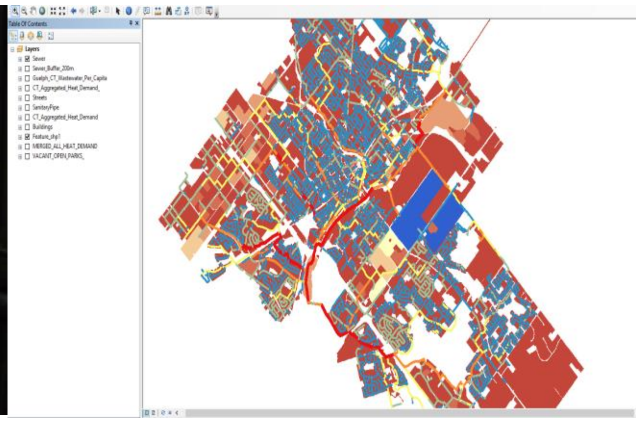
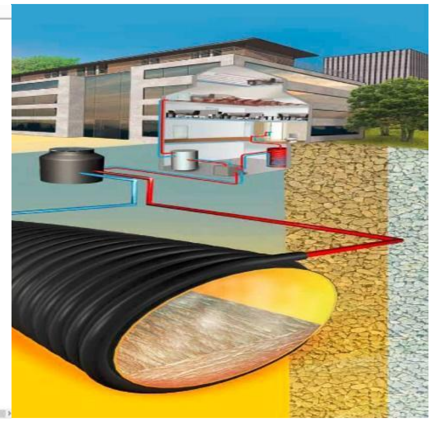
TOWARDS A CIRCULAR URBAN METABOLISM WITH SEWER WASTEWATER HEAT RECOVERY SYSTEMS (SWWHRS):

Introducing a SWWHRS Planning Decision Support System





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A Major Paper submitted to the Faculty of Environmental Studies
In partial fulfillment of the requirements for the degree of Master in Environmental Studies,
York University, Toronto, Ontario, Canada.

September 12, 2016 (Final Version)

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ACKNOWLEDGEMENTS

The completion of this research paper would not have been possible without the support of certain people.

Thank you to Justin Podur, my supervisor, for the invaluable guidance, encouragement, patience and understanding provided during the crafting of my research paper. Your unwavering support helped make this paper a reality.

Thank you to Christina Hoicka, my advisor and supervisor, for all the advice and support on developing this research topic and throughout my Masters degree. You helped me tremendously throughout this journey of knowledge exploration and growth.

Thank you to Alex Chapman and his team from the City of Guelph for providing me with the crucial spatial data for my case study. Without your generosity I would have been hard-pressed to demonstrate the validity of my research.

Thank you to Bryan Purcell from the Toronto Atmospheric Fund for providing me with a supportive work environment and accommodating my needs so that I could do what is necessary and still follow my dreams.

Thank you to the support of my family and friends who let me still be a reoccurring footnote in your lives while I finished this research paper. I will make up for lost time with all of you.

And last but definitely not least, thank you to my partner and best friend Erica. If not for you I would not have set out on this amazing journey of completing a Masters degree. I look forward to continuing our voyage together as students of life.

FOREWORD

My major research paper (MRP) is an exercise in implementing praxis in relation to both of my major learning components that are the basis of my plan of study. My two learning components for my plan of study are:

1. Theories and practice of climate change mitigation and adaptation as it relates to urban energy systems;

2. Theories and practice of achieving sustainability and resilience in cities through integrated community energy system planning.

My MRP supports my first learning component by demonstrating how spatial analysis can be used by community energy planners to utilize low carbon resources and reduce the use of fossil fuels for heating, significantly reducing carbon emissions and mitigating further climate change. My MRP accomplishes this by introducing the design and example implementation of the first component for a planning decision support system to be used for finding ideal locations within a city for recovering sewer wastewater heat and matching it with appropriate centres of thermal energy demand.

My MRP supports my second learning component by demonstrating how the model planning decision support system I introduce can be used as a community energy planning tool to reduce a community's reliance on fossil fuels and increase its sustainability and resilience to shocks from fossil fuel dependence. I accomplish this by demonstrating via a spatial analysis case study of Guelph, Ontario, Canada that there is significant potential for reducing natural gas use for space and water heating by recovering sewer wastewater heat, a low carbon renewable energy source, at multiple segments of Guelph's sewer network.

ABSTRACT

In this paper I describe how cities can reduce their dependence on fossil fuels for space and water heating by utilizing sewer wastewater heat as a low carbon energy source. I introduce the first stage of a planning decision support system for implementing sewer wastewater heat recovery systems. The model decision support system is intended for community energy planners and other relevant stakeholders to identify locations for matching sewer wastewater heat with appropriate thermal energy demand. This project demonstrates how ideal locations of sewer wastewater heat supply from municipal sewers can be matched with space/water heating demand using spatial analysis techniques and geographic information systems. This first proposed stage of a decision support system utilizes GIS to perform a site suitability analysis that can be used as the basis for further feasibility assessments in the planning of a sewer wastewater heat recovery system. Guelph, Ontario, Canada is used as a case study area. I go on to demonstrate the potential for reducing fossil fuel use in Guelph by identifying the volume of heat that can be recovered from each sewer segment and selecting several ideal locations that warrant further investigation into the feasibility of implementing a sewer wastewater heat recovery system. This proposed planning tool has potential for identifying significant carbon emission reduction opportunities in Ontario due to the large volume of natural gas consumed for space and water heating in the province`s urban residential and commercial zones and the prevalence of extensive sewer networks in all major urban areas. The decision support tool presented in this paper should however be utilized by a community energy planner in conjunction with other approaches for assessing how to reduce natural gas use for heating, as wastewater heat recovery is but one possible solution. Discussion of other approaches is beyond the scope of this research paper.

TABLE OF CONTENTS

INTRODUCTION

Transitioning to low carbon energy systems is a global priority. Even with escalating evidence of negative environmental, social, and economic impacts, fossil fuel demand in Canada continues to rise. If impending disasters are to be avoided, conventional energy supply-chains predicated on high-volume fossil fuel consumption must be altered. Reducing energy consumption in cities through energy efficiency measures and switching to renewable energy have been identified as ways to reduce the need for fossil fuel derived energy (Newman et al. 2009).

A crucial focus for planning this transition will be on cities due to their high concentration of total population, energy use, greenhouse gas emissions, and anticipated shocks from climate change and fossil fuel dependence. The transition to a low carbon energy system requires new planning tools to support planners and policymakers deciding on how best to go about implementing required changes in their respective communities. For energy sustainability to be achieved, spatial considerations will be crucial.

The recovery of wastewater heat from municipal sewer systems can reduce a community's reliance on fossil fuel use for space and domestic water heating. Latent heat in sewer wastewater can be recovered via heat exchangers installed in sewer pipes, upgraded to a useable temperature with heat pumps, and distributed to one or multiple buildings via a district heating system. This increases sustainability and resilience for cities and their energy systems by replacing fossil fuel derived heating with a locally sourced steadily available renewable resource. Despite the proven performance of this technology and the increased interest from urban areas to achieve sustainability and resilience through the use of more decentralized efficient and renewable energy systems, wastewater heat continues to be underutilized.

Municipalities can begin to identify the opportunities for wastewater heat recovery through spatial analysis. Spatial analysis can help to estimate the optimal location and amount of extractable heat as there are relationships between the spatio-temporal changes in wastewater (WW) volume across a city, distance WW travels, varying pipe and soil characteristics across a sewer network that affect temperature changes and volume capacity, and suitable recovery locations (Durrenmatt and Wanner 2014; Elias-Maxil et al. 2014). This information could be analyzed in a geographic information system(GIS) (Leduc and Van Kann 2013), in relation to estimated costs, supply and demand, (Rosen 2008; Rosen et al. 2008), assisting planners and policy makers to locate the ideal sites along a sewer network where heat could be extracted.

1. Sewer Wastewater Heat Recovery Systems (SWWHRS) as a part of a necessary transition to low carbon energy systems

1.1. PROBLEMS OF CONTINUED FOSSIL FUEL USE

Anthropogenic climate change is the global problem of our time. Increasing levels of anthropogenic greenhouse gas (GHG) emissions from the burning of fossil fuels, particularly carbon dioxide (CO_2), are unbalancing the Earth's climate by rendering natural carbon sinks ineffective in their ability to remove sufficient amounts of CO_2 from the atmosphere (IPCC 2014; IPCC 2013; IPCC 2007). This unbalancing has manifested as global average temperature rising noticeably since the early 20th Century (National Oceanic and Atmospheric Administration 2016).

The majority of emissions being released stem from energy consumption in urban areas (World Bank 2010; IEA 2008). Thus it must fall to cities to prevent continuing global mean temperature rise. However, an inequitable distribution of resources will make it difficult for all urban areas to participate. Therefore, policy makers at all levels of government will need to work together to make plans that can reduce emissions in a short timeframe across varying spatial scales.

Despite projections showing a reduction in fossil fuel demand growth due to falling renewable energy costs and accelerated adoption of energy efficiency policies, fossil fuels will remain a dominant source of energy into the future (IEA 2015). Warming will continue due to the CO_2 that has already been released in addition to what will continue to be released in the near and distant future if a drastic transition off of fossil fuel dependence does not occur.

Ontario cities are highly dependent on fossil fuels, primarily natural gas, for space and water heating. Ontario has become a world leader in GHG emission reductions through its unprecedented coal-fired power plant phase out in 2014 (Bradley, Hon James J. Minister of the Environment 2013). Commercial and industrial energy demand continue to rise, however, along with residential energy demand rising again into the next decade (Ministry of Energy 2013).

Of particular concern is Ontario's addiction to natural gas for space and water heating. Space and water heating account for 42% of Ontario's non-transportation related energy use (Natural Resources Canada 2016).

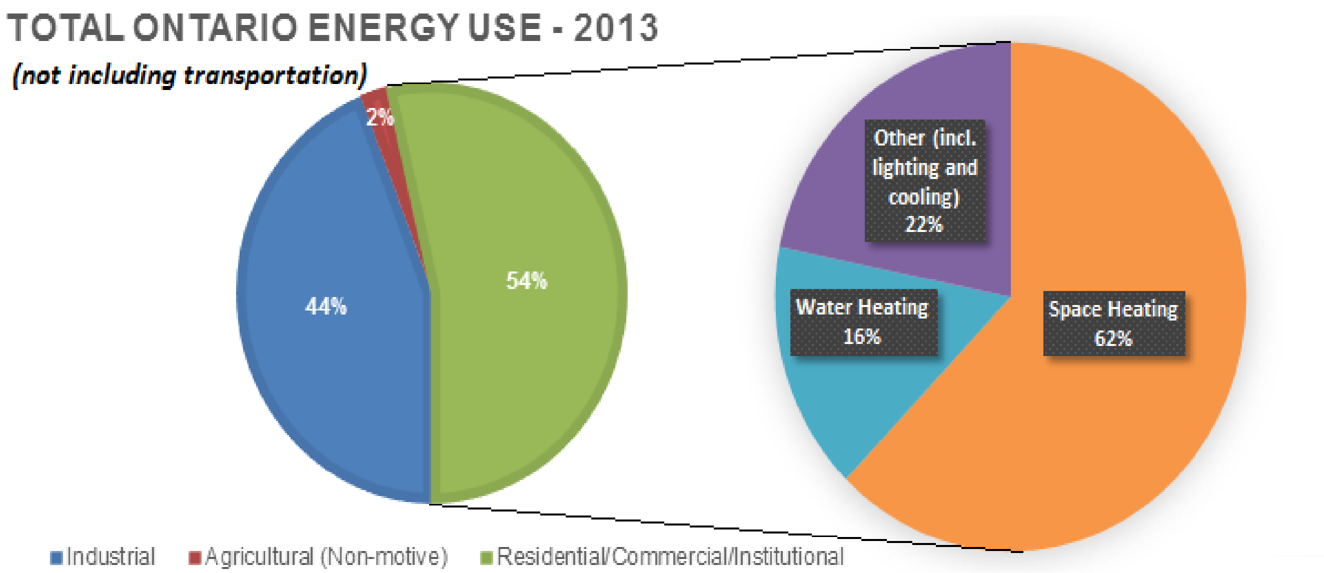


Figure 1: Ontario Energy Use by End Use – 2013 (Natural Resources Canada 2016)

TABLE 1: Total Annual Non-Transportation Related Energy Use for Ontario - 2013		
SECTOR	**TOTAL ENERGY USE** (Petajoules)	**TOTAL ENERGY USE** (%)
Industrial	740.8	44%
Agricultural (Non-motive)	38.6	2%
Residential/Commercial/Institutional	902.3	54%
TOTAL	1681.7	100%
Data source: Natural Resources Canada. 2016. Comprehensive Energy Use Database.		

TABLE 2: Ontario Annual Residential/Commercial/Institutional Energy Consumption by End Use – 2013		
END-USE	**TOTAL ENERGY USE (PJ)**	**TOTAL ENERGY USE (%)**
Space Heating	562.2	62%
Water Heating	142.8	16%
Space Cooling	32.8	4%
Lighting	50.2	6%
Other	114.3	13%
TOTAL	902.3	100%
Data source: Natural Resources Canada. 2016. Comprehensive Energy Use Database.		

Natural gas is used to meet 80.1% of Ontario's Residential/Commercial/Institutional sectors space and water heating demand (Natural Resources Canada 2016). The other dominant fuel source for space and water heating is electricity, which can also be generated by natural gas. Of the total natural gas demand in Ontario, 23% is utilized for electricity generation (HSB Solomon 2014). Most heating and ventilation systems consume electricity for auxiliary components increasing consumption of natural gas for space and water heating indirectly from gas derived electricity.

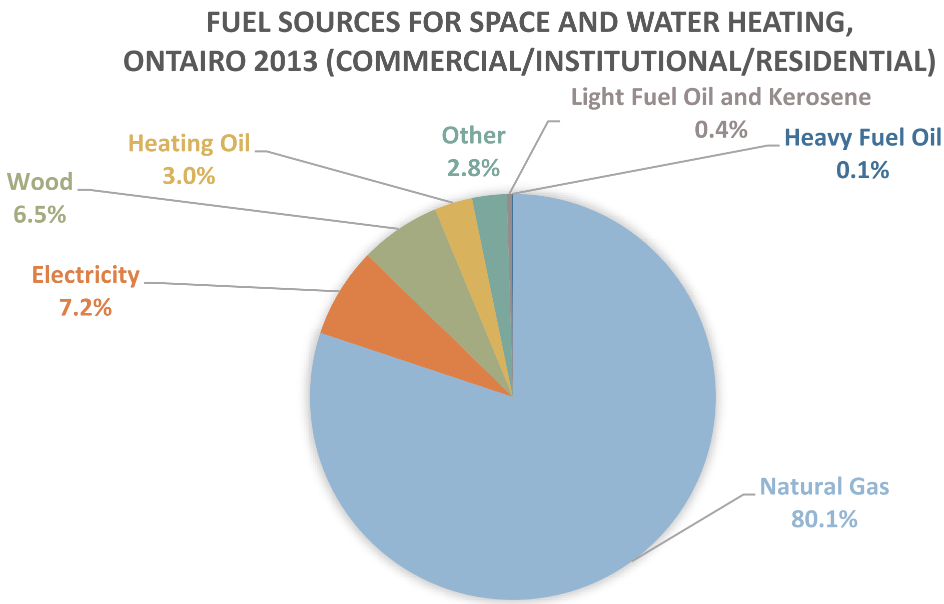


Figure 2: Space and Water heating fuel sources for Ontario`s Commercial, Institutional, and Residential Sectors (Natural Resources Canada 2016)

Despite Ontario government achievements in energy efficiency, the rising population coupled with increasing energy demand, will result in increasing use of fossil fuels, particularly for space conditioning and water heating in Ontario if no alternatives are adopted.

Near term increases in natural gas consumption will be due in part to the coal fired power plant phase out of 2014, and refurbishment of Ontario's nuclear power plants (Ministry of Environment and Climate Change 2014). Ontario gas consumption for electricity generation is forecasted to increase by 288 percent by 2025, with gas generated electricity equating to 30% of Ontario's total generation mix (Navigant 2014).

Large volumes of unconventional shale gas supply will meet future growing demand (Navigant 2014). Even with the new cap-and-trade plan expected increases in natural gas prices will be insignificant, approximately $5 more per month for the average household heating bill (CBC News 2016).

Extraction and burning of unconventional natural gas can have greater environmental impacts than equivalent activities for coal or oil. The burning of natural gas releases methane (CH_4), a greenhouse gas that has a shorter lifetime in the atmosphere compared to CO_2, but is over 25 times more effective at trapping the suns radiation and warming the planet compared to CO_2 (US EPA 2016). Hydraulic fracturing, the method for harvesting unconventional sources of natural gas can have significantly dangerous impacts on the environment as well, including higher lifecycle GHG emissions, contamination of water supply, triggering of earth quakes, and the high volume of water needed for extraction and processing contributing to droughts.

The conventional economic system hides the negative impacts of fossil fuel use. Fossil fuel prices are lower than low carbon energy solutions because true costs, or “externalities”, are hidden. Externalities such as negative impacts to the environment, societies, and economies are unmeasurable in conventional market terms. These negative externalities can stem from a variety of activities including mining, transporting and processing raw materials, generating energy from the processed fossil fuels, and ejecting and/or storing waste from all of these processes. Externalities can include a range of various types of perturbations, including pollution affecting terrestrial and aquatic ecosystems, which can negatively impact the environment, as well as human health, and economies (Owen 2004). Hiding the true cost of fossil fuel use makes transitioning to low carbon solutions difficult.

Fossil fuels will remain an attractive option so long as supplies remain abundant and prices stay low. Most capital from fossil fuel companies goes to exploring and developing high-cost reserves (IEA 2008). Physical shortages will not be the issue but rather a lack of investment in the expansion of production capabilities for unconventional sources (IEA 2008). This will only be exacerbated as the more easily extracted sources of fossil fuels decline, leaving only the more expensive harder to reach sources available for exploit. If Ontario's demand for natural gas outpaces extraction capabilities and a transition to alternatives has not been widely implemented issues of resource scarcity and economic shocks will arise.

This creates an opportunity whereby investment from fossil fuel industries can be transitioned to sustainable low carbon energy solutions and rid ourselves of the dependence on fossil fuels and the susceptibility to short-term market imbalances.

Ontario needs alternative planning tools for exploiting alternative low carbon and disturbed space and water heating options. Continued natural gas use, as already discussed, will lead to negative social, economic and environmental impacts both in Ontario and internationally. Ontario's aging energy infrastructure is highly susceptible to damage from extreme weather events causing cascading energy system failures. This is truer of aboveground electricity system infrastructure (i.e. powerlines and substations) as opposed to natural gas systems. However, even if natural gas supply is not disrupted many natural gas burning systems, particularly in the building sector, require electricity to run ancillary equipment. Therefore, disruption of one will affect the other.

Natural Resources Canada is predicting with confidence increasing frequency and intensity of extreme weather with continued warming (Warren and Lemmen 2014). These extreme weather events could be regarded as transformative impacts as there was no incremental lead up to the extreme event (Smith et al. 2011). This means that the next extreme weather event will appear without prediction. If Canadian communities have not implemented resilient infrastructure in time for the next major weather event serious societal impacts may occur.

Proper planning approaches and tools must be adopted to accelerate implementation of distributed renewable energy solutions. When energy systems fail cities are thrown into disarray due to heavy reliance on energy services. By increasing the availability of distributed renewable energy systems the impact to a city from disruptions to the energy supply can be greatly reduced. Future energy system planning must review renewable energy integration potential to avoid adoption of status quo solutions. This is a serious issue as energy system infrastructure, once constructed, is in place for decades. Much of Canada’s energy infrastructure is nearing the end of its service life or increasing demand is warranting system expansion. This makes for a great opportunity to conduct an overhaul on the entire system (albeit in feasible phases) towards a more efficient, sustainable, resilient, low carbon system. To avoid technological lock-in to status quo energy systems alternative options at comparable levels of implementation feasibility must be presented to decision-makers now ahead of system refurbishment. Renewable energy adoption requires tools to demonstrate their competitiveness to conventional energy systems to avoid further climate change exacerbation as well as social and economic shocks from the continued use of fossil fuel derived energy.

WHAT'S NEXT?

Continued reliance on fossil fuels makes communities and their economies highly susceptible to collapse based on impending economic, environmental, and social shocks. Societies must decouple reliance on fossil fuel imports through the utilization of local renewable resources and implementation of energy efficient energy systems in urban areas.

The energy system developed in the 20th century for supplying cities with thermal energy that perpetuated through to current day needs restructuring. For cities to avoid forecasted catastrophes, while managing the balance between energy supply and demand, conventional energy planning frameworks and perceptions must be altered. One such method would be to take advantage of resources that are generally discarded as waste but actually hold the potential to be valuable energy resources. More on this in the next section, ***Transitioning to a low carbon energy system***.

1.2. TRANSITIONING TO LOW CARBON ENERGY SYSTEMS

Cities can reduce their dependence on Fossil Fuels by altering the flow of energy and materials towards an urban system modelled on the principles of a Circular Urban Metabolism. Cities can reduce fossil fuel consumption by harvesting urban waste streams and achieve urban sustainability and resilience. A problem most cities face is that they are predicated on a linear urban metabolism (See Figure 1) (Agudelo-Vera et al. 2012). Large volumes of resources pass through the urban system inefficiently with large quantities of energy rich outputs underutilized as they are considered waste streams. The lack of waste recovery in a linear urban metabolism results in continued dependence on large volumes of resource imports.

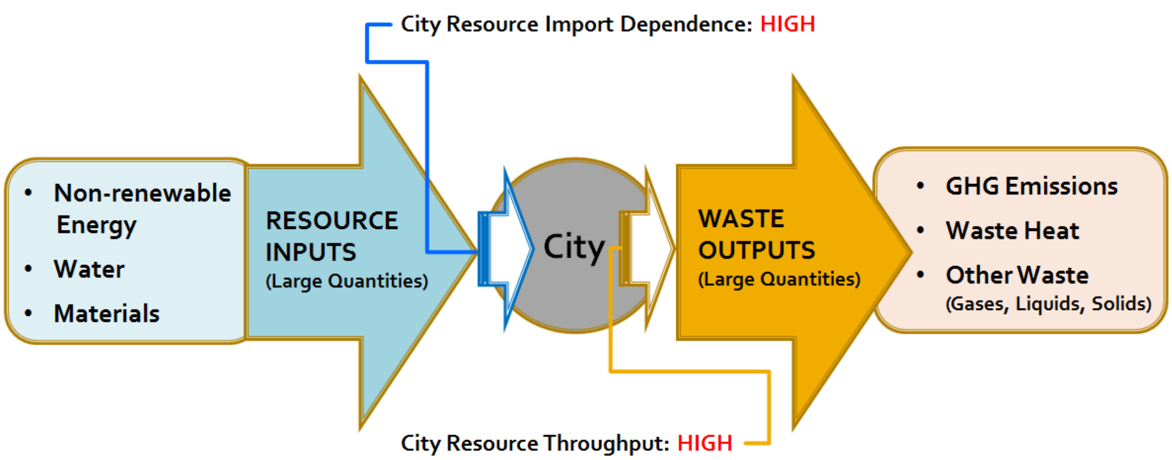


Figure 3: Linear Urban Metabolism (Calder 2016)

Alternatively, a ***circular urban metabolism*** (See Figure 2) functions on the premise of efficient material consumption from increasingly more local sources resulting in reduced energy and material throughput (Agudelo-Vera et al. 2012; Newman et al. 2009). This includes urban waste streams being repurposed for citizen benefit such as waste heat for energy (Leduc and Van Kann 2013).

A city premised on a circular urban metabolism reduces its reliance on fossil fuel imports as waste is perceived as a valuable renewable resource. Circular urban metabolisms predicated on harvesting urban waste streams can be developed through integrated planning approaches that collate land-use, energy, and resource management approaches (Owens 1992; Rotmans et al. 2000; Newman et al. 2009; Keeffe 2012; Leduc and Van Kann 2013). By studying the synergies between urban functions and utilizing these synergies for efficient and optimal productivity there is heightened potential for achieving urban sustainability and resilience (Leduc and Van Kann 2013).

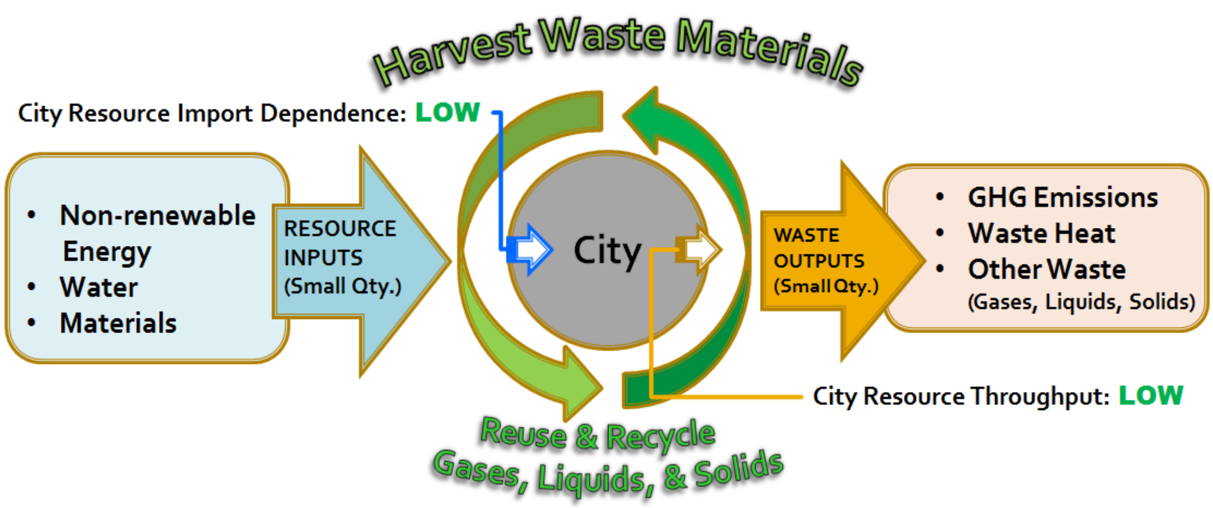


Figure 4: Circular Urban Metabolism (Calder 2016)

Cities will have to drastically alter community and energy system planning frameworks by finding synergies between spatial concepts and energy efficiency principles in order to achieve circular urban metabolisms. A growing body of research has demonstrated that spatial organization and built form characteristics of cities have implications on energy demand and supply (Bridge et al. 2013; Pasqualetti 2012; Stoeglehner and Narodoslawsky 2012; Newman et al. 2009; Owens 1992). Although energy demand is influenced by multiple variables, spatial and non-spatial respectively, the conscious intention or accidental outcome of spatial planning will affect how energy can be supplied and consumed, traditionally with negative impacts (Stoeglehner et al. 2011, 1).

The key spatial elements affecting urban energy demand and supply are the physical attributes of built form, and the spatial organization of that built form.

Built Form

Buildings account for half of energy demand in cities, with space conditioning and water heating dominant energy end uses greatly affected by a building's design, construction materials and mechanical systems (Zanon and Verones 2013, 345; Tooke et al. 2014).

Spatial Organization / Urban Form

Spatial organization of buildings can greatly affect energy demand and potential for supply. The three main influencing factors are found to be compactness, density, and urban form (Zanon and Verones 2013, 345):

- ***Compactness***: How contained or dispersed is the urban form of a community; distribution of individual buildings and/or land uses in relation to apparent centralities or subcentres.
- ***Urban Density:*** The concentration of either population, expressed in inhabitants per unit of area (e.g. population/km2)), or built form density (e.g. 'floor to area ratio' (FAR)).
- ***Urban Form:*** The design of urban spaces in relation to land use (e.g. mixed-use areas, available green spaces, site layout) and designated built form requirements (e.g. façade, orientation, site layout, size requirements)

Communities with an increasing trend towards built forms with low surface area to volume ratio, and mixed use spatial arrangements with higher net densities, and reduced urban sprawl have been identified as more energy efficient (Owens 1992; Zanon and Verones 2013). Conversely sprawling low density homogenous development has led to negative impacts upon urban areas in the form of inefficient use of fossil fuels, high levels of material and energy waste, human health impacts, and reduced mobility (Newman et al. 2009; Keeffe 2012).

With the integration of circular urban metabolism principles sustainable energy planning need not be bound by the conventional spatial considerations of renewable energy provision. An energy system that utilizes waste streams has flexibility to meet the spatial context of any community. Almost every area of a city produces waste thus providing multiple sources of potentially valuable distributed renewable resources. This is important as urban development in North America has been the result of inertial forces from popular objectives manifesting into the desired development style of the day (Sharpe 1982, 3). As such, cities of today are a patchwork of different planning and development legacies. For this reason, to achieve energy efficiency will require working with existing built form and spatial arrangements for many years to come. For example, harvesting waste heat from buildings can be accomplished within a mixed-use high density area and redistributed via a district heating system. Conversely, homogenous low density developments can also benefit from a waste heat recovery system with proper system design meeting realistic goals predicated on evidence based energy supply and demand analysis (i.e. a goal may be reducing a portion of fossil fuel dependence as opposed to meeting baseload). Waste streams can also be more reliable than reliable other renewable resources like solar or wind (Frijns et al. 2013).

Ultimately, there are spatial forms that affect energy efficiency more positively than other forms. As cities evolve over time the trend of development towards more energy efficient forms and arrangements should be a key goal for contemporary planners. Spatial planning will be crucial for ensuring there are no spatial conflicts due to land demand by employing such tools like comprehensive land use plans with complementary zoning (Stoeglehner et al. 2011, 2). Energy efficient land use planning needs to become a priority for all cities as it will support the realization of other social, economic, and environmental goals within a community (Owens 1992, 82).

Planning for the sustainable balancing of energy supply and demand can be accomplished through the use of spatial analysis via geographic information systems. Community Energy Planning (CEP) is a useful practice for cities to transition to a low carbon urban energy system. CEP is comprehensive and integrated energy planning at the community scale, taking supply, transmission/distribution, and demand into account. A key feature of CEP missing from conventional energy planning is the assessment of distributed low carbon energy supply options, with conventional planning being predominantly focused on demand management (Schroth et al. 2012; Stoeglehner and Narodoslawsky 2012).

Assessing the viability of distributed renewable resources can be accomplished with spatial analysis using a geographic information system (GIS). The usefulness of GIS for assessing renewable energy potential, modelling energy consumption at varying scales, site selection and energy infrastructure planning, and assessing impacts has been proven (see Resch et al. 2014 for a review). More on this in later sections.

Transitioning towards a Circular Urban Metabolism will require a community energy planning approach aided by a decision support system that compares and identifies the best low carbon energy solutions to leverage across a city. The remainder of this paper will describe how the first step in a model decision support system was developed and can be employed for identifying ideal locations for implementing a sewer wastewater heat recovery system (SWWHRS). The choice to focus on SWWHRS was made because sewer wastewater heat recovery addresses the issue of shocks from climate change, fossil fuel scarcity, and price volatility as it simultaneously reduces a community's reliance on fossil fuel imports and increases a community's utilization of local distributed renewable energy. Everyday urban dwellers discharge hot water into their municipal sewer system, and in the process waste large volumes of valuable thermal energy. Wastewater heat could instead be used as a renewable resource for space and water heating if the focus of managing wastewater was no longer simply to process an undesirable waste stream and instead harvest energy (Guest et al. 2009).

Frijns et al. (2013) have dubbed wastewater (WW) "resource water", finding it to be an underutilized resource carrying valuable thermal energy. Hot water from buildings is discharged into sewers while retaining thermal energy that can be recovered as a renewable resource (Cipolla and Maglionico 2014). WW is readily available and can be more stable than solar and wind (Frijns et al. 2013). Furthermore, a city's widespread sewer network offers the potential to utilize multiple locations for wastewater heat recovery (WWHR) (Frijns et al. 2013; Elias-Maxil et al. 2014). Currently, the largest use for waste heat via WWHR is for space heating (Elias-Maxil et al. 2014). However, air conditioning and water heating are other end-uses that can utilize WW heat (YaXiu et al. 2012).

1.3. SEWER WASTEWATER HEAT RECOVERY SYSTEMS (SWWHRS)

Wastewater heat can be successfully recovered from buildings, sewers, and wastewater treatment plants (Neugebauer et al. 2015; Frijns et al. 2013). However, recovering wastewater heat from sewers offers the greatest potential for significantly reducing fossil fuel use in a community for space and water heating. A barrier to observing significant community benefits by implementing WWHR at the individual building scale is that it requires widespread buy in from individual property owners to spearhead and implement the necessary equipment. Wastewater Treatment Plants (WWTP) would not be effective for widespread community benefits either, despite their large supply of waste heat. The usefulness of available thermal energy from a WWTP depends upon their proximity to end users, with nearby land uses not always being conducive to the quality of energy available (e.g. industrial, agricultural, non-energy using land-use). In comparison sewers are a better choice for communities as they are within close proximity to consumers, providing access to a greater thermal resource than would be available from a single building, particularly if there is a high enough density of buildings discharging wastewater, and consist of a widespread network spanning out across a city thereby providing the opportunity for greater synergies than would be offered by a spatially constricted WWTP (Elias-Maxil et al. 2014). Although communities are encouraged to investigate the opportunities for implementation of WWHRS in buildings, WWTP, and sewers, the sewer option is expected to offer greater communitywide benefits achievable within a shorter timeframe.

1.3.1. Components of Sewer Wastewater Heat Recovery System (SWWHRS)

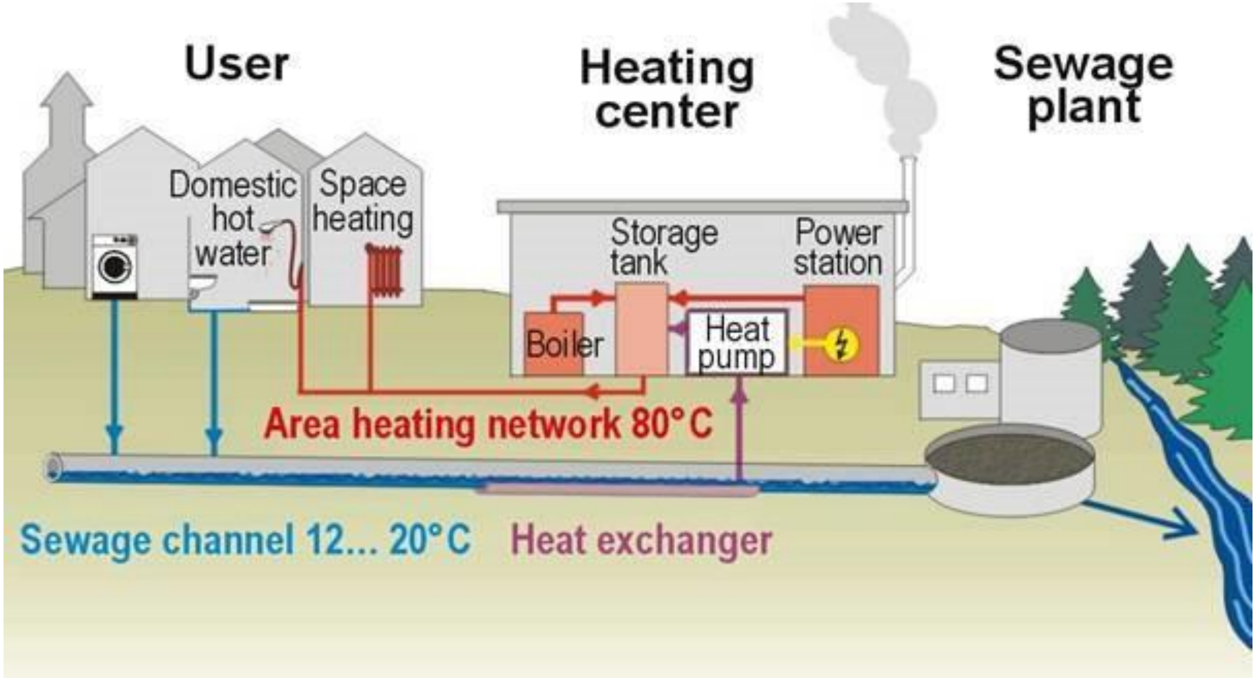


Figure 10: Example Sewer Wastewater Heat Recovery System (Rehva 2016)

Sewer Wastewater heat recovery systems (SWWHRS) are comprised primarily of ***heat exchangers***, ***heat pumps***, and a ***heating distribution network***. ***Thermal storage*** can also be employed if deemed project appropriate. Figure 10 provides an example of a typical design configuration for a SWWHRS.

Heat Exchangers

The Heat Exchanger (HE) is the component of a SWWHRS that harvests heat from wastewater. Styles of HE that can be used for a SWWHRS include:

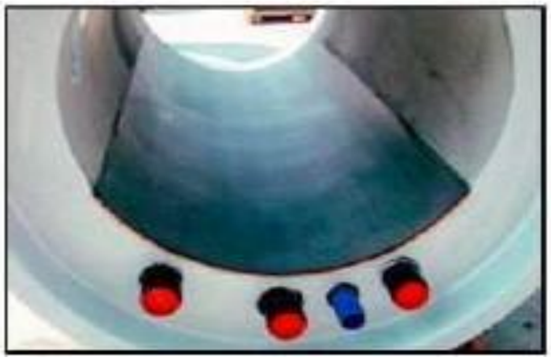


Figure 11: Integrated HE (Monslave 2011)

An **integrated heat exchanger (Figure 11)** employs heat transfer panels embedded directly in sewer channel inverts, which harvest and transfer thermal energy to pipes carrying heat transfer fluid (e.g. water/alcohol solution, refrigerant) encased in concrete below the heat transfer plate (CRM 2008).

Integrated HE are considered best suited for new sewer systems (van Odijk et al. 2011). Furthermore, an integrated HE system is expected to last as long, if not longer, as the lifetime of the sewer channel (up to 80 years) (van Odijk et al. 2011).

Figure 12: Modular Plate HE (Monslave 2011)

Modular plate heat exchanger is best suited for existing sewers due to the flexibility of implementation with HE plate modules capable of being adapted to any form and size of sewer channel (van Odijk et al. 2011). The modular plate is not an embedded component, so there is risk of flow obstruction because the modular plate rests on top of the surface of the sewer invert and also reduces the pipe diameter slightly (van Odijk et al. 2011).

Figure 13 - 15: Modular Plate Heat Exchangers (Cipolla and Maglionico 2014; Hamburg Wasser 2012; Pamminger et al. 2013)

Figure 16: Spiral tube HE (Monslave 2011)

Spiral tube heat exchangers are best suited where sewer flow is low (van Odijk et al. 2011). Spiral tubing is placed in a collection pit where wastewater accumulates and is capable of harvesting sufficient wastewater heat because the distance the thermal transfer fluid has to travel when passing through the immersed spiral tubes increases the time the fluid has to absorb heat, thus

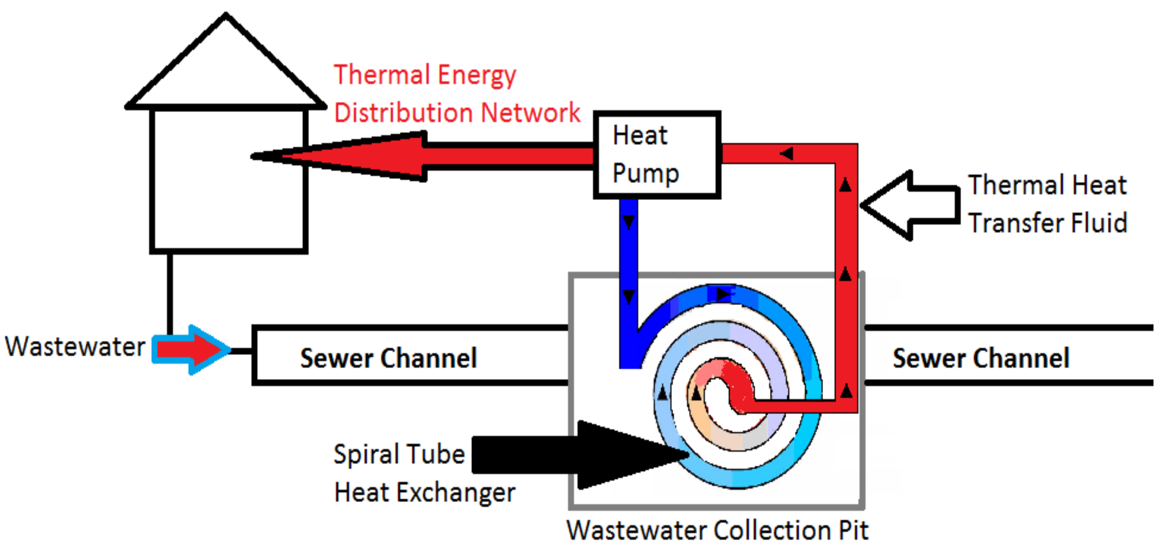


Figure 17: Example of how a Spiral HE operates (Calder 2016)

compensating for the low sewer flow (van Odijk et al. 2011).

Although there are significant advantages of using spiral tube HE, there is also a significant amount of space required for the collection pit and the potential for clogging (van Odijk et al. 2011).

Heat Pumps

Heat pumps are mechanical devices that recover thermal energy from a lower temperature source and transfer that energy to another location (heat sink) at an upgraded higher temperature. A heat pump is necessary for a SWWHR system to supply energy for space and water heating due to their ability to supply heat at a greater temperature than would be possible solely with a heat exchanger (Parker et al. 2013).

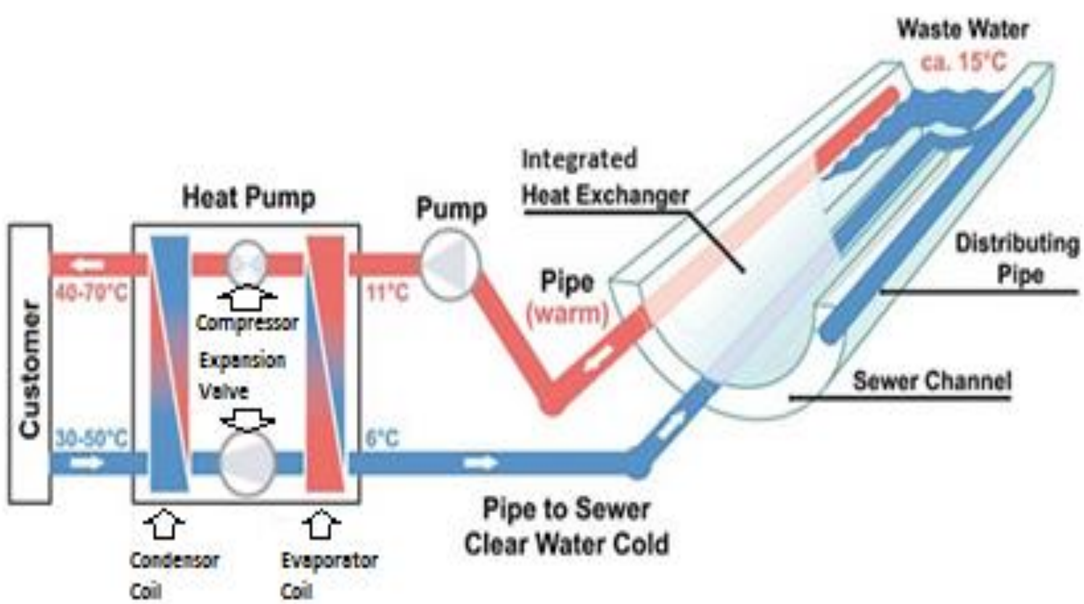


Figure 18: Sewer Wastewater Heat Pump configuration (Veolia 2016)

In general, heat pumps for sewer wastewater heat recovery systems (SWHHRS) are a reliable technology, with such examples including a SWWHRS in Luzern with a heat pump that has been in operation for 28 years with no need for parts replacement (Elias-Maxil et al. 2014).

Thermal Energy Storage

Thermal energy storage can be used in conjunction with a SWWHRS to compensate for fluctuations in available sewer wastewater heat and can be situated above or below ground in thermal storage vestibules (Elias-Maxil et al. 2014). The stored thermal energy can be used to offset short-term fluctuations in supply and demand or long-term storage for seasonal variability, stable for months at a time (Elias-Maxil et al. 2014). Storage increases the viability of a SWWHRS as temporal fluctuations can affect the balance of the supply and demand relationship.

Viable solutions for sewer wastewater heat storage include large hot water storage tanks and Borehole Thermal Energy Storage (BTES) systems. BTES consists of an arrangement of heat exchangers and drilled borehole wells with some boreholes working as a heat source and others as heat sink (Elias-Maxil et al. 2014). For an example of how these thermal energy storage solutions could work in conjunction with each other please see figure 20.

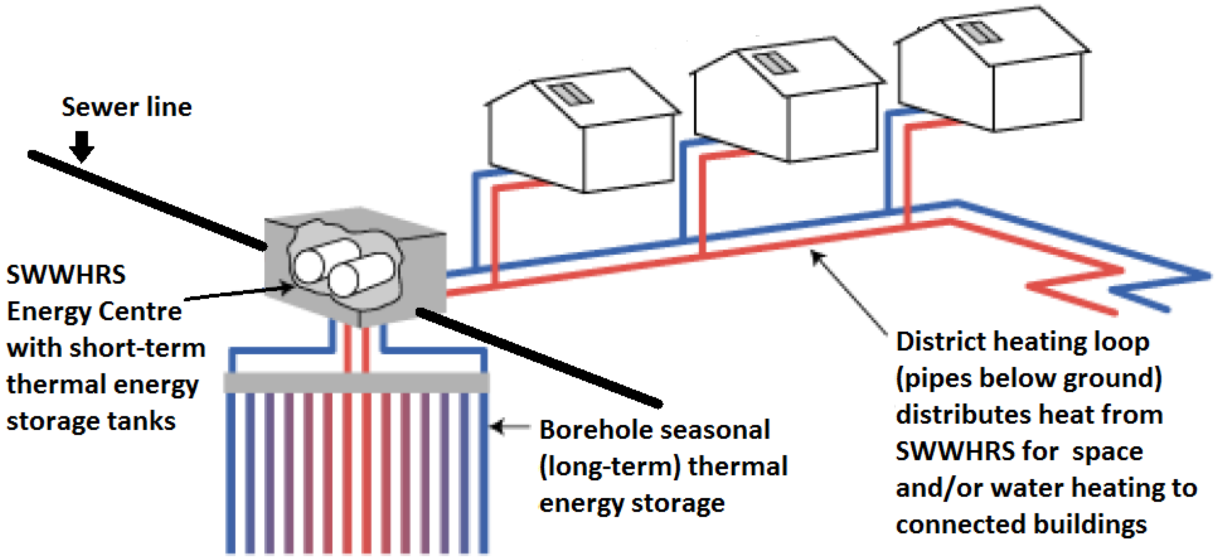


Figure 20: Thermal Energy Storage for a SWWHRS (Adapted from Drake Landing 2015)

1.3.2. SWWHRS Best Practice Examples

The following is a list of operational SWWHRS demonstrating the feasibility of this low carbon transition solution:

TABLE 3: SWWHRS Examples				
Location	**Description**	**Heating Capacity from System**	**Operational Date**	**Source**
Binningen, Switzerland	Heat pump system for apartment buildings	2400 MWh/year	2001	(Intelligent Energy Europe 2007, 8)
Sandvika, Norway (Sandvika fjernvarme)	District heating system	34 MW	2003	(Intelligent Energy Europe 2007, 17)
Sandvika, Norway (Skøyen fjernvarme)	District heating system	85 GWh/year	2005	(Intelligent Energy Europe 2007, 21)
Leverkusen, Germany	Heat pump system for medical centre	981 MWh/y - heating 545 MWh/y - cooling	2003	(Edie.net 2011)
Mülheim, Germany	Heat pump system for small neighbourhood	850,000 kWh/year	2013	(Celsius 2016)
Nippes, Germany	Heat pump system for small neighbourhood	2,130,000 kWh/year	2013	(Celsius 2016)
Wahn, Germany	Heat pump system for small neighbourhood	1,220,000 kWh/year	2013	(Celsius 2016)
Hastedtstraße, Hamburg, Germany	Heat pump system for apartment building	1100 MWh/year	2009	(Hamburg Wasser 2012)
Winterthur, Switzerland	Heat pump system for apartment building	585 kW	2016	(Huber 2016)
Lucerne, Switzerland	Heat pump system for commercial buildings	unknown	2007	(Schmid 2008)

1.3.3. Barriers for Implementing SWWHRS

There are multiple barriers affecting implementation and ongoing operation of a SWWHRS. However, this report will only focus on those barriers that are influenced by spatial factors. All other barriers are beyond the scope of this paper.

Heat Loss during transportation

As wastewater travels along a sewer channel heat is dissipated through the pipe walls to the surrounding soil (Elias-Maxil et al. 2014). Therefore, the distance from wastewater heat recovery point to a potential end user is important. Observations of wastewater heat loss during transport along a sewer pipe have shown wastewater to reach the same temperature as the surrounding soil after 10 km, with an even shorter distance required for pipe/soil temperature parity when the pipes and flow rate are smaller (Elias-Maxil et al. 2014; Ramos et al. 2010). The rate at which wastewater temperature decreases will be subject to a suite of context specific factors including sewer pipe material and thickness, surrounding soil type, local climate, and wastewater flow and volume. However just as an example, wastewater temperature was observed to decrease at a rate of up to 0.27 ˚C/km in rural Finland (Finland's winters are cold and wet, similar to Canada) (Sallanko and Pekkala 2008).

To ensure that wastewater heat is recovered at a sewer network point with sufficient heat supply sewer heat should be extracted where there is a high flow rate and/or high temperature typically found in close proximity to where wastewater originated. This will make servicing a demand site with a SWWHRS economically and technically feasible.

200 metres is a recommended maximum distance between a sewer and end use (Pamminger et al. 2013).

1.3.4. Implementing a SWWHRS

Using Spatial Analysis for SWWHRS site selection

Spatial analysis can be used to identify ideal locations for SWWHRS. Application of spatial modeling for urban energy system analysis has been increasing with more than 10 times the number of articles in 2016 than in 2003 on the subject. Horner et al.'s (2011: 764) review of spatial analysis via geographic information systems (GIS) correlated with energy issues tells us that the reason is likely due to climate change science fostering interdisciplinary research geared towards finding ways to reduce energy consumption, isolating sources of greenhouse gas emissions, and mitigating environmental damage, with GIS and other spatial analysis technologies (e.g. remote sensing) providing effective results.

Spatial modeling can assist practitioners to plan and develop a resilient urban energy system. A strong example is that of Leduc and Van Kann's (2013) advanced spatial planning methodology that illustrates the effectiveness of GIS for selecting sites for energy cascading. Energy cascading applies to thermal energy whereby the temperature of waste heat is matched to an urban function that requires such thermal energy at the waste heat temperature and this continues from land use to land use until no useful exergy remains (Stremke et al. 2011). Leduc and Van Kann's (2013: 182) spatial analysis found the results from spatial modeling demonstrating local waste heat harvesting potential via maps communicating quantitative and qualitative information can be utilized by a heterogeneous group of professionals with different organizational mandates, knowledge, and expertise (Leduc and Van Kann 2013). There is also flexibility with employing spatial analysis methodologies, especially the use of GIS, as new information can be added and analysis tailored on the fly.

Neugebauer et al.'s (2015, 12991) analysis of heat recovery potential from wastewater treatment plants revealed that "spatial analysis of energy efficiency, supply and resource potentials leads to a better decision base for energy planning". Particularly because energy sources and sinks can be analyzed spatially in terms of distance, useful for SWWHRS analysis when the length of the sewer can determine available heat, and distance to sink can determine potential heat loss. Additionally, other important spatial considerations can be taken into account to help with the analysis and integrated into the same spatial database (Neugebauer et al. 2015). For example, land-use and property size can assist with helping to estimate energy demand (Dorfner 2011). Other spatial considerations may be above ground obstructions or land-use conflicts across a sewer network that may affect installation.

In summary, spatial analysis has been proven to be effective with assessing the heating demand of a community (Calderón et al. 2015; Dorfner 2011; Finney et al. 2012; Möller 2008; Strzalka et al. 2010), and the planning of community heating networks (Gils et al. 2013; Gils 2012; Lund and Persson 2016; Möller and Lund 2010; Nielsen and Möller

2013; Nielsen 2014), and therefore would be an excellent way to assist in planning for the implementation of a wastewater heat recovery system.

Assessing energy demand

Assessing the viability of a sewer wastewater heat recovery system begins with identifying the location and intensity of thermal energy demand. This can be accomplished in several ways spatially including, but not limited to (see Table 5):

TABLE 5				
METHOD	**DESCRIPTION**	**STRENGTHS**	**WEAKNESSES**	**EXAMPLES**
Heat Atlas	A geographic database of all buildings in an area. Comprised of data on current heat supply and annual heat consumption, heat reduction potentials and associated implementation costs.	Accurate assessment of community wide energy usage and conservation potential.	Highly resource intensive approach contingent on large volumes of up to date real data.	(Nielsen 2014)
Energy Demand Mapping (Heat Mapping)	Using estimated energy use by building type in conjunction with spatial data can provide an estimate of community wide energy demand.	Can provide a wide area estimate when data availability is limited.	High level of generalization requires further analysis to be conducted in future if analysis results are to be used for project decision making.	(Rylatt et al. 2003; Dorfner 2011)

Assessing the quality and quantity of wastewater heat

Sewage flow rate and available heat for recovery can be assessed as follows:

TABLE 6: Methods to assess wastewater heat quality and quantity		
METHOD	DESCRIPTION	EXAMPLE OF USE
Calculate thermal extraction output from wastewater - Combine with map of sewer network	Available thermal energy extraction potential can be calculated using the following formula: $P_{WW} = V_{WW} \times c \times \Delta T$ (P_{WW}) = available wastewater heat (V_{WW}) = wastewater volume flow rate (c) = specific thermal capacity of wastewater; assumed to be equal to *(1.16 kWh/m³*K)* (ΔT) = temperature difference	(Neugebauer et al. 2015) - Neugebauer et al.'s application of this method was for assessing the WWHR potential from wastewater treatment plants. However, the principle can still be applied to the sewer network.
Model to predict heat recovery potential from sewer network. - Combine with map of sewer network	Input a set of parameters into a software program called TEMPEST developed specifically for the estimation of available sewer wastewater heat. Data parameter categories include: • Sewer pipe characteristics • Soil characteristics • Wastewater characteristics • In-pipe air characteristics	(Dürrenmatt and Wanner 2014)

Developing Site Selection Criteria for SWWHRS

Site selection criteria for a SWWHRS will be required for balancing the source-sink relationship. These selection criteria will be applied during the analysis after an inventory of wastewater heat and thermal energy demand has been conducted. There must be both adequate supply of wastewater heat and suitable levels of thermal energy demand to take advantage of the available source. Therefore, sources and sinks must be matched appropriately. However, it is acknowledged that each community is unique and will have their own context, including community specific goals and objectives. Therefore, like the nature of the source-sink relationship, each community must establish its own unique and realistic goals in accordance with its own characteristics. In other words, wastewater heat may not always be a viable option for reducing fossil fuel dependence for space and water heating for either technical or economic reasons. Therefore, wastewater heat should be only one of many renewable energy options considered when attempting to achieve a circular urban metabolism.

Table 7 is an example of ideal site selection criteria that planners should consider at the preliminary opportunity assessment stage for SWWHRS (Adapted from Parker, Germain, and Laurent 2013). These selection criteria assume that potential areas for matching sources with sinks have been identified through previous energy demand and wastewater heat inventorying.

TABLE 7: Criteria for selecting ideal locations for implementing SWWHRS	
Ideal criteria for sources (wastewater)	**Ideal criteria for sinks (sites)**
The sewer channel must have adequate sewage flow rates with flow rate greater than or equal to the flow rate required to meet the space or water heating demand of the site(s).	The site must be in close proximity to a viable sewer heat source for economically and technically feasible installation and maintenance. 200 metres is a recommended maximum distance (Pamminger et al. 2013).
Choosing a sewer channel in close proximity to an existing wet well or lift station is useful for gaining needed access for installation and maintenance of a SWWHRS. Having this type of access already reduces upfront as well as maintenance and operation costs.	The site should be a new construction or an existing site due for HVAC system replacement. The costs to be incurred by a property owner are less of a financial burden when the installation of a SWWHRS occurs at the time of site construction or system replacement since an HVAC system is required regardless.
Choosing a sewer channel that is either due for replacement or is located below a road due for significant repairs can significantly reduce installation costs.	The site(s) should have a year-round heating load (space and water heating) sufficient enough to reduce payback period.
The wastewater temperature should be evaluated for seasonal variability to ensure that heat exchanger and heat pump selected will operate efficiently year round.	The site should use the SWWHRS system to reduce fossil fuel use (e.g. natural gas) or supplement a renewable energy system (e.g. geothermal, solar thermal)
Assess the annual WW temperature variability along with site energy requirements to identify if space cooling is feasible, ensuring in the same way for space heating, that the appropriate heat exchanger and heat pump would be chosen.	
The SWWHRS uses electricity to run some of its components, therefore sufficient space should be available for a storage system to take advantage of off-peak Time-of-Use rates in order to achieve energy cost savings while meeting on-peak space and water heating demand.	

2. A Model Decision Support System for Sewer Wastewater Heat Recovery System Planning (SWWHRS)

A methodology for assessing wastewater heat recovery potential using limited data is proposed. Lack of energy data at a local spatial scale is cited as one of the most common issues hindering urban energy system analysis (Mikkola and Lund 2014; Østergaard and Sperling 2014; Keirstead et al. 2012; Perez and Robinson 2012; Canadian Urban Institute 2011; Sahely 2005). Yet there are ways to generate energy demand data without existing empirical values. Spatial analysis techniques have been shown to be effective at determining local energy demand at the building scale (Tooke et al. 2014; Mohammadi et al. 2013; Leduc and Van Kann 2013; Dorfner 2011).

Spatial analysis via GIS can provide a preliminary assessment of sewer wastewater heat recovery potential across a sewer network. Accurate wastewater heat availability assessment requires specific details such as actual sewage temperature and flow rate measurements from within a sewer channel, surrounding soil characteristics, in-channel air pressure and pressure drop (Dürrenmatt and Wanner 2014). However, a preliminary assessment of which sewer sections would be the best sites for implementing a SWWHRS can be conducted using at minimum sewer network characteristic data, such as length and diameter of sewer channels along with location of sewer pipes in relation to buildings. Once identified those sites can then be analyzed further to determine the technical and financial feasibility of implementing a SWWHRS.

Stakeholder engagement will be another crucial component to implementing a SWWHRS. Leveraging synergies between land uses is required to transition to a circular urban metabolism. Planning frameworks that establish a process of enhanced collaboration in order to develop planning goals based on local community stakeholder input are expected to develop planning principles and goals that have higher likelihood of being upheld. Diverse forms of knowledge, such as from local residents coupled with knowledge from expert practitioners (e.g. engineers, planners), will contribute to robust planning solutions. However, for the purposes of this project the primary focus will be on informing the design of the first stage in a SWWHRS implementation decision support system. Thus, further exploration around developing appropriate stakeholder engagement processes is beyond the scope of this discussion.

Economic considerations are paramount with regards to implementing a SWWHRS. If a potential SWWHRS project does not demonstrate financial feasibility it will not be implemented. A likely follow-up step to this first step of selecting ideal sites based on balanced supply and demand would be to conduct a financial feasibility assessment for implementing such a system at each site. However, an economic assessment is beyond the scope of this project.

This first stage of a SWWHRS Planning Decision Support System will comprise the technical opportunity identification, whereby ideal locations of supply and demand can be matched based on estimated resource availability and thermal energy demand.

MODEL

The SWWHRS Planning Decision Support System: STEP 1 is comprised of the following sub steps:

Step 1A – Data-mining exercise to establish Energy Use and Wastewater Flow Baseline

Step 1B – Heat Mapping

Step 1C – Wastewater Heat Availability Assessment

Step 1D – Identifying Ideal locations for SWWHRS and customer connection

DATA

The following is a data needs assessment summary for conducting SWWHRS Planning Decision Support System:

STEP 1

- Existing communitywide thermal energy use and wastewater volume data.
- Building attribute data (specifically gross floor area and land use type) and Building/property spatial data file
- Sewer network attribute data (specifically sewer channel diameter and length) and Sewer network spatial data

METHOD

SWWHRS Planning Decision Support System: STEP 1 – Identifying Ideal locations for matching supply and demand is conducted as follows.

Step 1A – Conduct a data-mining exercise to establish Energy Use and Wastewater Flow Baseline

Gathering and consolidating all available energy use and wastewater system information is a useful first step. Each community will have different levels of useful data available.

Gather any available estimates on community wide thermal energy use as a start. If there are none available, then proceed to Step 1B.

Next, gather any available information on wastewater flow volume for the entire community. If there is known available, then proceed to Step 1C. If total community or per capita flow volume data exists, such as from a municipally prepared annual wastewater treatment report, then wastewater heat recovery potential can be estimated. Using the equation $P_{WW} = V_{WW} \times c \times \Delta T$ with estimated total wastewater flow volume for a typical hour in a community, and assuming that *c* is constant (1.16 $kWh/m^3{*}K$) and ΔT will be the expected temperature drop equal to how much thermal energy will be extracted (e.g. extracting 5K will result in wastewater being cooled by 5°C. See (Neugebauer et al. 2015, 12999)), the estimated wastewater heat recovery potential for a community can be calculated.

Comparing the estimated wastewater heat available for recovery to total communitywide thermal energy demand (perhaps by sector) can demonstrate what portion of energy demand can be theoretically met by SWWHR. If the proportion is significant enough to warrant further investigation, then the following steps will assist planners in identifying potential areas for SWWHRS implementation.

Step 1B – Heat Mapping

Heat Mapping is an effective way to establish an understanding of estimated thermal energy demand across an urban area with limited data input required. Dorfner (2011) estimated heat energy demand for a residential area in Stuttgart, Germany by multiplying total floor area (TFA) for buildings in the region, by an energy intensity coefficient (kWh/m^2 per year, by sector (e.g. residential, commercial)). Similar methods exist. However, they either require higher levels of data input (Rylatt et al. 2003), albeit to achieve a greater level of accuracy, or propose a more generalized spatial analysis approach that amalgamates the energy demand of individual properties into a standard grid square laid over a community with each uniformly sized grid cell representing summarized property attributes and energy demand (Möller 2008). The shortcoming of all three methods, and those similar to them, are that they are only estimations and will never truly capture the nature of energy use within a community. However, they are useful in this early stage of identifying suitable areas for future in-depth investigation. It is recommended that an approach similar to that employed by Dorfner (2011) be utilized.

Step 1C – Wastewater Heat Availability Assessment

Thermal energy recovery potential along a sewer network can be estimated using available municipal sewer network and land-use data in conjunction with a sewer heat recovery coefficient. The minimum sewer data requirements are sewer channel diameter and length data, and estimated per capita wastewater flow by land-use area or region (such as per census tract) based on where a section of sewer channel is located. An estimate for maximum recoverable heat per unit area of a sewer heat exchanger will be used to calculate heat recovery based on sewer channel characteristics (e.g. 4 kW of recoverable heat per m^2 of sewer channel invert). A digital map file of the sewer network will contain all appropriate data on sewer characteristics and estimated recoverable heat (once calculated) and will be used at a later stage of the analysis for matching ideal locations of thermal energy demand with recoverable sewer waste heat. This approach assumes that actual wastewater flow data is limited or missing as disaggregated wastewater details by sewer channel are typically less readily available compared to flow and temperature data for a central wastewater treatment plant.

Table 8 is an example of available recoverable heat specific to a sewer channel of a certain size and was adapted based on manufacturer specifications for a Rabtherm integrated heat exchanger system (Pamminger et al. 2013; CRM 2008). These figures are technology specific and therefore a community performing a comprehensive assessment is encouraged to investigate and review heat recovery potential from several types of heat exchanger systems to identify the most suitable SWWHRS that meets the community's energy conservation and sustainability goals. Furthermore, it should be mentioned that a minimum sewer pipe diameter is deemed necessary to make a SWWHRS viable, for example some saying 400mm (Monsalve 2011) while others say a minimum of 800mm is required (Pamminger et al. 2013; Schmid 2008). However, for the purposes of this analysis all sewer channels are encouraged to be included since wastewater heat from multiple sewer channels of varying sizes could potentially be harvested and concentrated into a heating network or harvested and stored.

TABLE 8: Model WWHR potential by sewer size and length

Channel Diameter (mm)	Max. Recoverable Heat (kW/m)
50	0.28
75	0.42
100	0.56
125	0.7
150	0.84
200	1.12
225	1.26
250	1.4
255	1.428
300	1.68
350	1.96
375	2.1
380	2.128
400	2.24
450	2.52
500	2.8
525	2.84
600	3.70
675	5
750	6.5
825	7.26
900	8.00
975	8.05
1050	10
1200	12.24
1275+	13

Under the assumptions in Table 8, total heat capacity of a sewer channel can be estimated and visually represented with the use of a spatial data file that lays out an urban sewer network.

Step 1D – Identifying Ideal locations for SWWHRS and customer connection

Establishing system scope/boundaries: A wastewater heat recovery system would be bound by the extent of the sewer network.

Customer Catchment Zone: Distance/spatial connection threshold: Through the establishment of a feasible connection catchment area via estimated WWH availability and customer distance to source (taking into consideration volume of WWH resource, costs associated with servicing customer (e.g. connection, infrastructure) and heat loss, etc.). An optimal serviceable service area of a SWWHRS has been recommended to be within 200 metres of a sewer channel (Pamminger et al. 2013). This can result in multiple sewer channels demonstrating viability to service a single site.

Identifying potential customers/customer zones: To qualify if a potential customer is well suited for connection to a SWWHRS an inventory is conducted of thermal energy users within the municipal boundaries and their thermal energy needs, such as temperature and quantity. Alternatively, instead of a comprehensive audit of thermal energy users, categories could be established to denote the type of energy a certain user would require, with an estimated temperature range and quantity as opposed to exact, at least to begin the qualification process.

TABLE 9: Example Customer categories for WWHR			
CUSTOMER TYPE	**END-USE**	**TEMPERATURE GRADE**	**LEVEL OF POTENTIAL FOR MEETING THERMAL ENERGY DEMAND BASED ON REQUIRED TEMPERATURE GRADE**
Industrial	Pre-heating for various processes	High	Marginal
Institutional/ Commercial	Pre-heating steam boilers	Medium	Moderate
Commercial	Space and water heating	Medium – Low	Fair
Residential	Space and water heating	Low	Good

RESULTS

This first step of the SWWHRS implementation decision support system is a preliminary planning step that will identify suitable sites warranting further investigation into the feasibility for harvesting wastewater heat and distributing recovered heat for local space and water heating needs.

Recommendations for other Steps in the SWWHRS Decision Support System

The following are suggested steps that should be integrated into the framework of a SWWHRS Planning Decision Support System following Step 1. Detailed discussion regarding the formulation and implementation are beyond the scope of this report and are identified as potential areas for future research.

Following Step 1, those areas identified as potential candidate sites for a SWWHRS would need to undergo the following:

Step 2A: *Qualify the WWH resource via actual measurement of wastewater flow in as close proximity as possible to the potential area for heat recovery.*

Step 2B: *Generate a more accurate assessment of thermal energy demand for the identified potential wastewater heat customers either through detailed modelling or actual measurement of heating requirements.*

Step 3: *Perform an Economic Feasibility Assessment for implementing SWWHRS at each of the identified sites.*

Step 4: *Perform an Environmental and Ecological Assessment*

Step 5: Perform a Social/Community Assessment to help determine acceptance level and impacts within the local and regional urban community, as well as barriers to adoption and how might those barriers be addressed.

3. CASE STUDY: Applying the Decision Support System for SWWHRS Planning in Guelph, ON

3.1. CASE STUDY CONTEXT

CASE STUDY AREA: GUELPH, ON

SUPPORTING CONDITIONS IN GUELPH FOR SWWHRS ADOPTION:

Guelph is committed to reducing fossil fuel dependence. Guelph is a progressive Ontario community with a clear vision for climate change mitigation and sustainability through energy efficiency.

Guelph's Community Energy Plan (CEP) completed in 2007 was an unprecedented monumental undertaking for an Ontario community (City of Guelph 2007). The CEP was the first contemporary community energy plan geared toward greenhouse gas emission reduction and energy conservation. Prior to the CEP energy planning in Ontario had been the focus of the Ontario government and energy utilities.

Of particular importance for this study is the CEP's intention to meet at least 25% of local energy demand from locally sourced renewable energy sources.

Another important goal from the CEP is Guelph's intent to have the thermal energy demands of the community met by a renewable energy fueled district heating network (e.g. biomass combustion). As per the CEP, operationalizing such a system would be accomplished by “systematically [creating] an integrated energy metering, billing and management network across the entire city to allow cost-effective management of all energy forms” (City of Guelph 2007, 16).

Further to the CEP a “District Energy (DE) Strategic Plan for the City of Guelph” was prepared by Envida (Envida 2013). This plan addresses the CEP’s goals regarding the adoption of renewable thermal energy solutions by outlining an implementation approach for a district heating and cooling network for commercial, industrial, institutional, and residential end-users. In both the CEP and the Envida DE plan recovery of waste heat, particularly from industrial processes, is identified as a viable solution.

Wastewater heat recovery from sewers was not considered as an option in either plan. This is not surprising, despite the potential for reducing fossil fuel consumption and achieving energy savings, as wastewater heat has been given less attention in the realm of energy planning as it is not a standard renewable resource and so has been neglected from most urban energy planning analysis models in North America.

However, the goal with this SWWHRS planning decision support system is to provide energy planning practitioners the ability to identify an opportunity that would otherwise be overlooked due to lack of awareness about the potential of SWWHR, a lack of knowledge regarding how to go about assessing the opportunity, and/or a perception that it would not be a viable option in their community.

Infrastructure plans for Guelph are suitable for incorporation of SWWHRS. The age of Guelph's existing sanitary sewer system warrants replacement in the near future, which could be coordinated to improve the feasibility for implementation of a SWWHRS. A wastewater servicing master plan prepared for the City of Guelph revealed that Guelph's sanitary sewer network consists of sewer sections ranging from 1 to over 100 years old, with the oldest infrastructure generally found to be in the downtown area (Earth Tech 2008, 14). The older infrastructure so happens to also be located in proximity to areas of high thermal energy demand. The master plan has made sewer replacement recommendations based on short (0-5 years) and long-term (up to 25 years) necessity. Many trunk, or high volume sewer channels were identified to be in need of replacement, with several trunk lines identified as being in need of replacement in the short-term. It is unknown as to what the status is for all of the recommendations since the completion of the Master Plan. However, Guelph's 2015-2017 capital budget plan has listed engineering capital projects for replacing sewers as part of the "Sewer Replacement, Watermain Replacement and Storm Sewer Replacement capital accounts" (City of Guelph 2015). If more sewer replacement is being planned for the upcoming Capital budget period post 2017, then that would be an excellent opportunity for the City of Guelph to consider implementing a SWWHRS in tandem with any necessary sewer replacements. Not only would this create an opportunity for Guelph to help achieve its long term energy conservation and GHG emission reduction targets, but would also bring down the overall cost of implementing the SWWHRS as the cost could be shared across departments.

3.2. MODEL

These subsequent steps, as outlined in chapter 2, will be used for identifying ideal locations for implementing a SWWHRS in Guelph, ON:

Step 1A – Conduct a data-mining exercise to establish Guelph's Energy Use and Wastewater Flow Baseline

Step 1B – Generate a Heat Map of Guelph's thermal energy demand

Step 1C – Assess Wastewater Heat Availability across Guelph's sewer network

Step 1D – Identify Ideal locations for SWWHRS and customer connection in Guelph ON

3.3. DATA

TABLE 10: CH2M Hill Wastewater volume projections for Guelph				
YEAR	2024	2032	2039	2047
Millions of Litres per Day (MLD)	85	105	125	145

TABLE 11: GUELPH, ONTARIO Forecasted Thermal Energy Use and Wastewater Heat Recovery Potential													
Energy Demand Forecast by Sector													
SECTOR	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2030**	**2035**	**2040**
	GWh_{th}	**GWh_{th}**	**GWh_{th}**	**GWh_{th}**	**GWh_{th}**	**GWh_{th}**	**GWh_{th}**	**GWh_{th}**	**GWh_{th}**	**GWh_{th}**	**GWh_{th}**	**GWh_{th}**	**GWh_{th}**
Residential	788	791	796	788	790	791	783	785	787	789	802	812	831
Commercial	275	276	279	280	282	284	286	288	289	292	303	311	319
Industrial	610	614	620	624	628	633	637	641	645	650	672	694	721
Institutional	173	175	175	177	177	179	179	181	181	182	185	189	190
TOTAL	1,846	1,856	1,870	1,869	1,877	1,887	1,885	1,895	1,902	1,913	1,962	2,006	2,061
Average Daily WW Flow (Millions of Litres per Day)	60.2	63.3	66.4	69.5	72.6	75.7	78.8	81.9	85	87.5	100	113.6	127.5
Available Recoverable Heat (MW)	14.5	15.3	16.0	16.8	17.5	18.3	19.0	19.8	20.5	21.1	24.2	27.4	30.8
Total Annual Recoverable Heat Potential (GWh)	127.4	134.0	140.6	147.1	153.7	160.3	166.8	173.4	179.9	185.2	211.7	240.4	269.9
Portion of Thermal Energy Demand that could be met by leveraging 100% of Guelph’s SWWH resource													
TOTAL (All Sectors)	7%	7%	8%	8%	8%	8%	9%	9%	9%	10%	11%	12%	13%
TOTAL (Excluding Industrial)	10%	11%	11%	12%	12%	13%	13%	14%	14%	15%	16%	18%	20%
Residential (exclusive use)	16%	17%	18%	19%	19%	20%	21%	22%	23%	23%	26%	30%	32%
Commercial (exclusive use)	46%	49%	50%	53%	55%	56%	58%	60%	62%	63%	70%	77%	85%
Industrial (exclusive use)	21%	22%	23%	24%	24%	25%	26%	27%	28%	28%	32%	35%	37%
Institutional (exclusive use)	74%	77%	80%	83%	87%	90%	93%	96%	99%	102%	114%	127%	142%

TABLE 12: SPATIAL DATA			
File Name	**FILE CONTAINS**	**TYPE**	**SOURCE**
Addresses.*shp*	Street Address; GPID; ROLLNO; ADDID	Point Shapefile	City of Guelph
Buildings.*shp*	outline/shape of building	Polygon Shapefile	University of Waterloo
Details.*dbf*	Gross floor area; land use description; ROLLNO	database file	City of Guelph
Property.*shp*	Property parcel outline; GPID	Polygon Shapefile	City of Guelph

TABLE 13: NON-SPATIAL DATA			
DATA SHORT DESCRIPTION	**DETAILED DESCRIPTION**	**TYPE**	**SOURCE**
Ontario Residential and Commercial/Institutional Space and Water Energy Use Intensity (2013)	Data from each of the following Comprehensive Energy Use Databased tables contains information pertaining to total annual space or water heating energy use by Ontario sub-sector: RESIDENTIAL SECTOR Table 34 to Table 39 (Energy Use by Property Type) COMMERCIAL/INSTITUTIONAL Table 4 – Table 23 (Energy Use by Activity)	Government Statistics	Natural Resources Canada. Office of Energy Efficiency – Comprehensive Energy Use Database (NRCan 2016)

TABLE 14: Space and Water Heating Energy Information by Sector in Ontario								
END USE	Space Heating	Water Heating	Space Heating	Water Heating	Space Heating	Water Heating	Space Heating	Water Heating
SUB-SECTOR	**Single Detached**	**Single Detached**	**Single Attached**	**Single Attached**	**Apartments**	**Apartments**	**Commercial/ Institutional**	**Commercial/ Institutional**
YEAR	2012	2012	2012	2012	2012	2012	2012	2012
REGION	Ontario	Ontario	Ontario	Ontario	Ontario	Ontario	Ontario	Ontario
SECTOR	Residential	Residential	Residential	Residential	Residential	Residential	Commercial/ Institutional	Commercial/ Institutional
PJ	235	69.3	37.8	15.4	40.8	25.5	182.2294933	30.71477415
GJ	235000000	69300000	37800000	15400000	40800000	25500000	182229493.3	30714774.15
Total Floor Area (m2)	506,300,000	506,300,000	210,000,000	210,000,000	135,700,000	135,700,000	280,200,000	280,200,000
Total Floor Area (ft2)	5,449,767,844	5449767844	2260421188	2260421188	1460662644	1460662644	3016047699	3016047699
EUI (GJ/m2)	0.46	0.14	0.18	0.07	0.30	0.19	0.65	0.11
EUI (ekWh/m2)	128.931	38.021	50.000	20.370	83.518	52.199	180.654	30.449
EUI (ekWh/ft2)	**11.978**	**3.532**	**4.645**	**1.892**	**7.759**	**4.849**	**16.783**	**2.829**

TABLE 15					
Property Type	**Total Units in Ontario**	**Energy Use – 2013 (PJ)**			**Average Annual Heating Energy Use per Property Type Unit (kWh)**
		Space heating	Water Heating	TOTAL	
Single Detached	2,979,700.00	264.5	70.5	335	31,229.84

3.4. METHODOLOGY:

SWWHRS Planning Decision Support System: Preliminary Assessment

Due to limited data for Guelph, this new methodology was well suited for assessing the ideal locations for implementing a SWWHRS across the City.

Step 1A: Establishing Guelph Forecasted Energy Demand and Wastewater Heat Recovery Potential

Forecasting Guelph's future energy use and wastewater heat recovery potential was accomplished by utilizing data from City of Guelph's 2013 District Energy Strategy (Envida 2013), the 2009 Wastewater Treatment Master Plan (CH2M Hill 2009), and Guelph 2014 Wastewater Annual Report (City of Guelph 2014).

Information from the 2014 Annual Wastewater Report was used to establish the baseline volume for the projections in conjunction with forecast estimates from the Wastewater Masterplan report (CH2M Hill 2009, 9-12).

The reported per capita wastewater flow volume was 400 L/day, which equated to 54 million litres per day (MLD) based on a population estimate of 134,894.

Furthermore, the CH2M Hill report indicates future wastewater flow volume for Guelph as outlined in Table 10.

The difference between each forecast period (e.g. 2014 to 2024, 2024 to 2032) is calculated and divided by the number of years between each period to estimate the average year to year change in wastewater volume. That produced estimated annual wastewater flow from 2014 to 2047. However, since there was only energy use forecast data to 2040 that is where the analysis stopped.

Using the forecasted volume information, Guelph wastewater heat recovery potential was calculated based on the following equation:

$$P_{WW} = V_{WW} \times c \times \Delta T$$

Where:

V_{WW} = *Estimated volume converted to* m^3*/hour*

c = ($1.16\ kWh/m^3 * K$)

ΔT = K or (°C). *The expected change in wastewater temperature based on recovery.*

Based on the best available data sewer wastewater temperatures (during Winter) are estimated to be 10 to 20°C (Dürrenmatt and Wanner 2014) and as much as 12 to 27°C during other times of the year (Elias-Maxil et al. 2014; (Frijns et al. 2013). It is recommended that wastewater temperature entering a WWTP should not be below 10°C as a result of the total heat recovered from upstream sewers (Dürrenmatt and

Wanner 2014, 556). However, this is due to specific regulations for Swiss wastewater treatment plants. Neugebauer et al. (2015) analysis of wastewater heat recovery potential assumed wastewater temperatures of 10°C, with expected heat extraction of 5K resulting in the temperature cooling to 5°C. Still, there are methods for addressing this issue of lowered temperatures potentially affecting WWTP processes, such as increasing retention time of sludge tanks, which is anticipated to have a cumulative temperature increasing effect. Additionally, adjusting the amount of heat recovered across the network at different times can result in a reduced impact on cumulative influent temperature change at the WWTP (Dürrenmatt and Wanner 2014). Thus, for Guelph the assumed minimum temperature of sewer wastewater across the network will be 10°C and the assumed temperature extraction at each section of sewer will be 5K.

Therefore, the theoretical recoverable thermal energy from wastewater heat in Guelph ON from 2016 to 2040 is summarized in Table 11.

Step 1B: Creating the Energy Demand Heat Map

Input Data

The spatial and non-spatial data used in the creation of the space and water heating energy ‘heat map’ for Guelph is summarized in Table 12 and 13.

1. Calculating space and water heating energy use

Once all the necessary spatial data is imported data integration begins by using one of the base functions of ArcMap, the ***Join Data*** function. The crucial elements for this part of the analysis are the gross floor area (GFA) and land use type of each of Guelph's properties. These elements however are not part of the *Property.shp* file. To update the *Property.shp* file with GFA and land use information requires the following series of steps.

Join:
By Attributes From table

Join *Addresses.shp* and *Details.shp* by using the "join attributes from a table" using the Rollno field to match corresponding records. Now each address point record will contain GFA and land use data. Save as a new shape file: *Address_w_GFA_landu.shp*

Join:
By Spatial Location of Attributes

Next join *Address_w_GFA_landu.shp* with *Buildings.shp* based on "spatial location". The address points fall inside each of the corresponding building polygons. Save as a new shape file: *Buildings_w_GFA_landu.shp*

Join:
Sum of Attributes

The next step will require joining data from *Buildings_w_GFA_landu.shp* to each property parcel by spatial location. Since multiple building polygons can fall within a single property parcel polygon the attributes, primarily the GFA, will be summed.

2. Overcoming missing Gross Floor Area data

Missing GFA data was obtained by calculating the area of building polygons.

3. Total Energy Use estimation by property parcel

Using data from Natural Resources Canada's Comprehensive Energy Use Database for total annual energy use in Ontario allowed for energy use intensity coefficients to be calculated, summarized in Table 14.

The corresponding coefficients by respective land use are multiplied by GFA data for each property record.

4. Setting the scale

Using Natural Resource Canada Comprehensive Energy Use Database figures for Single Detached residential properties in Ontario reveals what is outlined in Table 15.

Using average GFA of commercial/institutional properties in Guelph multiplied by the energy use intensity coefficients for thermal energy demand from Table 14 reveals the following:

Average commercial/institutional property uses 58,522.708 kWh_{th}/year

Based on the two averages for residential (31,229 kWh_{th}/year) and commercial/institutional (58,522 kWh_{th}/year) it can be assumed that an identified annual thermal energy consumption of 58,222 kWh_{th} or less would not be greater than a single property's annual thermal energy demand. Therefore, anything below 60,000 kWh_{th} is considered the lowest energy use category. See Table 16 for a list of energy use categories.

TABLE 16		
THERMAL ENERGY USE (kWh)	QTY OF PROPERTIES	ENERGY USE CATEGORY
<= 60,000	33,189	Lowest
60,001 - 250,000	634	Low
250,001 - 500,000	263	Mid
500,001 - 1,000,000	182	High
1,000,000+	215	Highest

5. Heat Map estimates

The estimated heat map energy use baseline analysis results are displayed in Figure 21. The estimated thermal energy usage for Guelph in 2013 was 1,839 GWh_{th} (Envida 2013). The sum of thermal energy demand from the heat map spatial analysis equals 1,157 GWh_{th}. The difference between the two estimates is 37%, which is less than an order of magnitude and provides a measure of confidence in this method of estimation, especially in the absence of other data. Using the Heat Map method can assist planners at the preliminary stage to identify a potential area that warrants future investigation to assess SWWHRS implementation potential.

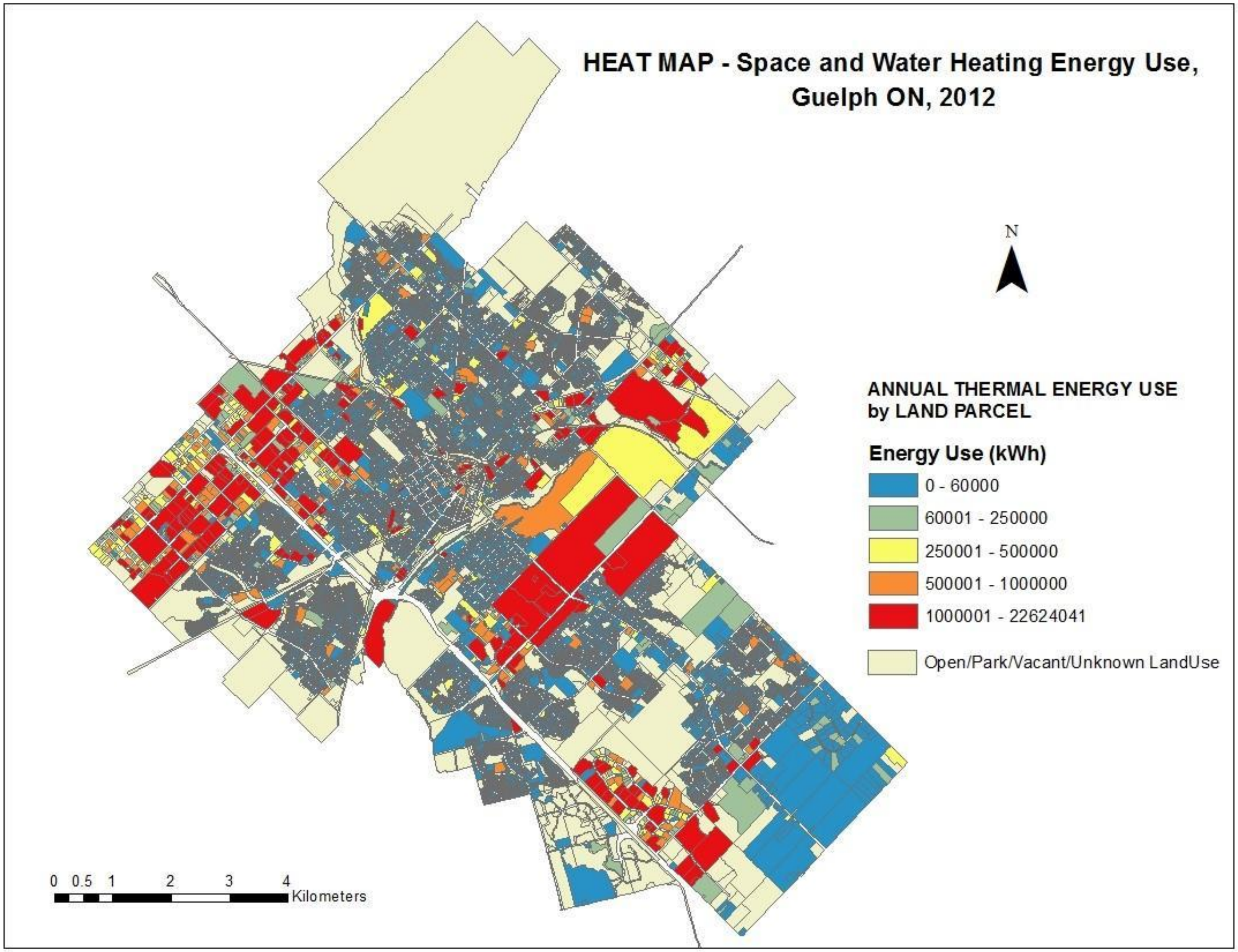


Figure 21: Guelph ON Thermal Energy Use Heat Map (Calder 2016)

Step 1C: Creating the Sewer Wastewater Heat Recovery Potential Map

1. **Estimating maximum recoverable wastewater heat**

Taking the appropriate maximum recoverable heat coefficient (kW/m) by sewer pipe diameter from TABLE 8 and multiplying the appropriate coefficient for each pipe segment in the Guelph sewer network by the length of each sewer channel segment generated the estimated recoverable heat based on location across the entire network. Figure 22 demonstrates those areas with low to high SWWHR potential.

2. **Establishing the SWWHRS Servicing Area Potential for Each Sewer Channel**

Based on the literature, energy demand (sinks) should be within 200 metres of a SWWHR heat exchanger (Pamminger et al. 2013). A buffer distance of 200 metres was set for each sewer channel based on this recommendation. The results from the heat recovery buffer analysis are demonstrated in Figure 23.

3. **Estimating the Wastewater Flow Volume by Census Tract**

Using wastewater per capita flow volume data and census tract population figures the estimated wastewater flow volume can be estimated for each census tract. See Figure 24 for the results of this analysis.

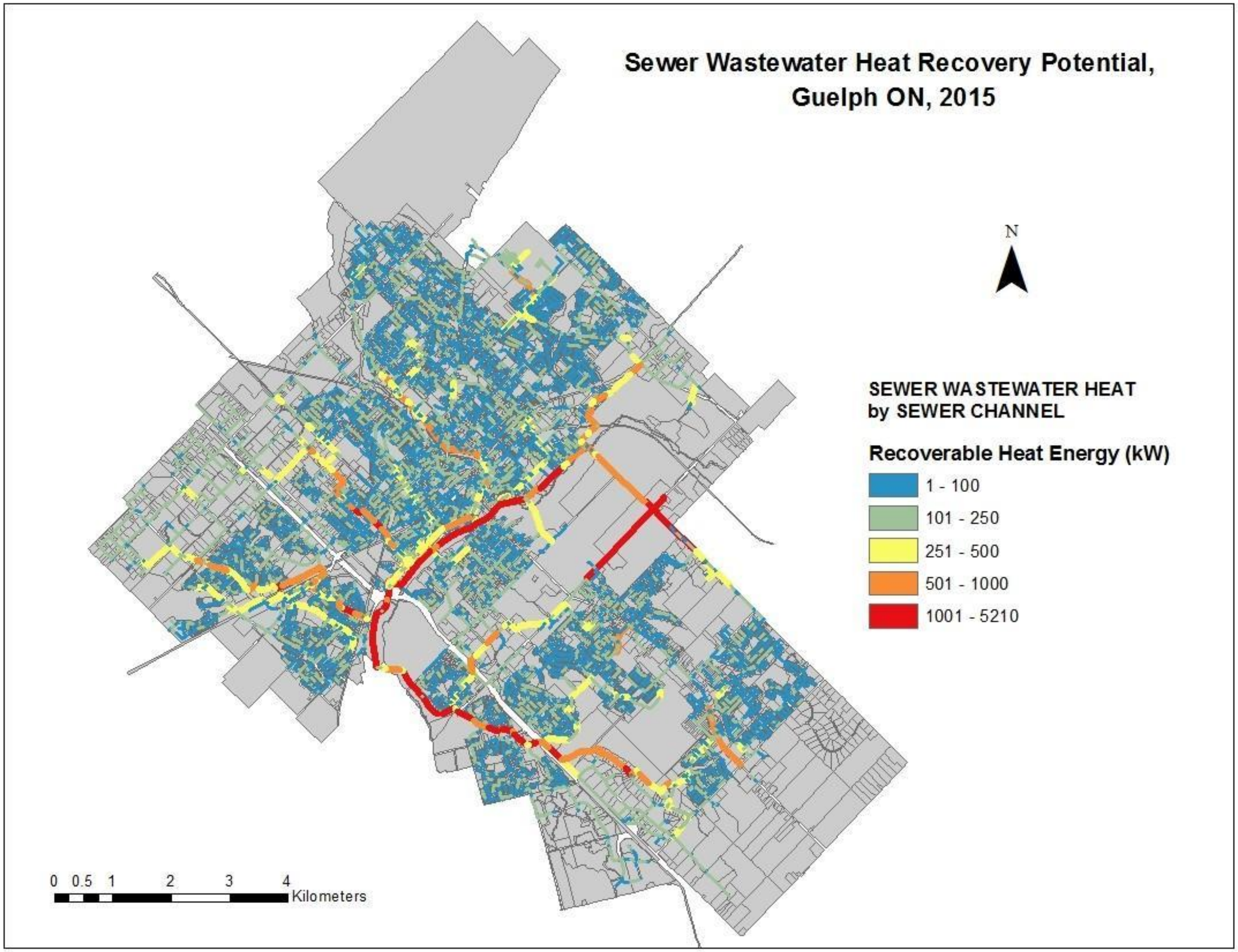


Figure 22: Identification of available wastewater heat recovery potential across Guelph's sewer network (Calder 2016)

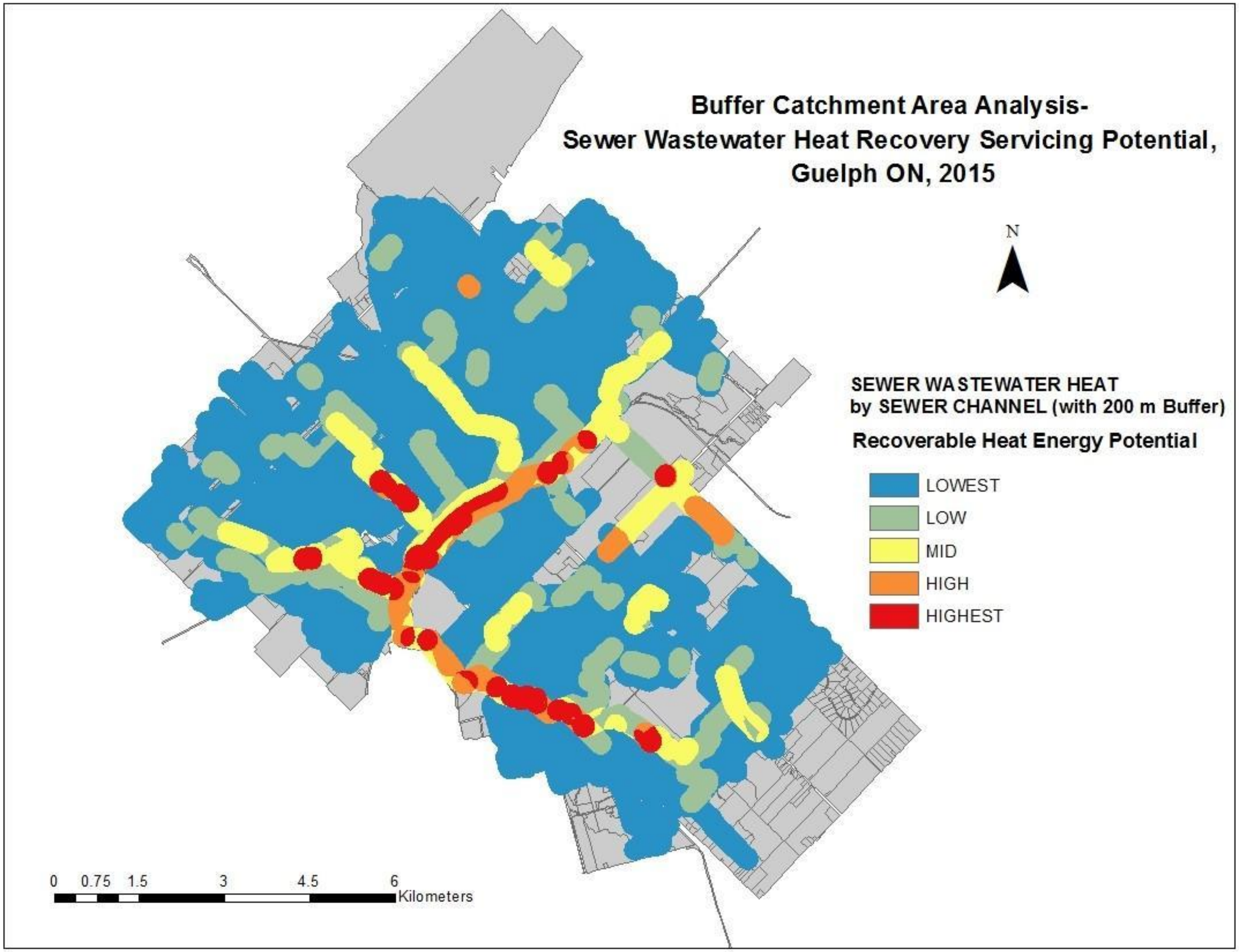


Figure 23: Buffer analysis demonstrating the serviceable area capacity level by sewer channel(s) (Calder 2016)

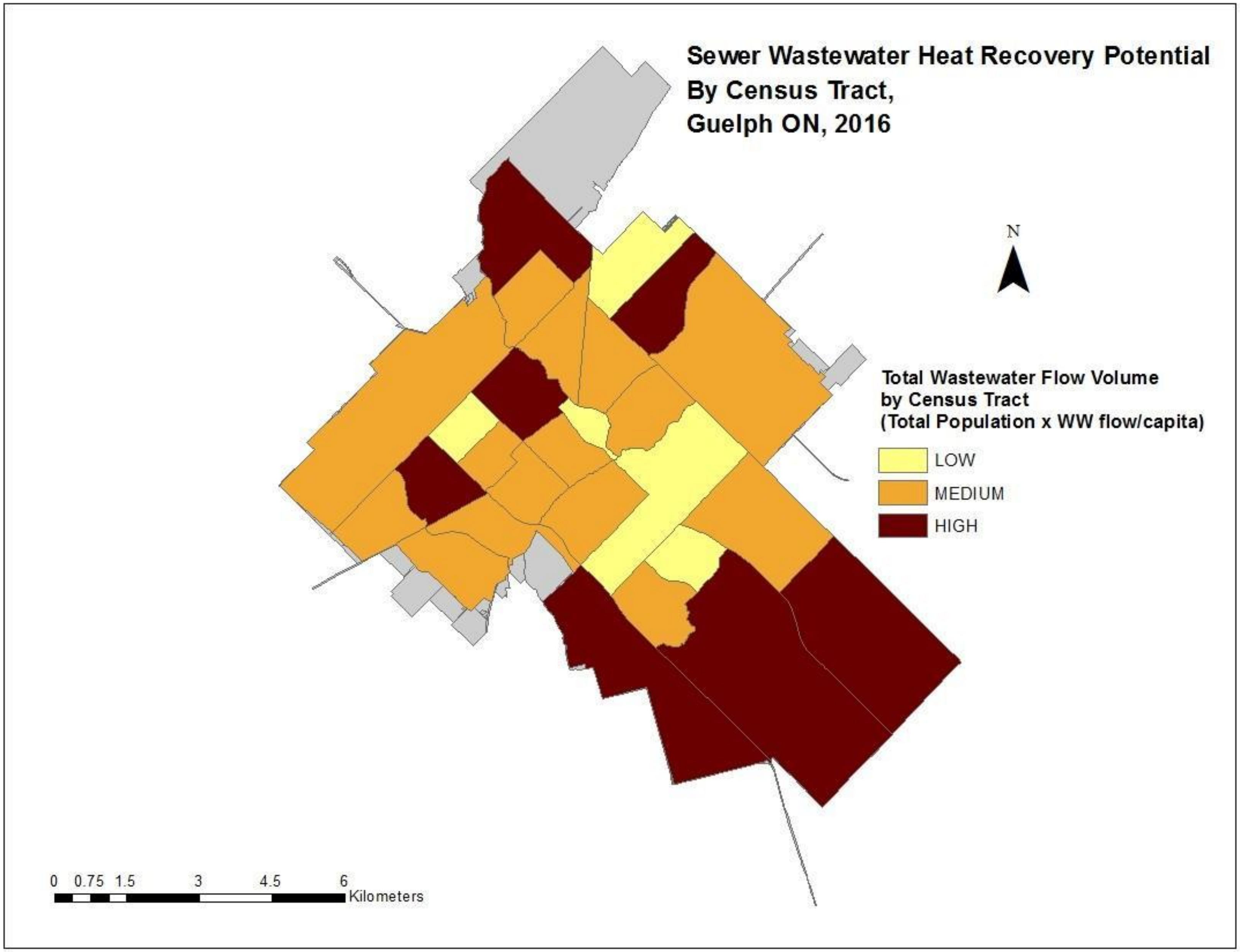


Figure 24: Total wastewater flow per census tract (CT) in Guelph calculated using CT population and wastewater flow per capita (Calder 2016)

Step 1D: Performing a SWWHRS Site Suitability Analysis

1. Raster Overlay Analysis: Setting the scale

After calculating the estimated available heat recoverable from each sewer channel section and applying a buffer of 200 metres, I converted the buffer vector shapefile into five separate raster files based on the criteria listed in Table 17.

TABLE 17

Potential Recoverable Sewer Heat (kW)	**CRITERIA CODE/ RASTER CELL VALUE**	**FILE OUTPUT**
<= 100	1	Ww_buf_100
101 – 250	2	Ww_buf_250
251 – 500	4	Ww_buf_500
501 – 1000	8	WW_buf_1000
1000+	16	WW_buf1000+

Next I converted the Energy Demand and Wastewater Volume by Census Tract vector files into raster files assigning raster cell values based on heat energy use (Table 18) and wastewater flow (Table 19).

TABLE 18

Heat Energy Use (kWh)	CRITERIA CODE/ RASTER CELL VALUE	FILE OUTPUT
<= 60,000	100	Heat_d_all
60,001 - 250,000	200	
250,001 - 500,000	400	
500,001 - 1,000,000	800	
1,000,000+	1600	

TABLE 19		
Wastewater Flow by Census Track (L/s)	**CRITERIA CODE/ RASTER CELL VALUE**	**FILE OUTPUT**
5 – 11	10,000	CT_WW_Cap
12 – 20	20,000	
21 – 39	40,000	

Once the files were converted to raster files using the following tools they were then consolidated into a single layer that could then help with identifying the best locations for implementing a SWWHRS:

TABLE 20		
Geoprocessing Tool	**Files Used**	**Rationale**
Mosaic to new raster	5 sewer heat buffer layers	Multiple sewer buffers overlapped, which meant that one site or heat recovery system could potentially draw from multiple sewer lines. Each buffer was given a unique value. When they were joined the values of the overlapping cells would be added. In all 31 potential combinations of overlapping layers emerged.
Raster calculator	1) Merged Buffer Raster (output from Mosaic to new raster function) 2) Heat_d_all 3) CT_WW_cap	The raster calculator tool added the three layers together with overlapping cells summed to produce a new value. Each value in the new file equated to an implementation feasibility scenario with certain values indicating more feasibility than others.

2. Raster Overlay Analysis: Setting the scale

After the raster consolidation operations, the next step was to identify which cell values were conducive to level of suitability. The most ideal locations based on highest level of available wastewater heat and level of thermal energy demand were categorized further from HIGHEST to LOWEST. The raster evaluation and identified scenarios are summarized in Table 21.

TABLE 21			
SITE SUITABILITY LEVEL	SCENARIO VALUES		
HIGHEST	41,616	To	41,631
	21,616	To	21,631
HIGH	40816	To	40831
	20816	To	20831
MID	40416	To	40431
	20416	To	20431
LOW	40216	To	40231
	20216	To	20231
LOWEST	40116	To	40131
	20116	To	20131

This information was applied to a map of Guelph. Please see Figure 25.

3. Convert the raster layer to polygons and add buffer

After converting the raster file to a vector file the polygons with values conducive to an ideal site can be selected, isolated, and converted to a separate layer file.

Following the raster to polygon conversion a buffer analysis was applied with a 200 metre buffer yielding seven ideal areas demonstrating high potential for SWWHRS implementation feasibility. See Figure 26.

3.5. RESULTS

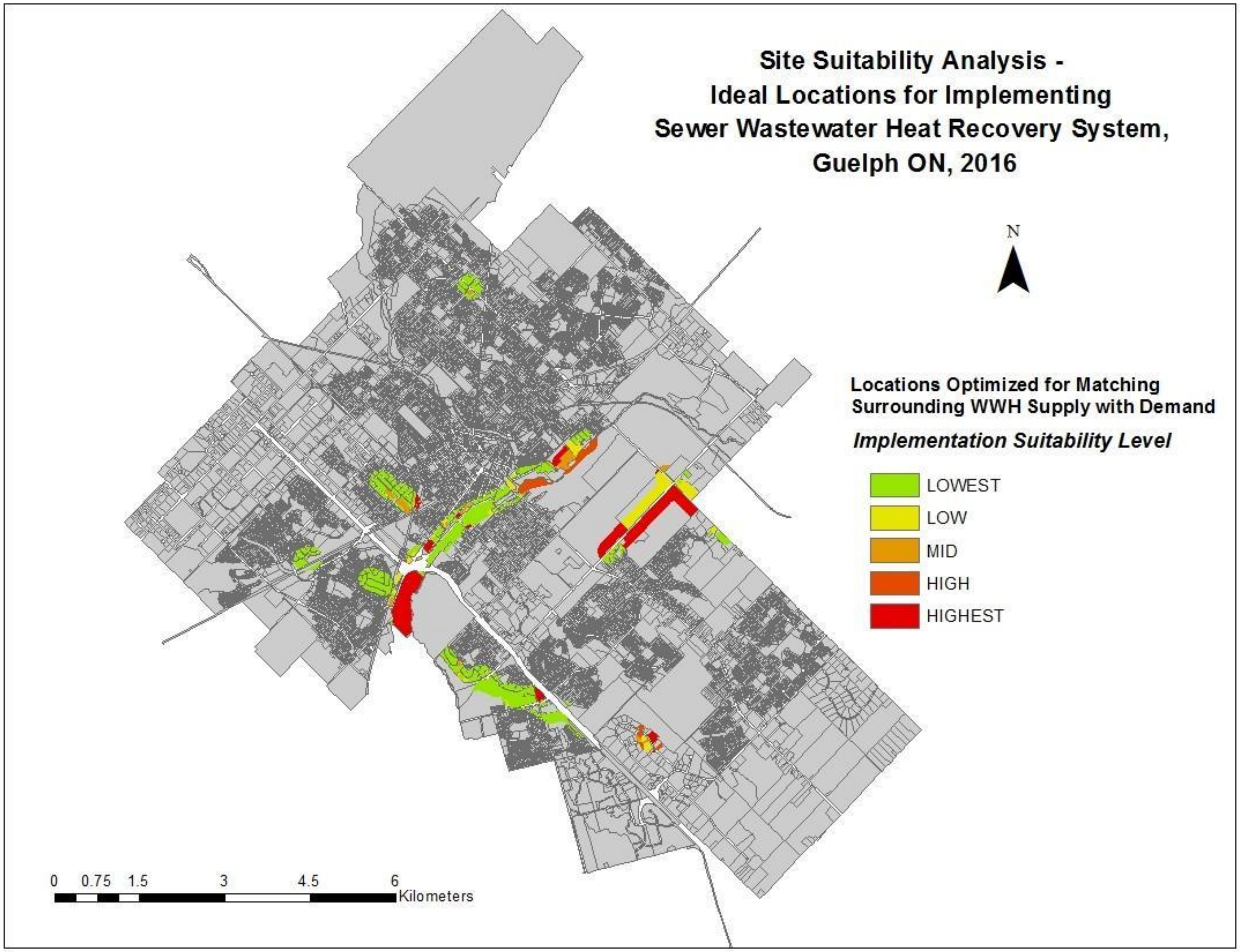


Figure 25: Areas suitable for further investigation to assess viability of implementing a sewer wastewater heat recovery system (Calder 2016)

Ideal Locations For Future Investigation
To Assess SWWHRS Implementation Feasibility, Guelph ON, 2016

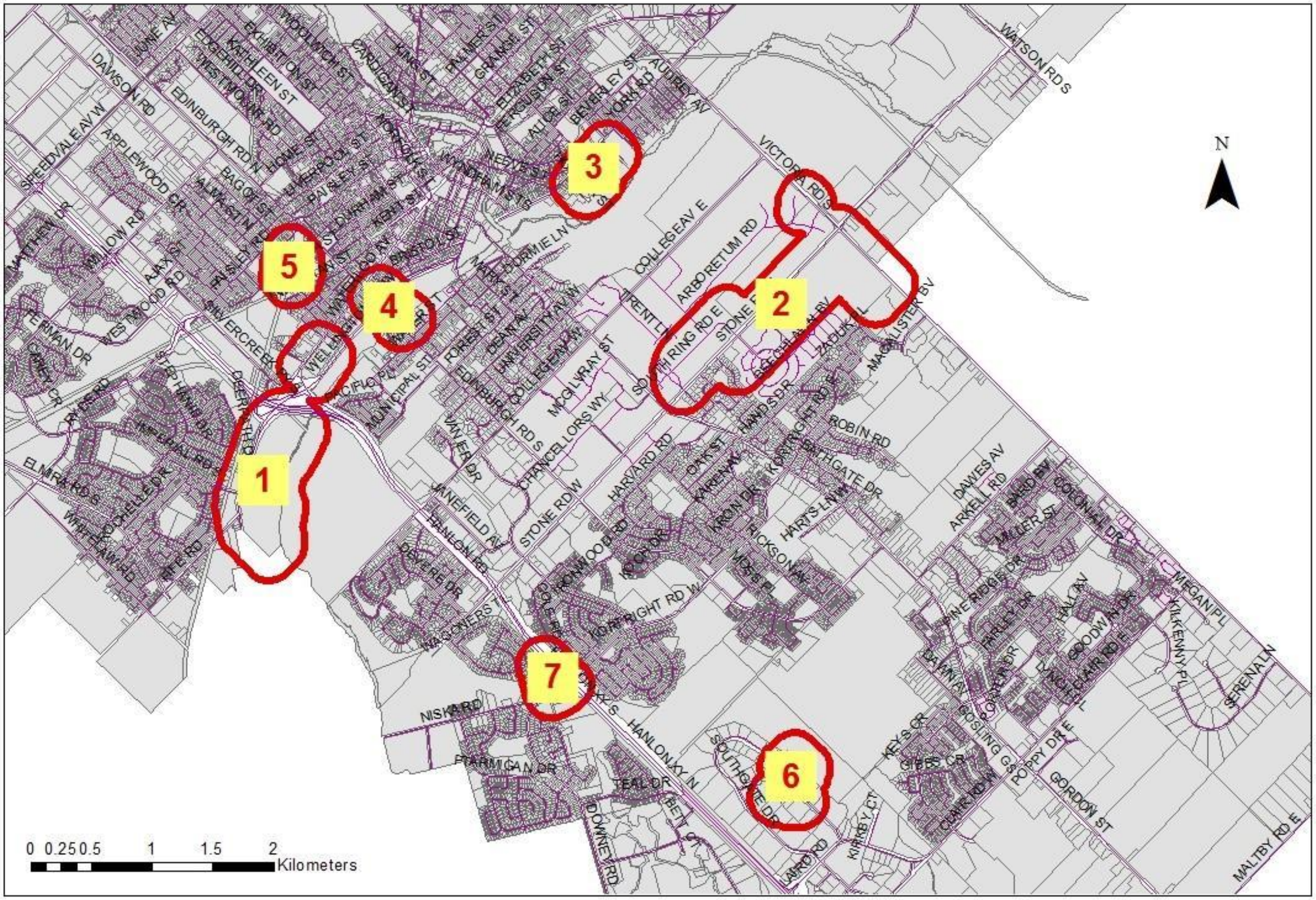
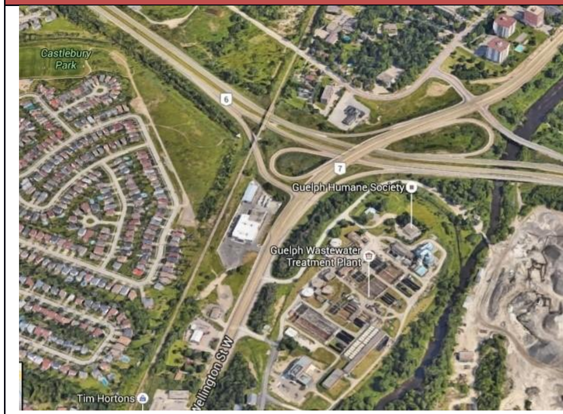
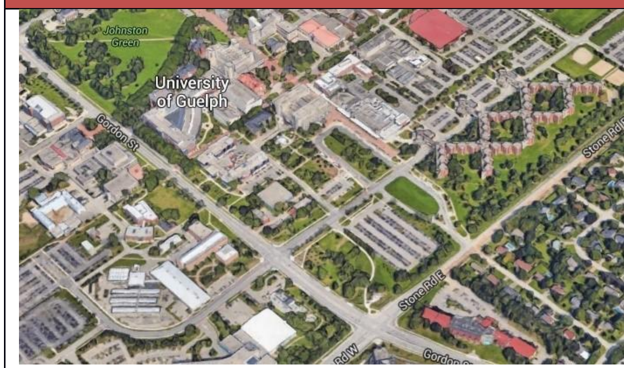


Figure 26: Areas suitable for further investigation to assess viability of implementing a sewer wastewater heat recovery system (Calder 2016)

Ideal Areas Demonstrating Highest Potential for SWWHRS Implementation

(Images taken from Google Maps)

<table>
<tr><th>AREA 1</th><th>DESCRIPTION</th><th>KEY FEATURES</th></tr>
<tr><td>
</td><td>A mix of commercial, institutional, and low and high density residential land uses.</td><td>Guelph wastewater treatment plant found within this area.</td></tr>
<tr><th>AREA 2</th><th>DESCRIPTION</th><th>KEY FEATURES</th></tr>
<tr><td>
</td><td>A mix of institutional, commercial, low and high density residential land uses.</td><td>University of Guelph found within this area.</td></tr>
<tr><th>AREA 3</th><th>DESCRIPTION</th><th>KEY FEATURES</th></tr>
<tr><td>
</td><td>Industrial, commercial, institutional, and low density residential land uses.</td><td>Guelph water works pumping station found within this area.</td></tr>
</table>

AREA 4	***DESCRIPTION***	***KEY FEATURES***
	***High rise and low rise residential, institutional, commercial.***	***Multiple apartment complexes and schools found within this area.***
AREA 5	***DESCRIPTION***	***KEY FEATURES***
	***Commercial, residential land uses***	***Multiple commercial and residential properties within this area.***
AREA 6	***DESCRIPTION***	***KEY FEATURES***
	***Commercial, industrial land uses***	***Multiple large industrial sites***

AREA 7	***DESCRIPTION***	***KEY FEATURES***
	***Low density residential, commercial/institutional land uses***	***YMCA at Hanlon and Kortright found within this site.***

3.6. Next steps for Guelph: Assessing technical and financial feasibility

With the identification of the seven areas demonstrating potential for SWWHRS implementation the follow up activities would involve qualifying the technical and financial feasibility for implementation in each of those areas and developing a decision support system to repeat this analysis as needed. ArcMap Model Builder offers one potential framework for such a decision support system.

3.7. How to apply to other municipalities in Ontario

Any municipality with sewer network and property characteristics (i.e. land use type and gross floor area) data and spatial data files can carry out this preliminary assessment of SWWHRS implementation viability.

4. CONCLUSION & RECOMMENDATIONS

Despite the benefits sewer wastewater heat recovery systems (SWWHRS) convey they remain an underutilized renewable energy solution. Sewer wastewater heat (SWWH) suffers less from intermittency issues compared to other renewable energy sources (e.g. wind and solar) due to the constant availability of the resource and the volume available to a community.

The decision support system introduced in this paper is a preliminary step in the planning of a SWWHRS and is recommended to be used in tandem with other technical, financial, and contextual data to inform the selection of a suitable site for implementing a sewer wastewater heat recovery system.

A key determinant of the viability of a SWWHRS will be actual wastewater flow measurements across the sewer network. However, measuring the flow across an entire network can be cost prohibitive. Therefore, employing the first stage of this proposed decision support system could contribute to the narrowing of candidate sewer sections warranting further investigation.

Furthermore, each urban community will have its own set of unique characteristics, including built form mix and density, which will affect the level of potential that a SWWHRS will demonstrate. For this reason, SWWHRS must not be considered the ideal answer for the provision of low carbon heating, but rather one of many possible decentralized renewable energy sources warranting assessment for utilizing in an integrated community energy approach.

Beyond the assessment of available local renewable resources for meeting energy demand urban centres must also reduce energy and material throughput by reducing demand through innovative conservation approaches. Transitioning toward a circular urban metabolism that not only values local waste streams, such as SWWH, as a viable resource but also values efficient use of resources, can lead to communities consuming less energy overall. Without reducing current levels of consumption or mitigating future increases cities will continue to rely upon exurban resources, such as fossil fuel imports, as levels of local available resources will not be able to sustain demand. This becomes a deeper issue than simply finding sustainable technology solutions. This requires a reprogramming of community values to the very core of our societies. The behaviour of our communities is predicated around constant consumption of new, fresh products at ever increasing levels. To change this behaviour will be no small feat and will not be accomplished in a short amount of time. However, the paradox is that we must change immediately if we are to avoid the impending catastrophic impacts that scientists from a wide array of disciplines (professions including but not limited to agriculture, architecture, biology, climatology, economics, ecology, energy, geography, medicine, engineering, politics, sociology, urban planning) are predicting will impact our urban communities if we continue importing and consuming non-renewable resources at increasing levels.

A single action may not be the answer. But an accumulation of sustainable actions predicated around changing how our urban societies consume energy, resources, and materials can contribute to sustainability becoming the standard as opposed to the alternative.

By investing in sustainable energy measures now will help to reduce much costlier repair and emergency response requirements later into the century when extreme weather events such as flooding, heat waves, and extreme precipitation become more common place. Scientific evidence is already overwhelming, and continuing to increase, with expectations of how devastating climate change will be. A decision support system such as the one presented in this paper could make possible tiered scenarios whereby a community wide or site specific implementation schedule can be established. Even incremental gains from implementing a few SWWHRS is better than none. Once in place the salience of SWWHRS benefits can potentially lead to greater demand and adoption of such solutions at varying scales. Decentralizing the energy grid will reduce potential for crippling shocks to infrastructure, business operations, and our lives in general.

To encourage Ontario communities to utilize sewer wastewater heat and begin transitioning toward a sustainable and resilient circular urban metabolism I recommend the following:

- Establish regional renewable thermal energy recovery targets across Ontario. Targets would be established for a variety of thermal resources including, but not limited to sewer wastewater heat, geothermal, solar, using a fully developed decision support system, beginning with a preliminary assessment encompassing spatial analysis techniques, that would assess the availability of all possible thermal renewable resources across Ontario. Targets could be achieved, in part, through revisions to the Planning Act and Ontario Building Code by setting requirements for new construction and/or significantly renovated property projects to submit as part of a project application package an assessment report that compares the level of feasibility present for implementing various renewable thermal energy systems as part of the project scope.

Planners could deem a thermal renewable energy system obligatory if a particular technical and financial feasibility threshold was achieved. Thresholds for sewer wastewater heat recovery systems, among others, could be established at a municipal context based on multiple criteria including resource availability, baseline and forecasted energy demand for proposed project and the area it would be situated, potential energy use and GHG reductions, and expected updates to existing sewer infrastructure. If municipalities decided to offer a cash-in-lieu-of option for project applicants, those funds could be utilized to help a community achieve its targets through the development of municipally owned and operated sustainable thermal energy systems. By setting regional targets multiple municipalities could benefit from the economies of scale associated with data collection and analysis efforts.

- Accelerate investment in sewer wastewater heat recovery systems, and other renewable thermal energy recovery systems, with a Federally and Provincially funded incentive program that offsets the upfront cost for project implementation. Provincial sources of funding could include revenues from the new Ontario Cap-and-Trade program, which is expected to be $2 billion per year. Natural Resources Canada funding could supplement Provincial funding, such as the 'Energy Innovation Program', in order to fund community demonstration projects and help kick-start technology adoption in Ontario.

- Update the Ontario Provincial Policy Statement to have a more detailed definition of renewable energy that includes sewer wastewater heat and provide a more articulated scope of how land use planning can contribute to effectively utilizing urban waste streams for reducing climate change impacts and increasing community energy efficiency. Despite the energy potential of sewer wastewater heat, consideration of it as a renewable resource is limited in the Ontario planning paradigm. Therefore, acknowledgement must be explicit if the awareness of planners is to be increased regarding how to achieve the benefits of sewer wastewater heat recovery.

- Mandatory requirements for municipalities to assess the viability of implementing a SWWHRS at time of new sewer line installation or replacement. Currently planning and implementation of sewers is a first-tier consideration during municipal budget decision-making, while renewable energy remains a secondary, non-mandatory item. Since there is complementarity with the planning and implementation of sewer systems and sewer wastewater heat recovery systems, including multiple environmental, social, and economic benefits from renewable resource harvesting, municipalities should make budgeting for SWWHRS a mandatory budget consideration.

- Mandatory requirements for municipalities to conduct updated assessments of the entire sewer system to be able to assess viability for a SWWHRS. Make sewer wastewater flow data by channel/line available to public stakeholders including, but not limited to, utilities and builders.

- Municipalities should begin a phased program of implementing monitoring equipment at locations deemed likely to be viable SWWHRS implementation points. Using a method, such as the first step of a decision support system introduced in this paper, can assist planners with narrowing down where monitoring equipment should be installed.

- Develop supporting regulations that allow for a variety of ownership models to operate. The Province of Ontario regulates the distribution of energy. Wide-spread adoption of SWWHRS will require multiple customer ownership models, which could include:
    - Private Owner(s): a privately owned system might be suitable for individual properties, with the property owner responsible for procuring funding and coordinating the implementation of the necessary system components for limited number of sites. The private ownership model may be more beneficial to high-rise commercial or residential developers, but with less likelihood for widespread uptake by property owners in lower density areas.

    - Municipal Utility: Municipalities possess several key attributes making them prime candidates to implement and own a SWWHRS. The benefit of a municipality owning the system is their ability to invest in large capital projects and infrastructure with long payback periods, the proven accountability to the community increasing the potential for widespread trust and buy in, ownership and engineering expertise with sewer infrastructure, customer relations and administrative capabilities. Although there is a lot of upfront requirements for a municipality the benefits include a long-term additional revenue stream for the city, increased economic independence and sustainability both for municipal operations (which can certainly benefit from a SWWHRS) and local community members.

    - Collaborative Utility: collaborative ownership model with a municipality and existing energy utility may be another promising option for communities to implement SWWHRS. For example, natural gas utilities are already well versed in the business of providing thermal energy services to customers. This not only includes the business model and administrative infrastructure necessary to manage customer relations, and a pricing model based on energy services delivery and distribution of a fuel source/ or heat energy. Gas utilities are also equipped with the technical expertise to implement new infrastructure necessary to deliver thermal energy in readily established urban areas or environmentally sensitive ones.

- Appoint an agency/ministry responsible for the regulation of SWWHRS implementation and develop a provincial streamlined implementation process that reduces the difficulties associated with conflicts in overlapping jurisdictions. Overlapping jurisdictions can create stakeholder conflict. Implementing a wastewater heat recovery system would likely involve municipal governments, municipal service departments responsible for water services (sewer infrastructure) and road repair, water and energy utilities, land use planners, local businesses and residents.

Further research is needed for investigating how to hasten the change in community perceptions around harvesting urban waste for energy use and for identifying how to hasten the uptake of wastewater heat recovery system implementation. Additionally, research for ways on how to streamline the assessment of wastewater heat potential so that planners and other stakeholders can more easily assess the feasibility of implementing a WWHRS in their community is recommended.

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