# 1907: Port Hope
# Wastewater Hydrological Model

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# ABSTRACT

## Context

Structural failures occur in wastewater pipes when pipe conditions have deteriorated, wastewater loads exceed the maximum capacity of the infrastructure, and when the pipes do not have proper flow due to invert elevations. These structural failures may cause sewage backups and overwhelm the wastewater treatment plant. Through this project, Port Hope is provided with the most cost-effective spatial GIS solution that enables a user-friendly and efficient system to access and edit wastewater infrastructure data. Furthermore, a model and workflow was developed to allow for the analysis of pipe conditions, locate pipes with the poorest conditions, problematic slope, and capacities of the pipe. This will help Port Hope decision making process to maintain, repair or replace the waste water infrastructure for future growth.

To empower the waste water team, a free and open source database management system, PostgreSQL and GIS software, QGIS was used to manage, analyze and visualize the data. The database allows for the security of the data and allows for integration with other software and tools used by the city. To determine the condition of the pipe, a PACP statistical analysis was used to visualize and quantify the condition of the waste water network. To provide automation, customization and analysis, a series of tools and calculations have been created to estimate waste generation at a parcel level, infiltration rates, maximum flow capacity and pipe utilization. As Port Hope continues to build a complete data set, more accurate results can be yielded by models and allow for more accurate interpretations of the model. In order to field crew to edit and update the sanitary data, a web application GIS Cloud Map Editor Product was configured. Coupled with an Amazon Web Services, which hosts the data, this provides real time update of the data reducing. This web deployment is compatible with any device and requires a monthly subscription.

Overall this project will provide Port Hope the means to assess inefficiencies in the wastewater system to accommodate current and future growth. Through the combination of QGIS, PostgreSQL and GIS Cloud, a seamless working environment was developed to add and edit the asset values. As well, the interoperability of QGIS will allow for the integration of this project with the internal asset management GIS, CityWorks to allow for further analysis their assets.



Key words: Open Source, Waste Water, Port Hope, QGIS, PostgreSQL, Amazon Web Services, GIS Cloud, PACP, Pipe Conditions, LiDAR, DEM, Slope, Profiles, Excel, Sanitary Laterals, Model, Waste Generation, Max Capacity, Flow, Asset Management, Field Crew, Configurable

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# 1. Introduction

Structural failures occur in wastewater pipes when pipe conditions have deteriorated and, or wastewater loads exceed the maximum capacity of the infrastructure (Marlow, Gould & Lane, 2015). Problems within the wastewater network can also occur where the slope or pitch of the pipe does not flow downhill, which can cause stagnant flow and lead to a backup in the wastewater pipe (IFI CLAIMS Patent Services, n.d.). Port Hope requires CARBS services to develop an analysis to identify areas of the city which may encounter any of these infrastructure deficits and provide recommendations based on findings.

Port Hope utilizes the Pipeline Assessment Certification Program (PACP) to assess pipe conditions. PACP was developed by the National Association of Sewer Service Companies (NASSCO) (NASSCO, 2018). The PACP assigns two sets of values that identify the pipe condition by assigning a value for the severity of the damage and another value for the frequency of the damage (NASSCO, 2018). Along with the overall health of the pipe, this value can also determine the risk of inflow and infiltration, which is external and unwanted water entering the wastewater system (York Region, 2019). Port Hope has identified several dates in 2014 alone where the influent flow has exceeded the 11,300 cubic meter design capacity of the waste treatment facility; attributed to inflow and infiltration by means of poor pipe condition.

Pinch points are areas the system lacking efficiencies where the current waste generation exceeds the flow in which the pipes were designed and, or where the slope of the pipe does not promote effective downslope flow. When pinch points are identified, the difference in elevation needed in order for the pipe to achieve optimal flow may be determined. Areas in Port Hope that may experience further development can also be planned accordingly to minimize future occurrences of pinch points in the network.

Port Hope requires a GIS to assess pipe conditions, identify pinch points through capacity in the system, and invert wastewater pipes that do not have proper flow due to their elevations. Through the identification of these structural failures, Port Hope may be provided with an asset management tool to aid decision-making on whether to maintain, repair or replace their wastewater infrastructure for future growth. When evaluating conditions for replacement, Port Hope will also be given a tool to identify pipes that do not have the proper pitch and is able to provide guidance on the elevation change required to achieve optimal downward flow.

## 1.1. Study Area and Client

Port Hope, a municipality in Southern Ontario, is located on the north shore of Lake Ontario and the Northumberland Hills (Figure 1). It is a well-preserved historic town halfway between Toronto and Kingston and is a well-known shopping destination for antiques (Port Hope, 2019a). The community has a population of 16,500 and is overlooked by Northumberland County with the Ganaraska River flowing through the city (Port Hope, 2019a).

The wastewater treatment plant is located on the southeast corner of the municipality, by Lake Ontario. The current treatment plant opened in 2010 and is able to process approximately 11,300 cubic metres of water per day (Port Hope, 2019a). The total length of Port Hope wastewater pipeline is around 15 kilometres (Port Hope, 2018). In this project, the client is the Port Hope Wastewater Operation Manager, Kris Montgomery, the Wastewater Operation Assistant, Allison Clark and the rest of his team as required; contact information listed in Table 1.

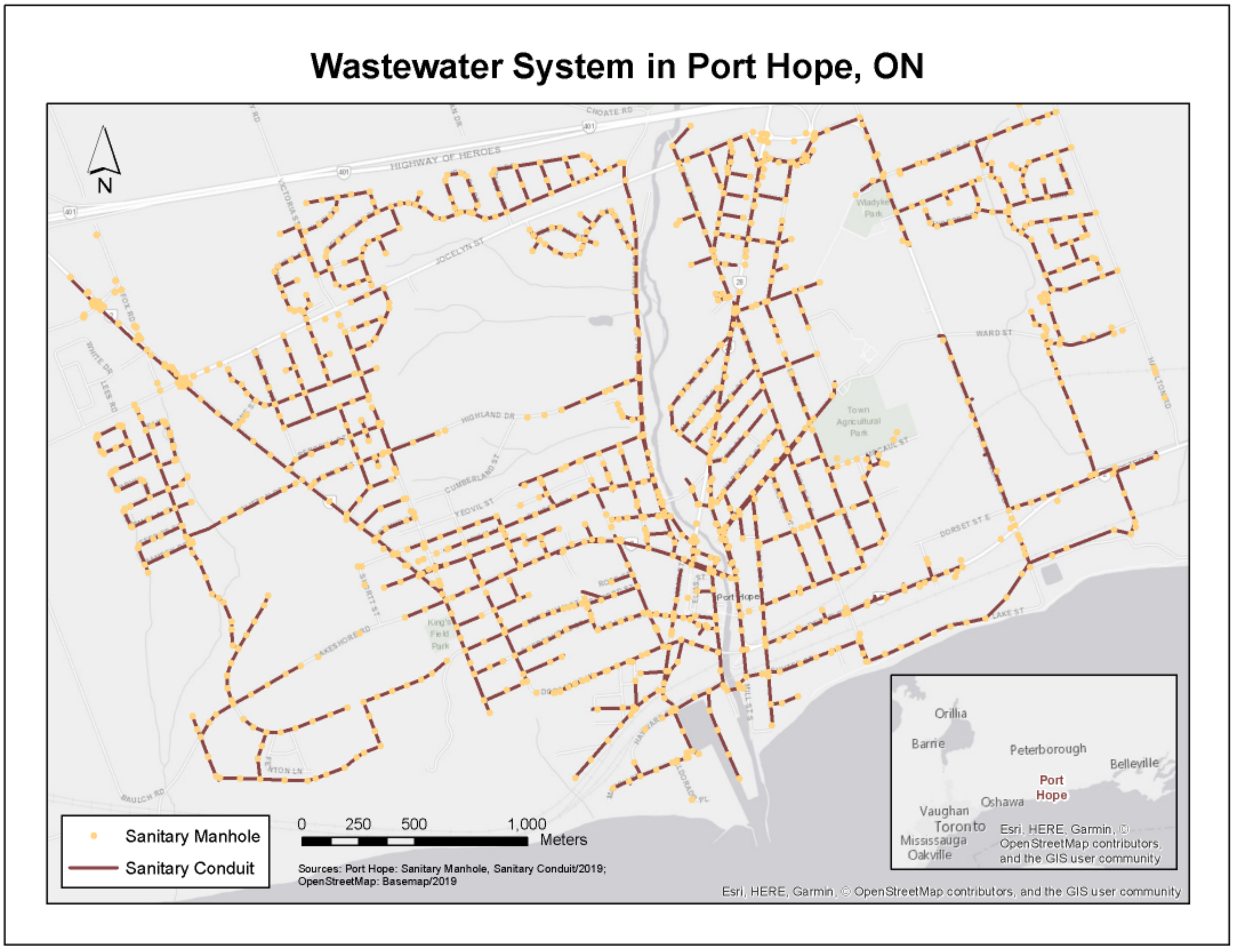



*Figure 1: Map of Port Hope*

*Table 1: Client Information*

| Name | Position | Email |
|---|---|---|
| Kris Montgomery | Wastewater Operation Manager | kmontgomery@porthope.ca |
| Allison Clark | Wastewater Operation Assistant | aclark@porthope.ca |

## 1.2. Previous Work

Port Hope has identified CIMA+, a third-party consultant firm that has recently digitized the city's wastewater network. This was provided in the form of a personal geodatabase composed of spatial data and attributes related to the pipe network that will be used for analysis. The client has also provided Closed-Circuit Television (CCTV) inspection data collected by Port Hope in Excel spreadsheets from 2016 and 2019. These spreadsheets contain additional attribution regarding the condition of the wastewater pipes. The CCTV data also corresponds to a map in Portable Document Format (PDF) also created by CIMA+.

## 1.3. Objectives

The goal of this project is to provide Port Hope a geospatial tool to document and assess the conditions of the city's wastewater infrastructure. It will contain several important attributes required for asset management that links to the internal asset management GIS viewer. The product will be easy to use and cost-effective, as the GIS budget and capabilities within the organization are currently limited. The six main objectives are outlined below.

1. Provide the most cost-effective solution that enables a user-friendly and efficient system to access and edit wastewater infrastructure data.
2. Develop a product to allow for the analysis of the wastewater network to assess the condition of the wastewater pipes, locate pipes with the poorest conditions, problematic slope, and capacities of the pipe.
3. Provide recommendations based on analysis and present findings to client by cartographic output.
4. Create an application for in-field viewing and editing.
5. Create a user-guide to ensure Port Hope staff understand the processes and methodologies implemented in this project to continue the maintenance and utilization of the product succeeding the completion of the project.
6. Allow for data to be integrated into CityWide, the internal asset management GIS viewer.

## 1.4. Literature Review

### 1.4.1. Municipalities and Waste Water Principles

**Wastewater System (Water Environment Federation [WEF], 2011)**

In municipalities there are three types of sewage systems: sanitary sewers, storm sewers and combined sewers. Sanitary sewers, also called wastewater pipelines, refer to the underground pipeline network system that transports wastewater from residential and commercial buildings to a centralized treatment plant, where wastewater is treated and sent back to the environment. Wastewater system is designed to be separated from storm sewers but there is always a problem of infiltration and inflow. Pipelines are built to allow wastewater to flow all the way downslope toward the treatment plant.

**Inflow, Infiltration and Leakage (York Region, 2019)**

Inflow and Infiltration occurs when water, groundwater and stormwater enter the wastewater system through sump pumps, downspouts, and/or holes and cracks in the pipes as seen in Figure 2. Inflow and Infiltration are problematic to the wastewater system because they reduce the system's capacity to accommodate existing residents as well as limiting future growth. The greater influx of water increases the cost of water for residence, as well as rendering the treatment of the wastewater less effective through the dilution. The overflow of water may also cause sewage backups in basements and overwhelm the wastewater treatment plant.

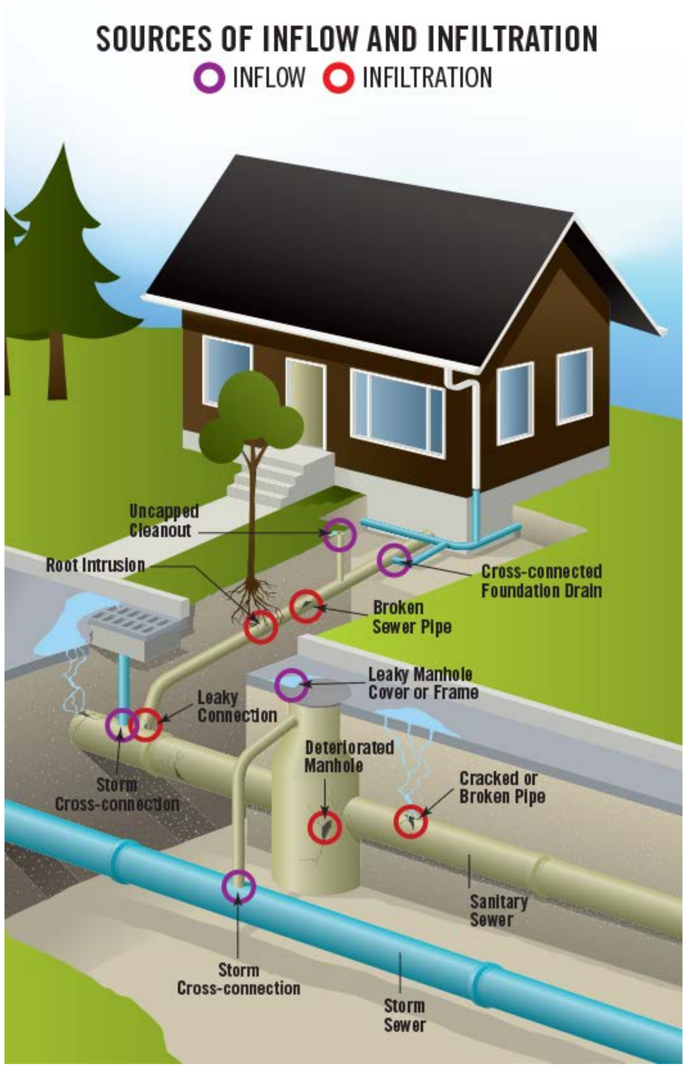



*Figure 2: Infiltration and Inflow of Wastewater System (York Region, 2019)*

**PACP Condition Grading System (National Association of Sewer Service Companies [NASSCO], 2016)**

The PACP (Pipeline Assessment and Certification Program) condition grading system uses four digits to evaluate the pipe condition. The first digit is the highest severity grade. The second is the total number of occurrences of the highest severity grade. The third digit is the second highest severity grade. The fourth digit is the total number of occurrences of the second highest severity grade. There are five severity grades from 1 (very light) to 5 (very severe). If the total number of occurrences exceeds 9, then alphabetic characters are used as follows: 10-14 = A, 15-19 = B, 20-24 = C, etc. For example, if the PACP value for a pipe is 4A24, then no grade 5 or 3 defects were found in this pipe, however, 10 to 14 grade 4 defects and four grade 2 defects were found.

**Municipality of Port Hope Design Specifications (The Municipality of Port Hope Works and Engineering Department [WED], 2002)**

The wastewater pipe that connects to the water users is called a service connection. In most situations, the diameter of a service connection should not be greater than half the diameter of the main pipe to which it connects. The exception is that a 150mm service connection is permitted to connect to a 200mm main pipe. A service connection for a single house is 150mm diameter. The size of service connections for multiple family and commercial/ institutional/ industrial uses depends on their specific cases. The depth of a service connection for a single house should be between 2.5m and 3m. The flow velocity should not be lower than 0.6m/s and the grade for a 150mm pipe should be greater than 1%.

**Waste generation Estimates and infiltration (*2010 Municipal Water Use Report, Environment Canada, 2010)***

The Government of Canada conducted a study on wastewater estimates per capita per day in Ontario, the average municipal wastewater consumed per day is approximately 330 liters per day. In this study, approximately 65% of waste is generated in the residential sector with the Industrial, Commercial and Institutional Sector following with 18 percent. While the infiltration rate is approximately 8%. The results from the study may be seen in Figure 3 below.

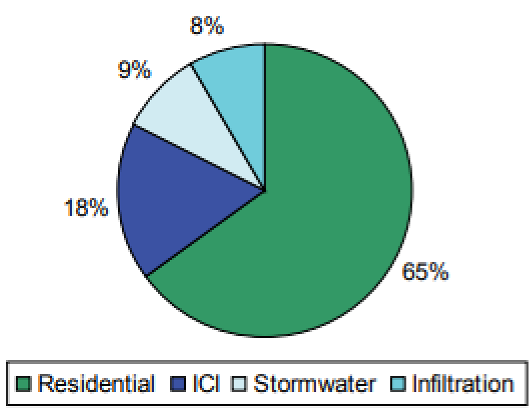



*Figure 3: Estimate of wastewater generation by sector.*

**Pipe Maximum Capacity Calculation for Sanitary Sewer (Environmental Engineering, 2015; Bengtson, 2010)**

Normally, the Manning Equation is used for the design of a sanitary sewer. The calculation involves sewer diameter and slope, a pipe roughness coefficient, flow velocity and wastewater runoff flow rate. The original Manning equation is as seen in Equation 1, where A is the channel cross sectional area, R is the hydraulic radius, S is channel slope and n is the channel roughness coefficient. The hydraulic radius is equal to channel cross sectional area over wetted perimeter. For a circular pipe flowing full, the hydraulic radius becomes pipe cross sectional area over pipe perimeter. The roughness coefficient for smooth inside surface like PVC is 0.01.

### 1.4.2. Software for sewage treatment

**QGIS (QGIS, 2019, QGIS 2018 & QGIS 2017)**

QGIS is an open source software program that executes spatial analysis and can deploy applications. It has plugins that model hydrological pipeline modeling, network, and flow management. QEsg is a plug in that assists in the design of sewage networks, showing flow direction (QGIS, 2019c). To create a pipe system in QGIS, there is a recommended workflow which outlines to identify direction, sum lots, join the pipes, and add profile to assess the grades (GIS StackExchange, 2018). In order to model this flow, GHydraulics, a QGIS plugin, analyzes water supply and calculates economic diametres based on given flow rates, this can be used to show which pipes are at a higher capacity (Macke & Epanet, 2014). Finally, QGIS has a mobile development platform to view and edit spatial data through QField (QGIS, 2019d). The VOSGIS Profile tool creates profiles from Digital Elevation Models (DEM) using vector geometries or a digitized line.

**SAGA (SAGA, 2018 & Mair et al. 2012)**

SAGA GIS stands for "System for Automated Geoscientific Analysis", with a claim of specializing in "higher level physical geoscientific applications". This software is very useful and specializes in 3D viewing and digital elevation models and working with LiDAR data. A sensitivity analysis for sewer models, used for capacity design, combined sewer systems and vulnerability assessment, uses SAGA software to create a SWMM5 model.

**GRASS (GRASS Development Team, 2017)**

GRASS an abbreviation for Geographic Resources Analysis Support System. The software was originally developed by a branch of the US Army Corp of Engineers to aid the military in land management and environmental planning. GRASS is utilized in academia, and private and public organizations around the world. GRASS is capable of many functions to manage and analyze geospatial data, produce maps and spatial modelling. As well, it also offers 3D visualization and ability to process LiDAR data and compatible on Mac, Windows and Linux systems.

**gVSig (GvSIG, 2009)**

This software is offered in Desktop, Online and Mobile versions. The desktop version can work with vector, raster, databases and remote services to analyze and manage geospatial data. The online component is offered through software as a service and installed on client servers. gvSIG Online allows geospatial information to be shared over the cloud and capable of creating applications. It is used by private and public entities over the world. gvSIG Mobile can produce applications used for data collection on Android devices and recommended for collecting data such as, inspections, and inventory.

**GeoDa (Geoda, 2019, Anselin et al, 2005 & GIS Geography, 2018)**

GeoDa specializes in spatial data analysis, geovisualization, and spatial autocorrelation. GeoDa supports spatial data formats such as shapefiles, geodatabases, GeoJSON, mapinfo, GML, KML and vector data formats supported by the GDAL library. The main objective of the software is to provide the user a way to look at empirical statistical data, beginning with simple mapping and geovisualization, exploration, spatial autocorrelation analysis, and ending up with spatial regression. This software has a user interface and a graphics window based on a Microsoft Windows platform. It is ideal for statistical analysis, although it is not a full-blown GIS package, it is a good starting software for beginner or non-GIS users.

**SQLite (SQLIte, 2019)**

SQLite is a databases management program that uses a file format storage in C language. The program is durable through power loses and can operate without a network connection once installed to a device, making it desirable for offline mobile applications.

**GDAL (GDAL, 2019)**

GDAL (Geospatial Data Abstraction Library) is a software library that handles raster and vector data in various file formats. It supports a variety of functions to process and analyze geospatial data, such as projection and transformation, translation between different formats, buffer making, polygonization, network analysis, etc. Languages initially used for commands are C or C++, but Python could also be used if there is a Python package.

**ESRI Platform (ESRI, 2019)**

Esri ArcGIS Solutions has a suite of software that relates to sewer collection examples deployed in other municipalities. This gallery shows applications to convert 2D sewer data into 3D, known as the 3D tools for Sewer. Furthermore, there are applications for deploying a sanitary network, manhole inspections and capital improvement planning for future development. ESRI is a proprietary software which requires a license to complete spatial analysis.

**PostgreSQL (PostgreSQL, 2019 & Postgis, n.d.)**

PostgreSQL is an open source object- relational database system which can work with a large network. This program works with php, Python and JDBC. It includes stored procedures, triggers, views and offers administration roles for management. PostgreSQL offers an extension, called PostGIS which enables the creation of a spatial database within PostgreSQL. PostGIS can be used amongst a plethora of open-source GIS software including QGIS, uDig and gVsig.

**GIS Cloud Spatial Web Solution (GIS Cloud, 2019)**

GIS Cloud offers a collaborative platform for field and office workflow. It provides real-time mapping to edit, and update point, line and polygon features over a web interface. With the map editor product, it allows for a cloud-based map tool for building and sharing maps of vector and raster formats. It allows for sharing, data analysis, selection, tools, map publishing, and data exporting to other formats such as Shapefiles and Keyhole Markup Language (KML).

**LAStool (Rapidlasso GmbH, 2019)**

Rapid lasso is an organization that developed LAStool. LAStool is a set of tools with highly efficient, batch scriptable command line tools to work with LiDAR data and can be used in ArcGIS and

QGIS. It provides a stable software that allows for the decompression of Laz to usable Las files (Rapidlasso, 2019).

### 1.4.3. Conclusion of Literature Review

Wastewater systems are built to transport various types of wastewater in a municipality downslope to the treatment plant. Wastewater modeling is also related to the amount that is produced per capita per day, 330 liters per day. Due to poor pipe condition, infiltration and inflow may enter the system and result in inefficiencies in the system of approximately 8%. In some municipalities, PACP values are used to evaluate wastewater pipe condition and provides a comparative rating system within the municipality. The risk level and condition of wastewater pipes can be mapped and analyzed in different GIS software to display areas to direct concern. This evaluation system would be adopted for this project. Municipalities have their own regulations on wastewater system. For example, Port Hope specifies the pipe size, pipeline depth and pipe grade. In this project, these would be the reference and guideline for the pipe slope analysis. Manning Equation will be used to calculate the maximum capacity of sewer pipes for the pinch point analysis.

To do this analysis, there are different programs that are suitable for the required workflow. To process LiDAR data, rapidLasso GmbH, Grass GIS, SAGA, and Hypercube will be explored. In order to complete the spatial analysis, it is determined that QGIS would be the primary solution explored, however other software will be explored if it is unsuccessful. Mobile deployment through QField and GIS Cloud will be options considered in this project. For effective database management, PostgreSQL and SQLite will be explored to see which environment works most efficient with the solution.

# 2. Methodology

Due to the nature of the project, an agile development methodology was adapted to accomplish all project deliverables. Agile development is considered the best practise and encourages “actively involving users throughout development to ensure high operational value” (Kramer & Wagner, 2019, p. 133). By providing our client weekly development updates, it allowed user input throughout the process to deliver the best solution. The following section outlines the methodology explained for each component of the project: pre-processing, database processing, spatial analysis, data collection and web application, and visual presentation.

## 2.1. Pre-Processing

### 2.1.1. LiDAR Data

The LiDAR data aided with the analysis of slope to determine the depth of the pipe compared the elevation. Data was provided by the Ministry of Natural Resources and Forestry (MNRF). To convert the LiDAR data into a DEM the following was completed:

1. Using the MNRF metadata, the LAZ tiles to be used in the analysis were identified. Table 2 shows the LAZ tiles that are within the projects scope.

2. The rapidLasso LAStools program was downloaded to decompress the LAZ to usable LAS format as seen in Figure 4.
3. In ArcMap, a Ground DEM was created from the LAS files using the 3-D Analyst Extension and LAS Dataset to Raster tool which resulted in DEM seen in Figure 5.

*Table 2: LiDAR Data LAZ Tiles within the study area.*

| | North | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1km177140487202016LPETERBOROUGH | 1km177150487202016LPETERBOROUGH | 1km177160487202016LPETERBOROUGH | 1km177170487202016LPETERBOROUGH | 1km177180487202016LPETERBOROUGH | 1km177190487202016LPETERBOROUGH | |
| | 1km177140487102016LPETERBOROUGH | 1km177150487102016LPETERBOROUGH | 1km177160487102016LPETERBOROUGH | 1km177170487102016LPETERBOROUGH | 1km177180487102016LPETERBOROUGH | 1km177190487102016LPETERBOROUGH | |
| West | 1km177140487002016LPETERBOROUGH | 1km177150487002016LPETERBOROUGH | 1km177160487002016LPETERBOROUGH | 1km177170487002016LPETERBOROUGH | 1km177180487002016LPETERBOROUGH | 1km177190487002016LPETERBOROUGH | East |
| | 1km177140486902016LPETERBOROUGH | 1km177150486902016LPETERBOROUGH | 1km177160486902016LPETERBOROUGH | 1km177170486902016LPETERBOROUGH | 1km177180486902016LPETERBOROUGH | 1km177190486902016LPETERBOROUGH | |
| | 1km177140486802016LPETERBOROUGH | 1km177150486802016LPETERBOROUGH | 1km177160486802016LPETERBOROUGH | 1km177170486802016LPETERBOROUGH | | | |
| | South | | | | | | |

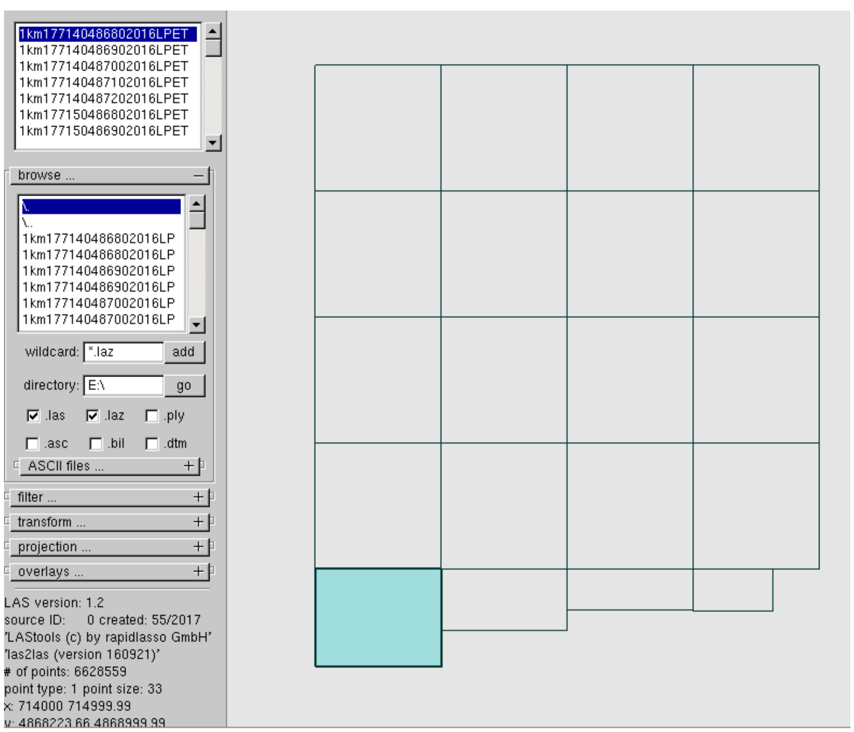



*Figure 4:rapidLasso Laz Decompression tool*

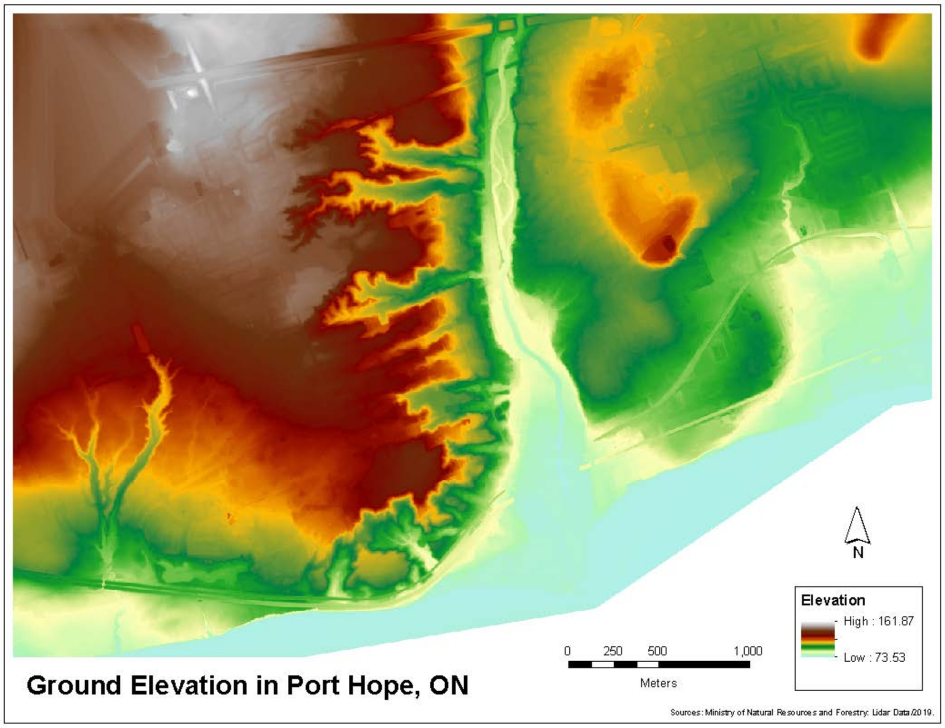



*Figure 5: DEM of Port Hope, ON*

## 2.2. Database Processing

The database was created using the data received from the client and modified, remaining fluid throughout the duration of the project to better accommodate varying project demands. The aspects influencing the database design were spatial analysis, web application and QGIS functionality. PostgreSQL and PostGIS were downloaded on an Amazon Web Services (AWS) server and QGIS was used to import the data to the new PostGIS database. The following section describes steps taken to ensure data efficiency, security, integrity and little maintenance.

### 2.2.1. PACP Values

To incorporate the PACP values into the analysis, the PACP values in the Closed-Circuit Television (CCTV) 2019 inspection spreadsheet were added to the sanitary conduit spatial data. This was accomplished through the following steps:

1. No primary key, foreign key relationship existed between the spatial and nonspatial data. Therefore, a composite key using existing data in both tables had to be created.
    i. A new field was added in ArcGIS and Excel spreadsheet to hold the new value.
    ii. The am_sa_id contained mostly unique values, so the am_sa_id was repopulated in the new column in both, ArcGIS and the Excel spreadsheet.
    iii. the non-unique values were selected using a Select By Attribute tool and the am_sa_id and the mh_to fields were concatenated to create a composite key in both, ArcGIS and Excel.

2. Once the unique values existing on both tables, the non-spatial data was joined to the spatial data using that new field and all 1229 pipe segments were validated.
3. The values were then parsed out using the index location within the rating.
4. The joins were removed from the sanitary conduit layer
5. The newly created column was deleted from the table.

### 2.2.2. Data Normalization

A primary key was created for each table using the smallserial datatype which created an automatically generated increment number with a non-null constraint (PostgreSQL Tutorial, n.d.). The non-null constraint was placed on all required fields in the database. It was especially important to place the non-null constraint on the am_sa_id, as this is how the asset management team will relate the assets to the corresponding item in CityWide. Where restrictions on the data entered by the user where necessary, constraints were created to prevent users from entering invalid values in order to keep data consistent. Using appropriate data types, the database was also designed to keep user inputs consistent.

The sanitary conduit layer being the only editable layer in the mobile application, most of the efforts were placed on this layer to ensure accurate and easy data collection. As mentioned previously, the PACP values were parsed into four separate columns to keep a normalized database. Table 3 displays the steps taken to ensure accurate data collection.

*Table 3: Display of data types and constraints used to ensure database normalization.*

| Field | Data Type | Constraint |
|---|---|---|
| pacp1 | smallint | ALTER TABLE sanitaryconduit_19 ADD CONSTRAINT pacp1_check CHECK (pacp1 >= 0 AND pacp1 <= 5 OR pacp1 IS NULL); |
| pacp2 | CHAR(1) | N/A |
| pacp3 | smallint | ALTER TABLE sanitaryconduit_19 ADD CONSTRAINT pacp3_check CHECK (pacp3 >= 1 AND pacp3 <= 5 OR pacp3 IS NULL); |
| pacp4 | CHAR(1) | N/A |

### 2.2.3. Function Triggers and Triggers

To minimize the maintenance required to the database, function triggers and triggers were utilized in PostgreSQL to automate calculations if a new feature was added or a features attributes were updated to the layer. The triggers automatically execute in response to an event on a table. Triggers were created on five fields that were required for the spatial analysis component; maximum capacity of pipe and the infiltration rate.

*Table 4: table of function triggers and triggers*

| Field and Trigger Name | Function |
|---|---|
| maxcap:<br>waste_capacity_calc_func<br>waste_capacity_calc_trg | Maximum capacity of the pipe in cubic metres per second<br>Equation:<br>$\pi \times (dia_{mm} \div 2000)^2) \times (abs(slope)^{1/2})) \times ((\frac{dia_{mm}}{4000})^{\frac{2}{3}} \div 0.01$ |
| maxcap_lpd:<br>waste_capacitylpd_calc_function | Maximum capacity of the pipe in litres per day<br>Equation: $maxcap \div 86400000$ |
| infilrate: infiltration_calc_func | Infiltration rate<br>Equation: $qsr^2 \div 100$ |
| maxcap_m3pd:<br>waste_capacitym3p_calc_function<br>waste_capacitym3p_trg | Maximum capacity of the pipe in cubic metres per day<br>Equation: $maxcap \times 3600 \times 24$ |
| slopecalc:<br>slopecalc_calc_func<br>slopecalc_calc_trg | The slope calculation using manhole invert values<br>Equation: $(to_{mh_{inv}} - mh_{inv}) \div shape\_leng$ |

**Maximum Pipe Capacity**

The maximum capacity of a pipe was calculated using the Manning Equation seen in Equation 2. The original Manning equation is seen in Equation 1. In this project, the flow equals the maximum capacity of the wastewater pipe. Below is a list of the variables used in the original equation:

$$flow = A \cdot R^{\frac{2}{3}} \cdot \frac{(S)^{\frac{1}{2}}}{N}$$

*Equation 1: Manning Equation in $m^3/s$*

- A = cross sectional area (m2), here it equals to the circular pipe cross sectional area
- R = hydraulic radius (m) = A/P
- P = wetted perimeter (m), here it equals to the pipe perimeter
- S = slope (dimensionless) = rise/run, here the absolute value is taken because there are negative slopes
- N = roughness coefficient (dimensionless), here it equals to 0.01 because the materials used for sanitary sewers are mostly smooth plastics like PVC

$$MaxCapacityofPipe(m^3/s) = \frac{[\prod *(\frac{PipeDiameter}{2})^2] * |PipeSlope|^{1/2} * [\frac{\prod *(\frac{PipeDiameter}{2})^2}{2*\prod *(\frac{PipeDiameter}{2})}]^{2/3}}{ManningRoughnessCoefficient}$$

*Equation 2: pipe maximum capacity.*

Therefore Equation 2 was the maximum capacity of the time and used in the function trigger to have these values update automatically when any features are added or have their pipe diameter and pipe slope values updated. Having the maximum capacity in cubic metres per second then leads to the other units of measure triggers to fire and the corresponding fields are updated. The queries used to create the function triggers and triggers may be seen in Figure 6, 7 and 8.

p1907 on p1907@terra

```sql
CREATE OR REPLACE FUNCTION waste_capacity_calc_func()
RETURNS trigger AS $maxcap$
    BEGIN
        IF NEW.dia_mm IS NULL THEN
            maxcap : = NULL;
        END IF;
        IF NEW.slope IS NULL THEN
            maxcap : = NULL;
        END IF;

        -- maximum capacity fields assigned product of formula
        NEW.maxcap := (pi()*(NEW.dia_mm/2000)^2)*(
            abs(NEW.slopecalc)^(1/2))*((NEW.dia_mm/4000)^(2/3))/0.01;
        RETURN NEW;
    END;
$maxcap$ LANGUAGE plpgsql;

CREATE TRIGGER waste_capacity_calc_trg BEFORE INSERT OR UPDATE
    ON public.sanitaryconduit_19 FOR EACH ROW
    EXECUTE PROCEDURE waste_capacity_calc_func();
```

*Figure 6: function trigger and trigger before being run in PostgreSQL*

p1907 on p1907@terra

```sql
CREATE OR REPLACE FUNCTION waste_capacitym3pd_calc_func()
RETURNS trigger AS $maxcapm3pd$
    BEGIN
        IF NEW.maxcap IS NULL THEN
            NEW.maxcapm3pd := NULL;
        END IF;
        -- waste capacity in calculate litres per day
        NEW.maxcapm3pd := NEW.maxcap * 3600 * 24 ;
        RETURN NEW;
    END;
$maxcapm3pd$ LANGUAGE plpgsql;;

CREATE TRIGGER waste_capacitym3pd_trg BEFORE INSERT OR UPDATE
    ON sanitaryconduit_19 FOR EACH ROW
    EXECUTE PROCEDURE waste_capacitym3pd_calc_func();
```

*Figure 7: waste capacity metres3 per day*

p1907 on p1907@terra

```
CREATE OR REPLACE FUNCTION waste_capacitylpd_calc_func()
RETURNS trigger AS $maxcaplpd$
    BEGIN
        IF NEW.maxcap IS NULL THEN
            NEW.maxcaplpd := NULL;
        END IF;
        -- waste capacity in calculate litres per day
        NEW.maxcaplpd := NEW.maxcap/86400000;
        RETURN NEW;
    END;
$maxcaplpd$ LANGUAGE plpgsql;;

CREATE TRIGGER waste_capacitylpd_trg BEFORE INSERT OR UPDATE
    ON sanitaryconduit_19 FOR EACH ROW
    EXECUTE PROCEDURE waste_capacitylpd_calc_func();
```

*Figure 8: litres per day*

**Infiltration Rate**

Infiltration rate is a function of the quality of the pipe. Therefore, to estimate the infiltration rate, the first condition value of the PACP was used to predict the amount of infiltration influx to each pipe (seen in Equation 3). This equation was then used in the function trigger as seen in Figure 9.

$$InfiltrationRate = \frac{QSRCode1^2}{100}$$

*Equation 3: infiltration rate estimate*

p1907 on p1907@terra

```
CREATE OR REPLACE FUNCTION infiltration_calc_func()
RETURNS trigger AS $infiltration$
    BEGIN
        -- if pacp1 is null the infilration remains null
        IF NEW.pacp1 IS NULL THEN
            NEW.infiltration := NULL;
        END IF;

        -- return the product of the infilration rate formula
        NEW.infiltration := NEW.pacp1^2/100;
        RETURN NEW;
    END;
$infiltration$ LANGUAGE plpgsql;

 CREATE TRIGGER infiltration_calc_trg BEFORE INSERT OR UPDATE
     ON sanitaryconduit_19 FOR EACH ROW
     EXECUTE PROCEDURE infiltration_calc_func();
```

*Figure 9: infiltration rate function trigger and trigger*

## 2.3. Spatial Analysis

This section will describe the processes and methods in order to analyze the pipe condition, the pitch slope, the capacity, waste generation and capacity calculations.

### 2.3.1. Poor Pipe Condition

As described in Section 2.2.1, the PACP values are parsed into their separate columns, no further spatial analysis was required beyond running the Select By Expression tool to locate the most critical pipe conditions. To provide recommendations on pipe conditions, the PACP values were then used to create cartography representation of the values.

### 2.3.2. Pitch / Slope

To determine optimal slopes of the manholes and generate a report of the slope compared to the DEM, the following methods are as follows:

1. In the database create a new field and calculated the slope using Equation 4 below.
2. Using the VoGIS Profile QGIS Plug In, extract the DEM elevation on a selected pipeline network see Figure 10 and 11 below.
3. Export the CSV table and built a graph using Excel with DEM elevations, From Manhole Elevations and To Manhole Elevations data, see Figure 12 below.

$$Slope = \frac{(ManholeToElevation - ManholeFromElevation)}{LengthofthePipe}$$

*Equation 4: pipe slope equation*

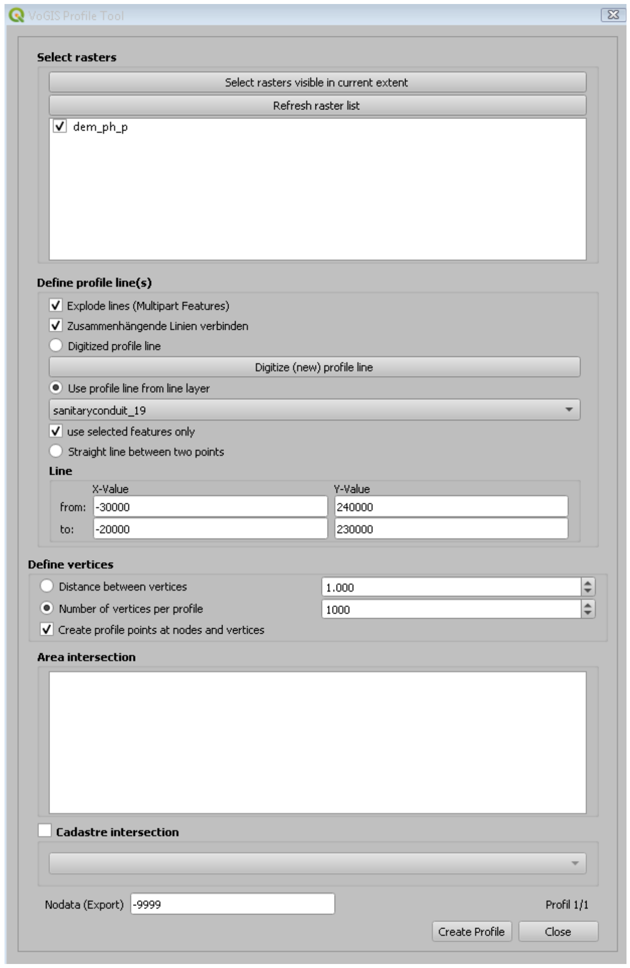


*Figure 10: VoGIS Profile Tool*

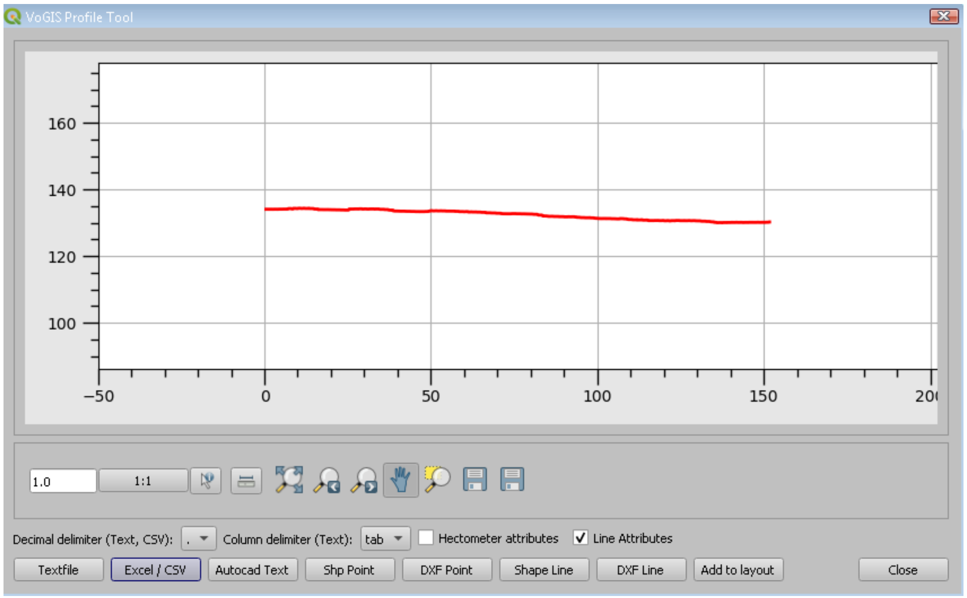



*Figure 11: example of VoGIS DEM profile output in the plugin*

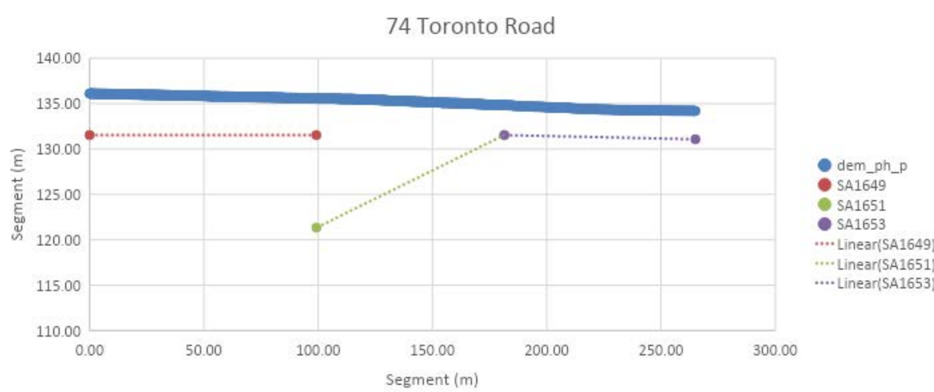



*Figure 12: example of pipe and DEM cross section in spreadsheet graph*

If the results of the equation are negative or zero, the pipe is flowing towards the wastewater treatment plant and the invert elevation of the pipe is considered optimal. Pipes that result in values greater than zero represent locations in the system which have poor pitch. With the spreadsheet graph, the client will determine the slope adjustments.

### 2.3.3. Waste Generation, Max Capacity

To determine waste generation, the following methods are as follows:

1. Create sanitary laterals from the parcel data using the near tool on ArcMap
    a. Refer to Figure 13 for model work flow
2. Populate sanitary laterals of total waste generated per lateral in litres per day (L/D) as estimates from Zoning and number of residents
    a. Refer to Equation 5 for equation of waste generation
    b. Refer to Table 4 for zoning code estimates

3. Build a QGIS Sanitary Waste Generation Model Figure 14 and 15
    a. Intersect and sum all the sanitary waste generated from the sanitary laterals that connect to the sanitary conduit.
    b. Calculate the total waste generated in the sanitary conduit that accounts for infiltration. See Equation 6
    c. Calculate a total waste and infiltration generated to the maximum capacity of the pipe outlined in Equation 7
4. Run the basic statistics for fields tool on QGIS to generate a statistical report on a field of inquiry. See Figure 16 for an example.

The client may add infrastructure to the system and re-run the QGIS sanitary waste generation model to examine the capacities of the pipe.

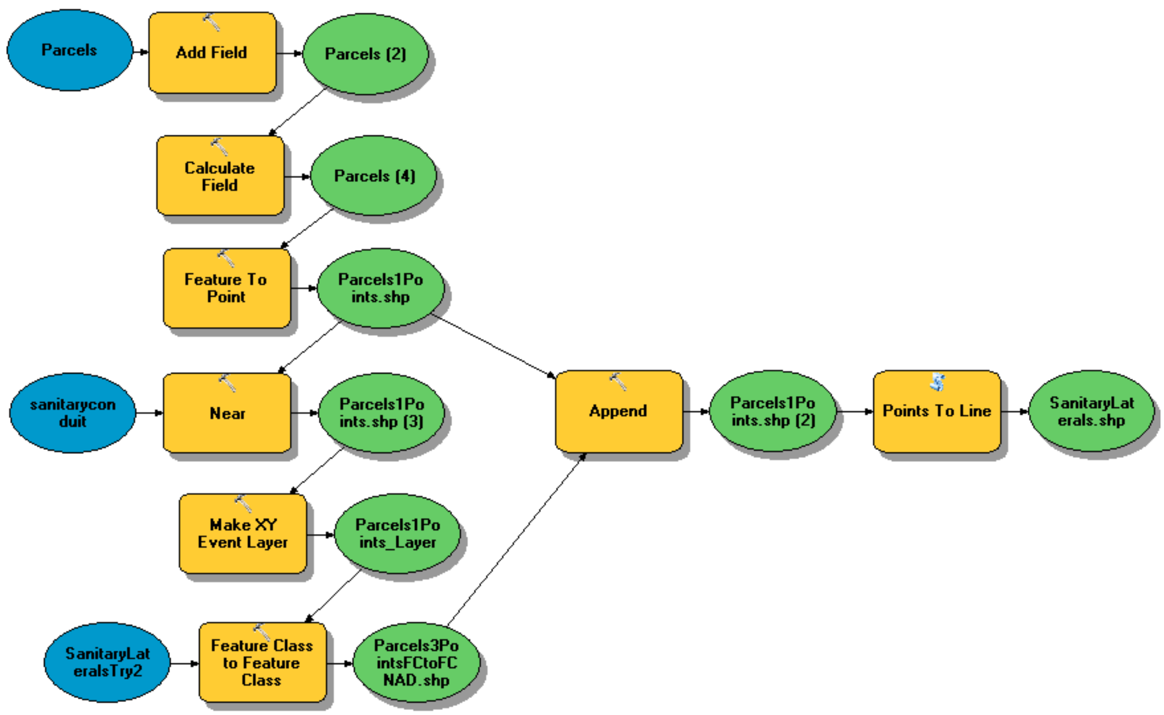



*Figure 13: generate sanitary laterals from Parcels to connect to sanitary conduit*

$$TotalWasteGenPerSanitaryLaeral = (Num_{Entities/Parcel}) * (Total_{WasteGenerated/Entity})$$

*Equation 5: total waste generated per*

*Table 5: Waste Generation Estimates from Zoning Codes*

| Zoning Code | Number of people/ entities (building or establishments) per parcel | Total waste generated per person/entity in liters per day | Total Waste generated per lateral per day<br><br>(Equation 4) |
|---|---|---|---|
| 1 Low Residential | 2 | 330 | 660 |
| 2 Low Residential | 3 | 330 | 990 |
| 3 Medium Density Residential | 3.5 | 330 | 1155 |
| 4 High Density Residential | 4 | 330 | 1320 |
| 5 Residential | 4 | 330 | 1320 |
| 6 Residential | 4 | 330 | 13220 |
| 7 Residential | 3 | 330 | 330 |
| 8 Residential | 4 | 330 | 1320 |
| 9 Commercial | 1 | 3000 | 3000 |
| 10 Commercial | 1 | 4000 | 4000 |
| 11 Commercial | 1 | 3000 | 3000 |
| 12 Commercial | 1 | 4000 | 4000 |
| 13 N/A | 0 | 0 | 0 |
| 14 Commercial | 1 | 3000 | 3000 |
| 15 Easement | 0 | 330 | 330 |
| 16 Residential | 3 | 330 | 330 |
| 17 Residential | 3 | 330 | 330 |
| 18 Residential | 3 | 330 | 330 |

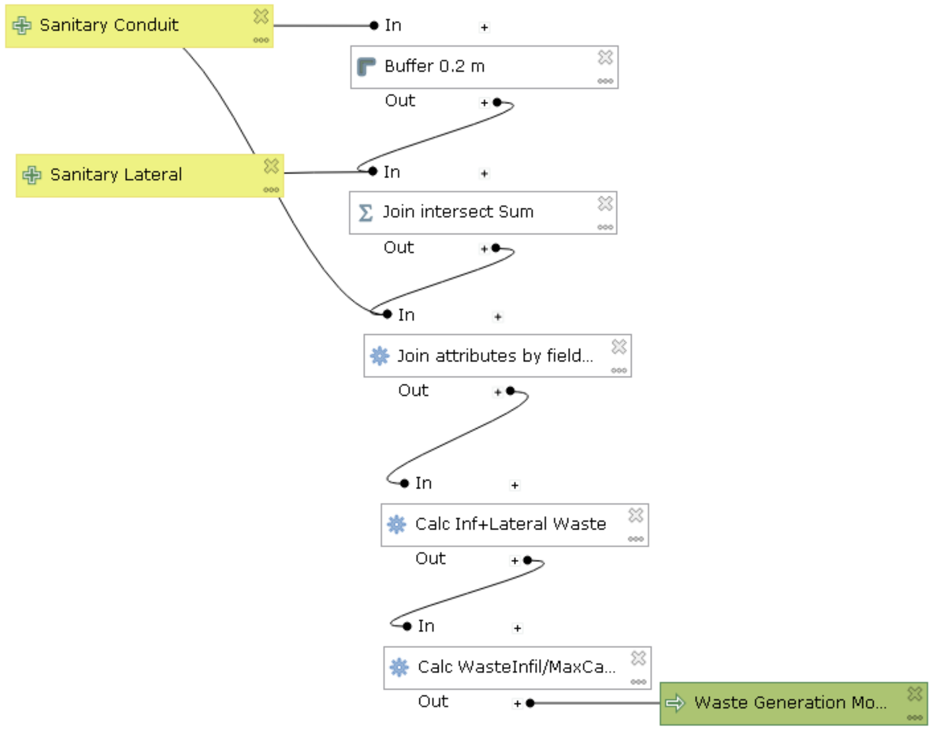



*Figure 14: model process of waste generation and maximum capacity analysis*

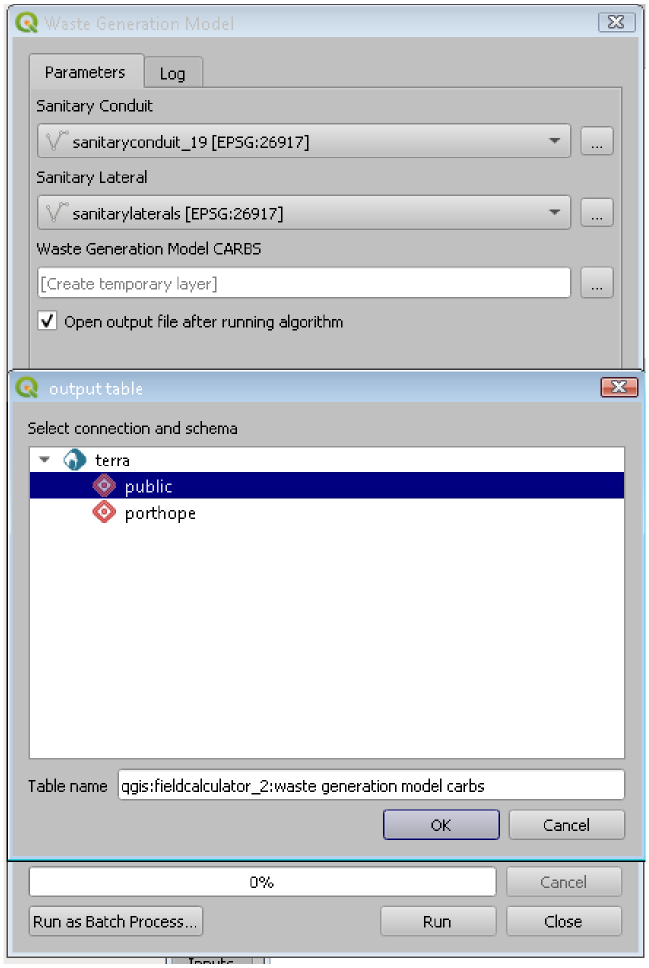



*Figure 15: Model  waste generation interface*

$$ConduitTotalWasteGenerated = (SumOfLateralWaste) * (1 + InfiltrationRate)$$

*Equation 6: the conduit total waste generated*

$$PercentConduitUtilization = \frac{ConduitTotalWasteGenerated}{MaxCapacityofPipe}$$

*Equation 7: percent conduit utilization*

Analyzed field: WasteInfil

Count: 997

Unique values: 246

NULL (missing) values: 232

Minimum value: 0.0

Maximum value: 52200.0

Range: 52200.0

Sum: 5677660.050000002

Mean value: 5694.744282848547

Median value: 4125.0

Standard deviation: 4869.777198706581

Coefficient of Variation: 0.8551353593476347

Minority (rarest occurring value): 1258.95

Majority (most frequently occurring value): 1999.8

First quartile: 2475.0

Third quartile: 7612.8

Interquartile Range (IQR): 5137.8

*Figure 16: Example of summary statistics of the waste generated in the conduit through the Basic Summary Statistics QGIS*

### 2.3.4. Pinch Point Analysis

Pinch point analysis is necessary to detect the locations where the actual wastewater flow has the potential to exceed the pipe's maximum capacity. The actual wastewater flow in a single conduit is the accumulated total conduit waste generation, in other words, it is the sum of wastewater that flows directly into the conduit through laterals and infiltration and that flows from the upstream conduits. This accumulated total conduit waste generation can be calculated for each conduit in ArcMap using a Python script. When calculations are completed for all conduits, the result will be compared with the maximum capacity of the network.

The accumulated total conduit waste generation needs to be calculated in the attribute table of the result from waste generation and infiltration analysis. The steps are as follows:

1. Add two new fields, one for elevation rank (field type = short) and another for accumulated flow (field type = double)
2. Use field calculator to calculate the initial accumulated flow. Make it equal to the total conduit waste generation for now
3. Sort the conduits from the highest to manhole invert elevation to the lowest and give a rank to each conduit according to the sorting using an update cursor

4. Using a search cursor, for each row, first select the conduit in that row by attribute and then select the intersecting conduits by location
5. Using another search cursor, for each intersecting conduit, if its “to manhole invert elevation” is higher than the “to manhole invert elevation” of the first selected conduit, then apply an update cursor to the first selected conduit and update the accumulated flow field by making it equal to the sum of the intersecting conduit’s accumulated flow and the first selected conduit’s accumulated flow
6. Loop step 4 and 5 until calculations for all conduits are done and then remove selection

The calculation is based on conduit elevation. It assumes that wastewater in the system always flows from conduits with high elevation to conduits with low elevation. The calculation loop ensures that the conduits with higher elevation will be calculated earlier than conduits with low elevation, so that the waste generation will be accumulated into the downstream conduits. The process is achieved with a Python script (Figure 17).

```
script.txt - Notepad
File  Edit  Format  View  Help
>>> #arcmap setting
... import arcpy
... from arcpy import *
... arcpy.env.overwriteOutput = True
... workspace = arcpy.env.workspace = "C:/temp/1907/TEST_DATA/TestAccumFlow" #the folder that contains the pipelines shapefile
...
... #create two new columns in the attribue table
... pipelines = "test_layer" #the pipelines shapefile
... arcpy.AddField_management(pipelines, "total_flow", "DOUBLE")
... arcpy.AddField_management(pipelines, "elev_rank", "SHORT")
... #make the initial total flow equal to waste generated by houses
... arcpy.CalculateField_management(pipelines, "total_flow", "!house_flow!","PYTHON_9.3")
...
... #sort the pipelines from the highest to manhole elevation to the lowest
... arcpy.Sort_management(pipelines, "test_layer_sort", [["mh_to_elev","DESCENDING"]] )
... #manually add the created shapefile into arcmap
... pipelines_sort = "test_layer_sort" #the sorted pipelines shapefile where total flow will be calculated
... #give a rank to each single pipe according to the sorting
... cursor_sort = arcpy.da.UpdateCursor(pipelines_sort, "elev_rank")
... i = 1
... for row_sort in cursor_sort:
...     row_sort[0] = i
...     cursor_sort.updateRow(row_sort)
...     i = i + 1
...
... #calculate the total flow for each pipe in order
... cursor_pipe = arcpy.da.SearchCursor(pipelines_sort, ["mh_to_elev", "elev_rank", "total_flow"])
... for row_pipe in cursor_pipe:
...     j = row_pipe[1]
... #select a pipe to calculate
...     pipe = arcpy.SelectLayerByAttribute_management(pipelines_sort, "NEW_SELECTION", """"elev_rank" = {}""".format(j))
... #select the pipes that intersect with the pipe being calculated
...     compare = arcpy.SelectLayerByLocation_management(pipelines_sort,"INTERSECT", pipelines_sort, "", "ADD_TO_SELECTION")
...     cursor_compare = arcpy.da.SearchCursor(compare, ["mh_to_elev", "total_flow"])
...     for row_compare in cursor_compare:
... #if the pipe's elevation is higher then it will flow into the pipe being calculated
...         if row_compare[0]>row_pipe[0]:
...             pipe_update = arcpy.SelectLayerByAttribute_management(pipelines_sort, "NEW_SELECTION", """"elev_rank" = {}""".format(j))
...             cursor_update = arcpy.da.UpdateCursor(pipe_update, "total_flow")
... #add the higher pipe's flow into the lower pipe
...             for row_update in cursor_update:
...                 row_update[0] = row_compare[1] + row_update[0]
...                 cursor_update.updateRow(row_update)
... arcpy.SelectLayerByAttribute_management(pipelines_sort, "CLEAR_SELECTION")
```

*Figure 17: Python Code Example for Accumulated Wastewater Calculation in ArcMap*

Due to data limitations (Figure 18), only example data was used to test the script. After the accumulate waste generation is calculated for all conduits, it can be compared with the maximum capacity. If the accumulated waste generation is smaller than 90% of the maximum capacity, then no pinch point occurs at this conduit; if the accumulated waste generation is between 90% and 100% of the maximum capacity, then there is a high possibility that pinch point occurs; if the accumulated waste generation is greater than the maximum capacity, then there is a pinch point at that conduit.

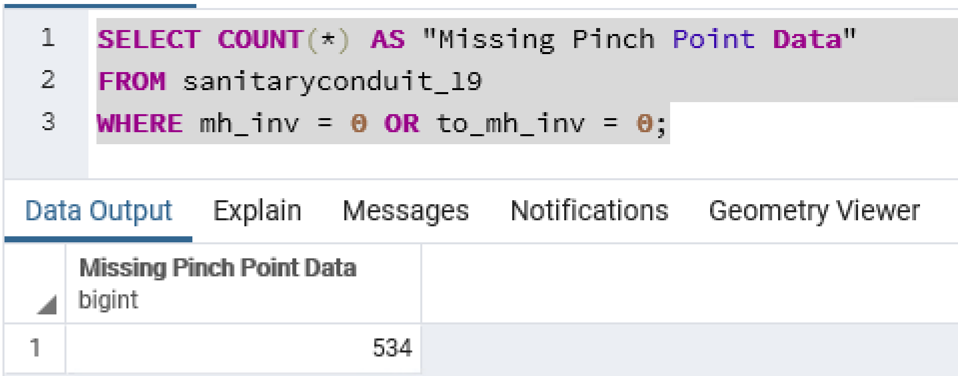



*Figure 18: Query and results displaying the lack of data required to calculate pinch points*

## 2.4. Data Collection and Web Application

There were two applications configured for data collection for this project; QField and GIS Cloud. QField was originally being developed as the data collection component due to its compatibility with QGIS and offline capabilities. However, the client's tablets operate using Windows 10 and QField is only available for download on android operating systems. To overcome this, a web solution was an alternative due to the client machines having access to a 5G network.

### 2.4.1. GIS Cloud

GIS Cloud was the best option for Port Hope's data collection and was configured to best maximize user function and usability. Manuals outlining how-to-use and configure the application were created to aid the continued use of the application. Connecting our PostGIS database hosted on an AWS server, to GIS Cloud allowed a seamless integration of the live data into the web application. The database was connected to GIS Cloud and the required layers were added to the map. The OpenStreet map Tile Map Service offered by GIS Cloud was added as a basemap to provide context to the user. Small adjustments were made to create aliases for layer names and field names to ensure they are clearer for the user to understand.

The sanitary conduit layer remains the only editable layer in the web application and the rest of the layers locked to disable users from entering data in other layers. GIS Cloud was configured in the Form Manager to display all the editable fields (seen in the list below), while datatypes and constraints ensure users only enter valid values.

- To manhole elevation
- From manhole elevation
- Pipe diameter
- Pipe material
- PACP values

## 2.5. Visualization Presentation

In this project, three poster format digital maps were created to visualize the results of analysis, namely the Pipelines Condition Evaluation map, the Waste Generation and Infiltration map and the

Pipelines Backflow Analysis map. The size of each map is 56’ x 39’ and the scale is 1:3500. Some base map layers (highways, streets, railways and waterbody) were extracted from Northumberland County’s ArcGIS Server. These maps were all created in QGIS and followed the basic cartographic design principles. Some design considerations will be discussed in the following subsections.

### 2.5.1. Colour

The theme colour of the map series was selected to be blue and white, which matches the colour used in Port Hope’s logo. For example, titles and text boxes used the exact same blue used in the logo; the lake was in light blue and the land was in white; a blue sequential colour scheme was also applied to pipelines on the Waste Generation and Infiltration map, where a darker blue represents more total waste generation. The advantages of this theme colour selection include: (1) there is a strong link between Port Hope and the map series (2) it successfully serves the theme of water flows (3) Lake and land can be harmoniously represented (4) the simple and clean theme allows the complicated pipeline information to be communicated clearly (5) by applying to all maps in the series it gives a consistent and professional appearance.

Other colours were selected to help convey information while increasing visual contrast and hierarchy. On the Pipelines Condition Evaluation map, a red-green diverging colour scheme was used to visualize the pipe’s highest severity grade. As the same with people’s common feeling, green was associated with good pipe condition and red was for bad pipe condition. Similarly, on the Pipelines Backflow Analysis map, a green pipe had a good slope and a red pipe had an inverse slope. On the Waste Generation and Infiltration map, the colour of laterals was selected to be orange - blue’s complementary colour, which increased the visual contrast. Lastly, grey was used to represent all pipes with no data, which should address less attention.

### 2.5.2. Symbology

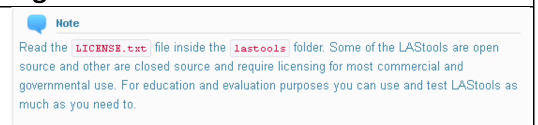
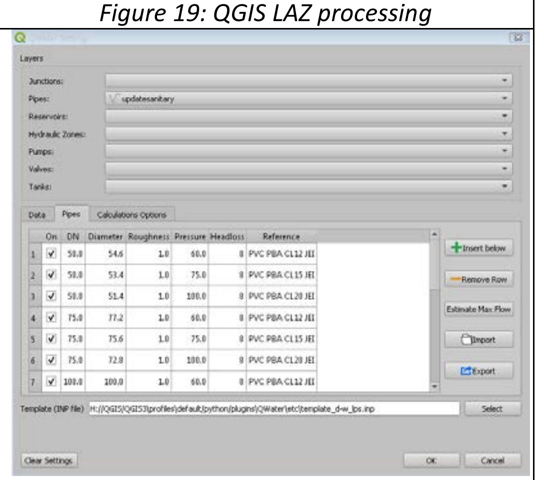
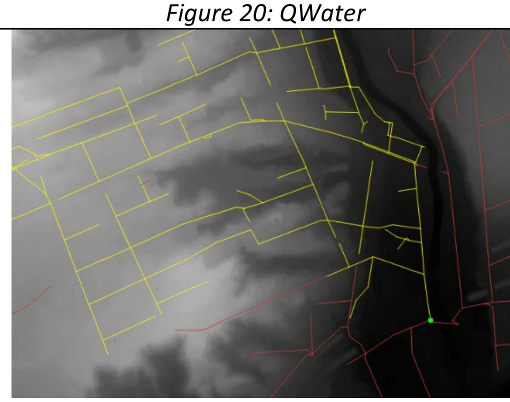
The major symbology used in the map series was the symbology for wastewater pipelines. Colour, pattern and line width are the components for a line symbology. As colour is always used to visualize one variable, line width can be used to visualize the second variable. On the Pipelines Condition Evaluation map, different line widths were assigned to pipes with different second PACP digits. If there are more occurrences of the highest severity grade, the pipe will be thicker. Rule based symbology method was used to achieve the bivariable symbology requirements.

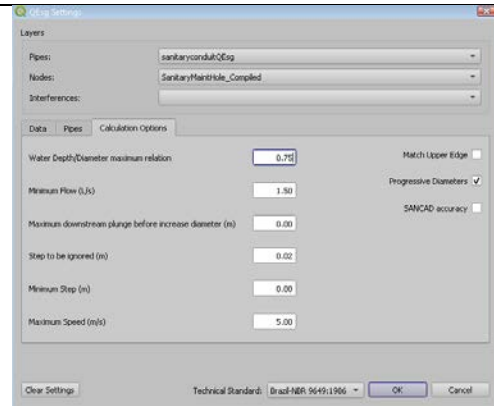
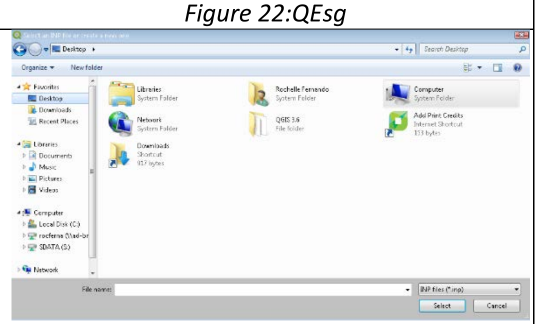
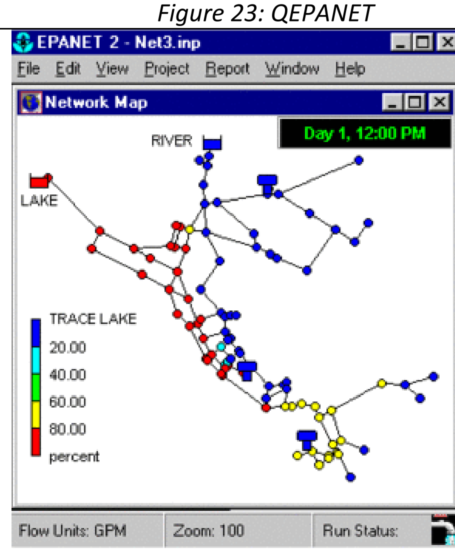
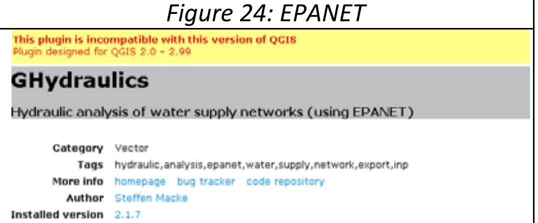
The symbology for base map layers were carefully considered as well. The colour and pattern selected for highways and railways were close to those widely used in other maps. Land parcel boundaries were used to represent both parcels and local roads. The symbology for local roads was omitted in case they overlapped the wastewater pipelines.

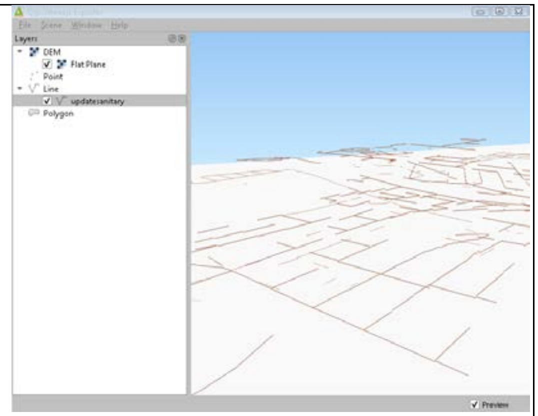
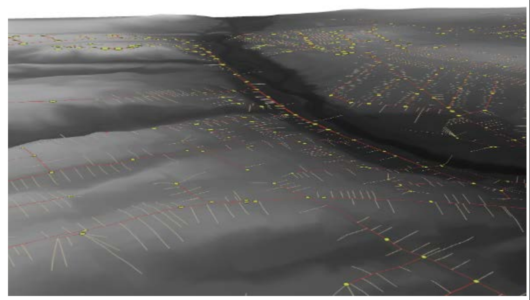
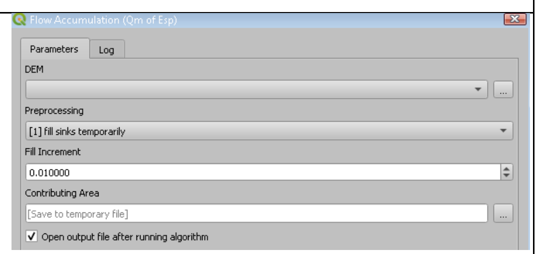
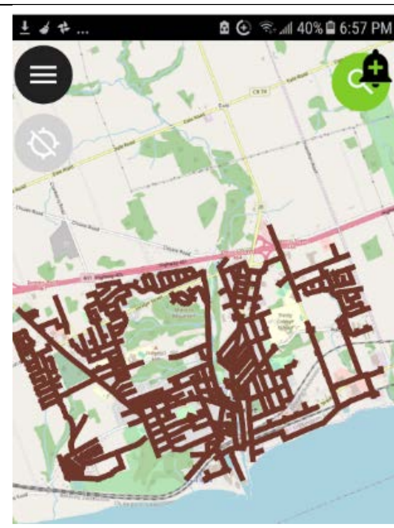
## 2.6. Ineffective Methods

This section outlines the ineffective methods throughout the duration of the project. Through research, development and trail and error, there have been methods that have been explored; however, were not the most adequate or effective in completed the needs of the client. These are outlined in the Table 5.

*Table 6: Ineffective Methods*

| Name | Reason for Inefficiencies | Figure |
|---|---|---|
| QGIS LAZ processing | This requires licensing to convert LAS to DEM (QGIS, 2019) | <br><br>*Figure 19: QGIS LAZ processing* |
| QWater | Requires specific layers and data set-up to run and there was not enough documentation provided on how-to-use the plugin. Not necessarily compatible with client data. | <br><br>*Figure 20: QWater* |
| Flow Trace | This tool calculates a flow upstream. However, does not allow for any additional analysis. This plugin also does not account for pipes that may actually connect to the network as seen in Figure 21. | <br>*Figure 21: Flow Trace - example of pipe flow* |

| | | |
|---|---|---|
| QEsg | This sanitary Sewage System Network Design is a structured design system of waste water networks. It does not provide flexibility of converting existing sewage network into the model. The client would have to restructure the spatial database to fit this model. |  *Figure 22:QEsg* |
| QEPANET | Uses the standard EPANET .inp file format to store all the data needed. Outside the scope of the project. |  *Figure 23: QEPANET* |
| EPANET | This program requires a specific format which the client did not want to work with. |   *Figure 24: EPANET* |
| GHydraulics | This plugin analyzes water supply and calculates diametres based on given flow rates using EPANET. The plugin is designed for QGIS 2.0 - 2.99 and not with the version used for this project. |   *Figure 25: GHydraulics* |

| | | |
|---|---|---|
| Qgis2threejs | This unstable product environment is not reliable at all deployments. It has limited functionality for accurate slope visualizations as seen in Figure 26. |  *Figure 26: Qgis2threejs* |
| 3d Map1 | This function in QGIS only views the DEM in 3-D space. This limited feature does not provide directions, search to areas, and has limited control.<br>This function has limited 3-d visualizations of linear features.<br>Because slope changes are minor it is difficult to view accurate slope changes.<br>An example of deployment is seen in Figure 27. |  *Figure 27: example of QGIS 3-D* |
| Saga Flow Accumulatio n | This is based on a DEM. This could be a possibility to look into by creating a DEM of the conduit pipe network, however it does not allow customization of flow calculations as seen in Figure 28. |  *Figure 28: SAGA Flow Accumulation* |
| QField | QField is not able to work with the client tablets. An example of QField is seen in Figure 29.<br><br>QField is also an offline mobile application which required user to download and synchronize edits when working in the field. Alternative methods were preferred to prevent data loss. |  *Figure 29: application configured using QField* |

# 3. Results

The resulting deliverables for this project are described in this section, which satisfy all off the client's needs. By providing the client with a spatial database, spatial analysis, data collection method, cartographic output and documentation for the continued use, it will allow them a cost-effective solution, which they can easily utilize to review and edit attributes, run their own spatial analysis and integrate into CityWide.

## 3.1. Database Structure

The database shows the processes and relations that the sanitary network has been compiled. This is seen in Figure 30 and is in the appendix.

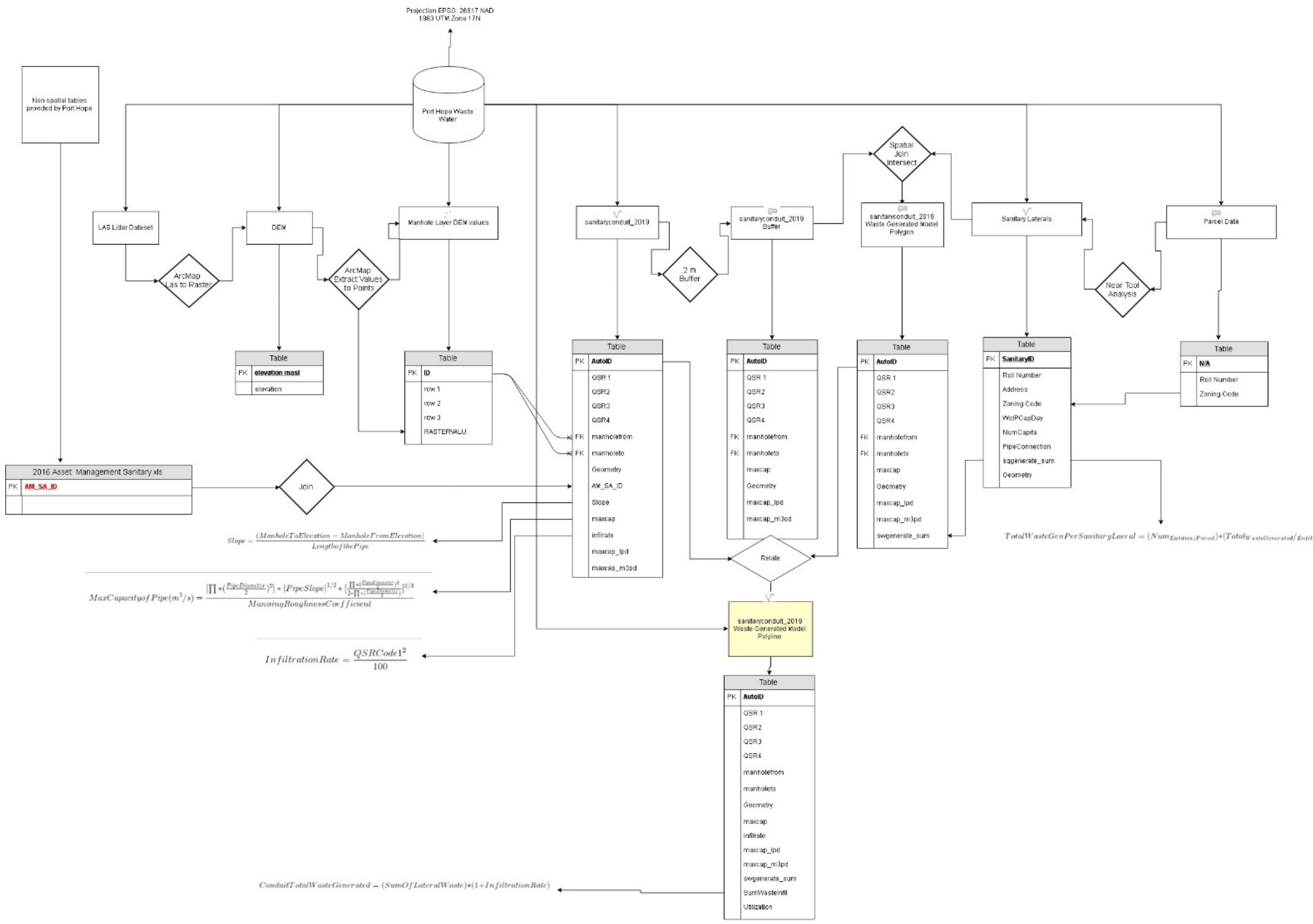



*Figure 30: database structure*

## 3.2. Tools to Analyze and Visualize Structural Failures - 2019 data

### 3.2.1. Condition Analysis

The visual presentation will allow Port Hope to understand if there are any spatial patterns in their pipe conditions. This analysis requires the visual representation of the PACP code as seen in Figure 31, 32, 33. Conditions have a total of four characters. The first character is a number that represents the most sever issue of the pipe quality, 1 being no major issues, 5 representing large fractures in the pipe (PACP, 2016). The second character represents the frequency of the issues within that section of pipe. The third character represents the second most sever issue of the pipe, and the fourth character resenting the frequency of the issue. A summary statistics tool was conducted on the first value of the PACP codes to determine the overall structural integrity of the system and it can be seen in Figure 33 which results to an average 1.9.

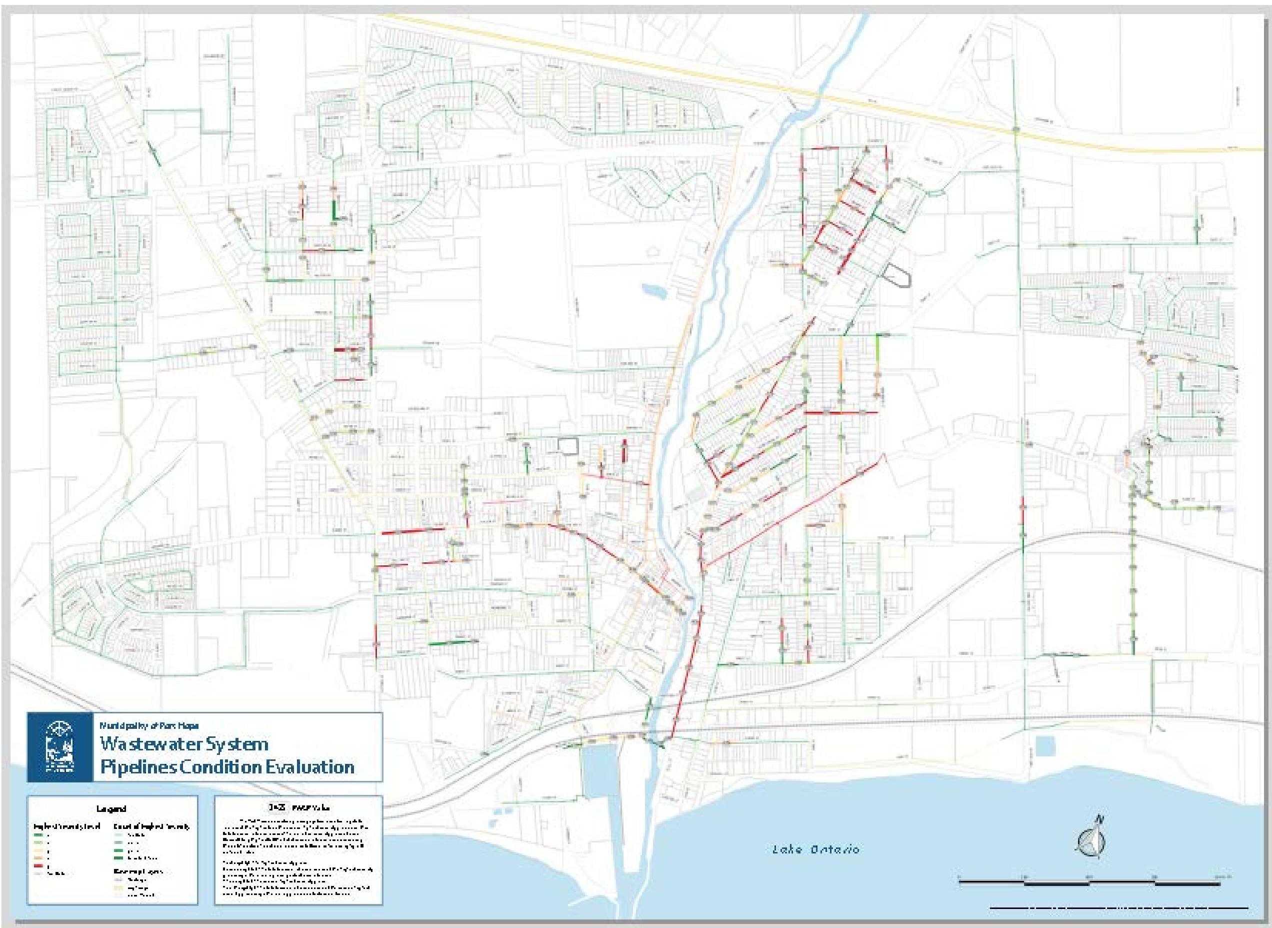



*Figure 31: wastewater system pipeline condition evaluation*

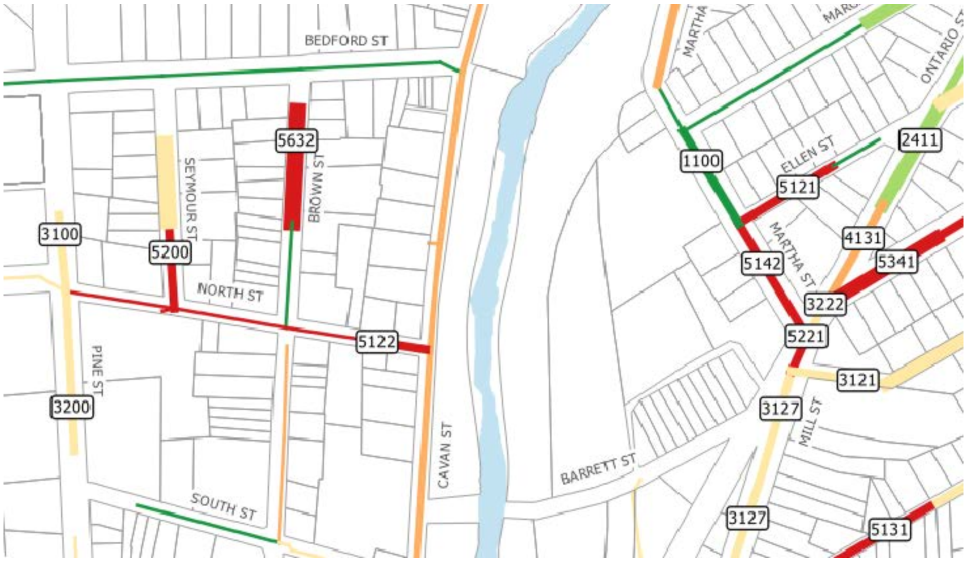



*Figure 32: example of wastewater system pipeline condition evaluation case study*

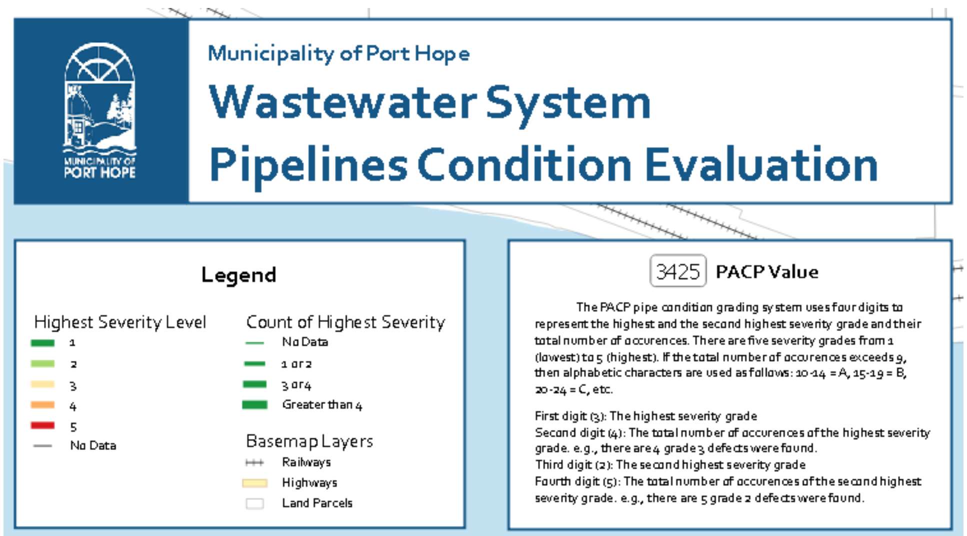



*Figure 33: wastewater system pipeline condition evaluation legend*

### 3.2.2. Slope Analysis

The slope analysis is important to ensure optimal flow of the sanitary system. The pipes with a positive slope are visualized as problem areas which may lead to sewage inefficiencies and backups as seen in Figure 34 and 35. Though the client has recorded a slope value in the feature class, not all were complete. The map features three case studies that show poor slope in the pipe network.

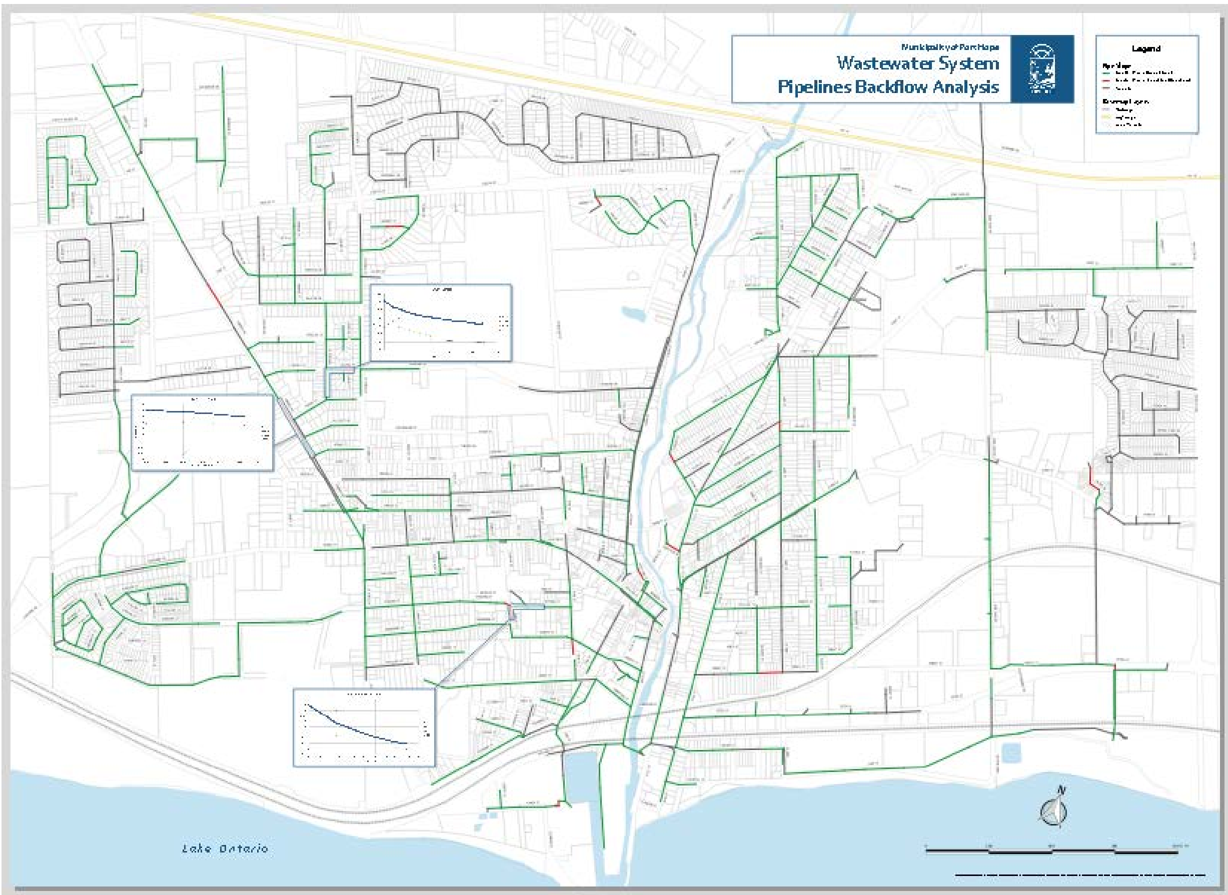



*Figure 34: slope analysis of Port Hope's wastewater treatment*

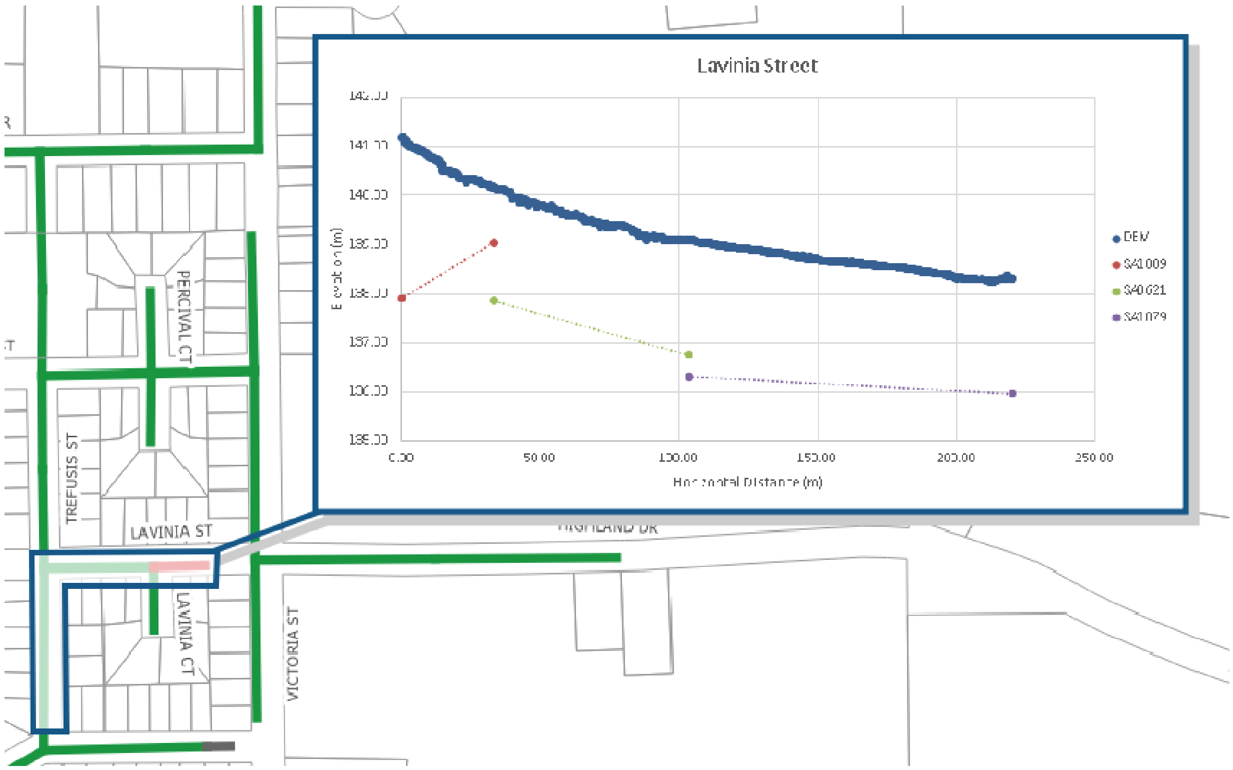



*Figure 35 Case study slope analysis pipeline cross section with respect to the ground elevation (DEM)*

### 3.2.3. Waste Water Generation Analysis

The model allows for the analysis of waste generated in the pipes. This data is visualized in Figure 36 and 37. The basic summary statistic tool provides the sum of the waste generated in the whole pipe network. These statistics calculate that the average daily sum of waste generation is approximately 5 700 000 liters per day = 5 7000 metres cubed/ day as seen in Figure 39.

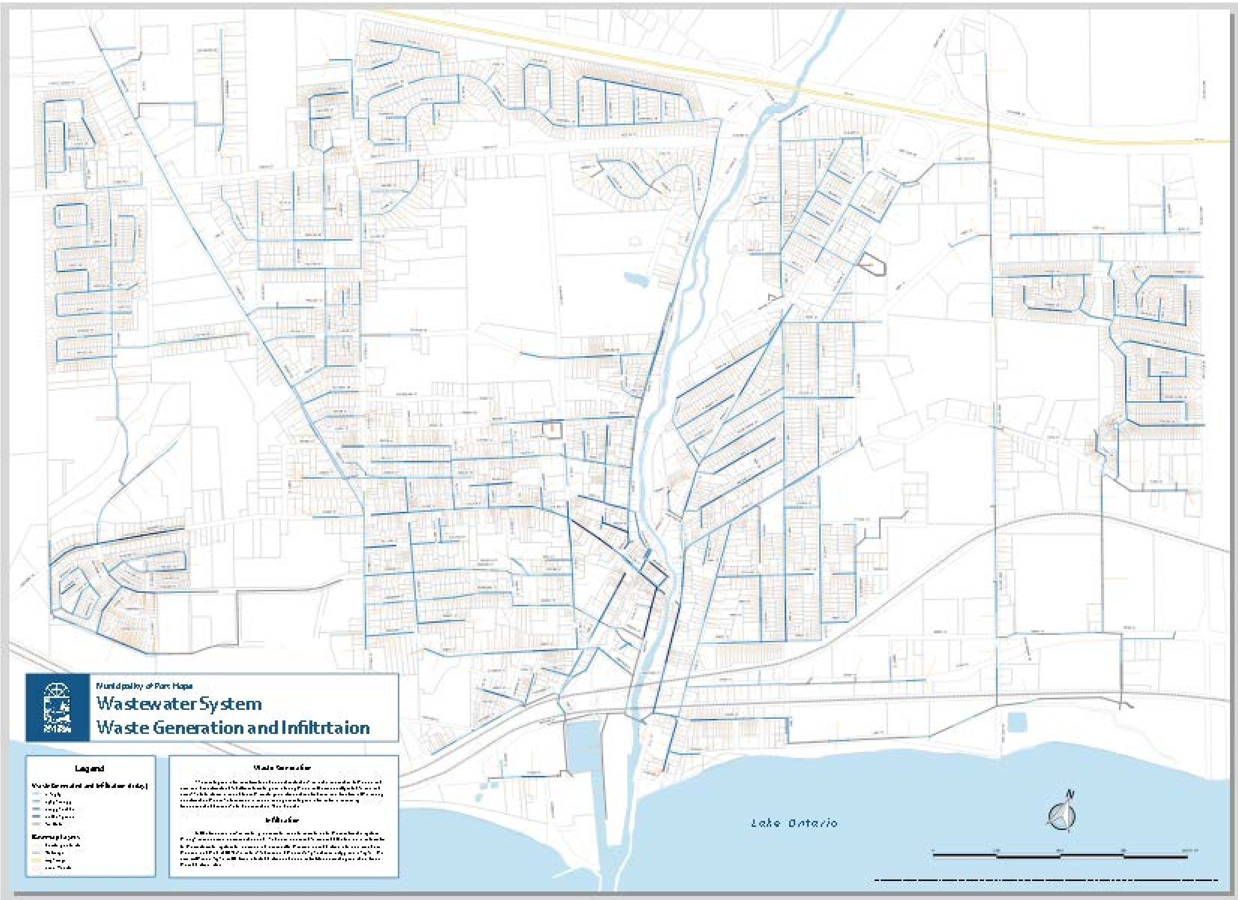



*Figure 36 wastewater generation and infiltration*

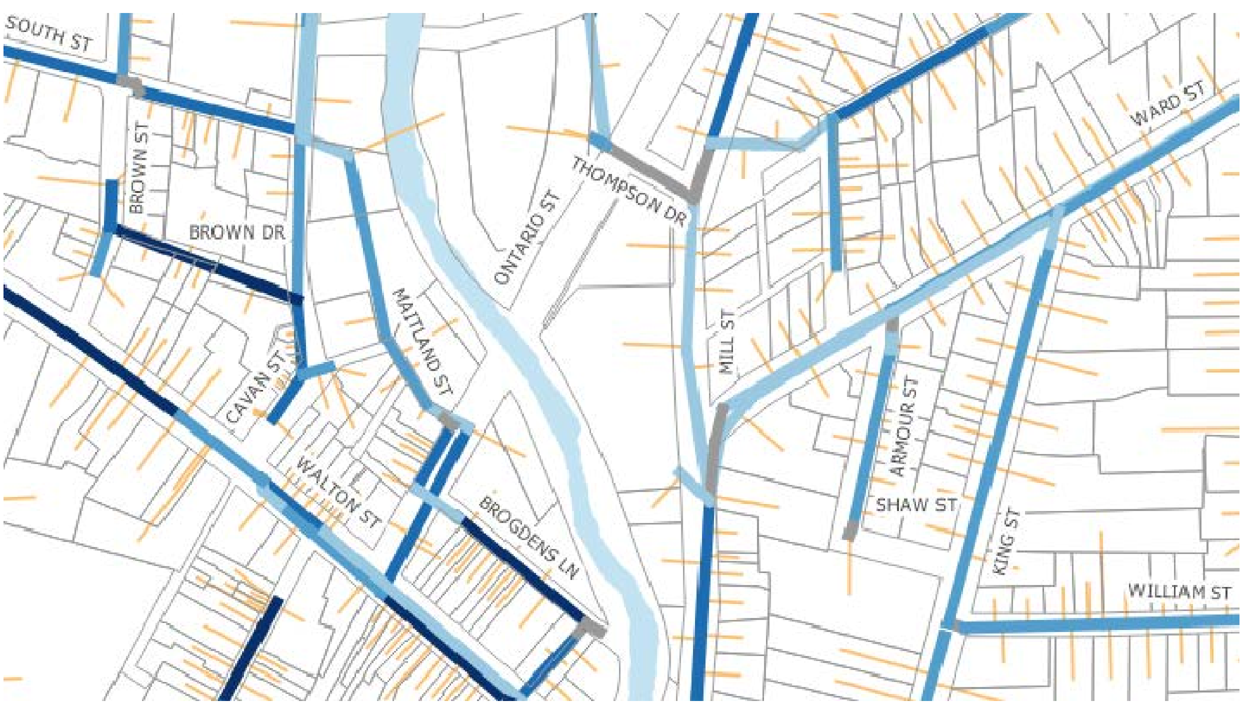


*Figure 37: wastewater generation and infiltration case study*

To verify accuracy of the model estimates, a summary statistic has been generated with our model showing an average of 5.7% Infiltration rate as seen in Figure 38. This is limited by incomplete data and can be improved by infiltration studies.

Analyzed field: Infil_Perc

Count: 1215

Unique values: 5

NULL (missing) values: 14

Minimum value: 0.01

Maximum value: 0.25

Range: 0.24

Sum: 68.66000000000034

Mean value: 0.0565102880658439

Median value: 0.01

Standard deviation: 0.07405594382604405

Coefficient of Variation: 1.3104860435281545

Minority (rarest occurring value): 0.25

Majority (most frequently occurring value): 0.01

First quartile: 0.01

Third quartile: 0.09

Interquartile Range (IQR): 0.08

*Figure 38 summary statistics of infiltration estimates*

Analyzed field: WasteInfil

Count: 997

Unique values: 246

NULL (missing) values: 232

Minimum value: 0.0

Maximum value: 52200.0

Range: 52200.0

Sum: 5677660.050000002

Mean value: 5694.744282848547

Median value: 4125.0

Standard deviation: 4869.777198706581

Coefficient of Variation: 0.8551353593476347

Minority (rarest occurring value): 1258.95

Majority (most frequently occurring value): 1999.8

First quartile: 2475.0

Third quartile: 7612.8

Interquartile Range (IQR): 5137.8

*Figure 39: summary statistics of the total waste generated from all sanitary laterals including infiltration rates (5,000,000 litres per day = 57000 metres^3 per day*

### 3.2.4. Capacity Analysis

The capacity analysis of the sanitary conduit is important to see how much the pipe can hold. With a database trigger, a volume of pipe is calculated to show the container size. The maximum capacity analysis is derived as a function of the X Y Z and is represented in m^3 per second, litres per day, liters per minute. Finally, the pipes are compared to the waste generated as a ratio to determine if the capacity of the pipe has been reached with its immediate lateral servicing. This is visualized in figure 36.

### 3.2.5. Network Capacity Analysis

A network was unable to be created due to QGIS limitations and incompleted data.

## 3.3. Data Collection and Web Application

Figure 40 displays the user interface of the web application on a Windows 10 desktop computer. This application will allow Port Hope to update and collect new data. It is a very easy to manage and easy to use. There are many capabilities accessible to the user within the web application, the functionality Port Hope is predicted to be most useful for Port Hope are outlined in Table 6.

*Table 7: User Tools and Functionality in GIS Cloud*

| Tool | Functionality |
|---|---|
| Search... X GIS Cloud Places | Search GIS Cloud layers or search by location to zoom into the location specified by the user. |
| Layer List | View/ hide the layer list |
| + − | Zoom in/ out of the map |
| i | Info - review attributes and select features for editing |
|  | Zoom to current GPS location |
|  | Open a Google map of the specified location |
|  | View the entire map extent |

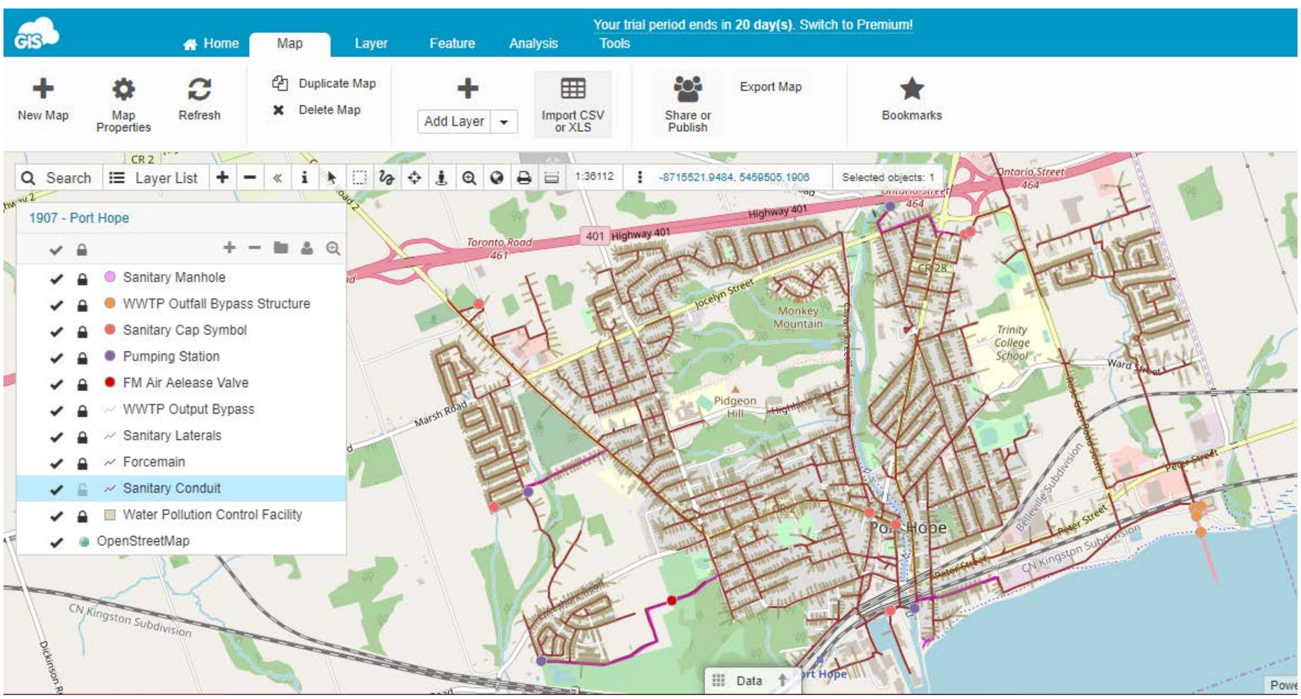



*Figure 40: User Interface on Windows 10 desktop computer*

The **i** icon at the top of the map allows the user to select Sanitary Conduit pipe segments, the attribute menu on the right side of Figure 41 will appear when an item is selected and displays the full list of attributes, when the user selects Edit attributes, the form in the centre of the screen appears and allows the user to view and edit the attribute available for editing.

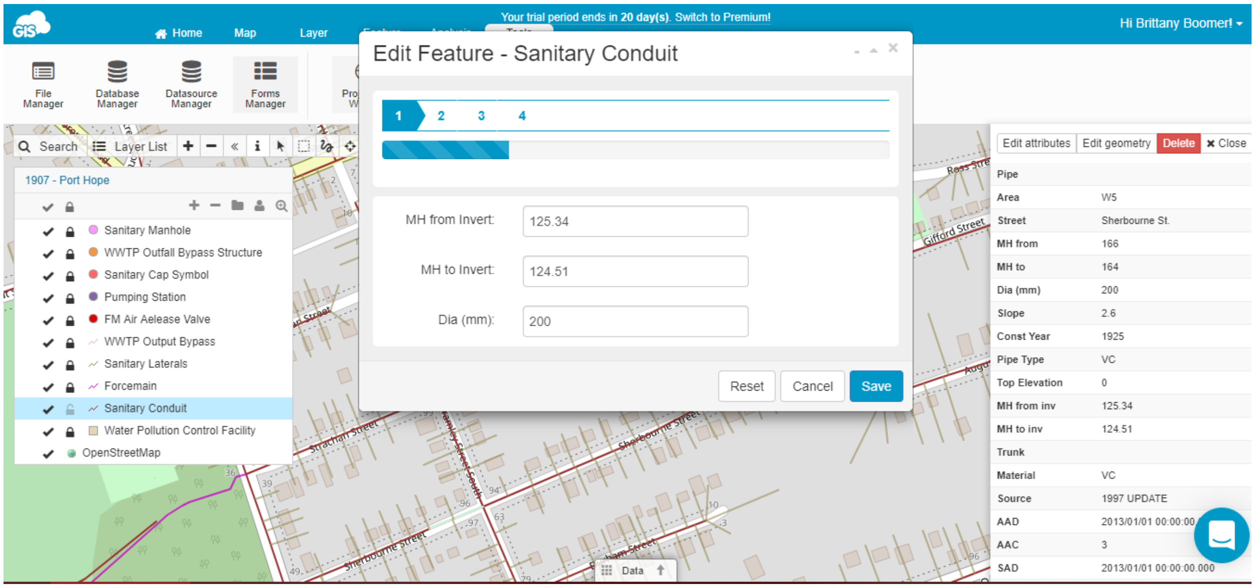



*Figure 41: User interface on Windows 10 desktop computer when editing features*

The fields in which data constraints were implemented, is also reinforced using GIS Cloud. Figure 42 displays the resulting message when the user enters a value outside the constraint place on the field in GIS Cloud notifying the user of an invalid value.


*Figure 42: error message when user attempts to input invalid values*

# 4. Discussion

## 4.1. Benefits

Overall this project will provide Port Hope the means to assess inefficiencies in the wastewater system to accommodate current and future growth. Through the combination of QGIS, PostgreSQL and GIS Cloud, a seamless working environment to view and edit the asset values was developed. Additionally, the interoperability of QGIS will allow for the integration of this project with the internal asset management GIS viewer, CityWorks to allow for further link with their assets. The cartographic output of spatial analysis findings effectively communicates the problematic areas of the wastewater pipe network and may provide insight toward directing assets according to those areas in the network.

Due to missing data, alternative methods were derived to obtain this data in a time and cost-effective manner. Slope values in the sanitary conduit layer were derived as a result of a difference in manhole invert elevations to provide slope values for analysis. This ensured better insight into conditions as well as accuracy in related calculations. The visualization of the pipe slope in Excel shows a more accurate comparison of the pipe to the ground elevations. The sanitary laterals were automatically generated according to parcel data as a time-saving method and estimates of waste generation values were calculated based on zoning, yielded accurate results. Furthermore, each pipe segment has an estimate of waste generated for the whole pipe, which allows to see how much the pipe is being utilized. Infiltration rates were included in the waste generation analysis to account for influence of infiltration that occurs in wastewater pipes.

Although not entirely cost-free, this solution remains extremely cost-effective. PostgreSQL and QGIS being free software, the web application is the only component requiring any cost. Table 7 displays alternative web applications explored and the cost per month. GIS Cloud appears to be the one the lowest cost options behind NextGIS. NextGIS is not recommended as it is in the early stage of the development life cycle. Therefore, GIS Cloud provides the most cost effective and efficient means to collect data for future analysis.

*Table 8: alternative web applications*

| Web Application | Cost |
|---|---|
| GIS Cloud | $55 per month* |
| Mango Maps | $99 per month* |
| QGIS Cloud Pro | 65 Euro per month |
| NextGIS | $10 per month* |

* assumed US currency

## 4.2. Limitations

The main limitation faced during this project was incomplete data. The dataset is missing crucial information for accurate results of the spatial analysis. Where data was not provided alternative methods of obtaining this data were used. For example, infiltration rates were estimates based on a calculation using the PACP1 value. The accuracy of these estimates is unknown against real-world conditions.

Producing the sanitary laterals automatically only provided an estimated location of the sanitary connections. This assumes one sanitary connection per parcel and may not account for parcels with multiple connections or reflect real-world conditions. Furthermore, the model recalculates the slope from the To and From Manhole Elevations which does not account for user input slopes. The slope profiles are not automatically generated and require a spreadsheet graph manipulation to produce the same profile reports. The slope analysis also operates under the assumption that all the pipes are linear and does not consider any dips that may occur in the wastewater network.

The Sanitary Waste generation estimates are based on Canadian National Studies and may not reflect the true waste generated per person in Port Hope. These estimates are calculated as liters per day and may not provide a dynamic model for waste generated at different times of day. These estimates were also calculated as a function of zoning. The generated sums vary when sanitary laterals connect to a manhole. Additionally, pipes intersecting with more than one sanitary conduit will be calculated incorrectly.

Analysis Downstream Capacity Network Analysis

1. The python script was created for ArcGIS and does not adapt to the QGIS environment. A conversion is required if the analysis needs to be completed in QGIS in the future. The logic will be the same, but the code needs to be rewritten for QGIS tools.
2. The analysis method requires a completed dataset. Since the calculation for accumulated waste generation was based on to manhole invert elevation, it is necessary for each conduit to have a to manhole invert elevation value in the attribute table. Also, to enable the pinch point identification, a maximum capacity for each pipe is required. To calculate the maximum capacity, the pipe diameter and slope are essential.
3. The analysis was only designed for a wastewater system which does not have an inverse pipe elevation, because it assumed that wastewater flows all the way downstream. Ranking conduits based on to manhole invert elevation is the key step in the accumulated calculation. However, there might be a way to generate an analysis method which is based on the actual flow direction.
4. The analysis fails to model the situation showed in Figure 43, where four conduits intersect at one point and wastewater flows from the two upstream conduits into the two downstream conduits. Using the current accumulated calculation method, the accumulated waste generation of the two upstream conduits are added to both the two downstream conduits, which doubles the total waste amount in the downstream system. The real situation is that, however, the wastewater flows separately into the two downstream conduits depending on the downstream conduit’s to manhole invert elevation. In the future a better model needs to be built to solve this problem.


*Figure 43: a problem occurs when four conduits intersect*

## 4.3. Recommendations

Due to time constraints on this project there are areas that have the protentional to be improved. There is currently no method of rolling back in the database or history tracking to keep track of previous assets. So, it is recommended they keep backup data as shapefiles in cause of database failures.

As well, there are things the client is recommended to complete to improve the analysis. It is highly recommended that the client has a connecting network and a complete dataset of values required for the analysis. This would include no null values for the PACP values, invert elevation and slope values. Once the dataset is complete, the model can be run to retrieve a more accurate analysis. It is also recommended the client maintains updating the sanitary laterals to create a more accurate dataset, but ensure they are not connected to man holes and should no cross over another sanitary conduit as to ensure the waste generation model is calculated correctly.

It is recommended that Port Hope conduct a study that determines waste generation at the residential, commercial and industrial levels and correct these attributes in the sanitary laterals and re-run the model. It is also recommended that infiltration studies occur to understand the infiltration rates found in the system to have a better representation of real-world conditions and the model should be re-run to obtain better results. Any database changes should not occur in the resulting waste generation model layer but should occur in the working sanitary conduit layer. The resulting output should also not be used for continuous asset management.

Although the final solution is not completely free-of-cost, it is recommended that the client continues the use of all three items within the project; PostgreSQL, QGIS and GIS Cloud. If the client does not wish to pay for a subscription to GIS Cloud, QGIS is compatible with the client tablet devices however, this is not recommended due to its processing power and difficult navigation.

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# 6. Appendices

Appendix 1: Files required for project

| Name | Projection | File Type | Source | Date Acquired |
|---|---|---|---|---|
| SanitaryMaintHole_Compiled | NAD_1983_UTM_Zone_17N | Feature Class | Port Hope | March 27, 2019 |
| SanitaryConduit_CofA | NAD_1983_UTM_Zone_17N | Feature Class | Port Hope | March 27, 2019 |
| SanitaryConduit | NAD_1983_UTM_Zone_17N | Feature Class | Port Hope | March 27, 2019 |
| FM_Air_Release_Valve | NAD_1983_UTM_Zone_17N | Feature Class | Port Hope | March 27, 2019 |
| Forcemain | NAD_1983_UTM_Zone_17N | Feature Class | Port Hope | March 27, 2019 |
| Pumping_Station | NAD_1983_UTM_Zone_17N | Feature Class | Port Hope | March 27, 2019 |
| SanitaryCapSymbol | NAD_1983_UTM_Zone_17N | Feature Class | Port Hope | March 27, 2019 |
| WWTP_Outfall_Bypass_Struct | NAD_1983_UTM_Zone_17N | Feature Class | Port Hope | March 27, 2019 |
| WWTP_Outfall_Bypass | NAD_1983_UTM_Zone_17N | Feature Class | Port Hope | March 27, 2019 |
| CCTV Inspection Excel spreadsheet 2016 | N/A | Excel | Port Hope | February 25, 2019 |
| CCTV Inspection Excel spreadsheet 2019 | N/A | Excel | Port Hope | May 28, 2019 |
| LiDAR | | Point Cloud | MNRF | March 27, 2019 |
| Water_Pollution_Control_Facility | NAD_1983_UTM_Zone_17N | Feature Class | Port Hope | March 27, 2019 |

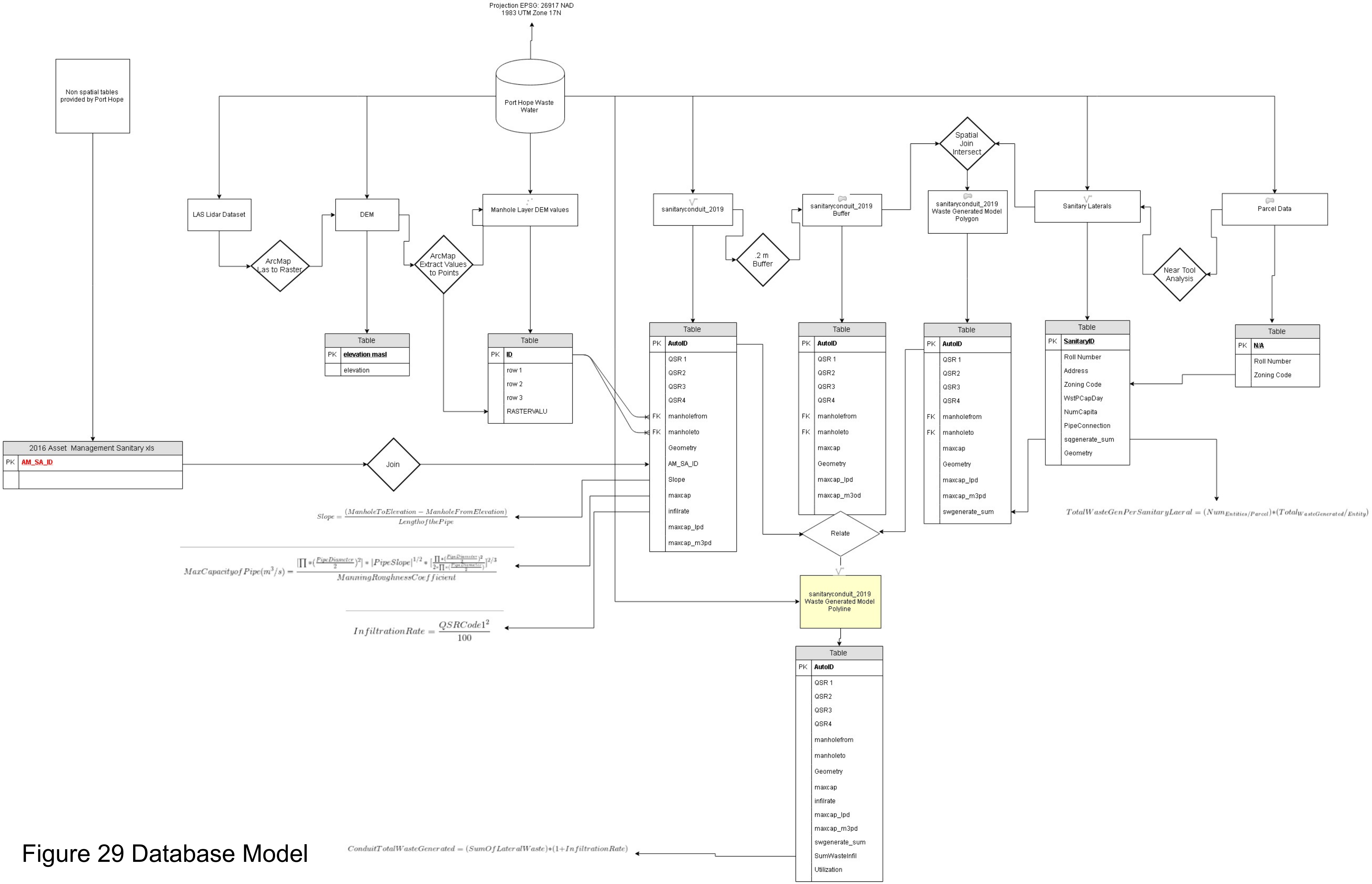


Figure 29 Database Model


Municipality of Port Hope

# Wastewater System Pipelines Condition Evaluation

## Legend

**Highest Severity Level**
- 1
- 2
- 3
- 4
- 5
- No Data
- 3425 PACP Value

**Count of Highest Severity**
- No Data
- 1 or 2
- 3 or 4
- Greater than 4

**Basemap Layers**
- Railways
- Highways
- Land Parcels

## 3425 PACP Value

The PACP pipe condition grading system uses four digits to represent the highest and the second highest severity grade and their total number of occurrences. There are five severity grades from 1 (lowest) to 5 (highest). If the total number of occurrences exceeds 9, then alphabetic characters are used as follows: 10-14 = A, 15-19 = B, 20-24 = C, etc.

First digit (3): The highest severity grade
Second digit (4): The total number of occurrences of the highest severity grade. e.g., there are 4 grade 3 defects were found.
Third digit (2): The second highest severity grade
Fourth digit (5): The total number of occurrences of the second highest severity grade. e.g., there are 5 grade 2 defects were found.

Map designed and created by CARBS GIS Group at Sir Sandford Fleming College in June 2019 using QGIS 3.6.0. Sources: Port Hope: Roads, Land Parcels, Wastewater pipelines/2019; Northumberland County: Highways, Railways, Waterbody/2019.


Municipality of Port Hope
Wastewater System
Pipelines Backflow Analysis
MUNICIPALITY OF PORT HOPE
Legend
Pipe Slope
Smaller than 0 (Good Slope)
Greater than or Equal to 0 (Backflow)
No data
Basemap Layers
Railways
Highways
Land Parcels
Lavinia Street
74 Toronto Road
Thomas Street and Gifford
Lake Ontario
N
0
250
500
750
1000 m
Map designed and created by CARBS GIS Group at Sir Sandford Fleming College in June 2019 using QGIS 3.6.0. Sources: Port Hope: Roads, Land Parcels, Wastewater pipelines/2019; Northumberland County: Highways, Railways, Waterbody/2019.


Municipality of Port Hope

# Wastewater System Waste Generation and Infiltrtaion

## Legend

Waste Generated and Infiltration (L/day)

- 0 - 4363
- 4363 - 10499
- 10499 - 20880
- 20880 - 52200
- No Data

Basemap Layers

- Sanitary Laterals
- Railways
- Highways
- Land Parcels

## Waste Generation

The waste generated is estimated at a parcel scale. Each parcel is connected to the nearest pipe and it is estimated that all wastewater generated by the parcel flows directly into the nearest pipe. The laterals were populated with waste generation estimates taken as a function of the zoning, an estimate of house hold members, and an average waste generated value provided by Government of Canada Water Consumption Report, 2016.

## Infiltration

Infiltration occurs when water, groundwater and stormwater enter the wastewater system through sump pumps, downspouts, and/or holes and cracks in the pipes. Infiltration are problematic to the wastewater system for a number of reasons. On this map, an infiltration rate is derived from the square of the first QSR character. That means, if the pipe's highest severaity grade is higher, the pipe will have a higher infiltrtaion rate. Infiltration values are calculated as waste generation times the infiltration rate.

Map designed and created by CARBS GIS Group at Sir Sandford Fleming College in June 2019 using QGIS 3.6.0. Sources: Port Hope: Roads, Land Parcels, Wastewater pipelines/2019; Northumberland County: Highways, Railways, Waterbody/2019; Government of Canada Water Consumption Report: Waste Generation Calculation/2016.