The Evolution of the Small Diameter Variable Gradient Sanitary Collection System into the Small Bore Sewer™

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ABSTRACT

During extended periods of wet weather and storm events, large volumes of groundwater and surface water can infiltrate typical sanitary collection systems, resulting in design requirements to oversize the piping network. Affordable and cost-effective sewage collection systems that maintain or improve environmental protection are often sought out by municipalities and design engineers; however, traditional gravity sewers typically allow excessive amounts of infiltration and inflow (I/I) to enter into the sewer network, overwhelming the treatment plant with surges of diluted sewage and leading to requirements for bypass of the treatment process. The evolution of the small diameter variable gradient (SDVG) sanitary collection system into the watertight Small Bore Sewer™ (SBS™) system has proven that removal of inflow/infiltration and removal of sewage solids at source can eliminate bypass occurrences and reduce the downstream wastewater treatment plant requirements and operation and maintenance costs.

KEYWORDS: inflow/infiltration, HDPE, flow attenuation, jointless collection system, clarifier.

INTRODUCTION

The efficiency of a sanitary collection system directly impacts the downstream treatment plant's footprint size, annual operation and maintenance costs, and reserve capacity; when considering a sewage treatment plant design, expansion or upgrade, improving the collection system's efficiency should be considered as an option. A jointless pipe and solids-free effluent system was developed in an attempt to make collection systems highly efficient. Two installations of this system will be presented in this paper as a demonstration of the improvements developed: the first was a 1989 pilot project and the second was a residential installation of the system in 2000.

Collection Systems' Impact on the Treatment Plant

Today, sanitary collection systems are typically installed similar to how they were installed over 100 years ago. Although measuring devices and construction equipment have advanced, the design criteria have remained stagnant, with large, oversized pipes laid deep under road surfaces, separated from watermains and stormwater pipes to ensure that leaks from the jointed pipes do not contaminate potable water networks or open water discharge systems. During storm events, large surplus flows of groundwater infiltration and surface water runoff enter sanitary collection systems through system deficiencies and openings on maintenance holes, overwhelming downstream treatment plants as operators bypass sewage around their facilities as equipment capabilities are exceeded; seasonal I/I flow can become present a few years after jointed sanitary sewer piping installation (Johnston, 2005). This unnecessary and excessive I/I flow of at least 9,640 gallons [36,000 litres] each year for every person connected to a jointed system must be considered during the sizing of pipe diameters and of pipe installation slope, in addition to the diurnal peak flow rates which must also be accommodated for the collection system and the wastewater treatment plant (Tchobanoglous, et al., 2003). With the removal of solids and I/I flow, both large pipe diameters and steep pipe slopes can be eliminated, and peak flows are attenuated to a consistent flow. SDVG sewers have evolved and improved with the goal to create a system that can eliminate many of the inefficiencies of an historic collection system.

Development of the Pilot Project

In response to the quagmire of widespread septic systems failures that polluted local aquifers and wells, the Ontario Ministry of the Environment (MOE) organized a research competition to seek out a new methodology to transfer sewage to a centralized plant which would remove the dependence on private, on-site systems that were harming rural water resources. The finalist selected was the SDVG sewer for the pilot project in Field, Ontario in 1989.

A northern community near the 49th parallel, Field contains approximately 40 homes and businesses which were connected to this cluster system technology. The collection system was designed according to the same parameters and methodology as those outlined in *Alternative Wastewater Collection Systems* and followed the recommendation to use thermally fused joints to provide watertight piping (U.S. Environmental Protection Agency, 1991). When completed, only the sum of the total effluent volumes leaving each home were received gradually throughout the day at the extended aeration treatment plant, which provided for a smaller plant footprint; plant size was modified to accept lower peak flows, decreasing the overall size of the plant's equalization tanks and headworks. Flow attenuation and inflow/infiltration prevention allowed for a more economical treatment plant to be sized by designers for this community.

The pilot project collection system was constructed in less than three months and cost 56% less than the estimated historic gravity sewer (Brinks, 1995). The monitored effluent generation at the treatment plant was 2,380 gallons per day [9,000 L/d] or, if 2.0 persons per connection is assumed, 34 gal/capita/day [129 L/capita/d] (Brinks, 1995). Before the discovery of an erroneous source of inflow connection was removed, the treatment plant had flows of 6,870 gal/d [26,000 L/d], indicating that that sealed sanitary collection sewer prevents 4,490 gal/d [17,000 L/d] of groundwater from entering the piping, mixing with raw sewage and flowing to the treatment plant, only to be processed at a greater cost and decreased treatment efficiency (Brinks, 1995).

Innovative Collection System Improvements

Although SDVG sewers have been in operation for over 45 years in Australia, issues with inflow/infiltration persisted (Otis, 1985). Once additional I/I volumes were removed, designers could accommodate consistent, regular flows with even smaller diameter pipe network possibilities and high density polyethylene (HDPE) pipe materials provided that solution. After the success of the Field pilot project, further modifications were made to the materials in order to ensure a watertight system, and improvements were made to the internal plumbing of the SDVG system's septic tank to increase suspended solids removal in subsequent projects. In 1999, the technology was patented in the United States and then in Canada in 2005, with the modified and improved system named the Small Bore Sewer™, or the SBS™ system. With the proprietary SBS™, non-jointed, thermally fused HDPE piping can be installed by directional drilling, with variable alignment and variable gradients. The resilient and strong sewer materials require minimal bedding and the system has more alignment tolerance than historic gravity sewer systems.

In the SBS™ network, raw sewage flows from the residential, industrial or commercial building into a modified septic tank; the clarifier was modified to have two compartments for pre-treatment, since two chamber tanks knock down more suspended solids than a traditional single chamber septic tank (Seabloom et al., 2004). The first chamber is extended to 82% of the total tank length to provide for a larger biodegradation window and to optimize the suspended solids settling corridor, as opposed to the range of 50% to 67% for septic tanks (Great Lakes – Upper Mississippi River Board of State Sanitary Engineers, 1980). This clarifier tank separates greasy scum, solids and liquids more efficiently than septic tanks; peak flows are detained within the tank baffle and the outlet's flow attenuation device, discharging consistent, even flows throughout the pipe network and softening peak flows. Additionally, in order to ensure the prevention of I/I into the clarifier, the tank is tested to Canandian Standards Association's watertightness test, CSA B66-05 Section 9.4, and has for inlet and outlet connections Polylok III High Pressure Closed End Boot Seals cast into the wall during tank pouring at Clearford's Brooklin Pre-cast Division plants; all tanks are manufactured in accordance with CSA B66-05.

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System access points (SAP) are provided at 500 feet [150 metre] spacing along the graded piping sections and at critical intersections; unlike historic manholes, SAPs to not need to be placed at changes in alignments and are not locations for high I/I flows. These modified manholes, named SAPs in the SBS™ system, are vertical thermally fused HDPE pipe sections, encased with vertical HDPE or cast iron piping, and accessed through a cast frame and cover. SAPs can also provide air flow through the pipe network with the additional of an air release valve in replacement of a threaded cap or air filter. These SAPs can be located in the grassy portion of the road allowance, or load bearing SAPs can be installed within the road surface, allowing for installation of the SBS™ system directly under the road deck or within the boulevard right-of-way for access ease. Pressure rated polyethylene pipes are used throughout the collection system, which provides municipalities with assurances that potable water is protected in common trench installations.

The functionality of the system mimics historic gravity sewers without the requirement for higher cleansing velocities and higher gradient slopes for the conveyance of solids. Effluent sewers can maintain a lower minimum scouring velocity, since the remaining solids and slime growths in the collection system are easily carried when flow velocities of 0.50 ft/s [0.15 m/s] are achieved (U.S. Environmental Protection Agency, 1991). The installation can be designed for variable grade and alignment without frequent manholes at every alignment change; only overall hydraulic gradient is necessary for proper functioning of the system. Minimum hydraulic gradients can be reduced to 0.11% due to lower cleansing velocities required in the effluent system design. This slope reduction results in fewer lift/pumping stations required for the project.

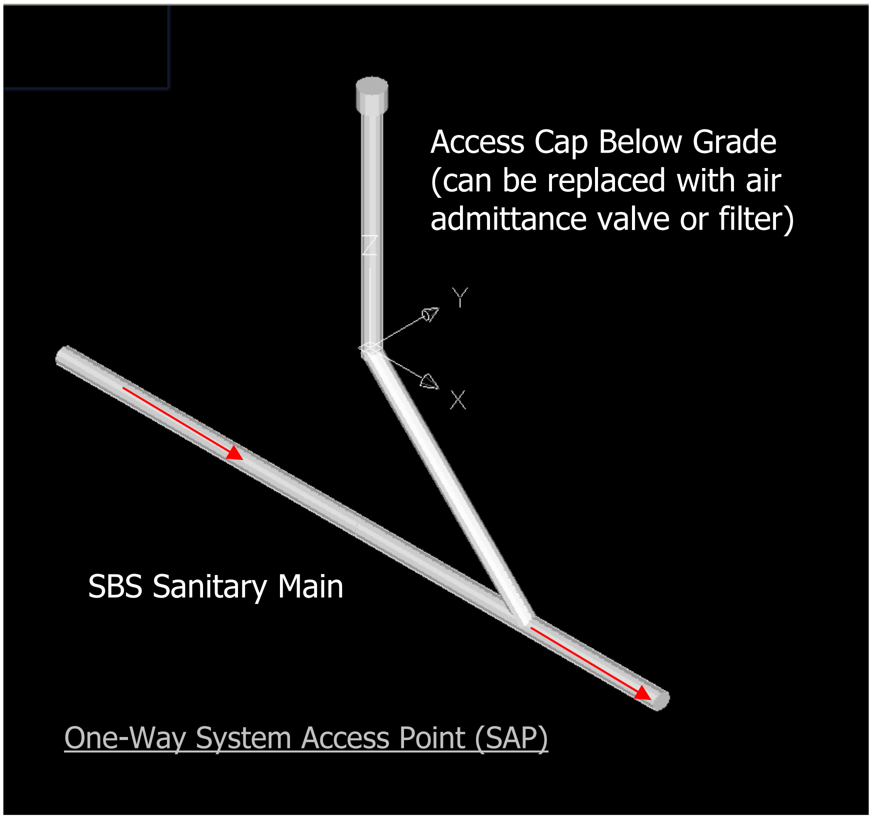


Figure 1 – Small Bore Sewer™ System Access Point (SAP).

METHODOLOGY

Large Scale Implementation of Improved SBS™ System

The Village of Wardsville is a small rural community in southwestern Ontario with approximately 170 homes and businesses, including a golf course and a large retirement home. In January of 1999, after having endured over 20 years of study and analysis, there were widespread failures of the communal and private sewage systems throughout the Village. Raw sewage was present in surface and sub-surface water throughout the community, as were unpleasant odors from breakthrough effluent. Through their research investigations, the Municipal Council identified an innovative solution using small diameter pipe sewer technology that provided a cost effective solution to reduce the total installation cost by more than 3 million (1999) Canadian dollars from the historic gravity sewer estimate.

Installation Techniques

In order to reduce installation costs and minimize disruption to the community, the Wardsville project constructed all sewer pipe networks by the use of horizontal boring technology. This technique avoided the need for hard surface replacement and minimized suspect soil removal. The total installation project was completed in eight months with no road closures and no detours.

Treatment Plant

A Napier-Reid extended aeration plant, designed to process 79,260 gal/day [300m^3/day], was selected for the Village. It consisted of two extended aeration sewage treatment process units in parallel, each rated at 49,630 gal/day [150 m^3/day]. The clarifier and filter in each unit were sized to accept a peak flow of up to 145,310 gal/day [550 m^3/day]. The ultraviolet disinfection system and the outfall are sized to meet a peak daily flow of 290,620 gal/day [1,100 m^3/day]. This flow criterion was set out by the Ontario Ministry of the Environment to support the empirical design flow from the existing community of Wardsville; the actual treatment load can be found in Table 1, in the following section of this paper.

Collection System Design
Approval from the Ontario Ministry of the Environment was necessary for the implementation of this project. From historic data collected from the Field, Ontario pilot project, the Ministry agreed to allow for the design of the collection system using a lower base flow of 60 gal/capita/day [225 L/capita/day], a lower peaking factor of 2.0, and if non-jointed pipe materials were selected, a lower I/I value of zero was approved. By applying the Manning's equation for gravity flow in pipes, the pipe diameter was calculated to be 3 inches [75mm] throughout the project site.

RESULTS

Economic Benefits
Installation of a backyard collection mains system allowed for residents to connect to the SBS™ clarifiers often using their existing septic tank connection plumbing, or minor modification thereof; no extensive internal plumbing was necessary, which an historic gravity sewer system would have required. In a letter of congratulations after completion of the project, Morrison (2002) indicates that the SBS™ installation cost $3.45 million (1999 Canadian) and the original cost for the historic gravity sewer was estimated to be $6.5 millions (1999 Canadian). The capital cost savings for sanitary sewer collection of 47% only represents each resident's tax savings; additional costs for home re-plumbing and frontyard connection to the gravity sewer would be an additional out-of-pocket expense to the homeowner, not covered by government grants.

Additional, immeasurable economic savings arose when no road closures occurred during the installation of the SBS™ system using directional drilling; no local businesses had their customer traffic interrupted because of sewer installation.

System Chemistry
Initial daily effluent generation was found to be lesser than the theoretical expectations and long term results have remained consistent. Contaminant concentrations were lower than typical septic tank discharge values, indicating better solids removal in the modified clarifier than historic septic tanks (Lowe et al., 2007). Measured average suspended solids concentrations was 27.8 mg/L for Wardsville (OCWA, 2006 and OCWA, 2007); in comparison, Lowe et al (2007) listed the suspended solids concentration for raw domestic wastewater as 285 mg/L and for septic tank effluent as 62 mg/L for Multiple Sources, see Table 1. Results from five years of continuous monitoring indicate that material degradation has not significantly altered the effluent generation flow values or the contaminant concentrations.

System chemistry was monitored by an independent third party, the Ontario Clean Water Agency (OCWA), and between 2001 and 2005 inclusive, the OCWA reports indicate that the monthly peaking factor averaged 1.35 in Wardsville.

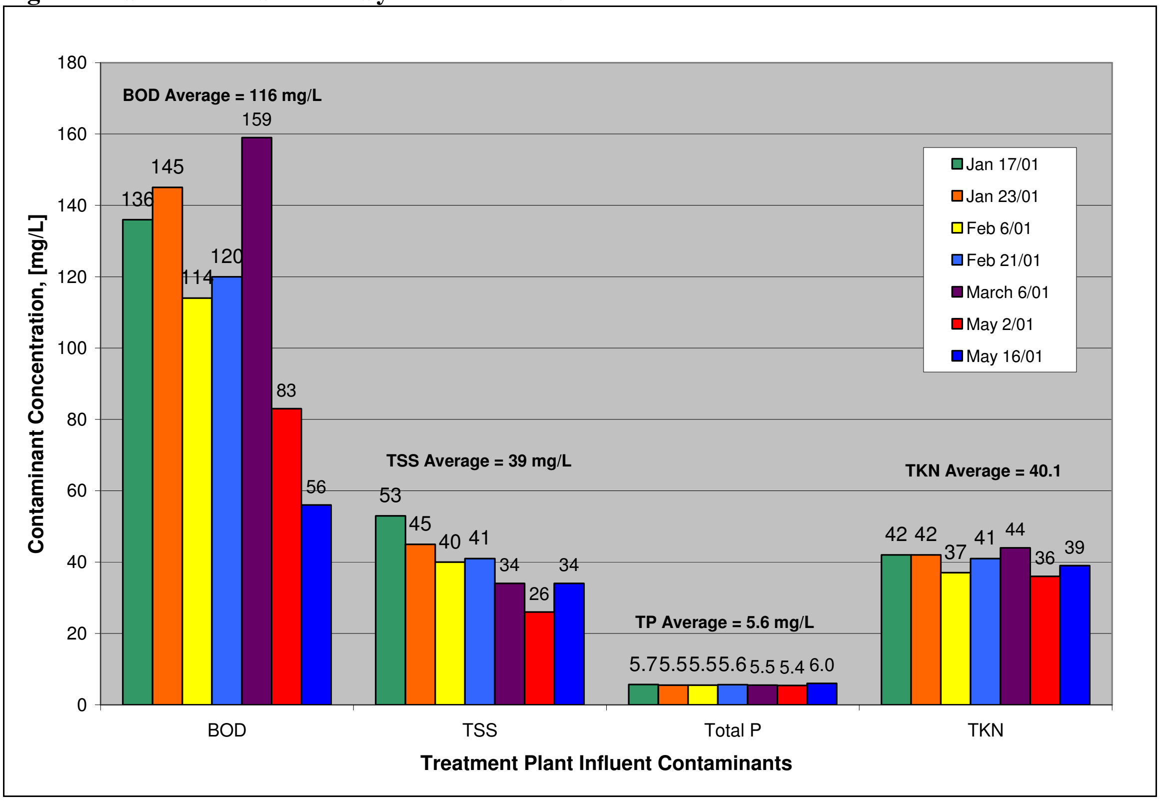
Table 1 – Small Bore Sewer™ Chemistry Results Comparison

Parameters	Raw Municipal Wastewater*	Small Bore Sewer™ Ontario MOE Approved	Reduction from Raw WW	Septic Tank Effluent*	Reduction from Raw WW	Wardsville Monitored Results	Reduction from Raw WW
Monthly Peaking Factor	4.3	2	53%			1.4	67%
Inflow/Infiltration, [L/cap/d]	100	0	100%			0	100%
Total Peak Design Flow, [L/cap/d]	1670	450	73%			392	77%
BOD_5, [mg/L]	210	120-160	33%	184	12%	116	45%
TSS, [mg/L]	237	35-55	81%	62	74%	39	83%
TKN, [mg/L]	38.9	35-45	-	46	-	40	-
TP, [mg/L]	7.1	5-6	54%	6.9	3%	5.6	21%

*Data from the Lowe et al. (2007) Literature Review Summary, Table 3-15

The concentrations of other contaminants were also lower than historic gravity sewer and septic tank effluent values, which the Ontario MOE used as benchmark for the SBS™ flows. The concentrations were also unaltered by the diluting effect of I/I flows typically seen in leaking historic gravity sewer years after installation. Monitored contaminant concentrations at the Wardsville treatment plant are presented in Figure 2.

Figure 2 – Small Bore Sewer™ System Effluent Concentrations in Wardsville.



Plant Re-Rating
The sanitary treatment plant design was required to meet the Ontario MOE guidelines. A one year re-rating of the treatment plant completed in early 2002 demonstrated that the plant receives an average daily flow of 33,300 gal/d [126 m^3/d] and is being used at 42% of its design capacity (Connelly, 2002). The plant has a significant additional reserve capacity which full usage should result in better overall treatment. Conditional to the design parameters being maintained, the core SBS™ system remains as the system to be utilized for in-fill and future growth, the main pumping station and sewage treatment facilities can be re-rated to accommodate a further 800 people or an equivalent flow of up to 47,600 gal/day [180 m^3/day]; this equates to 285 additional homes to the original 170 equivalent connections (assuming 2.8 persons per equivalent home, at 60 gal/capita/day [225 L/capita/d]).

Sludge Production
The pre-treatment occurs when suspended solids precipitate in the clarifier and collect on the tank floor, where anaerobic bacteria produce the most efficient digestion when the sludge is digested over several years, allowing for more mature anaerobes to become more efficient at sludge digestion before removal during desludging of the tanks.

Sludge retention in the clarifier tanks has been predicted using Bounds non-linear formula for sludge accumulation in tanks, which includes the efficiency of mature micro-organisms to digest sludge feedstock more readily (Bounds, 1997). As sludge ages, the accumulation rate is no longer a cumulative, linear rate but degradation occurs more rapidly, and the accumulation curve becomes exponential. Maximum retention of the sludge is encouraged by users connected to the SBS™ system in order to capture the benefits of advanced sludge degradation rates by mature anaerobes. Bounds formula,

$$N_{sl+sc} = 47 \times t^{0675} \qquad \text{(Eq. 1)}$$

where N_{sl+sc} is the volume of sludge and scum in gallons per capita and t is time in years, was used to develop the recommended seven to ten year desludging cycle for the clarifier tanks (Bounds, 1997).

Comparisons of the frequency results for the desludging rates for Wardsville tanks and the theoretical values calculated from the Bounds formula show that the clarifiers can extend pump-out frequencies to a longer time frame. The theoretical pump-out cycle, based on Bounds formula and assuming a one day HRT at maximum storage, is approximately 7 years; a monitoring study, conducted by a Queen's University master's student in the summer of 2007 supports that most tanks have not reached maximum sludge holding capacity 7 years after installation.

Aquifer Protection
Based on the Ontario Ministry of the Environment's dry weather I/I value for each resident of 24 gal/day [90 L/day] for design, each day nearly an estimated 22,200 gal [84,000 L] of groundwater and surface water I/I do not enter into the sealed sanitary collection system in Wardsville. Receiving water has been protected, as no bypass events have been necessary and no groundwater has infiltrated the sanitary system. By keeping the water source and the water return in close proximity, no aquifer migration occurs.

DISCUSSION

Municipal financial savings provided incentive for Wardsville Council to consider an alternative collection system; residents saved tax dollars on communal infrastructure capital costs, on operation and maintenance costs for their treatment plant and on their private property connection costs.

For a smaller wastewater treatment plant to be designed for Wardsville, the collection system had to complete three tasks: 1) the removal of sources of I/I flow, 2) a lower peaking factor, and 3) lower peak flows. In this community, the equalization of peak flows through attenuation devices at source prevents the over-sizing of the collection pipe network, of effluent pumps and pump stations, and of the treatment plant.

Re-rating the sewage treatment plant based on usage of 50% of the capacity clearly supports the anticipated performance of the SBS™ solution. The Wardsville example shows that wastewater treatment plants can be sized much smaller if at-source separation collection systems are used, which convey effluent in jointless piping networks.

CONCLUSIONS

Successful pilot and full scale installations of the SBS™ system show both the cost effectiveness and environmental advantages of these alternative sanitary collection systems. These advantages are:

- Sealed maintenance holes, known as SAPs
- Consistent, even effluent flow conveyance
- Variable alignment allows for flexible installation
- At-source solids removal reduces steeply sloped installation requirements, slower scouring velocities
- Fewer lift/pump stations are required for shallow sloped system
- Directional drilling methodology reduces community/business disruption
- I/I removal reduces necessary treatment plant capacity
- Increased sludge degradation in clarifier tanks
- Optimization of clarifier tank to extend and maximize desludging cycle

This successful full scale installation demonstrates that the sealed Small Bore Sewer™ is a sewage collection system solution that economically allows for the design of a smaller downstream treatment plant. Lower hydraulic and organics concentration at the treatment plant attached to the SBS™ collection system provide for lower operation and maintenance costs. The sludge production can be reduced; this lower volume will generate great savings in the long term, at the sludge disposal end of cycle. The cost savings afforded by this solution to the developer or municipality do not justify continuing with septic field installations, except in isolated, single user scenarios where potential cluster failures cannot occur. By properly selecting a sealed, jointless effluent collection system, smaller sewage treatment plants can be designed and commissioned, and groundwater will be preserved.

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