LISGAR DISTRICT
BASEMENT WATER INFILTRATION INVESTIGATION

SUMMARY REPORT

Submitted to:

City of Mississauga
Mississauga, Ontario

Submitted by:

Amec Foster Wheeler Environment & Infrastructure
A division of Amec Foster Wheeler Americas Limited
3215 North Service Road
Burlington, ON L7N 3G2

Tel: 905-335-2353
Fax: 905-335-1414

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EXECUTIVE SUMMARY

Lisgar District Basement Water Infiltration Assessment

Commencing in 2008 a number of homes in the Lisgar District experienced water seeping into their basements following certain rainfall events, with the largest number of homes impacted during a rainfall event in late 2011. A total of 187 homes are known to have been affected to date.

After becoming aware of the scale of this issue, the City undertook a number of actions, including:

- Video inspection and cleaning of the foundation drain collector (FDC) system;
- Removal of vegetation along Sixteen Mile Creek;
- Clean-out of bridge crossings and storm outfalls to Sixteen Mile Creek;
- Putting in place a High Water Protocol (deploy pumps during major storms);
- Sealing selected FDC manholes and pipe joints; and
- Adjustment to the Osprey Marsh Stormwater Pond outlet.

In October 2011, the engineering consulting firm of AMEC Environment & Infrastructure (now known as Amec Foster Wheeler Environment & Infrastructure) was retained to undertake an engineering study to determine the cause(s) of basement water infiltration and recommend corrective measures.

After a lengthy and comprehensive monitoring period and analysis, the study findings have determined the problem to be primarily related to the build-up of water in the bedding material of the utility trenches that contain the storm, sanitary and FDC sewer systems.

Leakage from the storm sewer, which is a normal occurrence, combined with the presence of slow draining native soils around the utility trenches has been found to result in water build-up within these trenches. If the build-up of water is significant enough it can travel up the bedding material around the FDC laterals servicing the homes and into the foundation weeping tiles. This water then drains directly into the FDC pipes through the weeping tiles which may result in excess flow in the FDC system (surcharge). However, this condition by itself may not lead to basement water seepage. It is this condition in combination with certain storm conditions (preceding rainfall followed by a sufficiently large storm event) and local lot drainage that may lead to water around the weeping tiles being unable to drain and potentially seeping into the basements of homes.

The exact reasons why homes in the Lisgar District have not had basement water seepage before 2008 are not known. It is considered that the increasing leakage of water from the storm sewers through normal aging gradually increased the volume of water collected in the trenches over time, ultimately contributing to the problems first experienced in 2008.

During the course of the investigations a number of other factors have been identified which may be impacting the overall operation of the FDC system; however, based on the information available, none of them, either alone or in combination would cause water to seep into the basements to the extent reported.

These factors include:

- The depth of the FDC system and utility trench relative to residential weeping tile systems in some areas;
- Capacity issues related to pipe sizes and slopes in some sections of the FDC system;
- Potential inflows to the utility trench from groundwater and surface water sources; and
- Rain water and runoff from the lot or roof entering drains in basement walkout areas that are connected to the FDC system

Based on the findings presented in this study, the following two measures are recommended as the highest priorities for the City to deal with the basement water infiltration issue:

- Strategic lining of priority storm sewers to minimize leakage; and
- Construction of a utility trench dewatering system.

Other actions that may be implemented after the highest priority measures are completed include:

- Build permanent FDC pumping stations for high flows; and
- Replace deficient FDC pipe lengths when they reach the end of their engineered lifespan.

It is also suggested that residents who qualify for the City's Lisgar District Sump Pump Subsidy Program take advantage of the program.

The findings of the engineering study represent a significant step in understanding the cause of a complex basement water infiltration issue in the Lisgar District. Implementation of the two highest priority measures to improve the drainage system's performance and minimize the risk of future basement water infiltration is recommended to be initiated as soon as funding and approvals are secured.

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1.0 INTRODUCTION

The Lisgar District is situated in the northwest corner of the City of Mississauga and is bounded by the Canadian Pacific Railway tracks to the north, Britannia Road West to the south, Ninth Line to the west and Tenth Line to the east. It is located within the Sixteen Mile Creek watershed and drains to a small tributary of the east branch of Sixteen Mile Creek (Figure 1).

The Lisgar District is mainly made up of single family homes which were largely built over a 25-year period starting in the early 1980s as shown in Figure 2.

Commencing in 2008, a number of homes in the Lisgar District have experienced water seeping into their basements following certain rainfall events. A total of 187 homes are known to have been affected to date.

In response to these events, the engineering consulting firm of AMEC Environment & Infrastructure (now known as Amec Foster Wheeler Environmental & Infrastructure) was retained in late 2011 to undertake an engineering study to determine the cause(s) of basement water infiltration and recommend corrective measures.

This Summary Report provides a high-level discussion on the following matters based on three years of comprehensive field monitoring (2012-2014) and engineering analysis:

- Description of the drainage system servicing the Lisgar District;
- Summary of City-led actions to proactively address concerns;
- Summary of potential causes of the basement water infiltration;
- Detailed description of study activities including field work, testing, monitoring and analysis; and
- Outline of the proposed mitigation approach comprised of priority-based actions for 2015 and beyond.

Figure 1: Subwatershed Map

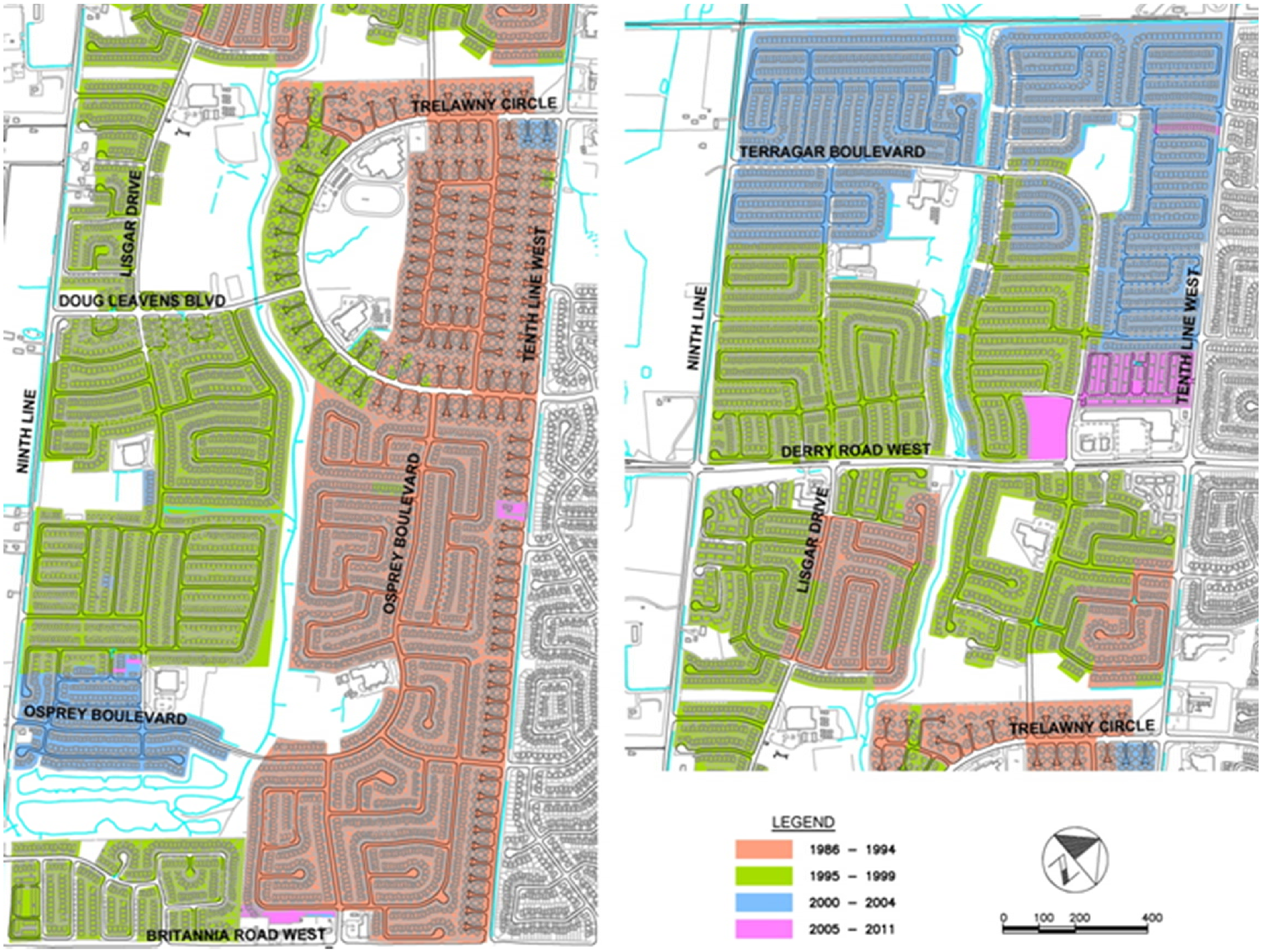


Figure 2: Historic Development of Lisgar District

2.0 OVERVIEW OF DRAINAGE SYSTEMS

When agricultural or open space lands are converted to urban uses, such as residential or employment, municipal services including watermains, sanitary sewers and storm sewers are typically constructed within road allowances or public easements to support these developments. The City of Mississauga is responsible for managing all aspects of stormwater within its jurisdiction, whereas the Region of Peel is responsible for stormwater on Regional roads, as well as drinking water, wastewater and solid waste management.

Storm sewers are designed to capture surface runoff from rainfall or snowmelt and then convey this water safely to a waterbody such as a creek, river or lake. In areas with stormwater management facilities (commonly referred to as ponds), designed to provide water quality and/or flood control, this water would first outlet into these ponds for treatment before being released to a waterbody. Where the waterbody is low in relation to the surrounding lands, the storm sewers can be built sufficiently deep below the ground surface to also capture and convey water draining from the weeping tiles around the basement foundations of homes (Figure 3). Alternatively, where the receiving waterbody is high compared to the surrounding lands and basement foundations, the weeping tiles around the homes would not be able to drain through gravity into the storm sewers. In these circumstances, one of two systems would be required to drain the foundation around the homes:

- Sump Pumps; or
- A Foundation Drain Collector.

A sump pump is a mechanical pump used to remove water captured by the weeping tiles around the basement foundations of homes that has been collected in a sump pit (basin) in the basement. Water from the sump pit would either be pumped to the ground surface or underground into a shallow storm sewer (Figure 4).

A Foundation Drain Collector (FDC), typically located in the same utility trench as other municipal services, is a sewer system dedicated to only collect and drain water from weeping tiles of homes to an outlet by gravity flow (Figure 5). The FDC system is often referred to as part of a 3-pipe system, the other two being the storm and sanitary systems. At the time of its construction, the FDC system was considered to be a preferred solution for many new areas. In fact, the text book *Modern Sewer Design (Canadian Edition, 1980)* states: "*This system virtually eliminates the probability of back-ups into foundation drains, which have caused considerable flooding, and damage to basements*".

The Lisgar District is one area that is serviced by a 3-pipe system. Figure 6 depicts the limits of the area within Mississauga served by an FDC system.

The following images graphically represent the three alternative systems designed to capture and drain water away from the foundations of homes.

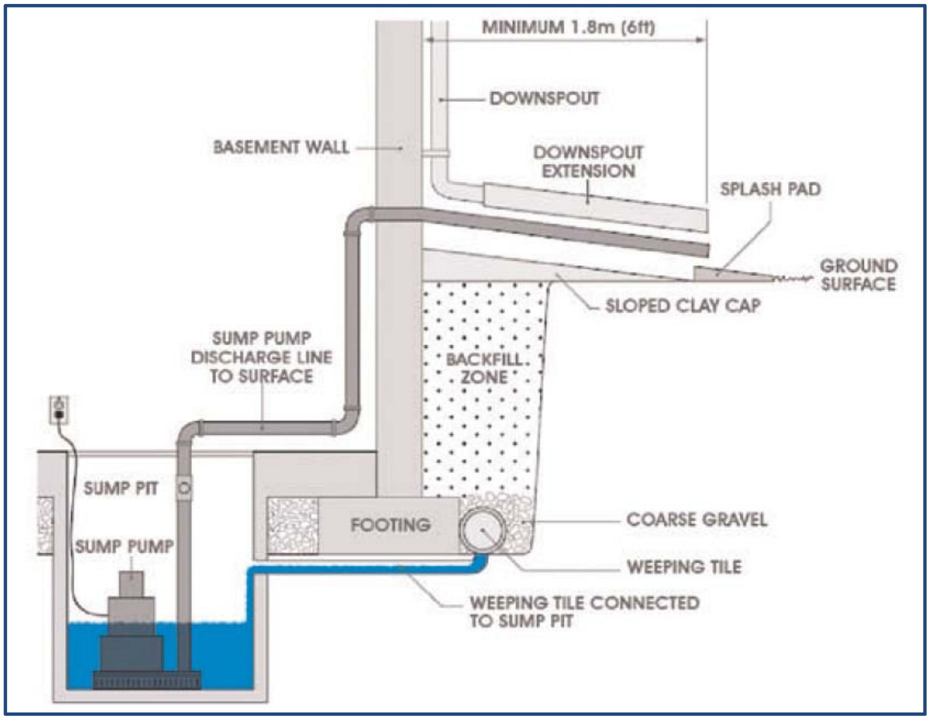


Figure 3: Conventional Foundation Drain connected to Storm Sewer

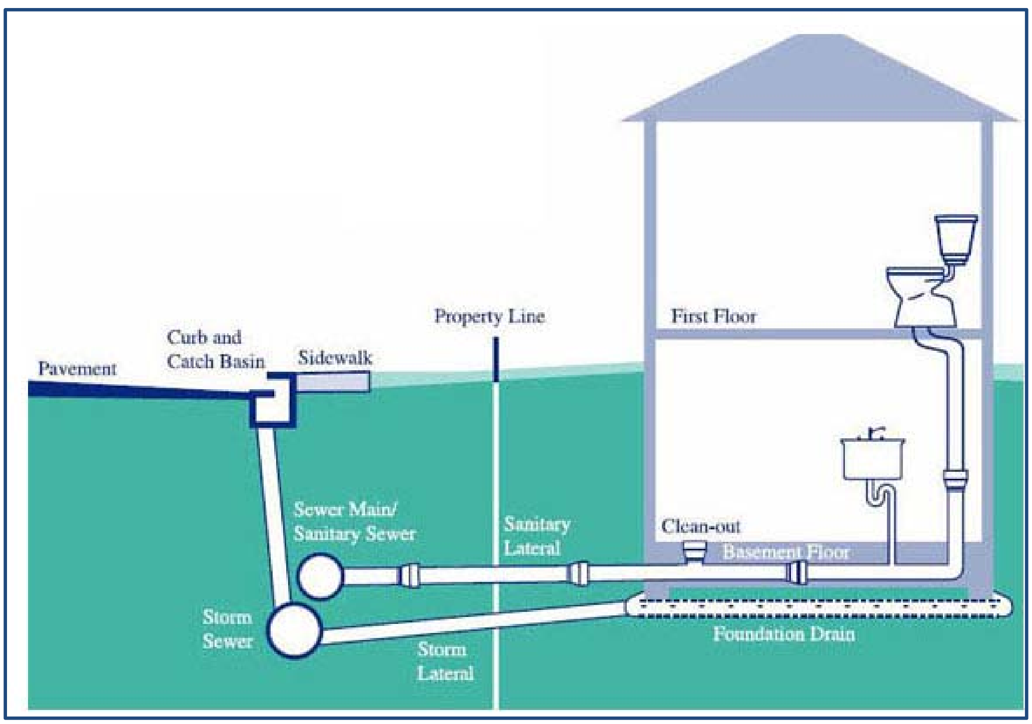


Figure 4: Sump Pump to Front/Rear Yards or Storm Sewer

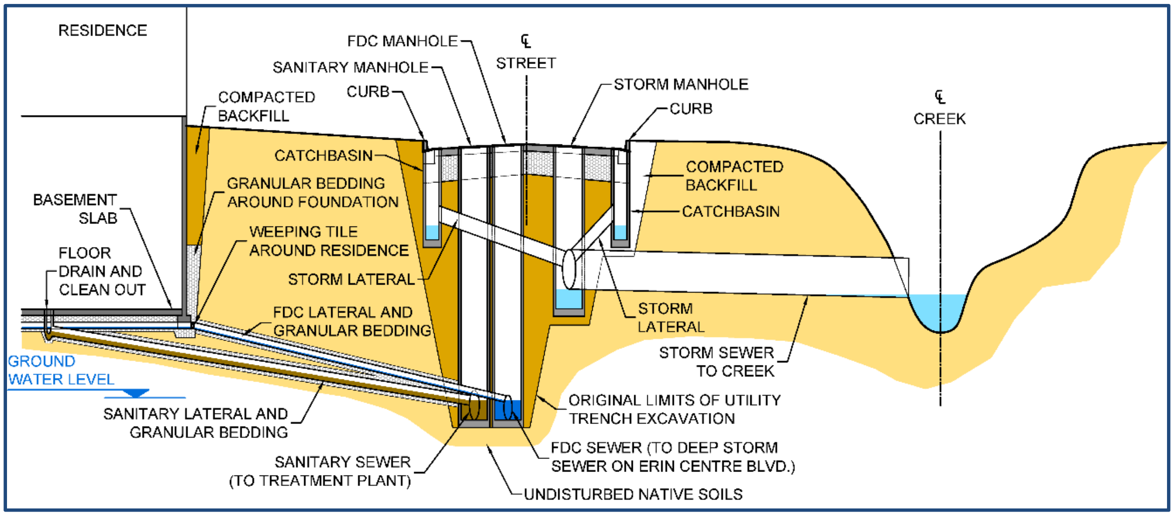


Figure 5: Foundation Drain Collector as Found in the Lisgar District

The following table provides a brief summary of the advantages and disadvantages of these three distinct foundation drainage systems.

Type	Advantages	Disadvantage
Gravity to Storm Sewer	• no additional infrastructure • comparatively low cost • no reliance on mechanical system or power	• may back up if storm sewer is overwhelmed • some additional cost to upsize storm sewers
Sump Pump	• disconnected from municipal system	• requires homeowner to operate and maintain the system • mechanical system needs to operate to function • relies on power
Foundation Drain Collector	• dedicated, providing drainage for foundation only • no reliance on mechanical system or power • “virtually eliminates the probability of back-ups into foundation drains” • allows for smaller sized storm sewers • successfully installed in numerous other municipalities without incident (Brampton, Vaughan, Barrie)	• comparatively high cost to install additional deep and long pipe systems

It should be noted that the technical term ‘surcharge’ is often used in this report when referring to the flow conditions of sewers. This term refers to a gravity sewer that is overloaded beyond its pipe full flow capacity such that the flow is under pressure.

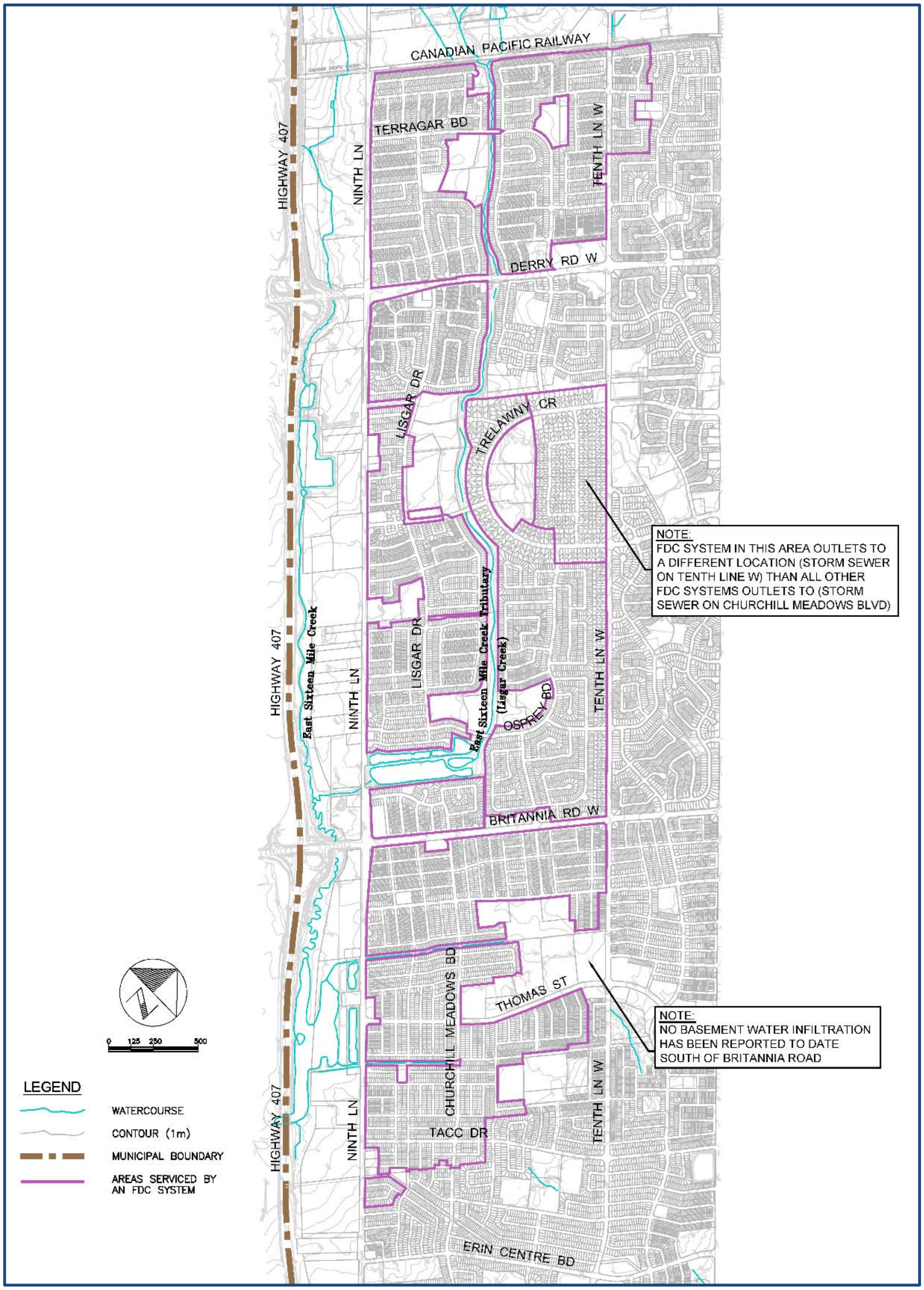


Figure 6: Servicing Limits of FDC System in Mississauga

3.0 CITY-LED ACTIVITIES

When the City of Mississauga first became aware of basement water seepage, the causes of this unexpected problem were not known. However, the City proactively undertook a number of precautionary, investigative and maintenance actions on the storm and FDC sewer systems, the tributary of the East Branch of Sixteen Mile Creek, and the Osprey Marsh Stormwater Management Pond. The following summarizes the work completed by the City in the Lisgar District.

<u>FDC and Storm Sewers</u>

<u>Video Inspection and Flushing of FDC and Storm Sewer Systems</u>

Video inspections of the FDC system and a large portion of the storm sewer system were carried out to identify any potential cracks and leaks (FDC system), as well as debris or obstructions (both systems). Only a few cracks and leaks were detected. Most of them have subsequently been repaired by the City. No significant blockages or debris were observed in either system.

Despite the lack of any significant debris or blockages in the storm and FDC systems, as a further precautionary measure, the FDC system and a portion of the storm sewer system were flushed to clean-out any minor debris accumulations.

Identifying Sewer Cross-connections

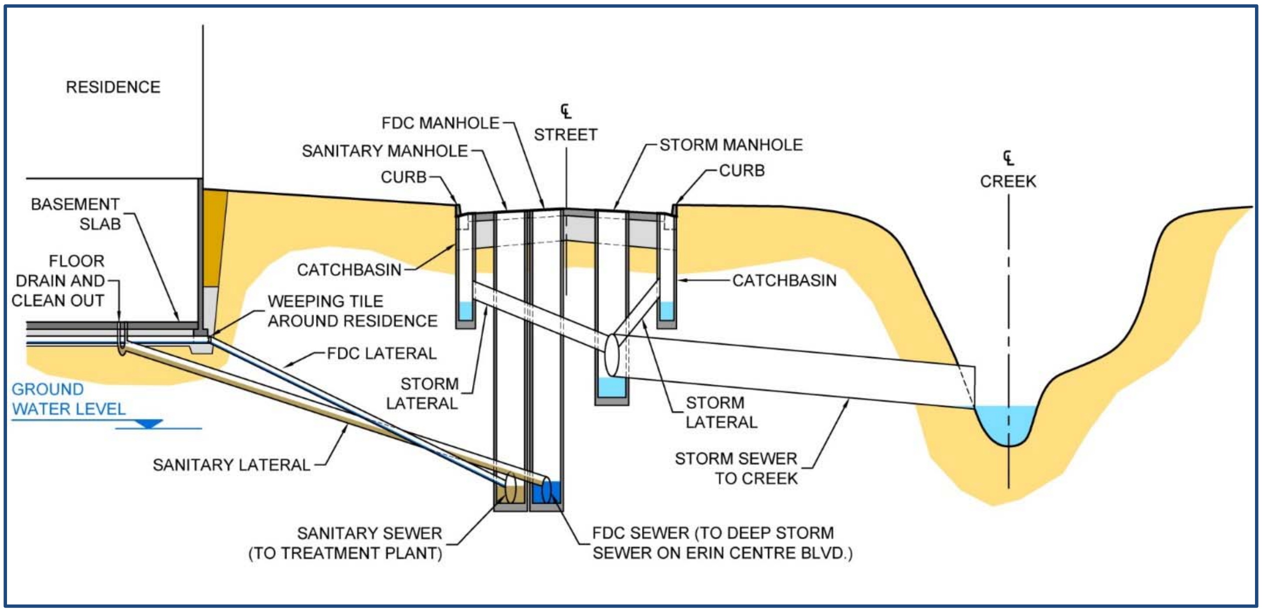


Figure 7: Schematic of Sewer Cross-Connection

The City used investigative techniques (video inspections and dye and smoke tests) to identify homes where cross-connections were suspected; specifically where a residential foundation drain is connected to the sanitary sewer system and the residential sanitary lead is connected to the FDC. Such an occurrence would be expected to increase flows to the FDC sewer system.

The investigation identified two cross-connections. Both have since been repaired.

Sealing FDC Maintenance Access Lids and Cracks

The lids of maintenance access chambers (commonly called “manholes”) to the FDC system were identified as being a potential source of surface water inflow to the FDC system. The City installed maintenance access lid seals to prevent this surface water from entering the FDC system in vulnerable locations; primarily where the FDC sewer is situated adjacent to the tributary of the east branch of Sixteen Mile Creek, and at low points along the roadway where water would be expected to pond during large storm events.

Cracks and leaks in the FDC system, as identified through the video inspection, have also been repaired as noted previously.

Cleaning Storm Sewer Outfalls to Creek

City staff conducted an inspection of the storm sewer outlets to the tributary of the east branch of Sixteen Mile Creek, and identified those where removal of accumulated sediment would benefit the proper operation of the storm sewer system. A total of ten storm sewer outfalls along the tributary between Doug Leavens Boulevard and Osprey Boulevard were subsequently cleaned-out.

Where conditions warranted, the outfalls were also lined with large stones to reduce erosion and ease future clean-out efforts.

Improvements to Overland Flow Routes

In response to reported roadway flooding during the large storm events in 2010 and 2011, grading improvements were undertaken at three locations along Black Walnut Trail (Cactus Gate, Smoke Tree Road, and Scotch Pine Gate) to better define the pathway for surface water to flow to the creek and reduce the potential depth of roadway ponding in these areas.

High Water Protocol

Since late 2011, the City has implemented a High Water Protocol for the Lisgar District. Under this protocol, weather forecasts and other weather-related information such as High Water Bulletins from local Conservation Authorities are continuously monitored by City staff. When unfavorable weather conditions are predicted, City staff and/or its contractors are deployed to three locations within the Lisgar District with portable pumps on standby to pump water from the FDC system if required.

Since this protocol was put into effect, City staff and/or its contractors have operated the pumps on several occasions, including April 10-12, 2013, June 11-12, 2014, and September 10, 2014. No basement water infiltration problems were reported during any of these events.

East Sixteen Mile Creek Tributary and Osprey Marsh Stormwater Management Pond

Creek Vegetation Trimming and Debris Removal

In response to concerns raised by residents, considerable effort and expense was spent by the City to trim the vegetation along the creek corridor between the Canadian Pacific Railway tracks and Doug Leavens Boulevard over the course of 2012. It should be noted that this is not a typical practice for the maintenance and stewardship of a naturalized creek corridor system. The trimmed vegetation re-grew very quickly and has subsequently re-established itself. Further trimming was not undertaken given the findings of this study.

Sediment and Vegetation Removal from Bridge Crossings and Storm Outfalls

Inspections of the bridge crossings and storm outfalls along the tributary of the east branch of Sixteen Mile Creek identified certain areas of sediment and vegetation accumulation. Although the potential impact of this in relation to the basement water infiltration issue was unclear at the time, accumulated sediment, vegetation and other debris were removed from several storm outfalls and beneath the bridges at Osprey Boulevard, Alderwood Trail, and Doug Leavens Boulevards in 2013.

Creek Inspection Protocol

A protocol for a more frequent regular inspection of the tributary of the east branch of Sixteen Mile Creek and bridge crossings was developed to proactively monitor and identify issues such as excessive sediment or debris in the creek which may impede its ability to safely convey water.

Reconfiguration of Osprey Marsh Stormwater Management Pond Outlet

Prior to this study, the City had an approved capital project planned to remove and reconfigure the outlet structures of the Osprey Marsh Stormwater Management Pond. These structures were not allowing the water in the pond to draw down in a timely manner resulting in a higher than normal pond water elevation for an extended period of time. In light of the basement water infiltration concerns, the City proactively cleaned out the accumulated sediment and vegetation around two of the pond outlet structures in late 2011/early 2012 to improve the drainage function of the pond. This was done in advance of the capital project undertaken in 2012 to reconstruct the entire outlet configuration of the pond.

4.0 SUMMARY OF POTENTIAL CAUSES

A main objective of this study was to identify and assess the potential causes of basement water infiltration in the Lisgar District in light of the fact that homes in this area have not had any known issues prior to 2008; more than 20 years since development of the area began. This section discusses a number of these possible causes with more detailed analyses and discussions to follow in subsequent sections.

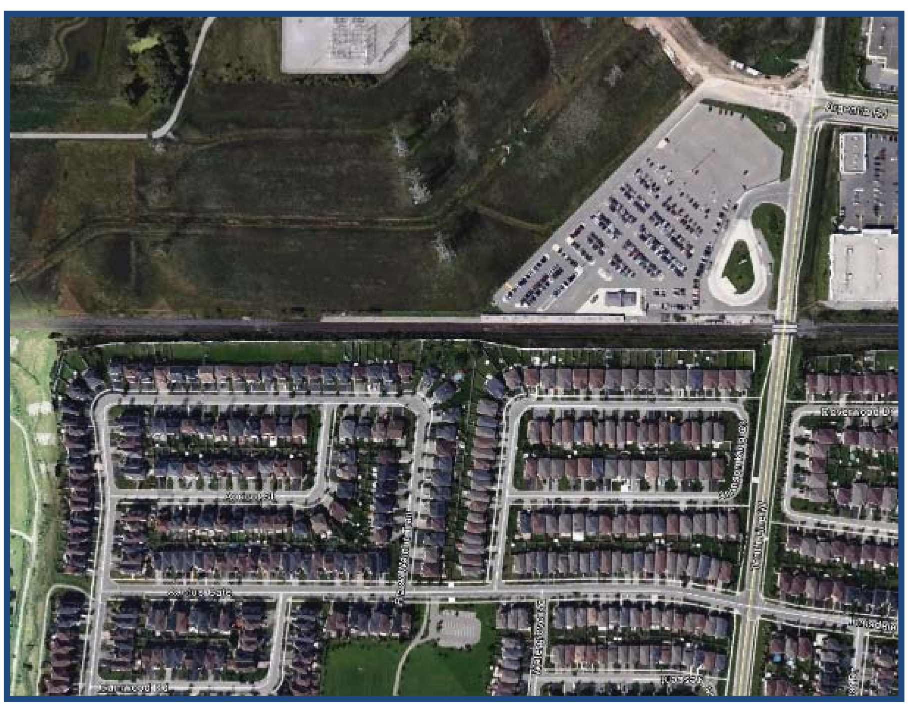
<u>Changes Since Development</u>

One of the initial steps undertaken in this study was to determine what changes could have possibly taken place since the development of the Lisgar District and how these changes may have contributed to basement water infiltration. A list was compiled in consultation with City staff and each possible change was screened based on engineering judgment for further consideration. The possible changes are discussed as follows:

<u>Climate</u>

Most experts agree that weather patterns are changing and extreme weather events are becoming more frequent and more intense. However, rainstorms more severe than those experienced during the basement water infiltration events have occurred over the Lisgar District without any known occurrences of water seepage in basements. While rainfall plays a role with respect to the infiltration events, it is not the more frequent and intense storms that seem to be causing the problem, as will be discussed later in this report. As such, intense storms due to a changing climate were ruled out as a contributing factor to the basement water infiltration issue.

<u>Development</u>



The Lisgar District has been more or less fully developed since the mid-2000s, with a small number of in-fill developments occurring over the past few years. The only significant development in the area was the Lisgar GO Station which was constructed to the north of the Lisgar District around 2007. Further investigation was undertaken to determine if the development of the Lisgar GO Station contributed to the basement water infiltration issue and is discussed later in this report.

Creek block maturing with vegetation

As the vegetation along the tributary of the east branch of Sixteen Mile Creek has matured over time, the carrying capacity of this channel, which local storm sewers drain into, has reduced somewhat. This vegetation also traps sediment causing a further loss in capacity, and thereby reduces the efficiency of the tributary to move water. However, the FDC system that conveys water from the foundations of basements does not outlet into this tributary. Nevertheless, investigations were carried out to determine if there are other ways that the tributary may potentially contribute to the basement water infiltration issue.

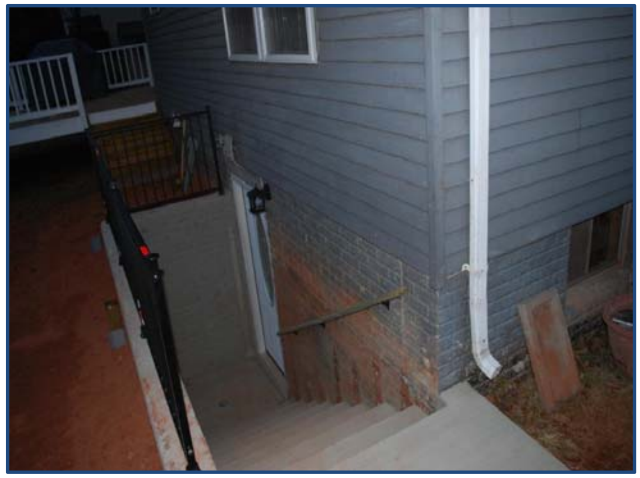
Osprey Marsh Stormwater Management Pond

The Osprey Marsh Stormwater Management Pond has been seen by some residents as a barrier to water conveyance from the tributary of the east branch of Sixteen Mile Creek. However, the pond serves the dual purpose of providing water quality treatment and quantity control for the upstream development lands.

As previously mentioned, the City had a planned and approved capital project to remove and reconfigure the outlet structures of the Osprey Marsh Stormwater Management Pond, prior to the City becoming aware of the scale of water seepage in basements of homes. As a proactive measure, two outlet structures in the pond, which had accumulated sediment and vegetation resulting in a higher than normal water level (1 m +/-), were cleaned out to improve drainage from the pond. The City has since completed the capital project to reconfigure the outlet of the pond, further reducing the drawdown time of the pond following large rainfall events.

It should be noted that the FDC system that conveys water from the foundations of basements does not outlet into this pond. However, further investigation was carried out to determine if other connections exist between the pond and the basement water infiltration issue.

Changes to homes/properties (lot grades, basement walkouts)



Over time, lot grades may change due to the settlement of soils or through physical alterations by homeowners. Depending on this change, the grades on a property may allow water runoff to flow back towards the house, instead of away, thereby increasing the amount of water which may drain to the foundation. However, there is insufficient information to predict with any certainty the level of influence altered grades may have on the basement water infiltration issue.

There are also a significant number of homes in the Lisgar District in which basement walkouts have been built. Rain water and runoff from the lot or roof which flows into a basement walkout can contribute directly to the FDC system since this water may be collected by a drain connected to the home's weeping tiles. While the lack of available information has made it difficult to determine if basement walkouts have contributed to basement water infiltration, further analysis was undertaken based on assumptions regarding the level of influence basement walkouts may be having on the operation of the FDC system.

Aging basement walls and foundations

Concrete foundations are not resistant to cracks. Cracks in a foundation wall can be caused by a number of factors such as concrete shrinkage, aging, settlement into the soil or poor drainage around the house. These cracks provide the opportunity for water to seep into the basement from the exterior. While cracks in foundations are not uncommon, it is challenging to obtain data to determine the level of influence this may have on basement water infiltration given that foundations are located on private property. As such, this possible cause was not analyzed further.

Aging Infrastructure

Like all infrastructure, stormwater related infrastructure gradually ages over time and its concrete components, such as pipes and manholes, typically have a service life of approximately 100 years. While the municipal services in the Lisgar District are comparatively young (less than 35 years), leakage from the storm sewer, which is a normal occurrence, can occur due to:

- cracks in manholes
- displaced/settled sewers
- seals and sewer joints breaking down

As storm sewers are not built to remain watertight, leakage from the system is considered normal. However, in locations where a 3-pipe system is used, opportunities may arise where water, which has leaked from storm sewers, may enter into the FDC system. Additional investigative work was carried out with respect to the issue of storm sewer leakage.

Other Potential Causes

In addition to examining changes that may have taken place since the development of the Lisgar District, other potential causes were also considered, as follows:

Groundwater

Groundwater can be a potential cause of water seepage into basements; however a review of groundwater levels in the area and the properties of the native soils suggest that water moves very slowly in this mainly clay/silt-based soil. This information formed the basis for a number of subsequent tests and analyses on the causes of basement water infiltration which are discussed later.

Foundation Drain Collector

As set out earlier in this report, the FDC system is a sewer system dedicated to only collect and drain water from weeping tiles of homes to an outlet by gravity flow. Issues related to the proper construction and operation of this system may affect the way water around the foundations of homes is conveyed away from the house. Significant efforts were dedicated to the review and analysis of this system. The information below highlights how design and construction issues may affect the proper operation of this system.

a. Maintenance

   Since the FDC system is essentially a closed system connected only to foundation weeping tiles, it would be expected only to collect clean filtered foundation drainage and that maintenance needs would be nominal.

b. Design

   Design criteria for FDC systems are not as well defined as for other infrastructure such as storm or sanitary sewers; hence values from designers are more difficult to verify based on conventional engineering principles. It should be noted, however, that the design of the Lisgar FDC system was based on the best engineering knowledge at the time.

c. Hydraulics

The capacity of the FDC pipe to carry flow is based on, among other factors, the proper size (diameter) and slope of the pipe for gravity drainage. If the FDC pipe is found to have capacity issues, it may surcharge (exceed capacity and flow under pressure), thereby placing those locations served by that FDC pipe at risk.

d. Outlet

The FDC sewer system ultimately outlets into a downstream storm sewer system at Erin Centre Boulevard. If the capacity of this storm sewer system was to be exceeded under large storm events, this could potentially affect the operation of the FDC system.

e. Depths

Locations with shallower FDC depths in relation to adjacent residential weeping tile systems may be at higher risk of basement water infiltration.

f. Inflow/Infiltration

Some FDC joints at manholes and other locations (cracks) have been shown, based on video camera inspections, to allow water to get into the FDC system. They were comparatively minor and most of them have subsequently been repaired by the City.

g. Construction

Similar to FDC hydraulics, if sections of the FDC system were not constructed in accordance with the specified design, this would be expected to have an impact on FDC conveyance capacity. The potential also exists for the FDC pipes and the utility trench, in which the sewers reside, to have been poorly constructed in a manner which would allow water to directly enter the FDC system. Unfortunately, this is difficult to determine without wide-scale, disruptive excavation. However, video camera inspections suggest that the occurrence of this is low.

Sanitary System

The water that seeped into the affected basements was found to be essentially clear, largely odourless and unlikely to contain sanitary sewage. These findings have been supported based on data collected by the Region of Peel which showed that the sanitary system did not experience any capacity issues. As such, it was determined early on in the study that the sanitary system did not contribute to the basement water infiltration problem.

Private Side of Weeper System (cross-connections and Weeping Tile System condition)

As discussed earlier, extensive testing identified only two cross-connections between the FDC and sanitary sewer systems, which have since been repaired. As there were so few cross-connections discovered, this potential cause has been ruled out as having any influence on the basement water infiltration problem.

The condition of the private side weeping tile system has also been considered as a potential source of the problem as some granular material was found in the FDC sewer through video inspection suggesting some possible localized failures. However, this is very difficult to validate without wide-scale and disruptive excavation around private homes.

Stormwater Leakage to Utility Trench

Storm sewer systems, which capture and convey surface water, are not designed to be water-tight. It is not uncommon or unexpected for storm sewers to leak. However, leakage of stormwater can be substantial and relatively continuous which can potentially fill the lower utility trench with water where the FDC and laterals reside. Investigation into this issue in relation to basement water infiltration was undertaken as part of this study.

5.0 STUDY ACTIVITIES

Amec Foster Wheeler has conducted an extensive program of activities in support of the Lisgar District Basement Water Infiltration Investigation. These activities, which included extensive field monitoring, testing, and analysis, have been undertaken to better understand the existing performance of the various drainage systems and their inter-relationships. These activities have also been conducted to either validate or rule out the possible causes of the observed basement water infiltration as discussed in the previous sections.

Field monitoring is heavily dependent on weather conditions and rainfall. Without the reoccurrence of weather conditions experienced during the basement infiltration events, it is difficult to fully assess how the drainage system responded during those events, and understand the likely primary causes of basement water infiltration. Accordingly, monitoring work has extended over multiple years in order to collect enough representative field data.

In addition, it should be recognized that the interactions between the various components of the drainage system in the Lisgar District have proven to be extremely complex and varied. In order to undertake a complete and thorough investigation, a review of all potential causes of basement water infiltration was required. As field monitoring data were collected and analyzed through the course of the study, Amec Foster Wheeler was able to eliminate some potential causes, and focus on others. As the potential causes were narrowed, additional field work, testing and analysis activities were carried out to clearly prove or disprove theories. This iterative process was lengthy and required a significant amount of time, necessitating multiple years of activities. This process has ensured that a complete and thorough investigation has been undertaken and that appropriate mitigation measures are recommended to reduce the risk of future instances of basement water infiltration.

The study activities completed by Amec Foster Wheeler are summarized as follows:

<u>Monitoring Work</u>

During the course of the study, a comprehensive monitoring program was undertaken over multiple years to collect field data needed to help understand the cause(s) of basement water infiltration and to provide guidance in finding the appropriate mitigation measures. The monitoring work undertaken is described as follows.

A. <u>Groundwater</u>

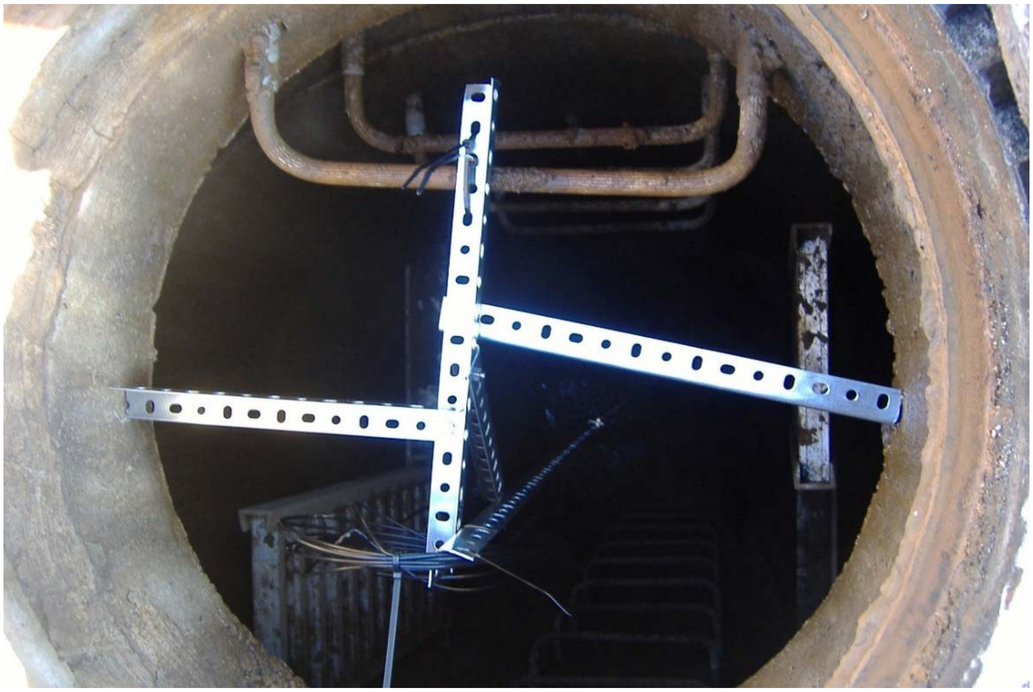
- Monitoring wells were installed at four main sites:
  - Black Walnut Trail at Scotch Pine Gate (late 2011);
  - Osprey Boulevard (late 2011);
  - Alderwood Trail (2013); and
  - Pondview Way (2014).
- Two primary types of monitoring wells were installed:
  - In the native (undisturbed) soils; and
  - In the gravel material found in the utility trench.
- Both water level and water temperature were monitored continuously at these sites.

Findings

1. Groundwater temperatures in the native soils do not vary greatly and are not affected by precipitation events.

2. The shallow groundwater levels in the native soils do not increase rapidly enough during precipitation events which proves that basement water infiltration is not caused by flow through the native soils from the Tributary to the East Branch of Sixteen Mile Creek or the Osprey Marsh Stormwater Management Pond.

B. FDC and Storm Sewer System



- Water level monitoring gauges were installed within the FDC and storm sewer systems in order to observe how water levels in these systems respond to storm events;
- The gauges also recorded water temperature, which is a useful parameter as it can distinguish between sources of water; and
- The number and locations of gauges were adjusted over the course of the study to the most suitable sites through interpretation of the collected data:
  - A total of 17 water level monitoring gauges were installed within the FDC sewer system; extending from the Canadian Pacific Railway tracks to Erin Centre Boulevard; and
  - Three additional water level monitoring gauges were installed over the course of the study within the storm sewer system.

Findings

Recorded data from these gauges have shown that:

1. The FDC system has been observed to surcharge rapidly in response to rainfall events (water levels exceed the top of the pipes meaning that the system is flowing under pressure); this surcharging occurs in different locations and in different amounts depending on the storm event.

2. Surcharging is most common along Black Walnut Trail and in the vicinity of Osprey Boulevard, which is generally consistent with locations of reported basement water infiltration.

3. The short period of time in which the water level in the FDC system has been observed to surcharge and then quickly drop back down strongly suggests that the water is coming in from surface water sources rather than groundwater, which moves much more slowly due to the properties of the native soils.

4. The water temperature data from the observed surcharge events also suggest that the water is coming from surface water sources (rise in water temperature over the summer months - warm surfaces, or a drop in water temperature over the early spring/fall/winter months – cold surfaces).

5. Water levels in the storm sewer along Erin Centre Boulevard, which takes drainage from the FDC system, show that it is not the cause of FDC surcharging.

C. Tributary and Stormwater Management Pond

- Water level monitoring gauges were installed and monitored at key locations along the tributary of the east branch of Sixteen Mile Creek and within the Osprey Marsh Stormwater Management Pond during non-winter periods (April to November);

- The number and locations of gauges were adjusted over the course of the study to the most suitable sites through interpretation of the collected data:
  - Gauges were installed at five different locations along the creek, as well as a gauge directly within the pond; and
  - A temporary rainfall gauge was installed for two of the monitoring years.

Findings

Recorded data from these gauges have shown that:

1. There is nominal creek flow from the GO Station channel, and no apparent connection between these flows and FDC surcharging.

2. There is no apparent connection between creek flows and FDC surcharging.

3. There is no apparent connection between water levels within the Osprey Marsh Stormwater Management Pond and FDC surcharging.

Testing Work

To better understand the interactions between the various water sources and components of the drainage system in the Lisgar District, testing work was undertaken through water sampling and 'in-ground' pilot projects to validate some of the theories. The testing work undertaken is described in the following:

A. Water Quality Characterization

- A characterization program was completed to assess the chemical properties of the water found in:
  - native soils (i.e. the groundwater);
  - utility trench (i.e. where the municipal services are);
  - creek;
  - Osprey Marsh Stormwater Management Pond; and
  - FDC system.

- The testing was able to identify commonalities among the various different water sources, and in particular the source of the water in the FDC.

Findings

1. Under expected operating conditions the quality of the water in the FDC system should show some similarities with the shallow groundwater. However, water in the FDC system water was found to be salt rich, similar to the utility trench, the tributary and the pond. This suggests that the water in the FDC system is very similar to surface water (and dissimilar to groundwater). This similarity is particularly evident in winter conditions when surface water was found to contain elevated salt concentrations from the application of road salt.

B. Storm Sewer Leakage Testing

- Storm sewer leakage testing was undertaken in 2013 at three sites where basement water infiltration occurred (Alderwood Trail and Black Walnut Trail at both Wild Cherry Lane and Scotch Pine Gate). The photos above illustrate some of the steps in the leakage testing process;

- The intent of the tests was to confirm whether or not, under high flows, the storm sewer system would be expected to leak and contribute water to the utility trench where the FDC system resides; and

- The tests were comprised of:
  - Blocking the storm sewers and filling them with water to replicate surcharge conditions (under pressure);
  - Addition of a green fluorescent dye to the storm sewer; and
  - Monitoring of the dye concentrations and water levels in the utility trench, groundwater and FDC system.

Findings

1. At all three sites, the storm sewers leaked and at two sites (Wild Cherry Lane and Scotch Pine Gate), the dye was detected in the FDC after two hours.

2. Tests have proven that there is a flow path from the storm sewer to the FDC through the utility trench with a response time consistent with that observed between major storm events and instances of basement water infiltration.

C. Storm Sewer Outfall Collar Testing

- Over the course of the study, it was speculated that water from the tributary of the east branch of Sixteen Mile Creek or the Osprey Marsh Stormwater Management Pond could possibly move upstream through the storm sewer bedding and contribute excess water to the utility trench;
- In order to verify if water in the utility trench was coming from the tributary or the Osprey Marsh SWM pond, a test was conducted at the end of 2014;
- Impermeable concrete collars were installed in the utility trench near the outfall of the storm sewers at two locations:
  - Sixteen Mile Creek (Scotch Pine Gate); and
  - Osprey Marsh SWM Pond (Pondview Way).
- These collars were installed with backflow valves that allow water from the utility trench to drain to the tributary and pond, but not in the other direction; and
- Monitoring is currently underway at both of these sites to assess the effectiveness of the collar in preventing elevated water levels in the utility trench which may be due to inflow from the creek or pond during larger storm events.

Analysis Work

Using the data collected over the monitoring periods, as well as additional information provided by the City on the FDC system and area services, Amec Foster Wheeler conducted a series of technical analyses as follows:

A. Groundwater analysis

Testing work and analyses were undertaken for both the native soils and granular materials (utility trench) at the groundwater monitoring sites.

Findings

1. Tests have shown that the permeability of the granular materials in the utility trench is up to 10 million times greater than the native soils. This has further confirmed that the utility trench is the primary linkage for surface water to reach the FDC system.

B. Design check of the FDC system

A review of the original design of the main FDC sewer system was undertaken. This analysis is described in greater detail as follows:

a. Comparison of the original number of intended residences to be served by the main FDC sewer system:

   - This analysis has shown that a larger number of residences are currently connected to the FDC system than what was intended in the original design; and

   - This was known by both the area developers and the City as the area was developed; a developer's consultant undertook a numerical analysis of the main FDC sewer using computer modelling to demonstrate that the system could accept the higher number of connected residences.

b. Comparison of original design sizes and slopes of the FDC sewers (which affect capacity – higher slopes provide more flow capacity, lower slopes less capacity) with as-constructed (current) characteristics:

   - This review has shown that some sections of the FDC trunk sewer were constructed flatter than intended, which is expected to decrease the available flow capacity.

c. Verification of the design of the FDC trunk sewer, to determine if there is sufficient available capacity to handle expected flow rates, using the original design approach, and current information on the FDC system (sizes and slopes) including the current number of residences serviced by this system:

   - The results of this analysis have shown that there are several sections of the FDC trunk sewer where the expected flow rates exceed the design capacity and would be expected to surcharge the FDC system in localized areas.

Findings

1. The results of these analyses have since identified deficiencies in the as-constructed design of the FDC trunk sewer system, which may contribute to FDC surcharge within localized areas of the overall system. However, given the results of the FDC monitoring,

these deficiencies are not considered to be a material contributor to FDC surcharging or a cause of the basement infiltration issue.

2. Observed FDC surcharging has also been noted in areas which are a considerable distance away from where FDC sewer deficiencies have been identified, which further suggests that these deficiencies, in and of themselves, are not a material contributor to the FDC surcharging or a cause of the basement infiltration issue.

C. Computer modelling of the FDC system

Computer modelling of the FDC system was undertaken in an effort to answer a number of questions related to its performance, and the impact of some of the potential causes. The performance questions and modelling results are provided in the following table.

Questions	Modelling Results
How much impact will high water levels at the downstream end of the FDC system (outlet) have on the Lisgar District?	Results show that high water levels downstream would have little impact on the FDC system performance within the Lisgar District, which further confirms that this is not a primary cause of FDC surcharging, although it may be a very limited contributing factor.
How much potential impact would water draining into basement walkouts be expected to have on the FDC system?	Results show that based on the number of basement walkouts identified by City staff (and the estimated flows from those walkouts to the foundation drain), basement walkouts are not the primary cause of FDC surcharging, although they may be a contributing factor at specific locations.
How much potential impact would storm sewer leakage have on the FDC system?	Results show that based on an average storm sewer leakage rate (calculated from the findings of the storm sewer leakage tests conducted in 2013), storm sewer leakage is the primary cause of FDC surcharging during storm events.
Are there certain areas within the Lisgar District which contribute higher flows to the FDC system?	Based on the modelling results for an observed surcharge event in the FDC system along Black Walnut Trail, north of Derry Road, several areas have been identified as having higher relative flow contributions to the FDC system. These identified areas are therefore considered a priority for the implementation of mitigation measures (ref. Section 6).
What measures would be most effective in reducing observed FDC surcharge?	Based on the modelling results for an observed surcharge event, two potential mitigation measures have been modelled and shown to be most effective at reducing FDC surcharge: • FDC sewer upgrades - increasing the sizes of the deficient pipes to better carry higher flows and reduce surcharge; and • FDC pumping - actively pumping out the FDC during surcharge events to limit the amount of surcharging. Both of these measures have been considered as part of the longer term mitigation action plan (Section 6).

Summary and Conclusions

Based on all of the comprehensive monitoring, testing and analysis work, Amec Foster Wheeler has concluded that the primary cause of the basement water infiltration relates to stormwater entering the utility trench.

As storm sewers are not built to be watertight, and due to cracks and leaks expected through aging, stormwater is able to leak out during storm events and migrate into the utility trench, where the bedding material, made of gravel and other granular soils can allow water to move very quickly. Over time, water builds up in the utility trench from storm sewer leakage, as well as through other sources (other utilities, groundwater, et cetera), and is unable to drain away quickly due to the relatively impermeable nature of the native soils surrounding the trench.

It is this situation, in combination with certain storm conditions and local lot drainage where issues may arise. For instance, where the ground and utility trench are already wet, possibly from an earlier storm event, and rainfall subsequently occurs, this may create a condition where there is enough leakage from the storm sewer system during the rainfall event to fill an already wet utility trench and push water up the bedding material around the FDC laterals servicing the homes and into the foundation weeping tiles. This water then drains directly into the FDC pipes through the weeping tiles, which may result in excess flow in the FDC system (surcharge). However, this condition by itself may not lead to basement water seepage. It is this condition, in combination with certain storm conditions (preceding rainfall followed by a sufficiently large storm event) and local lot drainage that may lead to water around the weeping tiles being unable to drain and potentially seeping into the basements of homes. This process is illustrated in Figures 8A to 8F.

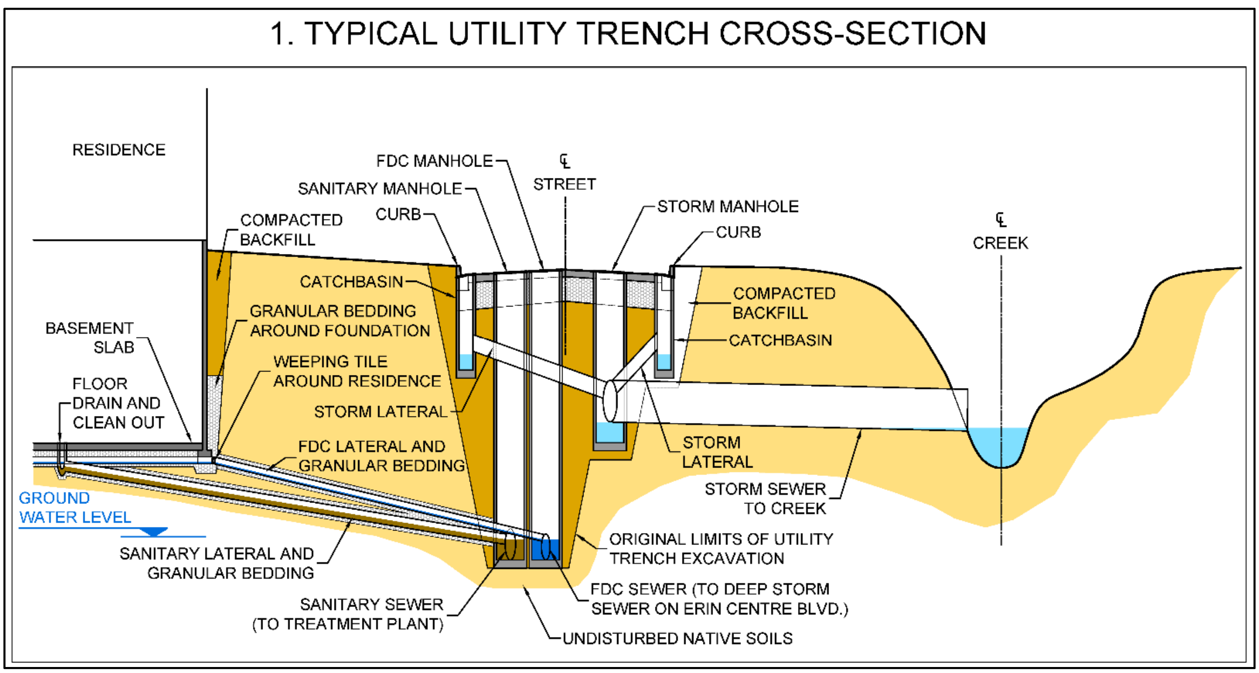


Figure 8A: Basement Infiltration due to water within the Utility Trench

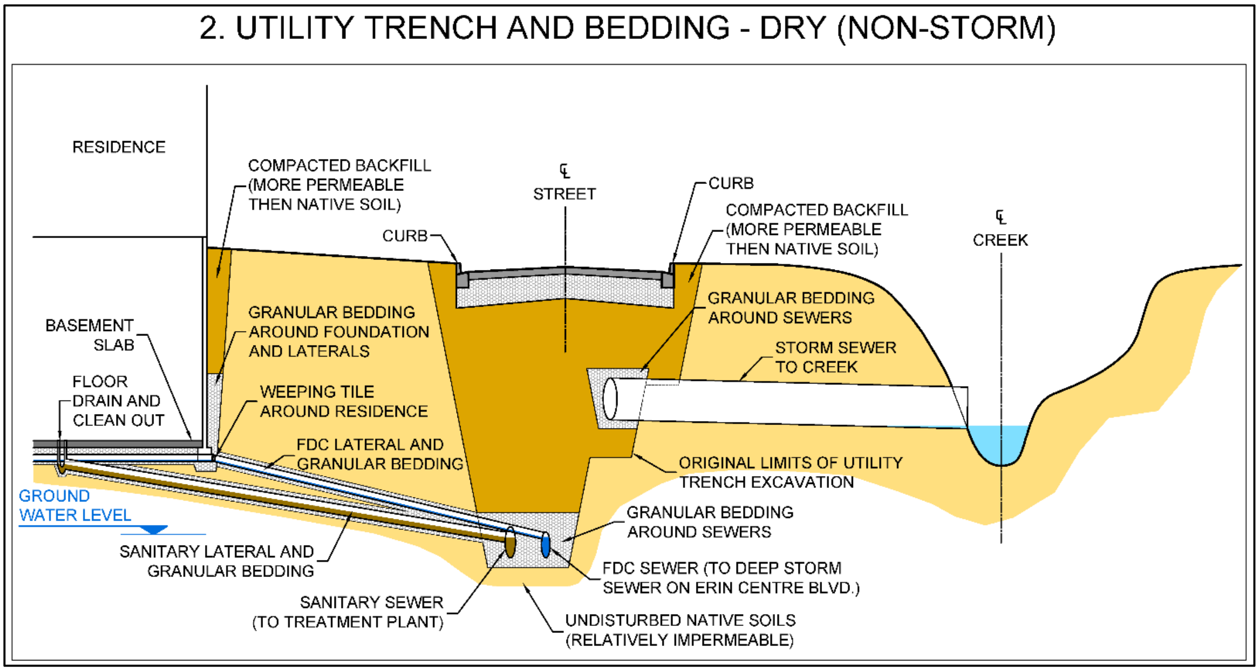


Figure 8B: Basement Infiltration due to water within the Utility Trench

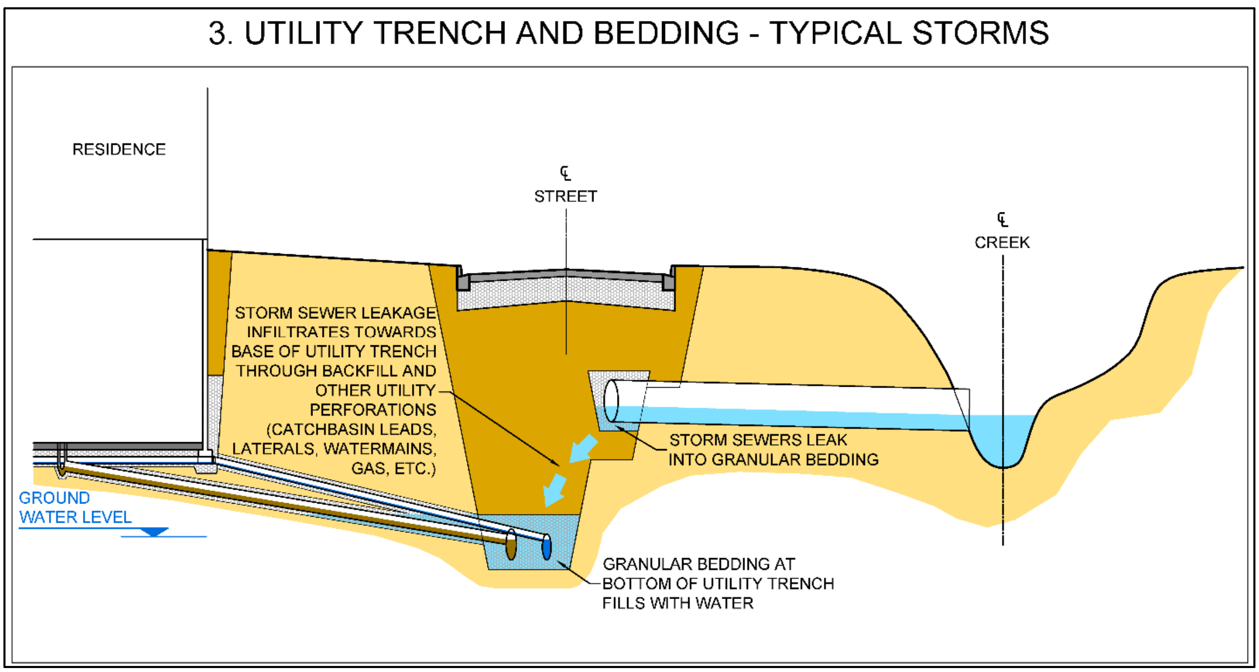


Figure 8C: Basement Infiltration due to water within the Utility Trench

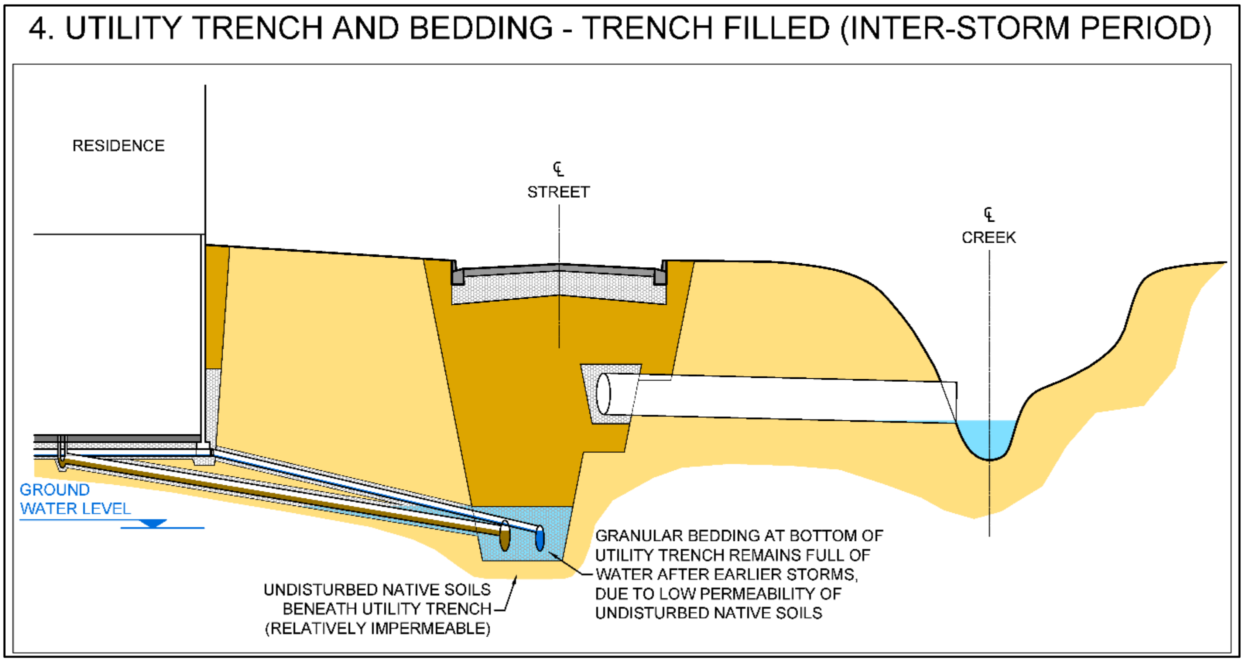


Figure 8D: Basement Infiltration due to water within the Utility Trench

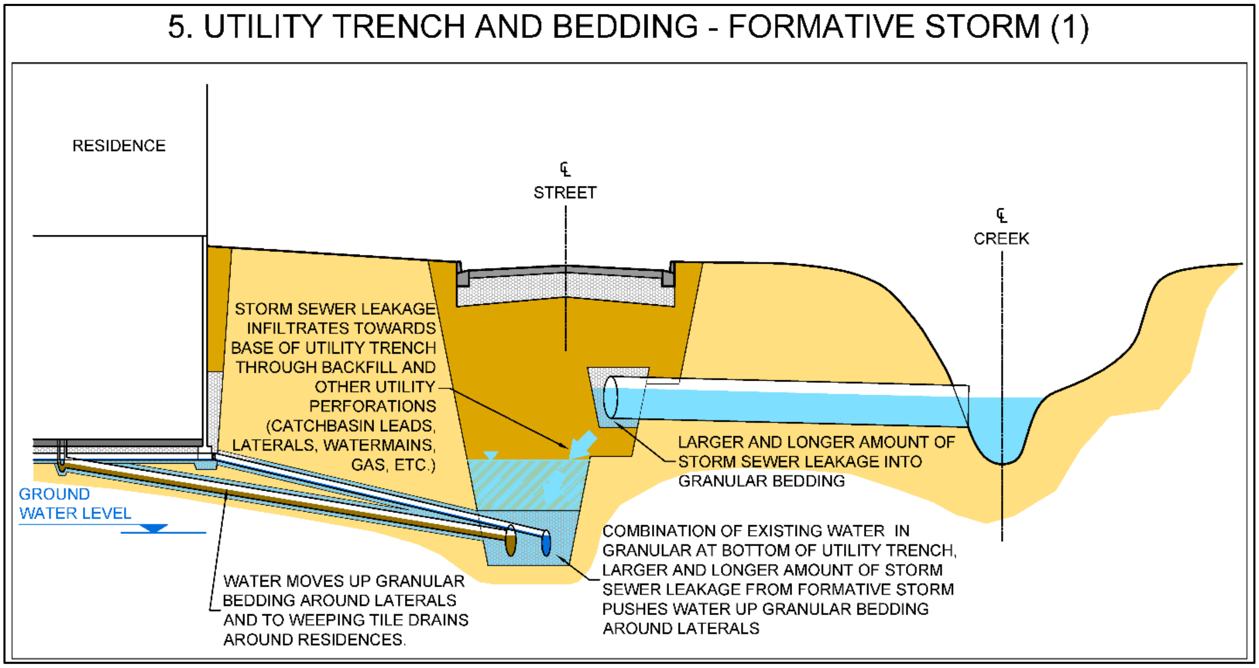


Figure 8E: Basement Infiltration due to water within the Utility Trench

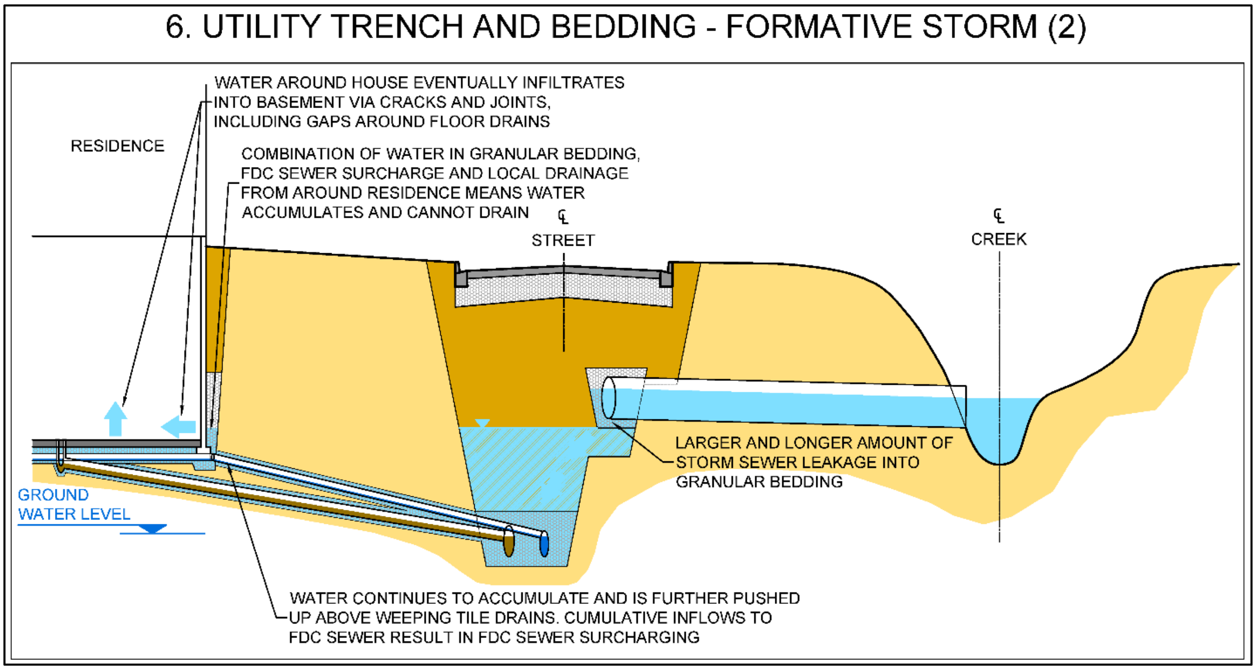


Figure 8F: Basement Infiltration due to water within the Utility Trench

The exact reasons why homes in the Lisgar District have not had basement water seepage before 2008 are not known. It is considered that the increasing leakage of water from the storm sewers through normal aging has gradually increased the volume of water collected in the trenches over time, ultimately contributing to the problems first experienced in 2008.

The risk of basement water infiltration is also connected to the relative depths of the FDC system and basements of homes in the different areas of the Lisgar District. Under the condition where water has moved up the bedding material surrounding the FDC laterals to the homes, the homes placed at greatest risk of basement water infiltration would be those where the FDC system (and thus the utility trench) is the shallowest. In other words, the less vertical separation between the FDC pipe/utility trench and the basements, the more susceptible basements will be to water seepage.

A number of other factors have been identified which may be impacting on the overall operation of the FDC system, however, none of them, either alone or in combination, would cause water to seep in to basements to the extent reported. The following table provides a summary of Amec Foster Wheeler's conclusions with respect to the potential contributing factors in the basement water infiltration investigation. A more extensive version of this table is provided as Appendix 'A'.

Summary of Assessment of Potential Factors in Basement Water Infiltration	
Potential Factor	**Level of Influence**
Stormwater to Utility Trench	Primary Cause
FDC and Utility Trench Depths	May increase risk of basement water infiltration at specific locations
Groundwater	May contribute additional/excess flows to the FDC and utility trench (Not sufficient to cause problem)
Creek Backwater	
Osprey Marsh Pond (SWM) Backwater	
Basement Walkouts	
Inflow/Infiltration to FDC	
FDC Hydraulics	May impair conveyance capacity of FDC system (Not sufficient to cause problem)
FDC Design	
FDC Tailwater	
FDC Maintenance	
FDC Construction	
Cross-Connections	Not Applicable
Creek Maintenance	
GO Station	
Sanitary System	
Lot Grading	Insufficient information
Basement Construction / Changes	

Based on the foregoing conclusions, Section 6 of this report describes potential mitigation measures which are intended to reduce the risk of future basement water infiltration.

6.0 MITIGATION PLAN

To address the basement water infiltration issue, eleven alternative actions were developed and evaluated for potential implementation. They are briefly described as follows:

1. *Strategic Lining of Storm Sewers* – line and seal the inside of selected storm sewers to minimize water leakage into the utility trench.

2. *Construction of a Utility Trench Dewatering System* - drain water from the utility trench at key locations to provide additional storage during storm events and reduce FDC surcharging.

3. *Construction of FDC Pumping Stations* – actively pump from the FDC sewer system to minimize surcharging of the FDC system.

4. *FDC Sewer Upgrades* – Strategically upgrade selected FDC sewers to increase capacity and reduce surcharging occurrences.

5. *Sump Pumps* - install new basement sump pumps to help in draining weeping tiles during storm events. The City should continue with its Lisgar District Sump Pump Subsidy Program for homes with reported basement water infiltration to assist homeowners with the cost of installing new sump pumps.

6. *FDC Backflow Preventers* – install a backflow preventer and clay barrier on residential FDC lateral pipes to prevent FDC surcharge from impacting weeping tiles.

7. *Storage* – construct a storage system (likely an underground tank) to temporarily store excess FDC flow during surcharge events and then release it in a controlled manner.

8. *Storm Sewer Outfall Collars* – construct concrete barriers at storm sewer outfalls (to creek or pond) to limit the ability of water to move back up through the utility trench.

9. *Basement Walkout Covers* – construct roofs/covers over residential basement walkout entrances, to limit stormwater from draining to the FDC.

10. *New FDC Outlet* – re-direct the FDC trunk sewer at the downstream limit away from the existing storm sewer and to a free flowing outfall (such as a creek).

11. *Creek Remediation* – trim or manage vegetation along creek corridor to improve capacity and reduce water levels during major storms.

These eleven actions were analyzed by the City and Amec Foster Wheeler for effectiveness (ability of proposed actions to reduce basement water infiltration) and feasibility (ease of implementation). Through this process, Actions #1 to #5 were carried forward to form a Prioritized Action Plan to reduce the risk of basement water infiltration while Actions #6 to #11 were screened out. A detailed matrix summarizing each of the eleven alternative actions is provided as Appendix ‘B’.

6.1 Prioritized Action Plan

The following five actions are recommended to be carried forward as mitigation actions based on their effectiveness and feasibility.

Item #	Action	Description
1	Strategic Lining of Storm Sewers	Sealing the inside surface of storm sewers in strategic locations with an impermeable liner to reduce/eliminate leakage into bedding (and ultimately into FDC system).
2	Construction of a Utility Trench Dewatering System	Dewater bedding material around the FDC system to limit the accumulation of water in the utility trench and provide additional storage volume during storm events.
3	Construction of FDC Pumping Stations	Install pumping stations at key locations of the FDC system which will activate when the system either approaches or reaches surcharge conditions and pump water to the ground surface.
4	FDC Sewer Upgrades	Upsizing selected FDC sewers to increase their conveyance capacity and reduce surcharge.
5	Sump Pumps	Home-owner installs a new basement sump pump system to help to drain the weeping tile system around the home; sump pump would discharge to ground surface.

Additional details related to the above Prioritized Action Plan are provided as Appendix ‘C’.

It should be noted that the basement water infiltration issue is extremely complex, and the selection of measures to appropriately address the problem remains an iterative process. Actions in the Prioritized Action Plan should be implemented in stages where constructed projects are monitored to assess their effectiveness and to assist staff in making informed decisions on subsequent Actions.

7.0 RECOMMENDED NEXT STEPS

Based on the Prioritized Action Plan, it is recommended that the two highest priority actions, Actions 1 and 2, be planned in order of implementation as soon as funding and approvals are secured to deal with the basement water infiltration issue. It is suggested that the following steps be undertaken:

a) Undertake the design, construction and monitoring related to the storm sewer lining (Action 1) of the Black Walnut Trail area (refer to Figure 9 for locations).

b) Conduct background work to refine key details of the utility trench dewatering system (Action 2) followed by detailed design, approvals, and construction.

c) Undertake additional monitoring to assess effectiveness of steps (a) and (b).

d) The balance of the recommended Actions (Actions 3 and 4) would be staged over time conditional on the results of steps (a), (b), and (c).

It is also recommended that residents who qualify for the City's Lisgar District Sump Pump Subsidy Program take advantage of this program (Action 5).

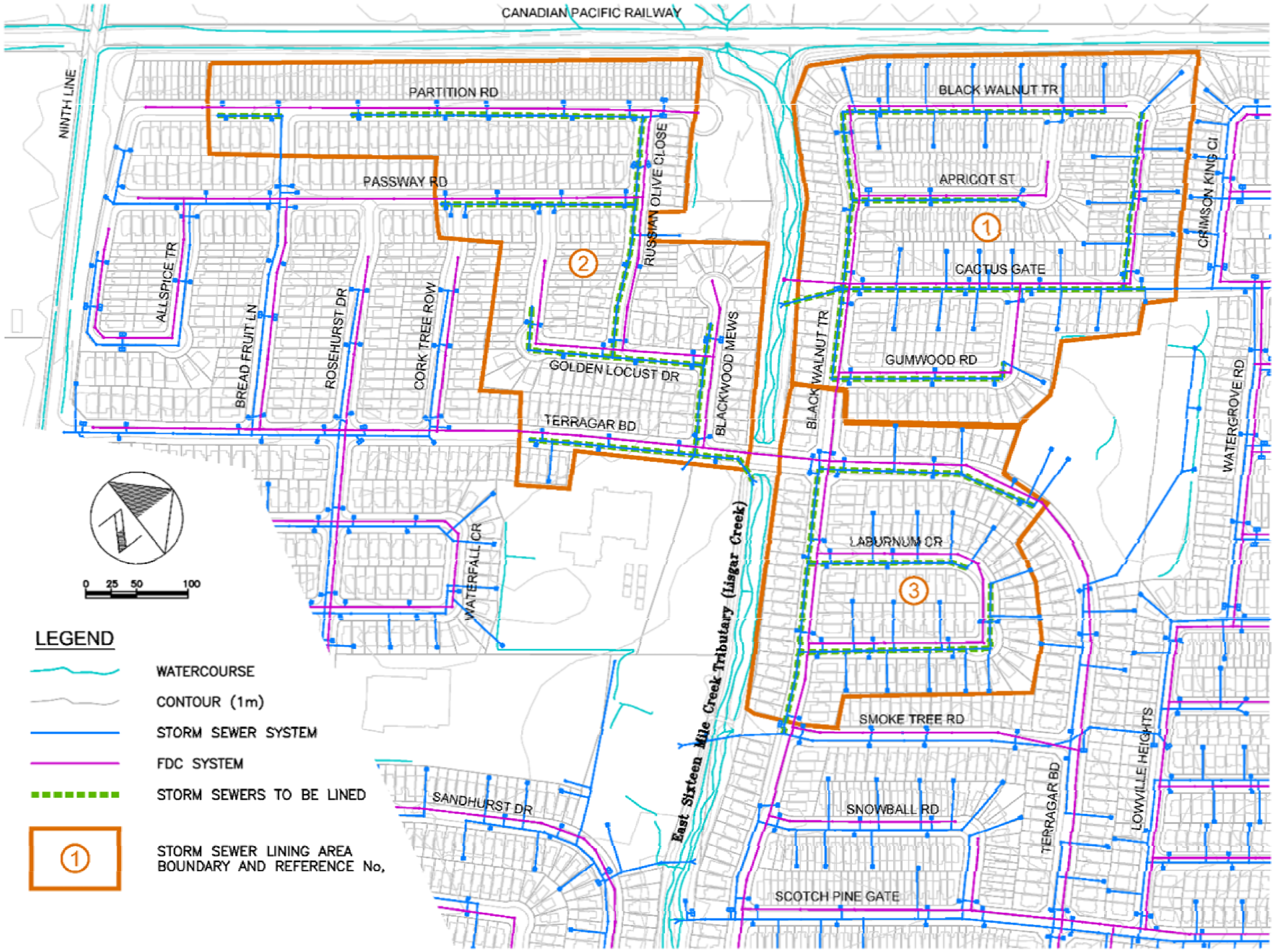


Figure 9: Locations of Proposed Storm Sewer Lining – Black Walnut Trail Area