Performance Comparison of Large Diameter Residential Drinking Water Wells

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

Published scientific work indicates that residential large diameter drinking water wells are at a higher risk of contamination from surface water impacts than drilled wells. The possibility of a higher incidence of contamination of large diameter wells is attributed to site selection and construction problems such as leaking joints in the well casing, ineffective annular sealant placed between the well casing and the formation, a poorly fitted cover with an access lid that promotes contaminant entry and air entry without adequate air filtration, well location down gradient of septic effluent sources, and depth limitations due to improper equipment used to advance the well which results in shallow wells often situated in topographical lows. In some situations, flaws in the well design were actually deliberate measures intended to capture surface water at sites with low groundwater yield.

Historically, residential drinking water well performance studies have focussed on existing wells; however, uncertainty in the actual well construction methods and materials, well age and maintenance efforts have been problematic. A field and laboratory study was completed to assess the performance of several design changes that were thought to improve the integrity of large diameter drinking water wells, and to determine whether one design is more prone to atmospheric and/or surface water contamination than the other.

Four large diameter residential wells were installed at a study site in Lindsay, Ontario. Three of these wells are constructed with enhanced construction methods (two using a cement tile casing and one using a galvanized steel casing) and annular sealants, while the fourth was constructed using conventional methods for cement cased wells. The enhanced test wells utilized a sealant between the casing sections, various annular sealants between the formation and the well casing, sanitary waterline connections, and ventilation with air filtration. The well constructed using outdated methods did not have any of these advanced features. An automated water extraction system removed about 875 L/day from each well to mimic residential usage.

Routine monitoring, and laboratory and field testing were used to collect pertinent data required for this performance assessment. Routine monitoring involved the visual inspection of the wells,

collection of well water elevation, collection of soil temperature profile data, collection and analysis of water samples, and collection of cumulative water volumes purged from the test wells. A biofilm cleaning study and analysis of cement-bentonite grout was conducted in the laboratory while smoke and aqueous tracer tests were conducted in the field. The biofilm cleaning study entailed growing a biofilm on different large diameter well casing materials and applying cleaning methods thought to be practical for cleaning the interior walls of large diameter wells. Different mixtures of cement-bentonite grout were subjected to volume measurements, vertical load bearing capacity analysis, and hydraulic conductivity analysis to determine their suitability as a potential annular sealant. The tracer tests were developed to determine whether pathways for either airborne contaminants or surface water to enter the test wells exist. The test wells were filled with smoke and monitored for potential atmospheric pathways. A tracer solution was infiltrated around the test wells and the interior of the tests wells were monitored for potential pathways for surface water to enter.

Bacteriological indicators were detected in all test wells. The smoke tracer tests demonstrated that pathways for airborne contaminants to enter the test wells exist with more pathways observed in the winter than the summer. The aqueous tracer tests highlighted several areas where surface water could enter the test wells if ponding occurred around the well casing. As expected the enhanced test wells performed much better than the conventional test well for both of these tracer tests. The results of the biofilm cleaning study indicated that galvanized steel or fibreglass casing materials were the only materials able to be cleaned effectively. The best method in this study to remove biofilm from casing materials was pressure washing. The results from the cement-bentonite grout investigation indicated that cement-bentonite grout with 5% bentonite would make the most suitable annular sealant as its volume changed the least during curing, it was strong enough to support the load from maintenance efforts, and was the most impervious.

The results of this study indicate that large diameter wells constructed with a proper annular sealant, sealant between casing sections and a sanitary waterline connection are less prone to contamination. Monitoring of the test wells should continue as they mature to determine whether this plays a significant role in their ability to prevent contamination of large diameter wells. Smoke tracer tests should be conducted again during the winter to determine if temperature was the cause of increased atmospheric pathways. A field-scale method to remove biofilm from the interior casing wall of large diameter wells should be developed and tested. A field-scale investigation of cement-bentonite grout for use as an annular sealant should be completed. Fibreglass casings can be fabricated as a continuous piece with no seams or joints and hence another well should be constructed and studied using corrugated fibreglass (NSF ANSI 61) casing.

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TABLE of Contents

Appendices

List of Figures

List of Tables

1.0 Introduction

In Ontario, about 30% of residential drinking water requirements are from groundwater sources, but the rural population depends almost entirely on the extraction of groundwater from private wells (Goss *et al*., 1998). The most common types of private water wells are either drilled or dug/bored (Gibb, 1973) (Figure 1.1). Drilled wells are constructed using mechanical devices to advance the hole and remove cuttings. These wells are typically 10 to 15 cm in diameter and use steel or polyvinyl chloride (PVC) casings (NGWA, 1998). Drilled wells are normally constructed in areas that are underlain by permeable deposits of sand and gravel, or bedrock formations that are capable of yielding water to a well as fast as it is withdrawn (Gibb, 1973). Dug/bored wells were historically dug by hand and cased with brick, stone or wood. Presently dug/bored wells are dug with excavation equipment or bored with boring equipment. These wells typically utilize prefabricated concrete tile or corrugated galvanized steel pipe ranging in diameter from 60 to 120 cm (Simpson, 2004). Large diameter drinking water wells are typically dug/bored wells. Dug/bored wells are constructed in areas where waterbearing materials are thin and relatively impermeable (Gibb, 1973). These types of aquifers cannot yield water as fast as it is withdrawn and require the large diameter of the well casing to act as a reservoir to store water.

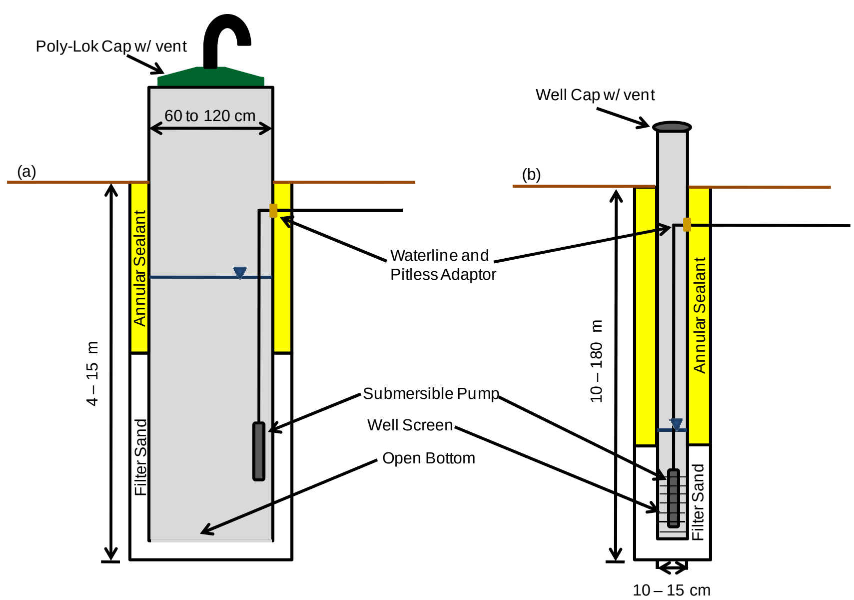

Figure 1.1. Schematic of (a) large diameter and (b) drilled wells.

The construction of wells in Ontario is governed by the Ontario Water Resources Act under Regulation 903 (last amendment is O. Reg. 372/07). This regulation states that all wells constructed in Ontario must be completed by licensed individuals who have undergone training and testing. The regulation also provides the standards that must be met to become a licensed well contractor or technician. Proper well locations, construction practices, and altering of wells are also standardized in the regulation.

Published scientific work (Goss *et al.,* 1998; Exner and Spalding, 1985; Glanville *et al.,* 1997) suggests that residential large diameter drinking water wells are at a higher risk of contamination from surface water contaminants than drilled wells. The possibility of a higher incidence of contamination of large diameter wells is attributed to site selection and construction problems such as leaking joints in the well casing, ineffective annular sealant placed between the well casing and the formation, poorly fitted lids, inadequate air filtration system, wells located down gradient of septic effluent sources, and depth limitations due to improper equipment used to advance the well which results in shallow wells often situated in topographical lows. In some situations flaws in the well design were actually deliberate measures intended to capture surface water at sites with low groundwater yield. The shallow depth of these wells increases the incidence of tapping unconfined aquifers which are more prone to contamination than the confined aquifers accessed by drilled wells.

Contamination of the well may be caused by contaminated ground water or contaminated surface water that infiltrates into the well casing. The Ontario Ministry of the Environment (2001) states that a water well is Groundwater Under Direct Influence of Surface Water (GUDI) where physical evidence of surface water contamination is evident (e.g. insect parts, high turbidity) or biological evidence of surface water organisms (e.g. *Campylobacter*, aerobic spores, *Cryptosporidium, Giardia*). While it is difficult to protect a well from contaminated groundwater, a well can be protected from surface water contamination. Older bored/dug wells were constructed without sealant between the concrete tile sections, and this, combined with the lack of a proper annular sealant, created a pathway for contaminated surface water to enter the well. Annular sealant is used to fill the void between the well casing and the existing formation to a depth of 2.5 m below ground surface (NGWA, 1998). This creates a watertight seal between the casing and formation to prevent water from short circuiting into the well. The sealant used should have a lower permeability than the surrounding native soils (St. Germain and Robin, 2007). Annular sealants that have a lower permeability than the surrounding native soils may include bentonite based products such as bentonite slurries, bentonite chips, and cement-bentonite grouts. Cement grouts are also used (NGWA, 1998). Appropriate sealant between concrete tile sections and a proper annular sealant should greatly reduce the risk of surface water entering the well.

Goss *et al.* (1998) completed a study comparing well construction types with nitrate and bacterial contamination of rural drinking water wells in Ontario and observed that dug/bored wells had a much higher incidence of nitrate and bacterial contamination than drilled wells. The higher incidence of nitrate and bacterial contamination increased with well age and decreased with depth. This suggests that newer wells with proper seals are less likely to be contaminated. They also observed that drilled wells that are completed in deeper aquifers are less likely to be impacted by surface water since the casings (steel or PVC) are less likely to transmit surface water. Steel and PVC well casings have fewer joints and these joints seal better than those used in large diameter wells. These general findings support the conclusions reached by Exner and Spalding (1985) who conducted a similar survey in southeast Nebraska and Glanville *et al.* (1997) who conducted a survey of wells in Iowa.

Well ventilation systems allow air to enter or exit the well as the water level rises or drops and prevent the well from becoming pressurized, particularly with the larger volume of stored well water exchange that occurs within a large diameter well. In the past, large diameter drinking water wells were not fitted with any ventilation system, or were fitted with open ventilation pipes to the atmosphere. Open vents will prevent the wells from becoming pressurized but airborne contaminants can enter the well through the open ventilation pipe (Trest *et. al.*, 1999). Trest *et. al.* (1999) studied bacterial contamination of drilled wells by airborne particulates. Other airborne contaminants exist; for instance, exhaust gases from an idling car or atomized crop control chemicals could enter a well. These airborne contaminants would normally have no route for direct contact with the well water. Open ventilation pipes also provide a means for vermin or insects, particularly those that seek cool humid locations, to enter the well, become trapped, and contaminate the water supply with their decaying corpses. New products on the market that utilize HEPA (high efficiency particulate air) filter technology provide filtration of the air as it enters or exits the well. HEPA filters use a mat of randomly arranged fibres that remove at least 99.97% of airborne particles less than or equal to 0.3 µm in diameter (TSI Inc., 2008). This level of filtration would prevent most particulates from entering a well and most bacteria, which range in size from 0.2 to 750 µm in diameter (Schulz and Jorgensen, 2001).

Biofilm is the natural habitat of bacteria and consists of the bacteria and the exopolymer they secrete. The exopolymer is a polysaccharide polymer produced by bacteria as a means of attaching to a surface, providing protection from chemical or physical activity, and facilitating nutrient capture (Schniders, 2003). Biofilm is beneficial in wastewater treatment as a means of removing contaminants; however, biofilm in a drinking water system can be a source of problems including pipe corrosion, filter clogging, and harbouring bacteria that contaminate water (Dreeszen, 2003). In large diameter wells biofilm could extend along pumping and water delivery equipment and reduce flow, and biofilm is also a persistent source of potential bacterial contamination.

Drinking water wells contain both planktonic bacteria (free swimming) and sessile bacteria (biofilm). The ratio of free swimming bacteria to bacteria contained in biofilm is 1:1 000 000 or for every single free swimming bacteria, one million bacteria are contained in biofilm (Schniders, 2003). LeChevallier (1988) demonstrated that free swimming bacteria can be removed through disinfection with chlorine whereas biofilm is able to resist most common disinfectants even at higher than normal doses. When disinfectants come in contact with biofilm, the biofilm shrinks and hardens. This results in a less penetrable biofilm that is more protective of the bacteria (Schniders, 2003). It is these bacteria contained in the biofilm that are a persistent source of potential contamination. Schniders (2003) found that it was necessary to use both mechanical and chemical activity to remove biofilm from a well.

Some types of mechanical activity used to remove biofilm in drilled wells include flushing and surge blocks. It is difficult to apply these to large diameter wells since the recharge rate in these wells is typically low and cannot create a flushing motion against the interior casing walls.

These mechanical methods assist in removing biofouling from drilled wells, a problem that large diameter wells do not have. Biofouling occurs when a biofilm develops in the sand pack around the screened interval or on the screen itself and reduces flow into the well. Large diameter wells with impervious casings are recharged through a large open bottom using no screens which reduces the likelihood of biofouling. The interior casing walls of both drilled and large diameter wells are susceptible to biofilm growth, which is the focus of this study.

Cement-bentonite grout is a common annular sealant used to seal water-supply, ground water monitoring wells and quite often geotechnical borings and mine exploration holes (Edil *et al.*, 1992). Cement-bentonite grouts shrink as cement is hydrated by the water; this shrinkage could create a void between the grout and the well casing, or between the grout and ground formation. Either of these situations could create a preferential pathway for surface water to infiltrate and contaminate the well. Cracking of the grout could also create a pathway for surface water to come in contact with the well casing. During well maintenance, a person would have to stand on or near the grout, applying a load which could cause cracks and create pathways. Maintenance equipment (lawnmowers, tractors, trucks, etc.) may also work near or on the grout. Cement-bentonite grout should be capable of withstanding these loads without cracking as well. Cement-bentonite grout should also have a permeability lower than that of the surrounding formation.

Historically, residential drinking water well investigations have been performed on existing wells (Goss *et al.,* 1998; Exner and Spalding, 1985; Glanville *et al.,* 1997). These studies have been unable to control the influence of design variations because of the different well ages, uncertainties about the actual well construction (portions of the well "as constructed design" are buried and not readily confirmable), and variable maintenance efforts. This project uses large diameter residential drinking water wells constructed for the purpose of research to control these design influences, which has not been completed in past investigations.

1.1 Thesis objectives

The objectives of this thesis are to:

1. develop a facility to study the performance of large diameter residential drinking water wells;

2. investigate the best annular sealant and casing material used in the construction of the test wells to reduce the influence of surface water contamination;

3. verify if pathways for airborne contaminants to enter the wells exist;

4. determine, in the laboratory, the most suitable casing material for ease of biofilm removal and a best method for the removal of biofilm from casing materials; and,

5. investigate, in the laboratory, the suitability of cement-bentonite grout as an annular sealant.

The results from this research may be used to improve large diameter well design criteria in water well regulations.

1.2 Thesis scope

To satisfy the thesis objectives, a field and laboratory study was completed to assess the performance of several design changes that are thought to improve the integrity of large diameter drinking water wells, and to determine whether one design is more prone to contamination than the other. To assess the design improvements, four "simulated" large diameter drinking water wells or test holes were constructed at the Fleming College Frost campus. According to Wells Regulation 903, these wells can be classified as "test holes" since the wells were "(a) made to test or to obtain information in respect of ground water or an aquifer, and (b) not used or intended for use as a source of water for agriculture or human consumption."

Although these test holes are exempt from some aspects of the Wells Regulations, the minimum construction features for water supply wells were applied during construction. Three of the test holes were constructed according to the current Wells Regulation and one was constructed using actual test hole regulation standards, for comparison. Although these wells are all classified as "test holes" under Regulation 903, in this thesis they are referred to as "test wells".

The relevant background and methods follow in Chapter 2, and the results and discussion in Chapter 3. Finally Chapter 4 presents major findings and outlines recommendation for future study. Well records for the monitoring wells and large diameter test wells are found in Appendix A. Detailed procedures for biofilm growth, cleaning and analysis are provided in Appendix B. Raw data relating to the water quality study, biofilm cleaning experiments and cement-bentonite grout experiments are found in Appendix C.

2.0 Methods and Materials

2.1 Field study site

The field study site is located west of the Scugog River, in a field bordered by forest and marshland, at the Fleming College Frost campus in Lindsay, Ontario, 90 km northeast of Toronto, Ontario and 35 km west of Peterborough, Ontario, Canada (Figure 2.1). Environment Canada reports climate norms from 1971 – 2000 for Lindsay as having an average annual temperature of 6.3 ˚C with a daily average annual maximum of 11.3 ˚C and a daily average annual minimum of 1.3 ˚C respectively. The average annual precipitation is 881.6 mm with 718.8 mm as rain and 162.8 mm as snow.

Gillespie and Richards (1957) report that the quaternary geology in the vicinity of the study site is classified as a Solmesville clay loam which is described as follows:

> "These soils have gently to very gently sloping topography resulting in imperfect drainage conditions within the soil profiles. Although generally there is at least a foot of lacustrine clay over the stony till, slight elevations occur in many fields where the clay deposit is very thin and stones appear on the surface. The profile development is characteristic of the Grey-Brown Podzolic soils."

Four conventional monitoring wells (MW1, MW2, MW3, and MW4) were installed on this site as part of a previous investigation and provide background information on both stratigraphy and groundwater hydraulics. Details of stratigraphy and installations are provided in Table 2.1, and the well records are found in the Appendix A. In general, an approximately 0.3 m thick layer of topsoil overlays 4.0 m of brown sandy clay that sits on weathered limestone. The well casing for the monitoring wells is white PVC with an inside diameter of 5 cm and the annular space is sealed with bentonite slurry to the top of the screened interval (PVC slot #0.10). The space surrounding the screened interval is filled with filter sand. The monitoring well is secured with a locking steel casing over the stickup.

Frequent water level measurements from the four monitoring wells indicate the flow direction is southeast toward the Scugog River (Figure 2.2). The Scugog River flows south toward Lake

Scugog. The water table is close to the ground surface at about 0.5 m below ground surface (bgs) suggesting that the higher conductivity weathered limestone zone provides the hydraulic support observed in the till. MW2 is located upgradient of the test wells and should not have been impacted by construction practices or materials and is used as a background well for the water quality study.

2.2 Large diameter drinking water well installations

2.2.1 General

Four large diameter drinking water test wells were installed at the field study site (Figure 2.3); three are an advanced design (ETH1, ETH2, and ETH3), and one a conventional design (CTH1)(see Table 2.2). Test wells were constructed and installed by licensed well technicians from Johnson and Baetz Well Boring. The test wells were located and water well records submitted in accordance with Wells Reg. 903. The concrete casing sections used for ETH1, ETH2 and CTH1 were fully cured and commercially manufactured (Acton Precast Concrete Ltd.). The casing sections for ETH1 and ETH2 were properly aligned in the hole so that the joints were flush and the casing was centered. The concrete casing sections were joined with a continuous cord of mastic sealing material that remains pliable and waterproof, and is approved for potable water use by NSF (National Sanitation Foundation) International. The casing sections for CTH1 were misaligned and no joint sealant was used as may occur during downhole assembly at elevations below standing well water with a turbidity that obscures visibility. The corrugated galvanized casing used for ETH3 is 18 gauge galvanized steel.

The large diameter test wells were bored with a bucket auger rig (Figure 2.4 (a)). The bucket auger bore was 132 cm (52”) in diameter and the precast concrete casing sections were 91 cm (36”) ID and 76 cm (30”) high. The outside diameter of the precast concrete sections was 112 cm (44”), forming a theoretical 10 cm (4”) annular ring around the casing. The galvanized well casing was 82 cm (32”) in diameter, forming a larger theoretical annular ring of 25 cm (10”).

The annular space was sealed to prevent any movement of water, contaminants or other material between subsurface formations, or between the subsurface formation and the ground surface by means of the annular space. From the ground surface to a depth of at least 2.5 m, the annular space was filled with non-hydrated bentonite chips (ETH2), bentonite slurry and sand (ETH1), bentonite granules and pea stone (ETH3), or drill cuttings (CTH1). The test wells were then fitted with secure covers and ventilation (except for CTH1). Each test well was installed with a portion of the well casing above the ground surface (stickup). This stickup provides protection from surface water entering the well in the event that water ponds around the well casing and entry of heavier airborne particles. The enhanced test wells have stickups that range in height from 0.55 m to 0.84 m, whereas the conventional well has a stickup of 0.47 m.

During construction of the test wells, observations of the stratigraphy were consistent with the existing monitoring wells (Figure 2.5). In general, observations made during test well installation indicate that an average 0.30 m of topsoil overlays an average 2.5 m of brown sandy clay. At all test wells the clay was underlain by weathered limestone. Copies of the well records are provided in the Appendix A.

Once the lower rings of the well casings were securely in place, a sand pack consisting of filter sand was placed in the annular space around each well. In the case of the galvanized casing the filter sand was placed once the entire casing was installed. MOE filter sand specifications specify that; 100% passes the 4.75 mm sieve, 89.0% passes the 2.38 mm sieve, 66.7% passes the 1.18 mm sieve, 32.4% passes the 0.800 mm sieve, 7.2% passes the 0.300 mm sieve, 2.1% passes the 0.150 mm sieve, and 1.0% passes the 0.075 mm sieve (Thomson, 2007). Figure 2.6 shows the particle size distribution of MOE filter sand and the filter sand used for the sand pack around the test wells (ASTM D422-63 Standard test method for particle-size analysis of soils). The filter sand used for the test wells matches the MOE specifications for a grain size <1 mm but has a higher percentage of larger diameter particles than the MOE specification. The coefficient of curvature (Craig, 2002) for the MOE filter sand specification and for the filter sand used here is between 1 and 3 which means it can be classified as well graded sand with little or no fines following the United Soil Classification System (Craig, 2002).

Test wells ETH1, ETH2 and ETH3 have air filters built into the air vents attached to the Poly-Lok lids (Figure 2.4 (c)). These air vents were constructed from 10 cm (4 inch) acrylonitrile butadiene styrene (ABS) pipe. The vent opening to the atmosphere points down to prevent precipitation from entering the test well and is covered with wire mesh (2 mm square) that inhibits the entry of vermin and most insects. The removable filter material is Polyveyor Air-Permeable Fabric (model 1950 – Low Permeability) and is sealed between two flanges. Polyveyor is nonwoven polyester material used for pneumatic conveying, it is rot and mildew resistant and has average pore openings of 4 μm (Albarrie Canada Ltd., 2009). This pore size is capable of preventing particulate matter and most bacteria from entering into the well through the air vent; however *Escherichia coli* (*E. coli*), a common bacterial contaminant, is ~1 x 2 μm in size (Schulz and Jorgensen, 2001) and therefore pose a concern. The air vents are permanently attached to the Poly-Lok lids and sealed with neoprene gaskets constructed from 4 mm thick neoprene sheets, and an outdoor silicone (Dap, acrylic latex caulk plus silicone).

2.2.2 Detailed installation summary

ETH1 is an advanced design concrete cased test well constructed using advanced methods. Concrete tile casing sections were placed and aligned using a hinged tile setter (Figure 2.4 (b)). Asbestos free ConSeal (Concrete Sealants Inc.) mastic sealant was used between the uppermost 2.5 m (8' 2") of tile joints and is suitable for contact with potable water. A working casing (temporarily installed steel casing with a diameter larger than the test well casing) was used to form an annular space with a diameter difference of 0.203 m (8") and prevent surface material from sloughing into the borehole opening. Centricity of the test hole casing was provided with the use of removable centralizers that were suitable for contact with potable water (untreated wood wedges). The annular sealant used was a mixture of bentonite slurry and sand, which was mixed by a mechanical mixer and poured into the annular space. The bentonite slurry and sand sealant is a mixture of equal parts sand and bentonite by volume, with slightly more than 3.78 L (1 gallon) of water per 0.454 kg (1 lbs) of sand (NGWA, 1998). Fine bentonite granules (Bariod Benseal, 85 % >2.36 mm and permeability <1 x 10^{-8} cm/s) and fine sand (Lauston Industries #2/12) were used. The inside of the test well joints in the uppermost 2.5 m (8' 2") were smoothly finished using a trowel and parging cement (Baroid, EZ-Mud). The uppermost rim of the concrete tile casing is bonded to the concrete cover with mastic sealant. The cover consists of an airtight PVC Poly-Lok lid, cast into the concrete cover. An air vent was permanently affixed to the Poly-Lok lid, which incorporates a filter for the purpose of removing airborne bacteria (Figure 2.4 (c)).

ETH2 is also an advanced design concrete cased test well constructed using advanced methods. This test well was constructed using the same materials and construction practices as ETH1 but with a different annular sealant. Sixty-three (63) 30 kg bags of 9.5 mm (3/8") dry bentonite chips (Baroid, Benseal) were placed in the annular space to form a uniform mixture. Additional instrumentation was installed in the annular sealant of ETH2. These consisted of three (3) nests of three (3) 25.4 mm (1") diameter piezometers installed to depths of 0.3 m, 1.5 m and 2.4 m to monitor the hydration of the bentonite chips.

ETH3 is an advanced design corrugated galvanized steel cased test well constructed using advanced methods. A single continuous riveted piece of 0.79 m (31") diameter corrugated galvanized steel casing was vertically placed to avoid damage to the casing or to the hole wall. A working casing (temporarily installed steel casing with a diameter larger than the test hole casing) was used to form an annular space with a diameter difference of 0.508 m (20"). The annular sealant consists of a mixture (1:1 by volume) bentonite granules (Bariod, Benseal, 85 % >2.36 mm and permeability <1 x 10^{-8} cm/s) and pea stone (1/2" prewashed), and was placed as a uniform mixture in the annular space. The uppermost rim of the corrugated galvanized steel casing was bonded to the concrete cover with mastic sealant. The cover consists of an airtight PVC Poly-Lok lid cast into the concrete cover. An air vent was permanently affixed to the Poly-Lok lid, which incorporates a filter for the purpose of removing airborne bacteria.

CTH1 was constructed using out-of-date construction practices which do not meet the minimum standards for water supply wells prescribed in the current version of Wells Reg. 903. Concrete tile casing sections were placed with the use of a hinged tile setter. Lower elevation concrete casing tiles were offset so that the tiles do not form a continuous cylinder. The annular sealant was side cast backfill (boring cuttings), which was excavated as separate soil layers and separately stored. The uppermost rim of the concrete tile casing was not bonded to the concrete cover. A concrete cover which includes a smaller square shaped removable concrete lid with rebar handles was placed into the top of the casing (Figure 2.4 (d)).

2.3 Water extraction system

The pumps and pitless adapters were installed by Greg Bullock of Eades Well Drilling. Pitless adaptors were installed in the enhanced test wells and an improper connection was made at the conventional test well (CTH1). Greg Bullock is a licensed well technician in the Province of Ontario and is experienced in the installation of pumps and pitless adaptors. Pitless adaptors are devices used to provide a sanitary connection through the casing wall between the submersible pump and water delivery line, and also provide a detachment point to the pump for maintenance or repair. The pitless adaptors employed in these test wells are constructed of brass and have an inside diameter of 25.4 mm (1”). To install the pitless adaptors and water lines, the soil material next to the test wells was excavated to an average depth of 1 m and 1 m in width. See Table 2.3 for installation details at each test well.

The holes for the pitless adaptors in the concrete cased test wells, ETH1 and ETH2, were bored with a 51 mm (2”) hammer core drill bit. These were drilled with a hammer drill above the static water level in the test wells at the time of installation. Some uncontrolled chipping was caused by the hammer core bit breaking through the inside of the casing. The pitless adaptors were then installed in the hole and tightened on the outside of the casing. Once the pitless adaptors were installed the annular sealant was replaced. A bentonite granule (Envirocore – Medium) was placed in the space around the ETH1 pitless adaptor and backfilled. Existing hydrated bentonite granules were placed around the ETH2 pitless adaptor and backfilled (Figure 2.7 (a)).

The test well with a galvanized casing (ETH3) utilized the same pitless adaptor as the concrete cased wells. Since the corrugations in the casing would not permit a proper seal between the gaskets of the pitless adaptor, the pitless adaptor was attached to a 30 cm long 25.4 mm threaded brass pipe. The brass pipe was then passed through a hole drilled in the casing and sealed with silicone on the outside and inside of the casing. Bentonite granules (Envirocore – Medium) were placed around the pipe on the outside of the casing and hydrated. Concrete was placed on top of the bentonite and pipe. The concrete was used to counter balance the weight of the pump and piping located within the well (Figures 2.7 (b) to (d)).

The conventional test well (CTH1) did not utilize a sanitary drinking water connection; instead a 63.5 mm (2.5”) hole was drilled using the same type of bit and drill as used for the ETH1 and ETH2 wells. The pipe and power cable for the pump were passed through the hole and existing material from the excavation was packed around the opening. The excavation was then backfilled.

A water delivery line (1.91 cm (¾”) PVC pipe) sloping away from the test wells at 0.5 % extends from the pitless adaptor (ETH1, ETH2 and ETH3) or pipe (CTH1) to a sample collection facility (Figure 2.8 (a)). This sample collection facility is comprised of a 170 L plastic barrel with screw top lid and allows water samples to be collected as required and provided a convenient location to place a cumulative flow gauge (Omega FTB-4000, turbine meter). The water line from the pitless adaptor enters the barrel and water exits through a 100 mm solid tile drain pipe located below the water line. A check valve was installed on the outlet of the water line to ensure that water cannot flow back into the test well. Water in the barrel is allowed to discharge by gravity through the drainage line to a drainage ditch that runs along the northern boundary of the field site (Figures 2.8 (b) and (c)). To reduce erosion in the drainage ditch and help prevent freezing the outlet of the pipe in the drainage ditch was covered with stone. To minimize the risk of freezing during the winter, straw bales were used to cover all sampling facilities and the water line from CTH1 since it is the shallowest.

Solar powered submergible impeller pumps (24 V, 16 Amp, Rule 3700) were selected for use in this test well project. These pumps are capable of pumping 20 L/minute at about 4.0 m of hydraulic head. The pumps were connected to the pitless adaptors using brass fittings and stainless steel hose clamps for ETH1, ETH2, and ETH3. For CTH1, galvanized fittings were used since they are not as safe for drinking water and may reflect a pump not installed correctly. Eades Well Drilling installed the electrical conduit to the enhanced test wells. The holes for the electrical conduit were drilled about 5 to 10 cm above the ground surface and the conduit was placed in the hole in the casing and secured with silicone. The pumps were wired and placed in the test well by Greg Bullock and connected to an automated control system with daily pumping beginning on November 25, 2008.

The power for these pumps is provided by 2-12 V deep cycle batteries in series providing 24 V of power. The batteries are charged by two 1.22 m x 0.61 m (48" x 24"), 24 Watt solar panels in series. The solar panels are set on the top of a steel pole in a central location relative to the test wells (Figure 2.8 (d)). The wires from each pump are buried 45 cm below ground in conduit and meet at the solar panel. The solar panel and all controls are contained in a fenced enclosure. The electrical equipment is secured in a large plastic box with desiccant packs to absorb any moisture. Due to the high amperage of the pumps only one pump can run at a time. An Allen-Bradley Pico programmable controller (model 1760-L12DWD) operates 30 Amp relays that turn the pumps on and off for set periods of time based on the flow rates and the desired amount of water to be removed.

2.4 Monitoring instrumentation

All of the test wells and two of the monitoring wells (MW2 and MW3) are instrumented with pressure transducers (Solinst Levelogger Junior in MW2, MW3, CTH1, ETH1, and ETH3, and a Solinst Levelogger Gold LTC in ETH2) to continuously monitor fluctuations in the water level in each well. The pressure transducer in ETH2 provides an accuracy of ± 0.3 cm and a resolution of 0.001 % of the full scale of the measurement, and the pressure transducer in the remaining wells provides an accuracy of ± 0.5 cm and a resolution of 0.028 % of the full scale of the measurement.

To provide soil temperature profile information, a thermocouple nest was installed between 30 cm and 135 cm bgs. Eight (8) thermocouples (Onset L-TMA-M006) with a range of -40˚C to 100˚C and an accuracy of ± 0.7˚C were vertically placed every 15 cm. Two 4-channel data loggers (HOBO U12-008) logged and stored the measurements. The thermocouples were affixed to a wooden dowel using shrink wrap sheets and placed into an augured hole that was then backfilled with bentonite slurry.

Mini-piezometers nests were installed in the dry bentonite chip annular sealant of ETH2 to allow air pressure tests to be performed to investigate the hydration of the bentonite chips used as an annular sealant for this test well. Three nests of three piezometers each were placed around ETH2. Each nest has a shallow (0.3 m bgs / orange), medium (1.5 m bgs / white), and deep (2.4 m bgs / grey) piezometer. The mini-piezometers are constructed from 25.4 mm (1") diameter PVC pipe and are capped at the end in the ground. The tops of the mini-piezometers have a removable screw cap. The PVC was slotted with a hacksaw to create a screen similar to a monitoring well screen. The slots are 1 mm wide, spaced ~5 mm apart, and are on two sides of the pipe. The screened section extends 50 cm up from the bottom of the mini-piezometers, with the exception of the shallow one, which only extends 15 cm up from the bottom.

2.5 Extraction and recovery tests

A series of extraction and recovery tests were conducted to determine the response of the water level in all the test wells due to pumping a single test well, and to establish the recovery behaviour of each test well. Water was extracted from one test well at a time and the response in the test wells and monitoring wells was monitored using the pressure transducers. The data collected provided well interaction information and recovery rates for each test well and were used to design the operation of the water extraction system.

2.6 Disinfection

Drinking water wells need to be disinfected upon completion of construction to ensure that the water is free from microorganisms. The objective of disinfection is to kill any microorganisms in the well and is typically undertaken with a household bleach. Several factsheets explaining proper disinfection procedures have been published by various levels of government across North America. For instance, Wells Regulation 903 states that "the water in the well is dosed to a concentration of not less than 50 milligrams per litre and not more than 200 milligrams per litre of free chlorine and left undisturbed for a period of at least 12 hours." The State of Illinois Department of Registration and Education uses tables with well depth and diameter to determine the total amount of chlorine laundry bleach to be added to the well for disinfection (Gibb, 1973).

To disinfect the test wells, 1.25 mL of bleach (6% HCl) was added for every litre of water stored in the test wells. Bleach was poured down the inside walls of the test well casing. Twelve (12) to twenty-four (24) hours after the bleach was added water samples were collected from the test wells and analyzed for free chlorine by Fleming College personnel. Free chlorine analysis followed Hach method 8021 for free chlorine determination and was analyzed using a Hach DR 2800 portable spectrophotometer. Samples were collected from the discharge of each monitoring barrel and rinsed with discharging water three times prior to sampling to ensure clean sample bottles. The free chlorine in the sample immediately reacts with DPD (N,N-diethyl-p-phenylenediamine) indicator to form a pink color, the intensity of which is proportional to the chlorine concentration. The results from the free chlorine test were <50 mg/L for all test wells. Due to the low free chlorine levels the water was pumped from the test wells until the free chlorine residual was <1 mg/L. The disinfection procedures were repeated and twenty-three (23) hours after the wells were dosed they were tested for free chlorine levels. This resulted in three (3) of the four (4) wells being in the proper range of 50 to 200 mg/L. ETH3 had a free chlorine concentration of 38.5 mg/L, whereas the other test wells ranged between 51 and 67 mg/L. Since wells are not used for a potable water supply and the harsh winter weather, it was decided that this was acceptable and samples were collected 24 hours later to establish baseline water quality conditions.

2.7 Tracer tests

2.7.1 Smoke tracer tests

Smoke tracer tests were used to assess potential pathways between the atmosphere and the interior of the test wells in December 2008 and May 2009. The potential for airborne contaminants to come in contact with water stored in the well was assessed by placing smoke generators within the well air space. Smoke pathways were identified visually, and the escaping flow rate and flow volume provides qualitative information on the degree of atmospheric interaction. The tests were completed using both pressure (provided by a Dewalt 1.6 hp, 56.8 L air compressor) and smoke (from a chemical smoke generator (Superior No. 1A)) to determine if there were any potential pathways between the atmosphere and the interior of the test wells. Each test well was tested by attaching the air compressor and increasing the air pressure from

68.9 to 103.4 kPa (10 to 15 psi) and holding it there for three 5 minute periods; the pressure was allowed to drop after 5 minutes and then increased again. The smoke generator was initiated and smoke was allowed to fill the air space in the test wells. The smoke generator was suspended in the test wells above the static water level. The air compressor pressurized the test wells from 68.9 to 103.4 kPa (10 to 15 psi) and visual recordings and observations were made. The test wells were then purged of smoke by removing the smoke generators and access lids.

2.7.2 Aqueous tracer tests

Aqueous tracer tests were used to determine if casing material, annular sealant or construction methods provide pathways for surface water to enter the well. To replicate a worst-case scenario a conservative tracer solution was ponded around each test well until a specified volume infiltrated. An infiltration gallery was constructed around each test well (Figure 2.9) and 500 to 700 L of conservative tracer solution was prepared and placed in the infiltration gallery and allowed to infiltrate. The conservative tracer solution was prepared using Rhodamine B (Sigma Aldrich) at a concentration of 50 mg/L and KBr (Fisher Scientific) at concentrations ranging from 8 500 mg/L to 12 000 mg/L. Water to prepare the tracer solution was provided from ETH2, since this well had the highest recharge rate and was the last well to be tested, to avoid contaminating the other tests. If tracer solution entered the well, the well water would increase in conductivity, which is directly related to total dissolved solids, and would have been expected because of an increase in dissolved solids from the added KBr tracer. Similarly adding tracer solution to the well water would result in an increase in fluorescence. The interior of the test well was visually inspected, and the effluent was monitored for indications of the tracer solution for a period of 24 hours. The test well was then pumped at a sustainable flow rate to maintain a decreased static hydraulic head relative to the potentiometric surface. The test wells were monitored during the initial 24 hours for indication of fluorescence, conductivity, and Br^-. Fluorescence was monitored by collecting samples from the surface water in the well or water discharged from pumping using a Turner Designs 10-AU fluorometer. The fluorometer allowed samples to be analyzed immediately after collection onsite and was calibrated to a detection level of 1 ppb. Conductivity was monitored using a Solinst Levelogger Gold with conductivity measuring capabilities and a resolution of 1 µS/cm and an accuracy of 20 µS/cm. Bromide was analyzed in the laboratory by ion chromatography (IC) scan calibrated to detection level of

1 mg/L. Daily samples of effluent water from each test well were collected for a period of ~3 weeks and analyzed for the presence of Br^- ions through IC scan.

2.8 Water quality

Water samples were collected from the test wells on March 04, 2008 (interim baseline) and then following the first smoke test and disinfection on February 11, 2009 (baseline). A water sample was also collected from monitoring well MW2 on February 11, 2009 and assumed to be representative of upgradient background water quality.

The March 04, 2008 water samples were collected with a pump (1/2 hp submersible sump pump) that was cleaned (by running a well water and bleach solution through it and its hoses) prior to being lowered into each test well. The sample collected from ETH2 was collected after the test well was purged of 3 volumes. Due to equipment problems onsite the remaining test wells were not fully purged. Samples were transported in a cooler with ice packs and stored in a refrigerator upon returning to the University of Waterloo before being sent to an external analytical laboratory (Maxxam Analytics Inc.) for analysis of major anions, cations and heavy metals (ETH3 only).

The water samples collected on February 11, 2009 were collected from the discharge of each monitoring barrel. These samples were not preserved as they were being received by SGS Lakefield Research Ltd. for analysis within a few hours of collection and would be preserved at the laboratory if required. The samples were transported to the laboratory in a cooler packed with ice. The monitoring well (MW2) was purged for 45 minutes using a Geopump (set at maximum rate, about 10 L/minute). The well was purged until dry, left to recharge, purged again and sampled. Two 500 mL HDPE bottles were filled at each test well and the monitoring well. The bottles were rinsed with sample prior to filling. Immediately after collecting the samples, the bottles were transported to the laboratory for analysis. A metal scan (ICP), drinking water scan (cations and anions), *E. coli*, and total coliform counts were completed by the laboratory.

Monthly water samples were collected and analyzed by Fleming College and duplicate samples were collected quarterly and sent to an external lab for comparison. Sampling began in May

2009 with samples being analyzed by both Fleming College and the external lab. Duplicate samples were collected again in August 2009. The collection of these samples was completed in the same manner as the baseline samples and the same analysis was completed.

2.9 Biofilm study

Three (3) different large diameter well casing materials (concrete, corrugated galvanized steel and corrugated fibreglass) were studied for ease of cleaning using four (4) different mechanical cleaning methods in the laboratory. The cleaning methods include scrubbing with a brush, scrubbing a bleach solution with a brush, steam cleaning with a brush, and pressure washing.

Biofilm was generated in a biofilm reactor (Figure 2.10) using raw water from Laurel Creek (a tributary running through the University of Waterloo campus) as a source of bacteria. The reactor was covered to prevent light from entering and causing algae to grow instead of biofilm and was kept in the lab at room temperature. Coupons of each material were vertically suspended in the system (Figure 2.11 (a)). A submergible pump was used to generate an upward flow that simulated water recharge in the wells. The samples were left for 5 to 7 days to develop a biofilm. Once a suitable biofilm developed the samples were removed from the biofilm reactor.

Five (5) coupons of each material type were suspended in the system. The first coupon was used as a control to determine the amount of biofilm accumulated. The four (4) remaining coupons were cleaned with the four (4) different cleaning methods and analyzed for biofilm removal. The four cleaned coupons were returned to the system once analyzed to determine the amount of re-growth.

Each coupon was ~7 cm x 7 cm. Within each coupon two areas were designated (each 2.5 cm x 5 cm); one to analyze after cleaning and one to analyze the amount of re-growth (Figure 2.11 (b)). This ensured that the analyses after cleaning did not affect the analyses for re-growth. Prior to the coupons being submerged in the biofilm reactor the coupons were placed in an autoclave at 120 ˚C for 20 minutes to sterilize the coupons and ensure that a new biofilm was developed on the coupons in the biofilm reactor (Forster C.J. et al, 2001).

Physically scrubbing the samples with a brush (Rubbermaid Nail Brush model #G119, 88 mm L x 24 mm W x 21 mm H, 105 bristle pods with 40 plastic bristles in each pod) involved wetting the brush in reactor water and scrubbing the sample in an up and down motion. The brush was wetted in the reactor water to replicate what would occur if one were to scrub the interior casing walls of a large diameter well. Physically scrubbing the coupons with a bleach solution (6% HCl, diluted in distilled water to 0.23 mg/L Cl^-) was conducted in the same manner as physically scrubbing but wetting the brush in the bleach solution. This was done to replicate scrubbing the casing wall immediately after disinfection of a well. A portable steam cleaner (Euro Pro Shark Steam Cleaner) with a brush on the end of the steam nozzle was used for the steam cleaning. The coupons were scrubbed while steam (~100ºC) was discharged. A pressure washer (8960 kPa (1300 psi) working pressure) with the nozzle set to a wide fan spray (25˚) was held 10 cm above the coupons and moved in an up and down motion to pressure wash the coupons. Each of these methods was applied for 15 seconds on each coupon to ensure repeatability of the method. Detailed descriptions of each cleaning method are found in Appendix B.

The samples were qualitatively analyzed using an Enliten® total ATP rapid biocontamination detection kit (Promega). All living cells rely on ATP (adenosine-5'-triphosphate) for metabolic energy and the detection of ATP can be used as an indication of the presence of living microorganisms (Promega, 2006). The light emitted by fireflies is produced by an enzyme called luciferase, which catalyzes an ATP-dependant oxidation of luciferin. This reaction is given by:

$$\mathrm{ATP} + \mathrm{D} - \mathrm{luciferin} + \mathrm{O_2} \rightarrow \mathrm{AMP} + \mathrm{oxyluciferin} + \mathrm{PPi} + \mathrm{CO_2} + \mathrm{light} \qquad (1)$$

Sterile swabs are supplied with the kit and used to sample the area of interest. The swabs with sample on them were initially immersed in the swab buffer, swab extractant was added and the rL/L (Luciferase/Luciferin) reagent was finally added. The solution is immediately analyzed using a luminometer (Turner BioSystems, Modulus 9988-9203 Fluorometer with liminometer module) which measures the amount of light produced. The light produced is proportional to the amount of ATP on the swab. Positive and negative controls were analyzed prior to each analysis to ensure the reagents were functioning properly. The result from the positive control is also used to determine if the coupon surface has been cleaned. The coupon surface is considered clean if the result is less than 2% of the positive control; if the result is higher it is not considered clean (Promega, 2006). Sampling methods are detailed in Appendix B.

2.10 Cement-bentonite grout

In addition to the annular sealants used in the construction of the large diameter drinking water wells a cement-bentonite grout was analyzed in the laboratory for suitability as an annular sealant. The cement-bentonite grout was analyzed for volume changes during curing, subsequent structural integrity (vertical load bearing capacity) and hydraulic conductivity. If the grout shrinks, swells, cracks, or allows water to easily flow through it may not be a suitable annular sealant.

Cement-bentonite grout is a mixture of cement (Portland Type 10), bentonite powder (Bariod - Quik Gel) and water. Different percentages of bentonite powder (1%, 3%, and 5%) per mass of cement were used to create the three mixtures analyzed. Cement grout, which is neat cement and water, uses a water to cement ratio of 0.46 (NGWA, 1998). This mixture is used as a basis for cement-bentonite grout. An additional 2.27 L of water per sack (42.64 kg cement) per 1% increase in bentonite is needed when modifying cement grout to cement-bentonite grout (NGWA, 1998). This provides a water to bentonite ratio of 5.28. Using the above two ratios a new mix design based on the percent of bentonite used can be made. The mix design in water to cement to bentonite and water to solids is presented in Table 2.4.

The samples used for analysis were cast in cylindrical plastic moulds (51.8 mm in diameter and 103.6 mm in height). A commercial countertop mixer (Hobart) was used to mix the grout since it provided high shear to mix the fine materials. The cement and water were fully mixed and bentonite was slowly added to this mixture while the mixer was in operation. This promotes proper hydration of the bentonite powder and prevents clumps of bentonite from forming (Mikkelsen, 2003). Grout was placed in the moulds in three lifts and vibrated, by tapping the outside of the moulds, to remove any entrapped air. Caps were placed on the moulds and left to set. The samples were removed from the plastic moulds 24 hours after they were cast. Half the samples were placed in a water bath to simulate saturated curing conditions (e.g., grout curing below the water table) and the remaining samples were placed in a moist room to cure. The moist room is an enclosed room with a regulated atmosphere that is kept at 23.0 ± 2.0˚C and above 95% relative humidity (ASTM C511-06). The water bath was placed in the moist room to regulate the temperature of the water. The samples were left to cure for 28 days.

The first sets of measurements were made once the samples set and were removed from the moulds. Measurements were then made 1, 2, 3, 7, 14, 21, and 28 days after the samples were removed from the moulds. The height and diameter were measured at three marked locations on each specimen, and an average value was recorded. The height and diameter was measured with digital callipers accurate to ± 0.01 mm. The mass was measured on a digital scale with an accuracy of ± 0.1 g.

Once cured the cement-bentonite grout samples were subjected to vertical load bearing capacity testing. The standard test method for compressive strength of cylindrical concrete specimens (ASTM C39 / C39M-05e2) was used. This method describes the testing procedure for all cylindrical concrete specimens, including the small 51.8 mm diameter specimens used. To properly assess the compressive strength, the cylindrical specimens require both ends to be perpendicular to the axis of compression. To achieve the perpendicular ends the cylinders were capped with sulphur mortar. This was conducted according to the standard practice for capping cylindrical concrete specimens (ASTM C617 – 09a). The cylinders were then tested for vertical load bearing capacity using an ELE International concrete compression tester. Measurements of peak load and stress were recorded. Peak load and stress were digitally recorded by the automated recording device on the compression tester. Peak load and stress occur when the cylinder is compressed to the point of failure.

The hydraulic conductivity was tested using a centrifuge apparatus. Typically a flexible wall permeameter hydraulic conductivity test would be employed to assess the hydraulic conductivity of a material in the laboratory. The centrifuge is not a typical method for assessing hydraulic conductivity however it has some distinct advantages over a flexible wall permeameter hydraulic conductivity test. The flexible wall permeameter requires at least five days to process a sample whereas the centrifuge can process a sample in twelve hours (Russier, 2008). This is accomplished through the use of centrifugal forces, spinning the sample can create in excess of 60 G's ($G = 6.6732 \times 10^{-11}$ $N \cdot m^2/kg^2$) of force, forcing water through the sample where it is digitally recorded (Russier, 2008). This provides a much more accurate estimate of the porosity and hydraulic conductivity of the sample. Samples were also processed by the flexible wall permeameter hydraulic conductivity test to confirm the results from the centrifuge method.

The flexible wall permeameter hydraulic conductivity test utilizes a confining chamber and a pressure source that supplies a confining stress by pressurizing the fluid surrounding the sample (ASTM D5084-03) (Figure 2.12 (a)). An upward pressure differential is then applied across the sample, creating flow in the direction of the gradient. The flow is measured over a period of time with a volumetric bladder. Pressure transducers record the top and bottom pressures applied and one records the confining pressure (Pernet, 2006).

The hydraulic conductivity, K, of the flexible wall permeameter hydraulic conductivity test is estimated by:

$$K = \frac{V}{A_s \cdot t \cdot \frac{P_2 - P_1}{h_s - \gamma_w}} \tag{2}$$

where V is the volume of fluid that passes through the sample, t the duration of the test, h_s the sample height, γ_w the unit weight of water, A_s the section of the sample, and P_1 and P_2 are the backpressures top and bottom, respectively (Pernet, 2006).

The centrifuge test uses a confining chamber very similar to the one used in the flexible wall permeameter (Figure 2.12 (b)) but the confining pressure is supplied by a head tank located 5 m above the sample. A reservoir above the sample supplies a constant hydraulic head for the duration of the test. The reservoir and confining chamber are monitored for pressure changes during the test to ensure the test functioned properly. This data is collected with a data logger and stored. Water that passes through the sample is collected in a drawer below the sample and weighed upon completion of the test. The water collected in the drawer and the length of the test is then used to calculate the hydraulic conductivity of the material using:

$$K = \frac{V}{N \cdot A_s \cdot t \cdot \frac{h_s + h_w}{h_s}} \tag{3}$$

where V is the volume of fluid through the sample, N is the acceleration factor (gravity in G's), t the duration of the test, A_s the section of the sample, h_s the sample height, and h_w the water head above the sample (Pernet, 2006).

Figure 2.1. Field site (Image © 2009 GeoEye).

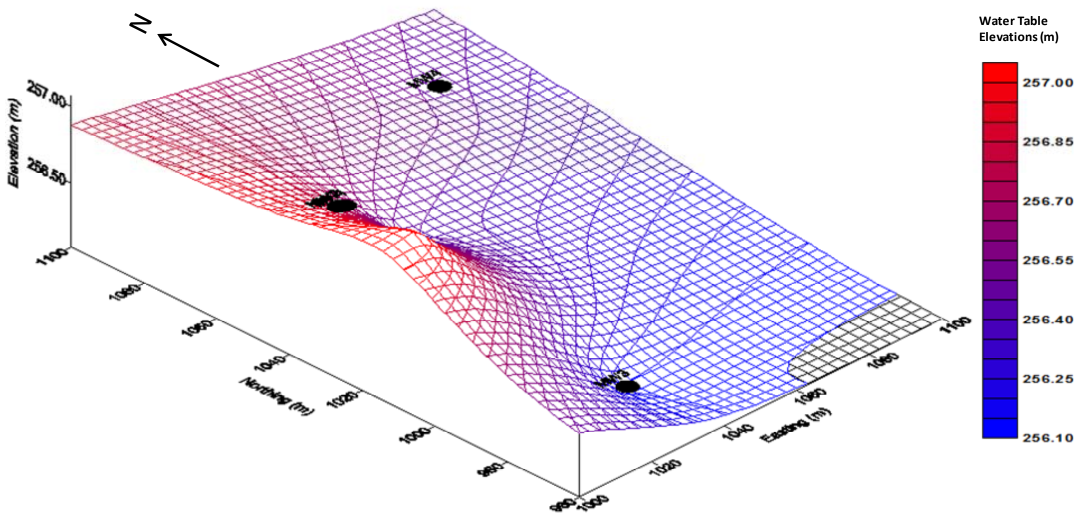

Figure 2.2. Water elevation contours from MW1, MW2, MW3 and MW4 data collected May 15, 2008.

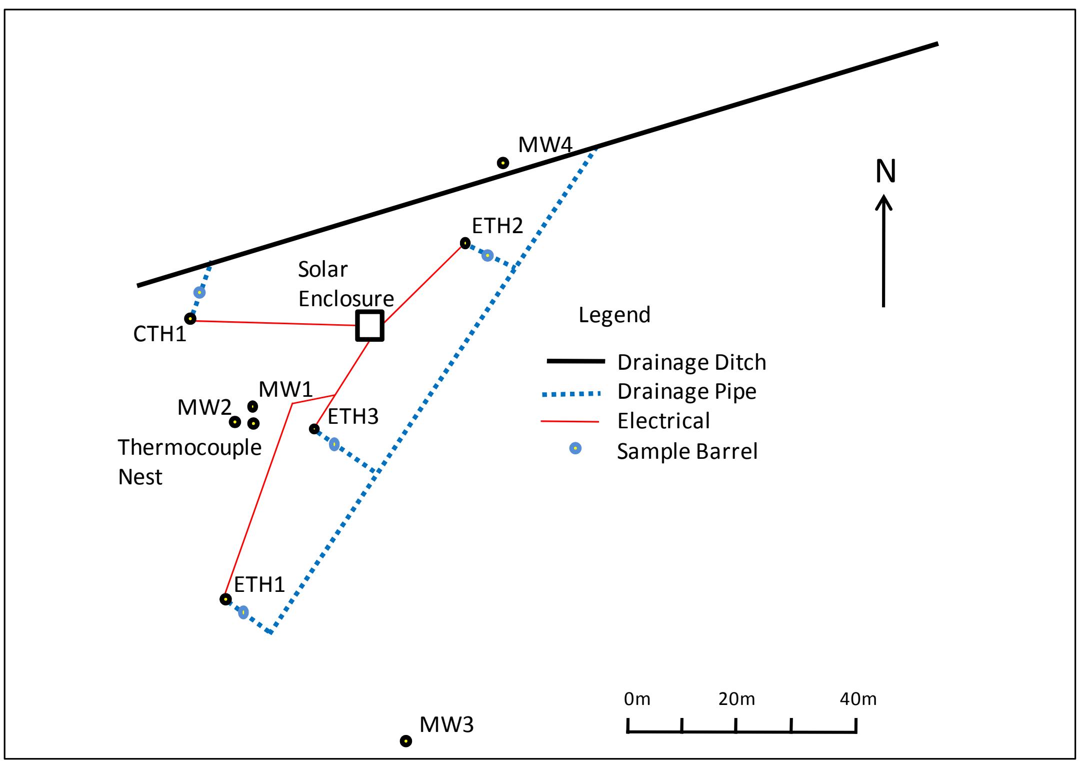

Figure 2.3. Site map.

Figure 2.4. Large diameter test well installation photos showing (a) bucket auger rig, (b) hinged tile setter, (c) Poly – Lok lid with air filter, and (d) concrete cover and lid at CTH1.

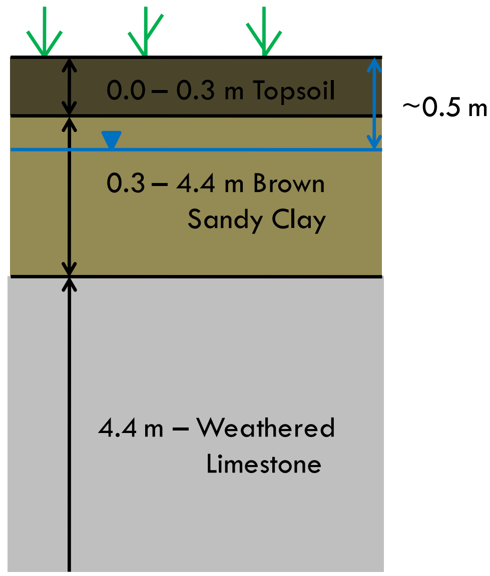

Figure 2.5. Typical soil profile.

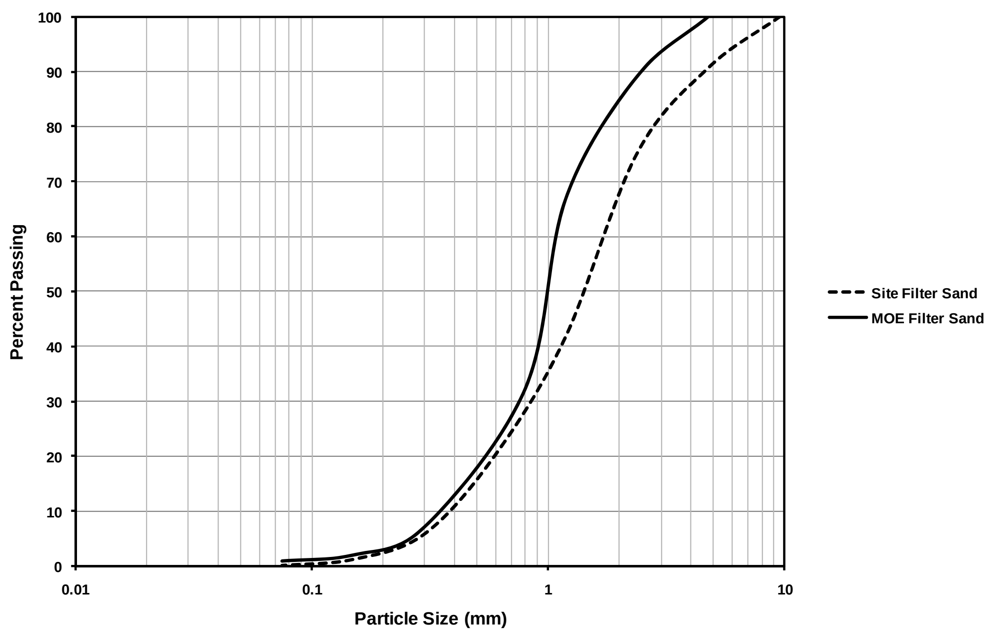

Figure 2.6. Filter sand particle size distribution.

Figure 2.7. Pitless adaptor installation photos showing (a) placement of existing hydrated bentonite granules at ETH2, (b) pitless adaptor inside casing at ETH3, (c) pitless adaptor outside ETH3 covered with non-hydrated bentonite granules, and (d) pitless adaptor and non-hydrated bentonite granules covered with concrete to counterbalance the mass of the pump.

Figure 2.8. Drainage system photos showing (a) sample collection facility for ETH3, (b) drainage line from sample collection facility, (c) drainage line and stone cover at drainage ditch, and (d) solar panel and electrical enclosure.

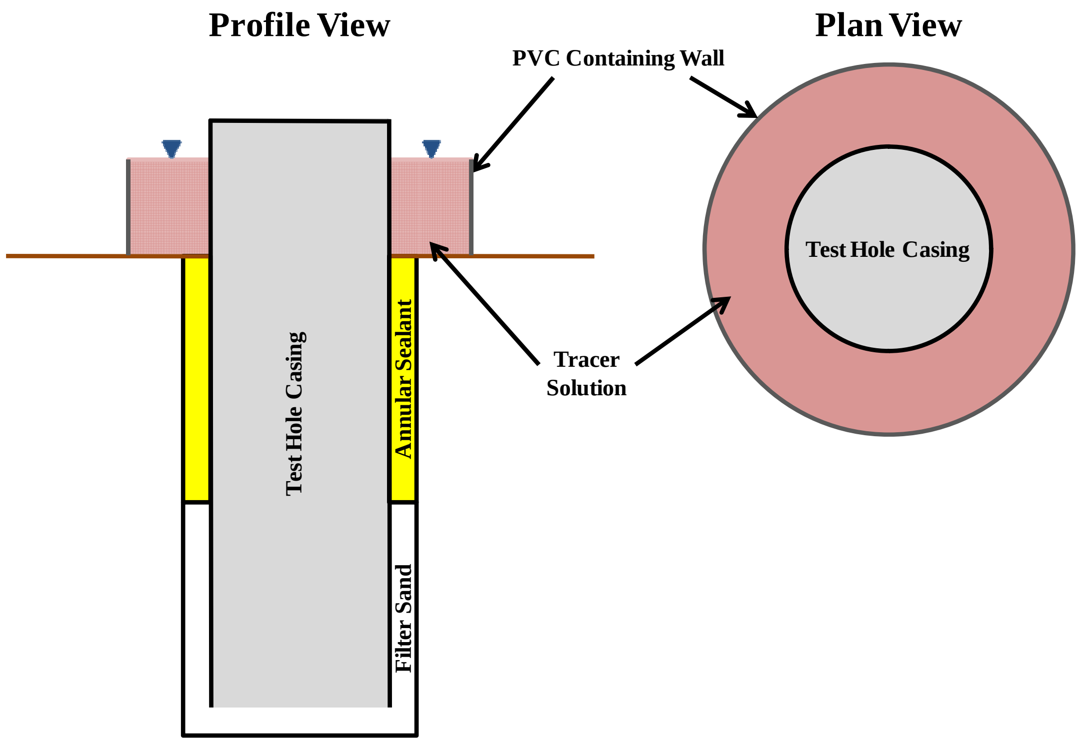

Figure 2.9. Infiltration gallery.

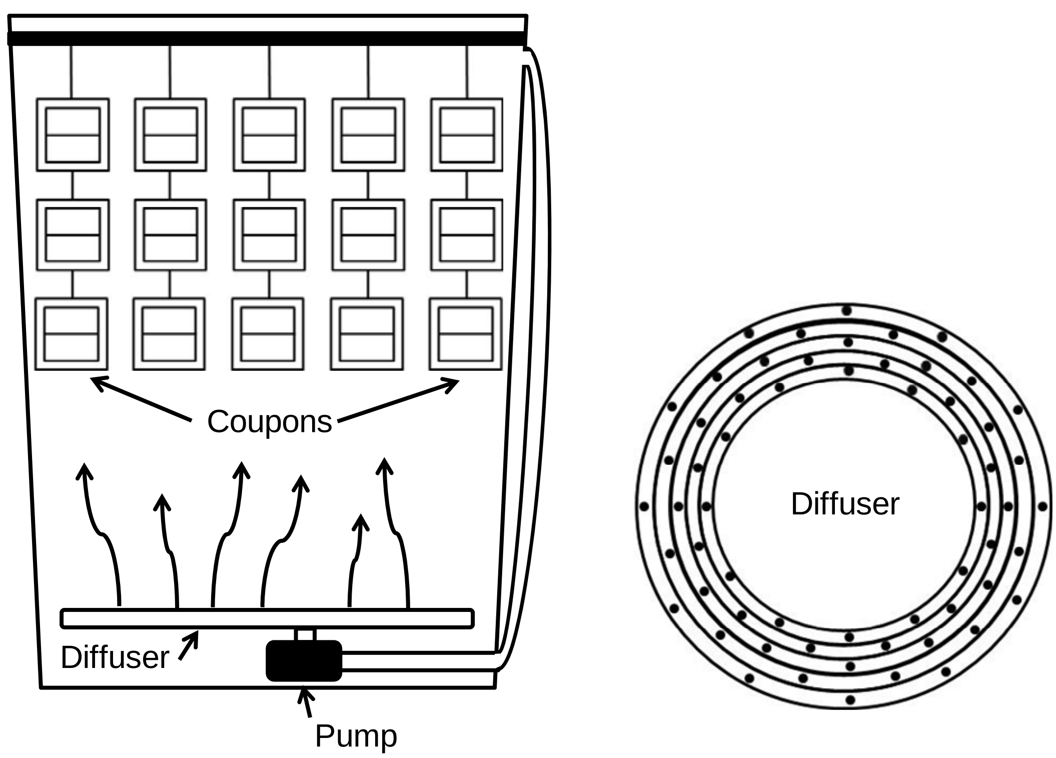

Figure 2.10. Biofilm reactor and diffuser.

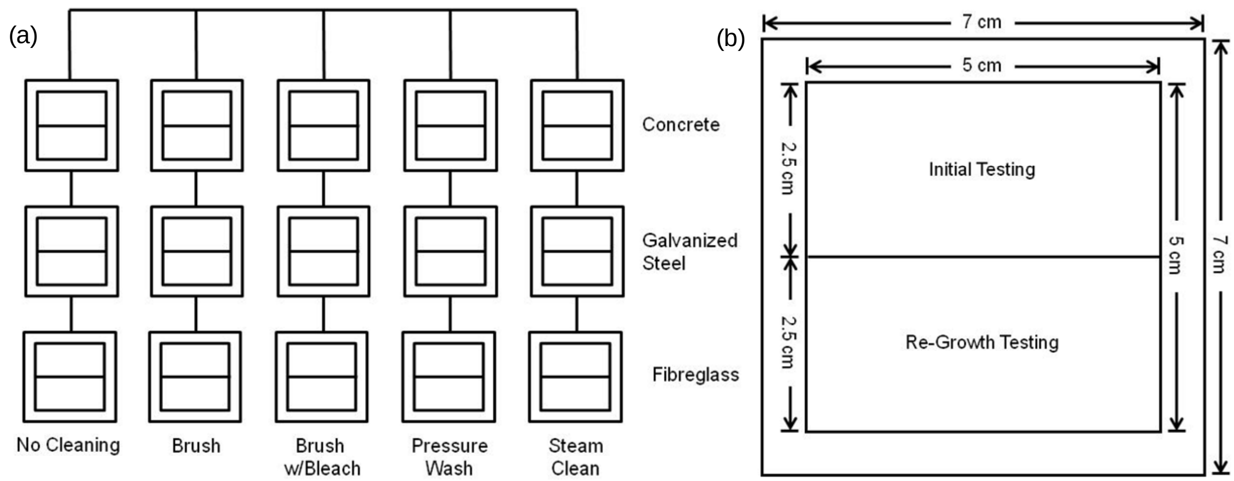

Figure 2.11. Biofilm equipment schematic for (a) coupon orientation, and (b) coupon.

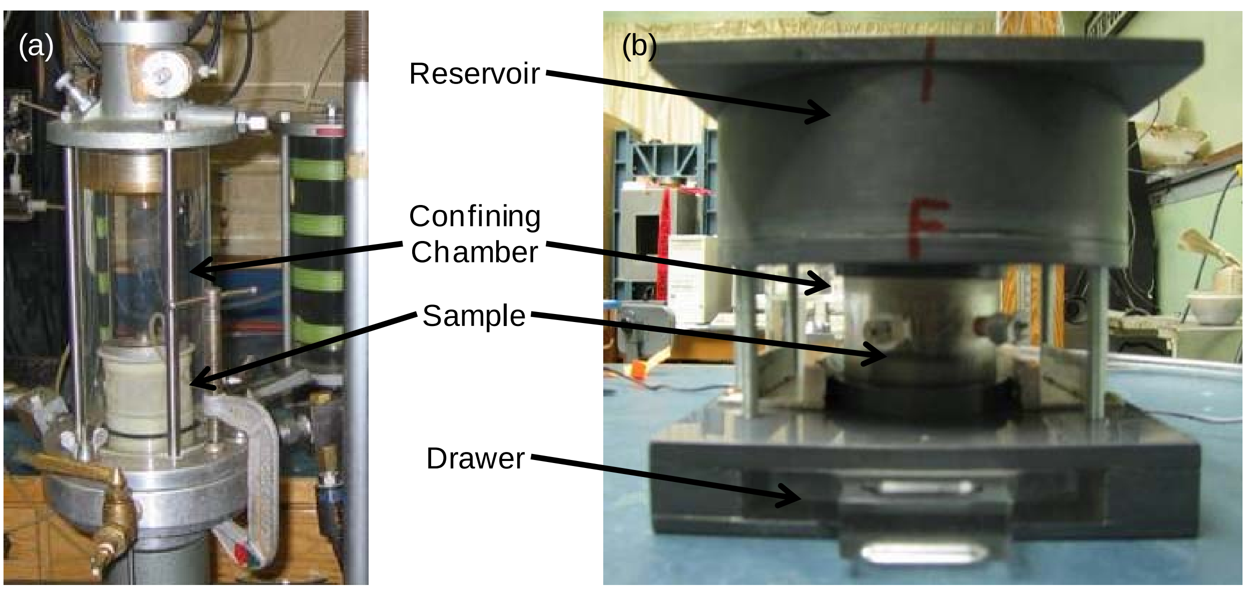

Figure 2.12. Photograph of (a) flexible wall permeameter confining chamber and (b) centrifuge confining chamber.

Table 2.1. Monitoring well stratigraphy and installation details.

	MW1 (m bgs)	MW2 (m bgs)	MW3 (m bgs)	MW4 (m bgs)
Topsoil	0.0 – 0.39	0.0 – 0.42	0.0 - 0.30	0.0 – 0.39
Brown Sandy Clay	0.39 – 4.40	0.42 – 3.96	0.30 – 4.42	0.39 – 4.39
Weathered Limestone	4.40 – 6.10			
Casing	0.0 – 4.7	0.0 – 2.34	0.0 – 2.83	0.0 – 0.39
Screen	4.7 – 6.1	2.34 – 3.96	2.83 – 4.35	0.39 – 4.39
Annular Sealant	0.0 – 4.7	0.0 – 2.34	0.0 – 2.83	0.0 – 0.39
Sand Pack	4.7 – 6.1	2.34 – 3.96	2.83 – 4.35	0.39 – 4.39

Table 2.2. Test well construction details.

	Date of Installation	Casing Type	Mastic Sealant	Annular Sealant	Air Vent w/ Filtration	Stickup (m above grade)	Depth Below Grade (m)
CTH1	Dec. 21/07	Concrete	No	Drill cuttings	No	0.47	2.99
ETH1	Dec. 20/07	Concrete	Yes	Bentonite slurry and sand (>20% bentonite solids)	Yes	0.84	3.81
ETH2	Dec. 19/07	Concrete	Yes	Non-hydrated bentonite chips	Yes	0.55	4.26
ETH3	Dec. 19/07	Galvanized steel	No	Mix of bentonite granules and pea stone	Yes	0.68	4.41

Table 2.3. Pump installation details.

	Top of Casing to Water Delivery Line (m)	Water Delivery Line to Pump Intake (m)	Depth of Pump Below Top of Casing (m)	Height of Pump Intake Above Bottom (m)
CTH1	1.27	1.22	2.49	1.04
ETH1	1.44	1.22	2.66	1.06
ETH2	1.05	1.65	2.70	1.54
ETH3	1.31	1.91	3.22	1.14

Table 2.4. Grout mix design.

	Ratio by Weight 1%	 3% Bentonite	 5%
Water:Cement:Bentonite			
Water	0.51	0.62	0.72
Portland Cement	1	1	1
Powdered Bentonite	0.01	0.03	0.05
Water:Solids			
Water	0.508	0.6	0.69
Solids	1	1	1

3.0 Results and Discussion

3.1 Water level measurements

Water level measurements collected from the test wells indicate that groundwater flows southeast toward the Scugog River, which is consistent with the hydraulic data collected from the monitoring wells. Since monitoring of water levels has begun, water table elevation fluctuations of as much as 0.8 m have been observed (Figures 3.1 and 3.2, data from pressure transducers). These fluctuations can be attributed to seasonal changes or periods of wet and dry weather. Since November 2008, much more variability in the water levels is observed. This is due to the daily pumping, to simulate regular usage of the wells, which causes daily drawdown and recharge. The water table is close to the ground surface (~0.5 m bgs), consistent with other observations. The water recharging the wells is supposed to enter the wells through the open bottom where much higher conductivity weathered limestone is located.

3.2 Extraction and recovery tests

The extraction and recovery tests were conducted on two separate days to determine the response of the water table to pumping the test wells, and if there exists a hydraulic interaction between the test wells. The data collected were used to design the pumping sequence for the automated pumping system. The response to the water level in each test well is presented in Figures 3.3 and 3.4 for each day of the extraction/recovery tests.

A total of ~5000 L of water was removed from ETH2 at a constant flow rate of ~100 L/minute for 50 minutes. The water level in ETH2 was quickly drawn down and reached steady-state in 15 minutes at about 30 cm of drawdown. It took about 10 minutes for the water level in ETH2 to recover. ETH2 has an extremely quick recharge of ~100 L/minute. As a result of pumping ETH2, the water level in ETH3 and CTH1 were drawn down to a maximum of 4 cm and 1 cm respectively. The water level recovered when pumping stopped. Test well ETH1 did not respond to pumping ETH2 at the resolution of these measurements.

A total of ~7600 L of water was removed from ETH3 over 2 hours using flow rates that varied from 20 to 100 L/minute. The varying flow rate accounts for the erratic ETH2 drawdown profile in Figure 3.3. The pump was turned off when 7600 L of water was removed; the weekly residential water usage. The water level in ETH3 was drawn down about 2 m during this test and recovered in ~45 minutes. As a result of pumping ETH3, the water level in ETH2 and CTH1 were drawn down to a maximum of 2 cm and 1 cm respectively. The water level recovered when pumping stopped. Test well ETH1 did not respond to pumping ETH3 at the resolution of these measurements.

A total of ~3700 L of water was removed from ETH1 over 64 minutes using flow rates that varied from 20 to 75 L/minute. ETH1 was pumped until the pump was no longer able to function (drawdown of about 2.2 m). The varying flow rate accounts for the erratic ETH1 drawdown profile in Figure 3.4. The flow rate was initially set at 75 L/minute and was lowered to 45 L/minute to slow the drawdown rate after 18 minutes. The flow rate was then reduced to 20 L/minute as the pump intake was moved to a lower elevation in the well and thus had to overcome more static pressure head. ETH1 did not completely recover but the water level rose 2 m in 100 minutes. In response to pumping ETH1, the water level in CTH1 was drawn down to a maximum of 1 cm. The water level recovered quickly when pumping stopped. Test wells ETH2 and ETH3 did not respond to pumping ETH1 at the resolution of these measurements.

A total of ~4400 L of water was removed from CTH1 over 70 minutes using flow rates that varied from 35 to 80 L/minute. CTH1 was pumped until the pump was no longer able to function (drawdown about 1.6 m). Water was removed at a flow rate between 80 and 65 L/minute for the first 30 minutes and slowed due to increasing static pressure head as the pump intake was lowered. The water level in the well increased after 45 minutes into this test because the pump was resting on the well bottom and the flow rate was only 35 L/minute. The pump was then raised and the flow rate increased to 72 L/minute. The flat section of the drawdown curve is where the water level logger was above the water surface. The water level in CTH1 recovered in 1.5 hours. During this test the water level in ETH3 was drawn down slightly (<1 cm), and recovered in less than 30 min. Test well ETH2 did not respond to pumping CTH1 at the resolution of these measurements.

These results indicated that a once weekly pumping schedule would not be feasible as the wells did not store enough water and recharge was slow. A daily pumping schedule was developed. Once the pumping system was installed, the pumps were run at short intervals to allow water to exit from the drainage system (Table 3.1). Based on data from November 2008 to August 2009 the pumps functioned properly but some problems occurred in the drainage system (Figure 3.5). Freezing problems in CTH1 prevented pumping during January 2009 and account for the lower volume of water pumped from the well. The flow gauge was removed from CTH1 during the winter of 2009 as it was found that this is where freezing was occurring and this accounts for the irregularity in the pumping profile. The pumps were operational for 272 days at the time of the last reading (August 24, 2009) and the desired amount of water to be removed from the test wells is 272,000 L. Approximately 250,000 L has been removed from ETH3 and 230,000 L from each of ETH1 and ETH2. The difference between these volumes occurred in June 2009 when the pumping rate in all wells, except ETH3, slowed. It is unclear what caused the decreased pumping rate. This is apparent in Figure 3.5 where the cumulative flow lines diverge. CTH1 has been in full operation since late February 2009 and has pumped ~163,000 L. In that time 180,000 L of water should have been removed from CTH1. The lower pumped volumes indicated that the goal of 1000 L/day of water is not being removed from the wells. Closer to 875 L/day is being removed from each well every day. This is due to the use of a solar powered system that may not be storing enough power in the batteries on cloudy days to run the full pumping event. During site visits on overcast days it has been observed that there is not enough power to run a full daily pumping event. Adding extra batteries to prevent this problem is under consideration but during a period of overcast days extra batteries may still not be enough to correct this problem. This is lower than the average household use but still creates a significant volume of recharge in the wells every day.

3.3 Soil temperature profile

A nest of 8 thermocouples, between 30 cm and 135 cm bgs, measured the soil temperature profile to help determine freeze – thaw cycles occurrences and the depth to which frost extends below the ground surface. Figure 3.6 shows the soil temperature profile from December 2007 to August 2009. Over this period two complete freeze-thaw cycles were observed. The average daily temperature recorded by Environment Canada at Trent University in Peterborough, ON is also shown. These data display a trend in the soil and air temperature as expected. Over the monitoring period the soil temperature was below freezing for a period in the winter of 2009 at the 30 cm depth. At no other depths was the temperature <0 ˚C. The information was used to assist in the design of the extraction/drainage system. Soil temperature profile data could also be used to assess damage caused to the annular sealants from frost heave. No damage to the annular sealants or well casing due to frost has been observed.

3.4 Hydration of the ETH2 annular sealant

Piezometers installed in the bentonite chip annular sealant of ETH2 were tested during the winter of 2008 (76 days after installation) and summer of 2008 (175 days after installation). During the winter of 2008 test, large volumes of air (9.5 m^3/minute) were forced into the piezometers using a wet/dry vac (Ridgid WD1250). It is thought that there was not enough pressure from the wet/dry vac to generate a interconnection between the piezometers by deforming the hydrated bentonite. When air was forced down the deep piezometers (2.4 m bgs) no air could be felt exiting any of the other piezometers suggesting that the bentonite was saturated at this depth at all nests. This is consistent with the water table location at less than a meter below the ground surface. When air was forced into the medium depth piezometers (1.5 m bgs) air could be felt exiting the other medium depth piezometers and the shallow depth piezometers (0.3 m bgs) for all nests. When air was forced into the shallow depth piezometers air could only be felt exiting the other shallow piezometers. This suggests that the bentonite is not saturated at the medium depth. Due to the water table location above the medium depth piezometers it was expected that these would be saturated. At ground surface the bentonite seemed to be saturated but during the winter testing the annular sealant was frozen at the surface. When the test was conducted again in the summer of 2008 all of the piezometers were sealed as air could not be felt exiting at any other locations. This indicates that the bentonite chips are fully hydrated. This conclusion was visually confirmed when the excavation work to install the pitless adaptors was completed and the seal was exposed 306 days after installation. It should also be noted that when the annular seal was installed it was flush with the surrounding ground (Figure 3.7 (a)) and as the bentonite chips hydrated they expanded and rose ~5 to 10 cm above the surrounding ground (Figure 3.7 (b)). ETH3 also used a non-hydrated bentonite seal and during waterline excavation (11 months) it was found that the seal was not fully hydrated. ETH3 used a combination of bentonite granules and pea stone and it is unclear why it did not hydrate.

3.5 Smoke tracer test

Smoke tracer tests were conducted to determine if any pathways for airborne contaminants exist. After the smoke generator was placed inside the test well and before the air compressor was connected, smoke was observed escaping from the casing, cover, and lid of all the wells during smoke tracer test #1. This indicated that the pressure created by the chemical reaction of the smoke generator was sufficient to show air leaks. Raising the pressure inside the test well did not increase the amount of visible smoke or location of leaks but forced the smoke out for a longer period of time, making it easier to observe the various pathways. Smoke tracer test #1 was conducted in December 2008 with an average temperature of ~-9 ˚C during testing. The temperature was well below freezing and the apparatus brought to seal the access to CTH1 would not function in the cold temperatures; therefore, rags were used to seal a large opening in the lid and encourage the smoke to escape from other unknown locations (Figure 3.8 (a)). Potential pathways were observed at this test well but over a shorter period of time.

During smoke tracer test #2 smoke was observed escaping from the Poly-Lok lid, and electrical conduit for the enhanced test wells and through all joints in the conventional test well. This test was conducted in May 2009 with an average temperature of ~23 ˚C during testing. CTH1 was sealed properly for smoke tracer test #2.

3.5.1 Smoke tracer test #1

At all concrete cased test wells smoke was observed escaping from around the interior geophysical access tubes and other joints in the casing. Since there is no mastic sealant between the casing sections in CTH1 it had much more visible smoke emitting from these locations. ETH3 (galvanized casing) had smoke emitting from around the joint between the concrete cover and the galvanized casing. When pressure was applied to ETH3 black air bubbles and dark coloured liquid appeared along the seams of the galvanized casing (Figure 3.8 (b)). The black air bubbles and dark coloured liquid may have been caused by machine oil left between the riveted seams from the manufacturing process. Both ETH1 and ETH2 have similar construction methods and had air leaks in similar places; small air leaks around the electrical conduit and around the Poly-Lok lid. Table 3.2 provides an overall indication of the observations from the smoke tracer test #1.

3.5.2 Smoke tracer test #2

At all enhanced test wells smoke was observed at the electrical conduit box, interior geophysical access tube, and along the seam of the Poly-Lok lid. The access lid in the cover of CTH1 was properly sealed during this test (Figure 3.8 (c)) and smoke was observed emitting from all joints in the casing construction. The smoke observed emitting from the seam of the Poly-Lok lid was caused by damage to the foam seal which occurred during smoke tracer test #1 (Figure 3.8 (d)). During smoke tracer test #1 smoke was visibly emitting from all the seams in the casing where mastic sealant was used, but during the test #2 no visible smoke emitted from these locations. During the test #1 the mastic sealant that was visible outside the casing was very firm to the touch; however, during test #2 the mastic sealant was soft and very malleable and could have created a better seal. The mastic sealant losing plasticity in the cold may have caused the seal to contract and create voids, which may be the cause of observed smoke pathways between the joints of the concrete cased. During test #2 smoke emitted from the seams in the galvanized casing where it was riveted together. This was not observed during test #1 and may have been a result of condensation freezing in the seam. Table 3.2 provides a summary of the observations from smoke tracer test #2.

3.5.3 Smoke tracer test summary

The smoke tracer test showed that all the test wells have pathways between the atmosphere and the interior of the test well. The smoke illustrated where it is possible for airborne contaminants to enter. A concrete cased well with mastic sealant in the joints provides the best protection from airborne contaminants. This could be improved by using thicker mastic sealant or a double application. The Poly-Lok lids would not have allowed an entry point were it not for the damage to the foam seal of the lid. This can be prevented by thawing the lid with warm water if it needs to be removed when conditions are below freezing. This test should be repeated again in the winter to determine whether there exists the possibility of airborne contamination every winter or if it was cold temperature induced loss of plasticity in the mastic sealant that was resolved as the wells matures and settled.

3.6 Aqueous tracer test

Aqueous tracer tests were used to determine if potential pathways exist for surface water to enter the well. The interior well casing was visually monitored for signs of the tracer and through the use of analytical equipment for a 24 hour period after the test was initiated. This included; fluorescence analysis onsite, conductivity analysis, and collection of samples for Br^- analysis for 2 to 3 weeks after the tests were initiated. The water levels in all the wells were lower than observed during past site inspections (~0.7 m). This may be due to the extremely dry preceding month (40.5 mm of precipitation in September 2009 compared to 84.3 mm of precipitation in the average September) (Environment Canada, 2009).

The first aqueous tracer test was conducted on October 5, 2009 at CTH1. ~700 L of tracer solution was prepared at a concentration of 8500 mg/L of KBr and 50 mg/L of Rhodamine B, and ~500 L was allowed to infiltrate. Within 2 minutes of beginning to fill the infiltration gallery, tracer solution could be heard entering the well through the well casing joints, and openings for the waterline and power supply (Figure 3.9). Tracer solution was observed entering the well through each casing joint above the static water level. It is unknown if tracer solution entered the well below the water level since tracer appearance occurred so quickly and poured down into the interior of the well air space that the standing water was too coloured to see below the surface. The rate at which tracer solution infiltrated was unexpected and analytical equipment was not set to analyze, or collect samples. The 500 L of tracer solution was added to the infiltration gallery in 12 minutes and completely infiltrated within 14 minutes of beginning to fill the infiltration gallery. Tracer solution was observed entering the well (through casing joints above the water level) for 15 minutes after the tracer solution had completely infiltrated. ~55 minutes after the test began the well was pumped at a flow rate of 7.5 L/minute for 72 minutes and then increased to 12.5 L/minute for 145 minutes. This was done to determine how much water would need to be removed from the well to remove the contaminated water. After 217 minutes ~2350 L of water was purged from CTH1 and the well water was still visibly stained with the tracer solution. The pump was turned on again ~15 hours after the initial 2350 L was purged the next day and ~610 L was purged before the battery for the pumps died since cloud cover prevented charging. At this time the well water was still visibly stained with the tracer solution. Samples were collected from the well during normal operation once the infiltration tests were complete for the analysis of Br^- by IC scan. Samples were supposed to be collected daily but weather did not permit daily sample collection and 2 samples were collected every week for 5 weeks. Results of this analysis indicate that regular pumping of the well removed all the tracer solution (Figure 3.10 (a)). As can be seen background levels of Br^- were reached 16 days after the initial infiltration. Samples collected on September 9, 2009 provide an indication of the background concentration of Br^- in the test wells, which were below 1 mg/L at all test wells and MW2.

The aqueous tracer test was conducted at ETH1 on October 6, 2009. ~700 L of tracer solution was prepared at a concentration of 8500 mg/L of KBr and 50 mg/L of Rhodamine B, and ~500 L was allowed to infiltrate. The tracer solution completely infiltrated in 18 minutes and within 2 minutes from the beginning of the test tracer solution was observed leaking into the well casing from a void around the electrical conduit (Figure 3.11 (a)). This leaking lasted for 1 minute while the tracer solution was above the electrical conduit and did cause visible staining of the surface of the water in the well (Figure 3.11 (b)). The well was monitored for a 24 hour period but no other signs of tracer solution were visually observed entering the well. Data collected from the conductivity probe placed in the well during this 24 hour monitoring period showed no signs of tracer present (Figure 3.12 (a)). The probe was located below the pump (~1 m below the static water level) and this shows that the tracer that entered the well from the electrical conduit did not diffuse down to the probe. Water samples collected from both the water surface in the well and from the sample collection facility were analyzed onsite for presence of fluorescence and showed little tracer entered the well aside from the initial amount from the leaking electrical conduit (Figure 3.13 (a)). Given the volume of water stored in the well at the time of the test (~800 L) and the highest concentration of fluorescence detected (12.7 ppb) ~200 mL of tracer solution entered ETH1. Due to cloud cover the pump was unable to function continuously during the test and was only used to collect water samples for short durations. This prevented a large exchange of water from occurring and the removal of the tracer from the well. Results of the Br^- analysis indicate that regular pumping of the well removed all the tracer solution (Figure 3.10 (b)). Background levels of Br^- were reached 21 days after the initial infiltration. This well had far less tracer solution enter the well than CTH1 and took longer to reach background levels since pumping did not occur during the first 24 hours of monitoring.

The aqueous tracer test at ETH3 was conducted on October 19, 2009. ~500 L of tracer solution was prepared at a concentration of 12 000 mg/L of KBr and 50 mg/L of Rhodamine B, and allowed to infiltrate. A higher concentration of KBr was used for the ETH3 and ETH2 to determine if an increase in KBr would be picked up by the IC or conductivity probe. The tracer solution was added in stages to avoid filling above the electrical conduit as occurred at ETH1. ~21 minutes were required to add 500 L of tracer solution to the infiltration gallery and an additional 63 minutes to completely infiltrate. A longer time was required for the tracer to infiltrate at this test well, presumed to be due to a thicker grass cover in the infiltration gallery (Figure 3.14 (a)) and higher initial moisture content as a result of increased precipitation between the 2 testing periods. Within 2 minutes from the tracer solution making first contact with the ground, tracer was visible on the interior casing wall. The tracer was observed leaking through the riveted seam of the corrugated galvanized casing (Figure 3.14 (b)). The leak occurred for approximately 54 minutes and caused visual staining of the surface water in the well. Pumping of the well began once the first of the tracer solution was added at a sustainable rate of 7.5 L/minute. Pumping continued for 22 hours and ~27 000 L of water was purged from ETH3. Data collected from the conductivity probe in the well during this 24 hour monitoring period showed no signs of tracer present (Figure 3.12 (b)). Water samples collected from the sample collection facility were analyzed onsite for presence of fluorescence and showed little tracer to have entered the well; this is thought to be from the initial amount leaking from the seams in the galvanized casing (Figure 3.13 (b)). Given the volume of water stored in the well at the time of the test (~750 L) and the highest concentration of fluorescence detected (21.4 ppb) ~300 mL of tracer solution entered ETH3. This combined with the length of visually observing the leak indicates a flow rate of ~5.6 mL/minute. The large quantity of water removed from the well also removed the initial tracer solution that entered the well through the seam in the galvanized casing in ~5 hours. Fewer samples were collected for analysis of Br^- by IC scan from ETH3 as a result of weather conditions. ETH3 is the last well to be pumped in the pumping schedule and as a result on some of the sampling days no power was left to pump this well and collect a sample. This resulted in the collection of 6 samples over 4 weeks. Results of this analysis indicate that irregular pumping of the well did not remove all the tracer solution (Figure 3.10 (c)). Twenty-seven days after the infiltration test was initiated background levels of Br^- have not been reached. This may be due to pumping problems that have been observed while collecting samples and not exchanging the water in the well or tracer solution may continue to enter the well. No evidence of tracer continuing to enter has been observed, however, and at these very low concentrations in the well water it is doubtful that it could be continuing to enter.

The aqueous tracer test at ETH2 was conducted on October 20, 2009. ~500 L of tracer solution was mixed at a concentration of 12 000 mg/L of KBr, and 50 mg/L of Rhodamine B and allowed to infiltrate. The tracer solution was added in stages at this test well to avoid ponding water higher than the electrical conduit. ~110 minutes was required to add all the tracer and more than 8 hours for it to completely infiltrate. The long infiltration time is attributed to grass cover and the soil being saturated. Pumping of the well began once the infiltration gallery was filled with tracer solution to just below the electrical conduit at a sustainable rate of 22 L/minute. Pumping was continued for 23 hours and ~15 000 L of water was purged from ETH2. During the visual inspection no sign of tracer was ever observed. The data collected by the conductivity probe did not show any occurrences of tracer solution (Figure 3.12 (c)). Water samples collected from the sample collection facility were analyzed onsite for fluorescence and provided results below the detection limits of the analytical method. Samples collected for analysis of Br^- by IC scan during normal operation of the well did not show any signs of Br^- (Figure 3.10 (d)). This information further proves that tracer did not enter ETH2.

3.6.1 Aqueous tracer test summary

The enhanced test wells have some design flaws, which include; the electrical conduit connection and the riveted seams in the corrugated galvanized casing. The problem of the electrical conduit could be fixed in the future and on future constructed wells by placing the conduit higher above the ground level and/or sealing it better. The riveted seams in the corrugated galvanized casing is an inherit problem that has to be solved by the manufacturer or through the use of a different casing material. The conventional test well demonstrated the benefits and need of; mastic sealant between concrete casing sections, annular sealants, and sanitary connections made between the pump and the waterline. Table 3.3 provides a summary of the observations from the aqueous tracer tests.

3.7 Water quality

Interim, baseline and routine monitoring water samples were collected from the test wells and an upgradient monitoring well thought to be representative of background water quality. The interim and baseline water samples were collected in March 2008 and February 2009, respectively, and sent to an outside lab for analysis. Routine monitoring samples were collected monthly (beginning in May 2009) and analyzed with duplicate samples sent to an external laboratory quarterly for comparison. Tables of these results are found in Appendix C.

The water quality data was compared to the Ontario Drinking Water Standards, Objectives and Guidelines (2006) and four parameters were above the criteria. These parameters are total coliforms (TC), chloride, zinc, and hardness (Figure 3.15). High levels of *E. coli* and fecal coliforms were also detected in CTH1 and ETH1 on August 5, 2009. The bacteriological parameters (TC, *E. coli* and fecal coliforms) have non-detectable maximum acceptable concentrations (MAC) whereas the remaining parameters have aesthetic objectives (AO) (chloride and zinc) and operational guidelines (OG) (hardness). Parameters that have AO may impair taste, odour, or colour of water, or may interfere with good water quality control practices. Parameters that have OG may negatively affect the efficient and effective treatment, disinfection and distribution of water (Ontario Drinking Water Standards, Objectives and Guidelines, 2006).

TC has been detected in all test wells and MW2 and was found in especially high concentrations in CTH1 and MW2. It was only toward the end of the summer (August 2009) that detectable amounts of TC were found in ETH1. *E. coli* and fecal coliforms were only detected in CTH1 and ETH1. These bacteriological parameters were found in MW2, which is a PVC cased monitoring well upgradient of the test wells that suffered some damage during installation of the test wells. PVC cased wells are expected to perform better than large diameter wells since there are no joints in the casing providing fewer entry points for surface contamination. This implies that CTH1 has been contaminated by surface water which was expected but ETH1 was also contaminated. The source of surface water contamination in ETH1 may be the electrical conduit as was seen in the aqueous tracer test. All of these wells draw water from a formation that is within 15 m of the surface; they are considered GUDI wells and are considered under direct influence of surface water (Ontario Ministry of the Environment, 2001).

In all test wells and the monitoring well the values for chloride and hardness are consistently above the AO of 250 mg/L and OG of 80 to 100 mg/L, respectively. These results indicate that the source water is hard and there is a source of chloride upgradient of the test wells. Zinc is found in both CTH1 and ETH3 but is only above the AO of 5 mg/L in ETH3 for the first water sample collected in March 2008. The high concentration of zinc in ETH3 can be attributed to the use of galvanized steel as a casing material. CTH1 is the only test well to use some galvanized fittings in the plumbing of the pump and water line, which may explain the higher concentration of zinc present in water from this well compared to the other concrete cased wells. CTH1 did not have a pump or galvanized plumbing fittings at the time of sampling in March 2008 and was below the detection limit for zinc. This confirms that the galvanized fittings cause the elevated zinc concentration in CTH1. The concentration of zinc in ETH3 dropped by almost 80 % in the 11 month span from March 2008 to February 2009. The data suggests that zinc was only leached from the casing during the first couple of months of the installation when the wells were not being purged of water. This may be due to the longer contact time when the wells were not being purged or the formation of biofilm on the interior casing wall has reduced the dissolution of zinc by providing a barrier.

3.8 Biofilm

Biofilm was allowed to develop on casing materials coupons (concrete, galvanized steel and fibreglass) and cleaned using a variety of mechanical, and a combination of mechanical and chemical methods. A method was developed for the analysis of biofilm growth on casing materials and was used to assess a best means of cleaning biofilm from different casing materials.

The analysis was conducted in triplicate and each analysis consisted of submerging five (5) coupons of each material in the biofilm reactor. The results of these analyses are comparable to each analysis only. This is due to variability in the analysis method and chemicals used. To assess the coupons for biofilm the amount of ATP was determined through the use of luminescent chemicals and a luminometer. To determine whether a method cleaned the coupon or not the value obtained from the coupon was compared to a positive control. The positive control (supplied in the ATP detection kit) was measured (for luminescence, relative light units (RLU)) before each analysis and a coupon was considered clean if the RLU were below 0.02 x the positive control as per the ATP detection kit guidelines.

The cleaning method results of the three (3) replicate analyses are presented in Figure 3.16. Scrubbing with a brush and scrubbing with a brush with bleach did remove biofilm from the casing materials but did not provide any clean results. Scrubbing with a brush when compared to scrubbing a bleach solution with a brush produced similar results which is surprising since bleach is a common disinfectant used to kill bacteria in a well. However, literature (Schniders, 2003) suggested that the biofilm hardens to protect the bacteria when in contact with disinfectants. Steam cleaning with scrubbing did not provide any clean results either. Steam cleaning with scrubbing did produce better results than either of the brush methods but even high temperature steam was unable to clean the coupons. Pressure washing was the only method to provide a positive clean coupon. This was only found on galvanized steel and fibreglass, the cement material was not able to be cleaned by pressure washing. The cement coupons were very porous when compared to galvanized steel and fibreglass and it is thought that these pore spaces allow the biofilm to attach more firmly and resist cleaning. The texture of the concrete was tactilely rougher when compared to the smoother galvanized steel and fibreglass materials. Pressure washing is able to provide much more pressure than the other methods which seems to be necessary to remove biofilm. Pressure washing also provides more even and consistent cleaning than the scrubbing methods which may play an important role in well casing cleaning in full scale applications. All methods did remove biofilm when compare to the un-cleaned coupons but only pressure washing provided promising positive results. Pressure washing was only able to remove biofilm from galvanized steel and fibreglass.

The results from the re-growth study are provided in Figure 3.17. The results show no cleaning method is any better at resisting re-growth over another. It is also clear that the coupon material is not a factor in the amount of re-growth.

3.9 Grout

3.9.1 Volume changes

For all three mixtures the greatest change in height and diameter occurred during the setting phase when the most water take up by the cement before the samples were removed from the moulds (Figures 3.18 (a) and (b)). There was very little change in height and diameter during curing in both the saturated and unsaturated conditions. The lower the bentonite content in the mixture the greater the change in height and diameter. This is due to the bentonite continuing to hydrate and swell during the setting and curing phase. Height and diameter are not presented near the end of the curing phase for the 3% samples due to a data collection error.

Mass was measured once the samples were removed from the moulds and as such only the changes during curing are captured. Figure 3.18 (c) depicts the increase in mass during the curing of the samples. A decrease in the 5% cylinders is noted for the 28 day measurement; the scale used for previous measurements was broken and another scale had to be used, which created discrepancies in the measurement. The continued hydration of the bentonite caused the samples to increase in mass and again the higher the bentonite content in the sample the greater the increase in mass. Hydration of the bentonite is an uptake of water which increases mass over time.

Figure 3.18 (d) shows the average percent change of height, diameter, mass, and total volume. The largest change in height is found in the sample with the 1% bentonite content and the lowest change was found in the 5% bentonite content grout. The curing condition seemed to make little difference in the change in height. The average change in diameter was uniform for each grout mixture and curing condition. This is due to the setting phase; as grout sets water is taken up by the cement and the height decreases but the mould contains the grout and prevents shrinkage in the diameter. The average change in mass was also uniform for each grout mixture and curing condition. This suggests that the 1% grout mixture will decrease in height the most next to the well both above and below the water table. The diameter will shrink the same amount with all mixtures both above and below the water table. A reduction of the diameter may present a problem since the grout could pull away from the formation, well casing or both causing a pathway for surface water to come in direct contact with the well casing. The percent change in total volume support these data.

3.9.2 Vertical load bearing capacity

Figure 3.19 (a) displays the average force required to break each mixture cured in both saturated and unsaturated conditions. Error bars provide the standard deviation for each sample set. The 1% bentonite mixture cured in both conditions was strongest, followed by the 3% bentonite mixture and finally the 5% bentonite mixture. From these results it is clear that bentonite reduces the vertical load bearing capacity of cement-bentonite grout. Figure 3.19 (b) displays the average pressure required to cause the specimens to fail. Even the weakest 5% bentonite mixture requires ~100 kg/cm^2 to cause failure. This is considerably higher than the amount of pressure a person could apply when working around a large diameter well. Even a pickup truck that weighs 2850 kg with a contact area of ~700 cm^2 per tire would create a pressure of ~1 kg/cm^2 and could not cause the pressure required for failure of the grout.

3.9.3 Hydraulic conductivity

A clay sample was analyzed in both the flexible permeameter and centrifuge to ensure that the apparatus' were functioning properly before the grout samples were analyzed. The centrifuge method provided a K of 4.54 x 10^{-8} cm/s and the flexible wall permeameter method provided a K of 2.77 x 10^{-9} cm/s. Given that these results were less than an order of magnitude in difference it was assumed that the centrifuge method was properly functioning.

The cement-bentonite grout samples were then analyzed in the flexible wall permeameter; however, no reliable results for grout samples were ever obtained. It is thought that the flexible wall permeameter was unable to fully saturate the grout samples due to the very rigid structure of the grout samples when compared to clay samples. ASTM D5084-03 states that a maximum hydraulic gradient of 30 can be used to analyze hydraulic conductivity in a flexible wall permeameter. This equates to a pressure differential across the sample of ~6 kPa which could not properly saturate the sample. The results seemed to indicate fluctuations in the volumetric bladder due to pressure and temperature changes. Over 2 weeks of monitoring the volume fluctuated by ±0.005 mL, which relates to a hydraulic conductivity of 4.6×10^{-12} cm/s. Therefore, grout samples were exclusively analyzed using the centrifuge method.

Duplicate samples of each grout mixture and curing condition were analyzed in the centrifuge and the average values are displayed in Figure 3.20. The hydraulic conductivity values range from 2.1×10^{-8} cm/s to 1.2×10^{-7} cm/s. The bentonite content and curing condition do not affect the hydraulic conductivity. The U.S. Environmental Protection Agency (1990) requires that soil liners used in the constructing of landfills are less than or equal to 1×10^{-7} cm/s. This minimum requirement ensures that leachate cannot rapidly pass through the liner and contaminate areas outside the landfill. Using this same standard for annular sealants the 5% bentonite grout mixture investigated here, cured in both saturated and unsaturated conditions, is the only mixture to exceed this requirement.

3.9.4 Grout summary

Cement-bentonite grout with 5% bentonite cured in both saturated and unsaturated conditions would make a suitable annular sealant provided that a reduction in the diametric volume does not create a vertical pathway on the geologic formation. The 5% bentonite grout investigated here was non-conductive and provided a suitable barrier against infiltrating water coming in contact with the well casing both above and below the water table. Based on the vertical load bearing capacity, each of the grouts analyzed would resist cracking or failure when the load of a man or truck is applied. The 5% bentonite content mixture also had the least vertical shrinkage and least overall volume change. Excess vertical shrinkage may cause a low spot around the ground surface which would allow water to pond in the vicinity of the well casing.

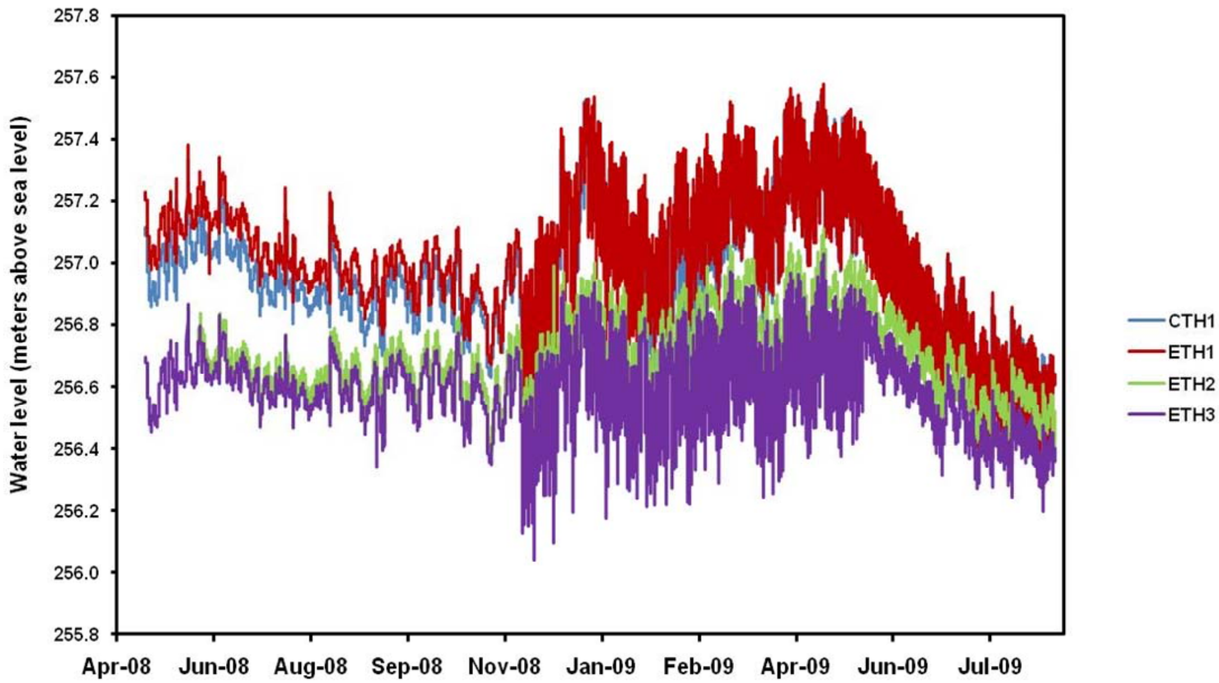

Figure 3.1. Test well water level measurements from pressure transducers.

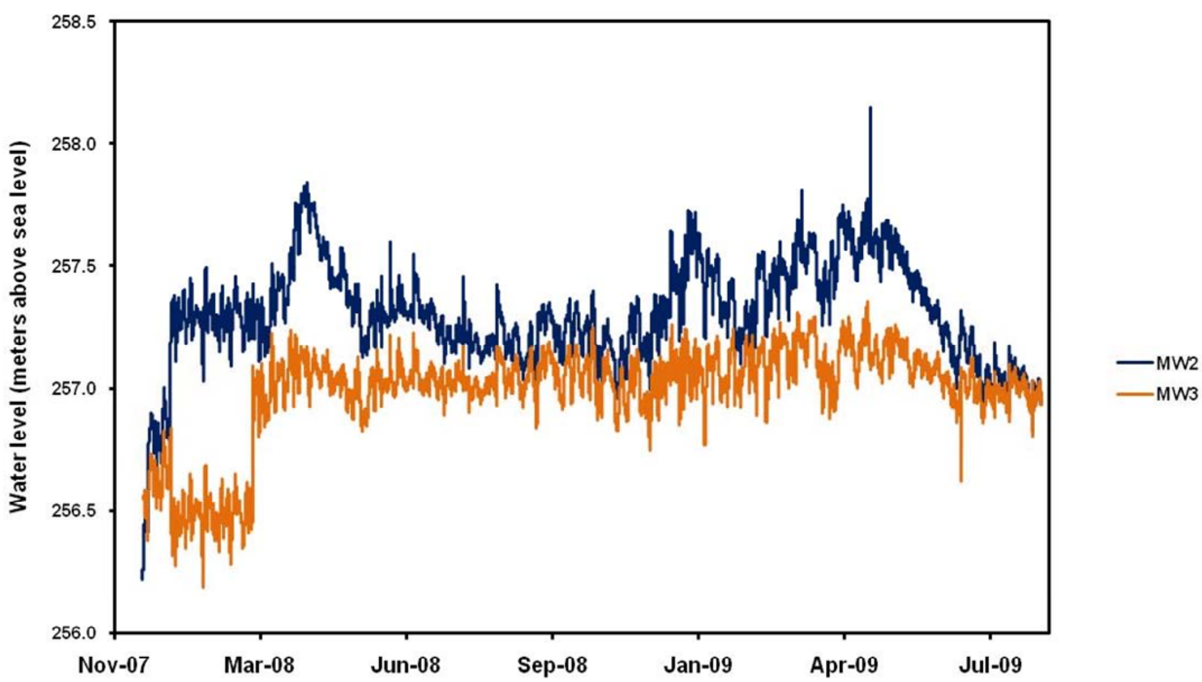

Figure 3.2. Monitoring well water level measurements from pressure transducers.

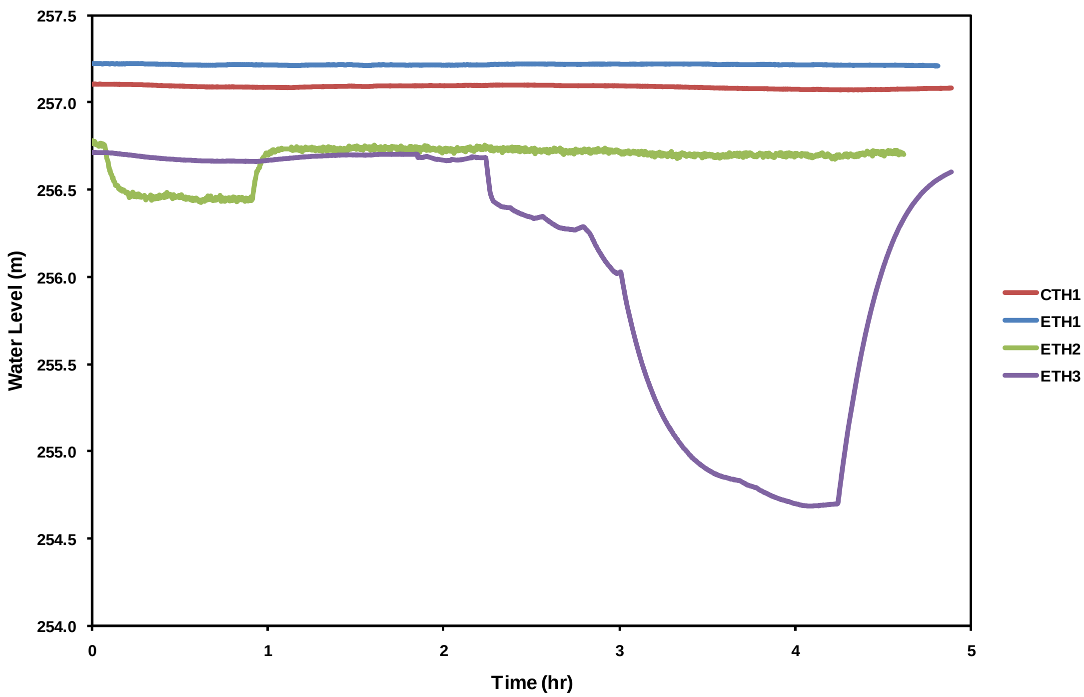

Figure 3.3. Day 1 water level response for ETH2 and ETH3 extraction and recovery tests.

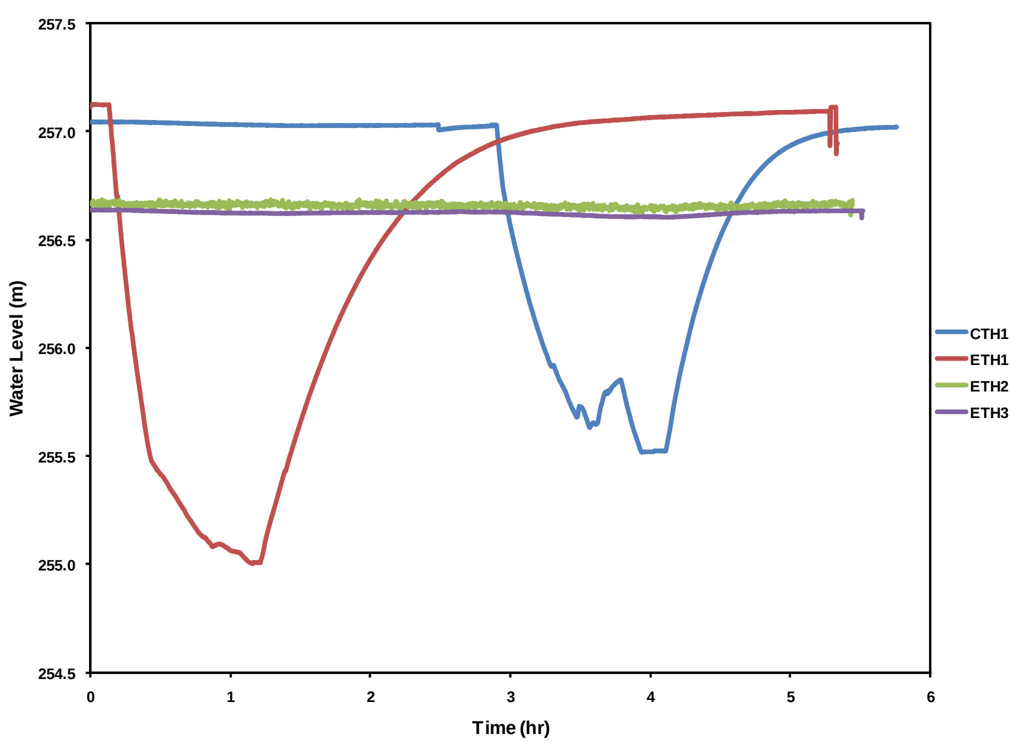

Figure 3.4. Day 2 water level response for ETH1 and CTH1 extraction and recovery tests.

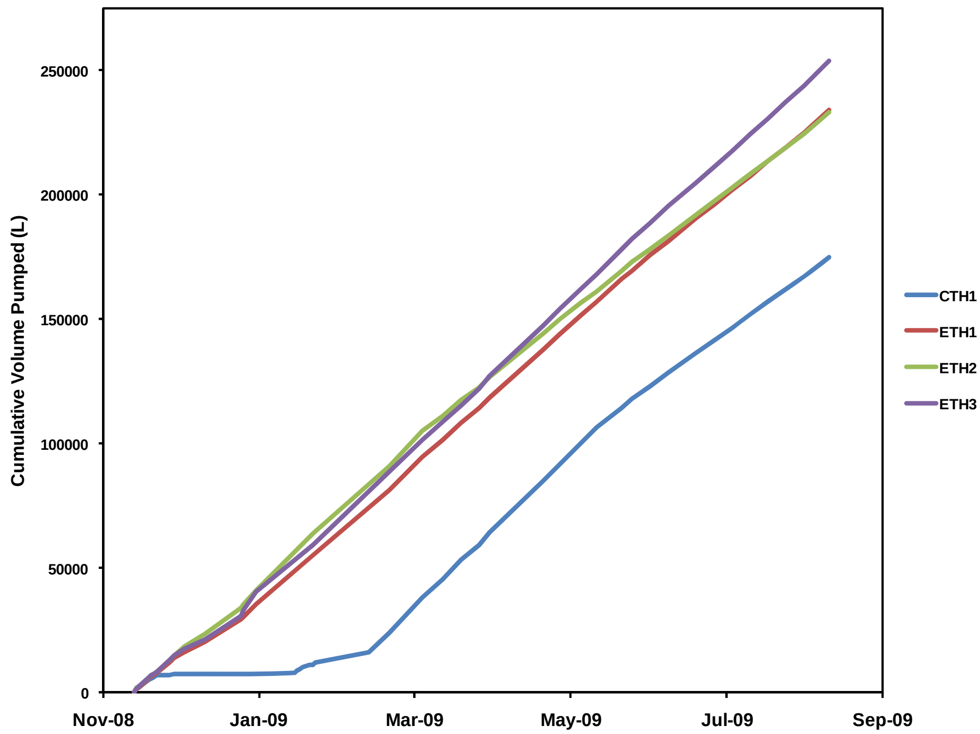

Figure 3.5. Cumulative volume of water pumped from test wells.

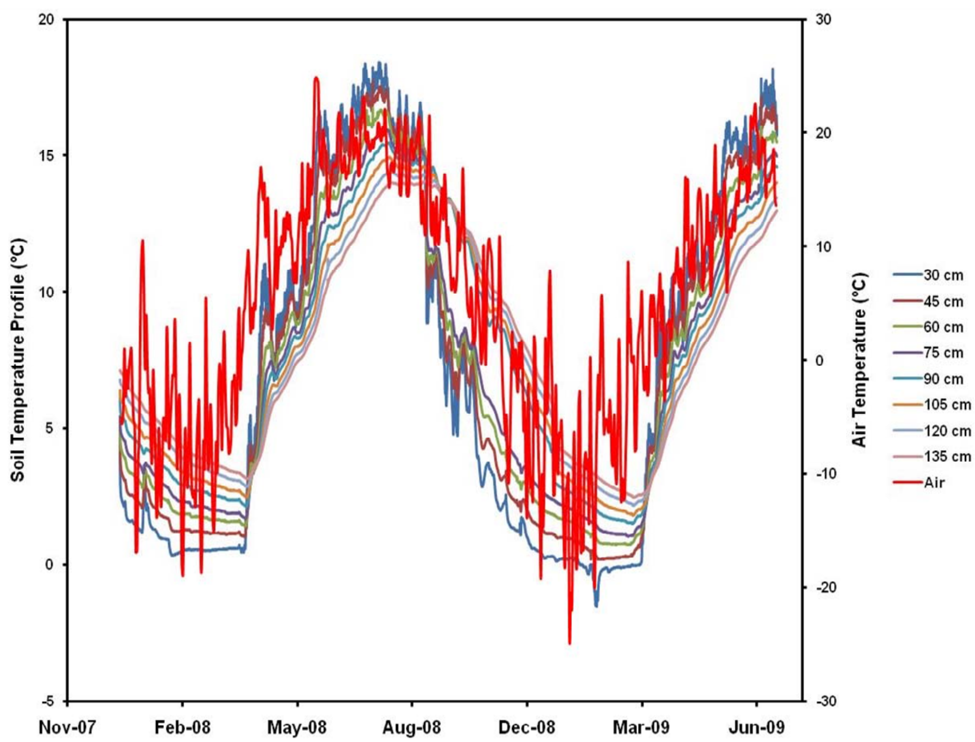

Figure 3.6. Soil temperature profile.

Figure 3.7. Photos of bentonite chip annular seal around ETH2 (a) annular seal during installation, and (b) annular seal after hydration and swelling.

Figure 3.8. Photos of smoke tracer tests showing (a) rags used to seal CTH1 during test #1, (b) dark coloured water leaking from seams of ETH3 casing during test #1, (c) apparatus properly sealing CTH1 during test #2, and (d) smoke escaping from Poly – Lok lid of ETH1 during test #2 caused by damage during test #1.

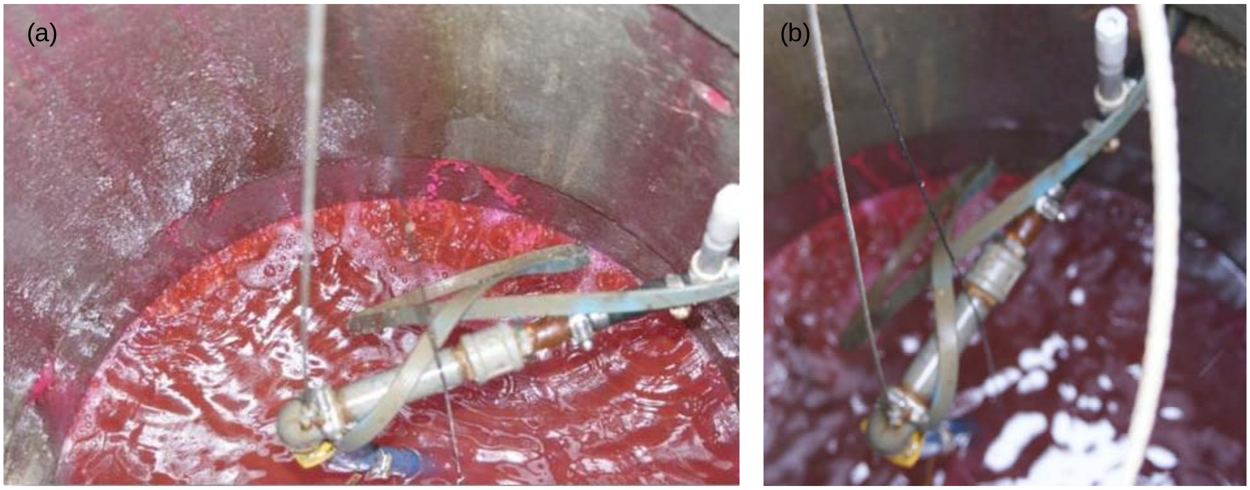

Figure 3.9. Photos of tracer solution entering CTH1 through (a) well casing joints, and (b) waterline and power supply.

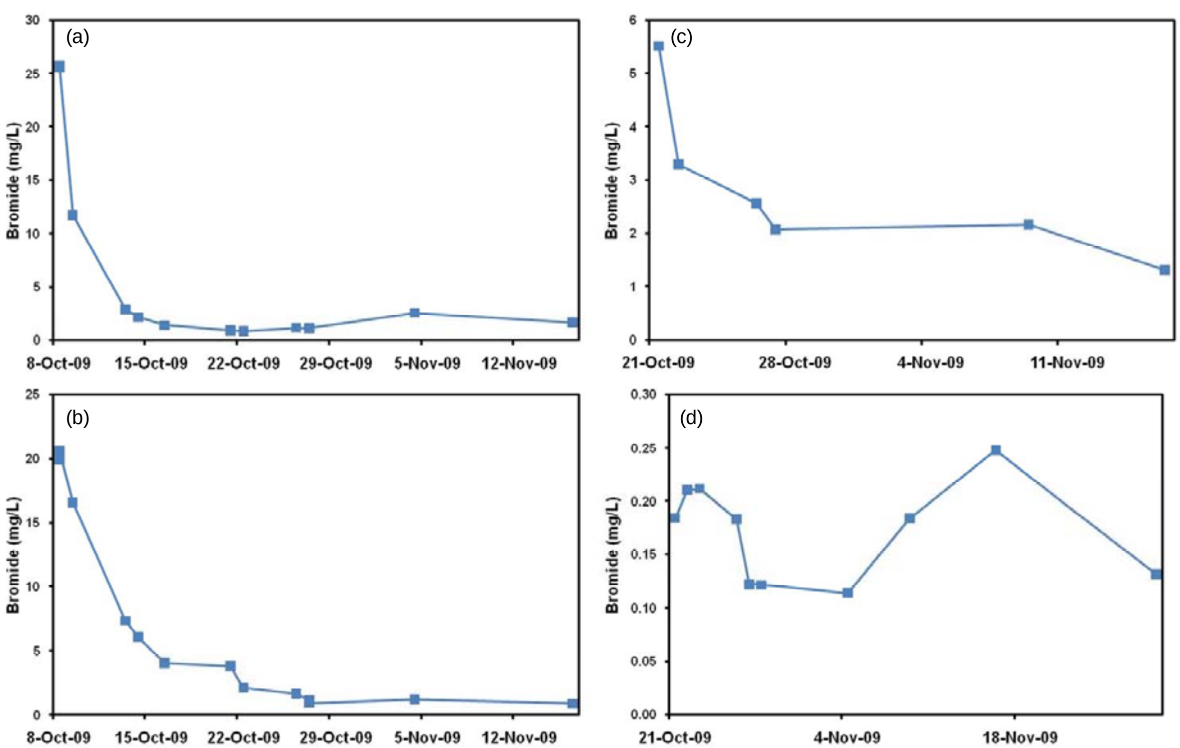

Figure 3.10. Results from Br^- analysis for (a) CTH1, (b) ETH1, (c) ETH3, and (d) ETH2.

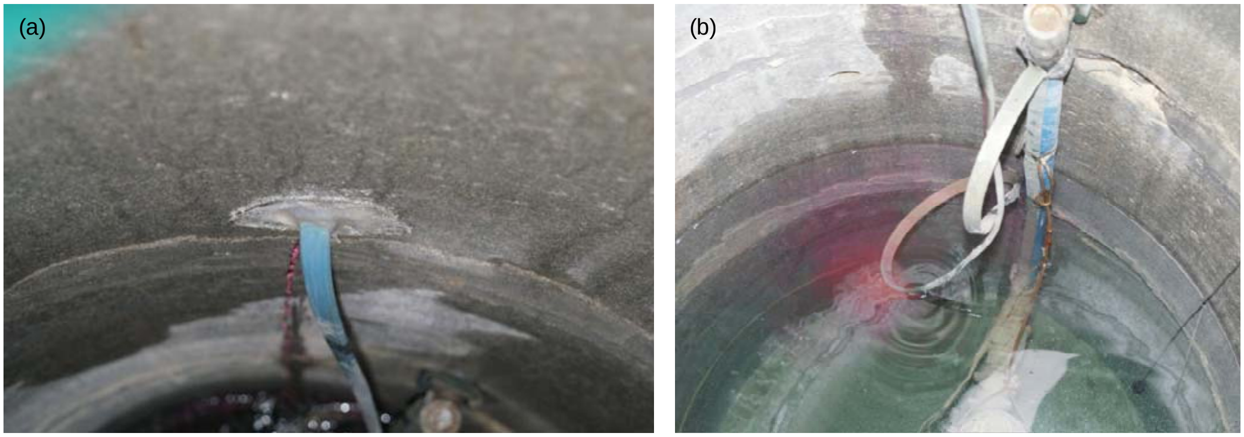

Figure 3.11. Photos of tracer solution entering ETH1 through (a) the electrical conduit and (b) the resulting contamination of the water in the well.

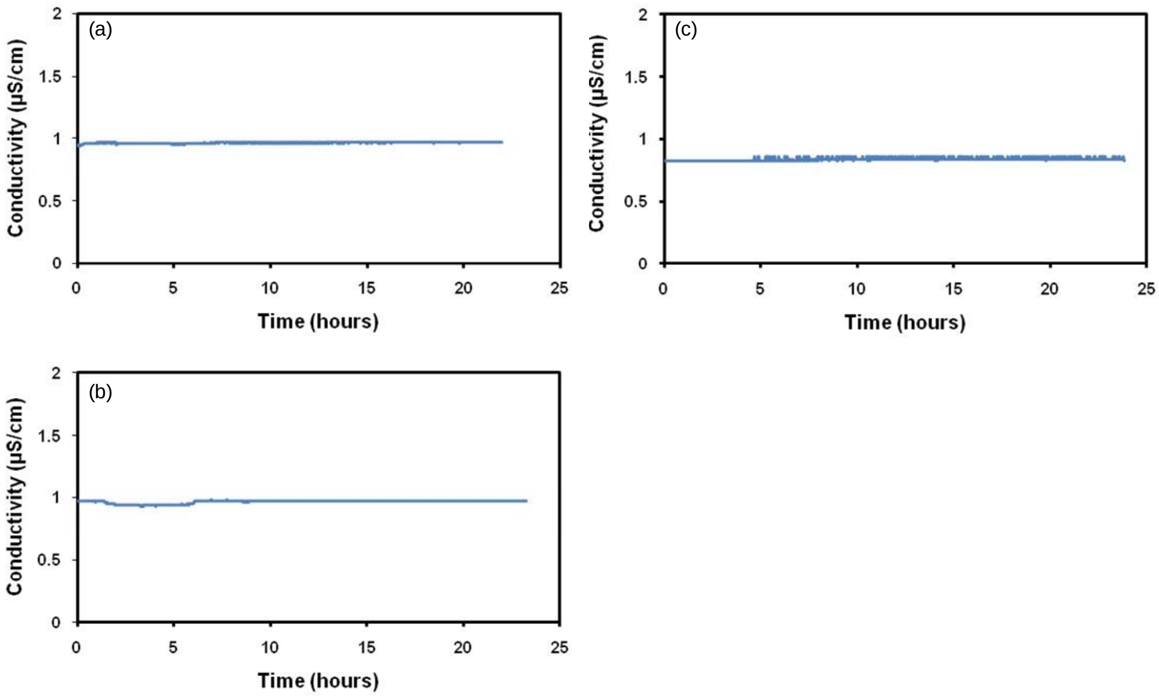

Figure 3.12. Conductivity data during the initial 24 hours of monitoring during the aqueous tracer test for (a) ETH1, (b) ETH3, and (c) ETH2.

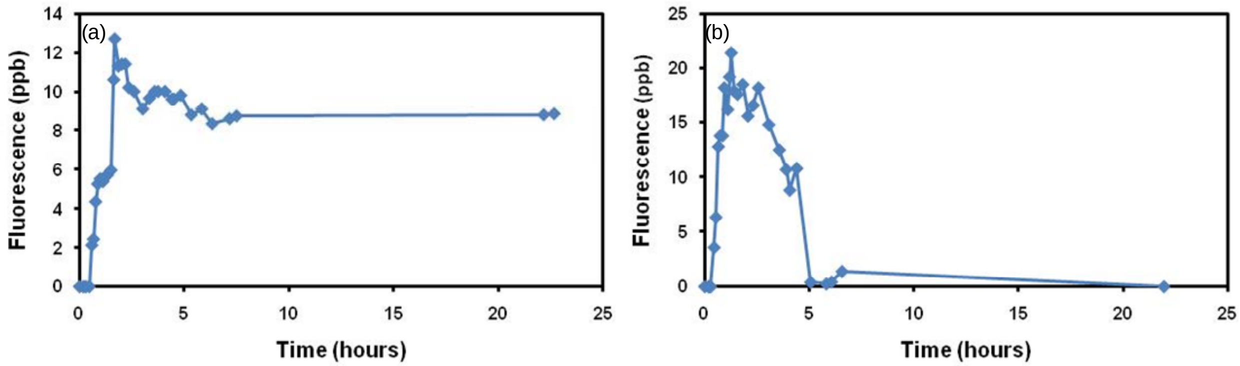

Figure 3.13. Fluorescence data collected during the initial 24 hours of monitoring during the aqueous tracer test for (a) ETH1, and (b) ETH3.

Figure 3.14. Photos of tracer solution at ETH3 (a) being placed on thick grass cover, and (b) leaking through the riveted seam in corrugated galvanized casing.

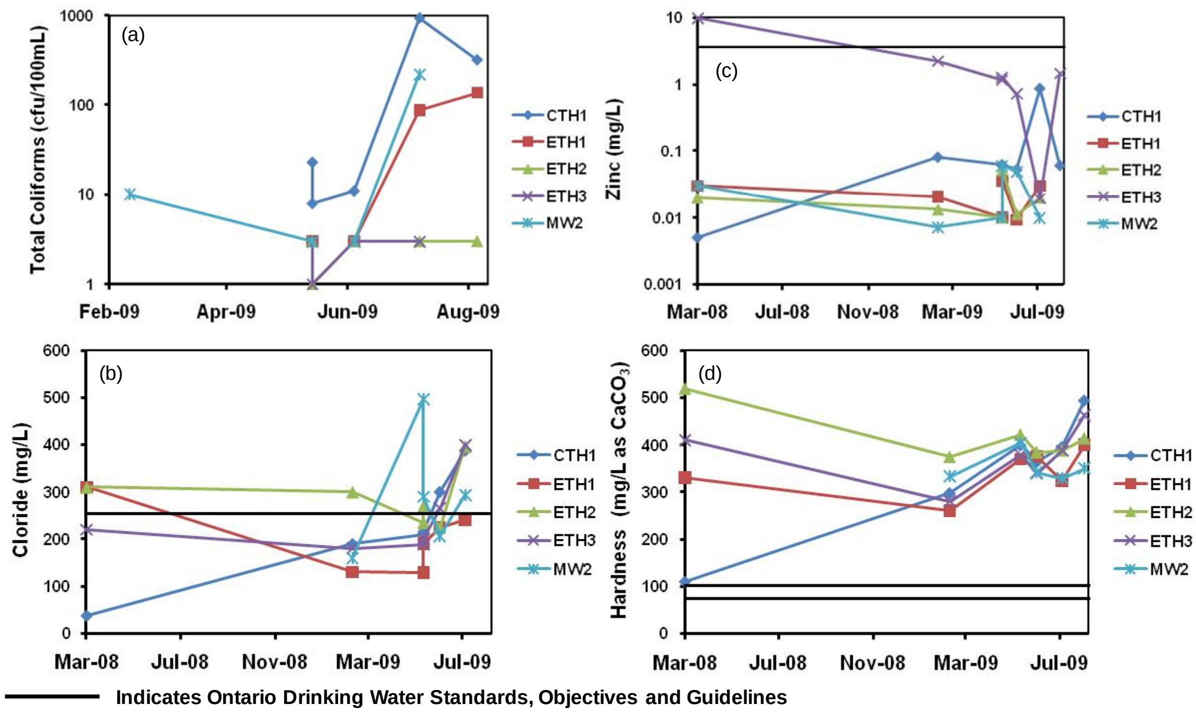

Figure 3.15. Water quality data from both external and internal labs for (a) total coliforms, (b) chloride, (c) zinc, and (d) hardness.

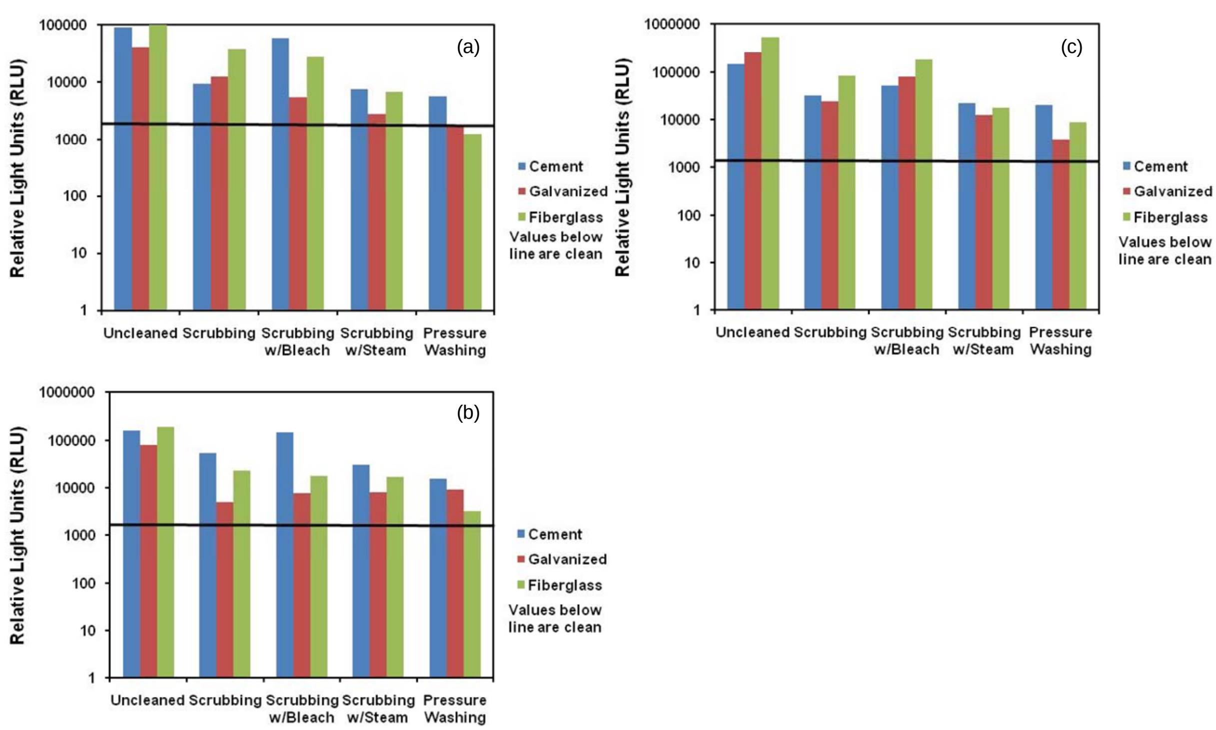

Figure 3.16. Biofilm cleaning methods results for three replicates.

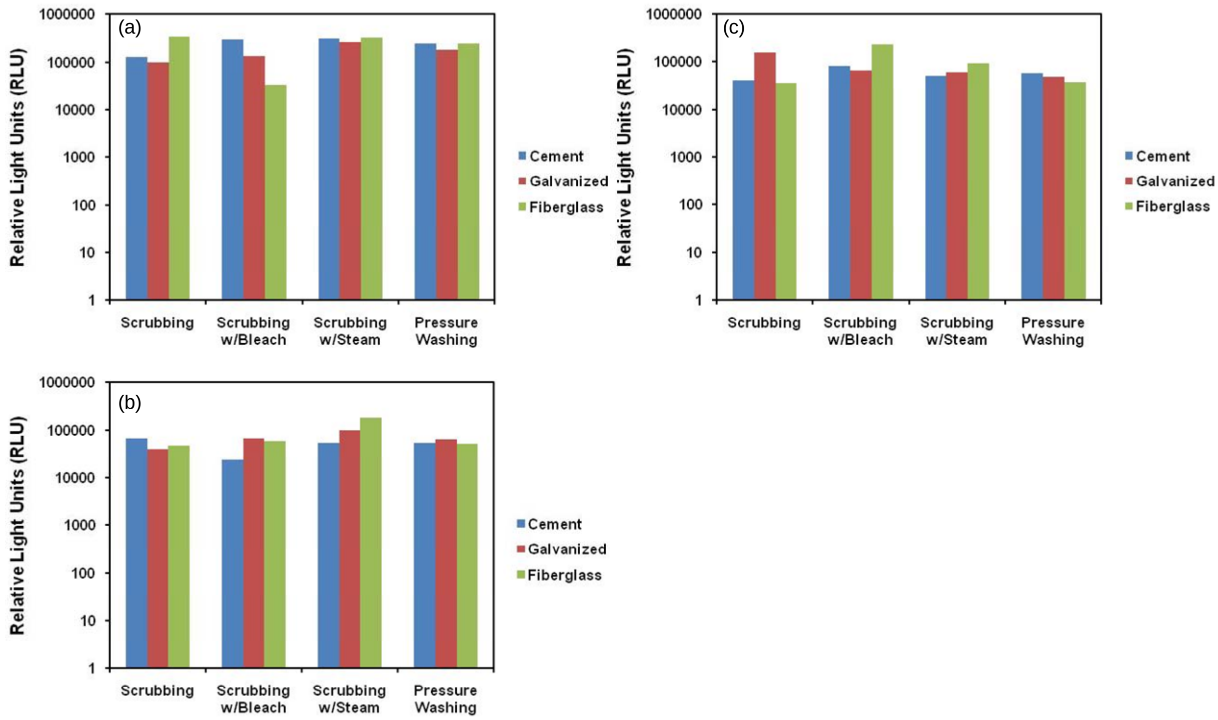

Figure 3.17. Biofilm re-growth results for three replicates.

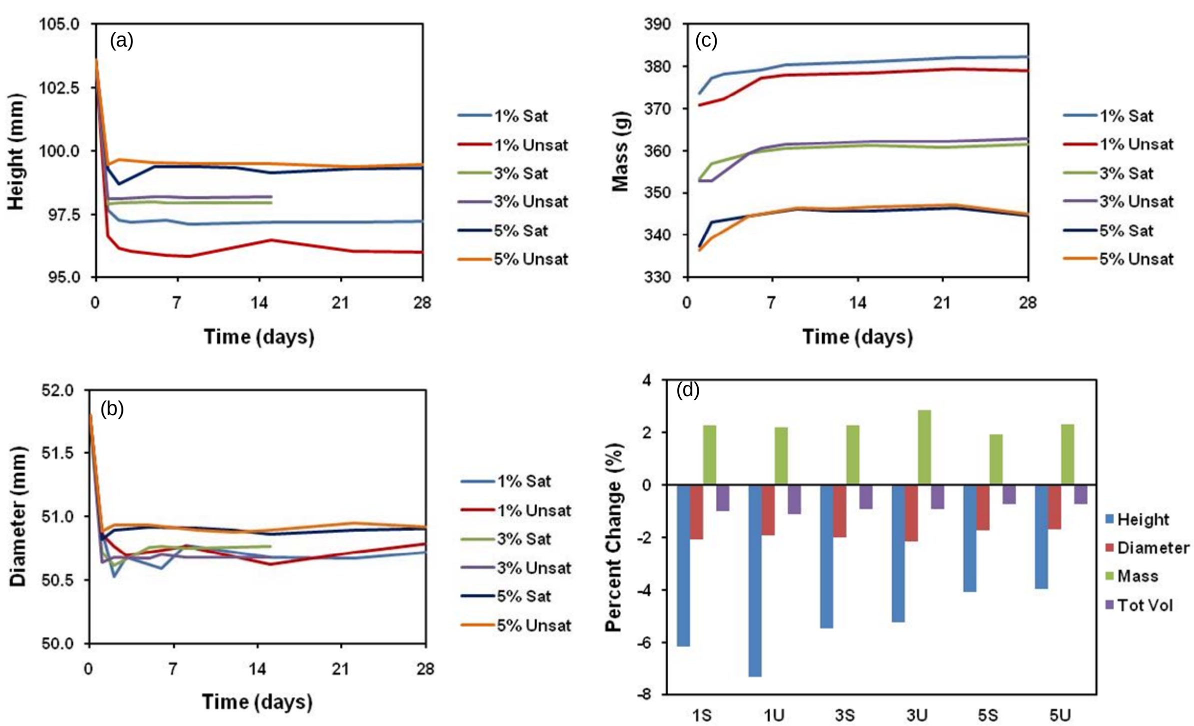

Figure 3.18. Grout volume changes during setting and curing for (a) height, (b) diameter, (c) mass, and (d) average percent change.

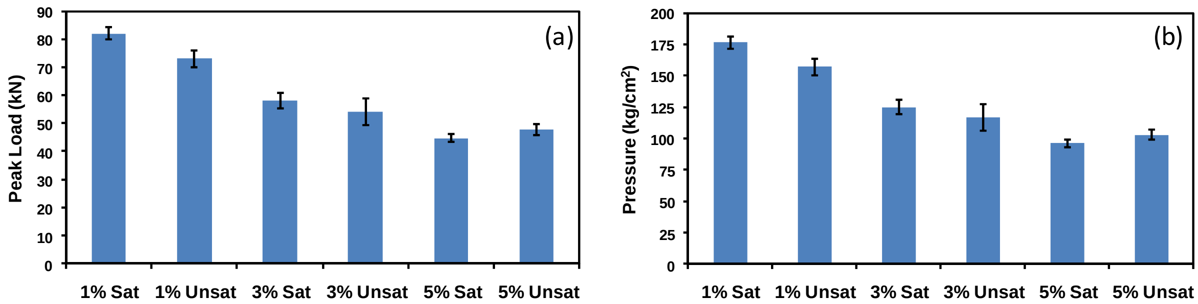

Figure 3.19. Average vertical load bearing capacity results: (a) average peak load, and (b) average breaking pressure. Error bars indicate one standard deviation.

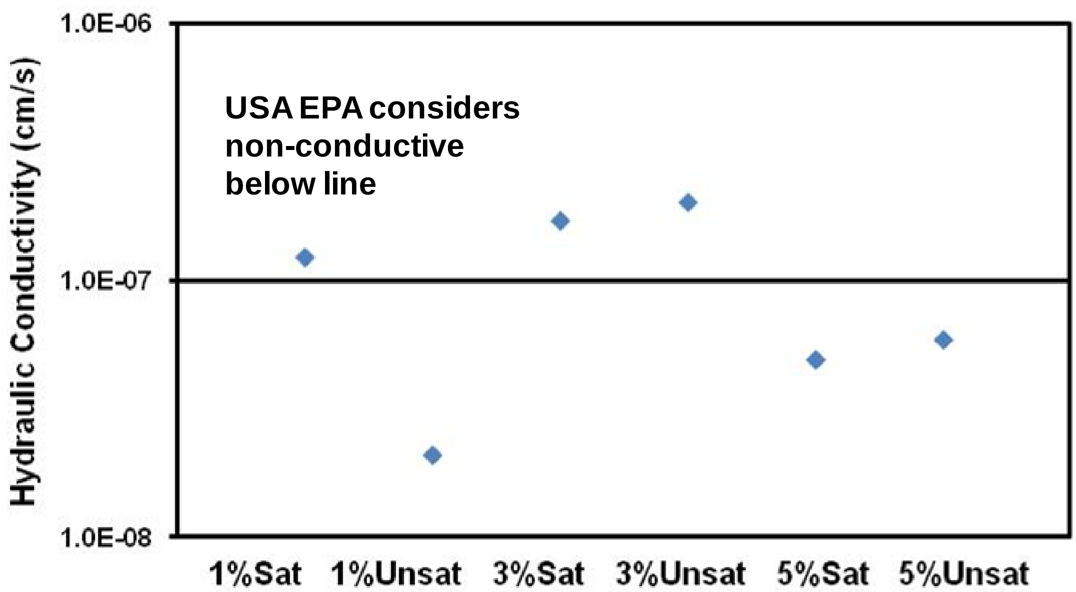

Figure 3.20. Average hydraulic conductivity of cement-bentonite grouts.

Table 3.1. Daily test well pumping program.

Well		Daily Program Times A	B	C	Total Pump Time
ETH2	On	11:40	13:20	14:45	40 min
	Off	12:00	13:30	14:55	
CTH1	On	12:01	13:31		40 min
	Off	12:21	13:51		
ETH3	On	12:22	13:52		40 min
	Off	12:42	14:12		
ETH1	On	12:50	14:20		40 min
	Off	13:10	14:40		

Table 3.2. Observations from smoke tracer test #1/ test #2.

Air Leak Location	CTH1	ETH1	ETH2	ETH3
Poly-Lok lid seam	NA/NA	Yes/Yes	Yes/Yes	Yes/Yes
Poly-Lok lid and concrete cover joint	NA/NA	No/No	No/No	No/No
Interior geophysical access tube	Yes/Yes	Yes/Yes	Yes/Yes	NA/NA
Electrical conduit	NA/NA	Yes/Yes	Yes/Yes	Yes/Yes
Water line entry	No/No	No/No	No/No	No/No
Casing joints or seams	Yes/Yes	Yes/No	Yes/No	Yes/Yes
Annular sealant	No/No	No/No	No/No	No/No
Exterior geophysical access tube	No/No	No/No	No/No	No/No

NA – Not Applicable

Table 3.3. Observations from aqueous tracer tests.

Air Leak Location	CTH1	ETH1	ETH2	ETH3
Electrical conduit	NA	Yes	Yes	Yes
Water line entry	Yes	No	No	No
Casing joints or seams	Yes	No	No	Yes

NA – Not Applicable

4.0 Conclusions and Recommendations

4.1 Conclusions

A facility to study the performance of large diameter residential drinking water wells was constructed in Lindsay, Ontario, on the Frost campus of Fleming College. This facility included three enhanced test wells and one conventional test well which were fully automated and operational. Water was purged from the test wells daily by solar powered pumps and was discharged to a drainage ditch through a drainage system. The drainage system incorporated a sample collection facility with a cumulative flow gage. The average daily pumping volume, 875 L/day, was lower than expected as a result of the solar energy collection system not receiving enough sunlight on overcast days to charge the batteries and power the pumps.

Monitoring data show that ground water flows southeast toward the Scugog River, and that the soil temperature follows expected freeze-thaw cycles. Monitoring of the non-hydrated bentonite chip annular sealant used at ETH2 indicated that it fully hydrated and created a seal around the well in about 6 months following installation. This was confirmed when excavated to install the sanitary waterline connection. ETH3 also used a non-hydrated bentonite seal and during waterline excavation (11 months after installation) it was observed that the seal was not fully hydrated.

Test well water quality data indicated that the wells were impacted with bacterial contaminants including total coliforms and fecal coliforms. The Ontario Drinking Water Standards, Objectives and Guidelines (2006) state that only non-detect limits are acceptable for these bacterial contaminants. Higher levels of zinc were found in wells ETH3 and CTH1 (9.80 mg/L and 0.87 mg/L, respectively) than the other wells (between 0.01 and 0.05 mg/L) and were assumed to be caused by the galvanized casing and galvanized plumbing fittings, respectively. Hardness ($CaCO_3$) and chloride were above the Ontario Drinking Water Standards, Objectives and Guidelines (2006) in all wells and are consistent with background water quality.

The results from the aqueous tracer tests highlighted that the design features of the enhanced test wells reduce the impact of surface water. These tests also identified flaws in both of the casing materials used in the construction of the test wells. The electrical conduit presents a risk of surface water contamination if water ponds above it, and the galvanized casing has inherit flaws in the design as surface water was able to penetrate through the riveted seams. The conventional test well demonstrated the need for annular sealants, mastic sealant, and a sanitary waterline connection since tracer solution was observed entering in these areas. The enhanced test wells that utilized these sealants and connections showed no influence of the aqueous tracer. A bentonite based annular sealant performed best during the aqueous tracer test. A concrete casing with mastic sealant between sections, and a bentonite based annular sealant was the best large diameter well design studied, as they were properly sealed to prevent surface water infiltration.

Two smoke tracer tests (conducted in the winter and summer) showed that pathways between the atmosphere and the interior of the test wells do exist. During the winter, many pathways were highlighted by smoke escaping, but during the summer, fewer pathways existed. Smoke was observed exiting CTH1 through all joints and openings located above the water table during both the winter and summer tests. During the winter test, smoke was observed escaping through all joints located above the water table in the enhanced test wells that were sealed with mastic sealant but during the summer these pathways were not observed. However, pathways for airborne contaminants did exist in the summer, including the electrical conduit and the seam of the galvanized casing. The results of these tests show that a concrete cased well with mastic sealant in the joints provides the best protection from airborne contaminants.

Coupons of concrete, galvanized steel, and fibreglass casing materials were allowed to develop a biofilm and then cleaned using practical methods developed for this study. The results of this analysis demonstrated that galvanized steel and fibreglass are more easily cleaned than concrete. The cement coupons were very porous when compared to galvanized steel and fibreglass, and it is thought that these pore spaces allow the biofilm to attach more firmly and resist cleaning. The texture of the concrete was tactilely rougher when compared to the smoother galvanized steel and fibreglass materials. The best method to remove biofilm from coupons of casing material in the laboratory was pressure washing as this method created more force than the brushing methods to physically remove the biofilm.

Three different mixtures of cement-bentonite grout were analyzed in the laboratory for volume changes during setting and curing, vertical load bearing capacity, and hydraulic conductivity. Only the 5% bentonite content grout was non-conductive and would prevent infiltrating water from coming in contact with the well casing. All three of the mixtures were able to support the weight of a man or equipment without causing failure and creating pathways for infiltrating water to come in contact with the well casing. The 5% bentonite content grout also had the least volume change during setting and curing, and would make the best annular sealant.

The results of this study indicate that when large diameter wells are constructed with proper annular sealants, sealant between casing sections, and a sanitary waterline connection, they are less prone to atmospheric and surface water contamination. This study also shows that cement is a better casing material than corrugated galvanized steel. The corrugated galvanized steel casing had many pathways for contaminants which were highlighted by the smoke and aqueous tracer tests. The results of this study also indicate that corrugated fibreglass may be the most suitable casing material since it does not have any seams, is impermeable, and is easily cleaned of biofilm.

4.2 Recommendations

This research focused on determining a best design to improve the integrity of large diameter drinking water wells, and to determine whether one design is more prone to contamination than another. The following recommendations are made for extending the results of this study:

- Continue with routine monitoring of the existing test wells to determine the effect of well age on performance. Activities should include monthly water quality sample collection, well water elevation, soil temperature profile, cumulative volume purged, and quarterly external and internal visual inspection;

- Install a second set of deep cycle batteries in parallel to the existing batteries in the solar energy collection system to provide more power storage during overcast periods;

- Investigate a higher location above ground surface for the electrical conduit and a better sealing method for future large diameter wells;

- Construct and monitor the performance of another large diameter well using a fibreglass casing, as this material may provide a better alternative to the continuous galvanized casing with riveted seams and the concrete casing with sealed joints;

- Construct another concrete cased enhanced large diameter test well to study the performance of cement-bentonite grout as an annular sealant;

- Conduct another smoke tracer test in the winter to determine whether the cold temperatures was the cause of the dissimilar results between the observations collected in winter and summer;

- Assess factors that influence biofilm development in large diameter wells and develop field-scale methods to remove biofilm from the interior casing wall of a large diameter well;

- Apply a liner to the interior casing wall of the conventional test well to determine if wells constructed using conventional methods can be retrofitted to prevent impacts of surface water.

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ASTM C511 – 06 Standard Specification for Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes, ASTM International.

ASTM C617 - 09a Standard Practice for Capping Cylindrical Concrete Specimens, ASTM International.

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Lindsay, Ontario, Map, Image © 2009 GeoEye, Google Earth, Oct. 21, 2007.

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Appendix A – Well Records

Appendix A contains the detailed copies of the Ontario Ministry of the Envirnmonet well records for the large diameter wells and the pre-existing monitoring wells at the field site.

Ontario Ministry of the Environment

Well Tag	A 054821	(er below)
	CTH1	

Well Record

Regulation 903 Ontario Water Resources Act

page ___ of ___

Instructions for Completing Form

- For use in the **Province of Ontario** only. This document is a permanent **legal** document. Please retain for future reference.
- All Sections **must** be completed in full to avoid delays in processing. Further instructions and explanations are available on the back of this form.
- Questions regarding completing this application can be directed to the Water Well Help Desk (Toll Free) at 1-888-396-9355.
- **All metre measurements shall be reported to 1/10th of a metre.**
- Please print clearly in blue or black ink only.

Ministry Use Only

MUN	CON	LOT

Well Owner's Information and Location of Well Information

First Name	Last Name	Mailing Address (Street Number/Name, RR,Lot,Concession)		
FLEMING	COLLEGE	599 BREALEY DRIVE		
County/District/Municipality	**Township/City/Town/Village**	**Province**	**Postal Code**	**Telephone Number** (include area code)
KAWARTHA LAKES	PETERBOROUGH	Ontario	K9J 7B1	
Address of Well Location (County/District/Municipality)	**Township**	**Lot**	**Concession**	
KAWARTHA LAKES	VICTORIA	17	5	
RR#/Street Number/Name	**City/Town/Village**	**Site/Compartment/Block/Tract etc.**		
200 ALBERT ST SOUTH	LINDSAY ~~KAWARTHA LAKES~~			

GPS Reading	NAD	Zone	Easting	Northing	Unit Make/Model	Mode of Operation:
	83	17	680561	4911940		☐ Undifferentiated ☐ Averaged ☐ Differentiated, specify

Log of Overburden and Bedrock Materials (see instructions)

General Colour	Most common material	Other Materials	General Description	Depth Metres From	Depth Metres To
BROWN	TOP-SOIL			0	.3
BROWN	SANDY CLAY			.3	1.82
BROWN	SAND			1.82	2.74
GREY	GRAVEL			2.74	3.81

Hole Diameter

Depth Metres From	Depth Metres To	Diameter Centimetres
0	3.81	121.92

Water Record

Water found at ___ Metres	Kind of Water
1.82 m ☐ Gas ☐ Other:	☐ Fresh ☐ Sulphur ☐ Salty ☐ Minerals
2.74 m ☐ Gas ☐ Other:	☐ Fresh ☐ Sulphur ☐ Salty ☐ Minerals
___ m ☐ Gas ☐ Other:	☐ Fresh ☐ Sulphur ☐ Salty ☐ Minerals

After test of well yield, water was
☐ Clear and sediment free
☐ Other, specify

Chlorinated ☑ Yes ☐ No

Construction Record

Inside diam centimetres	Material	Wall thickness centimetres	Depth Metres From	Depth Metres To
Casing				
91.44	☐ Steel ☐ Fibreglass ☐ Plastic ☑ Concrete ☐ Galvanized	7.62	0	3.81
	☐ Steel ☐ Fibreglass ☐ Plastic ☐ Concrete ☐ Galvanized			
	☐ Steel ☐ Fibreglass ☐ Plastic ☐ Concrete ☐ Galvanized			
Screen				
Outside diam	☐ Steel ☐ Fibreglass ☐ Plastic ☐ Concrete ☐ Galvanized	Slot No.		
No Casing or Screen				
	☐ Open hole			

Test of Well Yield

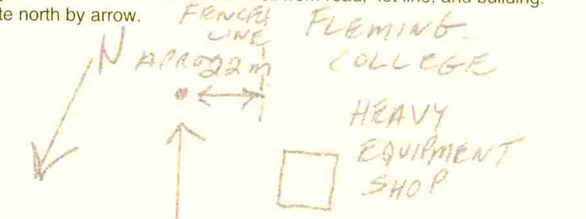
Pumping test method	Draw Down Time min	Draw Down Water Level Metres	Recovery Time min	Recovery Water Level Metres
Pump intake set at - (metres)	Static Level			
Pumping rate - (litres/min)	1		1	
Duration of pumping ___hrs + ___ min	2		2	
Final water level end of pumping ___ metres	3		3	
Recommended pump type. ☐ Shallow ☐ Deep	4		4	
Recommended pump depth. ___ metres	5		5	
Recommended pump rate. (litres/min)	10		10	
	15		15	
If flowing give rate - (litres/min)	20		20	
	25		25	
If pumping discontinued, give reason.	30		30	
TEST HOLE	40		40	
FOR GROUT	50		50	
	60		60	

Plugging and Sealing Record ☑ Annular space ☐ Abandonment

Depth set at - Metres From	Depth set at - Metres To	Material and type (bentonite slurry, neat cement slurry) etc.	Volume Placed (cubic metres)
0	2.45	CLAY FILL	
2.45	3.81	FILTER SAND	

Location of Well

In diagram below show distances of well from road, lot line, and building. Indicate north by arrow.



Method of Construction

Ontario Ministry of the Environment

Well A 054820 (number below)

ETH1

Well Record

Regulation 903 Ontario Water Resources Act

page ___ of ___

Instructions for Completing Form

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- **All metre measurements shall be reported to 1/10th of a metre.**
- Please print clearly in blue or black ink only.

Ministry Use Only — MUN ___ CON ___ LOT ___

Well Owner's Information and Location of Well Information

First Name	FLEMING
Last Name	COLLEGE
Mailing Address (Street Number/Name, RR,Lot,Concession)	599 BREALEY DRIVE
County/District/Municipality	KAWARTHA LAKES
Township/City/Town/Village	PETERBOROUGH
Province	Ontario
Postal Code	K9J 7B1
Telephone Number (include area code)	
Address of Well Location (County/District/Municipality)	KAWARTHA LAKES
Township	VICTORIA
Lot	17
Concession	5
RR#/Street Number/Name	200 ALBERT ST SOUTH
City/Town/Village	LINDSAY
Site/Compartment/Block/Tract etc.	
GPS Reading — NAD	83
Zone	17
Easting	680571
Northing	4911892
Unit Make/Model	
Mode of Operation	☐ Undifferentiated ☐ Averaged ☐ Differentiated, specify

Log of Overburden and Bedrock Materials (see instructions)

General Colour	Most common material	Other Materials	General Description	Depth Metres From	Depth Metres To
BROWN	TOP-SOIL			0	.3
BROWN	SANDY CLAY			.3	2.74
GREY	GRAVEL			2.74	3.65
GREY	CLAY			3.65	3.81
	ROCK OR SHALE IN BOTTOM				

Hole Diameter

Depth Metres From	Depth Metres To	Diameter Centimetres
0	3.81	121.92

Water Record

Water found at Metres	Kind of Water
2.74 m	☐ Fresh ☐ Sulphur ☐ Gas ☐ Salty ☐ Minerals ☐ Other:
___ m	☐ Fresh ☐ Sulphur ☐ Gas ☐ Salty ☐ Minerals ☐ Other:
___ m	☐ Fresh ☐ Sulphur ☐ Gas ☐ Salty ☐ Minerals ☐ Other:

After test of well yield, water was ☐ Clear and sediment free ☐ Other, specify

Chlorinated ☑ Yes ☐ No

Construction Record

Inside diam centimetres	Material	Wall thickness centimetres	Depth Metres From	Depth Metres To
Casing				
91.44	☐ Steel ☐ Fibreglass ☐ Plastic ☐ Concrete ☐ Galvanized	7.62	0	3.81
	☐ Steel ☐ Fibreglass ☐ Plastic ☐ Concrete ☐ Galvanized			
	☐ Steel ☐ Fibreglass ☐ Plastic ☐ Concrete ☐ Galvanized			
Screen (Outside diam)	☐ Steel ☐ Fibreglass ☐ Plastic ☐ Concrete ☐ Galvanized	Slot No.		
No Casing or Screen	☐ Open hole			

Test of Well Yield

Pumping test method	Draw Down Time min	Draw Down Water Level Metres	Recovery Time min	Recovery Water Level Metres
Pump intake set at - (metres)	Static Level			
Pumping rate - (litres/min)	1		1	
Duration of pumping ___hrs + ___ min	2		2	
Final water level end of pumping ___ metres	3		3	
Recommended pump type. ☐ Shallow ☐ Deep	4		4	
Recommended pump depth. ___ metres	5		5	
Recommended pump rate. (litres/min)	10		10	
	15		15	
If flowing give rate - (litres/min)	20		20	
	25		25	
If pumping discontinued, give reason.	30		30	
TEST HOLE	40		40	
FOR GROUT	50		50	
	60		60	

Plugging and Sealing Record

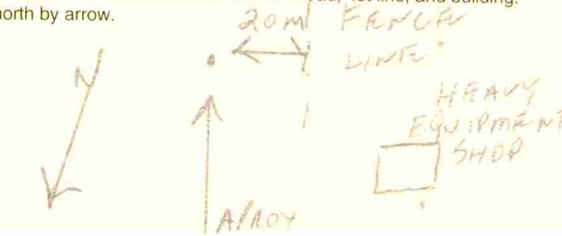
☑ Annular space ☐ Abandonment

Depth set at - Metres From	Depth set at - Metres To	Material and type (bentonite slurry, neat cement slurry) etc.	Volume Placed (cubic metres)
0	1.21	22.68 KG BENSEAL 22.68 KG SAND 1~~3~~ ~~LBS~~ 90 LITRES WATER.	
1.21	2.45	13.6 KG SAND EQUAL VOLUME BENSEAL 113 LITERS WATER.	
2.45	3.81	FILTER SAND.	

Method of Construction

Location of Well

In diagram below show distances of well from road, lot line, and building. Indicate north by arrow.



Ontario Ministry of the Environment

Well Tag No. (place sticker and/or print number below) A 054902

ETH2

Well Record

Regulation 903 Ontario Water Resources Act

page ___ of ___

Instructions for Completing Form

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- All Sections **must** be completed in full to avoid delays in processing. Further instructions and explanations are available on the back of this form.
- Questions regarding completing this application can be directed to the Water Well Help Desk (Toll Free) at 1-888-396-9355.
- **All metre measurements shall be reported to 1/10th of a metre.**
- Please print clearly in blue or black ink only.

Ministry Use Only

MUN	CON	LOT

Well Owner's Information and Location of Well Information

First Name	Last Name	Mailing Address (Street Number/Name, RR,Lot,Concession)
FLEMING	COLLEGE	599 BREALEY DRIVE

County/District/Municipality	Township/City/Town/Village	Province	Postal Code	Telephone Number (include area code)
KAWARTHA LAKES	PETERBOROUGH	Ontario	K9J 7B1	

Address of Well Location (County/District/Municipality)	Township	Lot	Concession
KAWARTHA LAKES	VICTORIA	17	5

RR#/Street Number/Name	City/Town/Village	Site/Compartment/Block/Tract etc.
200 ALBERT ST SOUTH	LINDSAY	

GPS Reading	NAD	Zone	Easting	Northing	Unit Make/Model	Mode of Operation:
	83	17	680613	4911959		☐ Undifferentiated ☐ Averaged ☐ Differentiated, specify

Log of Overburden and Bedrock Materials (see instructions)

General Colour	Most common material	Other Materials	General Description	Depth Metres From	To
BROWN	TOP-SOIL			0	.3
BROWN	SANDY CLAY			.3	2.43
GREY	GRAVEL		COARSE	2.43	4.26
	ROCK OR SHALE IN BOTTOM				

Hole Diameter

Depth Metres From	To	Diameter Centimetres
0	4.26	121.92

Construction Record

Inside diam centimetres	Material	Wall thickness centimetres	Depth Metres From	To
Casing				
91.44	☐ Steel ☐ Fibreglass ☐ Plastic ☒ Concrete ☐ Galvanized	7.62	0	4.26
	☐ Steel ☐ Fibreglass ☐ Plastic ☐ Concrete ☐ Galvanized			
	☐ Steel ☐ Fibreglass ☐ Plastic ☐ Concrete ☐ Galvanized			
Screen				
Outside diam	☐ Steel ☐ Fibreglass ☐ Plastic ☐ Concrete ☐ Galvanized	Slot No.		
No Casing or Screen				
	☐ Open hole			

Water Record

Water found at Metres	Kind of Water
2.43 m	☐ Fresh ☐ Sulphur ☐ Gas ☐ Salty ☐ Minerals ☐ Other:
m	☐ Fresh ☐ Sulphur ☐ Gas ☐ Salty ☐ Minerals ☐ Other:
m	☐ Fresh ☐ Sulphur ☐ Gas ☐ Salty ☐ Minerals ☐ Other:

After test of well yield, water was
☐ Clear and sediment free
☐ Other, specify

Chlorinated ☒ Yes ☐ No

Test of Well Yield

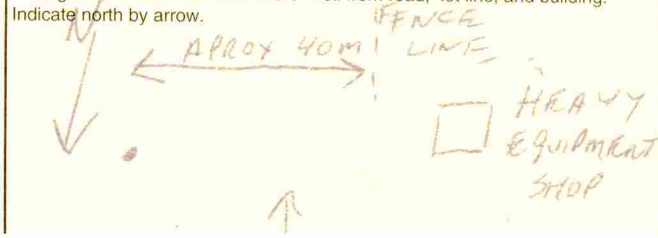
Pumping test method	Draw Down Time min	Water Level Metres	Recovery Time min	Water Level Metres
Pump intake set at - (metres)	Static Level			
Pumping rate - (litres/min)	1		1	
Duration of pumping ___hrs + ___ min	2		2	
Final water level end of pumping ___ metres	3		3	
Recommended pump type. ☐ Shallow ☐ Deep	4		4	
Recommended pump depth. ___ metres	5		5	
Recommended pump rate. (litres/min)	10		10	
	15		15	
If flowing give rate - (litres/min)	20		20	
	25		25	
If pumping discontinued, give reason.	30		30	
TEST HOLE	40		40	
FOR GROUT	50		50	
	60		60	

Plugging and Sealing Record ☐ Annular space ☐ Abandonment

Depth set at - Metres From	To	Material and type (bentonite slurry, neat cement slurry) etc.	Volume Placed (cubic metres)
0	2.45	BENITITE CHIPS	
2.45	4.26	FILTER SAND	

Location of Well

In diagram below show distances of well from road, lot line, and building. Indicate north by arrow.



Method of Construction

Ontario Ministry of the Environment

Well Tag No. A 054826 (number below)

ETH3

Well Record

Regulation 903 Ontario Water Resources Act

Instructions for Completing Form

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- All Sections **must** be completed in full to avoid delays in processing. Further instructions and explanations are available on the back of this form.
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- Please print clearly in blue or black ink only.

Ministry Use Only		
MUN	CON	LOT

Well Owner's Information and Location of Well Information

First Name	Last Name	Mailing Address (Street Number/Name, RR, Lot, Concession)
FLEMING	COLLEGE	599 BREALEY DRIVE

County/District/Municipality	Township/City/Town/Village	Province	Postal Code	Telephone Number (include area code)
KAWARTHA LAKES	PETERBOROUGH	Ontario	K9J 7B1	

Address of Well Location (County/District/Municipality)	Township	Lot	Concession
KAWARTHA LAKES	VICTORIA	17	5

RR#/Street Number/Name	City/Town/Village	Site/Compartment/Block/Tract etc.
200 ALBERT ST SOUTH	LINDSAY	

GPS Reading	NAD	Zone	Easting	Northing	Unit Make/Model	Mode of Operation
	83	17	680583	4911921		☐ Undifferentiated ☐ Averaged ☐ Differentiated, specify

Log of Overburden and Bedrock Materials (see instructions)

General Colour	Most common material	Other Materials	General Description	Depth From (Metres)	Depth To (Metres)
BROWN	TOP-SOIL			0	.3
BROWN	SANDY CLAY			.3	2.74
BROWN	GRAVEL	& SAND	COARSE	2.74	3.96
BROWN	SANDY CLAY			3.96	4.41
	ROCK OR SHALE IN BOTTOM				

Hole Diameter

Depth From (Metres)	Depth To (Metres)	Diameter Centimetres
0	4.41	121.92

Water Record

Water found at Metres	Kind of Water
2.74 m	☑ Fresh ☐ Sulphur ☐ Gas ☐ Salty ☐ Minerals ☐ Other:
3.96 m	☑ Fresh ☐ Sulphur ☐ Gas ☐ Salty ☐ Minerals ☐ Other:
___ m	☐ Fresh ☐ Sulphur ☐ Gas ☐ Salty ☐ Minerals ☐ Other:

After test of well yield, water was
☐ Clear and sediment free
☐ Other, specify

Chlorinated ☑ Yes ☐ No

Construction Record

Inside diam centimetres	Material	Wall thickness centimetres	Depth From (Metres)	Depth To (Metres)
Casing				
76.2	☐ Steel ☐ Fibreglass ☐ Plastic ☐ Concrete ☑ Galvanized	1.8	0	4.41
	☐ Steel ☐ Fibreglass ☐ Plastic ☐ Concrete ☐ Galvanized			
	☐ Steel ☐ Fibreglass ☐ Plastic ☐ Concrete ☐ Galvanized			
Screen				
Outside diam	☐ Steel ☐ Fibreglass ☐ Plastic ☐ Concrete ☐ Galvanized	Slot No.		
No Casing or Screen				
	☐ Open hole			

Test of Well Yield

Pumping test method	Draw Down Time min	Draw Down Water Level Metres	Recovery Time min	Recovery Water Level Metres
Pump intake set at - (metres)	Static Level			
Pumping rate - (litres/min)	1		1	
Duration of pumping ___hrs + ___min	2		2	
Final water level end of pumping ___metres	3		3	
Recommended pump type. ☐ Shallow ☐ Deep	4		4	
Recommended pump depth. ___metres	5		5	
Recommended pump rate. (litres/min)	10		10	
	15		15	
If flowing give rate - (litres/min)	20		20	
	25		25	
If pumping discontinued, give reason.	30		30	
	40		40	
	50		50	
	60		60	

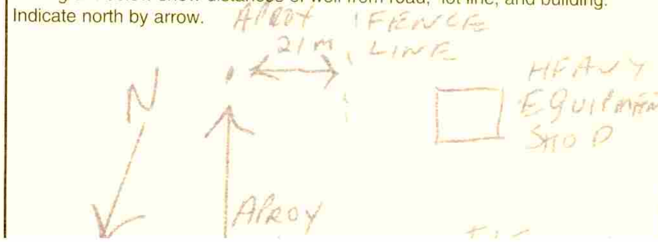
Plugging and Sealing Record

☑ Annular space ☐ Abandonment

Depth set at - Metres From	To	Material and type (bentonite slurry, neat cement slurry) etc.	Volume Placed (cubic metres)
0	2.45	BENTINITE GRANDUAL & PEA STONE	
2.45	4.41	FILTER SAND	

Location of Well

In diagram below show distances of well from road, lot line, and building. Indicate north by arrow.



Method of Construction

Ontario Ministry of the Environment

Well Tag Number (Place sticker and print number below)

MW1

Well Record

Regulation 903 Ontario Water Resources Act

Instructions for Completing Form

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- All Sections **must** be completed in full to avoid delays in processing. Further instructions and explanations are available on the back of this form.
- Questions regarding completing this application can be directed to the Water Well Management Coordinator at 416-235-6203.
- **All metre measurements shall be reported to 1/10th of a metre.**
- Please print clearly in blue or black ink only.

Ministry Use Only MUN | CON | LOT

Well Owner's Information and Location of Well Information

First Name: Fleming College
Last Name:
Mailing Address (Street Number/Name, RR,Lot,Concession): P.O. Box 8000 Conc 5 Lot 18 Ops Twsp
County/District/Municipality: City of Kawartha Lakes
Township/City/Town/Village: Lindsay
Province: Ontario
Postal Code: K9V 5E6
Telephone Number (include area code): 705 324 9144
Address of Well Location (County/District/Municipality): At College Campus ↳ Above, former Victoria County
Township: Ops
Lot: 18
Concession: 5
RR#/Street Number/Name: Albert St. South
City/Town/Village: Lindsay
Site/Compartment/Block/Tract etc.: N 1/2 of Lot 17 Conc 5 (wells)
GPS Reading: NAD 83 | Zone 17 | Easting 784409 | Northing 4420029
Unit Make/Model: Magellan 612
Mode of Operation: ☐ Undifferentiated ☐ Averaged ☐ Differentiated, specify

Log of Overburden and Bedrock Materials (see instructions) MONITORING WELL #1 (FOR TRAINING)

General Colour	Most common material	Other Materials	General Description	Depth Metres From	Depth Metres To
DK BR	SILT TOPSOIL		TOPSOIL	0	.39
YEL. BR	SILT TILL	FINE SAND, TRACE TO SOME CLAY, OCC. GRAVEL	SILT TILL	.39	4.4
GREY	LIMESTONE		WEATHERED LIMESTONE BEDROCK	4.4	6.1
			LOCKING STEEL SECURITY CASING OVER STICKUP		

Hole Diameter

Depth Metres From	Depth Metres To	Diameter Centimetres
0	6.1	15-20

Water Record

Water found at 3 Metres / Kind of Water

- m ☒ Fresh ☐ Sulphur ☐ Gas ☐ Salty ☐ Minerals ☐ Other:
- m ☐ Fresh ☐ Sulphur ☐ Gas ☐ Salty ☐ Minerals ☐ Other:
- m ☐ Fresh ☐ Sulphur ☐ Gas ☐ Salty ☐ Minerals ☐ Other:

After test of well yield, water was ☐ Clear and sediment free ☐ Other, specify

Chlorinated ☐ Yes ☐ No

Construction Record

Inside diam centimetres	Material	Wall thickness centimetres	Depth Metres From	Depth Metres To
Casing				
5	☐ Steel ☐ Fibreglass ☒ Plastic ☐ Concrete ☐ Galvanized	0.03	0	4.7
	☐ Steel ☐ Fibreglass ☐ Plastic ☐ Concrete ☐ Galvanized			
	☐ Steel ☐ Fibreglass ☐ Plastic ☐ Concrete ☐ Galvanized			
Screen (Outside diam)		Slot No.		
5	☐ Steel ☐ Fibreglass ☒ Plastic ☐ Concrete ☐ Galvanized	0.10	4.7	6.1
No Casing or Screen				
	☐ Open hole			

Test of Well Yield NONE

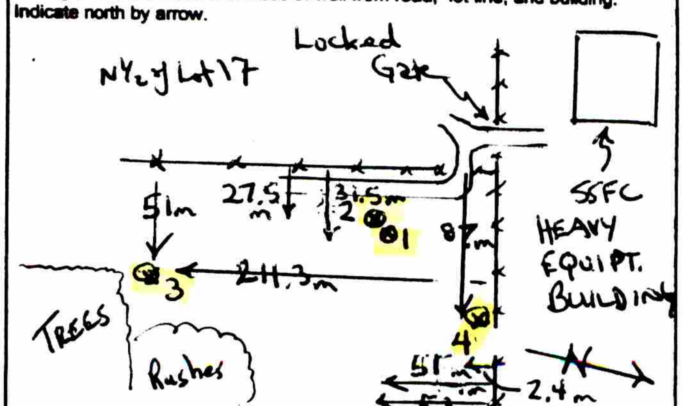
Pumping test method	Draw Down Time min	Draw Down Water Level Metres	Recovery Time min	Recovery Water Level Metres
Pump intake set at - (metres)	Static Level			
Pumping rate - (litres/min)	1		1	
Duration of pumping ___hrs + ___ min	2		2	
Final water level end of pumping ___ metres	3		3	
Recommended pump type. ☐ Shallow ☐ Deep	4		4	
Recommended pump depth. ___ metres	5		5	
Recommended pump rate. (litres/min)	10		10	
	15		15	
If flowing give rate - (litres/min)	20		20	
	25		25	
If pumping discontinued, give reason.	30		30	
	40		40	
	50		50	
	60		60	

Plugging and Sealing Record ☒ Annular space ☐ Abandonment

Depth set at - Metres From	To	Material and type (bentonite slurry, neat cement slurry) etc.	Volume Placed (cubic metres)
0	4.7	bentonite slurry	~0.2

Location of Well

In diagram below show distances of well from road, lot line, and building. Indicate north by arrow.



Audit No. Z 04042

Date Well Completed: 2003 09

Date Delivered: YYYY MM DD

Was the well owner's information package delivered? ☐ Yes ☒ No

Method of Construction

☐ Cable Tool ☐ Rotary (conventional) ☐ Rotary (reverse) ☐ Rotary (air) ☐ Air percussion ☒ Boring ☐ Diamond ☐ Jetting ☐ Driving ☐ Digging ☐ Other

Water Use

☐ Domestic ☐ Stock ☐ Irrigation ☐ Industrial ☐ Commercial ☐ Municipal ☐ Public Supply ☒ Not used ☐ Cooling & air conditioning ☐ Other

Final Status of Well

☐ Water Supply ☐ Observation well ☐ Test Hole ☐ Recharge well ☐ Abandoned, insufficient supply ☐ Abandoned, poor quality ☐ Unfinished ☐ Dewatering ☐ Replacement well ☐ Abandoned, (Other)

Well Contractor/Technician Information

Name of Well Contractor: SSFC
Well Contractor's Licence No.:
Business Address (street name, number, city etc.): P.O. Box 8000 LINDSAY K9V 5E6
Name of Well Technician (last name, first name):
Well Technician's Licence No.:
Signature of Technician/Contractor:
Date Submitted:

Ministry Use Only

Data Source | Contractor
Date Received YYYY MM DD | Date of Inspection YYYY MM DD
Remarks | Well Record Number

Ontario Ministry of the Environment

Well Tag Number (Place sticker and print number below)

MW2

Well Record

Regulation 903 Ontario Water Resources Act

Instructions for Completing Form

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Questions regarding completing this application can be directed to the Water Well Management Coordinator at 416-235-6203.
All metre measurements shall be reported to 1/10th of a metre.
Please print clearly in blue or black ink only.

Ministry Use Only: MUN | CON | LOT

Well Owner's Information and Location of Well Information

First Name	Last Name	Mailing Address (Street Number/Name, RR, Lot, Concession)			
FLEMING COLLEGE		P.O. BOX 8000 CONC 5, LOT 18, OPS TWSP			
County/District/Municipality	Township/City/Town/Village	Province	Postal Code	Telephone Number (include area code)	
CITY OF KAWARTHA LAKES	LINDSAY	Ontario	K9V 5E6	705 3249144	
Address of Well Location (County/District/Municipality)	Township		Lot	Concession	
AT COLLEGE CAMPUS	OPS VICTORIA COUNTY		18	5	
RR#/Street Number/Name	City/Town/Village		Site/Compartment/Block/Tract etc.		
	LINDSAY		NY 25 Lot 17 Cons 5 (wells)		

GPS Reading	NAD	Zone	Easting	Northing	Unit Make/Model	Mode of Operation
	83	27	704409	4914929	Magellan B12	☐ Undifferentiated ☐ Averaged ☐ Differentiated, specify

Log of Overburden and Bedrock Materials (see instructions) MONITORING WELL #2 (FOR TRAINING)

General Colour	Most common material	Other Materials	General Description	Depth Metres From	To
DK. BR	SILT TOPSOIL		TOPSOIL	0	.42
L. BR	SILT TILL	SANDY SILT TILL TRACE (+) CLAY OCC GRAVEL		0.42	3.96
			LOCKING STEEL SECURITY CASING OVER STICKUP		

Hole Diameter

Depth Metres From	To	Diameter Centimetres
0	3.96	15-20

Water Record

Water found at Metres	Kind of Water
m	☒ Fresh ☐ Sulphur ☐ Gas ☐ Salty ☐ Minerals ☐ Other:
m	☐ Fresh ☐ Sulphur ☐ Gas ☐ Salty ☐ Minerals ☐ Other:
m	☐ Fresh ☐ Sulphur ☐ Gas ☐ Salty ☐ Minerals ☐ Other:

After test of well yield, water was ☐ Clear and sediment free ☐ Other, specify

Chlorinated ☐ Yes ☐ No

Construction Record

Inside diam centimetres	Material	Wall thickness centimetres	Depth Metres From	To
Casing				
5	☐ Steel ☐ Fibreglass ☒ Plastic ☐ Concrete ☐ Galvanized	.03	0	2.34
	☐ Steel ☐ Fibreglass ☐ Plastic ☐ Concrete ☐ Galvanized			
	☐ Steel ☐ Fibreglass ☐ Plastic ☐ Concrete ☐ Galvanized			
Screen				
Outside diam	Material	Slot No.		
5	☐ Steel ☐ Fibreglass ☒ Plastic ☐ Concrete ☐ Galvanized	010	2.34	1.52
No Casing or Screen				
	☐ Open hole			

Test of Well Yield NONE

Pumping test method	Draw Down Time min	Water Level Metres	Recovery Time min	Water Level Metres
Pump intake set at - (metres)	Static Level			
Pumping rate - (litres/min)	1		1	
Duration of pumping ___hrs + ___ min	2		2	
Final water level end of pumping ___ metres	3		3	
Recommended pump type. ☐ Shallow ☐ Deep	4		4	
Recommended pump depth. ___ metres	5		5	
Recommended pump rate. (litres/min)	10		10	
	15		15	
If flowing give rate - (litres/min)	20		20	
	25		25	
If pumping discontinued, give reason.	30		30	
	40		40	
	50		50	
	60		60	

Plugging and Sealing Record ☐ Annular space ☐ Abandonment

Depth set at - Metres From	To	Material and type (bentonite slurry, neat cement slurry) etc.	Volume Placed (cubic metres)
0	2.34	BENTONITE SLURRY	

Location of Well

In diagram below show distances of well from road, lot line, and building. Indicate north by arrow.

See page 1

Method of Construction

☐ Cable Tool ☐ Rotary (air) ☐ Diamond ☐ Digging
☐ Rotary (conventional) ☐ Air percussion ☐ Jetting ☐ Other
☐ Rotary (reverse) ☒ Boring ☐ Driving

Water Use

☐ Domestic ☐ Industrial ☐ Public Supply ☐ Other
☐ Stock ☐ Commercial ☒ Not used
☐ Irrigation ☐ Municipal ☐ Cooling & air conditioning

Final Status of Well

☐ Water Supply ☐ Recharge well ☐ Unfinished ☐ Abandoned, (Other)
☒ Observation well ☐ Abandoned, insufficient supply ☐ Dewatering
☐ Test Hole ☐ Abandoned, poor quality ☐ Replacement well

Audit No. Z 04042

Date Well Completed YYYY 2003 MM 09 DD

Was the well owner's information package delivered? ☐ Yes ☒ No

Date Delivered YYYY MM DD

Well Contractor/Technician Information

Name of Well Contractor	Well Contractor's Licence No.
SSFC	
Business Address (street name, number, city etc.)	
P.O. BOX 8000, LINDSAY K9V 3V2	
Name of Well Technician (last name, first name)	Well Technician's Licence No.
Signature of Technician/Contractor	Date Submitted YYYY MM DD

Ministry Use Only

Data Source	Contractor
Date Received YYYY MM DD	Date of Inspection YYYY MM DD
Remarks	Well Record Number

Ontario Ministry of the Environment

Well Tag Number (Place sticker and print number below)

MW3

Well Record

Regulation 903 Ontario Water Resources Act

Instructions for Completing Form

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- Questions regarding completing this application can be directed to the Water Well Management Coordinator at 416-235-6203.
- **All metre measurements shall be reported to 1/10th of a metre.**
- Please print clearly in blue or black ink only.

Ministry Use Only MUN | CON | LOT

Well Owner's Information and Location of Well Information

First Name	Last Name	Mailing Address (Street Number/Name, RR,Lot,Concession)		
FLEMING COLLEGE				
County/District/Municipality: CITY OF KAWATHA LAKES	Township/City/Town/Village: LINDSAY	Province: Ontario	Postal Code: K9V3V2	Telephone Number (include area code): 705 324 9144
Address of Well Location (County/District/Municipality): AT COLLEGE CAMPUS	Township: OPS - VICTORIA COUNTY	Lot: 18	Concession: 5	
RR#/Street Number/Name	City/Town/Village: LINDSAY	Site/Compartment/Block/Tract etc.: N½ of Lot 17 Con-5 (wells)		
GPS Reading: NAD 83, Zone 17, Easting 704407, Northing 4920244	Unit Make/Model: Magellan 812	Mode of Operation: ☐ Undifferentiated ☐ Averaged ☐ Differentiated, specify		

Log of Overburden and Bedrock Materials (see instructions) MONITORING WELL #3 (FOR TRAINING)

General Colour	Most common material	Other Materials	General Description	Depth Metres From	To
DK BR	SILT TOPSOIL		TOPSOIL	0	0.3
EL. BR	SILT TILL	TRACE to SOME CLAY OCC. FINE GRAVEL		0.3	4.42
			LOCKING STEEL SECURITY CASING OVER STICKUP		

Hole Diameter

Depth Metres From	To	Diameter Centimetres
0	4.42	15-20

Construction Record

Inside diam centimetres	Material	Wall thickness centimetres	Depth Metres From	To
Casing				
5	☐ Steel ☐ Fibreglass ☒ Plastic ☐ Concrete ☐ Galvanized	.03	0	2.83
	☐ Steel ☐ Fibreglass ☐ Plastic ☐ Concrete ☐ Galvanized			
	☐ Steel ☐ Fibreglass ☐ Plastic ☐ Concrete ☐ Galvanized			
Screen (Outside diam)		Slot No.		
5	☐ Steel ☐ Fibreglass ☐ Plastic ☐ Concrete ☐ Galvanized	0.10	~2.83	4.35
No Casing or Screen	☐ Open hole			

Water Record

Water found Metres	Kind of Water
___ m	☒ Fresh ☐ Sulphur ☐ Gas ☐ Salty ☐ Minerals ☐ Other:
___ m	☐ Fresh ☐ Sulphur ☐ Gas ☐ Salty ☐ Minerals ☐ Other:
___ m	☐ Fresh ☐ Sulphur ☐ Gas ☐ Salty ☐ Minerals ☐ Other:

After test of well yield, water was ☐ Clear and sediment free ☐ Other, specify

Chlorinated ☐ Yes ☐ No

Test of Well Yield NONE

Pumping test method	Draw Down Time min	Water Level Metres	Recovery Time min	Water Level Metres
Pump intake set at - (metres)	Static Level			
Pumping rate - (litres/min)	1		1	
Duration of pumping ___hrs + ___ min	2		2	
Final water level end of pumping ___ metres	3		3	
Recommended pump type. ☐ Shallow ☐ Deep	4		4	
Recommended pump depth. ___ metres	5		5	
Recommended pump rate. (litres/min)	10		10	
	15		15	
If flowing give rate - (litres/min)	20		20	
	25		25	
If pumping discontinued, give reason.	30		30	
	40		40	
	50		50	
	60		60	

Plugging and Sealing Record ☐ Annular space ☐ Abandonment

Depth set at - Metres From	To	Material and type (bentonite slurry, neat cement slurry) etc.	Volume Placed (cubic metres)
0	2.83	BENTONITE SLURRY	

Location of Well

In diagram below show distances of well from road, lot line, and building. Indicate north by arrow.

See page 1

Method of Construction

☐ Cable Tool ☐ Rotary (conventional) ☐ Rotary (reverse) ☐ Rotary (air) ☐ Air percussion ☒ Boring ☐ Diamond ☐ Jetting ☐ Driving ☐ Digging ☐ Other

Water Use

☐ Domestic ☐ Stock ☐ Irrigation ☐ Industrial ☐ Commercial ☐ Municipal ☐ Public Supply ☒ Not used ☐ Cooling & air conditioning ☐ Other

Final Status of Well

☐ Water Supply ☐ Observation well ☐ Test Hole ☐ Recharge well ☐ Abandoned, insufficient supply ☐ Abandoned, poor quality ☐ Unfinished ☐ Dewatering ☐ Replacement well ☐ Abandoned, (Other)

Audit No. Z 04042

Date Well Completed: YYYY 2003 MM 09 DD

Was the well owner's information package delivered? ☐ Yes ☒ No

Date Delivered: YYYY MM DD

Well Contractor/Technician Information

Name of Well Contractor	Well Contractor's Licence No.
SSFC	
Business Address (street name, number, city etc.): P.O. Box 8000 LINDSAY, ONTARIO	
Name of Well Technician (last name, first name)	Well Technician's Licence No.
Signature of Technician/Contractor	Date Submitted YYYY MM DD

Ministry Use Only

Data Source	Contractor
Date Received YYYY MM DD	Date of Inspection YYYY MM DD
Remarks	Well Record Number

Ontario Ministry of the Environment

Well Tag Number (Place sticker and print number below)

MW4

Well Record

Regulation 903 Ontario Water Resources Act

Instructions for Completing Form

- For use in the **Province of Ontario** only. This document is a permanent **legal** document. Please retain for future reference.
- All Sections **must** be completed in full to avoid delays in processing. Further instructions and explanations are available on the back of this form.
- Questions regarding completing this application can be directed to the Water Well Management Coordinator at 416-235-6203.
- **All metre measurements shall be reported to 1/10th of a metre.**
- Please print clearly in blue or black ink only.

Ministry Use Only — MUN | CON | LOT

Well Owner's Information and Location of Well Information

First Name	FLEMING COLLEGE
Last Name	
Mailing Address (Street Number/Name, RR,Lot,Concession)	
County/District/Municipality	CITY OF KAWARTHA LAKES
Township/City/Town/Village	LINDSAY
Province	Ontario
Postal Code	K9V5E6
Telephone Number (include area code)	705 3249144
Address of Well Location (County/District/Municipality)	AT COLLEGE CAMPUS
Township	OPS, VICTORIA COUNTY
Lot	18
Concession	5
RR#/Street Number/Name	
City/Town/Village	LINDSAY
Site/Compartment/Block/Tract etc.	N½ of Lot 17 Conc 5 (wells)
GPS Reading NAD	83
Zone	17
Easting	784405
Northing	4902931
Unit Make/Model	MAGELLAN 812
Mode of Operation	☐ Undifferentiated ☐ Averaged ☐ Differentiated, specify

Log of Overburden and Bedrock Materials (see instructions)

MONITORING WELL #4 (FOR TRAINING)

General Colour	Most common material	Other Materials	General Description	Depth Metres From	To
DK. BR	SILT TOPSOIL		TOPSOIL	0	0.3
LT BR	SILT TILL	WITH SOME CLAY TO FINE SAND TILL OCC GRAVEL		0.3	4.39
			LOCKING STEEL SECURITY CASING OVER STICKUP		

Hole Diameter

Depth Metres From	To	Diameter Centimetres
0	4.38	15-20

Water Record

Water found at Metres	Kind of Water
___ m ☐ Gas ☐ Other:	☒ Fresh ☐ Salty ☐ Sulphur ☐ Minerals
___ m ☐ Gas ☐ Other:	☐ Fresh ☐ Salty ☐ Sulphur ☐ Minerals
___ m ☐ Gas ☐ Other:	☐ Fresh ☐ Salty ☐ Sulphur ☐ Minerals

After test of well yield, water was ☐ Clear and sediment free ☐ Other, specify

Chlorinated ☐ Yes ☐ No

Construction Record

Inside diam centimetres	Material	Wall thickness centimetres	Depth Metres From	To
Casing				
5	☐ Steel ☐ Fibreglass ☒ Plastic ☐ Concrete ☐ Galvanized	.03	0	2.77
	☐ Steel ☐ Fibreglass ☐ Plastic ☐ Concrete ☐ Galvanized			
	☐ Steel ☐ Fibreglass ☐ Plastic ☐ Concrete ☐ Galvanized			
Screen (Outside diam)		Slot No.		
5	☐ Steel ☐ Fibreglass ☒ Plastic ☐ Concrete ☐ Galvanized	010	2.77	4.30
No Casing or Screen	☐ Open hole			

Test of Well Yield — NONE

Pumping test method	Draw Down Time min	Water Level Metres	Recovery Time min	Water Level Metres
Pump intake set at - (metres)	Static Level			
Pumping rate - (litres/min)	1		1	
Duration of pumping ___hrs + ___ min	2		2	
Final water level end of pumping ___ metres	3		3	
Recommended pump type. ☐ Shallow ☐ Deep	4		4	
Recommended pump depth. ___ metres	5		5	
Recommended pump rate. (litres/min)	10		10	
	15		15	
If flowing give rate - (litres/min)	20		20	
	25		25	
If pumping discontinued, give reason.	30		30	
	40		40	
	50		50	
	60		60	

Plugging and Sealing Record ☐ Annular space ☐ Abandonment

Depth set at - Metres From	To	Material and type (bentonite slurry, neat cement slurry) etc.	Volume Placed (cubic metres)
0	2.77	BENTONITE SLURRY	

Location of Well

In diagram below show distances of well from road, lot line, and building. Indicate north by arrow.

See page 1

Method of Construction

☐ Cable Tool ☐ Rotary (conventional) ☐ Rotary (reverse) ☐ Rotary (air) ☐ Air percussion ☒ Boring ☐ Diamond ☐ Jetting ☐ Driving ☐ Digging ☐ Other

Water Use

☐ Domestic ☐ Stock ☐ Irrigation ☐ Industrial ☐ Commercial ☐ Municipal ☐ Public Supply ☒ Not used ☐ Cooling & air conditioning ☐ Other

Final Status of Well

☐ Water Supply ☐ Observation well ☐ Test Hole ☐ Recharge well ☐ Abandoned, insufficient supply ☐ Abandoned, poor quality ☐ Unfinished ☐ Dewatering ☐ Replacement well ☐ Abandoned, (Other)

Audit No. Z 04042

Date Well Completed YYYY 2003 MM 09 DD

Was the well owner's information package delivered? ☐ Yes ☒ No

Date Delivered YYYY MM DD

Well Contractor/Technician Information

Name of Well Contractor	SSFC
Well Contractor's Licence No.	
Business Address (street name, number, city etc.)	P.O. Box 8000 LINDSAY ONTARIO K9V3V2
Name of Well Technician (last name, first name)	
Well Technician's Licence No.	
Signature of Technician/Contractor	
Date Submitted	YYYY MM DD

Ministry Use Only

Data Source	Contractor
Date Received YYYY MM DD	Date of Inspection YYYY MM DD
Remarks	Well Record Number

Appendix B – Biofilm experimental method

Appendix B contains the detailed methods used to create biofilm in the laboratory, the cleaning methods used in this study and the analytical methods used in the analysis.

B1 Biofilm preparation

B 1.1 Materials

- large diameter well casing material coupons (7 cm x 7 cm) of cement, galvanized steel, and fibreglass (5 of each)
- an etching tool
- autoclave
- marker
- biofilm reactor

B 1.2 Procedure

1. Etch 2, 5 cm by 2.5 cm, rectangles (Figure 1) into the 5 coupons of each material (cement, galvanized steel, and fibreglass). Mark the areas for initial and regrowth with the etching tool.
2. Sterilize all coupons in an autoclave at 120 degrees Celsius for 20 minutes (Forster C.J. et al, 2001).
3. Prepare biofilm reactor (Figure 2) by filling with raw water (to promote biofilm growth).
4. Suspend the coupons vertically in the reactor in rows of 3 and columns of 5 (Figure 1).
5. Leave in biofilm reactor for 5 to 7 days for biofilm formation.
6. Once biofilm has developed, remove the samples from the biofilm reactor.

B2 Cleaning methods

Mechanical cleaning methods will be used to remove biofilm from the coupons of the different casing materials. Once removed from the biofilm reactor the cleaning methods will be tested. To ensure repeatable results standard methods for cleaning have been developed.

B 2.1 Materials

- Bleach - (6%)
- bucket
- scrub brushes (Rubbermaid Nail Brush model #G119, 88 mm L x 24 mm W x 21 mm H, 105 bristle pods with 40 plastic bristles each)

- pressure washer (25˚ nozzle tip, 1300 psi working pressure)
- steam cleaner (Euro Pro Shark Steam Cleaner)
- clamps
- stop watch
- coupons with biofilm growth

B 2.2 Procedures

B2.2.1 Physical brushing

1. Submerge the scrub brush in the biofilm reactor to wet.
2. Scrub the coupons in an up-down motion while applying pressure for 15 seconds.
3. Focus scrubbing on the sampling areas.
4. Refer to the sample collection section for the next steps.

B2.2.2 Physical brushing with bleach solution

1. Prepare bleach solution in bucket (1.25 mL bleach/L water).
2. Submerge scrub brush in bucket with bleach solution.
3. Scrub the coupons in an up-down motion while applying pressure for 15 seconds.
4. Focus scrubbing on the sampling areas.
5. Refer to the sample collection section for the next steps.

B2.2.3 Steam cleaning with brush

1. Clamp the coupons to a surface if necessary.
2. Fill steam cleaner with water and allow water to boil and build up steam.
3. Scrub coupon in an up and down motion while applying pressure with brush attachment emitting steam for 15 seconds.
4. Refer to the sample collection section for the next steps.

B2.2.4 Pressure washing

1. Clamp the coupons to a surface in a drainable area
2. Pressure wash each coupon individually, using a wide fan setting (25˚ nozzle tip). keeping the nozzle 10 cm above the coupons for 15 seconds.
3. Refer to the sample collection section for the next steps.

B3 Sample collection

To retrieve samples of the biofilm, the coupons will be swabbed and analyzed for residual biofilm on a sterile swab. To ensure repeatable results, standard methods for collecting samples of the biofilm have been developed.

B 3.1 Materials

- sterile swabs
- cleaned coupons
- background coupons

B 3.2 Procedure

1. Remove the coupons from the reactor.
2. Retrieve a sample from each of the initial growth sample locations on all coupons.
3. Sample retrieval involves twisting the swab between the sampler's fingers while moving the swab back and forth across the sample location. Swab the sample section of the coupon 10 times and repeat 2 more times, for a total of 30 strokes across the sample.

B4 ATP Analysis

B 4.1 Materials

Chemicals should be kept at -20 degrees Celsius.

- 1 vial of rLuciferase/Luciferin (rL/L) reagent
- 1 vial of rL/L reconstitution buffer
- 1.5mL positive control
- 12mL swab extractant
- 4 vials swab buffer/negative control
- 1 protocol
- 100 sterile swabs
- luminometer
- micropipettes (0.1 to 1mL)
- cuvettes

- cuvette rack
- nitrile/latex gloves

Chemicals should be kept at -20 ˚C.

B 4.2 Procedure

Method as outlined by Promega's Enliten Total ATP Biocontamination Detection Kit.

1. Tap the rLuciferase/Luciferasin (rL/L) to ensure that all dried material is at the bottom. Wear gloves to prevent contamination of the rubber stopper.
2. Combine the rL/L reconstitution buffer with the rL/L reagent buffer in the rL/L reagent buffer, in the rL/L reagent buffer container.
3. Let the reconstituted rL/L reagent settle and mix for 1 hour before use
4. Ideally, the solution will not be stored for more than 1 day. If intending to hold the solution for more than 5 days, freeze immediately after the 1 hour incubation period.
5. The negative control should have a reading that is close to the lower limit of the luminometer being used. The positive control should be at least 100x greater than the negative control value.
6. Label a clean test tube which is compatible with the luminometer for each sample.
7. Transfer 300 µl of swab buffer/negative control to each tube.
8. Insert the sterile swab in swab buffer/negative control for 30 seconds.
9. Swab the sample. Refer to Swabbing Method section for procedure. Put the swab in its labelled tube.
10. Swirl the swab in the swab buffer for 10 seconds, and press the swab tip against the test tube side to recover as much liquid as possible.
11. Discard the swab.
12. Add 100µl of extractant to each sample and mix.
13. Add 100µl of rL/L reagent to each sample. Mix and read the luminescence Immediately and record the RLU reading.

B5 Regrowth

B 5.1 Materials

- cleaned coupons
- biofilm reactor

B 5.2 Procedure

1. Place the coupons back into the reactor for 5 Days
2. Remove the coupons from the reactor and repeat the ATP analysis.

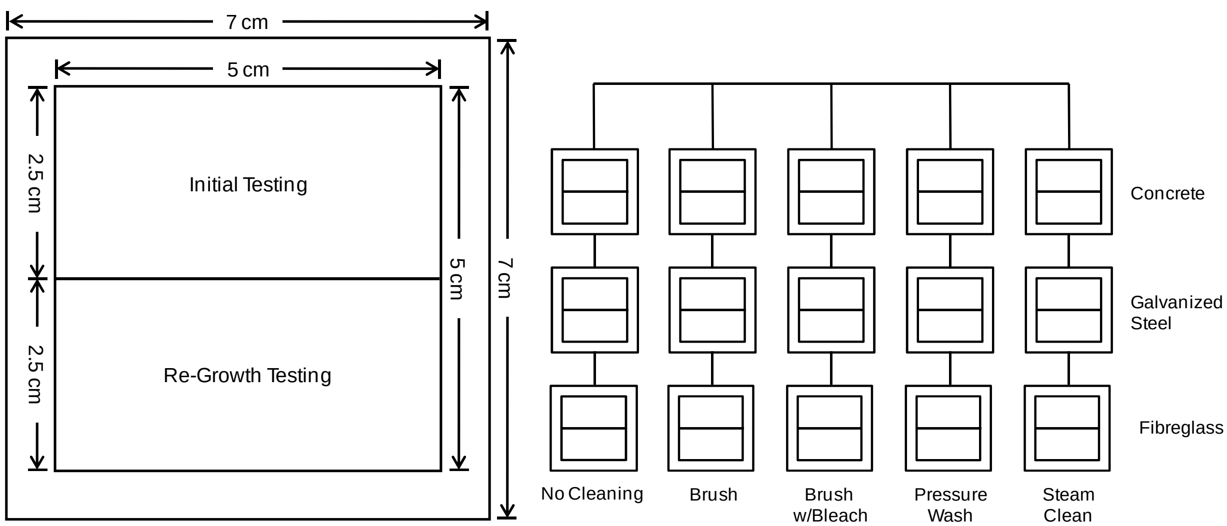

Figure 1: Individual coupon and coupon array.

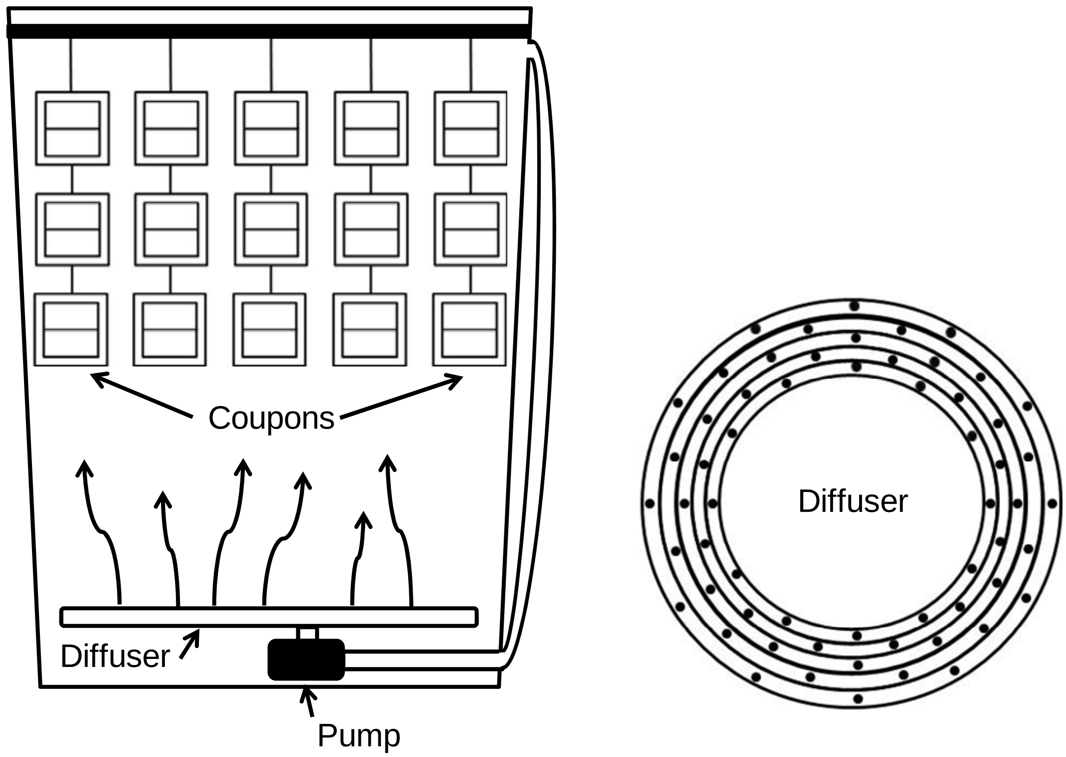

Figure 2: Biofilm reactor and diffuser.

Appendix C – Experimental Data

Appendix C contains raw data from water quality analysis, biofilm analysis, and cement-bentonite analysis.

Table C.1. CTH1 water quality data.

	Units	4-Mar-08	11-Feb-09	14-May-09	14-May-09	4-Jun-09	7-Jul-09	5-Aug-09	Ontario Drinking Water Standards, Objectives and Guidelines
Cations		**Lab**	**Lab**	**Fleming**	**Lab**	**Fleming**	**Fleming**	**Lab**	**Limits**
Alkalinity ($CaCO_3$)	mg/L	NA	318	312	308	304	279	291	30-500*
Hardness ($CaCO_3$)	mg/L	110	298	NA	400	364	396	495	80-100*
Calcium (Ca^{+2})	mg/L	38	108	135	130	138	145	181	
Magnesium (Mg^{+2})	mg/L	3.50	6.57	8.23	7.82	7.07	7.90	10.80	
Manganese (Mn^{+2})	mg/L	NA	0.008	0.013	0	0	0	0	0.05
Potassium (K)	mg/L	59.0	6.2	5.8	6.0	0.2	0.2	5.3	
Sodium (Na)	mg/L	29	116	105	67	84	85	120	200
Anions									
Chloride (Cl)	mg/L	38	190	210	216	301	388	370	250
Nitrite (N)	mg/L	0.020	<0.060	<0.060	<0.015	<0.015	<0.015	<0.060	1
Nitrate (N)	mg/L	0.90	2.21	2.03	0.20	2.05	2.44	2.59	10
Sulphate (SO_4)	mg/L	34	24	21	21	21	23	24	500
Metals									
Iron (Fe)	mg/L	<0.01	0.29	0.04	0.04	0.08	0.03	0.04	0.3
Lead (Pb)	mg/L	<0.0005	<0.005	<0.003	<0.003	0.005	0.016	<0.005	0.01
Zinc (Zn)	mg/L	<0.005	0.08	0.06	0.06	0.05	0.87	0.06	5
Bacteria									
Total Coliform	cfu/100mL	NA	0	23	8	11	938	320	Not Detectable
E. Coli	cfu/100mL	NA	0	0	<3**	<3**	<3**	19	Not Detectable
Fecal Coliforms	cfu/100mL	NA	0	0	NA	NA	NA	25	Not Detectable
Other Parameters									
pH		NA	8.08	7.69	7.08	6.99	6.99	7.71	6.5-8.5*
Conductivity	µS/cm	NA	1110	1120	1137	1275	1401	1660	
Total Dissolved Solids	mg/L	NA	623	706	NA	NA	NA	1070	500

* operational guideline range; (highlighted) Does not meet Ontario Drinking Water Standards, Objectives and Guidelines

** method used for analysis requires 0 counts to be reported as <3

Table C.2. ETH1 water quality data.

	Units	4-Mar-08	11-Feb-09	14-May-09	14-May-09	4-Jun-09	7-Jul-09	5-Aug-09	Ontario Drinking Water Standards, Objectives and Guidelines
Cations		**Lab**	**Lab**	**Fleming**	**Lab**	**Fleming**	**Fleming**	**Lab**	**Limits**
Alkalinity ($CaCO_3$)	mg/L	NA	335	305	307	306	286	284	30-500*
Hardness ($CaCO_3$)	mg/L	330	260	NA	370	376	324	400	80-100*
Calcium (Ca^{+2})	mg/L	120	94.2	120	155	122	123	145	
Magnesium (Mg^{+2})	mg/L	10.00	5.95	7.61	7.93	6.64	6.82	9.07	
Manganese (Mn^{+2})	mg/L	NA	<0.001	0.0003	<0.001	0.002	0.002	<0.001	0.05
Potassium (K)	mg/L	69.0	3.9	3.7	3.7	0.2	0.4	4.5	
Sodium (Na)	mg/L	150	107	65	102	72	65	75	200
Anions									
Chloride (Cl)	mg/L	310	130	129	190	224	240	220	250
Nitrite (N)	mg/L	<0.010	<0.060	<0.015	<0.060	<0.015	<0.015	<0.060	1
Nitrate (N)	mg/L	2.80	2.15	0.10	2.11	2.13	2.03	1.98	10
Sulphate (SO_4)	mg/L	31	23	18	20	20	19	18	500
Metals									
Iron (Fe)	mg/L	<0.01	0.02	0.12	<0.01	0.07	0.09	<0.01	0.3
Lead (Pb)	mg/L	NA	<0.005	<0.003	<0.005	<0.003	<0.003	<0.005	0.01
Zinc (Zn)	mg/L	NA	0.03	0.02	0.01	0.04	0.01	0.03	5
Bacteria									
Total Coliform	cfu/100mL	NA	0	<3**	0	<3**	87	137	Not Detectable
E. Coli	cfu/100mL	NA	0	<3**	0	<3**	<3**	66	Not Detectable
Fecal Coliforms	cfu/100mL	NA	0	NA	0	NA	NA	99	Not Detectable
Other Parameters									
pH		NA	8.02	7.14	7.70	7.01	7.04	7.74	6.5-8.5*
Conductivity	µS/cm	NA	995	1202	1070	1119	1081	1190	
Total Dissolved Solids	mg/L	NA	591	NA	669	NA	NA	709	500

* operational guideline range

[yellow highlight] Does not meet Ontario Drinking Water Standards, Objectives and Guidelines

** method used for analysis requires 0 counts to be reported as <3

Table C.3. ETH2 water quality data.

	Units	4-Mar-08	11-Feb-09	14-May-09	14-May-09	4-Jun-09	7-Jul-09	5-Aug-09	Ontario Drinking Water Standards, Objectives and Guidelines
Cations		**Lab**	**Lab**	**Fleming**	**Lab**	**Fleming**	**Fleming**	**Lab**	**Limits**
Alkalinity ($CaCO_3$)	mg/L	NA	327	296	300	292	282	299	30-500*
Hardness ($CaCO_3$)	mg/L	520	374	NA	422	384	388	414	80-100*
Calcium (Ca^{+2})	mg/L	190	137	137	137	119.96	187.7	152	
Magnesium (Mg^{+2})	mg/L	11.00	7.81	7.93	8.18	6.63	7.58	8.49	
Manganese (Mn^{+2})	mg/L	NA	<0.001	0	<0.001	0.001	0.001	<0.001	0.05
Potassium (K)	mg/L	2.8	2.9	2.3	2.3	0.4	0.4	2.6	
Sodium (Na)	mg/L	130	150	82	134	71	103	109	200
Anions									
Chloride (Cl)	mg/L	310	300	235	270	225	397	300	250
Nitrite (N)	mg/L	<0.010	<0.060	<0.015	<0.060	<0.015	<0.015	<0.060	1
Nitrate (N)	mg/L	2.30	1.94	0.10	2.23	2.12	1.92	1.86	10
Sulphate (SO_4)	mg/L	31	27	26	25	20	28	27	500
Metals									
Iron (Fe)	mg/L	<0.01	<0.01	0.03	<0.01	0.05	0.04	0.01	0.3
Lead (Pb)	mg/L	NA	<0.005	<0.003	<0.005	<0.003	<0.003	<0.005	0.01
Zinc (Zn)	mg/L	NA	0.02	0.01	0.01	0.05	0.01	0.02	5
Bacteria									
Total Coliform	cfu/100mL	NA	0	<3**	1	<3**	<3**	3	Not Detectable
E. Coli	cfu/100mL	NA	0	<3**	0	<3**	<3**	0	Not Detectable
Fecal Coliforms	cfu/100mL	NA	0	NA	0	NA	NA	0	Not Detectable
Other Parameters									
pH		NA	8.00	7.05	7.71	7.05	7.06	7.72	6.5-8.5*
Conductivity	µS/cm	NA	1390	1430	1350	1120	1428	1470	
Total Dissolved Solids	mg/L	NA	834	NA	843	NA	NA	826	500

* operational guideline range

(yellow) Does not meet Ontario Drinking Water Standards, Objectives and Guidelines

** method used for analysis requires 0 counts to be reported as <3

Table C.4. ETH3 water quality data.

	Units	4-Mar-08	11-Feb-09	14-May-09	14-May-09	4-Jun-09	7-Jul-09	5-Aug-09	Ontario Drinking Water Standards, Objectives and Guidelines
Cations		**Lab**	**Lab**	**Fleming**	**Lab**	**Fleming**	**Fleming**	**Lab**	**Limits**
Alkalinity ($CaCO_3$)	mg/L	NA	331	310	309	310	283	293	30-500*
Hardness ($CaCO_3$)	mg/L	410	280	NA	379	340	388	463	80-100*
Calcium (Ca^{+2})	mg/L	150	101	124	86	129	142	169	
Magnesium (Mg^{+2})	mg/L	9.40	6.39	7.86	8.11	6.96	8.07	10.20	
Manganese (Mn^{+2})	mg/L	NA	0.005	0.002	0.001	0.002	0.001	0.001	0.05
Potassium (K)	mg/L	4.0	3.6	3.3	3.3	0.1	0.1	4.3	
Sodium (Na)	mg/L	120	120	69	106	80	85	104	200
Anions									
Chloride (Cl)	mg/L	220	180	188	200	265	399	340	250
Nitrite (N)	mg/L	0.030	<0.060	<0.015	<0.060	<0.015	<0.015	<0.060	1
Nitrate (N)	mg/L	2.50	2.34	0.70	2.09	2.17	2.48	2.41	10
Sulphate (SO_4)	mg/L	33	24	18	21	20	22	23	500
Metals									
Iron (Fe)	mg/L	<0.01	0.17	0.04	0.03	0.10	0.04	0.01	0.3
Lead (Pb)	mg/L	<0.0005	<0.005	<0.003	<0.005	<0.003	0.016	<0.005	0.01
Zinc (Zn)	mg/L	9.80	2.23	1.16	1.28	0.72	0.02	1.46	5
Bacteria									
Total Coliform	cfu/100mL	NA	0	<3**	1	<3**	3	0	Not Detectable
E. Coli	cfu/100mL	NA	0	<3**	0	<3**	<3**	0	Not Detectable
Fecal Coliforms	cfu/100mL	NA	0	NA	0	NA	NA	0	Not Detectable
Other Parameters									
pH		NA	8.04	7.05	7.76	7.07	7.07	7.63	6.5-8.5*
Conductivity	µS/cm	NA	1080	1185	1140	1219	1375	1540	
Total Dissolved Solids	mg/L	NA	637	NA	671	NA	NA	969	500

* operational guideline range

[yellow highlight] Does not meet Ontario Drinking Water Standards, Objectives and Guidelines

** method used for analysis requires 0 counts to be reported as <3

Table C.5. MW2 water quality data.

	Units	4-Mar-08	11-Feb-09	14-May-09	14-May-09	4-Jun-09	7-Jul-09	5-Aug-09	Ontario Drinking Water Standards, Objectives and Guidelines
Cations		**Lab**	**Lab**	**Fleming**	**Lab**	**Fleming**	**Fleming**	**Lab**	**Limits**
Alkalinity ($CaCO_3$)	mg/L	-	313	266	272	266	250	289	30-500*
Hardness ($CaCO_3$)	mg/L	-	333	NA	405	342	329	350	80-100*
Calcium (Ca^{+2})	mg/L	-	122	79	147	67	67	69	
Magnesium (Mg^{+2})	mg/L	-	6.85	44.54	46.90	41.55	43.39	43.50	
Manganese (Mn^{+2})	mg/L	-	0.021	0.020	0.022	0.010	0.010	0.011	0.05
Potassium (K)	mg/L	-	3.5	9.8	9.7	0.2	0.2	9.6	
Sodium (Na)	mg/L	-	100	83	132	98	101	119	200
Anions									
Chloride (Cl)	mg/L	-	160	496	290	206	293	320	250
Nitrite (N)	mg/L	-	<0.060	<0.015	<0.060	<0.015	<0.015	<0.060	1
Nitrate (N)	mg/L	-	2.28	<0.10	<0.05	0.36	0.27	<0.05	10
Sulphate (SO_4)	mg/L	-	25	3	1	1	1	1	500
Metals									
Iron (Fe)	mg/L	-	1.31	0.88	1.12	0.05	0.12	0.73	0.3
Lead (Pb)	mg/L	-	<0.005	<0.003	<0.005	0.010	0.019	<0.005	0.01
Zinc (Zn)	mg/L	-	0.03	0.01	<0.01	0.06	0.05	<0.01	5
Bacteria									
Total Coliform	cfu/100mL	-	10	<3**	0	<3**	219	0	Not Detectable
E. Coli	cfu/100mL	-	0	<3**	0	<3**	<3**	0	Not Detectable
Fecal Coliforms	cfu/100mL	-	0	NA	0	NA	NA	0	Not Detectable
Other Parameters									
pH		-	7.89	7.43	7.95	7.44	7.54	NA	6.5-8.5*
Conductivity	µS/cm	-	994	1368	1330	1447	1407	1380	
Total Dissolved Solids	mg/L	-	566	NA	823	NA	NA	723	500

* operational guideline range

(yellow) Does not meet Ontario Drinking Water Standards, Objectives and Guidelines

** method used for analysis requires 0 counts to be reported as <3

Table C.6. Biofilm replicate #1 data.

Material	Uncleaned	Scrubbing	Scrubbing w/Bleach	Scrubbing w/Steam	Pressure Washing
			(RLU)		
Negative	453				
Positive	91213				
Baseline Cutoff	1824.26				
Cement	88675	9024	56783	7396	5604
Galvanized	40559	12376	5388	2654	1773
Fiberglass	98787	37092	27463	6738	1211
Regrowth					
Negative	165				
Positive	95673				
Baseline Cutoff	1913				
Cement		129350	300286	318952	246061
Galvanized		96859	134740	261241	179028
Fiberglass		348182	34038	334684	239525

Table C.7. Biofilm replicate #2 data.

Material	Uncleaned	Scrubbing	Scrubbing w/Bleach	Scrubbing w/Steam	Pressure Washing
			(RLU)		
Negative	1095				
Positive	76568				
Baseline Cutoff	1531.36				
Cement	159744	54283	146852	31368	15172
Galvanized	80988	5108	7633	8138	9034
Fiberglass	186606	22953	17385	16609	3205
Regrowth					
Negative	333				
Positive	51649				
Baseline Cutoff	1033				
Cement		67223	23423	53131	53204
Galvanized		39742	68125	97085	63201
Fiberglass		46801	59713	179724	50599

Table C.8. Biofilm replicate #3 data.

Material	Uncleaned	Scrubbing	Scrubbing w/Bleach	Scrubbing w/Steam	Pressure Washing
	(RLU)				
Negative	133				
Positive	68859				
Baseline Cutoff	1377				
Cement	143588	32727	52367	21280	20084
Galvanized	251334	23741	80807	12632	3894
Fiberglass	522156	84562	181684	17560	8909
Regrowth					
Negative	154				
Positive	152329				
Baseline Cutoff	3047				
Cement		41823	83234	50533	58765
Galvanized		156507	65544	59375	49241
Fiberglass		36492	230054	93921	37643

Table C.9. Cement-bentonite grout height measurements for 1% mixture.

Sample	Height (mm)							
Day	**1**	**2**	**3**	**6**	**8**	**15**	**22**	**29**
1S-A	98.94	97.56	97.13	97.07	97.21	97.22	97.43	97.28
1S-B	99.03	98.95	98.93	98.95	99.07	99.11	99.00	99.09
1S-C	98.73	98.39	98.37	98.57	98.19	98.51	98.33	98.33
1S-D	98.02	97.47	97.41	97.86	97.42	97.40	97.30	97.76
1S-E	94.42	94.22	94.31	94.43	94.23	94.25	94.40	94.27
1S-F	97.60	97.37	97.54	97.16	97.00	96.98	96.90	96.96
1S-G	96.97	96.85	96.75	96.80	96.78	96.93	96.99	96.94
1U-A	99.18	97.76	97.34	97.36	97.49	97.89	97.42	97.35
1U-B	98.06	97.95	97.78	97.86	97.67	98.16	97.83	98.03
1U-C	96.16	96.45	96.15	95.47	95.49	96.40	96.56	96.07
1U-D	94.67	94.66	94.70	94.58	94.57	94.71	94.69	94.57
1U-E	96.81	96.11	96.02	95.86	95.95	96.38	95.79	95.81
1U-F	96.73	95.69	95.63	95.94	95.59	97.26	95.83	95.72
1U-G	94.77	94.48	94.57	94.16	94.20	94.48	94.15	94.49

Table C.10. Cement-bentonite grout height measurements for 3% mixture.

Sample	Height (mm)							
Day	**1**	**2**	**5**	**6**	**8**	**15**	**21**	**28**
3S-A	98.79	98.81	98.80	98.81	98.77	98.80	98.93	99.63
3S-B	98.56	98.57	98.50	98.57	98.61	98.60	98.36	98.83
3S-C	98.70	98.63	98.67	98.68	98.64	98.69	98.86	99.52
3S-D	98.85	98.90	98.95	98.91	98.90	98.91	99.09	99.14
3S-E	95.75	95.79	95.80	95.81	95.78	95.75	97.68	98.78
3S-F	98.19	98.20	98.39	98.19	98.19	98.18	99.08	99.24
3S-G	96.68	96.69	96.77	96.82	96.70	96.64	98.83	100.28
3S-H	97.84	97.89	97.89	97.88	97.86	97.87	99.98	100.46
3U-A	98.87	98.89	98.99	98.92	98.92	98.94	99.15	99.42
3U-B	99.32	99.36	99.38	99.35	99.31	99.42	99.53	99.68
3U-C	98.97	99.08	99.12	99.06	99.07	99.08	99.14	99.21
3U-D	99.12	99.10	99.14	99.18	99.17	99.18	99.18	99.47
3U-E	96.94	96.97	97.02	97.01	97.01	97.05	98.76	99.74
3U-F	97.41	97.33	97.45	97.45	97.42	97.46	99.85	99.41
3U-G	96.62	96.75	96.93	96.79	96.75	96.75	99.02	99.62
3U-H	97.46	97.40	97.58	97.62	97.54	97.57	99.46	98.94

Table C.11. Cement-bentonite grout height measurements for 5% mixture.

Sample	Height (mm)							
Day	**1**	**2**	**5**	**9**	**12**	**15**	**22**	**30**
5S-A	99.12	99.21	99.28	99.20	99.16	99.16	99.17	99.16
5S-B	99.65	99.61	99.73	99.65	99.66	99.73	99.92	99.73
5S-C	98.96	98.80	99.02	99.10	98.99	98.98	99.17	98.98
5S-D	98.82	94.32	98.91	98.87	98.84	98.90	99.15	98.87
5S-E	99.06	99.51	99.13	99.11	99.12	97.46	98.85	99.12
5S-F	99.21	99.06	99.32	99.31	99.31	99.31	98.91	99.28
5S-G	99.95	99.68	100.03	100.05	100.04	100.03	99.92	99.99
5S-H	99.56	99.37	99.72	99.60	99.65	99.68	99.43	99.65
5U-A	99.44	99.78	99.50	99.46	99.49	99.54	99.43	99.47
5U-B	99.49	99.89	99.52	99.56	99.52	99.50	99.56	99.47
5U-C	99.24	99.50	99.33	99.32	99.33	99.29	99.08	99.30
5U-D	99.48	99.53	99.64	99.56	99.50	99.59	99.19	99.54
5U-E	99.49	99.10	99.56	99.53	99.56	99.56	99.32	99.49
5U-F	99.17	99.74	99.16	99.17	99.19	99.16	99.09	99.15
5U-G	99.69	99.93	99.80	99.79	99.75	99.73	99.78	99.76
5U-H	99.76	99.66	99.82	99.74	99.72	99.68	99.60	99.78

Table C.12. Cement-bentonite grout diameter measurements for 1% mixture.

Sample	Diameter (mm)							
Day	1	2	3	6	8	15	22	29
1S-A	51.04	50.54	50.67	50.59	50.65	50.84	50.68	50.75
1S-B	51.02	50.66	50.71	50.47	50.73	50.92	50.73	50.74
1S-C	50.96	50.49	50.69	50.90	51.33	50.56	50.71	50.66
1S-D	50.79	50.48	50.70	50.49	50.70	50.64	50.51	50.68
1S-E	50.92	50.63	50.99	50.27	50.68	50.58	50.71	50.75
1S-F	50.84	50.25	50.56	50.75	50.40	50.65	50.62	50.72
1S-G	50.61	50.66	50.42	50.67	50.92	50.56	50.73	50.76
1U-A	51.14	50.65	50.69	50.66	51.01	50.48	50.81	50.68
1U-B	50.91	50.87	50.94	50.61	50.71	50.83	50.66	50.77
1U-C	51.06	50.75	50.77	51.07	50.77	50.69	50.72	50.71
1U-D	50.81	50.75	50.60	50.76	50.66	50.61	50.76	50.84
1U-E	50.71	50.94	50.64	50.52	50.71	50.64	50.71	51.24
1U-F	50.69	50.70	50.74	50.69	50.75	50.59	50.62	50.60
1U-G	50.73	50.68	50.50	50.83	50.73	50.52	50.73	50.74

Table C.13. Cement-bentonite grout diameter measurements for 3% mixture.

Sample	Diameter (mm)							
Day	1	2	5	6	8	15	21	28
3S-A	50.96	51.05	51.05	51.02	51.01	50.94	50.96	51.95
3S-B	50.55	50.62	50.60	50.63	50.58	50.63	50.90	51.19
3S-C	50.48	50.58	50.52	50.62	50.55	50.67	50.90	51.08
3S-D	50.73	50.71	50.71	50.71	50.68	50.73	50.92	50.95
3S-E	51.18	50.21	51.23	51.22	51.22	51.23	51.08	51.61
3S-F	50.55	50.50	50.57	50.62	50.58	50.57	50.99	51.38
3S-G	50.55	50.62	50.64	50.63	50.68	50.65	51.28	51.04
3S-H	50.73	50.65	50.73	50.70	50.70	50.69	51.12	51.04
3U-A	50.69	50.72	50.69	50.73	50.67	50.68	50.94	51.25
3U-B	50.60	50.75	50.66	50.76	50.69	50.76	51.01	51.29
3U-C	50.68	50.69	50.66	50.71	50.63	50.64	50.89	50.18
3U-D	50.51	50.62	50.60	50.63	50.63	50.62	50.98	51.32
3U-E	50.66	50.66	50.68	50.71	50.68	50.69	50.90	51.60
3U-F	50.62	50.65	50.64	50.65	50.66	50.62	50.87	50.95
3U-G	50.70	50.67	50.74	50.74	50.75	50.73	50.97	51.00
3U-H	50.65	50.69	50.69	50.70	50.69	50.71	51.15	51.94

Table C.14. Cement-bentonite grout diameter measurements for 5% mixture.

Sample	Diameter (mm)							
Day	1	2	5	9	12	15	22	30
5S-A	50.99	50.93	51.05	51.02	50.99	51.01	50.93	51.04
5S-B	50.75	50.82	50.80	50.79	50.76	50.76	50.94	50.79
5S-C	50.67	50.85	51.08	51.10	51.08	50.75	50.89	51.06
5S-D	50.76	50.94	50.81	50.78	50.82	51.03	50.94	50.79
5S-E	50.71	50.92	57.48	50.77	50.76	50.53	50.85	50.79
5S-F	50.75	50.87	50.81	50.76	50.78	50.73	50.87	50.78
5S-G	51.18	50.93	51.24	51.24	51.22	51.30	50.92	51.29
5S-H	50.75	50.91	50.77	50.79	50.77	50.79	50.84	50.73
5U-A	50.79	50.89	50.80	50.76	50.78	50.80	51.07	50.80
5U-B	51.10	50.89	51.13	51.11	51.10	51.12	50.99	51.13
5U-C	51.12	50.85	51.16	51.14	51.15	51.14	50.90	51.13
5U-D	50.76	50.85	50.75	50.74	50.71	50.76	50.85	50.78
5U-E	50.74	50.85	50.77	50.75	50.72	50.73	50.97	50.78
5U-F	50.74	50.99	50.75	50.74	50.73	50.77	50.85	50.76
5U-G	50.81	51.12	50.90	50.85	50.81	50.79	51.04	50.83
5U-H	51.02	51.03	51.17	51.04	51.02	51.03	50.91	51.09

Table C.15. Cement-bentonite grout mass measurements for 1% mixture.

Sample	Mass (g)							
Day	1	2	3	6	8	15	22	29
1S-A	374.1	377.6	379.1	379.6	380.9	381.6	382.5	382.7
1S-B	376.1	380.4	381.4	382.4	383.1	384.4	385.1	385.4
1S-C	375.1	377.8	379.0	379.8	381.0	381.7	382.7	383.3
1S-D	375.1	378.9	379.5	380.9	381.8	382.6	383.7	383.8
1S-E	369.4	372.6	373.6	374.4	375.4	376.3	377.3	377.6
1S-F	373.5	378.0	378.8	380.0	381.2	381.6	382.5	382.0
1S-G	372.2	375.6	376.5	377.7	378.5	379.5	380.4	380.5
1U-A	375.1	376.4	378.1	382.0	382.9	383.4	384.3	383.9
1U-B	370.5	372.9	373.2	377.2	377.6	378.2	379.1	378.7
1U-C	371.3	371.2	371.5	377.4	377.8	377.7	378.7	378.2
1U-D	371.8	371.8	372.2	377.9	378.7	379.1	379.9	379.3
1U-E	369.8	370.8	371.7	376.5	377.1	377.7	378.7	377.9
1U-F	370.3	369.5	369.8	376.7	377.9	378.5	379.2	379.2
1U-G	366.7	368.0	369.1	373.6	374.0	374.9	375.2	375.3

Table C.16. Cement-bentonite grout mass measurements for 3% mixture.

Sample	Mass (g)							
Day	1	2	5	6	8	15	21	28
3S-A	352.9	357.7	359.7	360.4	360.6	361.9	361.3	361.8
3S-B	350.0	356.1	358.0	358.3	359.3	359.7	359.5	360.1
3S-C	355.9	359.7	361.9	362.2	362.8	363.4	362.8	364.0
3S-D	351.1	355.8	357.8	358.1	358.8	359.5	359.2	359.7
3S-E	353.5	352.8	354.2	354.9	355.4	356.5	355.7	356.5
3S-F	353.1	352.6	359.0	359.4	360.3	361.2	360.7	361.5
3S-G	352.4	357.4	359.4	359.9	360.6	361.3	361.1	361.7
3S-H	358.5	362.7	364.2	365.2	365.7	366.7	366.2	366.6
3U-A	356.4	355.6	362.6	363.3	363.9	365.1	365.0	362.1
3U-B	358.4	358.0	366.1	366.4	367.1	368.4	368.2	366.8
3U-C	352.2	351.3	358.2	360.7	362.6	363.6	363.4	356.0
3U-D	353.9	353.1	361.1	361.6	362.3	362.9	362.8	357.8
3U-E	344.5	347.2	353.0	353.7	354.3	354.8	355.0	345.1
3U-F	352.3	353.4	357.5	361.0	362.0	362.6	362.8	354.1
3U-G	351.7	351.7	357.7	358.2	358.9	359.0	359.7	351.7
3U-H	353.6	352.6	359.3	359.8	360.7	361.1	361.5	354.9

Table C.17. Cement-bentonite grout mass measurements for 5% mixture.

Sample	Mass (g)							
Day	1	2	5	9	12	15	22	30
5S-A	337.6	343.3	344.2	346.1	345.5	345.4	395.9	243.7
5S-B	337.9	343.9	345.2	346.7	346.6	346.4	347.0	244.3
5S-C	332.5	336.0	337.4	338.6	338.5	346.1	338.9	238.6
5S-D	336.3	342.5	344.2	345.5	346.1	338.3	346.0	243.6
5S-E	338.1	343.8	345.1	347.0	346.3	345.3	347.1	244.4
5S-F	337.3	343.1	344.5	346.0	345.5	345.8	346.2	243.9
5S-G	340.3	346.7	348.1	349.8	349.1	349.3	349.8	246.5
5S-H	339.1	346.2	347.8	349.1	348.9	349.2	349.6	246.4
5U-A	338.3	344.8	346.6	347.8	348.4	348.5	348.6	245.5
5U-B	333.4	334.0	341.2	342.3	342.7	343.2	343.7	241.7
5U-C	332.2	331.9	340.5	341.9	341.9	342.4	342.8	241.2
5U-D	338.4	336.8	346.9	348.6	348.8	349.2	350.2	246.3
5U-E	337.3	343.6	345.4	347.4	346.6	347.3	347.8	244.6
5U-F	337.8	344.3	345.9	347.9	347.3	348.0	348.5	245.0
5U-G	334.4	339.5	342.4	344.7	344.0	344.5	345.3	242.7
5U-H	339.2	339.9	348.0	350.3	349.8	350.4	350.9	246.7

Table C.18. Cement-bentonite grout vertical load bearing capacity data.

Sample	Peak Load (kN)	Peak Stress (Mpa)	Sample	Peak Load (kN)	Peak Stress (Mpa)	Sample	Peak Load (kN)	Peak Stress (Mpa)
1-SA	87.71	41.30	3-SA	57.56	28.17	5-SA	Damaged before test	
1-SB	82.43	38.82	3-SB	52.11	25.51	5-SB	42.90	21.00
1-SC	84.76	39.92	3-SC	63.50	31.08	5-SC	42.25	20.68
1-SD	84.38	39.73	3-SD	59.53	29.14	5-SD	45.85	22.44
1-SE	82.78	38.98	3-SE	61.05	29.30	5-SE	45.95	22.49
1-SF	82.31	38.76	3-SF	59.85	29.30	5-SF	42.00	20.56
1-SG	78.87	37.14	3-SG	47.92	23.46	5-SG	49.15	24.06
1-SH	73.45	34.58	3-SH	63.83	31.25	5-SH	Damaged before test	
1-UA	80.56	37.94	3-UA	61.56	30.14	5-UA	43.06	21.08
1-UB	78.06	36.76	3-UB	60.57	29.65	5-UB	47.65	23.33
1-UC	70.68	33.28	3-UC	43.09	21.09	5-UC	Damaged before test	
1-UD	Damaged before test		3-UD	47.16	23.09	5-UD	45.51	22.28
1-UE	72.12	33.96	3-UE	45.43	22.24	5-UE	Damaged before test	
1-UF	66.05	31.10	3-UF	60.63	29.68	5-UF	Damaged before test	
1-UG	78.11	36.78	3-UG	68.52	33.54	5-UG	52.69	25.79
1-UH	65.88	31.03	3-UH	47.19	23.10	5-UH	50.31	24.63

Table C.19. Cement-bentonite grout hydraulic conductivity data.

Sample	K (cm/s)	t (hours)	V (cm^3)	Sample	K (cm/s)	t (hours)	V (cm^3)	Sample	K (cm/s)	t (hours)	V (cm^3)
1-SA	2.44E-07	23.92	39.80	3-SB	3.26E-07	20.00	44.50	5-SB	1.57E-08	23.40	2.50
1-SD	3.20E-09	22.87	0.50	3-SF	1.58E-08	20.47	2.20	5-SF	8.27E-08	18.60	10.50
1-UB	1.01E-08	23.32	1.60	3-UA	3.15E-09	23.28	0.50	5-UE	4.09E-08	23.30	6.50
1-UC	3.18E-08	22.57	4.90	3-UB	4.01E-07	19.10	52.20	5-UF	7.71E-08	21.10	6.50
h_w (cm)	6.5										
h_s (cm)	3.01										
A_s (cm^2)	20										
N (-)	30										

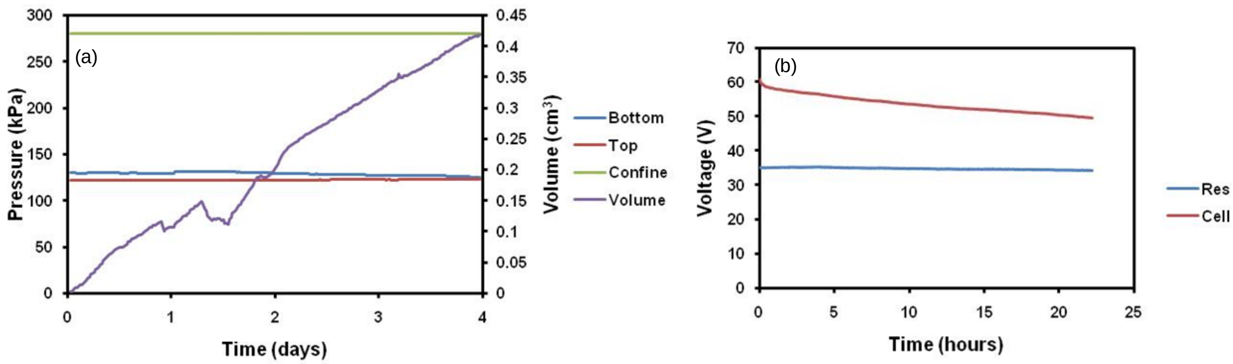

Figure C.1. Confining stress and reservoir level results of clay sample run in (a) flexible wall permeameter and (b) centrifuge.

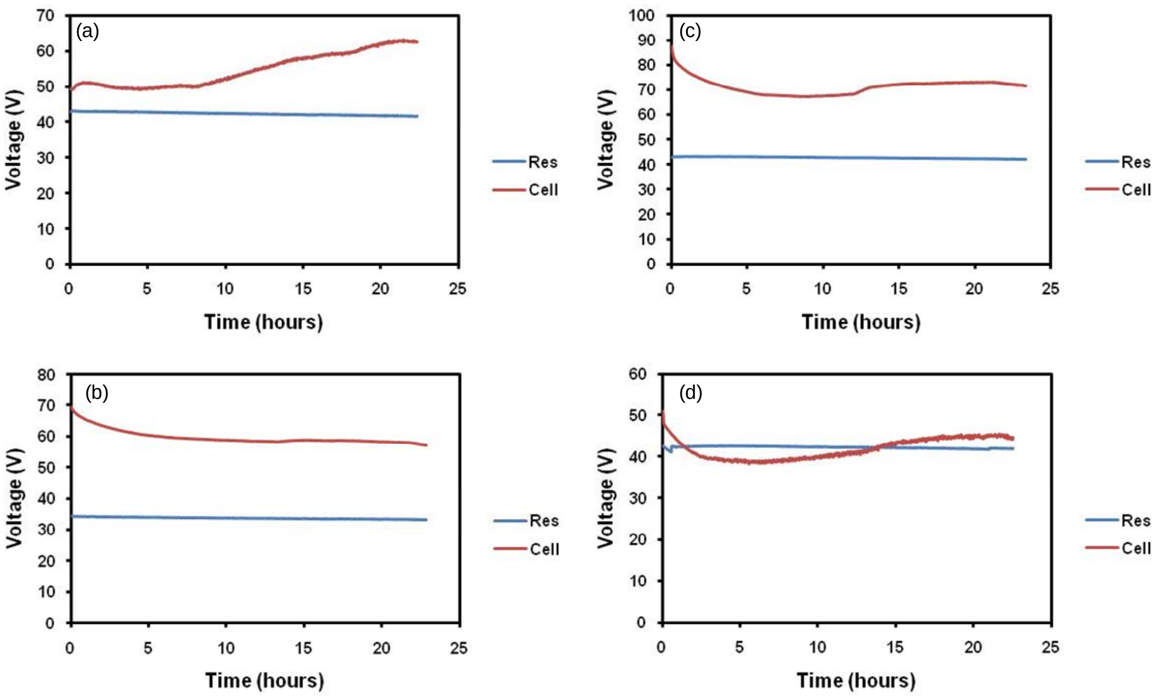

Figure C.2. Confining stress and reservoir level results of 1% bentonite content samples (a) 1SA, (b) 1SD, (c) 1UB, and (d) 1UC.

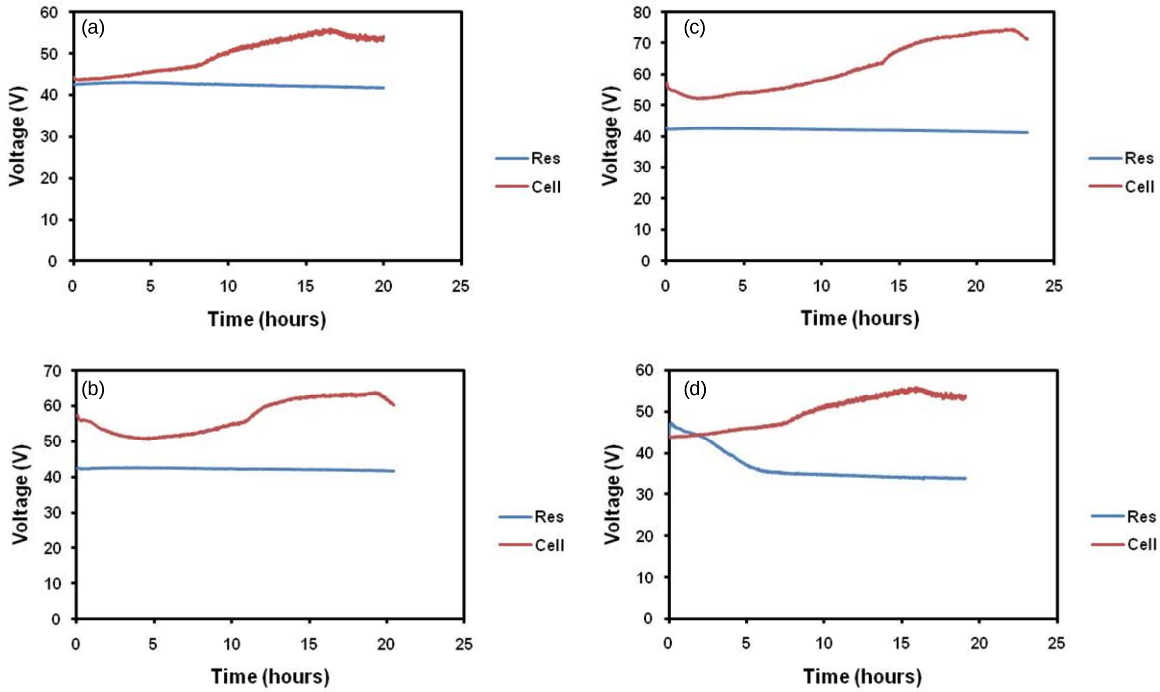

Figure C.3. Confining stress and reservoir level results of 3% bentonite content samples (a) 3SB, (b) 3SF, (c) 3UA, and (d) 3UB.

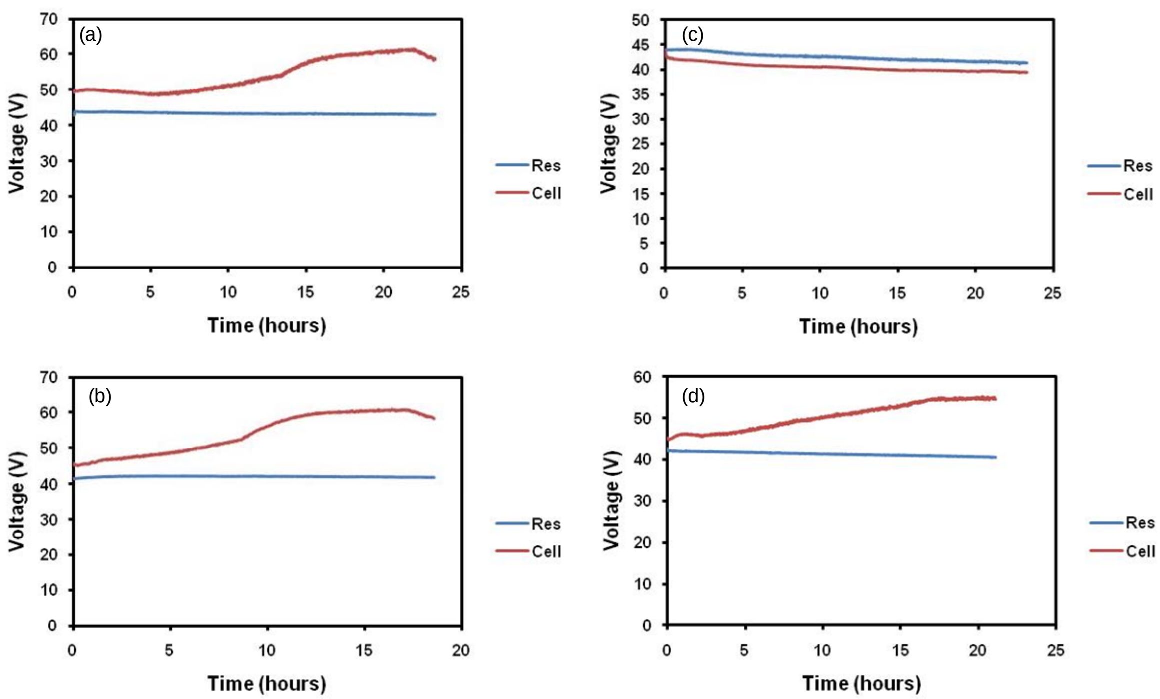

Figure C.4. Confining stress and reservoir level results of 5% bentonite content samples (a) 5SB, (b) 5SF, (c) 5UE, and (d) 5UF.