DEVELOPMENT OF A GUIDELINE FOR INTEGRATING MUNICIPAL INFRASTRUCTURE ASSET MANAGEMENT WITH WASTEWATER ENERGY RECOVERY SYSTEMS

by

Oloun Polda

Bachelor of Environmental Studies, University of Waterloo, 2013

A thesis presented to Ryerson University

in partial fulfillment of the requirements for the degree of

Master of Applied Science

in the program of

Environmental Applied Science and Management

Toronto, Ontario, Canada, 2020

AUTHOR'S DECLARATION FOR ELECTRONIC SUBMISSION OF A THESIS

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

I authorize Ryerson University to lend this thesis to other institutions or individuals for the purpose of scholarly research.

I further authorize Ryerson University to reproduce this thesis by photocopying or by other means, in total or in part, at the request of other institutions or individuals for the purpose of scholarly research.

I understand that my thesis may be made electronically available to the public.

Development of a guideline for integrating municipal infrastructure asset management with wastewater energy recovery systems

Oloun Polda
Master of Applied Science
Environmental Applied Science and Management
Ryerson University
2020

ABSTRACT

Wastewater energy recovery systems (WWERS) cycle residual heat from sewers back into a space for temperature conditioning. Using recovered energy instead of fossil fuels is a sensible direction towards a circular economy. Existing literature, while rich in technical considerations, does not analyze the decision-making process related to the wastewater infrastructure changes. Therefore, the purpose of this research was to bridge this gap in the literature through the development of a planning guideline, targeted to municipal owners of wastewater infrastructure. The proposed planning guideline was then applied to the Regional Municipality of York, a two-tier municipality in Ontario, Canada as a case study. The case study demonstrated the efficacy of the guideline, using publicly available municipal data to discern feasibility of centralized WWERS. Results may aid municipalities or WWERS proponents in advancing to a more widespread use, as an effective first step in bridging academic literature with often-stated municipal goals of increased sustainability of infrastructure systems.

ACKNOWLEDGMENTS

I would first like to thank my thesis advisor Dr. Darko Joksimovic of the Faculty of Civil Engineering at Ryerson University. He consistently allowed this paper to be my own work but steered me in the right the direction whenever he thought I needed it.

A big thank you to my advisory committee for providing guidance and enthusiasm about my work. Dr. Arnold Yuan and Dr. Dan MacGillivray I am gratefully indebted to them for the very valuable comments on this thesis.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1 INTRODUCTION

At the centre of the earth's climate crisis is energy production; mankind's largest category of release of greenhouse gases (GHGs) to the atmosphere (Hook & Tang, 2013). Nurtured in the seemingly vast natural abundance of earth, human development took its course, catalysed by energy rich fossil fuels. Not until the finite nature of oil reserves became apparent did society realize the impending energy crisis. The urgency to address this is exasperated by the negative environmental effects of combusting fossil fuels; GHGs throw the planet's usual heat balance off course, making flooding and other extreme weather events more common.

At the same time, fossil fuel-based energy production is a common national indicator of economic growth (Ameyawa, et al, 2019). For human development to become sustainable, energy scarcity must be addressed through increased use of sustainable energy sources (Elías-Maxil, et al, 2014). One nation with a particularly challenging road to GHG emissions reduction is Canada. The production of fossil fuels such as crude oil, natural gas and coal are wealth indicators in Canada, with both their export and distribution to local customers contended to be essential to maintaining standard of living for its residents (Statistics Canada, 2019). The nature of Canada's finite oil reserves as well as the by-products of their combustion is an item national leaders struggle with. Literature examines several energy efficiency shifts made by European nations, attributing success to the economic shift of replacing one energy source with a more efficient one (Ameyawa, et al, 2019), while making increased use of sustainable energy sources and capturing and reusing wasted energy.

Data analysis of commercial and residential sectors have shown that half of greenhouse gas emission are produced in residential sector, mostly in residential buildings (Durdevica, Balic, & Frankovic, 2019). Space heating and cooling, as well as domestic hot water preparation, represent the largest share in households' energy consumption (Durdevica, Balic, & Frankovic, 2019). Buildings energy demands take up to 2/3 of total electrical energy consumption, which produces 1/3 of total greenhouse gas emissions (Durdevica, Balic, & Frankovic, 2019). Natural gas is abundant in Canada and primarily used to warm spaces and water, and to produce a flame for gas-stove tops (Natural Resources Canada, 2015). Natural gas is combusted in a furnace, releasing energy for use as well as carbon dioxide and water (Natural Resources Canada, 2015). Most residential and commercial and institutional energy consumption is related to space heating and cooling, the biggest share of energy uses in homes (Statistics Canada, 2019). Canadian households consume approximately 1.3 million terajoules of energy in their homes annually (Statistics Canada, 2019). Fifty-one percent (663,000 terajoules) of this is attributed to natural gas (Statistics Canada, 2019), having the Carbon Dioxide equivalent (CO2e) of 33,326 Metric tons, or the emissions of 7,706 vehicles driven for one year (USEPA, 2018).

One promising alternative energy source that is often overlooked is wastewater. It is estimated that over 330 billion litres of wastewater are discharged globally through the sewer systems each day from sources like showers, dish washers, taps, laundry (SHARC Energy Systems, 2019). This wastewater has high heat content, and if harnessed has the potential to replace 1.5 billion MWh of the natural gas consumption used to provide space heating and domestic hot water every year (SHARC Energy Systems, 2019, p. 1). Given the nature of the energy and climate crisis, urban environments can't afford to waste this energy.

Wastewater energy recovery systems (WWERS) use heat exchangers and heat pumps to harness the thermal energy in wastewater. Typical WWERS consist of a heat exchanger and a heat pump. The heat exchanger uses a relatively small amount of electrical energy to raise the temperature of the working fluid, before the heat pump distributes the heat for utilization

(Culhaa, et al, 2015). Significant amounts of heat can be sustainably recovered from wastewater at economies of scale (Kollmann, et al., 2017). Despite this, these systems are not common installations in sanitary and combined sewers; instances of successful implementation are dominated by a few European nations.

While literature is rich in technical considerations for WWERS, it does not analyse the decision-making process relating to the wastewater infrastructure changes. The need to bridge the gap between the promising technical literature of WWERS and practical implementation becomes apparent as wastewater infrastructure is often in the hands of public entities, such as municipalities.

Overall, literature lacks standard terminology or design, varying with jurisdiction. This creates challenges when discerning what is applicable to any municipality. It also creates challenges with dissemination, as public infrastructure decision making is often guided by elected officials and public opinion. Additionally, scholars have examined the technical considerations and benefits of WWERS; however, their practical implementation, or lack thereof, has been largely overlooked in the literature. This makes it challenging for proponents or municipal bodies to consider these systems, as existing research has not yet examined public policy and decision making in the context of WWERS implementation. The importance of standardization becomes clear, as it filters out information based on a set of expert agreed indicators, reducing the need for feasibility research.

This was the identified gap that guided this research. It was hypothesized that if a bridge was made between policy and technical considerations, barriers to WWERS implementation would be lessened.

The purpose of this research is to contribute to a better understanding of the barriers to implementing WWERS. This is done by providing an overview of the current state of WWERS as well as an analysis of the delivery of wastewater infrastructure. The complexity of public infrastructure is examined, with a notion that the government structure is a barrier. Based on this, a root cause analysis is carried out, focusing on the roles that public opinion, bureaucracy, funding and politics play into the resulting projects that are delivered. Finally, the rectification of the impediments is suggested through a planning guideline, as existing literature does not publish results for consumption by municipalities/government policy makers. The planning guideline is then applied to the Regional Municipality of York, Ontario as a case study.

The specific objectives of this research are:

i) Identify WWERS barriers
ii) Address barriers through development of a WWERS planning guideline
iii) Demonstrate the developed guideline on the case study

This report will first provide an overview of the function and considerations of WWERS, focusing on where they have been successfully implemented, technical considerations and ways to measure the system performance. This is followed by reviewing the municipal processes and their potential shortcomings/barriers with respect to WWERS implementation. The report then explains the methodologies used to develop the guideline for addressing barriers. Finally, the developed guideline is demonstrated through application on to the case study in Ontario, Canada, followed by the analysis and discussion of results and overall conclusions of the study.

Chapter 2 WASTEWATER ENERGY RECOVERY SYSTEMS – LITERATURE REVIEW

To provide a foundation for this study, a literature review was conducted on wastewater energy recovery systems. The overall aim of the literature review was to provide a better understanding of technical and implementation features of WWERS: how they work, how much energy can be recovered and examples of existing facilities.

The literature helps frame the research narrative by understanding components found in cases of successful implementation; design considerations needed for implementation and the methods used to quantify energy recovery potential, providing the basis for the methodology used to address WWERS bariers.

2.1 Technical Overview of WWERS

Wastewater is a valuable thermal energy source that can be recovered and reused for households cooling and heating purposes (Durdevica, Balic, & Frankovic, 2019). The wastewater discharged into municipal collection systems contains high heat content. Cipolla and Maglionico, (2014) showed that wastewater temperature in Bologna, Italy can vary from 13.5 °C in winter period, to 20.9 °C in summer period. Research in colder climates shows that the wastewater temperature is similar. For example, in Ontario, Canada, hourly averages of wastewater temperature in the month of January – a cold winter month - ranges from 15 to 25 °C.

The most prominent and commercially successful facilities found in the literature are summarized in Table 1, based on analysis by Bush and Shiskowski (2008). The table provides a high-level summary of the wastewater energy recovery systems, as well as their outputs. In Canada, the largest system was successfully implemented in Whistler, British Columbia, as part of the design of the Winter Olympic infrastructure.

Table 2: Summary of existing WWERS

Location	Raw/effluent?	Screening	Extraction	Application
Whistler, BC Olympic village	Effluent	N/A	Parallel flow plate heat exchangers extract heat from effluent produced by the Whistler wastewater treatment facility.	11,000 MWh/yr to residential users. Supplemented with natural gas as needed
Vancouver, BC: Southeast False Creek	Raw wastewater	2 mm traveling screens, with screened solids returned to the effluent downstream of the heat exchanger	Shell and tube heat exchanger (brushes installed and reverse flushing to reduce clogging)	46,008 MWh/yr
Goteborg, Sweden: Göteborg Energi treatment plant	Effluent	N/A	Effluent is treated and pumped to nearby heat plant	150 GWh/yr of energy, 5% of total heating requirement of the DHS
Stockholm, Sweden: Fortum Energi facility	Effluent	N/A	Effluent is treated and pumped heat pump facility	250 MWh/yr, providing heating for 95,000 two bedroom apartments
Basel, Switzerland	Raw wastewater	Screening not used	Heat exchangers installed directly in sewer collection pipes	2.4 GWh/yr to the DHS of 300 apartments
Oslo, Norway: Skøyen Heat Pump Plant	Raw wastewater	Raw sewage screen prior to entering heat exchanger for extraction of energy	Shell and tube heat exchanger (Hourly changes in the flow direction of the raw sewage through the evaporator to reduce clogging)	85 GWh to the DHS for heating of 9,000 apartments. Supplemented with fuel oil, electricity and natural gas as needed

District heating is an interconnected arrangement of space heating, supplied by one central source (Fortum, 2019). Sweden has the largest national capacity of heat pumps in a district heating system (DHS) in the world, after the interest in heat pump technology use for heating increased in the 1980s (Averfalk, et al, 2017). Long-running plants in Stockholm and Goteborg plants are two of the largest heat pumps still in use in Sweden today (Averfalk, et al, 2017). The plants collect treated wastewater flowing out of a treatment plant (effluent) and distribute the thermal energy via a district heating system (DHS). The more common alternative for space heating, dominant in Canada, is individual supply of natural gas to homes and the use of space-heating furnaces.

2.2 Centralized or decentralized heat recovery

Several challenges exist in the design of WWERS relating to the interconnected nature of the wastewater infrastructure. An important consideration for heat recovery from wastewater is determining where in the collection system to install the heat exchangers (Hofman, et al., 2014). Bush and Shiskowski (2008) identified the challenge associated with locating the energy input (wastewater) with the output (electrical energy to user). Locations determine feasibility, appropriate technology and the application. The proximity of the recovery facility (input) to the sustainable energy user (application)is an important factor in determining the WWERS feasibility, however, locating a facility near the energy-users introduces the need to collect and screen raw wastewater (Bush & Shiskowski, 2008).

The heat content of wastewater can be recovered within houses (small scale applications), from the sewer (medium scale applications), or at wastewater treatment plants (large scale applications) (Cipolla & Maglionico, 2014). Common terminoilogy in the literature categorizes these considerations as centralized or decentralized. Recovery may be decentralized (heat is collected at the individual source) or centralized (combined wastewater from numerous sources throughout the wastewater system) (Sitzenfrei, et al, 2017). For example, wastewater heat can be recovered in showers/bathrooms, at a building block level (e.g. warm water tanks collecting all grey water), in sewers, or at the wastewater treatment plant (Sitzenfrei, et al, 2017). Figure 1 shows the options for locating WWERS (Culhaa, et al, 2015). Energy that is centralized or decentralized each have advantages and disadvantages (Culhaa, et al, 2015).

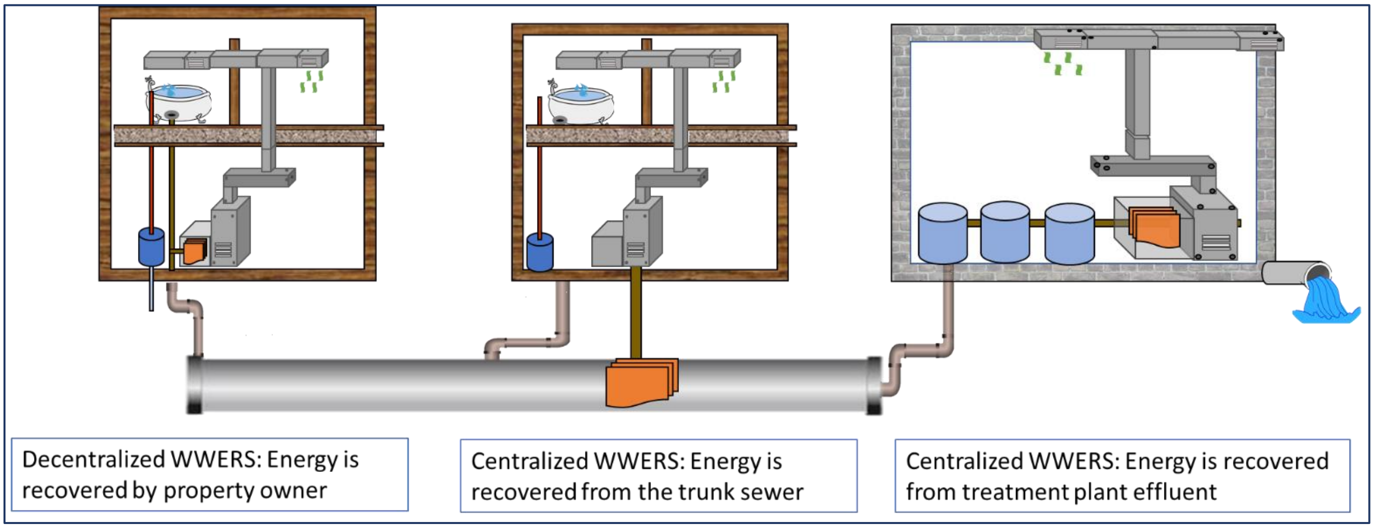


Figure 1: Locating WWERS (adapted from Culhaa, et al, 2015)

Centralized systems mean that a central collection point is recovering heat from multiple users. The benefit of collecting large amounts of heat from a widely distributed source is that it can serve a large geographic area with heat energy (Ichinose & Kawahara, 2017). Sewerage networks in urban municipalities are large and contain relatively low heat content, however this heat can still be recovered and distributed, if heat demand and heat recovery and use of recovered heat were aligned (Ichinose & Kawahara, 2017). However, as Sitzenfrei et al. (2017) noted, a centralized system requires access to publicly owned sewer systems, managed by a government body like a municipality.

In centralized systems, Ichinose and Kawahara (2017) determined that feasible locations for WWERS are where both the heat content of the sewage and the heat demand is high. This is because the recovered heat must be captured and used within a practical distance for use (Ichinose & Kawahara, 2017). Additionally, installing heat pumps in existing locations requires long lengths of sewage pipes, as longer pipes allow for more heat pumps (Ichinose & Kawahara, 2017). Pipe length then becomes an additional constraint when determining favourable heat pump locations (Ichinose & Kawahara, 2017). Evaluating this relationship between raw sewage heat content and heat demand lead the authors to find existing areas that have large amounts of recoverable heat, that also had long sewer lines (Ichinose & Kawahara, 2017).

Heat can be recovered from either effluent or raw wastewater (Bush & Shiskowski, 2008). Raw wastewater is generally ubiquitous, as most buildings and residences produce it (Kordana, 2017). Another advantage of heat recovery from raw wastewater is the ability to recover heat close to the source and feeding it back into the same building (Kordana, 2017). Challenges of recovering heat from raw wastewater exist largely in the form of temperature and flow inconsistencies throughout the year, which impacts how much heat can be recovered (Kordana, 2017). Other concerns include the prevalence of pollutants in raw wastewater, which may deposit on the surface of the heat exchangers, impacting their efficiency (Kordana, 2017). Heat exchangers would need to be installed in accessible areas in order to be cleaned; this poses challenges for systems located within sewers (Kordana, 2017). Further down the line, trunk sewers, which collect and transport raw wastewater, have large amounts of fast flowing, high temperature wastewater (Kordana, 2017). While there are more challenges in the operation and maintenance of raw wastewater energy recovery systems, relative to effluent applications, continued technology development will likely mitigate these challenges to some extent in the future (Bush & Shiskowski, 2008).

Effluent is the treated wastewater flowing out of a treatment plant (Kordana, 2017). Effluent is lower in temperature than raw wastewater, however this temperature is consistent, as it is not impacted by seasonal variations in temperature and flow that raw wastewater is (Kordana, 2017). Effluent also has significantly lower concentration of contaminants, reducing the pollutant deposition issue of raw wastewater (Kordana, 2017). Additionally, heat recovery from effluent results in a lower discharge temperature to receiving waters (Kordana, 2017). Disadvantages of effluent heat recovery systems are largely due to a transport issue, as treatment plants are typically remote from the potential user of the heat (Bush & Shiskowski, 2008). Treatment facilities are feasible to arrange only if heat exchangers can be installed to recover and use the thermal energy for heating of *nearby* neighbourhoods or office buildings (Frijns, et al, 2013). Additionally, most treatment plants have short outfall pipes, leaving limited areas for heat exchangers to be installed (Kordana, 2017).

2.2.1 Temperature and flow

The average temperature of wastewater (20-30 degrees Celsius) makes it ideal for use with heat pumps (Chang, et al, 2017). However, wastewater temperature is highly dynamic, and directly related to user consumption patterns, which dictate temperature and flow (Hofman, et al, 2014). Temperature of the wastewater is relatively high close to homes; however, the wastewater flow volume is low and constantly changes (Hofman, et al, 2014). Going further downstream the sewer system, flow is higher and more continuous; however, heat is lost in the transport process to the air and soil (Hofman, et al, 2014).

Another important but related consideration for heat transfer is temporary storage of heat in the pipe wall and exchange of heat between wastewater and the pipe wall (Durrenmatt & Wanner, 2014). In their study, Durrenmatt & Wanner (2014) recommend the installation of a heat exchanger at the bottom of the sewer pipe . Alternatively, wastewater can be pumped through a heat exchanger installed outside the sewer (Durrenmatt & Wanner, 2014).

2.3 System components

The main elements of the system are the heat exchanger and the heat pump (Cipolla & Maglionico, 2014). The heat pump is an energy efficient and environment-friendly apparatus for heating and cooling of built environment. In the past two decades, the wastewater source heat pump has become increasingly popular due to its advantages of energy-saving and environmental protection (Cipolla & Maglionico, 2014).

Heat exchangers have historically played an important role in reducing energy consumption and recovering energy in industrial processes (Shah, et al, 2000). Air source heat pumps for space heating have been studied by researchers and promoted by enthusiasts for decades (S.Ertesvåg, 2011). Heat exchangers are the components of a heat pump that facilitate the heat exchange between two fluids without mixing and exposing them to a direct contact (Culhaa, et al, 2015, p.217). Heat exchangers allow for the utilization of waste heat to reduce energy requirements, and energy to be exchanged between processes (Shah, et al, 2000, p. 632). The heat exchanger raises the temperature of the working fluid before releasing its heat for utilization (Culhaa, et al, 2015).

Figure 2 outlines the basic components of a WWERS, based on the HUBER ThermWin technology, which includes the added component of a wastewater screen (Noventa Energy Partners, 2019).

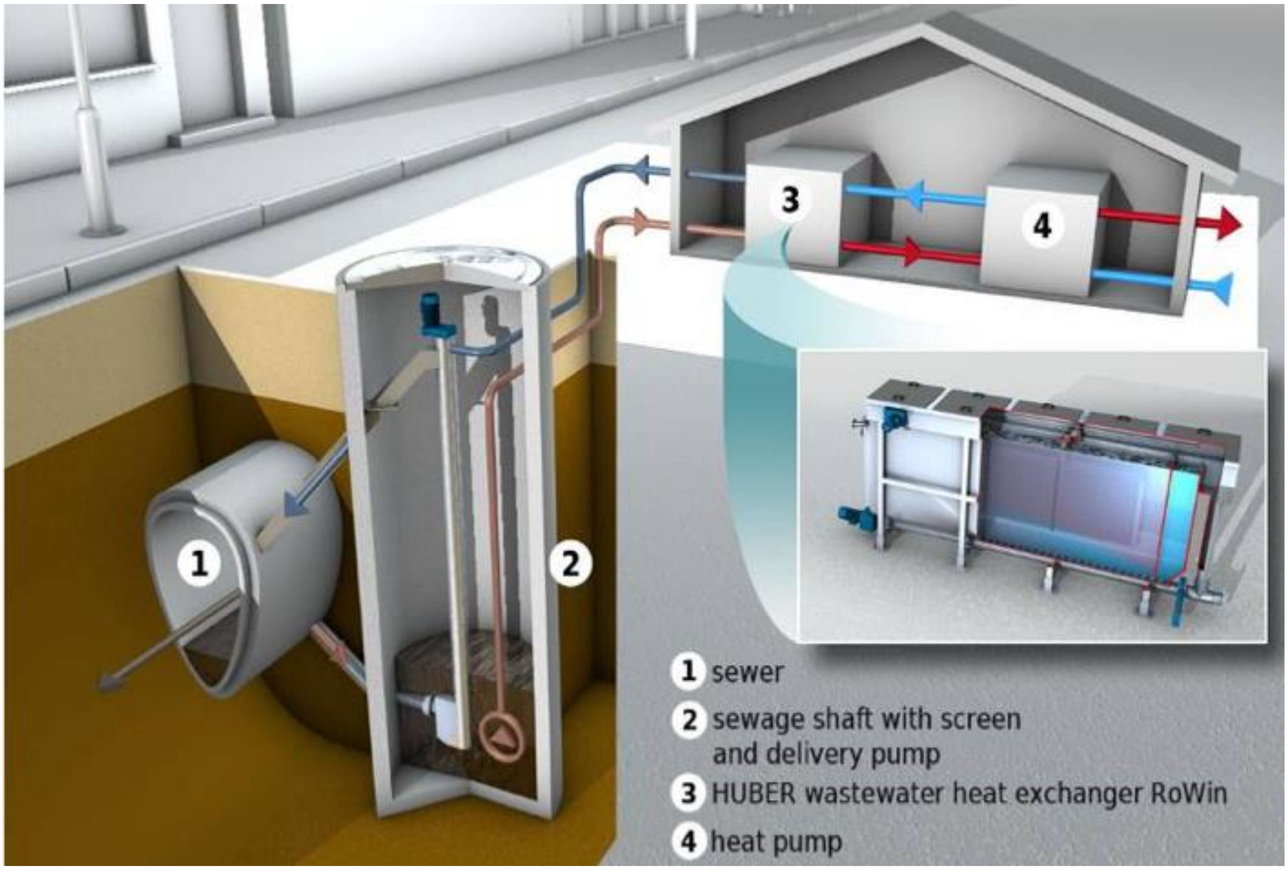


Figure 2: Components of a WWERS (Noventa Energy Partners, 2019)

The wastewater collector uses screens and filters to remove solids (Sohail, et al, 2019) to prevent formation of a biofilm on the stainless-steel plates in the plate heat exchangers (Chang, et al, 2017). This is represented by item “2” in Figure2. Due to the nature of wastewater, fouling and clogging are often cited as challenges in heat recovery (Müller-Steinhagen, et al, 2011).

Today, innovations in heat exchanger and heat pump technology continue to emerge, and manufacturers are under increasing pressure to produce products that are more efficient in heat recovery and use of inputs, while also being faced with fluids that are increasingly difficult to process (Müller-Steinhagen et al, 2011).

2.4 Measuring WWERS

Important considerations in the design and measurement of WWERS include: the flow rate and the temperature of wastewater, the temperature difference of the wastewater upstream and downstream from heat exchanger, the geometry of the pipe and of the heat exchanger, the viscosity of the wastewater, the velocity of the fluids in the heat exchanger, the fouling resistance caused by the formation of biofilm, the heat exchange coefficient and the heat transfer surface (Cipolla & Maglionico, 2014).

Alnahhala and Spremberg (2016) have shown that is it possible to recover up to 30% of thermal energy from wastewater, through implementation of appropriate combination of heat pumps and heat exchangers. Equation 1 provided the average acquired thermal power from wastewater:

$Q_F = \nabla T_m * c_w * \rho_w * V_f$ Equation 1

Where:

Q_F = thermal power (kW)
ΔT_m = temperature drop (K or °C)
$c_w =$ specific heat capacity (kJ/kg K)
ρ_w= density (kg/l)
$V_{f=}$ flow rate (l/s)

The wastewater flow rate was measured and analysed to be 1.23 l/s. The water enters the heat exchanger at a temperature of 14.68 C and will come out at a temperature of 9 C. Specific heat capacity was set at 4.186 (kJ/kg K) and density at 1 kg/l. Based on these variables, the average acquired thermal power from wastewater is about 30.21 kWh/h (Alnahhal & Spremberg, 2016).

The Coefficient of performance (COP) was recommended to be set at 4. COP is a measure of the power transferred from the heat pump for use, and the external work supplied to the heat pump by electricity. In their example, Alnahhal and Spremberg (2016) estimated this to be 10 kWh/h based on a COP of 4. Therefore, the recovered thermal power in-house wastewater will reach 40.21 kWh/h.

Considering the energy cost of 0.25 €/kWh in Berlin, the cost of recovered thermal power could be about 10 €/h, which equals to 230 €/day (Alnahhal & Spremberg, 2016). Therefore, the in-house wastewater energy recovery can contribute significantly to a reduction of hot water provision up to 30% by suitably adopting the heat exchanger and heat pump in a combined system (Alnahhal & Spremberg, 2016).

Bertrand et al (2017) conducted an analysis of costs of a decentralized, in-house heat exchanger used for recovery from showers, shown in Table 2. With the implementation of a horizontal shower heat exchanger, the total electricity consumption related to heating can be reduced between 6 and 14% according to the building type; single family building would save 191 kWh/a, while 772 kWh/a would be avoided in the multifamily building (Bertrand, Aggoune, & Maréchal, 2017).

Component (–)	Unitary price, excluding VAT (€)
Prefilter	330
Heat exchanger	45 €/kW
3 way valve	200
Sensor	70
Piping	50
Installation costs	200

Table 3: Cost breakdown of WWERS, Source: Bertrand et al (2017)

2.4.1 Coefficient of performance

A basic indicator of heat pump work is coefficient of performance (COP) factor (Durdevica, Balic, & Frankovic, 2019). It represents a ratio of produced useful high-temperature thermal energy and used electrical energy to power the heat pump (Durdevica, Balic, & Frankovic, 2019). COP factor mostly depends on temperature regimes; the lower the difference between heat sink and heat source, the higher the COP factor and vice versa (Durdevica, Balic, & Frankovic, 2019, p. 210). Heat pump performance is typically measured by the ratio of useful heat delivery to the electricity (or mechanical work) input, known as the coefficient of performance (COP) (S.Ertesvåg, 2011). This ratio varies with the energy source temperature and the temperature of the delivery (S.Ertesvåg, 2011). The value of the COP increases when the temperature difference between the two sources (wastewater and heat transfer fluid) decreases; if the temperature of the wastewater is about 10 °C, the COP ranges from 3.25 to 3.5; if the temperature increases also the value of the COP increases, in particular the value of the COP increases of about 0.3 every +2 °C (Cipolla & Maglionico, 2014).

Independently of the type of technology used, in order to correctly design these equipment, it is essential to have reliable information on wastewater flows and its temperatures, as these parameters will obviously affect the performance of the system and the related costs (Cipolla & Maglionico, 2014).

2.4.2 Energy Analysis

Quantifying energy demand throughout the wastewater distribution system becomes an important aspect of determining feasibility (Abdel-Aal, et al., 2018). WWERS need to integrate energy efficiency, carbon footprint accounting and other problems related to water quality in their operation (Durdevica, Balic, & Frankovic, 2019).

In order to determine heat source capacity, Durdevica et al (2019) determined temperature difference of wastewater at intake and outlet of heat pump heat exchanger. They set the temperature difference of wastewater to 6 °C, i.e. temperature level of wastewater will be decreased by 6 °C after it leaves heat pump unit. Available heat source capacity of wastewater was determined Equation 2:

$\phi = q_m * c * \Delta\vartheta$ Equation 2

where q_m q_m represents mass flow of wastewater, c the specific heat capacity of wastewater and $\Delta\vartheta$ Δv the temperature difference of wastewater after heat pump unit (Durdevica, Balic, & Frankovic, 2019). Theoretical calculations presented by Durdevica et al (2019) have shown that wastewater heat could be considered as a feasible solution to cover a significant share (75.24 MWt) of heat generation capacity in their case study city of Rijeka, Croatia (104 MWt), through district heating system.

One of the greatest challenges with efficient sewage heat recovery is being able to recover heat close to the points of demand, or end uses (Abdel-Aal, et al., 2018). The Sewer System Simulation Model (SSSM) outlines data collection requirements to calculate heat demand, calculate the sewage flow rate at sewerage line nodes, and calculate the amount of recoverable sewage heat at the nodes and surrounding grid cells (Ichinose & Kawahara, 2017). Based on an overlap of GIS data, sewage heat content and high heat demand, it was determined that ideal locations for heat recovery systems in sewerage systems is where both the heat content of the sewage and the heat demand is high, as the demand speaks to use of the recovered heat (Ichinose & Kawahara, 2017

When looking to implement energy reducing systems, such as WWERS, an energy analysis can help quantify returns (Fung et al, 2015). Energy audits are conducted to simulate building energy, which can be used to determine potential energy savings (Fung, et al, 2015). An energy audit is already an essential component of the energy management of buildings (Fung, et al, 2015). The PRISM® (Princeton Scorekeeping Method) is a standardized tool for estimating energy savings from billing data (Fung, et al, 2015), that has been widely used in energy modelling. Several commonly available inputs, such as monthly billing data, daily temperature data and long term degree days can be used to create an input data file, which determines base case heating and cooling demand (Fung, et al, 2015). Electricity billing data is used to determine cooling loads, and natural gas billing data is used to determine heating loads (Fung, et al, 2015). Maximum space heating loads are useful in determining seasonal demand variations (Fung, et al, 2015), which can be used to calculate energy offsets and financial returns.

2.4.3 Effects on the surrounding environment

It is important to understand the interactions of decentralized and centralized recovery systems, as they can produce downstream affects relating to the capture of heat upstream (Sitzenfrei, et al, 2017). If heat is extracted from sewage, water is eventually discharged at a cooler temperature, although the difference can be negligible (Cecconet et al, 2020).

One impact downstream of heat recovery of wastewater is relating to the nutrient rich nature of wastewater. Wastewater has high bacterial concentration and a nutrient rich environment, causing biofilms to form on components of the system, impeding function (Chang et al, 2017). Biofilms are a complex community of microbes, encased in the extracellular polymeric substance or the EPS, posing challenges for heat-exchanging systems (Chang, et al, 2017). Formation of biofilm is estimated to decrease system coefficient of performance by 50%, (Chang, et al, 2017), leading to additional costs and an estimated 2.5% of the total equivalent anthropogenic emissions of carbon dioxide (Müller-Steinhagen, et al, 2011). Therefore, efficient mitigation and cleaning methods must be available to safeguard the operation of heat exchangers (Müller-Steinhagen, et al, 2011).

Current practices in wastewater treatment transport raw wastewater through the distribution system and to a treatment facility. For example, many wastewater treatment plants involve nitrification; a temperature sensitive process used to treat ammonia found in sewage before it is discharged into the environment (Abdel-Aal, et al., 2018). In order for nitrification to be effective, temperatures between 25-30 degrees Celsius are required (Abdel-Aal, et al., 2018). Reductions in wastewater temperature may cause difficulties with existing treatment processes (Abdel-Aal, et al., 2018). Chemical energy currently is often harnessed from wastewater in treatment plants (Hao et al, 2019).

To address this potential impact of chemical energy potential loss, Hao et al (2019) conducted an analysis on the energy potential of wastewater, and determined that existing treatment processes are underutilising the thermal potential of wastewater. Based on an estimation of practically recoverable energy in wastewater, the potential for thermal energy (90% recovery from wastewater) is much higher than for chemical energy, which was calculated at 10% recovery, typically part of wastewater treatment (Hao, et al, 2019). The study therefore quantified the benefits of recovering thermal energy that it would be greatly beneficial if over its chemical potential. Because of this they suggest that municipal authorities should work together to jointly plan utilization of this thermal energy (Hao, et al, 2019).

2.4.4 Temperature modelling

Simulation models can be utilized to address the considerations above, for example, by predicting heat usage in homes and the heat balance of the sewage system (Hofman, et al., 2014). These predictions can advise methods of heat extraction and locations of installing sewage heat recovery systems (Durrenmatt & Wanner, 2014). Models that can predict the effects of sewage heat recovery on the surrounding systems, seasonal variations in sewage, and energy demand of potential end users of recovered heat are discussed below. Furthermore, there are legal/regulatory constraints in most countries on the permitted temperature changes for influents of wastewater treatment plants and receiving waters (Durrenmatt & Wanner, 2014). Successful planning and operation of heat recovery facilities require that their effect on the wastewater temperature be quantifiable (Durrenmatt & Wanner, 2014).

It becomes clear that planning of new systems requires predictive modelling to account for downstream impacts and risks. As mentioned above, altered wastewater temperatures may cause problems for the biological processes used in wastewater treatment plants and receiving waters (Durrenmatt & Wanner, 2014). In their study, Sitzenfrei et al (2017) modelled the effect that decentralized systems could have on a centralized system downstream, and reported a 40% performance reduction if every bathroom in their 10,000 person simulation installed a heat recovery system.

Heat balance of the sewer system itself describes the heat transport by the wastewater and the heat loss to the environment (Hofman, et al., 2014). A mathematical model to predict the effect of heat recovery on the heat balance of sewerage systems was developed by Durrenmatt and Wanner (2014). Their model calculates discharge in a sewer conduit and the spatial profiles and dynamics of the temperature in the wastewater, sewer headspace, pipe and surrounding soil

(Durrenmatt & Wanner, 2014). The simulation model called TEMPEST (for temperature estimation) predicts discharge time and temperature (Durrenmatt & Wanner, 2014).

It is important to note that seasonal variations in temperature are also a factor in temperature changes at treatment plants. For example, in Hamburg, Germany, wastewater temperatures range from 7 to 28 degrees Celsius each year (Abdel-Aal, et al., 2018). Seasonal variations are an important added dimension to the water usage model above, as winter months are cooler, and affect the amount of recoverable heat (Abdel-Aal, et al., 2018).

External heat sources, which represent the heat input coming from warm water discharged into the sewer system, can be predicted by stochastic demand patterns of drinking water (Hofman, et al., 2014). The discharge of wastewater and usage activities are closely linked, i.e. certain activities typically produced a predictable volume and temperature of water (Hofman, et al., 2014). The SIMDEUM model accurately predicts water use in minutes and temperature based on use type, such as showers and washing hands (Hofman, et al., 2014). Recoverable heat potential is found to be largely during daytime with peaks in the morning and evening (Hofman, et al., 2014).

2.5 Conclusions from the literature review

Literature overall appears to have components of WWERS which are well researched. Articles examine wastewater applications of heat exchangers, already in use in electrical furnaces, geothermal systems and drain water heat recovery pipes. WWERS can range from relatively simple systems of installation on a small (household) scale, or complex capital projects. Scholars have evaluated several successful scenarios in which efficient energy recovery can be made on large scale projects, and quantified the revenue potentials and greenhouse gas offsets.

Large scale implementation of WWERS appears to still be in its infancy and no design or performance standards exist, except in Germany (DWA, 2009). Patented technology systems can be accessed through public-private partnerships and energy contracts with companies like Noventa Energy (https://noventaenergy.com/) and SHARC Energy Systems (http://www.sharcenergy.com). These companies offer the sale of recycled heat to reduce heating needs through revenue sharing agreements with wastewater producers. For example, Noventa Energy provides installation and operation of proven technology, ThermWin and have arranged sharing agreements with municipalities, paying royalties to access wastewater from trunk sewers, and selling recovered heat energy to residential or commercial clients. Another example of this can be seen with the @Source-energy pipe, which is custom engineered at the design phase for installation into new builds (Renewable Resource Recovery Corp, 2009). Inclusions of such systems in technical specifications appears allows for all component to be considered in relation to the recovery system, maximizing the energy efficiency.

All examples in the literature acknowledge the need to have private sector involvement in some capacity, such as design, build operate contracts, or public-private partnerships. For example, the largest plant, in Stockholm, Sweden, is equally owned by Fortum and the city of Stockholm under the brand Stockholm Exergi (Fortum, 2019). Fortum provides district electricity, heating and cooling to all of the city of Stockholm. In Oslo, Norway, the production of district heating is owned together with the city of Oslo under the brand Fortum Oslo Värme (Fortum, 2019). Whistler BC's Olympic village is owned and operated by the Whistler 2020 Development Corporation; created to facilitate the construction of the 2010 Winter Olympics, the municipality is the sole shareholder of the corporation (Resort Municipality of Whistler, 2013). This is often referred to as "Design, build, operate" (DBO), where all aspects are contracted out but ownership remains with the municipality. Public-private partnerships are similar, seen in the city of Stockholm's partnership with private energy company, Fortum. Stockholm Exergi is equally owned and operated by the City and Fortum, providing district electricity, heating, and cooling to residents. Fortum, a private clean-energy company based in Finland, has integrated sustainability in all corporate decision making (Fortum, 2019). They believe combined heat and power (CHP) production is the most efficient fuel-based energy production (Fortum, 2019). When recovered heat is insufficient, the system will be supplemented with fuels, which they measure lowers the amount of GHGs released into the atmosphere (Fortum, 2019).

Because of the lack of standardization, comparing individual system components becomes challenging. At the end of the literature review questions still exist on practical implementation of WWERS. It can generally be concluded that while many technical considerations exist, they do not explain the lack of implementation. The current literature, which focuses on addressing technical barriers, does not appear to be sufficient to encourage centralized heat recovery of public infrastructure. Hao et al (2019) concluded that the limitations in utilizing thermal energy are not generally based on technical difficulties, but on government policies and recommended that service providers work together to jointly plan utilization of this thermal energy for the greatest benefit (Hao, et al, 2019). Large-scale implementation of centralized systems had common ownership structures involving public-private cooperation. Municipalities own and have access to the untapped feedstock that is wastewater heat. A retrofit within existing wastewater infrastructure may allow for significant revenues from recovered energy sales.

Finally, the literature review identified the next logical step in the research - the exploration of public infrastructure integration with WWERS. Because of the impact that the legislative context has on WWERS projects, it becomes important for this research to focus on one geographic set of boundaries. This will help not only in determining climate and design, but also to integrate with the local laws and governance structures.

Chapter 3 : Methodology

Three research methods were undertaken for this study: literature review, root cause analysis and case studies. A description of each method is provided below in relation to the objectives.

3.1 Literature review

A well-conducted literature review as a research method creates a firm foundation for advancing knowledge and facilitating theory development (Snyder, 2019). With this in mind, the research method followed was based on an integrative review. An integrative review method aims to assess, critique, and synthesize the literature on a research topic in a way that enables new theoretical frameworks and perspectives to emerge (Snyder, 2019).

Based on Snyder's research, the following steps were followed to conduct the literature review; (1) designing the review, (2) conducting the review, (3) analysis and (4) writing up the review (Snyder, 2019). Figure 3 visualizes the "designing the review" approach application on the investigation of issues relevant to WWERS implementation.

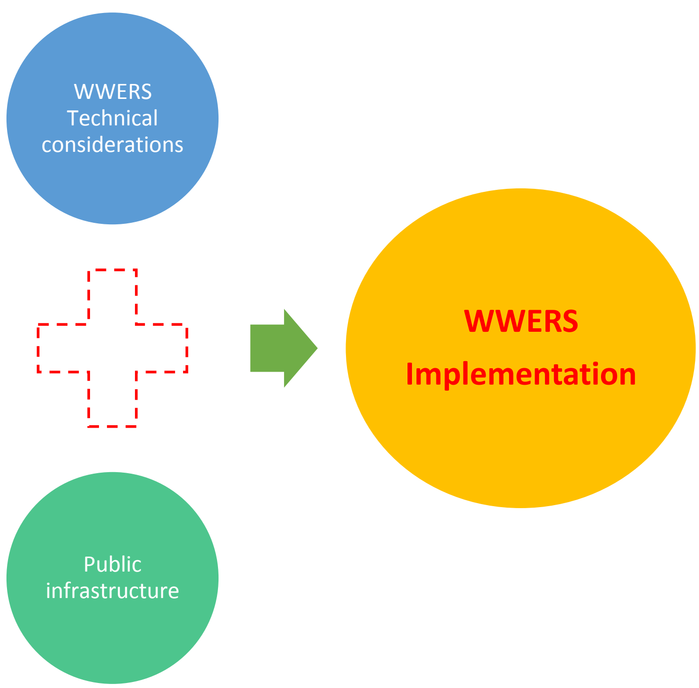


Figure 3: Research gap

The overall aim of the literature review was to provide a better understanding of i) the current consideration of WWERS in the municipal planning process, ii) ideas on how to develop an approach for increasing WWERS implementation, and iii) providing rationale for the scope and boundary of this study. The literature review was conducted to provide a baseline and broad understanding of the current state of WWERS considerations in the structured municipal planning processes and to determine what technical constraints may be addressed through energy and wastewater models, which may increase WWERS. It became clear after the first literature review that a large gap existed in examining the ownership role in WWERS.

3.2 Municipal review

The municipal review was conducted to grasp a better understanding of the current public infrastructure process. It was broadly hypothesized at this time that municipalities may be acting as a bottleneck. The proposed planning guideline borrows heavily from the format of the Ministry of Ontario's "*Planning guidelines for Sewage works*", a government guideline document developed in consultation with public sector, private sector and academic infrastructure experts (Government of Ontario, 2008). The guideline was well researched and written for a broad audience that includes design engineers, Provincial compliance review staff, and the municipal owners of the sewage based work. While the guideline does not mention heat recovery from wastewater design considerations, many aspects of it were useful for broader application to wastewater system design, particularly the legislative context section which outlines all applicable laws as of a current date and notes the next date of review.

3.3 Root cause analysis

The root cause analysis was conducted as discussions with research advisors and municipal experts. Municipal veteran John Nemeth, who has been in the public infrastructure sector for over 30 years, provided valuable insights and helped guide the direction of the analysis.

Fishbone diagrams also allow users to identify and uncover the causes of organizational and process gaps (Rodgers & Oppenheim, 2019). Additionally, they were developed to determine interdisciplinary causes in mechanical processes. This aspect of it makes it attractive for evaluating WWERS, as they help tie engineering considerations with social, governance and economic ones. Table 3 provides a description of the common causes used in fishbone diagrams.

The fishbone diagram was populated using a variation of the "5-Whys" Analysis; a problem-solving technique that helps users get to the root of the problem by asking "why" and "what caused this problem" (Stoehr, 2019). Often the answer to the first "why" prompts a second "why", and so on until a logical end is found. Based on this, the questions outlined in Table 3 were asked and then presented in the fish bone diagram.

Table 4: Explanation of cause categories (Stoehr, 2019)

Cause	Description
Process	What are typical municipal processes associated with infrastructure? How does one go about implementing a change to infrastructure?
Systems	What about WWERS makes it difficult to implement? Are there sufficient technology options? Are the costs prohibitive? Does implementation mean service disruption or other negative impacts?
People	Who are the stakeholders? Are they knowledgeable? Will these systems require additional training? What are their motivations? Are they sufficiently compensated?
Measurement	Can the system benefits be easily measured? Is data on the key stakeholder metrics collected? Are our measurement systems effective?
Environment	Can wastewater infrastructure integrate with these systems? Are there downstream impacts? Is energy demand in line with recovery? Where would heat be distributed?
Equipment	Do inputs from suppliers meet requirements? What are the maintenance requirements?

Causes were examined from 2 levels; either physical causes or system causes (Stoehr, 2019). **Physical causes** are proximal or direct causes, stemming from a specific physical item that if it were to be rectified would allow the process to work correctly (Stoehr, 2019). For example, a heat exchanger failure due to raw wastewater clogging, pointing to issues related to the robustness of the exchanger itself. Further questioning may show that cleaning the heat exchanger plates is the mechanism that will allow the system to work correctly. A **system cause** is distal or latent, causing or allowing for the physical cause to occur (Stoehr, 2019). If the heat exchangers are not regularly washed or cleaned at the recommended intervals, the problem will reoccur (Stoehr, 2019). System causes are more difficult to address, as organizational tendency is to stop once the physical cause is found and corrected (Stoehr, 2019).

Applying these questions from a municipal process lens, impediments were determined through discussions with municipal experts and brainstorming draft of the fishbone diagram in Microsoft Office’s SmartArt function in PowerPoint.

3.4 Case study

This study will focus on Ontario, Canada, due to the extreme variations in temperature, high online data availability, and Canada’s commitment to the Paris agreement. Variations in seasonal temperatures will help determine system suitability in hot and cold climates. Canadian agency Statistics Canada provides census based data, updated every 4 years. Additionally, Canada’s commitment to the Paris agreement has allowed for energy reporting data, as well as significance for the study, as results can be used to help the nation consider another sustainable technology solution.

3.5 Limitations, assumptions and challenges

Variations in terminology and jurisdiction indicated the need to select a definition for the study. Heat pumps and heat exchangers, the major components of wastewater heat recovery, are broadly used to describe HVAC equipment (including air source, and geothermal systems). Additionally, literature interchangeably uses the terms “sewage” and “wastewater”. While there are distinctions between the two, they do not impact the review. Lastly, wastewater heat recovery is proving to be effective running in reverse to provide space cooling. For this reason, some companies and studies remove the reference to heat altogether. Therefore, for the purpose of this study, the Wastewater Energy Recovery System (WWERS) term is used, meaning a whole system solution that could be operated year-round.

Several challenges existed in this study. The first and largest is the variations in jurisdiction and information, and the immense challenge of narrowing the scope based on a logical and systemic approach. Once the scope is narrowed, much of the implications then become jurisdiction-specific. However, this can’t be avoided as legislation plays a large role in WWERS implementation, and to broadly explore this would not allow for appropriate analysis.

Another challenge is related to data availability. Depending on jurisdiction, data availability varies as requirements are mandated and not. Two types of literature were reviewed - academic journals and non-academic literature (grey literature). Academic articles were retrieved from membership-based online journal databases. Grey literature was retrieved from government organizations and associations, such as the United Nations, the Governments of Ontario and professional associations (such as Association of Municipalities of Ontario (AMO)). Due to the nature of the research, grey literature was heavily relied on. If completed from a municipal perspective, greater data availability and expertise is observed. For example, the case study was applied from an external perspective; a municipality with access to updated lists and central data repositories.

Finally, this study was conducted with the participation of municipal authorities and know-how of Ontario municipal processes. This may have created biases, however the opportunities outweighed the bias threat, and was addressed through participation of neutral reviewers and experts.

Chapter 4 Results

Objective 1: Identify WWERS barriers

The literature review determined the scope and goals of this research. As mentioned in the methodology, there existed a glaring gap in research between technical considerations of WWERS in the municipal infrastructure planning process. As owners of public infrastructure, municipalities are instrumental in determining overall community goals, and then implementing them through available mechanisms. An integrative review of literature was conducted to understand the role of ownership in WWERS implementation. The Olympic Village example in British Columbia shows promise for implementation in colder climates. Evaluation of an eastern province adds to knowledge of WWERS, and helps narrow the scope for to practically apply the method.

4.1 Municipal structure

Municipal structure evolves over time through legal processes of boundary change such as annexation and incorporation (Wu & Chen, 2016). When a developed area outside the municipal boundary decides to form its own municipality, instead of being annexed into the nearby community, a new municipality is formed at the urban fringe (Wu & Chen, 2016). As a federation, Canada allows its provinces to make decisions independently in the structure of their municipalities (Terry, et al, 2017). Canada's largest province, Ontario, is divided into districts and municipalities, with 95% of Ontario's residents living in single-tier municipalities (standalone cities or towns that plan, design, and fund infrastructure) or two-tier municipal structures (regions governed by two levels of government with established sharing arrangements for public infrastructure and operations (Terry, et al, 2017). In regions with higher agricultural rents, higher construction costs, and uncertainty of income growth, cities tend to be less spreadout and include a small number of larger municipalities (Wu & Chen, 2016). Smaller municipalities then have financial constraints, the result of having a smaller revenue stream from a smaller population (Nemeth, 2019).

Municipalities are overseen by local councils, elected by local residents (AMO, 2019). The job of municipal councils is to make decisions about financing and services (AMO, 2019). Municipal officials prioritize managing public services to maintain affordability and ensure cost effectiveness (AMO, 2019). This means that any sustainable infrastructure investments will require additional funding from reliable long-term partners in other levels of governments (AMO, 2019).

Wastewater collection and treatment is a necessary service and is thus typically owned and operated by public utilities (Vedachalam et al, 2014). Municipalities started taking control of these services by the end of the 19th century, due to concerns with quality of service and lack of record keeping (Vedachalam et al, 2014).

4.2 Legislative context

Guiding documents, such as Acts, by-laws, design standards and approvals are developed to ensure compliance with local legislation. They also ensure all planned works are in line with resident service level expectations (AMO, 2019). For example, the *Municipal Act, 2001* outlines laws for Ontario municipalities and the agreements that guide the relationship between municipalities and the Province (Ministry of Municipal Affairs and Housing, 2019). The Act is a framework document for municipal government, and provides a foundation for municipal powers, structures, and governance (Ministry of Municipal Affairs and Housing, 2019).

Wastewater infrastructure projects are heavily regulated, with requirements such as Environmental Assessments (EAs) to ensure compliance with legislation (Government of

Ontario, 2018). Prior to development of any kind, municipalities have approval requirements which typically include the features and layout of the site development together with the detailed engineering that demonstrates the feasibility of the services requiring approval (Government of Ontario, 2018). Additional legislation establishes the basic structure for regulating discharges of pollutants into the waters, and regulating quality standards for surface waters (Vedachalam, et al, 2014).

4.3 Funding

Generally, financing of municipal services is done primarily through the property taxes and user fees paid by residents and businesses (AMO, 2019). These are considered steady revenue streams and are reserved for essential operation of services. Capital construction budgets for infrastructure depend on municipalities, but largely come from debt, reserves and development charges. Governments at all levels, with occasional contributions from private corporations, have a role to play in financing infrastructure upgrades, even as the proportion of their contributions remains a topic of debate (Vedachalam, et al 2014).

Federal and Provincial funding sources can account for significant contributions for projects that align with respective plans. For example, the Green Infrastructure stream, as per federal parameters, aims to support the reduction of greenhouse gas emissions, enable greater adaptation and resilience to the impacts of extreme weather, and disaster mitigation. Approximately $200 million dollars is available in federal and provincial funding for projects that meet these criteria (Government of Ontario, 2019).

4.4 Design standards

Engineering design standards and technical specification are a component of municipal infrastructure design that ensures consistency and fairness (Freimuth, Oelmann, & Amann, 2018). Design standards have successfully been developed as part of community planning documents. For example, Official Plans or asset management plans may include goals for energy efficiency, and design standards may be a way to achieve the objective (2019). Peterson et al (2019) found that planning documents are often successfully implemented through tie in with design standards. They found that having a plan with a higher number of objectives supportive of active living is associated with a higher prevalence of design standards (Peterson, Carlson, Schmid, Brown, & Galuska, 2019). Therefore, community plans must first identify a desired high level outcome, for example, increased energy efficiency through use of sustainable technology, and then integrate design standards for implementation (Peterson, Carlson, Schmid, Brown, & Galuska, 2019).

Design standards and feature requirements may provide an opportunity for municipalities to be integrated with the private sector manufacturers or service providers. Practitioners may wish to consider integrating planning documents with design standards to support community goals (Peterson, Carlson, Schmid, Brown, & Galuska, 2019). Because of the variations that exist across areas, it becomes important to select one jurisdiction. Applicable legislation is important in developing planning guidelines.

4.5 Asset Management

The infrastructure responsible for the provision of wastewater services represent a major portion of the value of municipal physical assets and are expected to be managed for current and future generations (Amarala, et al, 2017, p. 128). Asset management is a strategic approach to managing infrastructure assets that helps infrastructure owners (i.e. municipalities) maintain and operate infrastructure effectively and without interruption to services (Canadian Infrastructure Report Card, 2019). Asset management plans typically describes the characteristics and condition of infrastructure assets, the level of service expected from them, planned actions to ensure the assets are providing the expected level of service, and financing strategies to implement the planned actions (Canadian Infrastructure Report Card, 2019). Seventy percent of large urban municipalities (populations of 30,000 or more) have documented asset management plans (Canadian Infrastructure Report Card, 2019).

Municipal or provincial associations often conduct research to identify best practices and utilize them in government processes (Government of Ontario, 2018, p. 2). Literature on the current state of asset management often cite the International Organization for Standardization's (ISO) 55000:2014 asset management standard. The ISO 55000 standard defines asset management as the 'coordinated activity of an organisation to realise value from assets' (Amarala, et , 2017). When establishing or reviewing its asset management system, an organization should consider its internal and external contexts (ISO, 2014). The external context includes the social, cultural, economic and physical environments, as well as regulatory, financial and other constraints (ISO, 2014). The internal context includes organizational culture and environment, as well as the mission, vision and values of the organization (ISO, 2014). Stakeholder inputs, concerns and expectations are also part of the context of the organization (ISO, 2014). The influences of stakeholders are key to setting rules for consistent decision-making and contribute to the setting of organizational objectives, which in turn, influence the design and scope of its asset management system (ISO, 2014).

Cost savings and efficiencies can be realized when asset management is integrated across departments and infrastructure (Samra, et al, 2018). This is referred to as integrated asset management (IAM) (Samra, et al, 2018). It can be shown that good asset management can save a business up to 35% on maintenance costs and increase asset availability by up to 20% (van der Westhuizen & Myburg, 2014).

For public services, the focus is on the physical assets, and on the physical systems directly supporting the service provision (Amarala, et al, 2017). The application of IAM principles in the water sector has significantly advanced in the last decades, particularly in developed countries, but an increased focus on the IAM challenges in many developing countries has been observed (Amarala, Alegreb, & Matosa, 2017).

4.6 Conclusions from municipal review

Private sector involvement is seen as another solution to address the funding challenges, with the added benefit of not burdening the public dollars with its management (Nemeth, 2019). Several causes have driven the growing privatization of the water and wastewater sector in the past two decades, one of the most prominent is the inability of municipalities to finance the capital investments needed to maintain and upgrade existing infrastructure (Vedachalam, Kay, & Riha, 2014). However, lack of confidence in private management is attributed to a lack of experience with privatization in the water and wastewater services or a satisfactory experience with public management of local utilities (Vedachalam, Kay, & Riha, 2014).

Additionally, with wastewater collection and treatment being part of the public sector, public procurement and its interrelation with technical standards play a significant role and further increases the relevance of standards in the sector (Freimuth, Oelmann, & Amann, 2018).

It becomes curious that asset management planning is dominant and well documented in large urban municipalities. Therefore, based on the literature, effective asset management planning allows for effective management of assets.

The following conclusions were made.

i) WWERS are technically feasible, with examples of them being implemented successfully.

ii) The lack of implementation does not appear to lie with limited technology options or high capital expenditures.

iii) Municipalities as owners of public infrastructure are well suited to implement these systems. Planning guidelines can be tied to measurable achievements to municipal goals.

iv) The legislative context is important in developing planning guidelines; because of the variations that exist across areas, and the substantial implications of the legislative context, it became important to select one jurisdiction. Ontario, Canada was selected to set the research scope.

The municipal analysis provided a wealth of information to inform the implementation barriers. To combine the concept of public infrastructure and WWERS, a root cause analysis was conducted.

4.7 Root cause analysis

Root cause analysis is divided by the main categories and associated causes. Detailed explanations are provided following Figure 4. The fishbone diagram is particularly useful when identifying overall causes that appear in multiple categories. This helps flag an issue as an item to further examine.

Process impediments in municipalities can come from several sources. Process impediments of WWERS were identified to be relating to Procurement and Funding challenges. Procurement is a complex process in municipalities, usually governed by a purchasing by-law. The purchasing by-law's main purpose can vary but is generally based on encouraging competitive bidding. Why is competitive bidding a challenge? Because it often does not ensure that the best technology or proponent is selected, as the price factor plays such a large role in determining proposal prices. Procurement also requires staff expertise and drive. This is because the creation of public procurement documents, such as specifications, tenders, and proposal requests, are written by municipal staff. This becomes a challenge when staff are introduced unprepared in the process, new hires lack training, or existing staff that struggle to keep up with changing protocols. This becomes a challenge when new and emerging technologies are not fairly evaluated or considered. This leads to the final impediment under procurement; slow to adopt. The nature of government process makes it difficult to quickly adopt new technology, as lengthy protocols and mandated requirements, for example, quality record keeping requirements and purchasing bylaw compliance (Government of Ontario, 2018).

Well-funded public infrastructure is at the crux of efficient municipal function. Funding is applied for in Ontario for most capital growth projects, typically requiring asset management plans as part of applications. When examining innovative technology solutions, a properly designed, integrated asset management system should be the starting point (van der Westhuizen & Myburg, 2014). Governments require asset management plans to assess funding requests from municipalities (Government of Ontario, 2018). However, these complex and multidisciplinary documents require staff time, budget and expertise in order to be competitive for funding consideration. Asset management requires a thorough understanding of the characteristics and condition of infrastructure assets, as well as the service levels expected from them (Government of Ontario, 2018, p. 2). It also involves setting strategic priorities to optimize decision-making about when and how to proceed with investments (Government of Ontario, 2018). Finally, it requires the development of a financial plan, which is the most critical step in putting the plan into action (Government of Ontario, 2018). Considering the resources required to produce documentation for funding support, it becomes challenging to secure funding if a municipality does not have asset management resources already in place.

Funding needs are also at the mercy of public priorities, as new and emerging issues may increase or decrease allocated funding in programs or projects. The knowledge of public finance mechanisms among residents and decision makers may be deficient (Terry, et al, 2017). Government and elected officials allocate funding and implement policy alternatives based on broad public opinion (Vedachalam, et al, 2014). More on Public priorities is discussed in Section 6.3.1.

Impediment from a ***systems*** perspective appears to be the overall complexity of wastewater infrastructure. Construction is a resource intensive process, requiring design expertise, regulatory approvals, and capital construction costs. In addition, departmental collaboration is required in order to engage all stakeholders, including the operations and maintenance staff who will be taking over the systems once the construction is complete. Additionally, risks exist with residents experiencing nuisances from construction, such as service disruptions and road delays. These are difficult to contend with, especially at a planning or design phase when approvals are not yet in hand. Lastly WWERS have may have implications for downstream processes, such as the potential to require changes to the wastewater treatment process. If the removal of heat energy will require additional equipment or energy generation requirements to maintain sewage temperature, then the benefits of WWERS become diminished.

The ***people*** category of potential causes includes the voting public, councillors, and municipal employees. Councillors base election platforms on public priorities, which in turn inform municipal staff on policy mechanisms. While public opinion can often be misinformed or disengaged from important issues, it still forms the basis of a democratic processes (Vedachalam, et al, 2014). Public opinion surveys, voting results and purchasing decisions reveal public attitudes and engagement (Vedachalam, et al, 2014). Policymakers then use this understanding on the range of public support for various kinds of policy alternatives (Vedachalam, et al, 2014). An informed voting public and a responsive government can together address complex challenges facing the water and wastewater (Vedachalam, et al, 2014). Therefore, if sustainable energy sources, such as WWERS, are not top of mind priorities for the voting public, funding is limited.

Measurement relates to the availability of data and program measurement. Additionally, several aspects of WWERS require complex measurements in order to track system performance and impacts, for example biofilms impact sewer mains, and therefore must be accounted for. Additionally, the measurement of these systems to operate and monitor their performance requires additional staff time, training and equipment purchases. In order to track sustainability, selecting methods and calculating energy offsets and CO_2 equivalents are also a challenge. Despite having emissions measurements, because of the pivotal role of energy in routine activities of all economic units, it is difficult to measure and monitor. Governments are often required to monitor regulatory parameters relating to wastewater to ensure public safety; therefore availability is an impediment if models and computations are not accepted alternatives when data is not available.

Environmental causes of barriers are related to the location of WWERS, and downstream impacts. For example, centralized WWERS must be in areas of high wastewater generation (buildings) and must also utilize the recovered heat within close proximity (Ichinose and Kawahara, 2017). Additionally, collecting heat from wastewater that is normally higher in temperature may have implications to wastewater treatment processes, levels of bacteria in the water, and soil temperature of pipes. If heat recovery has additional implications from this, existing wastewater treatment processes would require downstream treatment amendments, which may become a barrier to implementation.

Equipment presents challenges when selecting technology options. Procurement is often cited as a challenge for not only municipal staff and councillors, but also for proponents (Allen-Muncey, 2019). Expertise is required when submitting bids, but also when drafting project requirements in an RFP (Allen-Muncey, 2019). This can create challenges with public bid submissions of technology, as such variation in price and product is difficult to capture. This can also be linked to people-based causes, particularly when innovations in technology are being evaluated by municipal staff that lack the expertise to correctly identify the best option.

A summary of the issues discussed above is presented in the fishbone diagram in Figure 4.

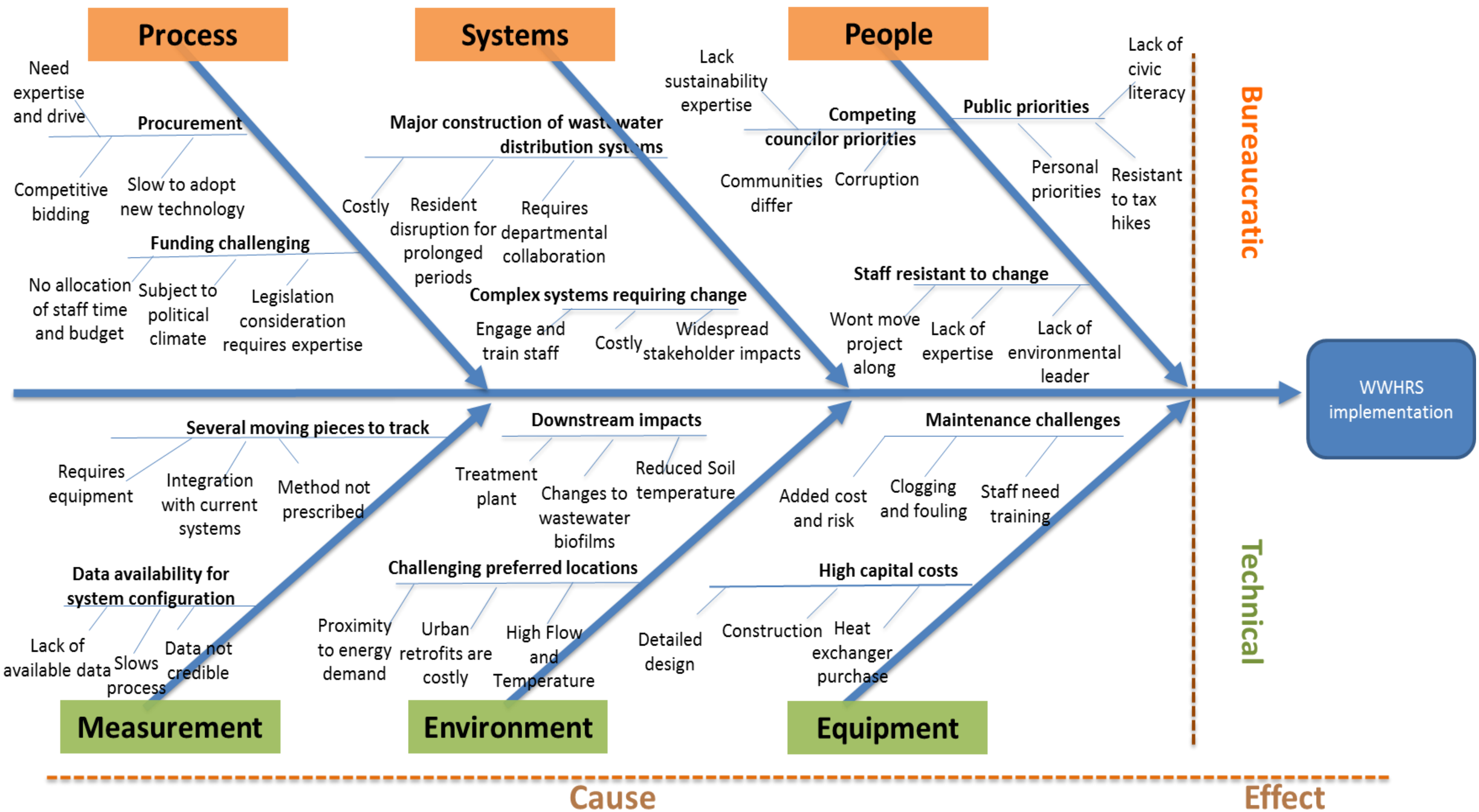


Figure 4: Fishbone diagram

4.8 Conclusions from the root cause analysis

Conducting the root cause analysis helps demonstrate the interconnected nature of municipal impediments of WWERS implementation. Finding the common causes in the analysis, the municipal impediments can be summarized into the following three categories.

1. **Process:** This relates to organizational protocols
    a. Public engagement: Civic literacy is an issue when residents often don't know the tools available to them or are unable to navigate through all the services (Nemeth, 2019).
    b. Regulatory: Provincially mandated plans contain activities that are required by law. Other promises/goals cannot be upheld legally, therefore become a lesser priority item (Nemeth, 2019).
    c. Standard operating procedures (SOP): Many municipal processes are designed to be easily and simply replicated, for example, common ISO SOPs. Often, the people who have the expertise are not the ones who conduct process improvement analysis (Nemeth, 2019).
2. **Resourcing:** This relates to funding, staff expertise and availability
    a. Staff expertise and engagement: Experts in heat exchanger technology, as well as wastewater systems are required to develop these systems.
    b. Funding challenges: Funding requests are dependent on the project type and political climate.
3. **Leadership:** Having a political and/or administrative leader that sees value in the innovation or undertaking. It is difficult to drive change by following an existing process, as this can only be done with attitude changes of staff (Nemeth, 2019). There are

numerous drivers that direct political agendas and election platforms. Prioritizing sustainable energy recovery is possible but dependent on leadership (Nemeth, 2019).

Typically, if major impediments do not exist in implementing these systems, there is likely a visionary leader (i.e. CAO, Councillors) who identifies sustainability or greenhouse gas reduction as a priority. For example, the Climate Change Master Plan, developed by the urban two-tier municipality Peel Region, was developed as part of council's priority of building environmental resilience (Region of Peel, 2019). The plan also includes financial forecasting of climate change impacts, as well as encouraging innovative solutions through incentive programs, feasibility studies and knowledge sharing (Region of Peel, 2019).

At the end of this analysis, it became apparent that there are some common themes in municipal impediments that can be rectified through existing mechanisms. Municipalities typically set corporate and community goals. In cases where these goals are tied to infrastructure, they were most also tied to community goals. For example, the case of planning guidelines for sidewalks to encourage healthy and accessible communities. One guideline that advises three major stakeholders at once can help harmonize the design and approval process.

Objective 2: Address WWERS barriers

The guideline prescribes steps for the integration of WWERS with public infrastructure, based on industry best practices. An overview is provided in Figure 5.

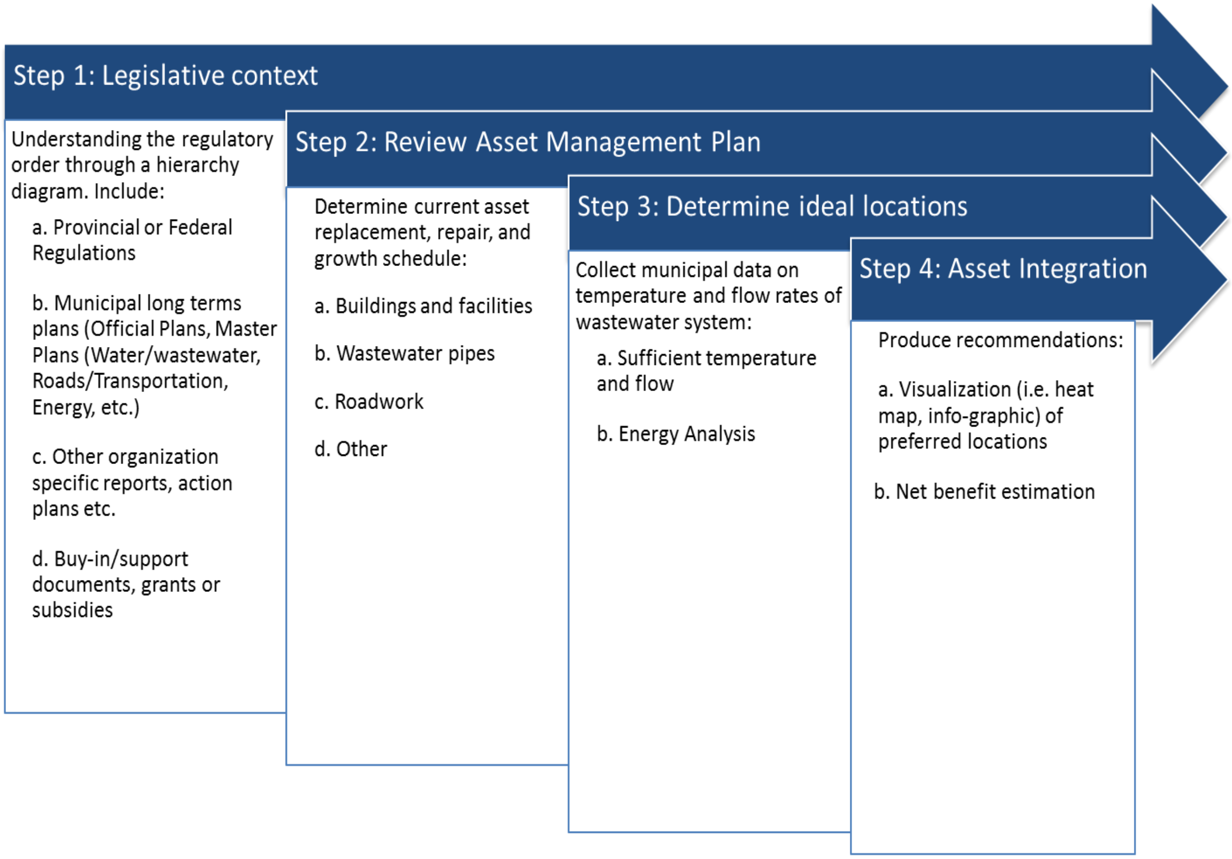


Figure 5: WWERS Guideline

It is intended for the guideline to be used in conjunction with the Case Study, attached as a sample. It should be noted that the sample is only included as a reference, and any legislative changes that occur after the guideline is applied, are still relevant and applicable to analysis the proponent is conducting.

Step 1 allows for the organization of applicable documentation, which has been determined to be an essential step when evaluating WWERS.

Step 1: Legislative framework

Understanding the regulatory order through a hierarchy diagram. Include: a. Provincial or Federal Regulations b. Municipal long terms plans (Official Plans, Master Plans (Water/wastewater, Roads/Transportation, Energy, etc.) c. Other applicable documents, action plans etc. d. Buy-in/support documents, grants or subsidies	1.1 Create an exhaustive list of all applicable legislation • Start with broad and generally applicable documents and filter down • *Example*: Municipal Act, Environmental Protection Act 1.2 Identify all municipal long terms plans (Official Plans, Master Plans (Water/wastewater, Roads/Transportation, Energy, etc.) • Look for any plans that may be related to infrastructure construction or environmental initiatives. These will help build your understanding and your case 1.3 Other applicable documents, action plans etc. • Buy-in/support documents, grants or subsidies • Provincial and Federal funds and plans should also be identified 1.4 Highlight most relevant documents for insertion into hierarchy • It is not necessary to include all documents in the hierarchy • Microsoft Office SmartArt has several Hierarchy diagrams. Other visualization software tools are also acceptable. **<u>Step 1 Deliverables:</u>** ☐ Hierarchy document

Step 2: Review Asset M

Step 3: Determine pref

Step 4: Asset Integration

Figure 6: Step 1

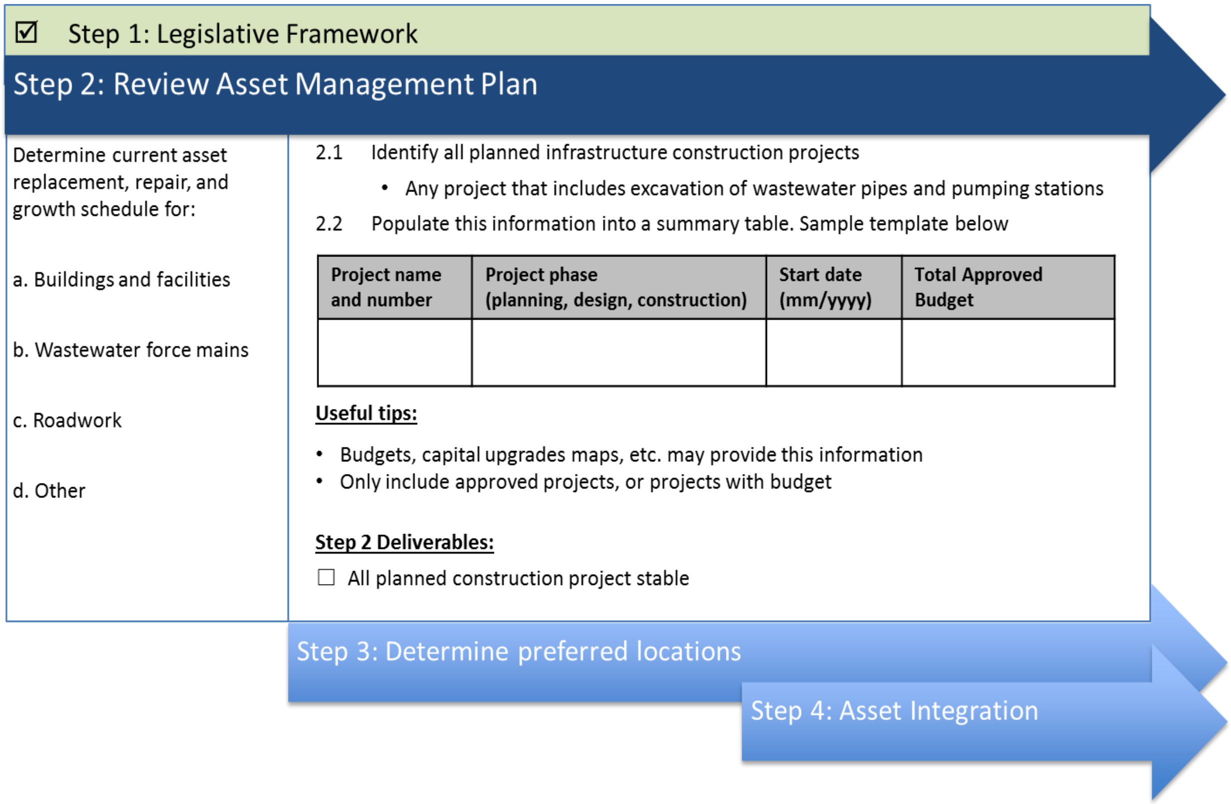


Figure 7: Step 2

Once all applicable documentation has been established, existing plans specific to wastewater infrastructure are to be reviewed. Figure 7 outlines the requirements of step 2. This can help reduce costs, an attractive option for municipalities and technology proponents alike. Outline projects with budget, that are still in the planning phases mark the most desirable, as a planning guideline could be integrated with tender documents.

Step 3 (Figure 8) will help in system design and measurement. As the root cause analysis identified, funding constraints and measurement of these systems appear to be the first impediment.

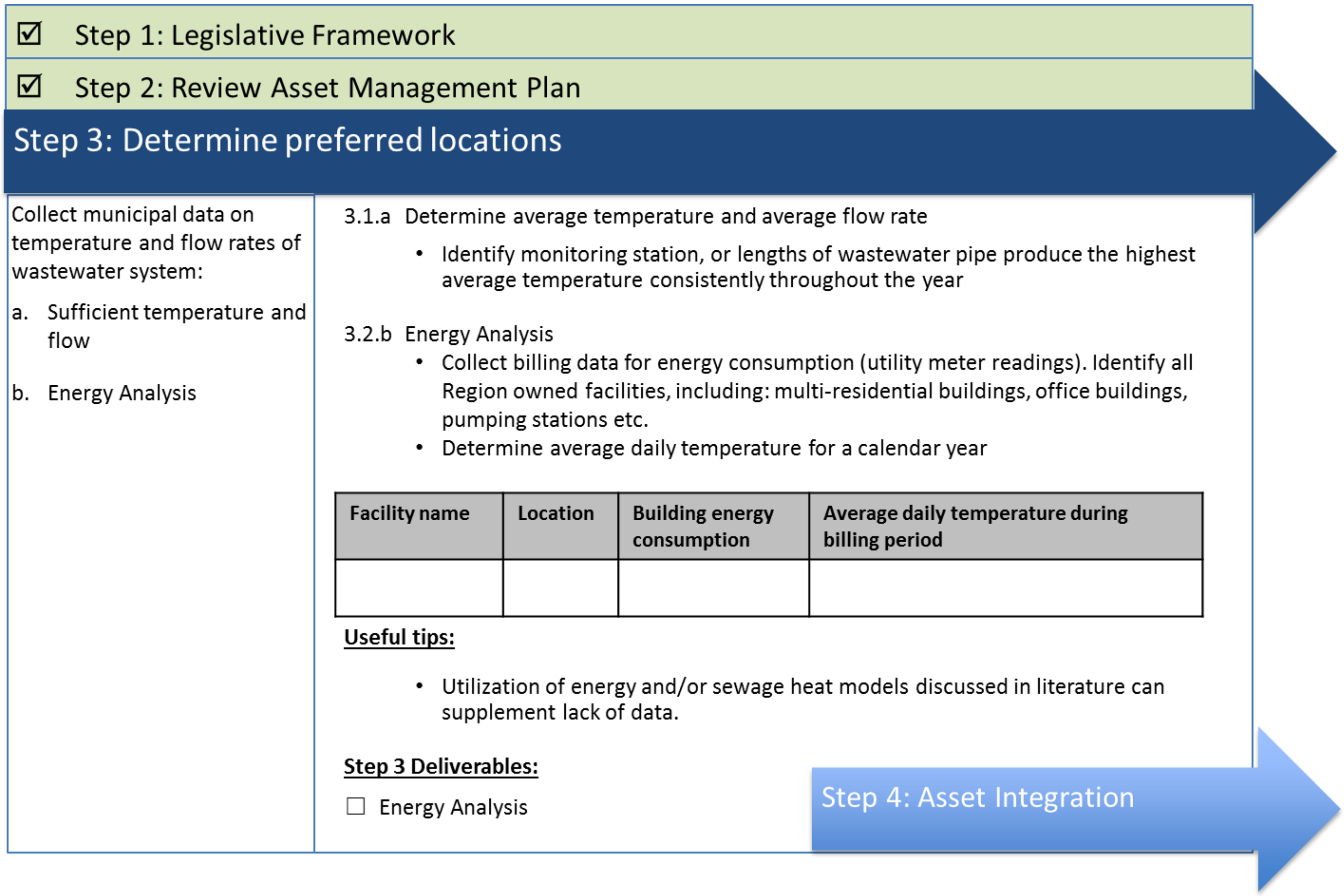


Figure 8: Step 3

Step 3 is based on best practices in energy analysis, discussed in Chapter 3. An energy audit or analysis is a useful part of energy management and efficiency. Effective energy management may help reduce the impacts of increasing energy requirements (Fung, Taherian, Hossein, Rahman, & Selim, 2015). By simulating a building's energy, the WWERS design modifications may be tested (Fung, et al, 2015). Temperature of the wastewater is relatively high close to homes; however, the wastewater flow volume is low and constantly changes (Hofman, et al., 2014). Going further downstream the sewer system, flow is higher and more continuous; however, heat is lost in the transport process to the soil (Hofman, et al., 2014).

☑ Step 1: Legislative Framework

☑ Step 2: Review Asset Management Plan

☑ Step 3: Determine preferred locations

Step 4: Asset Integration

Produce recommendations and determine your audience: a. Visualization (i.e. heat map, infographic) of preferred locations b. Recovery potential c. Dissemination	4.1.a Using ArcGIS, Microsoft Office Smart Art, or other software as appropriate • Summarize the information from Steps 1-3 into a visual 4.2.b Based on heat recovery potential energy analyses in Step 3, the greenhouse gas offsets and potential revenue should be presented here. • The USEPA has an online Carbon Dioxide Equivalent (CO2e) calculator tool, based on the intergovernmental panel on climate change's (IPCC) published warming potential calculations 4.2.c Determine appropriate audience and maximize potential • Contact via email, the mayor, ward/area councillor, and city manager or Chief Administrative Officer, and Commissioner of public works • Attach the visual and recovery potential, and request a meeting to discuss potential • Follow up until a response is given. **Step 4 Deliverables:** ☐ Visualization and recovery potentials ☐ Meeting request sent to municipal authorities and councillors

Figure 9: Step 4

The final step in the guideline examines dissemination potential. A key finding from the root cause analysis cited the personnel issue associated with these systems, which overlapped throughout all identified causes. Therefore, in order to bridge an expertise gap, the importance of communicating the benefits and feasibility of these systems can encourage their use. When councillors, members of the public and municipal staff all have common understanding, through a standardized visualization, implementation may be increased.

OBJECTIVE 3: CASE STUDY

To demonstrate its use, the implementation guideline is applied to the Regional Municipality of York ("York Region"). York Region is a large urban municipality in Ontario with a growing population of 1.16 million people (Regional Municipality of York, 2017). In York Region, wastewater is defined as any water used in residential, commercial, industrial and institutional buildings that leaves through a drain (York Region, 2018). Raw wastewater is collected in sewers and then treated at plants to remove contaminants before being returned to the environment as effluent (York Region, 2018). York Region collects and monitors wastewater flow and temperature data on a regular basis using web-based monitoring tool FlowWorks. It is used for monitoring, analysis and reporting of all wastewater systems.

Step 1: Legislative Context

Step 1 addresses the regulatory requirements of WWERS. It is essential to confirm any legislative requirements with the most up to date version, therefore Step 1: the legislative context, helps organize and identify the legislation as it applies to the location. The proponent of a wastewater energy recovery system is responsible for incorporating all requirements in the planning, design, construction and operation of the systems, and for being as aware of any pending legislative requirements that may impact design considerations.

In this study, Microsoft Office's hierarchy SmartArt graphic was used. It is recommended that a hierarchy diagram be utilized as an organizational tool for depiction of these intricacies. The applicable documents in Ontario have been outlined in Figure 10. From a legislative perspective, Ontario municipalities are required to produce Official Plan documents, however the contents and sub-plans vary across municipalities (Nemeth, 2019). The remaining documents, such as asset management plans are recommended best practices, and are used to meet provincial requirements for municipalities seeking funding outside of resident taxes (Nemeth, 2019). It is important to outline the strategies; plans report etc. that support any kind of sustainable technology or green energy and infrastructure initiative. These documents are usually mentioned or tied in legislation and can help promote greater buy-in with the promise of provincial alignment and funding dollars. This may include formal laws and/or regulations that generally govern municipalities or could include long term planning documents or corporate missions.

York Region's Water and Wastewater Master Plan has language speaking to maintaining existing processes for "Climate resiliency, water conservation and reuse and energy conservation are concepts embedded in the One Water approach to ensure sustainability" (York Region, 2016). The One Water Report highlights cost saving initiatives, a major concern for York Region, a landlocked community that has high water and wastewater infrastructure costs due to the purchase and transport of water and wastewater (MBNC, 2018). The One Water report highlights the priority of servicing options that are "less energy intensive", however no evaluation criteria to measure this, and no measurable goal is provided (York Region, 2016).

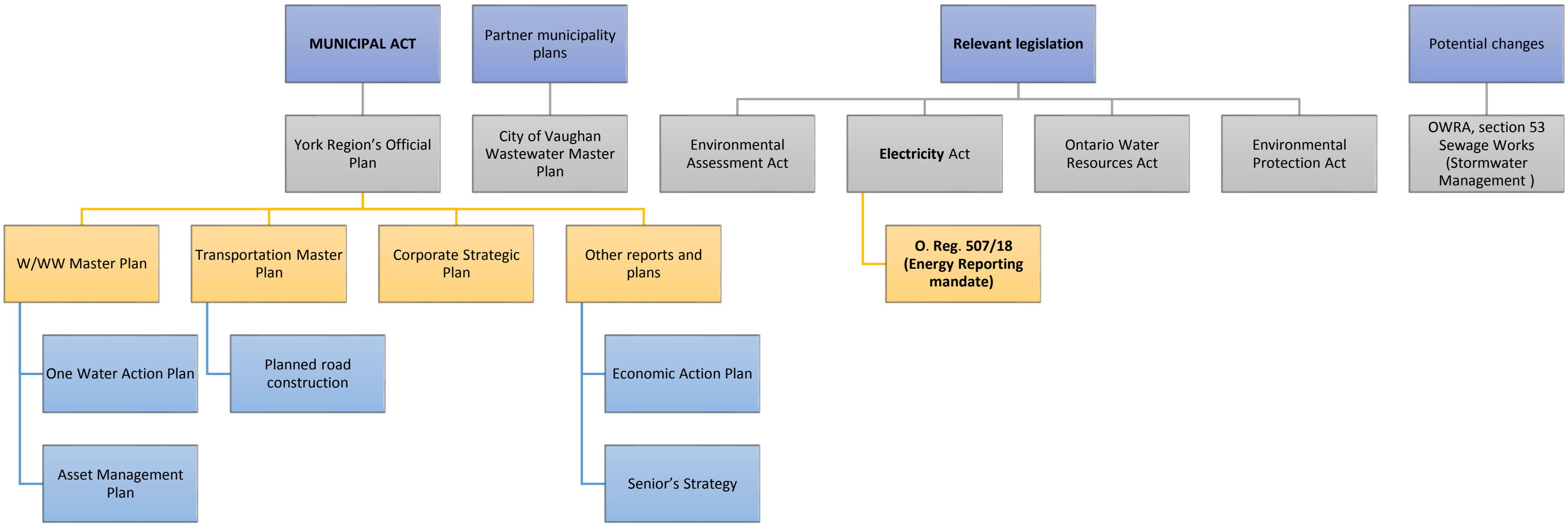


Figure 10: York Region's legislative context hierarchy diagram

Step 2: Review Asset Management Plan

Step 2 allows for the integration of WWERS with infrastructure upgrades a municipality is planning. Assets are maintained and expanded on a regular basis to maintain a prescribed level of service (Government of Ontario, 2018). Roadwork, sewer expansions and maintenance involve capital construction costs, i.e. excavation. Therefore, including integration of asset management when implementing WWERS at the planning and design phase can produce considerable cost savings, as excavation and/or retrofitting costs are shared.

> *York Region assets will be managed through a coordinated approach that ensures financial sustainability following recognized asset management principles guided by the Region's Strategic Plan and Vision 2051.* (York Region, 2016, p. 1)

At York Region all infrastructure projects have criteria applied in order to determine feasibility at the planning phase. Therefore, in order to ensure alignment with asset management, criteria should be reviewed. Based on the requirements and scoring, for the servicing criteria, a sewage energy recovery system would be considered a favourable strategy from a technical perspective, as it increases climate change resilience and energy efficiency. Areas that may suggest an unfavourable strategy may fall into constructability challenges, as well as maintenance complexity. Addressing these challenges will be important in making a case for WWERS.

Figure 11 demonstrates the planned wastewater upgrades for the next 10 years from their Water and Wastewater Master Plan. Since asset management plans are regularly updated by municipalities (i.e. every 5 years) to comply with provincial funding applications (Government of Ontario, 2018), this step looks to integrate asset management with WWERS. As suggested in chapter 4 and explaining the widespread use and certification of ISO 55000, asset management may achieve cost savings when it is integrated with construction (Samra, et al, 2018).

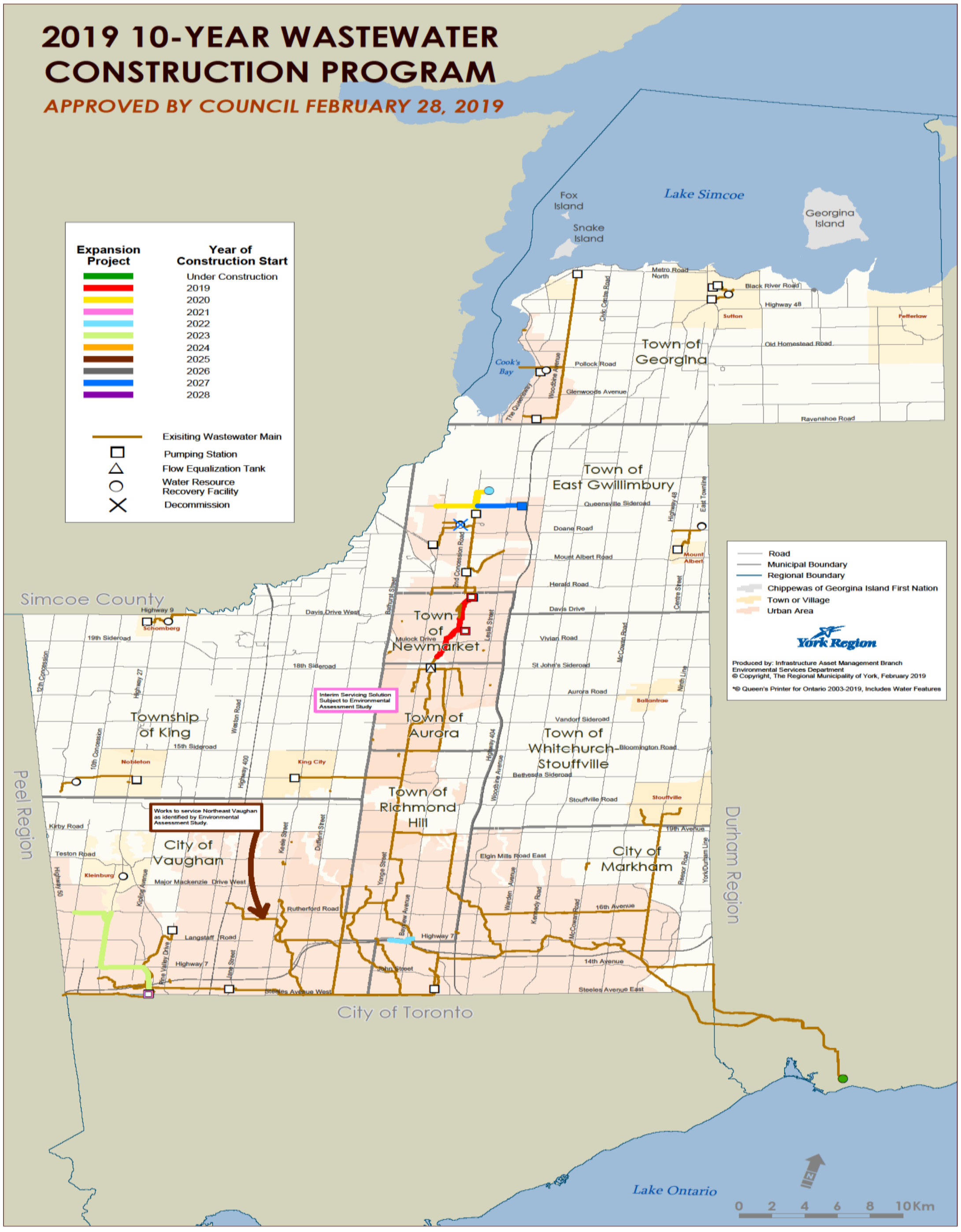


Figure 11: Infrastructure upgrades for the next 10 years (York Region, 2016)

Projects with “Year of construction start” occurring further in the future suggest the project is either in its planning or design phases. This helps capture any design standards or overall project requirements, and to capture them at time of design, before anything has been constructed or purchased. Because the construction map only provides a snapshot from the last update of the master plan, the most reliable document is the budget. Figure 12 is taken from the 2019 approved Council budget, with potential broad categories of projects highlighted. For the purpose of this case study, the focus will be n wastewater “growth” and “rehabilitation” projects.

Ten-year capital funding by program

($ in 000s)	Development Charge Reserves	Asset Replacement Reserves	Debt Reduction Reserve	Program Specific Reserves	General Capital Reserve	Federal Gas Tax Reserve	Grants & Subsidies	Other Recoveries	Planned Debenture Proceeds	Ten-Year Total
Transportation Services										
York Region Transit:										
Rehabilitation and Replacement	-	475,301	-	-	-	-	105	-	-	475,406
Growth	83,597	-	44,317	-	-	148,552	-	-	-	276,466
	83,597	475,301	44,317	-	-	148,552	105	-	-	751,872
Roads:										
Rehabilitation and Replacement	28	730,564	7,294	-	-	-	-	2,868	42,786	783,540
Growth	413,359	145	-	114,412	-	12,945	-	78,807	619,942	1,239,610
	413,387	730,709	7,294	114,412	-	12,945	-	81,675	662,728	2,023,150
Subtotal	**496,984**	**1,206,010**	**51,611**	**114,412**	**-**	**161,497**	**105**	**81,675**	**662,728**	**2,775,022**
Environmental Services										
Water:										
Rehabilitation and Replacement	-	275,111	-	-	-	-	-	1,140	-	276,251
Growth	79,464	2,090	-	-	-	-	-	-	116,128	197,682
	79,464	277,201	-	-	-	-	-	1,140	116,128	473,933
Wastewater:										
Rehabilitation and Replacement	-	686,052	-	-	-	-	-	52,651	-	738,703
Growth	208,236	5,574	-	-	-	-	-	4,627	982,425	1,200,862
	208,236	691,626	-	-	-	-	-	57,278	982,425	1,939,564
Waste Management:										
Rehabilitation and Replacement	-	-	-	16,683	-	-	-	-	-	16,683
Growth	509	-	80,030	10,016	-	-	-	-	-	90,555
	509	-	80,030	26,699	-	-	-	-	-	107,238
Forestry	10,456	-	-	11,130	-	-	-	-	-	21,586
Energy Management	-	9,486	-	-	-	-	-	-	-	9,486
Subtotal	**298,665**	**978,312**	**80,030**	**37,829**	**-**	**-**	**-**	**58,418**	**1,098,553**	**2,551,807**

Figure 12: 2019 Budget snapshot (York Region, 2019)

Following the trail of budgets, one can then identify details on upcoming project plans. It is recommended that individual projects be evaluated, and can be organized in table form, as shown in Table 4. Further diving into the budgets, a breakdown of capital projects by number, title, and budgeted capital spending authority forecasts are provided in Figure 13.

Wastewater

10-Year Capital Project Expenditures and Capital Spending Authority by Program Group

(in $000s)	Spent to Date Dec 31/2017	Year End Forecast	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	1 - 10 Year Total	Balance to Complete	Total Estimated Cost	Capital Spending Authority
Program Group: Growth																
Gross Expenditures																
70080 : UYSS Interim Servicing Solution	-	630	992	3,060	10,220	8,840	10	10	-	-	-	-	23,132	-	23,762	23,132
70530 : Yonge St Sewer Twinning	-	-	-	-	-	-	-	-	-	-	-	522	522	51,670	52,192	-
71220 : Queensville Holland Landing Sharon York Durham Sewage System (YDSS) Connection	115,827	500	55	-	-	-	-	-	-	-	-	-	55	-	116,382	55
71230 : Holland Landing Lagoons Decom	-	-	-	-	-	-	-	-	-	100	1,000	-	1,100	-	1,100	-
72240 : Keswick Water Resource Recovery Facility Expansion	98,335	-	10	-	-	-	-	-	-	-	-	-	10	-	98,345	10
72360 : Duffin Creek Water Pollution Control Plant (WPCP) Outfall Effluent Strategy	7,342	1,900	4,000	5,500	4,030	1,970	1,000	1,000	2,000	3,000	2,500	2,000	27,000	234,900	271,142	15,000
72530 : Duffin Creek Stage 1 & 2 Upgrades	200,778	4,010	500	50	-	-	-	-	-	-	-	-	550	-	205,338	550
72580 : Inflow & Infiltration Reduction Implementation	7,500	16	-	-	-	-	-	-	-	-	-	-	-	-	7,516	-
73640 : Inflow & Infiltration Reduction	3,171	3,163	3,601	3,751	3,539	3,562	3,648	3,872	2,350	2,350	2,350	2,350	31,373	22,952	60,659	10,891
73720 : York Durham Sewage System (YDSS) - Duffin Creek Water Pollution Control Plant Phase 3 Expansion	626,023	313	7,000	2,150	50	-	-	-	-	-	-	-	9,200	-	635,536	9,200
74040 : York Durham Sewage System (YDSS) - Southeast Collector	574,123	1,700	390	-	-	-	-	-	-	-	-	-	390	-	576,213	390
74270 : Upper York Sewage Servicing	80,186	6,450	20,633	55,482	72,030	61,000	95,000	90,000	90,000	66,900	36,000	12,865	599,910	44,000	730,546	221,045
75290 : North Markham Trunk Sewer	-	-	-	-	-	-	-	-	-	-	348	696	1,044	33,787	34,831	-

Figure 13: Budget snapshot

Once project numbers and titles are identified, information on them can be obtained easily, through public records such as council reports. These reports often have regular updates on project status. Growth projects denote new builds and extensions or expansions to existing wastewater infrastructure. Based on titles and additional research, appropriateness can be discerned.

Looking at these projects and the forecasted budgets must guide the direction of identifying and populating the table. For example, Figure 13, some projects have large amounts of budget allocated 10 years into the future. This is an indication of the stage the project is in and can be confirmed through a search of public council records with project number and title.

Table 5: Future construction projects

Project name and number	Project phase (planning, design, construction)	Start date (year)	Balance to be spent
70530: Yonge St. Sewer Twinning	Planning	2028	$52,192,000
74270: Upper York Sewage Servicing	Planning	2010	$44,000,000
75290: Markham Trunk Sewer	Pre-planning	2027	$33,787,000

Projects with long term forecasts are good examples to explore WWERS integration, as the goal is to insert WWER components into the planning and design phases. Table 4 provides a sample of some potential projects and their costs.

Step 3: Determine preferred locations

The recovered heat is highest close to large wastewater users (i.e. buildings). Therefore, York Region has the potential to benefit from using recovered energy at several of its office space, pumping stations and treatment facilities. Proponents can install these systems in the government owned buildings. Additionally, in Ontario, all municipalities are mandated to conduct Energy Reporting on the facilities they own and manage, required under the Province of Ontario Regulation 507/18 (York Region, 2019). This provides useful energy consumption data, such as electricity, natural gas and emissions data.

York Region data on the wastewater system was available through FlowWorks and All Pipes online software systems. Figure 14 illustrates the locations of the monitoring stations.

Monitoring stations measure and collect temperature, flow rate data every minute. The usefulness of monitoring stations is the real time collection of wastewater temperature and flow rates from within the sewers. This includes rainfall and snowmelt coming from stormwater systems. Figure 15 outlines this data for one monitoring station, of over 300 installed in York Region's sewers, in the month of January 2018.

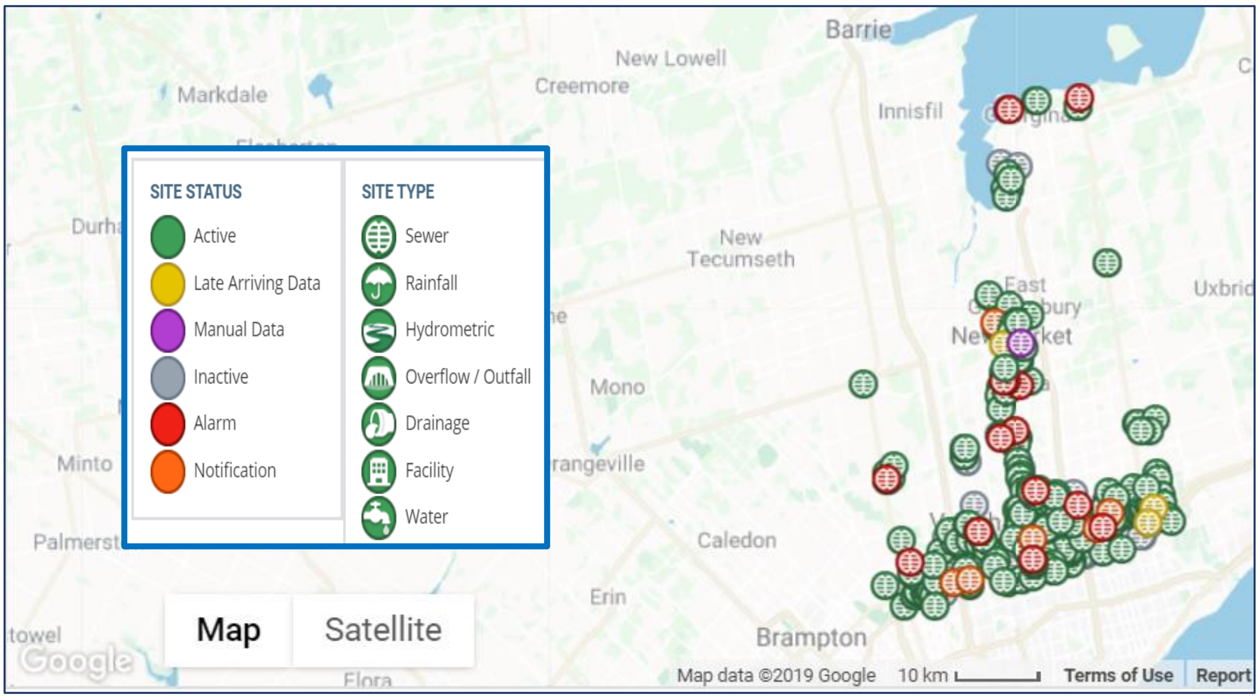


Figure 14: Screen capture of Flow Works monitoring stations

Data from monitoring stations can be used to determine flow rates and temperature suitability of wastewater for energy recovery.

Municipally owned facilities appear to be good candidates, as constant high demand is observed. Temperature measurements from monitoring stations may be used to determine flow rates and temperature of wastewater downstream of municipal buildings. Table 4 outlines energy (natural gas) demand based on historical data as well as temperature and flow measurements. These measurements can be used to determine energy recovery potential, by using the formula:

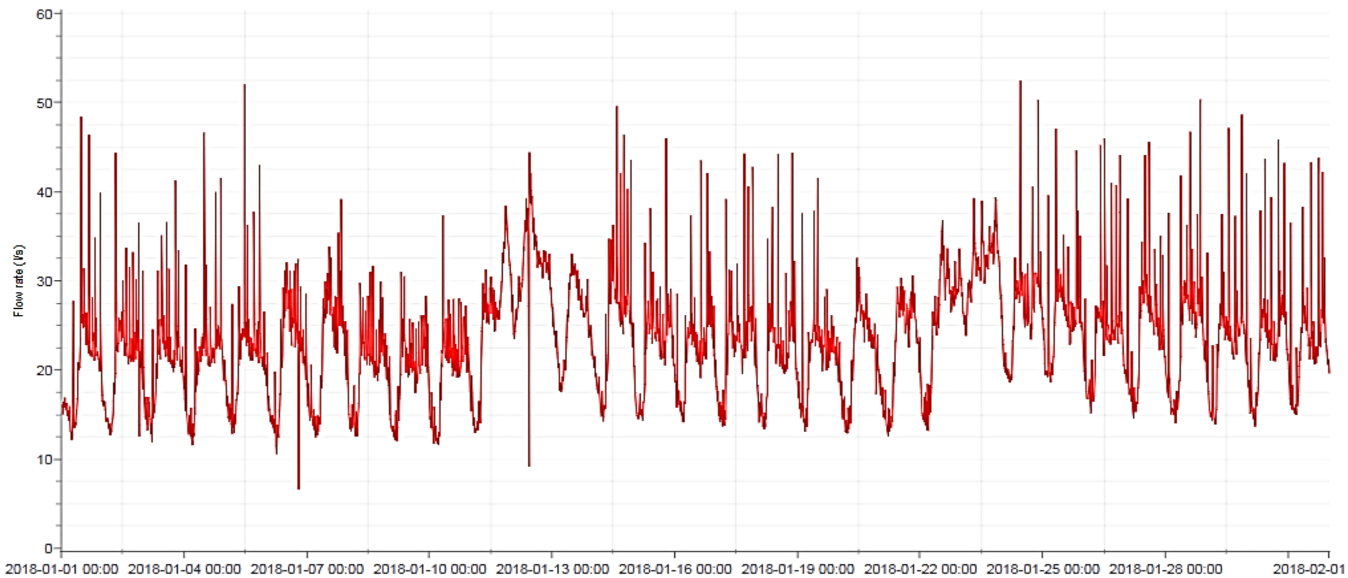
York Region collects and monitors wastewater flow and temperature data on a regular basis using web-based monitoring tools like flow work for analysis and reporting of all wastewater systems.

There is also a lesser burden on the approval process, as the proponent of the project would have much fewer constraints as the owner. Data from NE6, the monitoring station outlined in Figure 15, shows that average temperature in January, the coldest month, remains steadybetween the ranges of 10-25 degrees celcius.

Figure 15: York Region Admin Centre site and Wastewater infrastructure (FlowWorks, 2019)

The monitoring station NE06 can be seen downstream of the sewage flow, which is channeled from the administrative centre building, to the direction of the monitoring station. The numbers denote the size of the wastewater pipe diametre in millimetres. Therefore based on data from NE06 monitoring station, it can be concluded that constant flow and temperature exist throughout the year.

Figure 16: NE06 Flow rate, Jan. 1-31, 2018 (York Region, 2019)



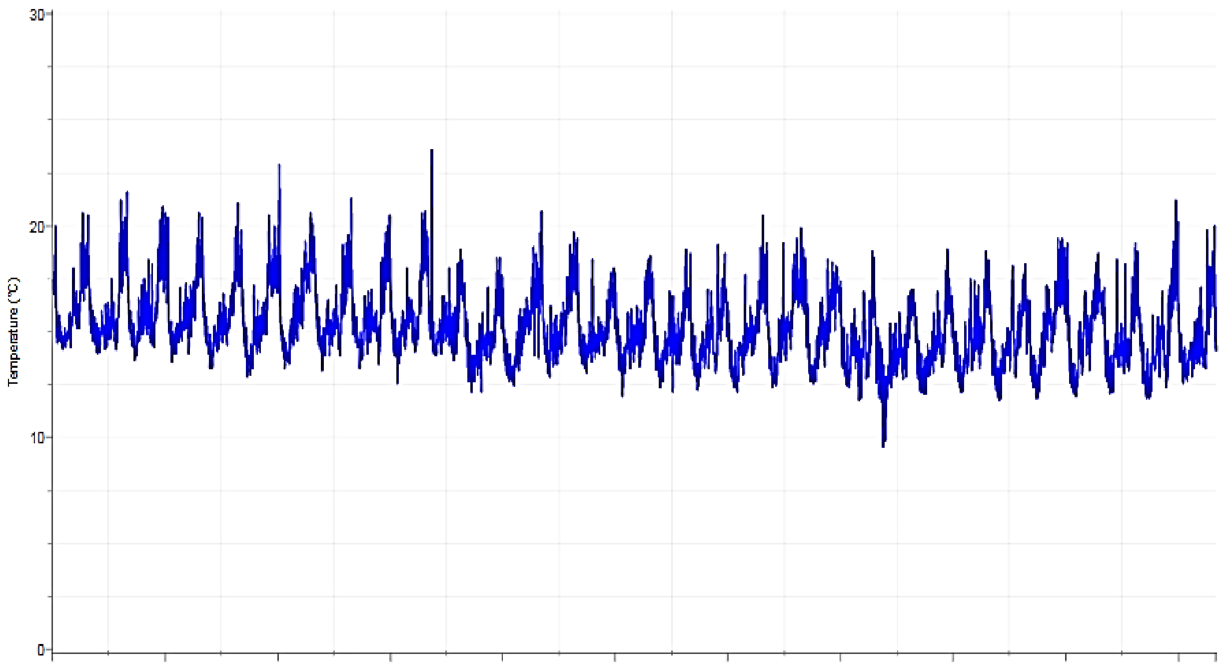


Figure 17: Average Temperature, Monitoring station NE06, January 1-31, 2018 (York Region, 2019)

Step 4: Asset Integration

Energy potentials and GHG emission offset calculations are top of mind for councillors and management, therefore it is recommended to highlight this information. Revenue calculations vary based on the technology selected but can have a hypothetical example to demonstrate a recovery potentials. For example, using a heat balance formula, and inserting recommended basic variables, 865 MWh/year may be recovered.

Based on a cost of 9.6268 ¢/m^3 for natural gas and the emissions data reported from previous years, the natural gas savings and the carbon offsets can be outlined, as in Table 5.

Table 6: Net savings

Building name	GHG Emissions (Kg):	Natural Gas (cu. M.):	Potential Natural gas savings ($/year)
York Region Administrative Centre	727,978	339,411	$32,674
East Gwillimbury and York Regional Police Operations Centre	1,845,303	861,977	$82,980.80
145 Harry Walker Parkway	181,022	87,546	$8,427.88
South Services Centre	119,580	42,369	$4,078.78
Vaughan Integrated Office Facility	116,012	52,039	$5,009.69

Natural gas costs savings were calculated by the following formula:

Potential savings = *cost* x *usage (cubic metres)*

=9.6268 339,411*

=$32,674

Where n= current natural gas market price, obtained in this example from Enbridge, at $0.0962 per cubic metre and usage is the quantity consumed in prior year's report, in cubic metres.

This step should also include any innovations or potential technology that may increase stakeholder engagement. For example, the @Source-Energy Pipe system is energy efficient system used for heating and cooling for buildings in Ontario (Renewable Resource Recovery Corp, 2009). The system functions as a standard sewer pipe and heat recovery system with precast concrete pipes, custom engineered for new builds (Renewable Resource Recovery Corp, 2009). A 100 ft. long pipe system has the capacity to remove 37,000 BTU/hr/100 ft. from the effluent (Renewable Resource Recovery Corp, 2009).

For retrofits, Noventa's patented HUBER *ThermWin*® wastewater energy transfer system could be an example for consideration. With this system, the energy is either extracted from the sewer to supply heating to buildings in the winter or heat is rejected to the sewer to provide cooling to buildings in the summer (Noventa Energy Partners, 2019). Generally, the temperature of municipal sewage is relatively constant in the range of 10 °C to 20 °C throughout the year and therefore ideal to heat and cool buildings. Up to 5 kW eco-friendly energy can be generated by investing 1 kW electric energy (Noventa Energy Partners, 2019). Based on a minimum temperature of 10°C, and 5 L/s of wastewater, 40kWh of energy may be produced (Noventa Energy Partners, 2019). Figure 18 provides a snapshot of 24 hours of data, on December 2, 2019, a date with ambient temperatures of -4 °C.

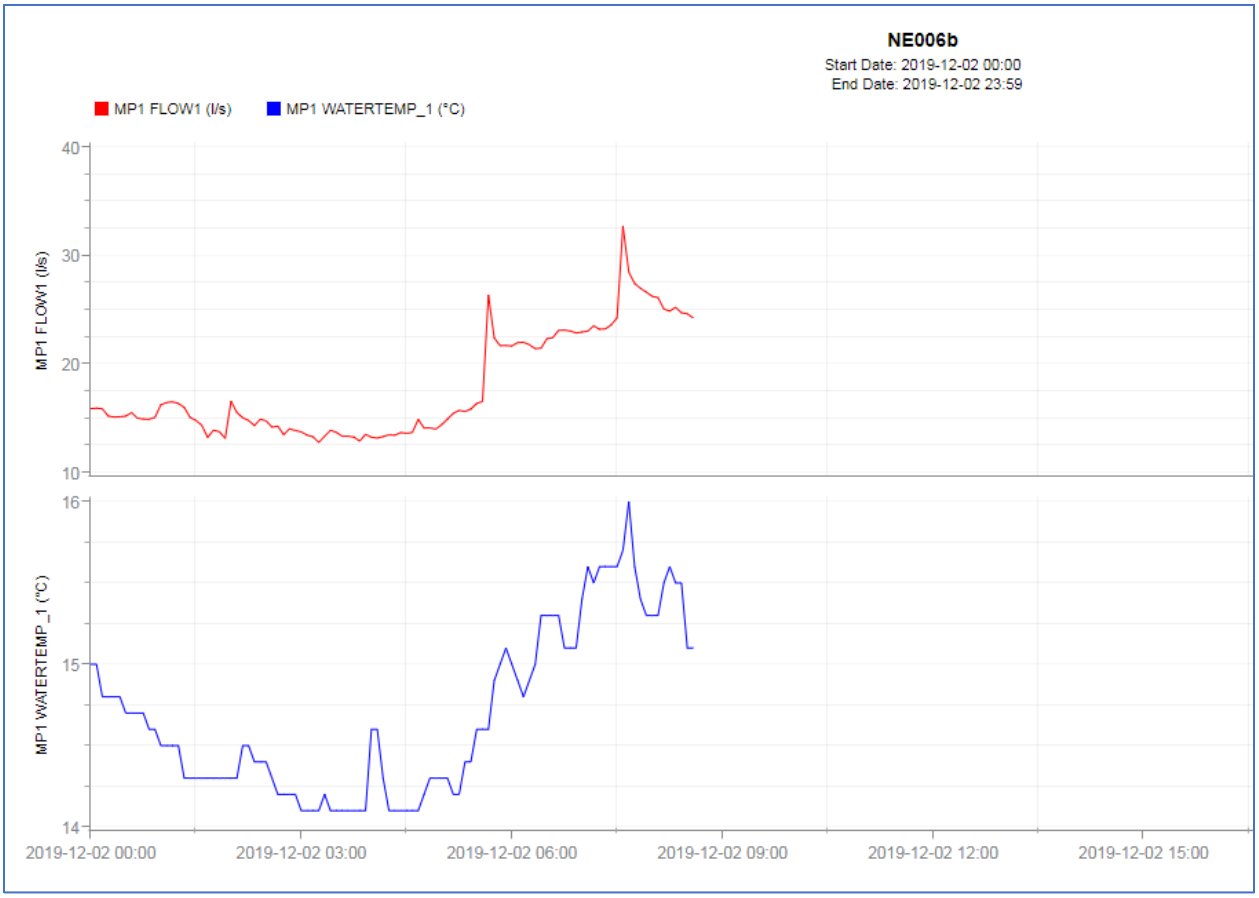


Figure 18: 24-hour data for NE06

The HUBER system also promises a self-cleaning and easy retrofitting heat recovery system, which addresses maintenance and construction concerns related to retrofits (Noventa Energy Partners, 2019).

Step 4 also provides guidance for including any funding support or tie-in to Provincial plans must be highlighted to make a stronger case. For example, the Province of Ontario's Green Infrastructure stream, and all other guiding documents identified from Step 1. Listing greater support for the project will aid in decision-makers next steps.

Chapter 5 Summary and Discussion

The objectives of this study and ways in which each was achieved is summarized as follows:

1. Identify WWERS barriers: This was done by the root cause analysis
2. Address barriers: This was done by the WWERS planning guideline
3. Case study demonstration of guideline: Guideline was applied to York Region

Institutional barriers were identified and addressed through the guideline. Additionally, the guideline was demonstrated to quantify WWERS in the case study in York Region. Results provided several locations for WWERS were generated including revenue estimates, and GHG offsets.

While government is the owner of public infrastructure, due to bureaucratic process, it becomes difficult to implement new or innovative changes. Due to the nature of public infrastructure, several challenges exist in fair procurement and purchase of technology, such as competitive bidding. This creates challenges when innovative or unique technology is introduced, as the tendering process often does not consider differences in proposed solutions, if the overall criteria are met. For example, a tender requesting construction of heat recovery systems may not effectively consider the ease of maintenance between bids.

Several sustainability and green energy claims were made, few of them were implemented in the York Region example. Unless reports are tied to Master Plans with specific or measurable language, the action is not mandated to occur (Nemeth, 2019). For example, in York Region's Water and Wastewater Master Plan, there is a section on heat energy recovery with language that suggests work is only done in a voluntary nature "Continue Energy Optimization and Renewable Energy Initiatives" (York Region, 2015). However, even without mandated requirements, tie-in to plans and corporate objectives are still an important item to outline, especially with measurable benefits that can be quantified through analysis performed in the guideline.

Chapter 6 Conclusions and Recommendations

This study is one of the few attempts made to facilitate greater adoption of WWERS, and the first to explicitly consider their integration into the municipal planning processes. The guideline was developed to aid other regions, municipalities and researchers in evaluating feasibility of WWERS. It is expected that municipalities equipped with this knowledge will manage their future investments in wastewater infrastructure to maximize opportunities for heat recovery. Particularly, this implementation guideline is helpful for smaller municipalities with limited resources and expertise. The results of this study can be feed into activities to reduce GHG emissions as well. It will also allow municipalities to effectively consider WWERS as a sustainable energy programs and policies that should be implemented.

It is recommended that municipalities implement WWERS in new facilities being built, or if there are retrofit plans. This makes the most logical sense, as it can align with the integrated asset management principles that municipalities are so fond of, but struggle to coordinate.

Having a lens of municipal impediments has revealed that technological solutions could potentially eliminate several municipal impediments. For example, the demonstrated self-cleaning nature of some technologies (e.g. Noventa's HUBER Thermwin system) greatly addresses the concerns of maintenance staff being trained and having to manually perform routine maintenance on clogged heat exchanger plates. Additionally, the amount of effort, lack of expertise and other issues identified in the root cause analysis would be avoided, as well as the burden onto the taxpayer, as a private organization is already an expert with significant operating experience in other jurisdictions.

The implementation guide is written for the WWERS proponent which may be a government, entrepreneurs, technology manufacturers or researchers. The study objectives were developed to bridge the gap between industry and government in terms of WWERS implementation. Item 1 looks to identify the challenges from a government perspective; this helps capture the points outside of the control of the proponent/reader of the guide, as well as gives insight into the local legislative context. The second objective was designed to collate and disseminate the results from objective 1, but with a view to facilitate WWERS from a business perspective. This means that the guideline can be used as a feasibility tool, as regulatory, social and technical items are considered. Lastly, the guideline also considers methods of dissemination to local government officials and provides guidelines on this as well.

Because it is not within the scope of this research, future areas of research should determine how public-private partnerships may be integrated into the procurement process. It is recommended to transition heat recovery and other innovative technology to the private sector. Fewer funding challenges and public opinion drivers make private sector a reasonable implementer of WWERS. Additionally, the risk averse nature of government results in fewer risks taken for efficiencies and innovative technology (Maeda, 2019). The private sector is profit driven, allowing for better management of resources and for championing innovations (Maeda, 2019). In addition to government funding mechanisms, privatization or jointly owned and operated ventures, other funding mechanisms, such as public private partnerships should be examined. This is like the examples in Chapter 3, where both Sweden and Norway have partnered with energy company Fortum (Bush and Shiskowski, 2014).

Several options exist for privatization. One model can be seen through EPCOR in Edmonton, Alberta, Canada. The EPCOR model has been successfully running in Edmonton for over 125 years (EPCOR, 2019). EPCOR is a municipally owned electric and water utility company (EPCOR, 2019). They build, own and operate electrical, natural gas and water transmission and distribution networks, water and wastewater treatment facilities, sanitary and stormwater systems, and infrastructure in Canada and the United States (EPCOR, 2019). The City of Edmonton is EPCOR's sole Shareholder, and they operate as a commercial entity, governed by an independent Board of Directors (EPCOR, 2019). Since incorporating in 1996, they've achieved exceptional growth and have more than doubled their dividend (EPCOR, 2019).

The removal of regulatory barriers to encourage renewable energy innovations, particularly to develop policy or funding mechanisms to encourage innovative partnership in the public sector, is recommended. The effect of WWERS on carbon markets, both actual and theoretical, may also be an area that will allow for the benefits of WWERS to become more important in industry as well as positively influence the public opinion. This will allow for the private sector to pioneer resource effective implementation, without added cost to taxpayers. Examples of this have been demonstrated in Scandinavia, and even in Calgary and Vancouver, Canada.

Wastewater infrastructure today represents multifunctional systems where technological as well as management choices influence the different functions and overall environmental impacts. To decrease these impacts, the decision-making process relating to the infrastructure changes must be modified with greater civic literacy and by engaging the private sector.

REFERENCES

Abdel-Aal, M., Schellart, A., Kroll, S., Mohamed, M., & Tait, S. (2018). Modelling the potential for multi-location in-sewer heat recovery at a city scale under different seasonal scenarios. *Water Research,145,*618-630.

Allen-Muncey, K. (2019, October 29). Director, Halifax Civic Innovation Lab. (O. Polda, interviewer)

Alnahhal, S., & Spremberg, E. (2016). Contribution to Exemplary In-House Wastewater Heat Recovery in Berlin,. *Science Direct*, *40*, 35-49.

Amarala, R., Alegreb, H., & Matosa, J. S. (2017). Highlights of key international water infrastructure asset management initiatives, and trends, challenges and developments in Portugal. *Water Policy,9,*128-146.

Ameyawa, B., Yao, L., Opponga, A., & Agyemana, J. K. (2019). Investigating, forecasting and proposing emission mitigation pathways for CO2 emissions from fossil fuel combustion only: A case study of selected countries. *Energy Policy,130*, 7-21.

AMO. (2019, n.d. n.d.). *Municipal Government Explained*. Retrieved from Association of Municipalities of Ontario (AMO): http://www.amo.on.ca/YourAssociation/Municipal101

Averfalka, H., Werner, S., Ingvarsson, P., Persson, U., & Gong, M. (2017). Large heat pumps in Swedish district heating systems. *Renewable and Sustainable Energy Review,79*, 1275-1284.

Bertrand, A., Aggoune, R., & Maréchal, F. (2017). In-building waste water heat recovery: An urban-scale method for the characterisation of water streams and the assessment of energy savings and costs. *Applied Energy*, 110-125.

Bush, K., & Shiskowski, D. (2008, July 21). *Discussion Paper – Heat Recovery*. Retrieved May 7, 2018, from Capital Regional District : https://www.crd.bc.ca/docs/default-source/seaterra-pdf/related-articles/2009_discussion-paper-031-6--heat-recovery.pdf?sfvrsn=0Cecconet, D.; Raček, J.; Callegari, A.; Hlavínek, P. Energy Recovery from Wastewater: A Study on Heating and Cooling of a Multipurpose Building with Sewage-Reclaimed Heat Energy. *Sustainability*, 12, 116.

Canadian Infrastructure Report Card. (2019). *2019 Canada Infrastructure Report Card.* Retrieved from Canadian Infrastructure Report Card: http://canadianinfrastructure.ca/downloads/canadian-infrastructure-report-card-2019.pdf

Cipolla, S. S., & Maglionico, M. (2014). Heat recovery from urban wastewater: Analysis of the variability of flow rate and temperature. *Energy and Buildings, 69*, 122-130.

Chang, S., Chen, J., & Shi, L. (2017). Using Thermal Shock to Inhibit Biofilm Formation in the Treated Sewage Source Heat Pump Systems. *Applied Sciences,7,*343.

Culhaa, O., Huseyin, G., Emrah, B., Orhan, E., & Arif, H. (2015). Heat exchanger applications in wastewater source heat pumps for buildings: A key review. *Energy and Buildings , 104*, 215-232.

Durdevica, D., Balic, D., & Frankovic, B. (2019). Wastewater heat utilization through heat pumps: The case study of City of Rijeka. *Journal of Cleaner Production, 10*, 207-213.

Durrenmatt, D. J., & Wanner, O. (2014). A mathematical model to predict the effect of heat recovery on the wastewater temperature in sewers. *Water Research , 48*, 548-558.

DWA. (2009). Energy from Wastewater - thermal and potential energy: Advisory guideline DWA-M 114E. Edition M 114.

Elías-Maxil, J., van der Hoek, J. P., Hofman, J., & Rietveld, L. (2014). Energy in the urban water cycle: Actions to reduce the total expenditure of fossil fuels with emphasis on heat reclamation from urban water. *Renewable and Sustainable Energy Reviews , 30,* 808–820.

Fortum. (2019, April 1). *Combined Heat and Power*. Retrieved from Fortum: https://www.fortum.com/about-us/our-company/our-energy-production/combined-heat-and-power-chp-more-efficient-power-generation

Freimuth, C., Oelmann, M., & Amann, E. (2018). Development and prospects of standardization in the German municipal wastewater sector. *Science of The Total Environment, 635*, 375-389.

Frijns, J., Hofman, J., & Nederlof, M. (2013). The potential of (waste)water as energy carrier. *Energy Conversion and Management , 65,* 357-363.

Fung, A. S., Taherian, H., Hossein, M., Rahman, Z., & Selim, M. H. (2015). Energy Audit and Base Case Simulation of Ryerson University Buildings. *ASHRAE Transactions , 121*, 84-98.

Gartlehner, G., Schultes, M.-T., Titscher, V., Morgan, L. C., Bobashev, G. V., Williams, P., et al. (217). User testing of an adaptation of fishbone diagrams to depict results of systematic reviews. *BMC Med Res Methodol , 17* (169), 1-9.

Government of Ontario. (2018, June 8). *Building together – Guide for municipal asset management plans*. Retrieved December 10, 2018, from Government of Ontario: https://www.ontario.ca/page/building-together-guide-municipal-asset-management-plans#section-3

Government of Ontario. (2008). *Planning guidelines for Drinking-Water Systems* . Retrieved from Ministry of the Environment: Planning guidelines for Drinking-Water Systems

Government of Ontario. (2018, December 3). *Data catalogue: Energy use and greenhouse gas emissions for the Broader Public Sector.* Retrieved from Energy, Northern Development and Mines: https://www.ontario.ca/data/energy-use-and-greenhouse-gas-emissions-broader-public-sector

Hao, X., Li, J., C.M. van Loosdrecht, M., Jiang, H., & Liu, R. (2019). Energy recovery from wastewater: Heat over organics. *Water Research , 161,* 74-77.

Hofman, J., Bloemendal, M., Wols, B., Agudelo-Vera, C., Elias Maxil, J., Boderie, P., et al. (2014). Modelling of Thermal Energy Balance in Sewer Systems. *International Conference on Hydroinformatics* , Paper343.

Hook, M., & Tang, X. (2013). Depletion of fossil fuels and anthropogenic climate change—A review. *Energy Policy , 52*, 797–809.

Ichinose, T., & Kawahara, H. (2017). Regional feasibility study on district sewage heat supply in Tokyo with GIS. *Sustainable Cities and Society , 32*, 235–246.

IPCC. (2013). *IPCC Special Report.* Retrieved July 12, 2018, from Intergovernmental Panel on Climate Change: https://www.ipcc.ch/site/assets/uploads/sites/2/2018/07/SR15_SPM_High_Res.pdf

ISO. (2014, January 15). *ISO 55000:2014(E).* Retrieved 2019, from ISO: http://www.irantpm.ir/wp-content/uploads/2014/03/ISO-55000-2014.pdf

Kollmann, R., Neugebauer, G., Kretschmer, F., Truger, B., Kindermann, H., Stoeglehner, G., et al. (2017). Renewable energy from wastewater - Practical aspects of integrating a wastewater treatment plant into local energy supply concepts. *Journal of Cleaner Production , 155*, 119-129.

Kordana, S. (2017). SWOT Analysis of Wastewater Heat Recovery. *Web of Conferences , 17*, 1-8.

Maeda, C. (2019, October 10). President and CEO, Brick Street Software. (O. Polda, Interviewer)

Mikkonen, L., Rämö, J., Keiski, R., & Pongrácz, E. (2013). Heat recovery from wastewater: Assessing the potential in northern areas. *Water Research at the University of Oulu* (pp. 161-164). Oulu: University of Oulu. doi:10.13140/2.1.1728.8326

Müller-Steinhagen, H., Malayeri, M. R., & Watkinson, A. P. (2011). Heat Exchanger Fouling: Mitigation and Cleaning Strategies. *Heat Transfer Engineering , 32*, 3-4.

MBNC. (2018, November 1). *2017 Performance Measurement Report*. Retrieved November 4, 2018, from Municipal Benchmarking Network Canada: http://mbncanada.ca/app/uploads/2018/11/2017-Final-Report.pdf

Meggers, F., & Leibundgut, H. (2011). The potential of wastewater heat and exergy: Decentralized high-temperature recovery with a heat pump. *Energy and Buildings , 43*, 879–886.

Mildenberger, M., Howe, P., Lachapelle, E., Stokes, L., Marlon, J., & al., e. (2016). The Distribution of Climate Change Public Opinion in Canada. *PLoS One , 11*, e0159774.

Ministry of Municipal Affairs and Housing. (2019, January 18). *How municipalities and Ontario work together*. Retrieved from Ontario: https://www.ontario.ca/page/how-municipalities-and-ontario-work-together

Natural Resources Canada. (2015, 11 27). *Natural Gas: A Primer*. Retrieved from Natural Resources Canada: https://www.nrcan.gc.ca/energy/energy-sources-distribution/natural-gas/natural-gas-primer/5641#who

Nemeth, J. (2019, October 29). Expert, Infrastructure Programming and Studies . (O. Polda, Interviewer) Toronto, ON, Canada.

Noventa Energy Partners. (2019, n.d. n.d.). *Huber and the Huber Thermwin System*. Retrieved August 21, 2019, from Noventa: Reimagining Energy: https://noventaenergy.com/technologies/wastewater-heat-recovery/huber/

Park, S., Park, S. I., & Lee, S.-H. (2016). Strategy on sustainable infrastructure asset management: Focus on Korea's future policy directivity. *Renewable and Sustainable Energy Reviews , 62*, 710-722.

Pasquini, L., Ziervogel, G., Cowling, R. M., & Shearing, C. (2015). What enables local governments to mainstream climate change adaptation? Lessons learned from two municipal case studies in the Western Cape, South Africa. *Climate and Development , 7,* 60-70.

Peterson, E. L., Carlson, S. A., Schmid, T. L., Brown, D. R., & Galuska, D. A. (2019). Supporting Active Living Through Community Plans: The Association of Planning Documents With Design Standards and Features. *American Journal of Health Promotion, 32*, 191-198.

Racoviceanu, A., Karney, B. W., Kennedy, C., & Colombo, A. F. (2007). Life-Cycle Energy Use and Greenhouse Gas Emissions Inventory for Water Treatment Systems. *Journal of Infrastructure Systems , 13*, 261-270.

Region of Peel. (2019). *Climate Change Master Plan.* Brampton: Region of Peel.

Regional Municipality of York. (2016, November 1). *Water and Wastewater Master Plan*. Retrieved April 25, 2018, from York Region: https://www.york.ca/wps/wcm/connect/yorkpublic/9602fc09-22ec42028ce6f2287a7b1aee/York+Region+Water+and+Wastewater+Master+Plan+2016pdf.pdf?MOD=AJPERES

Renewable Resource Recovery Corp. (2009, October 9). @Source-Energy Pipe. Sudbury, Ontario, Canada.

Resort Municipality of Whistler. (2013, November 21). *Affiliated organizations*. Retrieved from Resort Municipality of Whistler: https://www.whistler.ca/about/affiliated-organizations

Rodgers, M., & Oppenheim, R. (2019). Ishikawa diagrams and Bayesian belief networks for continuous improvement applications. *TQM Journal , 31*, 294-318.

S.Ertesvåg, I. (2011). Uncertainties in heat-pump coefficient of performance (COP) and exergy efficiency based on standardized testing. *Energy and Buildings , 43* (8), 1937-1946 .

Samra, S. A., Ahmed, M., Hammad, A., & Zayed, T. (2018). Multiobjective Framework for Managing Municipal Integrated Infrastructure. *J. Constr. Eng. Manage. , 144*, 04017091.

Shah, R., Thonon, B., & Benforado, B. (2000). Opportunities for heat exchanger applications in environmental systems. *Applied Thermal Engineering , 20,* 631-650.

Sitzenfrei, R., Hillebrand, S., & Rauch, W. (2017). Investigating the interactions of decentralized and centralized wastewater heat recovery systems. *Water Science and Technology* , *75*, 1243-1250.

Skinner, J. F., Gasciogne, G. B., Gregory, J. H., Hatton, C., Mohlman, W., & Stevenson, W. (1925). Definitions for Sewerage and Sewage Disposal Practice. *American Journal of Public Health* , *15* (4), 327-333.

Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, *104*, 333-339.

Sohail, U., Kwiatek, C., Fung, A. S., & Joksimovic, D. (2019). Techno-economic feasibility of wastewater heat recovery for a large hospital in Toronto, Canada. *CANCAM*. Sherbrooke: CANCAM.

Statistics Canada. (2019, July 01). *Energy statistics*. Retrieved from Statistics Canada: https://www150.statcan.gc.ca/n1/en/subjects/energy/energy_supply_and_use

Statistics Canada. (2017, 12 01). *Households and the Environment Survey: Energy use, 2015*. Retrieved from Statistics Canada: https://www150.statcan.gc.ca/n1/daily-quotidien/171201/dq171201f-eng.htm

Stoehr, A. (2019, February 7). Root Cause Analysis. *Certificate in Continuous Process Improvement* . Richmond Hill, ON, Canada: Excellence Canada.

Tomic, T., & Schneider, D. R. (2018). The role of energy from waste in circular economy and closing the loop concept – Energy analysis approach. *Renewable and Sustainable Energy Reviews* , *98*, 268-287.

United Nations. (2016, January 29). Report of the Conference of the Parties on its twenty-first session, held in Paris from 30 November to 11 December 2015. Addendum. Part two: Action taken by the Conference of the Parties at its twenty-first session. Retrieved December 10, 2018, from United Nations Framework Convention on Climate Change: https://unfccc.int/resource/docs/2015/cop21/eng/10a01.pdf

USEPA. (2018, December 1). *Greenhouse Gas Equivalencies Calculator*. Retrieved October 10, 2019, from United States Environmental Protection Agency: https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

van der Westhuizen, J., & Myburg, J. (2014). Mobile mapping: optimising total infrastructure asset management . *Civil Engineering : Magazine of the South African Institution of Civil Engineering* ,*22* (4), 33-36.

Vedachalam, S., Kay, D. L., & Riha, S. J. (2014). Capital Investment and Privatization: Public Opinion on Issues Related to Water and Wastewater Infrastructure. *Public Works Management & Policy* , *19* (2), 118-147.

Wu, J., & Chen, Y. (2016). The evolution of municipal structure. *Journal of Economic Geography, 16*, 917-940.

York Region. (2018). *Wastewater Collection and Treatment*. Retrieved September 10, 2018, from York Region: http://www.york.ca/wps/portal/yorkhome/environment/yr/waterandwastewater/wastewatercollectionandtreatment/wastewatercollectioandtreatment/!ut/p/a1/rVbdcqIwGH2WvfCSyQ-RhEvWdhWs0G07VrhxIgTFlWAx1XaffoNbZ3W1amfCBZPv4-Qk50zmEJCAEUgkXxdTropK8kVTJ87Y97p-r9eHQURY

York Region. (2016, November 1). *Water and Wastewater Master Plan*. Retrieved April 25, 2018, from York Region: https://www.york.ca/wps/wcm/connect/yorkpublic/9602fc09-22ec-4202-8ce6f2287a7b1aee/York+Region+Water+and+Wastewater+Master+Plan+2016pdf.pdf?MOD=AJPERES

York Region. (2019, July 9). *Broader Public Sector Energy Report*. Retrieved from York Region Open Data:https://insightsyork.opendata.arcgis.com/search?q=Broader%20Public%20Sector%20Energy%20Report&tags=electricity