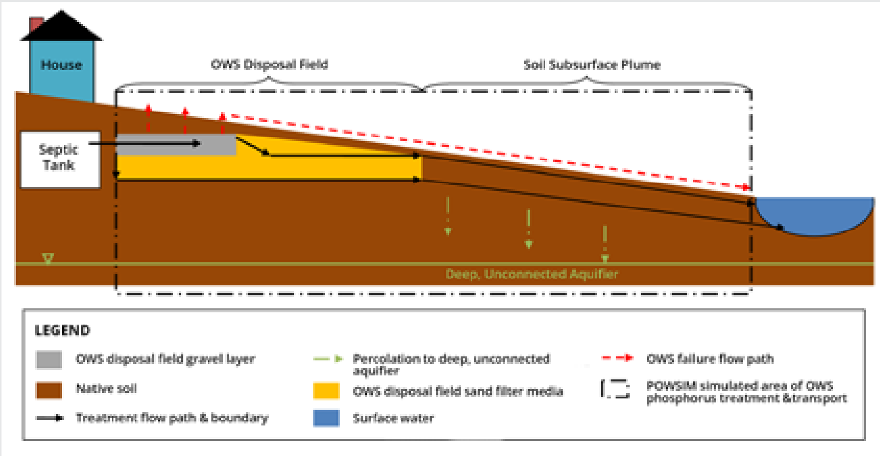
WHAT DID WE DO?



Profile diagrams of field scale Type 2 raised contour trench and lateral flow sand filter designs at the Bio-Environmental Engineering Centre.

To investigate the long-term performance of various, unique OWS disposal field designs, field scale OWS were constructed and monitored, starting in 2004. The research site was located at the Bio-Environmental Engineering Centre located in Bible Hill, NS and operated by Dalhousie University. The OWS technologies examined were lateral flow sand filters (LFSFs), also known as sloping sand filters, and Type 2 raised contour trenches. The field scale OWSs were constructed to be fully contained systems and have controlled inflow rates. There were eight LFSFs constructed that varied in design by drainage slope (5%, 30%), filter length (5.5 m, 8 m) and sand type (fine, medium, coarse). An investigation of the impacts of increasing the LFSF inflow loading rate (95 L day^{-1} to 175 L day^{-1}) on treatment efficiency was completed as well, beginning in 2007. The two Type 2 raised contour trenches differed in influent loading method with one being dosed via a pump at regular intervals and the other being gravity fed. The effluent flow rate for each system was continuously monitored for each of the ten OWS and one day per month influent and effluent water quality samples were collected using an autosampler. The samples were analysed for biochemical oxygen demand, total suspended solids, total nitrogen, total phosphorus and the pathogen E. coli. Tracer studies were conducted to analyze the mean residence time for contaminants.

The results of the field scale OWS monitoring programs were then used to develop two different watershed scale computer modeling tools. The first was a geographic information system (GIS)-based risk assessment tool that uses nine parameters related to OWS design, age, local soil and hydrogeology characteristics, and the contaminant pathways in the soil and surface environments. The GIS-based risk assessment tool was applied to the Huron-Kinslow Township in Ontario to determine what areas were at the highest risk from OWS contaminant loading. The second modeling tool was the phosphorus on-site wastewater simulator (POWSIM), which simulates phosphorus treatment and transport from an individual or cluster of OWS(s) to a neighbouring surface water course. The POWSIM model was used in conjunction with the watershed scale Soil and Water Assessment Tool (SWAT) computer model to simulate phosphorus loading from agricultural land uses and residential OWS in the Thomas Brook Watershed. The Thomas Brook Watershed is a small (~650 ha) mixed land use watershed located in the Annapolis Valley region of Nova Scotia.



Profile diagram of phosphorus treatment processes simulated by the POWSIM model.

WHAT DID WE FIND?

TREATMENT PERFORMANCE STUDIES

The research examining the long-term treatment performance of the eight LFSFs and two contour trenches found that they provided an excellent level of treatment that was equal to or exceeded secondary treatment standards *(Atlantic Canada Standards for the Collection, Treatment, and Disposal of Sanitary Sewage, 2004)*. The eight LFSFs that varied in design by slope, sand type and filter length did not have significant differences in removal rates for *E. coli*, total suspended solids, total nitrogen and biochemical oxygen demand when monitored for a six year period (2004 to 2009). Tracer studies conducted before and after the increase in LFSF hydraulic loading rate found no significant change in filter residence time, suggesting that flow is highly controlled by the formation of a biologically active layer at the gravel-sand interface called a biomat. Investigation of changes in phosphorus treatment in the six 8 m long LFSFs for the 2004 to 2011 study period found a significant reduction in total phosphorus removal, particularly for the filters with the coarse sand type. Overall, the LFSFs were not effective as a long-term phosphorus removal treatment technology.

The two Type 2 raised contour trenches with either gravity-fed or periodically dosed loading conditions were studied for a period of three years (2007 to 2010). Both systems performed well with significant removal of biochemical oxygen demand, total suspended solids and the pathogen *E. coli*; however, the gravity-fed system produced statistically lower effluent concentrations for total phosphorus and total suspended solids, possibly because of biomat formation. The gravity-fed contour trench did experience ever increasing depths of ponded water in the distribution trench, suggesting that progressive clogging of the trench with solids was occurring and this eventually caused surface hydraulic failure. Reduced removal rates were observed in both contour trenches following a precipitation and snowmelt event in March 2010, possibly caused by reduced contaminant retention times from the six to eight times higher than average flow rates. This study demonstrates that effluent quality from OWS can be variable because of precipitation events (i.e. rainfall, snowmelt) and the loading method (periodic-dosing vs. gravity-fed).

Average effluent concentrations and %/log reductions for Type 2 raised contour trenches and 8 m long lateral flow sand filters (LFSFs).

OWS DESIGN	PARAMETERS					
	E. COLI (CFU 100 mL^{-1} [LOG])	TOTAL SUSPENDED SOLIDS (mg L^{-1} [%])	BIOCHEMICAL OXYGEN DEMAND (mg L^{-1} [%])	TOTAL PHOSPHORUS (mg L^{-1} [%])	AMMONIA AS N (mg L^{-1} [%])	TOTAL NITROGEN (mg L^{-1} [%])
TYPE 2 RAISED *DOSED*	2.7 [5.6]	3.3 [95.0]	2.5 [98.0]	0.31 [90.1]	0.57 [97.1]	9.36 [69.4]
TYPE 2 RAISED *GRAVITY*	2.1 [6.0]	2.3 [99.3]	2.4 [99.0]	0.13 [96.8]	0.40 [98.0]	8.07 [79.9]
LFSF *FINE SAND*	55 [4.8]	5.4 [93.4]	2.6 [97.4]	1.4 [69.7]	0.2 [99.0]	16.6 [45.7]
LFSF *MEDIUM SAND*	33 [5.0]	5.6 [93.2]	2.8 [97.3]	1.5 [68.0]	0.2 [99.2]	16.1 [47.3]
LFSF *COARSE SAND*	29 [5.0]	4.0 [93.6]	2.6 [97.5]	2.6 [45.1]	0.2 [99.2]	16.3 [45.8]

MODELING TOOLS

The GIS-based risk assessment tool successfully determined the most at-risk areas in the Huron-Kinloss Township in Ontario that were confirmed and validated by local experts (e.g. public health inspectors, chief building officials). The risk parameters that predominantly contributed to the highest risk areas were soil type, OWS age and level of water flow connectivity between the ground surface and the local groundwater table.

Flow, and sediment and total phosphorus loading were adequately simulated by POWSIM in conjunction with the SWAT model for the Thomas Brook Watershed in Nova Scotia. The modeling framework under-predicted both stormflow (precipitation event flows) and baseflow (no preceding precipitation event) total phosphorus loads in the watershed, but performed better than using only the SWAT model. The agricultural and OWS land uses were simulated as the largest sources of phosphorus in the watershed and their phosophorus loads were the same order of magnitude even though residential land uses were only 4% of the watershed area compared to 60% for agriculture. The POWSIM model simulated peak OWS phosphorus loading occurring in the Thomas Brook Watershed at greater than 30 yrs of continuous OWS operation. Simulation of different OWS management strategies found the most effective were using high phosphorus removal OWS filter media and reducing the OWS surface hydraulic failure rate from the watershed default value of 15% to 5%.

CASE STUDY: LATERAL FLOW SAND FILTERS IN NOVA SCOTIA

Prior to this research study, the lateral flow sand filter (LFSF) in Nova Scotia was only used to replace OWS technologies that had suffered surface hydraulic failure. Many of the other Nova Scotia Environment approved OWS technologies required building relatively large and costly systems that made placement on small building lots particularly difficult for OWS designers and installers. The LFSF is a smaller OWS than the other designs and is typically less costly to install.

The long-term treatment performance research on LFSFs carried out at the Bio-Environmental Engineering Centre in Bible Hill, NS found that LFSFs provide an excellent level of treatment that meets and exceeds secondary treatment standards. This led to the adoption of LFSFs as an approved technology for new developments by Nova Scotia Environment in 2009. By 2010, the LFSF was the second most installed OWS technology in the province. This has created benefits to both homeowners, OWS designers/ installers and regulators in that the LFSF can be constructed on smaller lot sizes compared to other approved OWS technologies and still provide excellent treatment of domestic wastewater.

WHAT DO THESE FINDINGS MEAN FOR MUNICIPALITIES?

TREATMENT PERFORMANCE STUDIES

The main outcome of the long-term performance studies of the LFSFs and Type 2 raised contour trenches is that they both provide excellent levels of domestic wastewater treatment and would be applicable for use in regions in Canada that have adverse and challenging soil and geologic conditions. This allows for more OWS technology options for municipalities and regulators to better protect and manage their surface- and groundwater resources, which would typically be at high-risk in areas with impermeable soils, shallow groundwater tables and bedrock outcroppings. These technologies have already been adopted as approved disposal field options by Nova Scotia Environment. The results of this research program are currently (Jan 2014) being used by Nova Scotia Environment to provide science-based evidence in a reassessment of the OWS technical guidelines to update some of the disposal field design specifications (e.g. filter length).

Another implication is that the dosing method for the OWS disposal field (e.g. gravity-fed, periodically pumped) and inflow rate is important to manage to prevent surface hydraulic failure. The Type 2 raised contour trench that was gravity-fed experienced increasing depths of ponded water caused by solids clogging the filter media that eventually lead to surface hydraulic failure. It would therefore be preferable to use an inflow system, such as periodic pumping, to more evenly distribute the domestic wastewater in the OWS and improve treatment efficiency. However, if an OWS already has a gravity-fed inflow design then installing a septic tank effluent filter would reduce solids loading into the distribution trench. Overall, it is a good general practice that all septic tanks have effluent filters to minimize solids transfer to the OWS disposal field.

MODELING TOOLS

The GIS-based risk assessment model can be used by municipalities to assist with identifying and designating at-risk areas regions that would be susceptible to contamination from OWS. This would be particularly useful in regions where there are no nearby visually noticeable surface water features in a potential development area and the local groundwater system would be the freshwater resource of interest. Designated at-risk areas would then have additional development and OWS design requirements applied to minimize the contamination risk. Examples of these requirements include increased OWS setback distances from wells, water features and wetlands, larger lot sizes and advance OWS treatment technologies. The risk assessment model could also be applied to current developed regions to identify at-risk areas to better strategically target OWS re-inspection and maintenance programs to ensure surface- and groundwater resources are properly protected and managed. It would be recommended that municipalities that currently have or are planning large developments where OWSs will be the primary treatment method consider using the GIS-based risk assessment model to assist in identifying their at-risk areas for surface- and groundwater OWS contamination.

The results of developing and testing POWSIM in conjunction with the SWAT model found that residential OWSs were a potentially significant source of phosphorus in a small rural, mixed land use watershed. Surface water monitoring programs and setup of modeling tools in watersheds where residential OWS are present need to ensure they properly evaluate the relative contributions of phosphorus from OWS to determine whether it is a source of concern. This would include adding a monitoring station downstream of a subcatchment that is predominantly residential land use or ensuring a model includes a phosphorus loading rate to represent OWS.

The study also found that OWS phosphorus loads may not reach their peak value until 30+ years after they have begun operation. If watershed managers want to properly evaluate OWS as a potential source of phosphorus they will need to ensure their investigations are for at least 30 years to capture the beginning of peak phosphorus loading from OWS and its full impact on a surface water system. This could be done through updating phosphorus capacity modeling scenarios, which are commonly applied in many provinces, including Nova Scotia, that are used to determine the impacts of residential, commercial and industrial development on water quality in a lake environment. Currently, the OWS phosphorus load coefficients in these scenarios do not reflect peak OWS loading after 30+ years. These OWS phosphorus load coefficients need to be updated to reflect decreased treatment performance over time to fully capture the impacts of OWS on a lake environment. Watershed management plans can then be updated to help reduce these OWS phosphorus loads through OWS disposal field filter media replacement programs, advising installation of OWS technologies that specifically target phosphorus and increasing water course setbacks for OWS disposal fields.

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