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Sewer Waste Heat Scoping Study

Final Report

J.L.Richards
ENGINEERS · ARCHITECTS · PLANNERS

Value through service and commitment

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1.0 Introduction & Background

1.1 Project Context

J.L. Richards & Associates Limited (JLR) was retained by the City of Ottawa (the City) to provide a scoping study of the resource potential, and viable use cases for implementing below-ground thermal energy resources from Ottawa's sewer system and aquifer systems. The scope of this project is being executed under Standing Offer for Professional Engineering Services 30717-92500-S01 - Category 1 - Planning, Feasibility, Pre-Engineering, Environmental Studies and Assessments (the SOA).

The City of Ottawa Energy Evolution Program has set a goal for the City to achieve carbon neutrality by 2050 and for the City's corporate operations to achieve carbon neutrality by 2040. One key need within this plan is for buildings to move to zero carbon heating using a range of viable technologies including air source heat pumps, ground source heat pumps, district energy systems that in turn have low carbon thermal supplies, and waste heat recovery. An opportunity, in relation to this, is to harvest heat from underground City sewer lines, either for direct use or in combination with heat pumps.

The purpose of the Sewer Waste Heat and Geothermal Energy Study (the Study or Project) is to identify and quantify sources of below-ground thermal energy resources from Ottawa's sewer system and aquifer systems, and then provide guidance on how they might be employed. The project outcomes will be used by the City in the drafting of a policy for the use of municipal infrastructure by third parties for development of projects.

The main phases of the project were as follows:

1. Undertake a review of sewer heat exchange technologies that are in commercial operation.
2. Using a GIS framework, collect and review relevant information on the Ottawa sewer system towards assessing its potential as a resource for heat exchange opportunities; this focuses on temperature and flow information.
3. Develop archetypes of sewer thermal exchange utilization projects to evaluate various implementation opportunities in Ottawa.
4. In parallel to the above, develop an understanding of deep aquifer resources in Ottawa that may support open-loop ground-source heat pumps, which similarly may avoid some of the expensive drilling of a typical (closed loop) ground-source heat pump system.

The contents of this final report summarize the results of Phases 1, 2 and 3. A report for Phase 4 of the project was submitted to the City under a separate cover titled "Geothermal Heat Resource Scoping: Open Loop Geothermal Potential," dated May 11, 2021.

1.2 Heat Pump Technology Context

A key element of low carbon buildings is to avoid combustion of fossil fuels for heating. This is typically replaced by electrically powered heat pumps, which draw or reject heat from the surrounding environment. The ambient air and the ground are the most common renewable resources that are used as the source/sinks for the heat pumps and are known as air-source heat pumps (ASHP) or ground-source heat pumps (GSHP) systems.

ASHPs and GSHPs can be implemented in many circumstances with varying advantages and disadvantages. ASHPs are essentially air conditioners that can be operated in two directions, pumping heat into or out of the building. There are now cold-climate ASHPs that can operate in cold winter climates, such as Ottawa, though they are still challenged with achieving attractive efficiencies, since they must draw heat from cold winter air and dump heat into hot humid summer air. Closed-loop GSHPs are able to take advantage of the more stable temperature of the ground as the source/sink but have high capital costs due to the extensive number of boreholes that must be installed, and they can only support an approximately balanced heating and cooling load on an annual basis, otherwise the ground temperature will shift with time. Open-loop GSHPs make use of a free-flowing deep underground aquifer as the source/sink. These require fewer boreholes and can support unbalanced loads and can be lower cost to develop but are limited to certain locations where suitable aquifers exist – a separate study and report within this project examined available geohydrological data to identify potential for development within Ottawa.

It is only relatively recently that the opportunity to tap into municipal wastewater pipes as a thermal supply has been considered in North America. The sewage collection system provides a stream of flowing liquid (i.e., sewage) with relatively stable temperatures. Similar to GSHPs, the sewage provides a medium for heat recovery or heat rejection (a source/sink) for building heating and cooling when coupled with a heat pump. The sewer lines can be thought of as “pre-existing ground loops” or shallow brown aquifers. Their use could thus be termed a **“sewer-source heat pump”** system. There are in fact multiple names used in the industry to describe the approach – **the term wastewater energy transfer (WET)** is accurate and convenient.

Because wastewater temperatures are even warmer than ground temperatures in winter, and because of the high efficiency of water-to-water/refrigerant energy transfer, this system is the most efficient of all three choices, and where wastewater flows are high, a single station can serve a very large building load. Furthermore, very strong performance benefits occur in cooling mode as well, and the WET system avoids the need for cooling towers, which have high maintenance costs and water usage. And it is worth repeating that there is no need to balance between heating and cooling thermal energy, since the source/sink is a continuously flowing medium.

The heart of a WET system is the specialty heat exchangers designed to work with wastewater. They have been developed in several quite different forms, as will be explained in Section 3. Other main equipment includes wastewater filters (separating solids from liquids), wet wells, hydraulic pumps and heat pumps – these are common equipment in wastewater and mechanical systems.

WET projects are not common in North America, but they have been implemented and are quickly being realized in many municipalities across Canada and the United States. They are more prevalent in Europe where there are higher costs for natural gas. The oldest running facility in Canada is the Southeast False Creek Neighborhood Utility in Vancouver, first developed in 2010. It currently is a 3 MW WET system, to be expanded by 5 MW in 2022, and supplemented with natural gas boilers that service a large district energy loop. Other major facilities include American Geophysical Union (AGU) in Washington DC, supplying 480 kW, the National Western Centre in Denver supplying 3.8 MW, as well as planned projects at the Toronto Western Hospital (TWH, 8.5 MW) and the Cogswell development in Halifax (22 MW).

1.3 Wastewater Energy Transfer Context

In Ottawa, on average, people generate hundreds of liters per person per day of sewage. This sewage contains significant quantities of heated water, from domestic hot water use, laundry, industrial processes, heating systems condensate output, etc. When sanitary supplies from buildings merge together in the municipal sanitary line, the typical temperatures are in the range 10 to 20°C, varying with time of day, season, and building catchment. These high volumes of warm liquid contain enormous quantities of heat, which typically is just thrown away. Lack of use of the resource has been in part because it is a low-grade heat source - that is, it is low temperature and requires additional heating (e.g., via a heat pump) to be useful for most applications.

There are four different types of WET systems:

1. Individual sanitary drainpipes within a building: At the in-building scale, thermal energy can be captured through individual sanitary drainpipe heat recovery to preheat water going to domestic hot water tanks. These components are relatively low cost and maintenance free, and are on the market, but have surprisingly low uptake. The availability of heat on a single drain is intermittent, though matched to the specific building's water usage.
2. Combined building/campus sanitary drain: For space heating, a more continuous heat supply is required, which can be done through WET systems at the building scale. These systems are designed to use short term thermal storage by collecting all sewage from a building or campus prior to discharging into a sanitary sewer.
3. Municipal sewage collection system: Heat can also be recovered from existing municipal sewage collection infrastructure using heat exchangers integral to the sewage collection pipes, or by diverting sewage to temporary storage. **The focus in this study is to examine WET systems that couple with municipal wastewater pipes, which have more consistent flows and thus can support space heating**.
4. Wastewater treatment plant effluent: One final configuration is to harvest waste heat from a wastewater treatment plant's effluent – this implementation is particularly attractive because the effluent has very high flow rates (the wastewater of the entire municipality) and it is clean water that is being discharged into the environment. Its heat capacities exceed the heat needs of the treatment plant, but it typically is only economic to export excess heat short distances, so large heat loads need to be nearby. Given that this is not the case in Ottawa, this opportunity was not explored in detail in this report.

1.4 Key Thermal Parameters of Wastewater Systems

Sewage flow and temperature within the sewage collection system are two key parameters that must be investigated when considering the sewage collection system as a thermal resource.

1.4.1 Sewage Flow

Technologies used to recover or reject heat to sewage have minimum sewage flow requirements. Thus, it is important to understand the minimum sewage flow available at locations where sewage is being considered as a thermal resource. However, the design of municipal collection systems is typically focused on understanding what the average and peak flows are throughout the system, based on the sewage generation from a contributing population and the effects of inflow and infiltration due to runoff and groundwater. Typically, minimum flow rates are not a focus during sewage collection system design.

As the generation of sewage in the City is the result of human activities throughout the day, it is intuitive to expect that the flows within the piping system fluctuate throughout the day. In general, peak flows occur in the morning and late afternoon relating to residential pre- and post-work usage. Flows are also reasonably high throughout the day and drop off substantially at night. Flows from major facilities such as universities, large manufacturing sites, and hospitals can be significant and with their own unique patterns. Although the flows fluctuate throughout a day, human-generated sewage flows are very consistent on a weekly, monthly, and even seasonal basis. In general, elements that impact sewage flow volumes include:

- Potable water consumption;
- Industrial water use;
- Infiltration flows from rain, snow melt, and groundwater; and,
- In the case of combined sewer pipes (sanitary plus stormwater), flow is greatly influenced by rain and snow melt.

In areas where the minimum sewage flows are short in duration (a few hours) and less than the desired flow rate for the heat load, there may be opportunities to buffer the minimum flows through the use of larger wet wells that can act as temporary storage. This buffering or storage would increase the area requirements and costs of the system but could provide opportunities in areas with marginal sewage flow rates. The daily average sewage flow rates would need to exceed the WET system requirements.

1.4.2 Sewage Temperature

It is important to establish the temperature profile (including minimum and maximum sewage temperature) at the location of interest. Understanding the temperature fluctuations in the sanitary sewer flows is important in determining (i) the amount of heat that can be extracted from or injected into the sewer lines without adversely influencing the operations of the system, and (ii) the efficiency of the heat pump system (generally described by the coefficient of performance).

Sewage temperatures vary on a daily basis in relation to amount of facility hot water use. They also fluctuate throughout the year. In general, elements that impact sewage temperature include the following:

- Potable water distributions temperatures;
- Ground temperatures encasing the piping system which fluctuate with depth and season;
- Air temperatures (both seasonal and daily changes);
- Air movement within the sewer system;
- Infiltration flows from rain, snow melt, and groundwater;
- Land use; and
- Large facilities with high hot water usage, such as hospitals.

As sewage is comprised mostly of water it is assumed to have the same specific heat capacity as water, which is 4.18 kJ/kg·K. It is well understood that this specific heat capacity is high, meaning that a lot of thermal energy is contained in water, and a lot of thermal heat can be extracted per degree of temperature change to the water/sewage. As a corollary to this, which will impact the data analysis below, it is also true to say that the temperature of small flows will be more influenced by new input streams and above-mentioned factors than large flows.

In general, sewage temperature is colder in winter when heat extraction is desired, and warmer in summer when heat rejection is desired. Although this is not the ideal scenario, sewage heat exchange systems are expected to be viable for most applications as the sewage still provides a source/sink with a more consistent temperature and higher heat capacity than ambient air provides for an ASHP. A more detailed examination of these issues is found in Section 4 of the report.

More analysis of the temperature profiles is contained in Section 3, including a preliminary consideration as to the various influences, heat exchange with the environment, and impacts on downstream parts of the system, including the treatment plant.

2.0 WET System Technology Review

The WET system technologies reviewed in this section are specific to heat exchange systems that may be deployed at relatively major municipal sewer pipes and that provide a low-grade heat supply to thermal loads at a facility. In general, the heat exchangers are expected to recover low grade heat for supply to a heat pump that would be coupled with an HVAC distribution system within a building. Sewage heat exchange technologies also exist for within-building applications, such as a drain water heat recovery unit, for preheating incoming water for domestic hot water, or other similar applications. These technologies are not in scope for this Project. This report generally uses the terms sewer *heat recovery*; however, it should be understood that the technologies reviewed also support heat rejection for cooling applications.

WET systems generally consist of a heat exchange processes combined with pumping loop for sewage. The technologies commonly available can be classified according to the location of the main heat exchanger used to extract waste heat from the sewage. These categories include:

- Technology 1 - Internal Sewer Pipe Heat Exchanger (inserted inside the pipe);
- Technology 2 - Integral Sewer Pipe Heat Exchanger (integral to the pipe wall);
- Technology 3 - External Heat Exchanger.

These WET system technologies were characterized by a list of criteria generated based on the Sewage Waste Heat Recovery Terms of Reference (Appendix A) developed by City of Ottawa and JLR. These criteria were further reviewed with the City of Ottawa on December 4th, 2020 and updated by JLR to incorporate comments. The criteria used to characterize each technology and the general information provided for each item are listed in Table 1 below.

Table 1 – WET System Technology Review Criteria

Criteria	General Information Provided
Technology Overview	• Technology general description. • Major sewage heat transfer system equipment identification. • Example of equipment suppliers and associated products.
Typical Applications and Project Examples	• Typical technology applications. • Notable project examples.
Key Technology Parameters	• Sewage flow requirements. • Sewage temperature requirements. • Sewage collection pipe size. • Energy recovery/rejection potential. • Maximum allowable distance from building load(s) to sewer pipe. • Footprint / land use requirements of sewage heat transfer system.
Operations and Maintenance (O&M) Requirements	• General requirements. • Solid waste production and disposal requirements. • Operation complexity and ease of use. • Estimated equipment lifespan. • Required energy inputs.
Order of Magnitude Cost	• Equipment supply and installation cost per kW.
Installation Considerations	• Description of potential impacts on existing municipal infrastructure, including the sewage collection system, wastewater treatment plant and pumping stations.
Health, Safety and Environmental Impacts	• Description of potential health, safety and environmental impacts related to the equipment and systems installed.
Advantages and Disadvantages	• General summary of technology advantages and disadvantages.

Information was gathered on each technology by reviewing available case studies, scientific journals, and publicly available information and discussions with equipment suppliers who provide equipment specific to sewage waste heat recovery. Where applicable, each technology was given a qualitative rating of Low, Medium or High for qualitative comparison to other technologies. Key information is tabulated in the Technology Review Summary Table included in Appendix B.

2.1 Technology 1 – Internal Sewer Pipe Heat Exchanger (Inserted Inside the Pipe)

2.1.1 Technology Overview

This technology requires installation of heat exchanger plates or tubes directly inside the existing sewage collection pipes. Fluid (e.g., water, glycol, etc.) is pumped in a closed loop from a mechanical room or building to the submerged heat exchanger tubes where it absorbs heat from sewage flowing through the sewer pipe. Heated fluid then returns to the mechanical room and passes through a separate heat recovery system for distribution to building loads. Auxiliary heat is supplied to the loads by boilers or other sources to supplement the WET system when required. This process can be used for both heating (heat extraction) and cooling (heat rejection) applications. A general schematic outlining a typical heat recovery process using this technology is shown in Figure 1 with key, proprietary components highlighted in green. The system is also capable of rejecting heat to sewage for cooling applications.

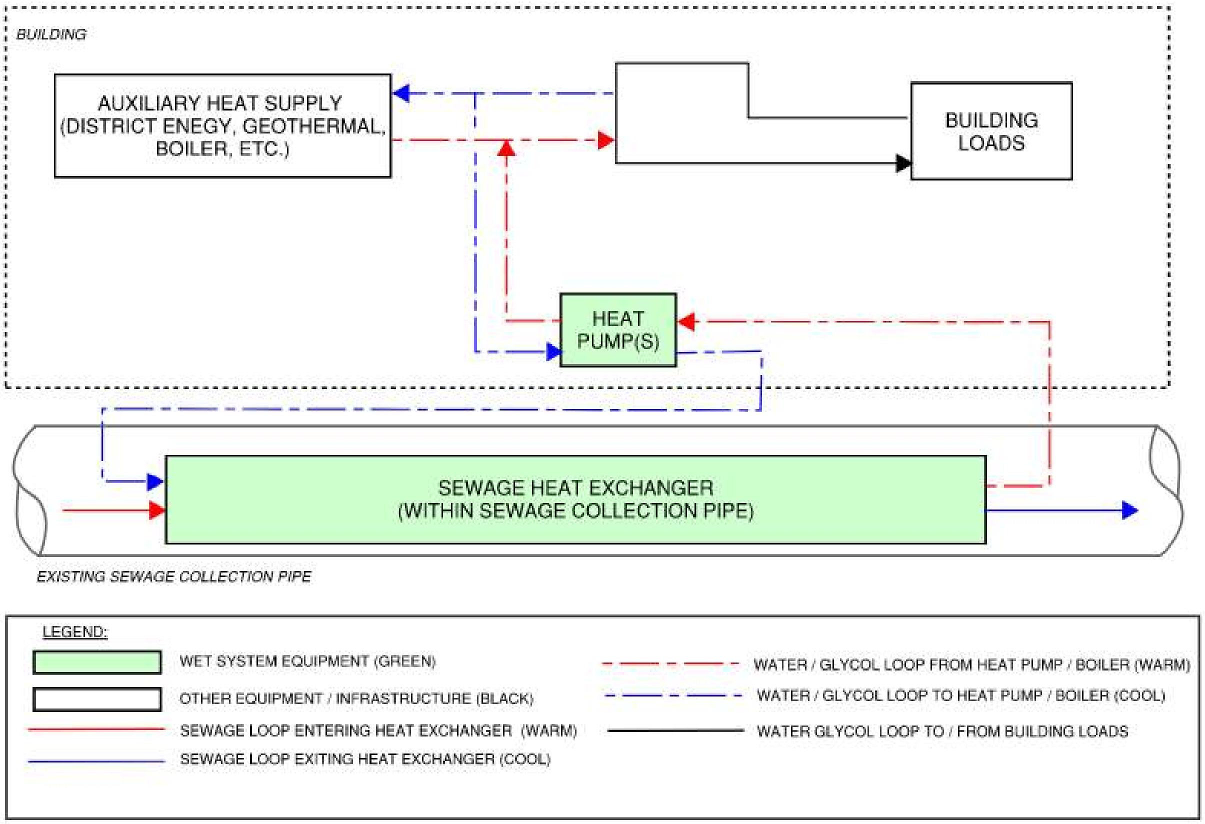

Figure 1: Example Internal Sewer Pipe Heat Exchange Heat Recovery Schematic

UHRIG Group (UHRIG) is a German company that manufactures and distributes products within this technology category. The UHRIG Therm-Liner system is a heat exchanger that is supplied in 1 m lengths for direct installation within sewage collection piping. The heat exchanger is installed at the bottom of the sewer pipe using a clamping system that eliminates the need for interior sewer pipe wall penetrations (i.e., fasteners). A simple visualization of the Therm-Liner technology and two heat exchanger types and installation options are presented in Figures 2 and 3. Additional background information related to the Therm-Liner system is provided in Appendix C.

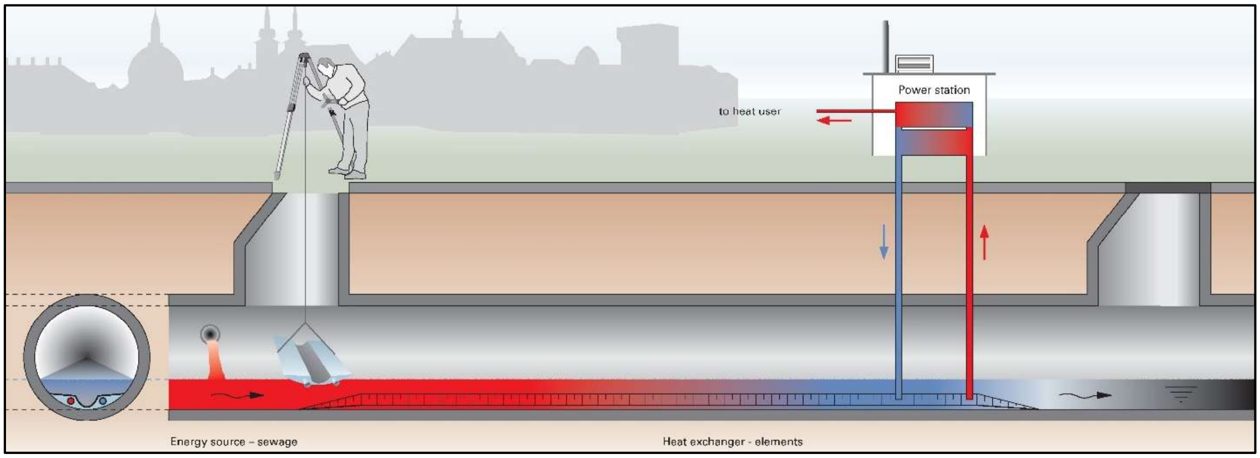

Figure 2: UHRIG Therm-Liner Schematic

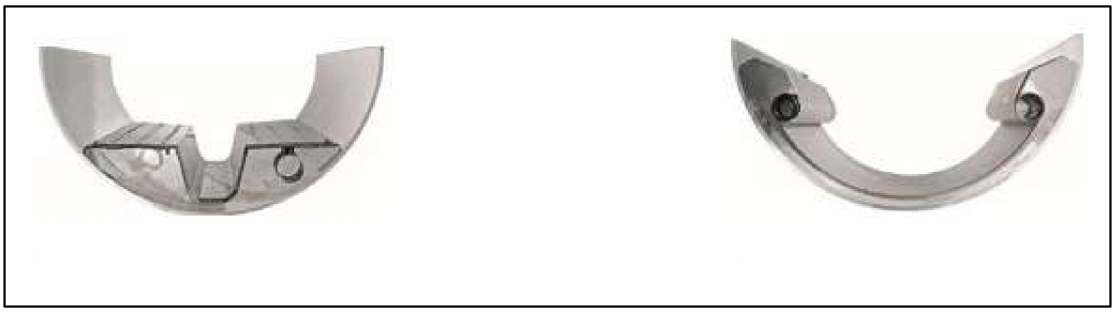

Figure 3: UHRIG Therm-Liner Heat Exchanger Types

2.1.2 Typical Applications and Project Examples

This technology is typically installed to serve a network of buildings or campuses with a heating or cooling demand under 200 kW. For example, a UHRIG Therm-Liner system installed in Bretten, Germany generates 120 kW of heating through 102 m of installed sewer pipe.

According to literature published by UHRIG, the Therm-Liner system is currently operating in over 80 locations throughout Europe.

It appears that there are no Therm-Liner systems installed in North America.

2.1.3 Key Technology Parameters

The key technology parameters for implementing this technology are shown in Table 2 below.

Table 2 – Key Technology Parameters

Parameter	Value
Sewage Flow Requirements [1]	> 10 L/s for 400 mm diameter sewer pipe
Preferred Sewage Temperature Requirements	> 5 °C (heating applications) < 20 °C (cooling applications)
Sewage Collection Pipe Size	400 mm to 3,250 mm
Energy Recovery/Rejection Potential [2]	< 450 kW
Maximum allowable distance from building load(s) to Sewer Pipe	< 200 m
Footprint / Land Use Requirements of Sewage Heat Transfer System	Building Mechanical Room: < 20 m^2

Notes:
1. Minimum flow requirements vary depending on sewer pipe diameter. Refer to Table 3 below for minimum sewage flow rates that correspond with various sewer pipe diameters.
2. Evaluating the energy recovery potential is determined by the equipment supplier using a combination of the pipe dry-weather flow conditions (i.e., minimum sewage flow available), pipe diameter and the length of heat exchanger being installed. Increased energy recovery may be available depending on site specific examples. In estimating heat recovery, UHRIG suggests applying a 40% multiplier to account for biofilm that accumulates on the heat exchanger during regular operation and reduce heat transfer efficiency.

Table 3 – Estimated Minimum Flow for Specified Sewer Pipe Diameter

Nominal Pipe Diameter	Estimated Minimum Flow Rate [1]
400 mm (16 in)	> 10 L/s
800 mm (32 in)	> 20 L/s
1200 mm (48 in)	> 30 L/s
160 mm (64 in)	> 40 L/s
2000 mm (80 in)	> 50 L/s
2500 mm (96 in)	> 60 L/s
2850 mm (112 in)	> 70 L/s
3250 mm (128 in)	> 80L/s

Notes:
1. Minimum flow rates are estimates based on general information provided for the UHRIG Therm-Liner system. Flow requirements should be evaluated with the supplier on a case-by-case basis to optimize system design.

2.1.4 Operations and Maintenance Requirements

As noted above, the main heat exchanger used to recover heat from sewage is installed directly within existing or new sewage collection piping infrastructure. Although calculations used to determine heat recovery potential for this technology account for biofouling, manufacturers recommend annual cleaning of the heat exchanger to remove biofouling and potential buildup of debris (i.e., ragging). Cleaning is typically achieved by pressure wash trucks used during scheduled sewer cleaning events.

Flushing of the closed loop fluid piping within the sewage heat exchanger is also expected annually to remove potential scaling.

There is no solid waste production or solid waste disposal required for this technology.

Once commissioned, the heat recovery system, including equipment in the mechanical room or building, can operate unattended with periodic operator checks and scheduled maintenance. Alarms can be implemented to notify an operator of upset conditions that require operator intervention.

UHRIG has indicated that their Therm-Liner system has a life expectancy of up to 50 years, however this may not be true for all mechanical components that make up the system. Based on industry experience and typical equipment installations, life expectancy of mechanical equipment used for this technology likely ranges from 10 years (heat exchangers and pumps) to 50 years (process piping). A breakdown of estimated component life is presented in Table 4 below. Maintaining a spare parts inventory for critical components and scheduling equipment replacement is suggested to reduce the impacts of potential component failure.

The required energy inputs for this technology vary depending on the size of the recirculation and heat pumps used for the application. The recirculation pump used to supply water or glycol to the heat exchanger inside the sewer pipe is expected to range from 2.2 to 5.6 kW (3 to 7.5 HP), depending on the size of the heat recovery system. The power supply for these components is flexible to suit site conditions where the equipment will be installed (e.g. 600V/3P/60Hz, 230V/3P/60Hz, etc.).

A summary of operations and maintenance requirements is provided in Table 4 below.

Table 4 – Operations and Maintenance Requirements

Criteria	O&M Requirements
General Requirements	Medium to High • Annual pressure washing/cleaning of heat exchanger submerged in sewage pipe. • Annual flushing of heat exchanger closed loop piping to remove scaling. • General maintenance of equipment (pumps, valves, controls, etc.).
Solid Waste Production / Disposal Requirements	Not required.
Operation Complexity and Ease of Use	Low to Medium: • Minimal mechanical equipment for sewage heat exchange process relative to other technologies. • Can operate unattended with periodic operator checks and scheduled maintenance. • No sewage pre-treatment required.
Estimated Equipment Lifespan [1]	Heat Exchanger Components: 10 to 20 years Pumps: 10 years Piping and Valves: 50 years

Criteria	O&M Requirements	
Required Energy Inputs	Power Supply: Recirculation Pump:	Per site conditions 2.2 to 5.6 kW (3 to 7.5 HP)
Notes: 1. Estimated life expectancy is based on typical mechanical equipment installations. 2. Low, Medium and High ratings are applied to select criteria to provide qualitative comparison between technologies reviewed.		

2.1.5 Opinion of Probable Cost

An opinion of probable costs (OPC) for installation of small (80 kW) and large (450 kW) sewage heat exchange systems utilizing Technology 1 are presented below in terms of capital cost and cost per kW. The OPC provided represents an order of magnitude cost for a typical wastewater heat exchange system based on general information that is publicly available; note that the costing herein does not include the heat pump or other heat distributions components. A more detailed cost estimate is recommended when evaluating feasibility of specific projects.

Table 5 – Opinion of Probable Cost

Heat Recovery System Size	Capital Cost	Cost per kW
Small System (80 kW)	$370,000	$4,600 / kW
Large System (450 kW)	$1,200,000	$2,600 / kW

The OPC presented above includes the following components:

- Supply and installation of equipment:
  - Heat exchanger located with existing sewage collection piping.
  - Heat exchanger located within mechanical room / building.
  - Recirculation pumps.
  - Recirculation piping installed between mechanical room / building and sewer heat exchanger.
  - Control system for pump control and monitoring.
- Dedicated 10 m^2 mechanical room / building, assumed at $4,840/$m^2$.

Assumptions:

- Heat exchanger within sewage pipe is located less than 15 m from the mechanical room / building.
- Total sewage pipe heat exchanger lengths of 80 m and 450 m are assumed for the small and large systems, respectively.
- Sewage pipe heat exchangers will be installed utilizing existing maintenance holes.
- Costs associated with operations and maintenance not included.
- Costs associated with the heat exchange process required to distribute recovered heat to building load(s) are not included (e.g., heat pumps, distribution piping, etc.).
- Costs do not include relocation of utilities that may interfere with new infrastructure.
- Costs do not include rock excavation.

2.1.6 Installation Considerations

Factors that should be considered for installing this technology include potential impacts on existing municipal infrastructure of the sewage collection piping system and adjacent surface improvements (e.g., roads, sidewalks, landscaping, etc.) both during regular operation and during construction. Impacts to the sewer pipe, where the heat exchanger is being installed, is minimal as the heat exchanger and associated water supply and return piping can be installed without taking the sewage piping out of service. This has been a key factor noted by UHRIG that has allowed them to install their system in large cities within Germany and Europe.

Installation of equipment within sewage collection piping reduces the cross-sectional area of the pipes and therefore will reduce the operational capacity of the sewage collection system. In addition, there is a risk of debris (i.e., rags, hair, etc.) buildup getting caught on the heat exchanger structure leading to further flow reduction and potential sewer blockage. Installation of additional maintenance hole accesses may also be required to provide access to the heat exchange for inspection, depending on the location chosen for the equipment. Installation of a gravity bypass sewer pipe may also be considered during system design to further reduce the potential risk of sewer backup.

2.1.7 Health, Safety and Environmental Impacts

The main health and safety concern associated with this technology is access to the heat exchanger within a live sewer line for inspection and non-routine maintenance or repairs. Remote access through the use of closed-circuit television (CCTV) would be suitable for most maintenance, however, if personnel access is required, it would require work in confined spaces with suitable personal protective equipment (PPE). UHRIG reports that this level of operator intervention is not necessary on a regular basis, however the actual interval of accessing the installation may depend on the sewage collection system design and sewage quality.

The main benefit of this technology relative to health, safety and environmental (HSE) impacts is that all sewage remains contained within the sewage collection piping rather than pumping the sewage to a central heat exchange process. Apart from the initial installation and infrequent service maintenance, no health risks arise from operators coming in direct contact with sewage.

2.1.8 Summary of Advantages / Disadvantages

A summary of advantages and disadvantages related to this technology is shown below in Table 6.

Table 6 – Summary of Advantages and Disadvantages, Technology 1

Advantages	Disadvantages
• High potential heat recovery from direct contact inside the sewer pipe. • Heat exchanger and associated supply/return piping can be installed	• Risk of potential sewer backup from heat exchanger biofouling and ragging. • Biofouling of heat exchanger reduces heat transfer efficiency and requires manual cleaning (pressure washing).

Advantages	Disadvantages
inside sewer pipe without sewer shut down. • Does not require sewage pumping or pre-treatment. • Limited number of mechanical components (pumps, heat exchangers, valves, piping)	• No known North American distributor or installation support. • Additional heat exchanger required at mechanical room / building for distribution to building load(s). • Not applicable for sewer pipes smaller than 400mm diameter.

2.2 Technology 2 – Integral Sewer Pipe Heat Exchanger (Integral to the Pipe Wall)

2.2.1 Technology Overview

This technology requires the replacement of existing sewage pipes with customized sewer pipes that contain heat exchanger coils integral to the sewer pipe wall. Fluid is pumped in a closed loop from a mechanical room or building to the heat exchanger for heat recovery or rejection, similar to Technology 1. The key difference is that the heat exchanger coil is integral to the pipe wall or wrapped around the pipe, rather than submerged in sewage inside the sewer pipe. The pumped fluid absorbs or rejects heat to the ground surrounding the sewer pipe and the sewage flowing within. Heated or cooled fluid returns to the mechanical room and passes through a separate heat exchanger for distribution within the building. A general schematic outlining an example heat recovery application using this technology is shown in Figure 4 below, with key proprietary components highlighted in green. The system is also capable of rejecting heat for cooling applications.

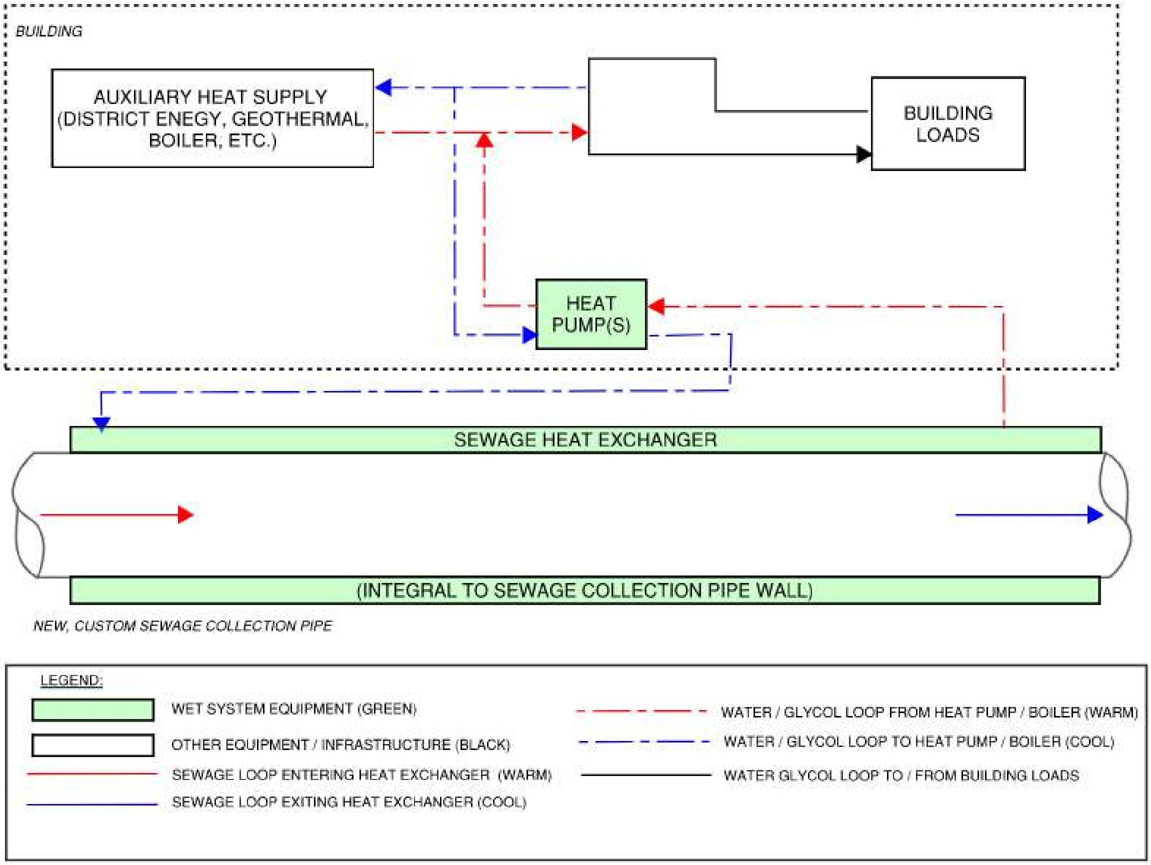

Figure 4: Example Integral Sewer Pipe Heat Exchanger Heat Recovery Schematic

Two European companies were identified that manufacture and distribute custom sections of sewage collection piping for heat recovery: Frank PKS NZ Ltd. (PKS) of Germany, and Rabtherm AG of Switzerland.

PKS manufactures the Thermpipe, which is a custom sewer pipe wrapped in a separate pipe coil. A below-grade distribution shaft is often provided with the Thermpipe to provide a central location for supply and return pipe manifolds and valving. This reduces the system footprint requirements and number of pipe penetrations required at the mechanical room or building. Alternatively, a corridor within the mechanical room or building can be reserved for this equipment. An example schematic illustrating the PKS-Thermpipe system is provided in Figure 5. Additional background information related to the PKS-Thermpipe is provided in Appendix D.

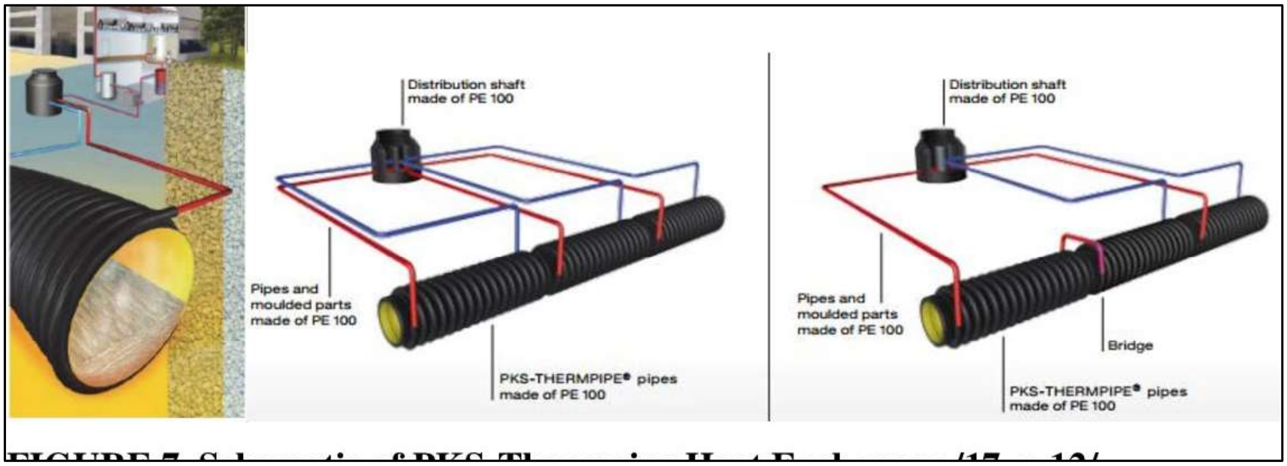

Figure 5: PKS-Thermpipe Schematic

Rabtherm provides a similar system, however, the pipe coil is integrated into the outer wall thickness of the sewer pipe. An example schematic of the Rabtherm Energy System is provided in Figure 6. Additional background information related to the Rabtherm Energy System is provided in Appendix E.

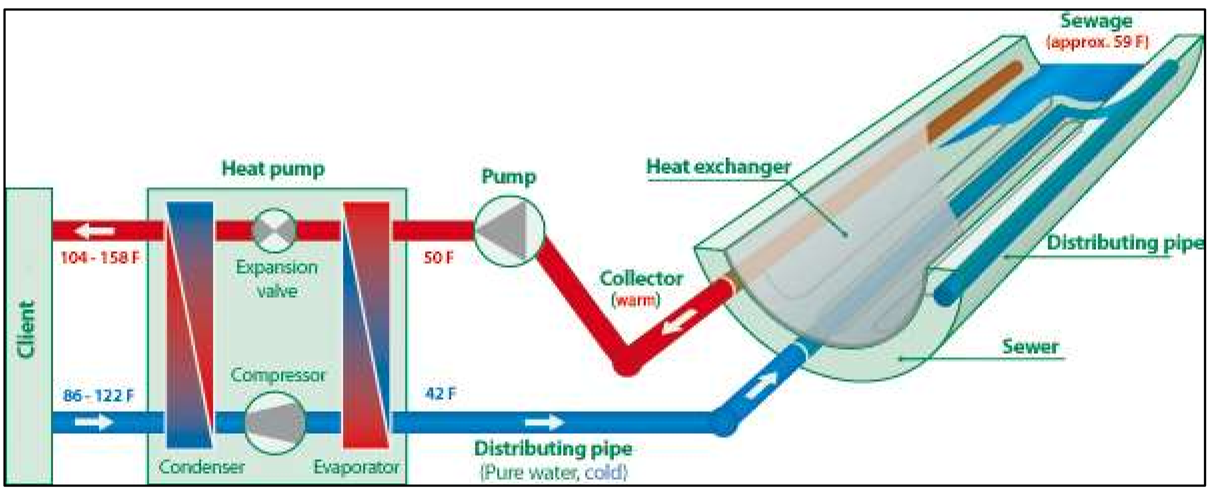

Figure 6: Rabtherm Energy System Schematic

2.2.2 Typical Applications and Project Examples

This technology is commonly used to recover or reject heat to the sewage system to serve a medium to large sized commercial buildings (such as a stadium, or sports complex) or a small campus of buildings.

For example, the PKS Thermpipe is installed at a sports complex in Germany. The system uses the wastewater generated by the approximately 5,000 inhabitants of the area. The wastewater temperature varies between 15 and 20 degrees Celsius. The 36 m of

Thermpipe installed provides approximately 22 kW of energy, primarily for domestic hot water production.

Another example includes installation of a 110 kW Rabtherm Energy System at a medical center in Leverkusen, Germany.

Both of these manufactured products appear to be commonly supplied in place of standard sewage collection piping; however, a detailed list of examples was not publicly available during review.

JLR was unable to identify any installations of either system in North America.

2.2.3 Key Technology Parameters

The key parameters for implementing this technology are shown in Table 7 below.

Table 7 – Key Technology Parameters

Technology Parameter	**PKS-Thermpipe**	**Rabtherm Energy System**
Sewage Flow Requirements [1]	> 15 L/s	> 12 L/s
Preferred Sewage Temperature Requirements	> 5^{o}C (heating applications) < 20^{o}C (cooling applications)	
Sewage Collection Pipe Size	300 mm to 1,800 mm diameter	800 mm to 1,800 mm diameter
Energy Recovery/Rejection Potential [2]	< 540 kW	80 kW to 400 kW
Maximum Allowable Distance from building load(s) to Sewer Pipe	< 500 m	< 200 m
Footprint / Land Use Requirements of Sewage Heat Transfer System	Building Mechanical Room: < 20 m^2 Distribution Shaft / Corridor: 0.3 to 2 m diameter, 3 to 6 m deep/long	

Notes:
1. Minimum flow requirements are expected to vary depending on sewer pipe diameter. Public information was not available at the time of this review to correlate flow requirements with sewer pipe size.
2. Evaluating the energy recovery potential is determined by the equipment supplier using a combination of the pipe dry-weather flow conditions (i.e., minimum sewage flow available), pipe diameter and the length of heat exchanger being installed.

2.2.4 Operations and Maintenance

The PKS-Thermpipe is a closed-loop system with polyethylene construction that requires little maintenance of the heat coil itself, as it is not in direct contact with the sewage. Biofilm may still accumulate within the interior wall of the sewer collection pipe, reducing heat exchanger efficiency. Similar to Technology 1, annual cleaning via pressure washer is recommended as part of routine sewer pipe maintenance.

Flushing of the PKS-Thermpipe internals are recommended annually to remove potential scaling. The distribution shaft or piping corridor includes regulating valves and pumps that balance flow to the PKS-Thermpipe external coils. These valves need periodic inspection and maintenance.

No literature was publicly available to describe any specific maintenance requirements for the Rabtherm Energy System. Due to the similarity in design concept, it is assumed that general operations and maintenance requirements are similar to the PKS-Thermpipe.

There is no solid waste production or solid waste disposal required for this technology.

Once commissioned, the heat recovery system, including equipment in the mechanical room or building, can operate unattended with periodic operator checks and scheduled maintenance. Alarms can be implemented to notify an operator of upset conditions that require operator intervention.

Suppliers of this technology indicate that their equipment has a life expectancy of up to 50 years; however, this may not be true for all mechanical components that make up the system. Based on industry experience and typical equipment installations, the life expectancy of mechanical equipment used for this technology likely ranges from 10 years (general heat exchangers, pumps) to 50 years (custom sewer pipe, process piping). A breakdown of estimated component life expectancy is presented in Table 8 below. Maintaining spare parts inventory for critical components and scheduling equipment replacement is suggested to reduce the impacts of potential component failure.
The required energy inputs and power supply requirements for this technology are expected to be identical to Technology 1.

A summary of operations and maintenance requirements is provided in Table 8 below.

Table 8 – Operations and Maintenance Requirements, Technology 2

Criteria	**O&M Requirements**	
	PKS-Thermpipe	**Rabtherm Energy System**
General Requirements	Low: • Annual flushing of closed loop heat exchanger piping/coil. • General maintenance of mechanical equipment (pumps, valves, controls, etc.).	
Solid Waste Production / Disposal Requirements	Not required.	
Operation Complexity and Ease of Use	Low to Medium: • Minimal mechanical equipment for sewage heat exchange process relative to other technologies. • Can operate unattended with periodic operator checks and scheduled maintenance. • No sewage pre-treatment required.	
Estimated Equipment Lifespan [1]	Heat Exchanger (Custom Sewage Pipe): 30 to 50 years Heat Exchanger (In Building): 10 to 20 years Pumps: 10 years Piping and Valves: 50 years	
Required Energy Inputs	Power Supply: Per site conditions Recirculation Pump: 2.2 to 5.6 kW (3 to 7.5 HP)	

Criteria	O&M Requirements	
	PKS-Thermpipe	Rabtherm Energy System
Notes: 1. Estimated life expectancy is based on typical mechanical equipment installations. 2. Low, Medium and High ratings are applied to select criteria to provide qualitative comparison between technologies reviewed.		

2.2.5 Opinion of Probable Cost

An opinion of probable costs (OPC) for installation of small (80 kW) and large (450 kW) sewage heat exchange systems utilizing Technology 2 are presented below in terms of capital cost and cost per kW. Note that the costs provided are intended to be incremental costs for sewer collection infrastructure already planned for replacement (i.e., cost does not include civil works associated with sewage collection pipe replacement). The OPC provided represents an order of magnitude cost for a typical wastewater heat exchange system based on general information that is publicly available; note that the costing herein does not include the heat pump or other heat distributions components. A more detailed cost estimate is recommended when evaluating feasibility of specific projects.

Table 9 – Opinion of Probable Cost, Technology 2

Heat Recovery System Size	Capital Cost	Cost per kW
Small System (80 kW)	$250,000	$3,100 / kW
Large System (450 kW)	$1,125,000	$2,500 / kW

The OPC presented above includes the following components the following items:

- Incremental costs associated with replacing existing sewage collection piping with custom heat exchanger piping associated with Technology 2.
- Supply and installation of equipment:
  - Heat exchanger located within mechanical room / building.
  - Recirculation pumps.
  - Recirculation piping installed between mechanical room / building and sewer heat exchanger.
  - Control system for pump control and monitoring.
- Dedicated 10 m^2 and 20 m^2 mechanical room / building for the small and large systems respectively, assumed at $4,840/$m^2$.

Assumptions:

- Custom sewage pipe is located less than 15m from the mechanical room / building.
- Custom sewage pipe diameters of 1.0 m and 1.8 m for small and large systems, respectively.
- Total custom sewage pipe heat exchanger lengths of 80 m and 450 m are assumed for the small and large systems, respectively.
- Cost does not include civil works associated with sewage collection pipe replacement).
- Costs associated with operations and maintenance not included.
- Costs associated with the heat exchange process required to distribute recovered heat to building load(s) are not included (e.g., heat pumps, distribution piping, etc.).

- Costs do not include relocation of utilities that may interfere with new infrastructure.
- Costs do not include rock excavation.

2.2.6 Installation Considerations

Similar to Technology 1, impacts on municipal infrastructure of the sewage collection piping system and adjacent surface improvements need to be considered during regular operation and construction.

Installation of this technology requires taking existing infrastructure offline for replacement with new custom sewage piping. Although this may not be practical in some scenarios, it could be advantageous for new infrastructure installations or in situations where sewer piping is scheduled for replacement or significant repairs. Construction time for the custom sewer pipe is expected to be similar to standard polyethylene piping. Once installed, impacts on municipal infrastructure is considered minimal since there are no heat exchanger components in direct contact with sewage within the pipe.

2.2.7 Health, Safety and Environmental Impacts

Similar to Technology 1, all sewage remains contained within the sewage collection piping rather than pumping the sewage to a mechanical room or building. In addition, the heat exchanger components are not in direct contact with sewage at any time, and thus risks of direct contact with sewage during operation and routine maintenance is minimal.

2.2.8 Summary of Advantages / Disadvantages

A summary of advantages and disadvantages related to this technology is shown below in Table 10.

Table 10 – Summary of Advantages and Disadvantages, Technology 1

Advantages	Disadvantages
• Heat exchanger closed loop piping does not come in direct contact with sewage. • No increased risk of sewer backup. • Does not require sewage pumping or pre-treatment. • Limited number of mechanical components (pumps, heat exchangers, valves, piping)	• Integration with existing infrastructure requires replacement of sewage collection piping. • No known North American distributor or installation support. • Additional heat exchanger required at mechanical room / building for distribution to building load(s). • Not applicable for sewer pipes smaller than 300 mm diameter or larger than 1,800 mm diameter.

2.3 Technology 3 – External Heat Exchanger

2.3.1 Technology Overview

The biggest difference between Technology 3 and the other technologies reviewed is that sewage is being pumped directly to a heat exchange system external to sewage collection system. Sewage is diverted from the City’s sewage collection system to fill a separate sump pit or tank for temporary sewage storage. Sewage contained in the pit is filtered to remove large solids and pumped to a heat exchanger within a mechanical room or building to recover or reject heat. The sewage heat exchanger can be integrated with a facility's heat distribution process to limit the need for a second heat transfer system for distribution to loads. After passing through the heat exchanger, the pumped sewage is combined with filtered solids and discharged to the municipal sewer downstream of the point of diversion. Equipment used to filter the raw sewage can be located in the sump pit itself, or within the mechanical room. General schematics of these two process configurations used for heat recovery applications are shown in Figure 7 and Figure 8 below, respectively, with key proprietary components highlighted in green. These systems can also be used to reject heat to sewage for cooling applications.

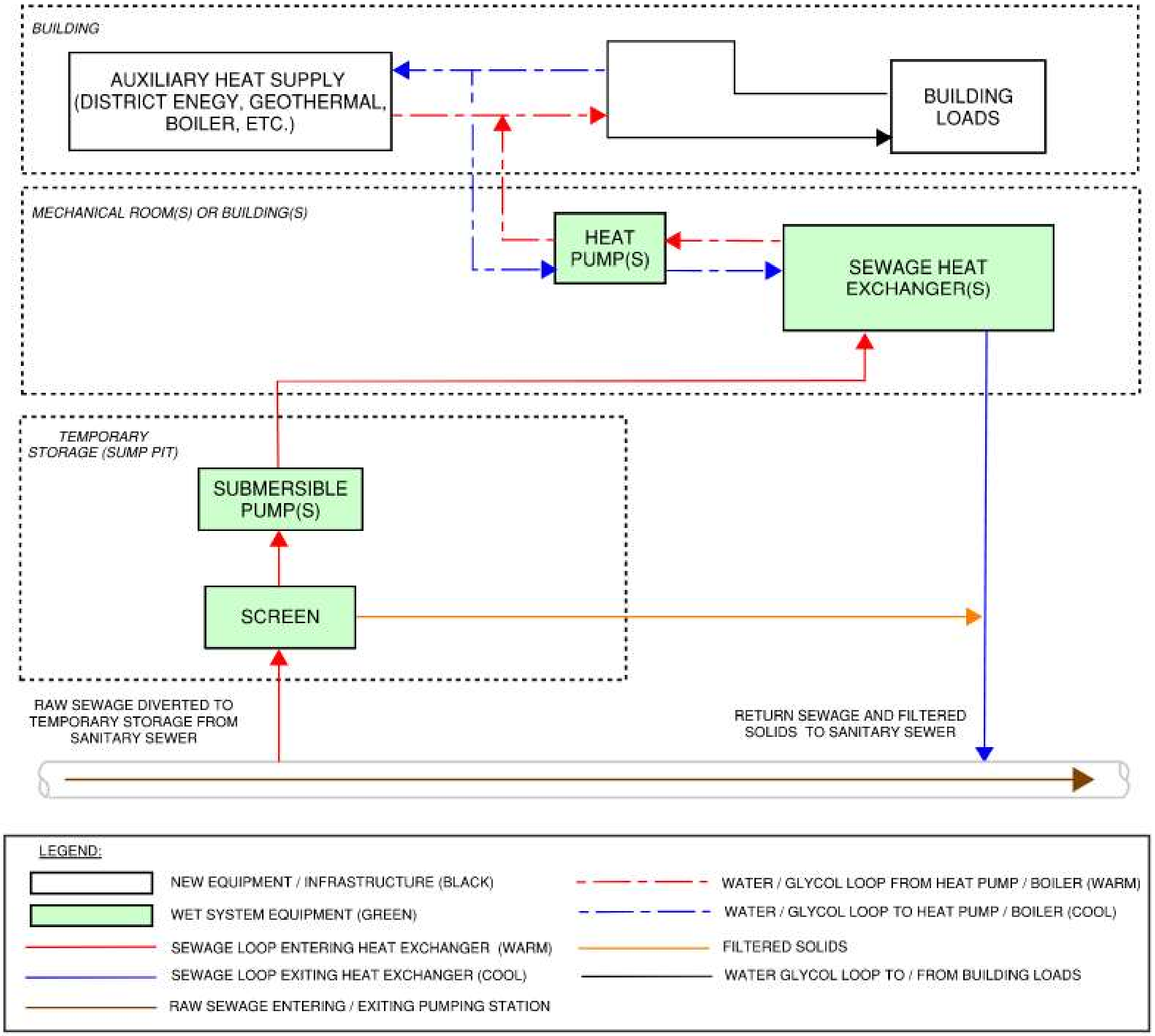

Figure 7: Example External Heat Exchanger Heat Recovery Schematic 1

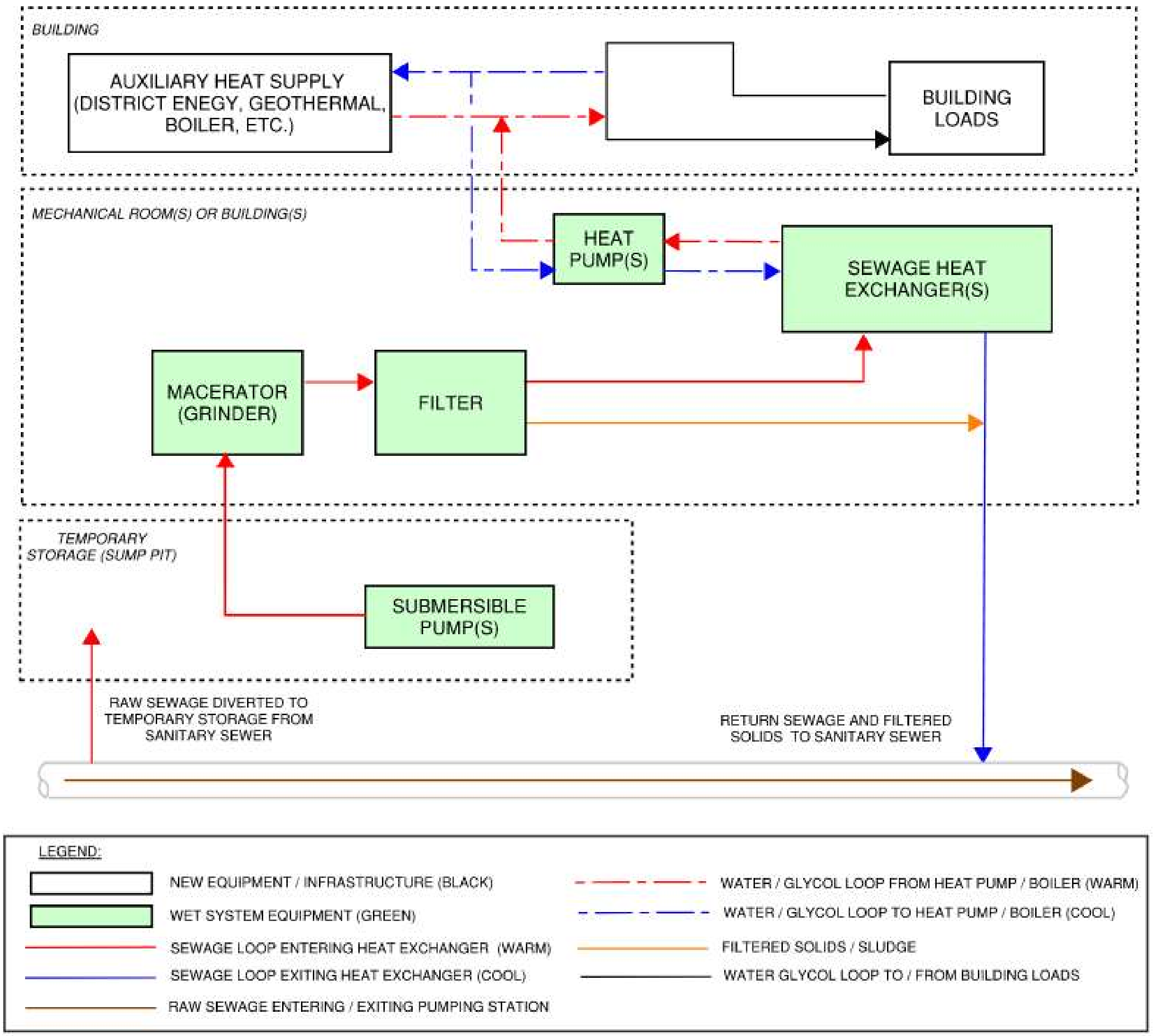

Figure 8: Example External Heat Exchanger Heat Recovery Schematic 2

JLR reviewed products from two manufacturers of this technology: Huber Technology Inc. (Huber) and Sharc Energy Systems (Sharc).

Huber is a German company that specializes in the supply of wastewater treatment process equipment for municipal and industrial applications. Their Thermwin sewage waste heat recovery equipment line is represented locally by Noventa Energy Partners (Noventa), located in Toronto, Ontario. Noventa provides detailed design services specific to applying Huber's Thermwin technology and partners with local engineering firms for certification of these designs.

The Thermwin system consists of a sump pit, an automatic mechanical screen, sewage pump, and a heat exchanger. This configuration is similar to the schematic shown in Figure 6 above. A mechanical screen removes solids from the sewage and transports them to the top of the sump pit via auger for discharge back to the sewer collection pipe.

The sewage is pumped to a heat exchanger within the mechanical room, where it transfers heat to a refrigerant or water. Sewage is returned to the sump pit where it is combined with screenings and discharged to the sewage collection pipe. A schematic of the Huber ThermWin system is provided in Figure 9 below. Additional background information related to the Huber ThermWin system is provided in Appendix F.

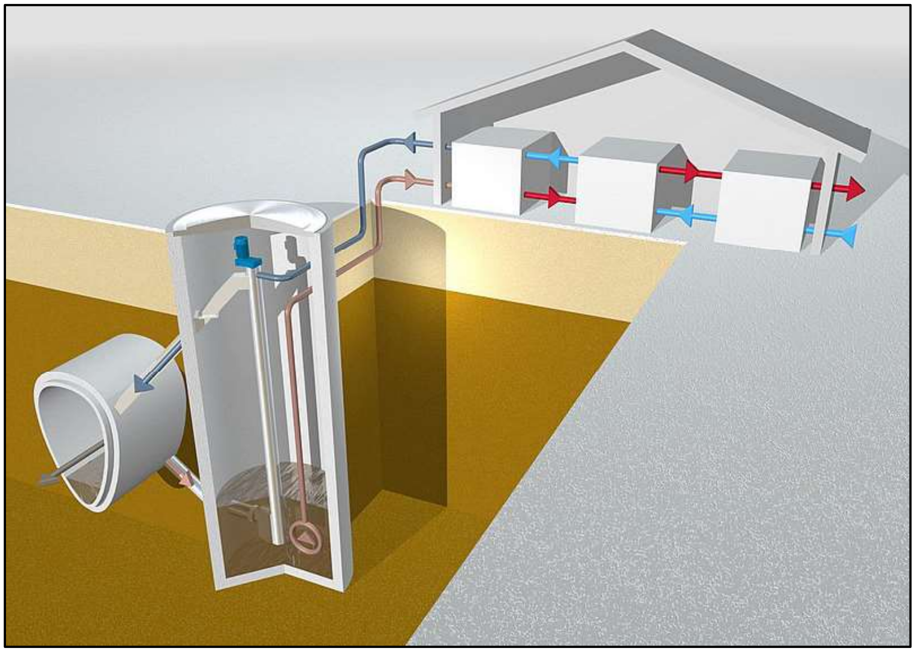

Figure 9: Huber ThermWin Schematic

Sharc is a Canadian company based in Vancouver, BC. Sharc works with engineering partners Canada-wide, including HTS Engineering, with offices in seven Ontario cities including Ottawa, to provide design services specific to the integration of their system. Sharc currently offers two systems designed for sewage heat recovery: the Sharc and the Piranha. The Sharc system is used for large scale heat recovery systems involving multiple buildings or district heating systems. The Piranha is a small-scale version of the Sharc used for applications involving single buildings. Information provided in this report is specific to the Sharc system.

Similar to the Huber Thermwin, the Sharc system includes a sump, sewage pumps, solids removal and a heat exchanger. Sewage is diverted to the sump pit from the sewage collection system by gravity. Submersible sump pumps convey the sewage to a macerator (i.e., grinder) followed by a proprietary Sharc filter unit designed to remove suspended solids from the sewage. This process is similar to the example schematic shown in Figure 10. The filter unit uses an auger used to press the macerated sewage through a fine screen filter. Filtered effluent is discharged to a heat exchanger for distribution to loads. The sewage discharge from the heat exchanger is combined with the solids collected by the filter and discharged back to the sump pit. The sump pit contains a gravity overflow for discharge of sewage back to the sewage collection pipe. A sludge pump is also installed in the sump to return potential accumulated sludge back to the sewage collection pipe. A schematic of the Sharc system is provided in Figure 10 below. Additional background information related to the Sharc system is provided in Appendix G.

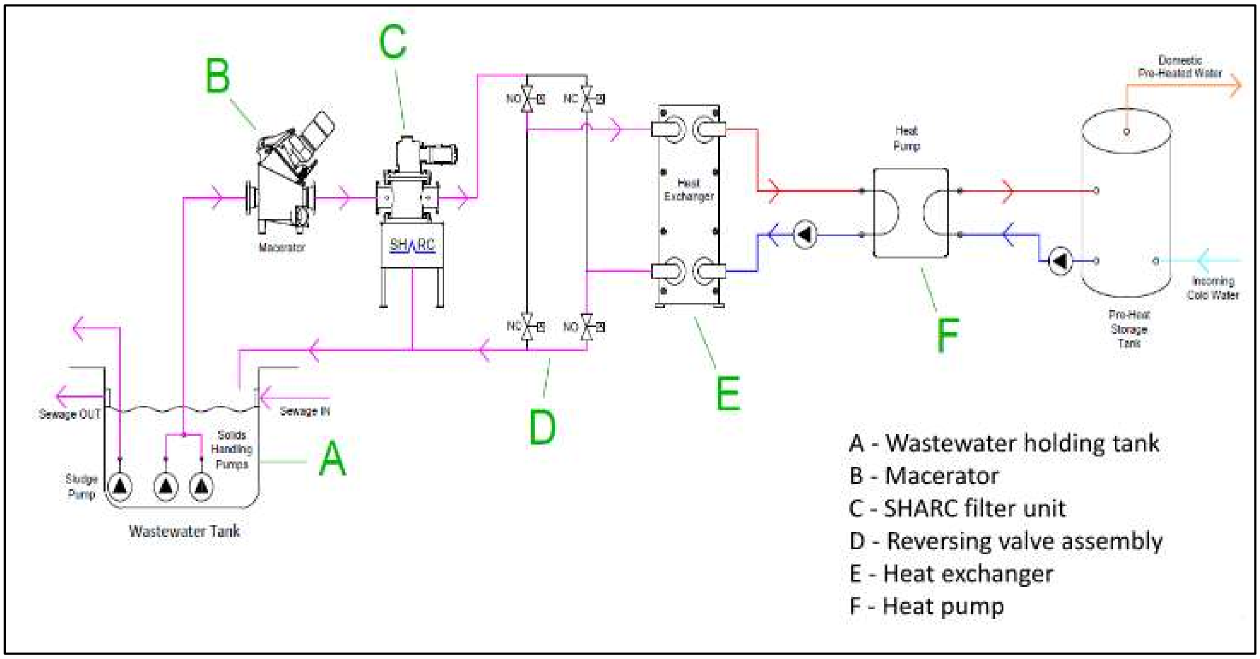

Figure 10: Sharc System Schematic

2.3.2 Typical Applications and Project Examples

Similar to the other technologies reviewed, this technology is commonly used to recover or reject heat to the sewage system to serve medium to large commercial buildings or a small campus of buildings. This technology is also well suited for integration with municipal wastewater treatment plant processes and municipal sewage pumping stations.

One installation of the Huber ThermWin system is located at the American Geophysical Union in Washington, D.C. The building is a 7-storey structure featuring 62,000 square feet of office space. The sewer flow rate is approximately 6,400 gallons per minute, or 400 liters per second. The system provides 480 kW of heating, as well as 840 kW of cooling. The coefficient of performance (COP) of the entire installation is above 6. The COP is a term of define the efficiency of a refrigeration or heat pump system, calculated by dividing the amount of cooling (or heat) generated by the amount of electricity consumed by the system. Systems with COP above 4 are generally regarded as well-performing systems.

The Huber ThermWin has many other installations in Europe, particularly in Germany and Switzerland. Noventa is currently in the process of developing additional projects within Canada, including an Ontario-based hospital expected to achieve up to 8.5 MW of heating and 8.4 MW of cooling using sewage.

Sharc has implemented their system in Southeast False Creek, BC, in conjunction with the neighborhood energy utility. The existing system has a capacity of 3.2 MW, and the recovered heat serves multiple types of buildings over 5 million square feet. There is a planned expansion to upgrade the plant to provide 8 MW over an area of 20 million square feet. Sharc has multiple installations in North America, including Vancouver, Seattle, Washington, and Colorado.

2.3.3 Key Technology Parameters

The key technology parameters for implementing this technology are shown in Table 11 below. Of the constraints reviewed, sewage flow requirements and available footprint for mechanical equipment and the sewage sump pit appear to be most critical in evaluating potential applications.

Table 11 – Key Technology Parameters

Parameter	**Huber ThermWin**	**Sharc**
Sewage Flow Requirements [1]	> 34 L/s	
Preferred Sewage Temperature Requirements	> 5 ^{o}C (heating applications) < 20 ^{o}C (cooling applications)	
Sewage Collection Pipe Size	No Restriction	
Energy Recovery/Rejection Potential [2]	40 kW to 40 MW	
Maximum Allowable Distance from Loads to Sewer Pipe	< 200m	
Footprint / Land Use Requirements of Sewage Heat Transfer System	Building Mechanical Room: 20 to 60 m^2 Sewage Sump Pit: [3] 1.5 to 10 m diameter	

Notes:
1. Minimum flow requirements are based on sewage flow required through the heat exchanger. The sewage sump pit can be sized to accommodate fluctuations in sewage flow diverted from municipal infrastructure. However, performance guarantees of the system are based on dry weather flow conditions, similar to Technologies 1 and 2.
2. Heat recovery or rejection potential is dependent on sewage flow and the number of heat exchangers installed in parallel.
3. Sewage sump pit depth typically ranges from 4 to 8 meters, depending on sewage flow requirements and system size.

2.3.4 Operations and Maintenance

This technology requires the highest operations and maintenance requirements and highest level of operational complexity relative to the other technologies reviewed. This generally stems from pumping sewage directly to a heat exchanger, which requires the use of a sump pit for sewage storage and additional mechanical equipment for sewage screening/filtering. The level of maintenance required for the sewage sump pit is significantly high compared to other technologies and is expected to be similar to a small sewage pumping station (i.e., maintenance of submersible pumps, grinders, filters, mechanical screen).

This technology requires solids removal and disposal prior to pumping sewage to the heat exchanger. The suppliers reviewed provide different solid waste management strategies. This process adds complexity to the regular operations and maintenance of the system relative to other technologies reviewed. The mechanical screen provided with Huber's ThermWin system removes solids from the sewage as it enters the sump pit, prior to pumping. This prevents the accumulation of settleable solids and sludge in the sump pit. The screenings are transported to the top of the sump pit by an auger. The solid waste is re-combined with sewage from the heat exchanger discharge returned directly to the sewage collection pipe. Huber does not recommend the use of grinder pumps in place of the mechanical screen due to the construction and performance of their heat exchanger unit.

Alternatively, the sump pit used for the Sharc system receives raw sewage diverted from the sewage collection pipe. Solids are removed from the raw sewage at the mechanical room by a macerator and custom filter. Solid waste from the filter is re-combined with sewage from the heat exchanger discharge and returned to the sump pit. Solids that accumulate in the sump pit are pumped to the municipal sewer by a sludge pump.

Similar to Technology 1, regular heat exchanger cleaning to remove biofouling is required to maintain system efficiency. Cleaning is generally automated by the technology equipment supplier. For example, Huber's Thermwin system includes a self-cleaning mechanism consisting of brushes that automatically move back and forth along the water or refrigerant piping within the heat exchanger to provide regular cleaning. The Sharc heat exchanger is cleaned by periodically reversing flow through the unit to prevent biofilm from accumulating.

Based on industry experience and typical equipment installations, the life expectancy of the mechanical equipment used for this technology is estimated to range from 10 years (heat exchangers, pumps, etc.) to 50 years (process piping). A breakdown of estimated component life expectancy is presented in Table 12 below. Maintaining a spare parts inventory for critical components and scheduling equipment replacement is suggested to reduce the impacts of potential component failure.

The required energy inputs for this technology vary depending on the size of the motors driving mechanical components, similar to Technologies 1 and 2. An estimated breakdown of energy inputs required for the system supplied by Huber and Sharc are provided in Table 12 below.

Table 12 – Operations and Maintenance Requirements, Technology 3

Criteria	O&M Requirements	
	Huber ThermWin	**Sharc**
General Requirements	Medium to High: • General maintenance of mechanical equipment (pumps, screen/filter, heat exchanger, valves, controls, etc.). • Periodic cleaning of heat exchanger to remove biofouling (automated process, may require occasional manual cleaning).	
Solid Waste Production / Disposal Requirements	Medium to High: • Raw sewage screened prior to entering sump pit. • Screened solids discharge to municipal sewer pipe	High: • Raw sewage filtered in mechanical room. • Filtered solids accumulate in Sump Pit. • Submersible pump discharges accumulated solids to municipal sewer pipe.

Criteria	O&M Requirements	
	Huber ThermWin	Sharc
Operation Complexity and Ease of Use	Medium to High: • High number of mechanical components used for sewage heat exchange process relative to other technologies. • Requires solid waste management. • Sump pit may require odour control system. • Can operate unattended with periodic operator checks and scheduled maintenance.	
Estimated Equipment Lifespan [1]	Sewage Pump(s): 10 years Screen: 15 to 20 years Piping and Valves: 50 years	Sewage Pump(s): 10 years Sludge Pump(s): 10 years Macerator: 15 to 20 years Filter: 15 to 20 years Piping and Valves: 50 years
Required Energy Input [2]	Power Supply: Per site conditions Sewage Pump(s): 3.7 kW per unit Screen Auger: 1.1 to 2.2 kW	Power Supply: Per site conditions Sewage Pump(s): 3.7 kW per unit Sludge Pump(s): 0.7 kW per unit Macerator(s): 3.7 kW per unit Filter Auger(s): 0.7 kW per unit

Notes:
1. Estimated life expectancy is based on typical mechanical equipment installations.
2. Multiple units can be installed in parallel to achieve a wide range of potential heat recovery/rejection. Total utility requirements will depend on the amount of equipment required for specific applications and overall sewage flow rate.
3. Low, Medium and High ratings are applied to select criteria to provide qualitative comparison between technologies reviewed.

2.3.5 Opinion of Probable Cost

An opinion of probable costs (OPC) for installation of small (250 kW) and large (1.5 MW) sewage heat exchange systems utilizing Technology 3 are presented below in terms of capital cost and cost per kW. The system sizes presented for Technology 3 are larger than those used in the OPC for other technologies because the information provided by suppliers indicates that it is capable of supporting much larger heat exchange applications and may also become too expansive for very small heat exchange applications. The OPC provided represents an order of magnitude cost for a typical wastewater heat exchange system based on general information that is publicly available; note that the costing herein does not include the heat pump or other heat distributions components. A more detailed cost estimate is recommended when evaluating feasibility of specific projects.

Table 13 – Opinion of Probable Cost, Technology 3

Heat Recovery System Size	Capital Cost	Cost per kW
Small System (250 kW)	$800,000	$3,200 / kW
Large System (1.5 MW)	$2,700,000	$1,800 / kW

The OPC presented above includes the following components the following items:

- Supply and installation of equipment:
  Submersible sewage recirculation pumps.
  Submersible sludge pumps.
  Macerator.

Sewage filter/screen.
Sewage heat exchanger.
Connections to existing sewage collection piping (sewage supply and return).
Control system for equipment control and monitoring.
Concrete sewage holding tank.

- Dedicated 20 m^2 to 60 m^2 mechanical room / building for the small and large systems respectively, assumed at $4,840/$m^2$.

Assumptions:

- Sewer heat source is located less than 400 m from the sewage holding tank.
- Sewage holding tank assumed to be constructed of cast-in-place concrete.
- Sewage holding tank capacities assumed to be 16 m^3 and 100 m^3 for small and large systems, respectively.
- Costs associated with operations and maintenance not included.
- Costs associated with the heat exchange process required to distribute recovered heat to building loads are not included (e.g., heat pumps, distribution piping, etc.).
- Costs do not include relocation of utilities or infrastructure that may interfere with new infrastructure.
- Costs do not include rock excavation.
- Costs do not include odour control system. Costs do not include instrumentation for continuous air quality or odour monitoring.

2.3.6 Installation Considerations

The installation has low impact on the city's sewerage infrastructure, with most of the construction requiring a separate parcel of land, such as within the property line of the building or district to be served or within adjacent City-owned land. Two pipe connections to the sewer collection pipe being used for sewage waste heat recovery are typically required: one connection to divert sewage flow by gravity to the system sump pit; and one connection to return sewage to the collection pipe downstream of the first connection. No additional equipment installation within or at the sewer collection pipe is required.

Of the two equipment suppliers reviewed, the Huber ThermWin system appears to be well suited for integration with new or existing municipal sewage pumping stations and wastewater treatment plants. For example, the heat exchanger can be installed directly in open channels used to transport wastewater within a wastewater treatment plant downstream of solids removal processes. Also, integration with a pumping station could be considered to reduce or eliminate the need for additional sewage storage via a sump pit, provided the pumping station includes a mechanical screening process. Sewage pump sizing and available space at the pumping station needs to be considered to validate feasibility.

2.3.7 Health, Safety and Environmental Impacts

Technology 3 involves diverting sewage from municipal infrastructure and recirculating it through one or multiple heat exchangers at a central heat plant. This increases the risk of operators coming into direct contact with sewage during maintenance.

As described previously, the sump pit and associated mechanical equipment functions in a similar way to a municipal pumping station. Thus, control of odour emissions at the sewage holding tank and mechanical equipment room may be required depending on the location of the system installed and odour emitted from the WET system equipment. Regular hydrogen sulfide (H2S) monitoring at the sewage holding tank and potentially at the building mechanical room may also be required.

2.3.8 Summary of Advantages / Disadvantages

A summary of advantages and disadvantages related to this technology is shown below in Table 14.

Table 14 – Summary of Advantages and Disadvantages, Technology 3

Advantages	Disadvantages
• Minimal impacts on existing sewage collection infrastructure (i.e., pipe replacement not required, and minimal connections to existing piping) • Wide range of potential energy recovery/rejection. • Local manufacturers, distributors and engineering support. • Pre-treated sewage allows for lower risk of biofouling compared to Technology 1. • Technology can be integrated with existing pumping stations or wastewater treatment plants. • No size restrictions for sewer collection pipes. • Very high capacity systems can be supported with a single installation.	• High number of mechanical components, footprint, and operational complexity relative to other technologies. • Solid waste management system required (mechanical screen or grinder/filter). These components are high cost and maintenance compared to other equipment. • Odour control system may be required for sump pit, depending on application location. • Biofouling of heat exchanger reduces heat transfer efficiency (automated cleaning).

2.4 WET Technology Summary

There are some clear differences in the impacts of the three technologies in terms of the impacts and interactions with the sewerage system. In summary:

- Technology 1: One or multiple metal heat exchangers are inserted in series within the sewage collection pipe. Although this sewage heat exchange technology can be integrated with existing sewage collection infrastructure, the added equipment within the pipe may increase the risk of damming and sewer backup. Biofouling of the heat exchanger is expected and would be worked into performance estimates and physically managed during annual maintenance of the sewer piping via pressure washer.

- Technology 2: A customized sewer collection pipe is used to replace existing sewage collection piping. The custom pipes are installed in series and contain coils for water or glycol within the pipe walls or wrapped around the pipe. Sewage within the collection pipe is not in direct contact with the heat exchange coils, reducing the risk of damming or sewer backup. Biofouling within the sewage pipe is expected to be managed during annual maintenance of the sewer piping, similar to Technology 1. This technology is more difficult to integrate with existing sewage collection infrastructure since direct replacement of collection piping is required, however it can be a potential candidate for use with infrastructure scheduled for replacement.

- Technology 3: Sewage is diverted from the sewage collection pipe to a localized sump pit. The sewage is filtered and pumped through a heat exchanger located within a mechanical room or building. This is the only technology reviewed that involves removal of sewage from the sewage collection system. Thus, this technology has higher maintenance requirements, higher operational complexity, and a higher overall footprint for installation relative to the other technologies reviewed. An odour control system may also be required for the sump pit and associated equipment, pending installation location and site constraints. Biofouling of the heat exchanger is managed by automated processes provided by equipment suppliers. This technology seems of being scalable to very large systems.

Each of these technologies have their own advantages and disadvantages. A key parameter is to outline the preferred method of operating and maintaining the heat recovery system. Another key parameter is the magnitude of the wastewater flow and of the heat loads. For large wastewater trunks sump pit and heat exchange system will be able to extract the most energy from the sewer system because theoretically, all the sewage could be diverted through the optimized specialty heat exchanger. Fixed civil deployment costs are likely to make small systems, relatively speaking, more expensive per kW of heating provided. Technologies #1 and #2 have smaller footprints and equipment complexities, which allow them to be suitable for smaller flow rates. They may even have caps or upper limits on heat extraction capacities. The minimal additional footprint and maintenance of pipes heat exchange tubes built right into the pipe (Technology #2) may be particularly attractive, but they are only available in situations where wastewater piping is set to be replaced *and* there is a suitable building load.

3.0 Ottawa Sewage Collection System Data

3.1 City of Ottawa Sewage Collection System Description

The City of Ottawa sanitary sewer system flows to a single wastewater treatment plant, the Robert O. Picard Environmental Centre (ROPEC), located in the eastern portion of the City along the Ottawa River. In general, the contributing sewers flow in northerly or southerly directions, until they intercept the larger trunk sewers that flow in easterly or westerly directions to discharge into ROPEC.

- West of ROPEC, the flows are directed north into either the West Nepean Collector / Ottawa Interceptor Sewer (OIS) along the Ottawa River or towards the Lynwood Collector which generally encircles the southern portion of the city, running parallel to and slightly north of the National Capital Commission's Greenbelt.

- East of ROPEC, the flows are generally directed to the north to the Orleans Cumberland Collector running westward along the Ottawa River.

JLR employed the software ArcGIS as a means of assembling and reviewing information on the sewer system – including City GIS information on the system, temperature and flow measurements points, and certain energy users and loads of interest. The computer interface is highly useful for examining possible locations for WET projects. Figures 11 and 12 are images extracted form Arc GIS that highlight several key elements of the assembled information.

Figure 11 shows a view of the entire sewage collection system – this figure shows colour-coded sanitary trunk lines and combined trunk lines. Symbols are included in the figure to indicate locations where key measurement points for flow or temperature were used in the project (as are further explained in Section 3.2).

Figure 12 shows a zoom-in of the urban core with major sanitary and combined sewer lines identified in pink and orange, respectively.

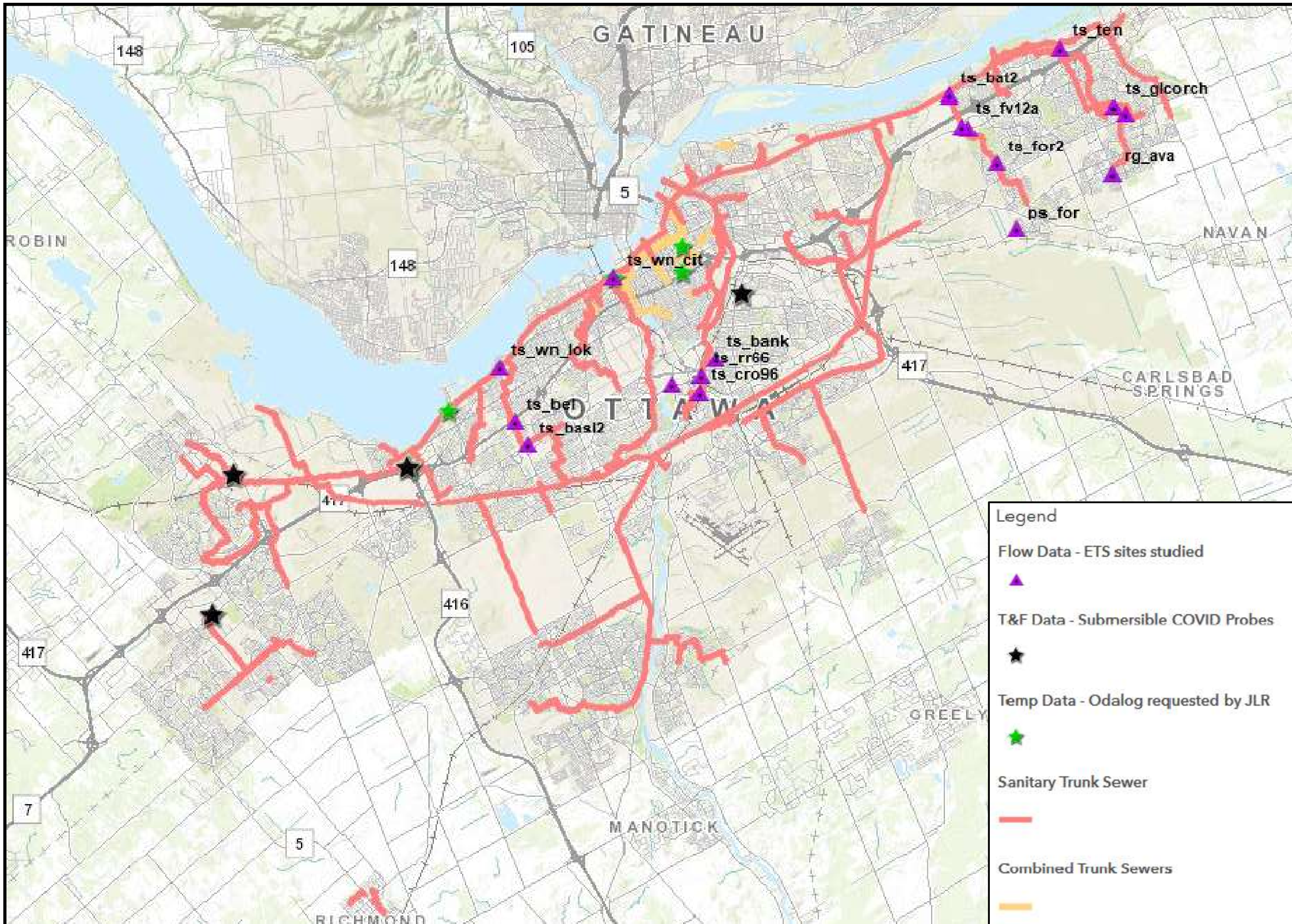

Figure 11: Screen capture of ARCGIS platform showing sanitary and combined trunks, and probe locations

Figure 12: Screen capture of ARCGIS platform zoomed in on the downtown core

3.2 Temperature and Flow Data

The City has been collecting both sewage flow and temperature data at various locations within their sewage collection system for many years on both a continuous and intermittent basis. As part of this study, the City provided JLR a list of location nodes throughout the system where data is currently being collected, and where historic data is available. JLR reviewed the available data collection locations and selected specific locations for review and analysis. To supplement the available sewage temperature data, JLR worked with the City to determine a small number of additional locations of interest where temporary instrumentation could be installed.

In general, data collection locations were selected for review and analysis based on the following criteria:

- locations of interest for potential sewage energy recovery applications;
- to cover a wide variety of land use contributors (e.g., municipal, commercial, institutional, and industrial developments); and
- to gain a basic understanding of how sewage temperature is affected by combined sewer inputs, as the City will continue to operate with combined sewer systems for the foreseeable future.

The data provided to JLR for review consisted of several different types of data sets. Though they amounted to many points of measurement, they often only covered a short period of time, were geographically scattered, and were scatted over a wide number of years. This means that there were very few datasets that captured key information on the system as it pertained to a full winter season, and few that had coincident temperature and flow measurements. Herein, a brief summary of each dataset is provided as well as the key findings that were developed from the data. Key findings are shown in blue font with arrow bullets. This section is a summary of more detailed analysis that was described in an Interim Report #2 – Sewer System as a Thermal Resource (Appendix H).

Environmental Time Series (ETS) Sites [Flow, short term data from 1993 to 2019, 16 sites]:

The City collects various flow related information for the sanitary sewer system at ETS Sites. These sites include temporary flow monitoring stations in maintenance hole (MH) structures, SCADA collection at pumping stations, and other types of measurements totaling more than 600 sites. For this study JLR chose to review the temporary flow data collected at 16 of a total 23 sites provided by the City. The purpose of this data analysis was to verify typical daily flow patterns and to correlate average and minimum daily flows at various locations across the city.

- ➢ Despite the number of measurements, historic ETS flow measurements are still relatively sparse versus the extent of the wastewater system and they are not coincident in time with each other; thus, they are insufficient on their own to quantify overall flows of the system.
- ➢ The City uses these measurements towards validating their system flow model; thus, modeled flow profiles from the City should acceptable for indicative evaluation of WET capacity across the system.

- In the limited number of locations where existing ETS measurements do coincide with a location of interest for a WET project, the data can be useful for pre-feasibility analysis.

JLR found a location that had coincident measurements at two points along the same collection path (ts_for1 and ts_for2 within Orleans). These datasets were analysed to review flow trends along a sanitary sewer line. As anticipated, the *peak* and *average* flows were higher for the downstream location. However, there were two observations that are counter to intuition for the downstream location: (i) the *minimum* flow rates do not scale – they remain nearly identical to the upstream site; and (ii) the downstream site exhibits a higher variance between minimum and peak flows throughout each day than the upstream site (one might have anticipated variability would decrease as more flows were aggregated). These attributes are likely because ts_for2 receives inflows from three elementary schools and several car dealerships, which introduces new variability in users during the daytime but very little additional use in the evening and nighttime.

- The above observations indicate that there are local influences on the flow patterns such that flow patterns on moderate-sized collectors are hard to predict without direct evaluation of the types of upstream inflows. Should a project be pursued, inference from other locations will have a degree of uncertainty, especially on minimum flow rates. A more thorough understanding of these flow patterns will be relevant when evaluating potential WET projects.

JLR also examined this full dataset of 16 ETS sites to develop a statistical understanding of *average* flow rate and *minimum* flow rates. Further analysis is contained in Section 3.3.

Historic OdaLog Locations [Temperature, short term data in 2015, 9 sites]:

Short-term historic temperature data at various manhole locations throughout the wastewater collection system was provided. The temperature data was collected via OdaLog probes during various maintenance and monitoring activities, in particular during 2015, and typically collected over a one to three-month period. The OdaLogs are placed within maintenance hole structures in the air *above* the wastewater (above the high flow limits).

- Historic OdaLog data was sparse, short in length, and mostly measured in the summer, such that, in general, it did not provide useful datasets for this study. They may be of some value for analysis of summertime cooling applications of WET systems but ultimately, longer term continuous measurements across both winter and summer seasons are preferred.

Select New OdaLog Locations [Temperature, short term data in 2021, 5 sites intended]:

Near the onset of the project, the City proposed that OdaLog probes could be deployed to gather temperature data at specific locations of interest for the study. In coordination with the City, these were deployed during the winter of 2021 at select location of interest identified by JLR and deployed by the City. There were two main findings:

One study compared OdaLog data to submersible probe data and showed that the OdaLog produced less accurate data than submersible probes. Specifically, OdaLog data from Acres was 1°C to 5°C lower than the submersible probe and had a less definable daily pattern, as shown in

Figure 13. Additional analysis led us to believe that the OdaLog was influenced by ambient air flows, which vary with pipe and manhole configuration. Refer to Interim Report #2 for additional details (Appendix H).

- ➢ OdaLog measurements, because the sensor is located in the air above the sewage, were inconsistent or insufficiently accurate measures of wastewater temperature for the needs of this study.

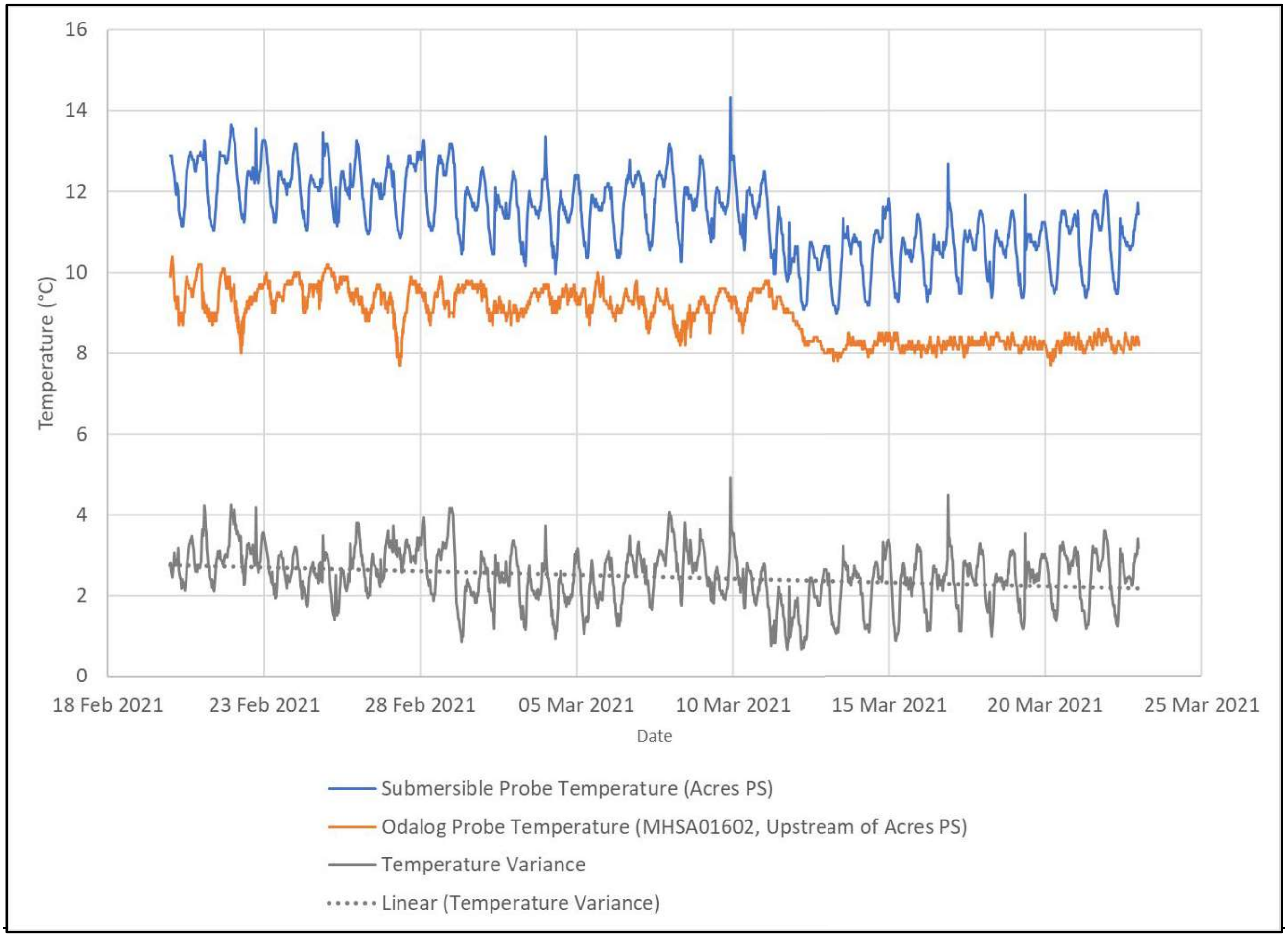

Figure 13: Acres Air Temperature vs. Sewage Temperature

Second, an OdaLog was deployed at the intersection of Lisgar Avenue and the Queen Elizabeth Driveway. It was intending to measure the temperature profile of the Rideau Interceptor combined line, however, the dataset exhibited quite high temperatures and, with examination of the manhole configuration, JLR believes it was actually predominantly influenced by sanitary inflow from the dense urban neighbourhood around Lisgar Avenue and not of the Rideau Combined Collector.

- ➢ This *may* indicate that downtown sanitary lines *can* have quite elevated temperatures. This should be further investigated with several probes at different points in the system.

COVID Study [Flow and/or Temperature, short term data in 2021, 4 sites]:

Sewage collection system data is currently being monitored and collected at maintenance hole locations within the sewage collection system for ongoing University of Ottawa COVID research that is monitoring COVID levels in the wastewater. The City reported to us that locations were selected based on being downstream from key locations such as hospitals, universities, and retirement residences. The data includes, among other things, sewage flow data collected via in-line flow devices and sewage temperature collected via submersible temperature probes.

Table 15 – Summary of COVID Probe Locations

Location ID	Description	Flow Data Available	Temperature Data Available
MHSA01603	Acres Pumping Station, 2 Aero Drive, Nepean	Yes	Yes (Submersible)
MHSA72293	Kanata West Collector, 63 Royal York Street, Richmond	Yes	Yes (Submersible)
MHSA01106	March Road Collector, 305 Leggett Drive, Kanata	Yes	Yes (Submersible)
MHSA30153	Ottawa General Hospital area, 501 Smyth Road	No	Yes (Submersible)

- The submersible temperature probes appeared to be reliable for accurate temperature measurements. Using submersible temperature probes for future investigations is strongly recommended.
- The coincident measurement of temperature and flow was found to be very useful for the needs of this study. It allowed hour-by-hour analysis of heat capacity. More detailed analysis of these datasets is contained in Section 4.0.

ROPEC [Flow, Temperature, long term daily data for 5 years, 1 site] and
Potable Water Distribution [Temperature, long term weekly data for 3 years, 8 sites]:

Historic sewage flow and temperature data at ROPEC and from potable water monitoring locations provide long term continuous datasets – they are useful to compare with the submersible probe datasets and to review long term daily and seasonal temperature fluctuations, as contained in Section 3.5. Both the influent and effluent data sets from ROPEC are used at times in the analysis – they are assumed to be sufficiently identical for the trend analysis herein.

3.3 Flow Patterns across the system

3.3.1 Typical Sewage Flow Pattern

Flow data from various ETS sites was reviewed to gain a general understanding of daily flow patterns over multiple seasons. The data provided by the City for each temporary site reviewed consists of flow data recorded every 5 minutes over multiple months.

Figure 14 below presents an example of typical daily flow patterns observed each week from March to June 2000 at Chapel Hill West Forest Valley Drive near Orleans Boulevard (ts_for2). Maximum, average, and minimum daily sewage flows were calculated for each week based on the raw data provided. For example, the minimum flow rate at 12:00am (Hour 0) for Week 10 was determined by finding the minimum flow recorded between 12:00 am and 1:00 am for all days within Week 10. This process was repeated for each hour of the day for each week of data collected.

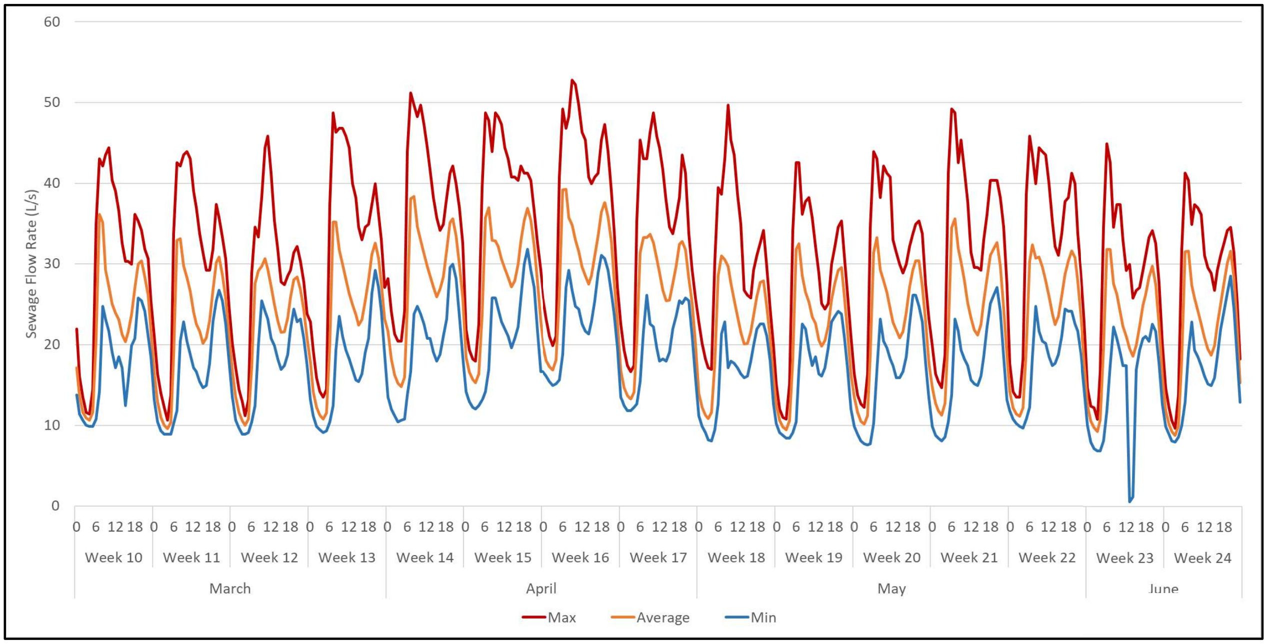

Figure 14: Typical Daily Flow Pattern at Chapel Hill West Forrest Valley Drive, near Orleans Boulevard (ts_for2)

- The sewage flow data reviewed at these locations confirms the following assumptions:
  - Daily flow patterns are consistent:
  - Peak daily flows occur in the morning (6:00 am to 10:00 am) and early evening (6:00 pm to 8:00 pm);
  - Minimum daily flows occur overnight (midnight to 4:00 am);
  - Flow rates are the highest during the peak runoff periods of snowmelt in the early spring; and
  - Daily flows are generally higher during the "wet season" (i.e., early spring and late fall).

3.3.2 Estimated Minimum Daily Flow Rate

The *minimum daily flow* expressed as a percentage of the *daily average flow* was calculated at 16 ETS locations where average flow recorded was greater than 10 L/s. Average daily flow is the most common parameter used to quantify wastewater flow rates; the intent of this analysis was to gain a general understanding of how minimum sewage flow relates to average daily flow at multiple locations within the sewage collection network.

The minimum percentage of average daily flow was calculated by dividing the minimum flow each hour by the average daily flow rate calculated each week. The minimum percent of daily flow measured at this location is estimated to be 32% of the average daily flow. The calculation methodology was repeated for all 16 ETS sites. The minimum flow was found to vary between 20% and 65% of the average daily flow. Although it is not clear why some minimum flows are a higher percentage of the average flow, it is reasonable to assume minimum flow can be as low as 20% to 30% of the average daily flow as an initial screening tool for determining the minimum flow at a particular location of interest.

- Flow patterns, and especially the ratio between the minimum and average flow rates, appear to vary substantially at different points in the system.

Certain influences on the flow pattern will be included in the City modeling, such as pipe type, amount of infiltration, generalized profiles based on the type of users in the catchment, and travel time down the pipe system. But some influences may be quite particular, and may change with time.

- Risk mitigation during WET system design should include sensitivity analysis of the WET system performance to changes in flow rates, in particular for smaller collector lines or where the WET system size is depending on the full flow rates.

3.4 Trunk Line Temperature Profiles

Submersible temperature data from four uOttawa COVID-19 Wastewater study locations is presented in Figure 15, showing the entire winter season and a zoom in on two weeks in the month of March.

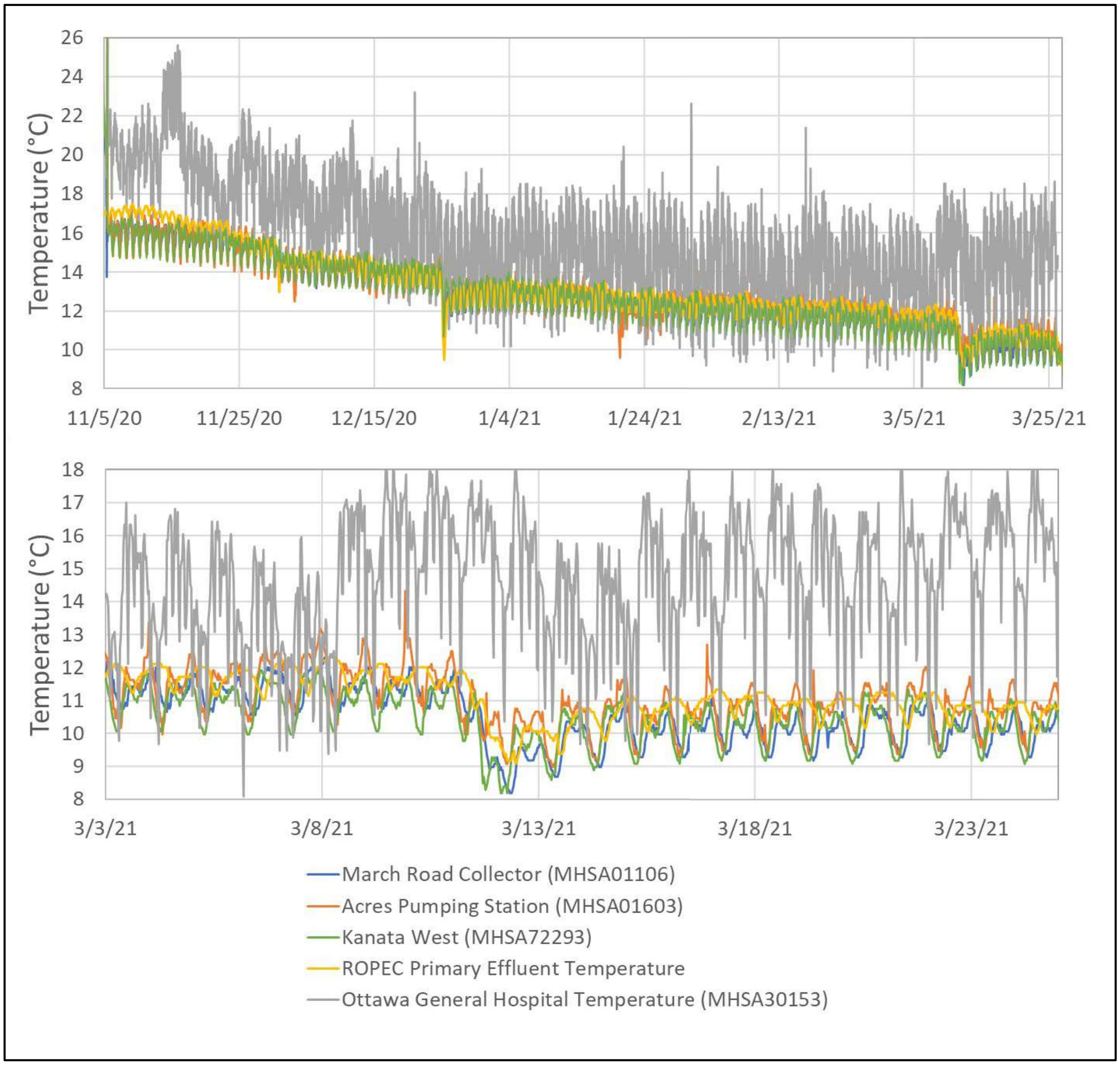

Figure 15: Submersible Temperature Probe Data measured over the winter season and with a zoom-in on two weeks in the month of March

Several useful observations can be made from the datasets. First, the submersible temperature probes located at the March Road Collector (MHSA01106), Kanata West (MHSA72293) and at Acres Pumping Station (MHSA01603) are similar to each other and to the primary effluent temperature recorded at ROPEC; ROPEC does tends to be slightly warmer and less variable than the large trunk lines.

- Major collectors studied here exhibited nearly identical temperature profiles.
- Temperatures fell over the course of the season and were lowest at the end of March (and thus after the peak winter heating loads are past).
- Short term temperature dips occurred during wet-weather events.

- ROPEC effluent profile was very similar to the above trunk lines, which indicates reasonably consistency across the system.

Figure 15 also includes a submersible probe that was located in a mid-sized sanitary line that collects exclusively from the hospital campus that includes the Children's Hospital of Eastern Ontario, the Ottawa General Hospital, the National Defense Medical Centre, and the cogeneration power center that produces steam and hot water for the facilities. The data for the hospital sewer temperatures exhibits a considerably higher average temperature compared to other sewers but with *minimum* temperatures that are similar to other sanitary lines. The high temperatures are likely attributable to significant use of domestic hot water. The low minimum temperatures occur at night (12am to 6am) presumably coincide with low flows, and lower consumption of hot water within the hospitals. There is a semi-regular drop in temperatures (around every 4½ hours) that must relate to a water use process specific to the location. There was unfortunately no flow data available for this location – JLR expects it would also exhibit high variability and, thus would be crucial to have in order to determine the heat capacity at this location.

- Outflows from hospitals present unique temperature (and likely flow patterns), with elevated temperatures in the daytime relative to typical municipal wastewater lines.

As described previously, sewage temperature drops to a minimum overnight as both sewage flow and air temperature decreases. Temperature data collected via submersible probes at Acres Pumping Station was plotted to determine the total temperature drop relative to average temperature at a typical pumping station. Maximum, minimum, and average sewage temperatures and temperature drop relative to the average temperature are plotted in Figure 16 below. On average, the sewage temperature drops 1.2°C overnight relative to the average sewage temperature at this location.

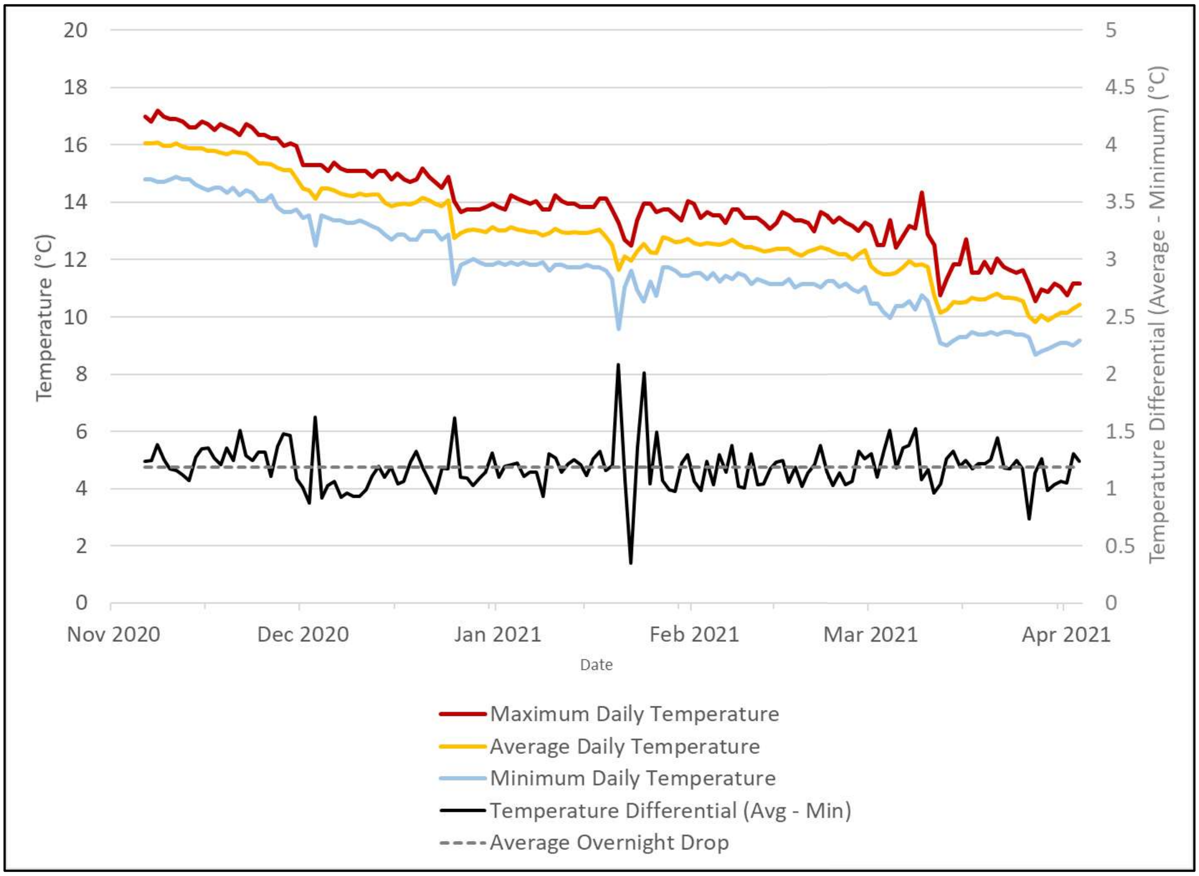

Figure 16: Average, maximum and minimum temperature values from submersible probes at Acres Road

3.5 Temperatures at ROPEC

WET projects will drop the wastewater temperature at their outflow, so there can be concern that too many sizeable WET projects could cause a measurable drop in the temperature of the wastewater as it enters ROPEC, which could negatively affect the overall treatment processes. The sewage treatment plant currently experiences large fluctuations in temperature in the order of 8°C to 25°C, so it would predominantly be effects of drops (or rise) in temperature outside of these ranges that would be of highest concern. A full analysis of this topic was outside of the scope of this project, but the various incoming information and datasets are analyzed briefly to shed some light on this topic.

In general, suppliers noted that a 2°C to 5°C temperature drop can be expected at the output of a WET system. Suppliers reported that this temperature typically recovers within one to two hundred meters downstream of the WET system. JLR was unable to confirm this possibility at this time. If true, this implies that the impacts on the temperature of wastewater entering ROPEC would be negligible.

It has also been reported to JLR by City staff that temperatures observed at ROPEC are quite consistent with time. This point is examined in more detail in Section 3.5.2 below.

3.5.1 Comparison with Potable Water Temperatures

The source water for potable water is the Ottawa River where the water temperature does fluctuate seasonally. Potable water distribution temperatures at various locations throughout the city were compared to the effluent sewage temperature at ROPEC, as shown in Figure 17 below. The figure shows that potable water temperatures do influence the ROPEC effluent temperatures as they fluctuate seasonally. However, the data also indicates that there is a larger fluctuation in the potable water distribution temperatures compared to the sewer temperatures. The potable water system can fluctuate up to 10 °C colder than sewage flow in winter months (red arrow) and up to 5 °C warmer than sewage flow in summer months (cyan arrow). Furthermore, the ROPEC temperatures show a sloped decrease across the winter months (green line). Several factors are thought to contribute to these differences including, but not limited to, (a) the moderating effect of the ground temperatures on the sewer temperatures: cooler in the summer and warmer in the winter; and (b) the increased heating of the potable water within buildings during the winter months to bring water up to washing temperatures.

- Due to these variances, the correlation between potable water distribution temperatures and sewage temperatures should not be considered as a method to accurately estimate sewage temperatures at locations of interest.

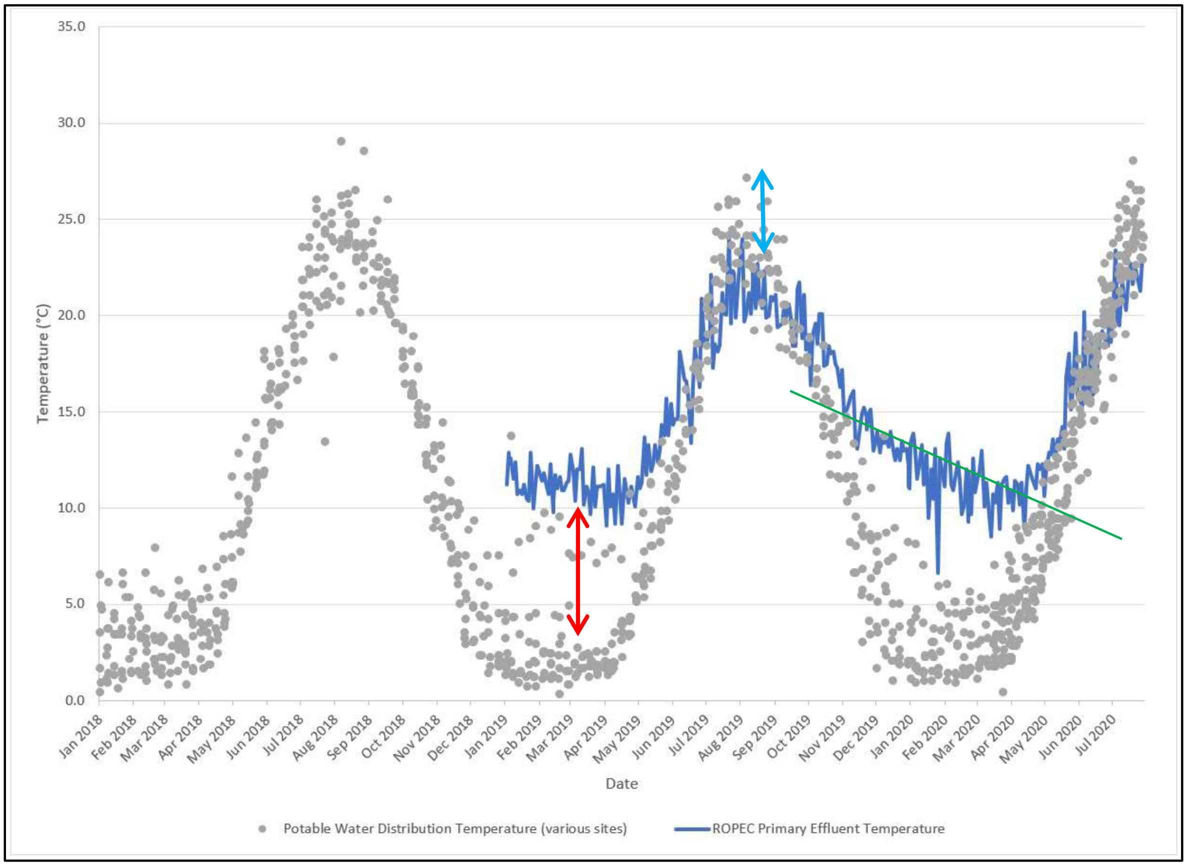

Figure 17: Potable water temperature versus ROPEC effluent temperature

3.5.2 Influence of Stormwater and Snow Melt

The predominant factors causing increases in flow at ROPEC are snow melt and high precipitation events. Stormwater will typically be colder than sewage, which should result in periods of high flows being colder than dry weather sewage temperatures.

This was examined using a dataset provided from ROPEC. Figure 18 shows the timeseries of daily temperature and flow over a 5-year period. The temperature data is very consistent from year-to-year, without generally showing drops in times of high flows. The lack of a relationship is further proven in Figure 19, which takes this same data and plots it as a scatterplot of temperature vs flow. If there were a dependency of temperature on flow, there would be a sloping trend, but there is none. Instead, all four seasons show a similar lack of dependency, just with different temperatures ranges for each season relating to other effects.

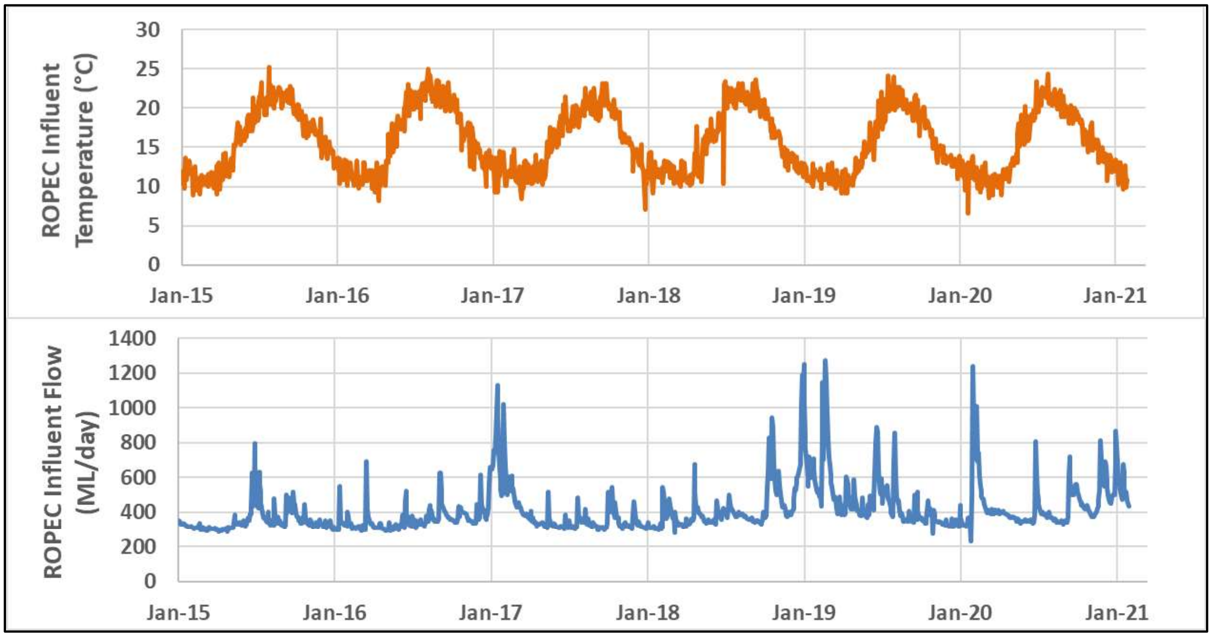

Figure 18: Temperature and flow at ROPEC wastewater treatment plant (daily values over a 5-year period)

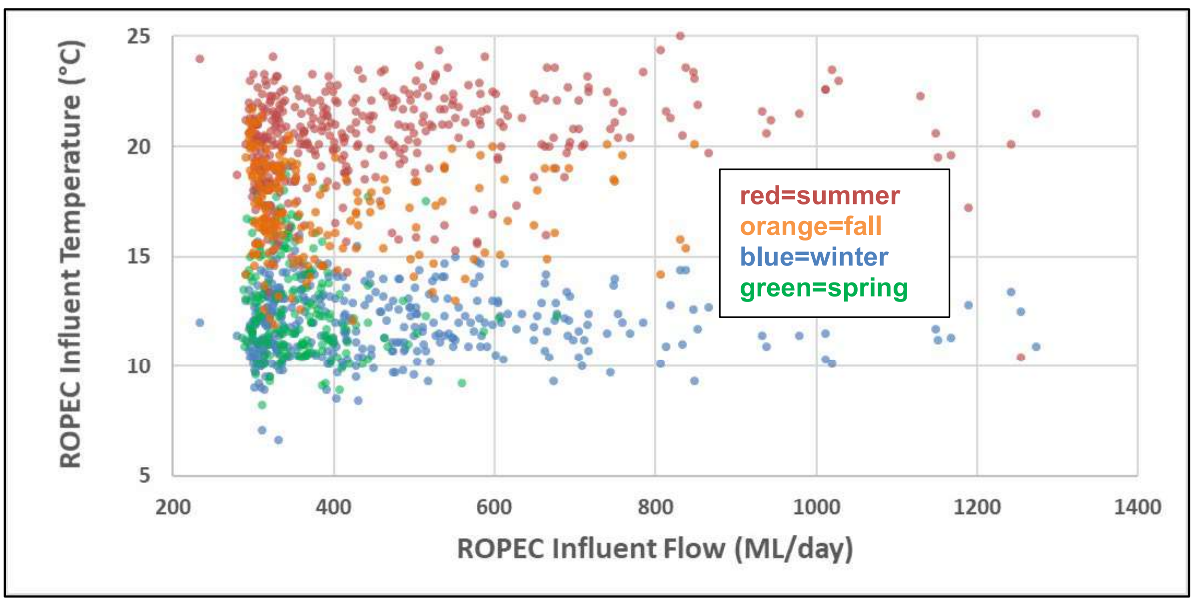

Figure 19: Scatterplot of influent temperature and flow at ROPEC wastewater treatment plant grouped by season over a 5-year period

3.5.3 Environmental Influences

JLR suggests that the reason for the lack of correlation is that wastewater temperature tends to normalize with the environment as it flows through the system. The rate at which sewage within the pipe normalizes with its environment is a complex issue and will depend on a number of factors including:

- Heat exchange with the ground, which in turn is influenced by pipe material, soil conditions, and soil temperature (which changes with pipe depth).
- Heat exchange with the air and the amount of interaction in a particular sewer line with ambient air, including at manholes.
- The temperature difference between the sewage and the ground and the air, all of which vary with time; heat exchange rates are higher when temperature differences are large.

With ROPEC being located in the northeastern corner of the Greenbelt and quite distanced from dense urban developments, the relatively long pipe lengths that transport wastewater to the plant may enable the significant equalization of temperatures in advance of entry into the plant.

Since high volumes of cold rain and snow melt seem not to have influence over the temperature at ROPEC, it seems logical that a small number of WET developments would also be expected to cause minimal impacts. However, this has not yet been accurately modeled, nor proven in the field.

- ➢ Inferring from these datasets, WET projects are expected to have minimal impact on temperatures at ROPEC.
- ➢ In particular, a small number of first WET projects are unlikely to impact ROPEC.
- ➢ Because the temperature of the sewage is influenced by many factors, it is recommended to monitor the sewage temperatures upstream and downstream of the first Ottawa WET projects to get a better understanding of the impacts.

Furthermore, the work in this project did not examine the impact of decreases of temperature within the short distances downstream of the WET system. Concerns about changes to chemical or biological processes (such as the solidification of fats, oils and greases or odour production) should be evaluated. Scientific papers may provide some insights, as would conversations with municipalities that have existing projects. JLR is not aware of any reported concerns or issues from WET system that do exist.

- ➢ Further examination of temperatures changes downstream from a WET system are merited, either by modeling using hourly performance models of the WET system, and/or through monitoring of a project.

3.6 Summary of System Understanding

3.6.1 Measurements Methods

Assessment of WET potential requires minimum sewage temperature and minimum sewage flow data, which is information that is not normally comprehensively captured in the management of the wastewater linear system. Although the study could not review/analyze all the datasets available, the physically measured ETS datasets of flow and temperature that were analyzed have been found to be insufficient to develop a comprehensive understanding of temperatures and flow of the entire City of Ottawa system. Available data was collected over too short of a duration and sites are too scattered in location and timing. That said, JLR was able to create localized studies using the available small datasets towards developing a preliminary understanding of the Ottawa wastewater system.

OdaLog sensors are the most common way the City measures sewage temperatures. They are hung in the air space above the sewage water level, making them less prone to the problems associated with submersible sensors. They are relatively inexpensive and convenient to deploy at maintenance hole stations, while submersible temperature sensors require longer set-up times and can be subject to collecting debris, or even being pulled away in high flow pipes. Because the air in the sewer line is strongly influenced by the sewage, OdaLogs are expected to have only a small temperature offset versus the sewage temperature. However, the analysis found that the temperature differences seemed variable and seemed to be influenced by several factors relating to deployment. This made it challenging to be confident in the temperature data provided by the OdaLogs. JLR instead recommends that submersible probes be used for evaluating WET potential.

If OdaLogs are to be used in future investigations, careful review of the locations must be undertaken to fully understand these influences and the reliability of the data collected. JLR recommends using submersible sensors to help ensure consistency in the temperature readings.

It is most valuable to have temperature and flow at the same location, thus one suggestion for on-going investigations of WET potential is to deploy temperature monitoring at pumping stations, as there are already flow measurements taken at pumping stations.

To assess capacity for heat recovery applications, sewage temperatures must be measured over the winter and spring period when sewage temperature is expected to be lowest. Dataset collected over the summer period could also be accumulated to assess potential for heat injection (cooling load) applications.

3.6.2 Understanding Flow

Minimum flow rates will be a key consideration to the design of WET projects and the amount of heat that can be used in a building heating system. The data reviewed in this Report clearly confirmed that minimum flows occur over the night and early morning. These are the same hours when, in winter, the ambient temperatures are lowest and thus the heating needs of the building are highest.

Based on the information presented in Section 2, equipment suppliers typically suggest minimum flow rates for a WET project. These minimum flows were in the range of 12 L/s to 15 L/s for the in-pipe technologies, while wet well technologies (such as Technology #3) recommended minimum flows of 34 L/s. These minimum requirements will typically make WET systems unviable in the upstream ends of the collection system where available sewage flow is minimal and more variable.

Understanding minimum flow values over the system will be key to characterizing it for potential WET system installation. However, designers typically use average and peak flows as key parameters for sewage collection system design. From an analysis of 16 points in the system, it was found that the minimum flows were generally 20% to 35% of the average flow, though in a few instances, they were in the 50% to 65% of the average flow. For evaluating locations of interest for a WET project, it should be reasonable to assume the minimum flow rate at the location is 20% to 30% of the average daily flow as an initial estimate. Alternatively, modeled wastewater flow rates utilizing the City's sanitary sewer model could also be utilized where available. In either case, these values should be considered a rough order of magnitude or indicative values of the potential for a WET system. Verifying flow rates with direct measurements is recommended.

3.6.3 Understanding Temperature

Sanitary Pipes:

It is fortunate that the COVID probe study includes data collected through the winter and spring months and was able to observe the sewage temperature fluctuations when the sewage is at its coldest temperatures.

As observed, the temperature of the sewage within the sanitary sewer system is typically the coldest in early morning hours, 4 to 6 am. This is also typically the period of lowest flow. Temperature then rises relatively quickly in the morning when showers are taken and washing has begun. Over the course of the day, most sanitary lines show a similar daily pattern with temperature fluctuations as was seen in flow data but to a lesser extent: one peak in the morning and another in the evening. The temperature variability for the dataset studies showed a minimum temperature typically 1.2°C lower than the average temperature.

Temperatures in sanitary pipes within dense residential areas (downtown core) or next to major uses of domestic hot water (hospitals) appear to have higher peak temperatures and daily averages than the system as a whole. This phenomenon is likely due to the measurements being made in close proximity of the heat sources for the sewage generation in the system and before the temperatures normalize in the system. However, the minimum temperatures in the middle of the night were observed to be as low as in other parts of the system. Temperatures in downtown sanitary lines and other dense urban locations should be further investigated with new submersible temperature sensors on select locations.

At present, for analysis of heat capacity in Section 4 of the report, the temperature of one of the submersible probe datasets will be used as a proxy for temperatures in other locations.

Combined Pipes:

In this project, there was not have enough data to draw conclusions on temperature profiles in combined sewer lines. However, there are two reasons to expect that combined lines may still be viable for WET projects: (i) WET system evaluation is based on minimum sewage flow conditions, which are experienced during dry-weather conditions (i.e., when there is little to no stormwater influence on the combined line); and (ii) though temperatures drop during periods of increased runoff during the winter and early spring season, the higher flow volumes in combination with the high latent heat capacity of water will compensate and the available heat is actually higher than during dry periods. This could be further investigated with new submersible temperature sensors and co-located flow sensors.

Environmental Influences:

The data analyzed herein, though indirect, suggests a significant exchange of heat with the ground (a geothermal exchange). And although the time and distance the sewage takes to normalize temperature within the sanitary system is not known, it is evident that the sewage temperatures are buffered by the ground temperature. Observations to support this are as follows:

- Sewage temperatures tend to increase the longer they are within the system in the early part of winter when the ground temperatures are higher than air and water temperatures.
- Sewage temperatures, which also fluctuate with the potable water temperature, show the largest deviation in the early parts of winter when the ground temperature remains high compared to the corresponding potable water temperatures.
- Sewage temperatures continue to drop in the spring (beyond the coldest months of winter), which likely correlates with ground temperatures that are lowest in spring. The falling temperature trend continues until the start of start of spring runoff when cold water infiltration is anticipated to lower the sewage temperature.

Should WET systems be developed in proximity to each other, it will become important to understand the thermal transfer and rate of normalization between the sewage and its environment. As more WET systems come on-line, there is the concern that incremental energy withdrawal from the sewage may become problematic and affect the treatment processes in the sewage treatment plant.

Installing temperature sensors in strategic locations of the sanitary system following the installation of WET facilities is required to acquire more data to develop further understanding of how the temperature of the sewage is affected by the energy exchange systems.

Flow and Temperature Measurements for WET Resource Analysis:

Direct measurements of flow and temperature are recommended during feasibility studies of WET systems. These measurements should cover the full winter heating season and likely the full summer cooling season as well. The City could proactively deploy some sensors on areas of key interest for WET system development to better understand downtown and combined line parameters. The City should also be a central party to collect any and all measurements that are measured by others. Co-located sensors for temperature and flow are advantageous.

4.0 WET Heat Capacities & Archetypes

4.1 Heat Capacity Calculations

The COVID submersible probes provide the most useful temperature measurement data as they are measured over the entire 2020-2021 winter season and three were co-located with points in the system that have continuously measured flow data. Statistics of temperature and flow from the datasets are provided in Table 16. Because of the quality of the data at these sites, they are used for calculations within the report.

Table 16 - Flow and temperature parameters over the 2020-21 winter

Location	Average Flow (L/s)	Minimum Hourly Flow (L/s)	Minimum Temperature (°C)	Minimum Heat Capacity (kW)
March Road	90	21	8.2	442 / 615
Kanata West	125	51	8.2	1,063
Acres	662	345	8.7	7,231

The heat capacity that can be extracted from the sewage at a given time requires only three inputs: the sewage flow rate, the temperature drop in the heat extraction process, and the specific heat capacity of sewage (the value for water is generally assumed to be valid for sewage).

$$H\ (kW) = Flow\ x\ 4.128\ x\ \Delta T$$
$$\Delta T = Tin - Tout$$

Where:

Flow is flow rate of the wastewater (herein assumed to be the entire flow) in L/s (and since 1 L of water weights 1 kg, the units are interchangeable to kg/s

4.128 is the specific heat capacity of the wastewater (assumed to be identical to water), in kJ/kgºC

ΔT is the difference between the wastewater temperature at the input (T_{in}) and the output (T_{out}) of the heat exchanger, and is dependent on the technology and design as further explained below

The temperature drop created by the heat exchanger is a design variable that is dependent on the technology, the design application, and the size of the heat load being served. The maximum heat that can be extracted in any hour from a sewage line will be limited by two main factors:

- The heat exchanger can only extract so much heat before it becomes ineffective, in particular in this application where the temperatures of the sewage (10 to 20 °C) and of the heat transfer working fluid (2 to 10 °C using water or water-glycol mix) are typically not very different. More heat exchanger area and lower temperature working fluid is required for each additional degree exchanged. An aggressive design may be able to cause a ΔT of 5 °C, which is what is modelled herein to give a feel for the maximum potential of these sewer lines. Dependent on technology and other design conditions, the ΔT may be as small as 2 °C. This report assumes values of 2.4 °C for Technologies #1 and 2, and 5 °C for Technology #3, respectively based on information available from suppliers.
- The exiting sewage temperature (T_{out}) should stay above a minimum temperature in order to avoid changing the performance of the sewage system, including avoiding freezing, solidification of fats, etc. This constraint is assumed to be 5 °C for calculations in this report.

Heat capacity calculation for the three temperature probe locations are shown in Figure 20. The top row of graphs provides the temperature profiles, the middle row the flow data, and the bottom row shows the calculated heat capacity for the three locations. Graphs on the left show the entire dataset, which covers the 2021-2022 winter season, while graphs on the right show a zoom in of two weeks in January. Given the very different flow rates of March Road or Kanata North versus Acres Road, the resultant heat capacities are also remarkably different. Acres Pumping Station is a major point in the western portion of the City's sewer system, where flows from Kanata, Bells Corners, and Stittsville combine before being pumped into the Lynwood Collector. In the graphs, the Acres Road flow and heat capacities are tied to the right-hand axis which has a larger scale.

When examining the graphs, it is clear that the heat capacity predominantly follows the patterns of the flow data (blue curves in the top row graphs). It is worth noting that during periods of high flow, such as around December 24, March 11, and March 25, even though the temperature of the sewage drops slightly (orange curves), the heat capacity of the sewage is increased.

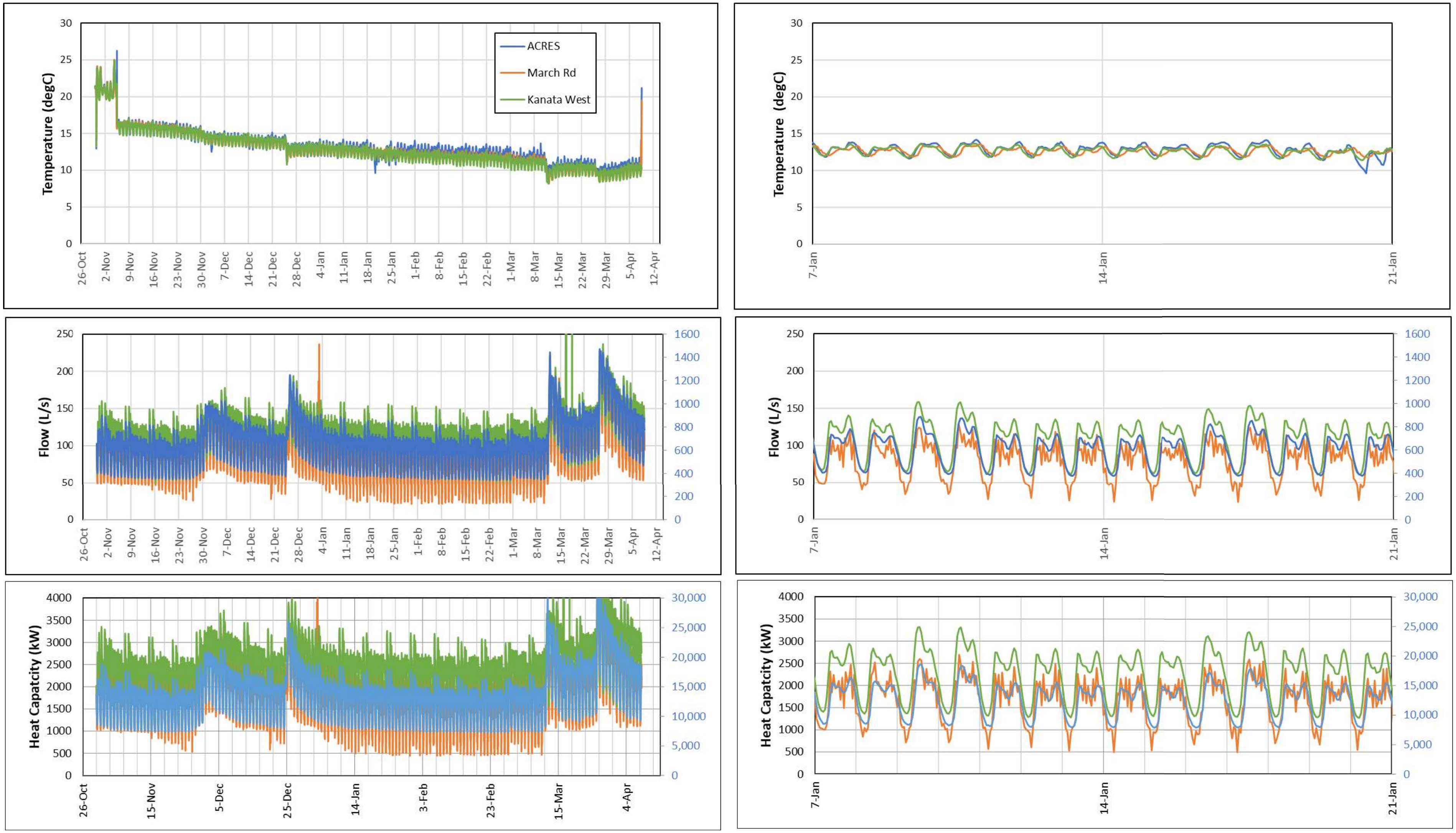

Figure 20: Temperature, flow, and heat capacity for three locations

This suggests that combined sewer lines, with higher flows and lower temperatures during wet weather events, may be as valid as sanitary lines as sources of heat, though data was not directly obtained to confirm this.

The right-hand graphs, which are a zoom in of two weeks, show the expected drop at nighttime. They also show that the higher flow at Acres Rd has a smoother heat capacity curve. For the March Road curves, it can be noted that the nighttime minimums are short lived, lasting 1 to 3 hours.

Figure 21 shows heat capacity duration curves of the three locations, which are the same data as from the bottom row of the previous figure but sorted from highest to lowest heat value. These indicate that the minimum heat capacity of March Road, Kanata West, and Acres Road locations are 442, 1063, and 7,231 kW, respectively. The two smaller lines have heat capacities of the order necessary to heat one sizable building (of the order 5,000 to 15,000 m^2) depending on the performance of its building envelope, while the Acres Road line could likely heat a collection of buildings.

As a quick investigation of the value of thermal buffering, Figure 21 also shows the duration curve for March Road after a 3-hr averaging of the heat capacity data is undertaken (dotted orange line), which might be something that can be accomplished with a larger wet well or similar storage method. The minimum heat capacity is now 615 kW, or 40% higher. The impact of this same 3-hr averaging was minimal for the Kanata West and Acres Road heat capacity curves.

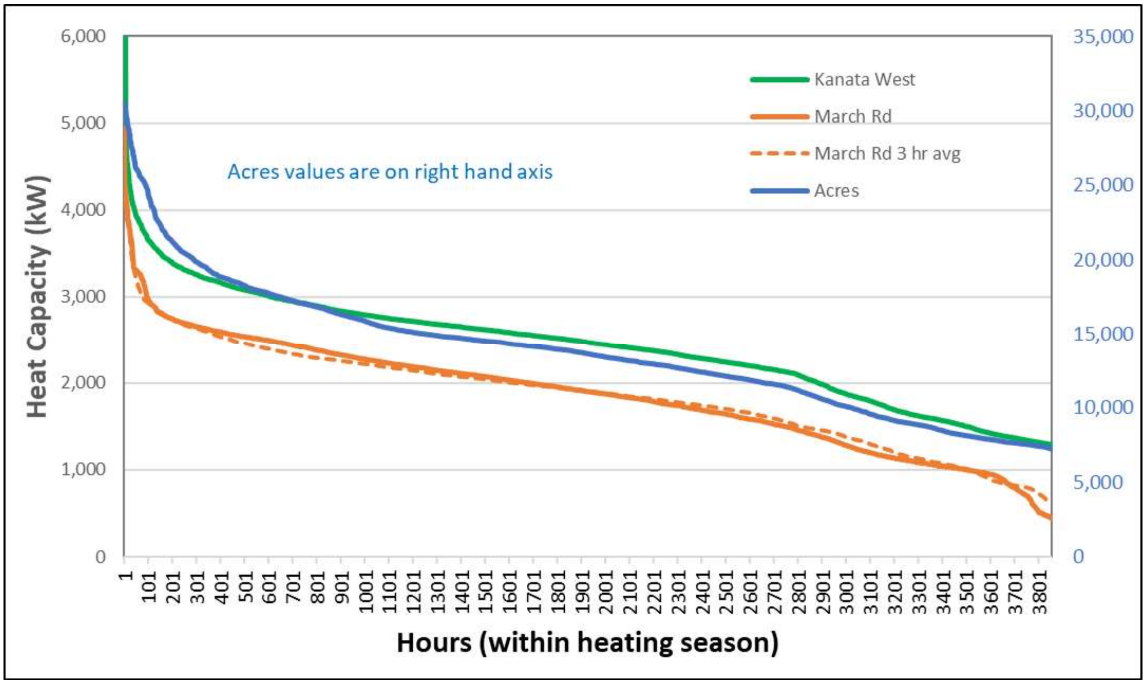

Figure 21: Heat Capacity Curves for 3 Locations

4.2 Principals of Design

If the heat demand in a building is lower than the minimum value of the heat capacity of the sewer line, then the WET system can be counted on to deliver 100% of the heating needs of the building. Above these minimum values, the heat capacity of a WET system will vary by the hour, which is very unlike a natural gas or other combustion-based heating system. It can be valid to design a hybrid system that includes a WET system sized to meet a portion of the building's heat demand along with a secondary or auxiliary heating supply to supply peak heating as required, as illustrated in Figure 22. This approach reduces carbon-based heating as much as possible and may be the most economical solution as well - the WET system will have high installation costs but low operational costs, so the best economic design is to size it to cover a majority of the heating hours and thus be running near its full capacity throughout most of the season and then use the cheaper-to-install heating supply for the hours of high demand.

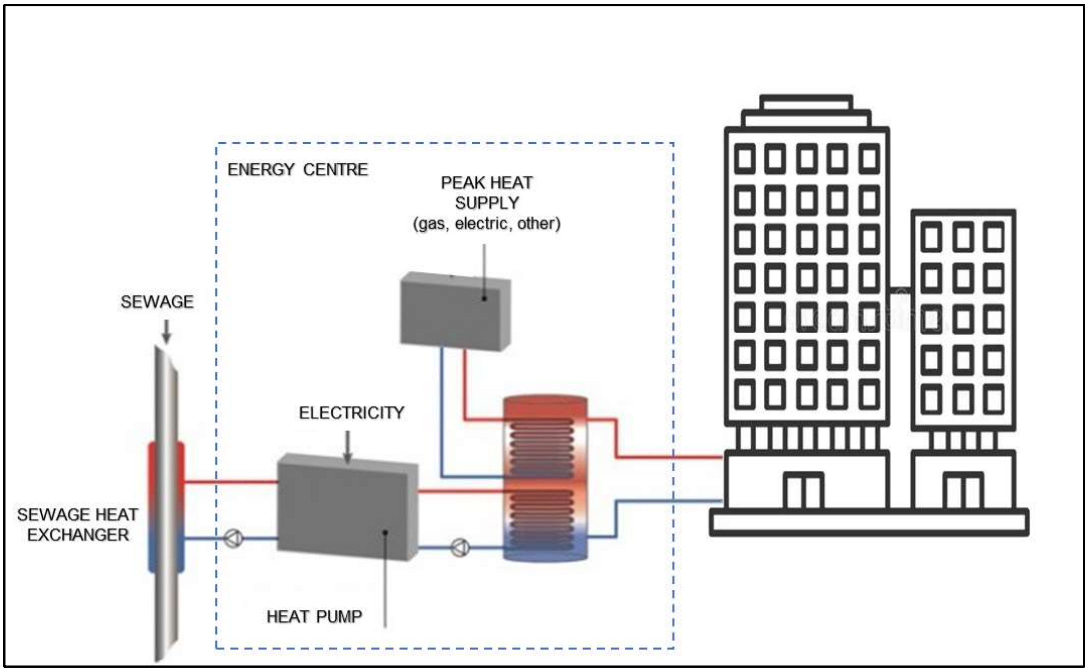

Figure 22: Example of a WET system with secondary heat supply

Because the WET supply capacity and the building heating demand both vary hourly, the match between the two, on an hour-by-hour basis, will be interesting to analyze - this analysis is undertaken in two of the four archetype studies below.

4.3 Archetypes Studies

The Project was tasked with undertaking four archetype studies. Each archetype study considered a hypothetical WET project that encompasses certain core characteristics that may be applicable to a number of projects in the future. Each archetype also demonstrates a different application opportunity. Their purpose herein is to help illustrate the key design parameters and cost parameters of potential WET deployments. The City also requested that the Project select real locations that have some potential for realization. At the same time, the project was constrained in scope to have them be brief analyses, so only readily available building archetype models were used (no new energy models were developed). Table 17 describes the locations that were considered and the ones that were selected.

The project was also constrained by having minimal access to measured data that included coincident temperature and flow data. The quality dataset for March Rd (from above) was used in its entirety for Archetype 2. As was learned in Section 3, temperature exhibits a high level of consistency from one trunk line to another, so the Kanata West temperature dataset was used as a proxy for temperature for the three other archetypes. Flow data for these three locations was developed using modeled flow data obtained from the City.

The flow data received was for dry-weather conditions (i.e., no stormwater infiltration). A synthetic dry-weather temperature profile was created from the Kanata West dataset, where short-term weather-induced changes to temperature were removed – this was done manually and such that the daily and seasonal trends of temperature were still maintained.

Table 17 - List of archetype locations considered

#	Name	Character of Sewer Line / Load	Study Type	Temperature Data	Flow Data	Building Model
1	Ottawa Community Housing McAuley Place 450 Laurier Ave.	Downtown collector / MURB	Heat Capacity vs Building Load with Costing	Synthetic from Kanata North	Modelled	A similar MURB in Ottawa
2	March Road Pump Station 305 Leggett Dr.	Pump Station / Office Building	Heat Capacity vs Building Load with Costing	March Road Covid probe	March Road Covid-probe	A 2001 office building model
3	New Civic Hospital (eastern edge of the Experimental Farm)	Urban collector / planned new hospital	Capacity & light context	Synthetic from Kanata North	Modelled	n/a
4	LeBreton Flats (future parcels west of Booth St.)	Major trunk lines / planned new district energy system	Heat capacity & light context	Synthetic from Kanata North	Modelled	n/a
n/a	Ottawa General Hospital Campus	Outflow of hospital / existing hospital	Reason for not studying: Flow patterns would be unique to the site and no measured flow data was available. It likely is a viable opportunity that could be pursued			
n/a	City of Ottawa large office 100 Constellation Dr.	Municipal line / existing office building	Reason for not studying: City is planning retrofits at this building and they desire carbon emissions reductions, but no suitably sized municipal sewer line exists in proximity			

The first two of the archetypes include concept designs with costing, including capital, maintenance, and utility operational costs. In general, WET systems have relatively high capital costs and relatively low operational costs. To determine an "average" cost of heat over their lifetime, a lifecycle cost analysis is done, which specifically is called the levelized cost of heat (LCOH). LCOH, in $/kWh, considers all costs of the project life divided by all heat produced over the project life. Future costs and future energy are both discounted as per this equation:

$$LCOH = \frac{sum\ of\ costs\ over\ lifetime}{sum\ of\ energy\ produced\ over\ lifetime} = \frac{\sum_{t=1}^{n} \frac{C_t + M_t + U_t}{(1+r)^t}}{\frac{H_t}{(1+r)^t}}$$

Where C_t is the Capital expenditures in the year t
M_t is the operations and maintenance expenditures in the year t
U_t is the utility costs in the year t
H_t is the heat produced in the year t
r is the discount rate
n is the lifetime of the project

4.4 Key Findings from the Archetypes Studies

It is important to note that this brief exercise was a trial comparison of available sewer line data with available building energy demand data; certain implementations are far from optimal but they are intended to trial some combinations and be *illustrative* of issues affecting viability.

The first general learning was that modeled flow data has a fairly large uncertainty for minimum flow rates – two different models were received from the City and the difference in values was enough to change the viability of a project. Yet, using flow models gives access to estimated flow values across the entire system.

- The City and JLR both concur that these values can be *indicative*, but flow rates should be investigated and measured during feasibility work on a particular project.

The second general learning was that each project has a number of different variables to take into account and will therefore also require design optimization to achieve the best economic returns. Figure 23 illustrates many of the design variables that can play a role; parameters that may vary on an hourly basis as given in blue font. It was debatable (in particular because these were invented projects) where to draw the boundary of the WET project when examining costs, for example whether to include costs for retrofits to a heating distribution system for the MURB, or if new odor control costs would be required for the March Road pumping station.

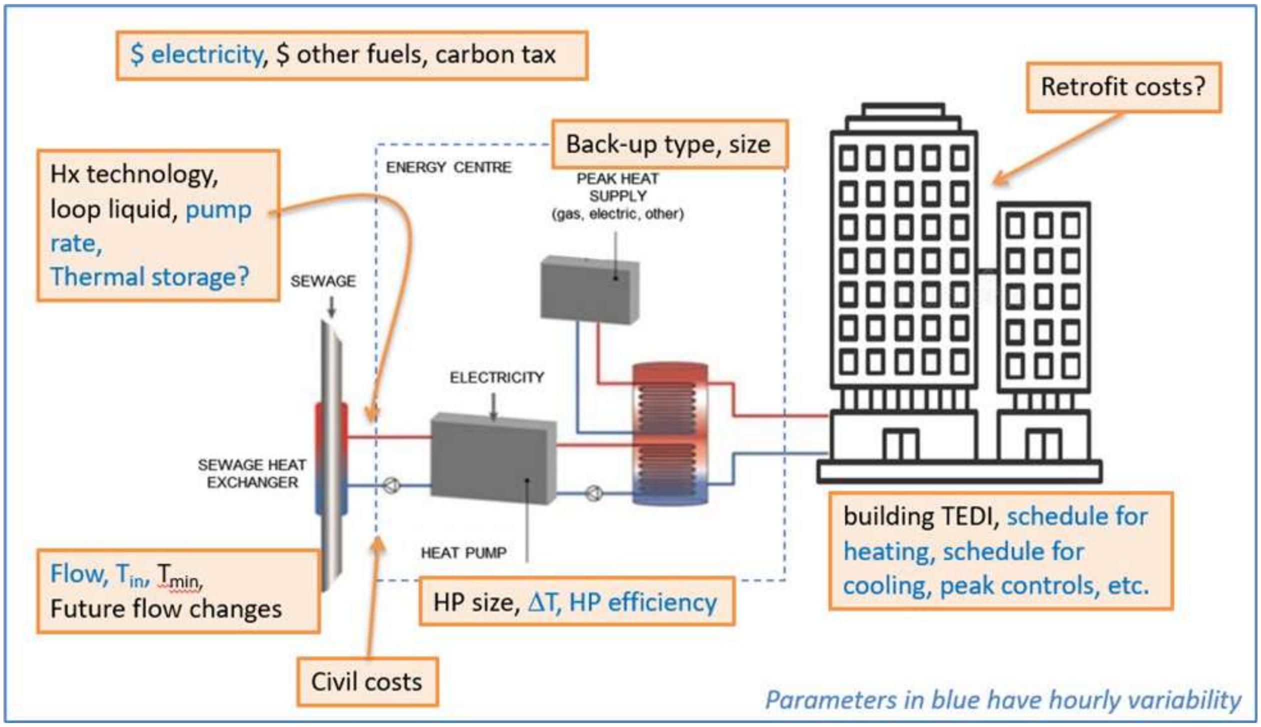

Figure 23: Illustration of many of the WET system design parameters

Variability: In cases where there is a very large flow and only small heat demand (such that demand is always below the minimum heat capacity available), the WET system can provide all the heat that the building needs. WET heating for large buildings loads using of smaller lines is still possible but there will be variability in the WET heat supply. This supply variability needs to be evaluated against the heat demand variability of the building, and the role and economics of the secondary heating supply should also be evaluated. Archetypes 1 and 2 explored this situation.

- The interplay between building heating patterns and WET heat supply (which each may vary hourly) affects design and economics but different approaches can be considered. The system sizes quoted in Table 18 are for WET systems that are larger than the minimum heat capacities but that tap in to heat that is available for a majority of the winter.
- Integration of thermal energy storage would help reduce variability and better support nighttime minimums in flow. This could be short term storage of the wastewater through a larger wet well, or tighter envelopes or higher thermal mass in the building, or other options.

Maximizing the use of the system: Archetype 2 was of an office building that was heated only during weekdays, which diminished the utilization of the WET equipment investment, and which was argued to be one factor that increased the LCOH.

- Buildings with a more continuous heating demand due to occupancy, envelope performance, and flatter heating schedules (less nighttime setback) will have better financial returns.

Economies of scale: Archetypes 1 and 2 explored wastewater lines with relatively small flow rates as a test of the viability of smaller systems on small flow rates. Archetype 1 examined a very low flow rate (12 L/s) that could only be viable with Technology #1 (in-sewer heat exchanger), which tends to be better for smaller heating demands. The LCOH was found to be competitive with natural gas heating once carbon pricing is considered. Specifically, at $0.12/kWh, it is comparable to LCOH for natural gas of around $0.08/kWh[1] plus up to $0.04/kWh for Federal carbon pricing that will be in place by 2030. Larger capacity systems are possible with Technology #1, but it may have upper limits on viable size due to a limitation of deployment length in the sewer and its less effective heat exchanger. Archetype 2 examined a slightly larger flow rate (21 L/s) in combination with Technology #3. This concept design was at the very low end of what would be recommended for Technology #3, which was apparent in the resultant LCOH, which was not particularly compelling ($0.18/kWh).

- Technology #1 has reasonable economics for smaller projects in the >10 L/s range, Technology #3 is economic only for larger projects >34 L/s due to its more significant fixed costs (including civil works and wastewater handling components).
- There will be lower effective cost of heat as system sizes increase beyond these values, in particular for Technology #3, which has notable fixed costs.

What should be included in the financial analysis: A WET system can provide cooling for very little additional capital cost and will operate at an efficiency that will typically be better than standard cooling equipment. Financial evaluations that included these effects would lead to an improved return on investment. Also, it can be debatable whether to include the costs of following items: the cost of building floor space that would house the WET system, the potential reduction in building space and maintenance by a customer connected to an energy loop, and the costs to retrofit the heating and cooling distribution systems.

- Levelized cost of heat may not be the best metric for the full value of a WET system.
- Return of investment for projects with both heating and cooling should be investigated as a priority.
- WET system economics need to consider capital and operational costs. It is typically project-specific factors that determine which system costs be included in the financial analysis (e.g. which assets are near or at end-of-life, or which existing systems are incompatible with the WET system, etc.). Within the project-specific context, the same list of inclusions should be equivalent for all the heating and cooling system options that are to be compared within the project feasibility study.

[1] This number is taken from the few references that exist in the field listed herein and is generally expected to consist of $0.04/kWh for all in costs of a natural supply (consumed fuel and other account charges) and approximately $0.04/kWh for system costs over life, including initial capital costs, annual maintenance costs and asset renewal costs over a long lifespan. The LCOH of any system will vary significantly dependent on many factors, including system boundary definition, financial parameters, jurisdictional cost differences, project lifespan definition, etc.

- K. Hansen, “Decision-making based on energy costs: Comparing levelized cost of energy and energy system costs”, Energy Strategy Reviews, Vol. 24, Apr 2019, pgs 68-82. ISSN 2211-467X, https://doi.org/10.1016/j.esr.2019.02.003.
- Li, H., Song, J., Sun, Q. *et al.* "A dynamic price model based on levelized cost for district heating”. *Energ. Ecol. Environ.* Vol. 4, 15–25 (2019). https://doi.org/10.1007/s40974-019-00109-6.
- K. Ravi Kumar, N.V.V. Krishna Chaitanya, Natarajan Sendhil Kumar, “Solar thermal energy technologies and its applications for process heating and power generation – a review”, J. of Cleaner Production, Vol.282, 2021, ISSN 0959-6526, https://doi.org/10.1016/j.jclepro.2020.125296.

Archetypes 3 and 4 were less detailed analyses because their main intent was to examine the possibility for a WET system for important city-building developments that are anticipated to occur in the near future, namely: the development of the new Civic Hospital and LeBreton Flats. Building heating demand profiles are not at all known yet, but both may include high performance and low carbon design attributes, which will be a good fit for a WET system. The flow rates at the new Civic Hospital location were moderate and anticipated to be of a size that supported some, but not all, of the hospital's heat needs. At LeBreton Flats, where there are two major Sanitary Collectors, it may be possible to develop WET system(s) that provide a notable heating capacity for an anticipated district energy system at the site.

Table 18 – Summary of the four archetypes

#	Name	Character of Sewer Line / Load	Study Type	Minimum Flow (L/s)	Technology	WET system size (kW)	LCOH ($/kWh)
1	Ottawa Community Housing McCauley Place 450 Laurier Ave.	Downtown collector / MURB	Heat Capacity vs Building Load with Costing	12	#1	150	0.12
2	March Road Pump Station 305 Legget Dr.	Pump Station / Office Building	Heat Capacity vs Building Load with Costing	21	#3	1,400	0.18
3	New Civic Hospital (eastern edge of the Experimental Farm)	Urban collector / planned new hospital	Heat capacity & light context	31	#3	~ 1,400	n/a
4	LeBreton Flats (future parcels west of Booth St.)	Major trunk lines / planned new district energy system	Heat capacity & light context	72 (CCC) 371 (WNC)	#3	≤ 17,000	n/a

5.0 Alternate Approaches to Municipal WET Projects

A few additional applications for WET technologies are briefly considered herein. The first two are applications already in use, but outside the scope of this study, and the latter two are interesting outside-the-box implementations that (a) consider how this low-carbon nearly free heat can be used to reduce other (non-space heating) fossil fuel use and (b) avoid the daily temporal mismatch between building peak heating needs and wastewater heat capacities.

5.1 Using a WET system for Cooling

This project's focus was specifically on heating applications, as a WET project provides low-carbon heating that can replace natural gas heating. However, the WET system can provide cooling as well, as the heat pump and heat exchangers can be operated to reject heat into the sewage flows. This would typically replace air conditioners, chillers, and cooling towers that use electricity as the energy supply, so on a clean grid there is not nearly as large of a carbon reduction compared to a heat recovery project. However, the WET system will be more efficient (water to water heat transfer), consume no water, and have a reduced footprint and maintenance cost compared with more traditional cooling systems. The value of the WET system for cooling is attractive and should be evaluated in the future. Inherently, if a WET system were installed for heating purposes, the same equipment could be used for cooling as well with little to no additional capital costs. Additionally, further temperature and flow data of the sewage lines during the summer should also be collected and examined to quantify cooling capacities.

Hybrid combination with other Heat Pumps

There are attributes of a WET system design and performance that are different but synergistic with open-loop and closed-loop GSHPs, these are briefly presented in Table 19. Each of the technologies may have limits on total size that can be developed at a site, to limited wastewater flow rate, aquifer flow rate, or land area for a borehole field, respectively for WET, open loop, and closed loop GSHP. It is relatively straightforward to integrated a WET system with one of the GSHP options, which may in fact yield the best net system outcomes.

Table 19: Summary of key development and performance attributes of different heat pump technologies

	WET	Closed-Loop GSHP	Open-loop GSHP
Daily variability	Maybe, if project uses full flows	none	none
Seasonal restrictions	~ none	Heating = cooling	~ none
Geographic distribution	Linear along pipes	Nearly anywhere	Local geology dependence
Feasibility assessment	Deploy sensors	~ none	Hydrogeologist consult & drill deep well
Costs	$	higher	$

5.2 In-building WET systems

This project focused on the implementation of WET projects using municipal sewer lines and generally to larger lines where flows and temperatures are aggregated. However, in-building waste heat capture systems also exist that collect and harvest thermal energy from the building's sanitary output. The advantage of these systems is that they capture the highest temperature sewage closest to the source and may have low capital costs to install, but they will also likely be subject to significant flow variability. That said, the higher sewage temperatures leaving the building are often inherently synchronized with heating needs for domestic hot water, so pre-heating hot water is a simple and useful undertaking that can be implemented. For example, commercial products often called drain heat recovery utilize a coiled heat exchanger around the drain line where water going to the hot water tank is preheated. Suppliers of the equipment, which are sold extensively in European countries, claim the units can offset 50% of the domestic hot water heating costs. Larger commercial systems also exist that use the waste heat for space heating – these require an on-property wet well. Additional thermal storage may also be required. The City may wish to encourage building owners and developers to consider these solutions, for both large and small buildings alike.

5.3 Municipal Potable Water Heating

Similar to in-building WET systems as described above, in discussions with City staff, an idea was raised where sanitary waste heat could be used to warm up the water in the potable water system. The City's potable water supply is the Ottawa River, where water temperature varies significantly over the course of the year (as was shown in Figure 17) and is only a couple of degrees above freezing in the middle of winter. One concept is to heat the potable water at the main supply point of Lemieux Island during the very coldest portions of the winter. The motivations are twofold:

- Very cold potable water requires more input energy to be heated for domestic hot water and, for the majority of Ottawans, this is done using natural gas, which emits greenhouse gases.

- Very cold potable water is also a cause of maintenance issues due to localized freezing within pipes. This occurs in both municipal lines and within peoples' houses, during the coldest days of cold years (i.e., not every year, but frequently enough). In the worrisome cold weather conditions, City issues alerts for people to be cognizant of this issue and to run a trickle of water through their pipes on a continuous basis to prevent burst pipes. There are a small number of points within the municipal system and/or municipal buildings where this can be an issue as well.

The City's potable water mains that originate at Lemieux Island are in close proximity to the major trunk lines of Cave Creek Collector and West Nepean Collector in the vicinities of LeBreton Flats, Bayview Station and Tunney's Pasture. Since a temperature increase of only a few degrees is desired, this could potentially be accomplished with a WET heat exchanger without the need for a heat pump. It was out-of-scope for JLR to undertake any evaluation of this concept although some considerations are noted. A system with two heat exchangers with an isolation loop between the two could provide the required safety separation/isolation between the sanitary and potable supplies. A combination of high flow rates in the potable water system in the vicinity of Lemieux Island and the depth of the sanitary sewer lines may require a considerable capital investment that may be difficult to quantify against the offsetting benefits to the water system. Initial next steps might include further examining the geographic and physical arrangements of these systems, the required energy transfers, technical and economic viability, implications on various categories of potable water users, and the maintenance cost savings. The analysis needs to also confirm that heat injected near the Lemieux Island supply during these coldest days of the winter would not simply be lost back to the ground as it travels through the distributions system – the geographic location of existing frozen pipes and quantification of heat exchange with the ground would be required.

5.4 Snow Melting

Somewhat similar to the above concept, it was discussed whether the waste heat of the sanitary lines could be put to purpose in reducing snow volumes that develop during snow clearing processes in winter. Two concepts are lightly considered. A first concept was to reduce the snow volumes at City snow dumps and, in particular, at inner-city snow dumps so that they could then receive higher volumes of snow, thereby reduce trucking to sites at the edges of the city. However, upon review of the locations of snow dumps, the only inter-city municipal dump was the Clyde Ave location, which does not have any sizeable sanitary lines in close proximity to it. This concept could be useful to private operators, though it is was out-of-scope to review their relevant operational information, and doubtful many would have enough volumes to achieve economies of scale.

A second concept is to use sanitary waste heat to keep key pedestrian or bicycle lanes free of snow. Appropriate piping would need to be embedded in the concrete. The benefits would include improved safety for pedestrians, a potential added benefit for tourists (if a location such as Parliament was chosen), and reduced salting and maintenance work, which have monetary costs, carbon emissions, and other environmental impacts. This concept might be most economic when integrated with a large-scale WET project. For both concepts, JLR did not evaluate what temperatures would be required for the “melt loops” and thus whether a simple heat exchanger would be sufficient or if a heat pump is required, or any other design aspects. Both concepts would perhaps be good topics for university engineering projects. Practical aspects, such as longevity of piping and superior drainage to prevent icing, need to be evaluated

5.5 ROPEC Effluent

ROPEC’s effluent discharge is equivalent to all the wastewater of the municipality, offering very high economies of scale for a WET system, and the fluid stream is aggregated and thus has reasonably smoothed temporal variations for dependability of flow across each hour. Furthermore, it has been processed into clean water, so biofouling of a heat exchanger is no longer an issue, thereby simplifying system operations and maintenance and allowing for a broader range of heat exchanger products. It is estimated that there is the opportunity for tens of MW of heat, which could easily support ROPEC’s space heating and cooling needs as well as its process heat needs; this may require upgrades to the plant heat distribution system, so timing with other asset renewals would be best. The heat capacity may further allow for export of large quantities of thermal energy to nearby thermal loads. Unfortunately, there are very few large buildings near ROPEC. Possible heating and cooling loads to consider would include: (i) a small district energy loop that served the Sheffield Business park, the Richcraft Sensplex, and any new commercial developments along Sheffield Rd; and (ii) new facilities developed on adjacent lands, such as greenhouses on the NCC Greenbelt lands. Greenhouses may have relatively low requirements for the heating supply temperature (for example, if it is used to slightly raise local ground temperature) and thus be great fit for the WET thermal energy supply. Furthermore, the development of greenhouses for increased local food production may align with other sustainability objectives of the City and the NCC.

6.0 Recommendations

Assumed Temperatures: The temperature profiles for three suburban collectors (March Road, Kanata West, and Acres Road) were all very similar, and should be reasonable estimates for temperatures elsewhere in the system for the purposes of indicative estimates of heat capacity. Certain locations immediately downstream from a high urban density may have higher temperatures during hours of operation, but similar nighttime temperatures. These higher temperatures improve the efficiency of the heat pumps during those hours of operation but will not change the minimum heat capacity of the line.

New Temperature Measurements: New submersible probe temperature sensors should be deployed in select trunks, especially those of high interest for the high flows and new developments that may have high heating loads, including:

- locations examined in two of the archetypes:
  - the West Nepean Collector and Cave Creek Collector in LeBreton Flats
  - the Mooney's Bay collector that passes through the New Civic Hospital site.
- Other locations that were noted during the conversations of the project
  - A large length of the West Nepean Collector which essentially runs parallel with the Confederation Line of the Light Rail Transit System, along which there are many intensification projects planned
  - The Preston Street combined collector and the Mooney's Bay Collector, which could support intensification in Little Italy including the planned Gladstone Village project
  - Opportunities using campus-level sanitary lines at universities and hospitals
- At least one combined pipe
- It would be highly informative to deploy more than one sensor along a trunk line to ascertain temperature equalization effects:
  - one sensor upstream and one sensor downstream of a new inflow from a sizeable development to examine the impact of new inflow on temperature
  - a third sensor a few hundred meters away, to examine the downstream impacts of the WET system, if any.

Preferably, temperature probes will be co-located with flow measurements. Pump stations or other locations that already have installed continuous flow measurements may thus present certain advantages, though they may not coincide with potential project sites.

New Flow Measurements: Areas of high interest for WET development should have new sensors deployed to get a better confirmation of flow rates. Quality flow rates collected over a long term (e.g., one year) are crucial for WET system feasibility analysis. Although this can be initiated by developers for specific project proposal submissions, a full year of site measurements may be long for their development plans. The City may wish to consider initiating flow measurements at various strategic sites immediately. Confirming flow modeling in areas of interest ahead of developer design submissions can more proactively encourage WET developments at even earlier stages of projects.

Indicative Heat Capacity for the Entire System: City already manages models of the system flow; these have been calibrated been calibrated using short term ETS measurements. The dry-weather modeling scenario should be used as the basis for developing a city-wide preliminary assessment of heat capacity.

$$H\ (kW) = Flow\ x\ 4.128\ x\ \Delta T$$

Where H is heat capacity available in the sewer line in kW, and ΔT is the temperature drop across the heat exchanger in °C, and *Flow* is the flow rate in L/s of the pipe. A value of ΔT = 5 °C is appropriate for indicative values for Technology #3 (>34 L/s), which will be larger trunk lines and larger project. Smaller flows (10 to 34 L/s) could be harvested with Technology #1, in which case a ΔT = 2.4 °C is more appropriate.

Minimum flow rates ($Flow_{min}$) and thus minimum heat capacity (H_{min}) is the single most useful value to characterize a pipe. Average values of these two parameters can also be useful to designers, or ultimately an hourly profile may be desired. The City can also hourly profiles using the more detailed approaches described in Section 4.1.

Technologies, Ownership Models, and Polices: City has a few choices on the role it can play during WET developments ranging from: (a) full developer and owner of the WET system along with being the seller of the thermal energy, to (b) simply allowing developers access rights to the wastewater system. City staff were researching the various policies developed by other municipalities. Business models were *not* in scope of the project, but JLR can remark on a few factors that the City may want to consider.

As discussed in the Archetype section of the report, there are different values that a WET development may provide, including heating, cooling, shift of O&M, reduced GHG emissions, future proofing of thermal costs, reduction or elimination of other mechanical system capacities and space allocation, lower peak cooling demands, etc. Each project may have a different collection and magnitude of these benefits and different risk profiles for the realization of the benefits. A challenge for the City, if it were to be the owner of the WET system, would be to properly monetize all these benefits and justify the capital costs involved to install a system.

City staff reported hesitancy with Technology #1 since the heat exchanger is inserted directly into the flow channel of sewer line and may result in more sewer maintenance. However, it should be noted that this option is viable in smaller sanitary pipes than where Technology #3 will work – thus its approval can enable more projects to be developed. Further discussion with the supplier and investigation of performance of installed systems is recommended. Technology #1 may be more viable if the City wishes to assume ownership of the in-sewer portion of the system, with fixed fees charged to developers for use of the infrastructure. These fees may help to recover any added maintenance costs.

Alternative Applications: JLR suspects that a cooling-only deployment may be economically viable, at least for large buildings. Though the carbon footprint of cooling is typically lower, The WET system still reduces emissions: WET-based cooling will tend to be more efficient that other cooling options, and cooling peaks are the cause of electricity demand peaks, which have substantive marginal carbon emissions factors.

As described in Section 5, there are smaller scale in-building WET technologies that the City could encourage building owners to incorporate in their buildings. The alternative uses of WET using municipal lines, such as snow melting and potable water warming, as were examined briefly in Section 5, were interesting, but further study is recommended to evaluate their practicality and business case.

Final Remarks: The development of carbon reduction strategies and building standards has resulted in WET systems being of interest to a number of developers, including several in Ottawa. There is quite a bit of interest and uptake in other municipalities across Canada. Therefore, JLR encourages the City to continue to advance their policies and find means of support the projects.

7.0 Basis of Use and Reliance

This report has been prepared for the exclusive use of City of Ottawa, for the stated purpose, for the named facility. Its discussions and conclusions are summary in nature and cannot be properly used, interpreted or extended to other purposes without a detailed understanding and discussions with the client as to its mandated purpose, scope and limitations. This report was prepared for the sole benefit and use of City of Ottawa and may not be used or relied on by any other party without the express written consent of J.L. Richards & Associates Limited.

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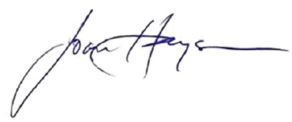

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Appendix A

Sewer Waste Heat Recovery Study – Terms of Reference (October 28, 2020)

Sewer Waste Heat Study
– Terms of Reference

Background

In 2017, city council approved Phase 1 of the *Energy Evolution Strategy*, which identified a project to survey the waste heat available in Ottawa that can be captured for beneficial use[i]. This project aligns with Ottawa's greenhouse gas reduction targets and may contribute to the federal government's district energy plans and zero carbon objectives.

A portion of this this project is this study which will focus on waste heat from the City of Ottawa's sewer system. It will join other work which will examine other sources of waste heat and survey geothermal resources of the City. The goal of this set of work (in this study and others) will be to determine what are the best heat sources in various areas of the City according to the location specific heat resources available. With resources assessed policies and programs will be considered and enacted as appropriate to put these resources to beneficial use.

The City of Ottawa's wastewater collection system, its network of sewer pipes and associated infrastructure, could provide a source of low carbon, distributed thermal energy. Given that much of the water that enters the sewer system is warm, the sewers contain heat that can be captured for beneficial use by public or private entities. There are examples of heat capture from sewers in other municipalities as well as equipment designed to capture sewer heat.

The federal government, as part of their Energy Services Acquisition Program (ESAP), through Public Works and Government Services Canada, performed an initial review of the thermal energy opportunities available in Ottawa and determined that, due to lack of information available from the City, the thermal energy opportunity of the sewer system was not an option they could assess.

This study will collect and quantify temperature data from strategic sewer locations. Additional thermal energy sources will be identified and quantified where possible. Also, beneficial uses for this thermal energy will be identified. Technologies to capture the thermal energy will be reviewed and assessed for applicability. Both internal and external stakeholders will be consulted where necessary.

The study planning started in 2019 and this study expected to be complete in May 2021 with recommendations for be considered and implemented as applicable. The results of the study will help inform the Community Heating Strategy (one of Energy Evolution's 21 initial proposed projects) and may help inform the ROPEC Site Master Plan and City renewal planning generally. The study results will be shared publicly to assist the community in evaluating emissions free thermal sources in the City which they could endeavor to employ.

Sewer Waste Heat Study
– Terms of Reference

Scope of Work

The purpose of this study is to identify and quantify sources of thermal energy (heat) from Ottawa's sewer system and how they might be employed. To the maximum extent possible, the thermal properties of the sewer system will be examined and detailed. These properties will be examined as a potential thermal resource and related to projects that can further the goals of Energy Evolution and reduce the costs of operating the City on a community wide basis.

The objectives and deliverables are outlined as follows:

1. Assess sewer heat capture technologies

2. Describe and detail the sewer system as a heat resource.

3. Architypes of waste heat utilization projects

4. Summary of findings

Each project step will be provided initially in draft format for review by the City (a charter related to this terms of reference document discusses resources which support this study). The City's Project Manager will circulate the documents for review and comment, compile the comments and arrange for a meeting between the City and the consultant, as required. The consultant will update the draft based on the City's review and comment. This process may be repeated based on the number or complexity of the comments. The consultant will provide a final document based on the City's feedback.

Project Description

1. **Federation of Canadian Municipalities feasibility study program application**

To extend the funding available for this project, the first step in the scope of work will be to apply for match funding from FCM. The City's Project Manager will be available to support the consultant in preparing this application. A successful application is expected to enable more thorough data collection techniques in step 4, the addition of step 5 of this project, and additional scope in deliverable 6.

2. **Geothermal Potential Study**

The City wishes to support the uptake of geo-exchange and develop a project that reduces risk to stakeholders through a survey of the resource. The goal of this small study is to advise on how this could be accomplished. The study will include the following steps to develop a preliminary GIS interface:

- consult with geothermal suppliers;

- review the publicly available Ontario well records (from MECCP) and convert relevant geo-exchange parameters into a dataset within ArcGIS;
- if relevant, implement geological information into the same ArcGIS;
- include as possible other well records;
- overlay City heat load data from other phases of the project;
- delineate areas of high likelihood of viable open loop geo-exchange installations;
- if needed for controlling effort, focus on areas of high interest for geo-exchange such as district heating areas;
- identify information gaps and next steps;
- discuss the lifecycle cost of heat for geo-exchange; and
- if possible within allotted budget as a stretch goal, include the geo-exchange option in the Phase 5 archetypes .

3. Assess sewer heat capture technologies

Through literature review and consultations with owners and operators, commercially viable and locally applicable technologies to capture and repurpose the sewer sourced thermal energy will be identified. Any technologies that are cutting edge and promising may also be identified, but their stage of viability should be clearly identified.

Technologies will be reviewed with consideration to a variety of uses of the heat being accessed. Most heat capture systems employ a heat pump to boost the heat resource to higher and therefore more usable temperatures. This temperature boosting requires energy to be employed, however so use of sewer heat through simpler recovery, such as a heat exchanger will also be investigated. Two uses of un-boosted recovered heat, snow melting and preheating the domestic water[1] supply, will also be investigated.

The identified technologies will be evaluated qualitatively with quantitative data supplied when it is relevant and available. The list of criteria for evaluation will be as flows:

- Inherent health, safety and environmental attributes
- High level cost to develop: i) as a retrofit; or ii) during upgrades or installation of related infrastructure – for example, street redevelopment
- Cost to operate and maintain with some consideration of economies of scale
- System and major components life-cycle
- Density of possible energy supply required and minimum system size
- Space and/or land requirements
- Impact on the sewer system and wastewater treatment plant
- Creation of solid waste, if applicable

[1] As all of the domestic water inside the urban boundary are sourced from the Ottawa water, the temperature of supplied water drops dramatically in the winter. This represents a notable thermal load on a City where heating is close to half of our community greenhouse gas emissions.

- Utility requirements
- Ease and simplicity of operation
- Example of where the technology is currently employed if applicable
- Robustness to changes in the heat resource available. An example would be the wastewater temperature changing as a result an evolution in the use of a section of a sewer line over time
- Any other important criteria identified through the course of the study

The results of the technology review will be related to the actions in deliverable 4 below. This will determine which technology(ies) if any, would be appropriate to various areas of the sewer system

4. Describe and detail the sewer system as a heat resource.

To the maximum extent possible, Ottawa's sewer system will be mapped out with as many locations as possible showing the value of the local heat resource. The consultant's staff will work with City of Ottawa Public Works and Environmental Services staff to determine good locations for investigation and optimize the volume and quality of collected data.

The amount of areas which could be surveyed is potentially vast and could represent virtually perpetual scope of work. As such, the study will use the following criteria to determine higher priority areas to assess the thermal resource as follows:

I. Sources of Heat
- Quantity of waste heat available
- Expected wastewater temperature
- Practical siting considerations such as utility availability and space

II. Uses for Heat
- Locations in areas identified as potential district energy areas by Energy Evolution
- Corridors which might connect areas potentially served by district energy
- Areas where snow melting would be beneficial to reduce trucking on management of snow
- Areas where it would be easy to transfer heat into the domestic water system
- Areas with multiple uses for the heat identified

With areas identified which rate highly on the above criteria, data collection will be set up in as many locations as possible. The following table details of how collected data the assessment of heat resources at specific locations.

Table 1: Heat Resource Assessment Analysis

Criteria	Examination Period	Criteria	Comments
Heating Season Resource	Nov 1, - Apr 10	Average Temperature and Average Tonnage	This assesses total resource size to give an idea of the opportunity
Peak Heating Periods	All hours where the Ottawa temperature < -18 C	Average Temperature and Average Tonnage	Other resources could supplement if peak period heat supply is low or non-building heat uses could be considered
Minimum Resource Available	The 10 hours with the least heat available	Average Tonnage during a one-hour period	Brief periods of low heat supply could be supplemented with thermal storage or non-building uses of heat could be considered

The heat resources available at each location should be related to the other aspects of this study (technologies reviewed, uses for the heat). When complete, each studied location should prioritize technology which could be employed and potential uses for the waste heat. Practically speaking this is illustrated in a couple examples as follows:

- An area with a variable heat resource which doesn't align well with building heating demand, might be better employed in other roles. The heat supply might be better employed in roles with different temporal demands such as snow melting or domestic water preheating
- An area with a heat resource of limited size might be appropriate for certain heat collection technologies but not others

When complete, each studied location will prioritize technology which could be employed and potential uses for the waste heat.

The survey will also note the areas where storm or tile water enter sewer lines as these water sources have the potential to have sudden disruptive impacts on the thermal resource available at specific locations.

5. Architypes of Waste Heat Utilization Projects

With the data collection and compilation complete and provided good heat sources have been identified, the consultant, in consultation with the City, will develop architypes of uses waste heat. There will be four architypes: i) One examples waste heat supporting district energy systems, ii) One of waste heat supporting a major building iii) One of waste heat to snow melting and iv) One of waste heat to domestic water preheating.

The purpose of the architypes will be to give a conceptual understanding of what waste heat recovery and utilization would look like and how it would work. It would introduce the report reader to the how and why of the waste heat systems being proposed and identify items for further consideration or study. Each architype would have the following components:

- An easy to understand schematic which shows the key elements of the system and how they work together
- The rationale for setting up such a system. Reasons would include improved GHG displacement and energy cost reductions vs. other options for example
- Co-benefits. Examples could include benefits to the sewer system or enhanced public health and safety
- Conditions and Actions that support installation of a system. This could include space for installation, utility availability or actions which support district energy systems such as higher density or buildings able to utilize lower temperature heat sources
- Items which require further investigation. Consider all items we would need to know to develop a business case. Also consider how the architype development would fit with some relevant Energy Evolution targets. Examples include geothermal district energy systems, expansion of district energy systems into higher density areas, reduction of existing building heating demand by 60-70%, net zero energy buildings by 2030, and electrification of domestic hot water heating.

6. Report on the findings

The final report will summarize the findings in the above steps and include links to Ottawa's unique financial, environmental, health, and social aspects. It will relate the finding to the relevant targets of Energy Evolution and prioritize next actions either in the form of further study, changes in policy, legislation or practices or the development of projects. Recommendations may be broad of specific and could apply to all types of private or community organizations and all levels of government. All maps will be delivered in shape file format for use in an ArcGIS system. Also, all final deliverables must be AODA compliant.

Project Deliverables and Timeline

Item	Deliverable	Timeline	Basic Survey	Enhanced Survey
1	Project Definition and support for FCM funding application.	Aug - Oct 2020	$10,000	$10,000
2	Geothermal potential study	Oct 2020	$5,000	$15,000
3	Assess sewer heat capture technologies	Oct 2020	$20,000	$20,000

4	Describe and detail the sewer system as a heat resource.	Nov-Mar 2020/21	$25,000	$33,000
5	Architypes of Waste Heat Utilization Projects	Mar-Apr 2021	n/a	$42,000
6	Report on the findings	Apr – May 2021	$5,000	$15,000
	TOTAL		$65,000	$135,000

Schedule and Target Completion Dates

The deadline for the final report is June 30, 2021.

Special Requirements

The consultant is to describe any special requirements for the proposed work, including but not limited to:

- Health & Safety issues,
- Environmental aspects,
- Site Orientation Visits, Site Accessibility circumstances,
- Equipment needed, and
- City reports and documents needed.

Appendix

The following is a list of documents the consultant will review to inform work on this study

Document Name & Number (if applicable)	Date	Owner	Location
Sewer waste heat charter	Pending	City of Ottawa	Upon request
Council accepted 100% scenario Energy Evolution Model	2020	City of Ottawa	Upon request
City of Ottawa community heating strategy	2020	City of Ottawa	Upon request
Map of district energy zones modeled by Energy Evolution with available sewer temperature data points mapped	2020	City of Ottawa	Upon request
Heating demands projected within district energy zones, as modeled by Energy Evolution	2020	City of Ottawa/ SSG	Upon request
Map of sewer diameters and depths	2020	City of Ottawa	Upon request

Document Name & Number (if applicable)	Date	Owner	Location
Pathway Study on Solid Waste, Wastewater and Other Waste Sources in Ottawa	2019	City of Ottawa/ Sustainability Solutions Group	https://documents.ottawa.ca/sites/documents/files/pathway_study_waste_en.pdf
ACS2017-PIE-EDP-0048 – Energy Evolution: Ottawa's Community Energy Transition Strategy, Phase 1	December 2017	City of Ottawa	https://documents.ottawa.ca/sites/documents.ottawa.ca/files/energy_evol_staff_rept_en.pdf
Energy Evolution: Ottawa's Community Energy Transition Strategy, Phase 1	November 2017	City of Ottawa	https://documents.ottawa.ca/sites/documents.ottawa.ca/files/energy_evol_phase1_en.pdf
Energy Evolution: Summer 2017 Pathway Workshops As We Heard It	October 2017	City of Ottawa	https://documents.ottawa.ca/sites/documents.ottawa.ca/files/energy_evol_awhi_report_en.pdf
Compilation of Energy Pathway Studies	October 2017	City of Ottawa	https://documents.ottawa.ca/sites/documents.ottawa.ca/files/energy_evol_pathways_en.pdf
Baseline Energy Study for Ottawa 2015	October 2017	City of Ottawa	https://documents.ottawa.ca/sites/documents.ottawa.ca/files/energy_evol_baseline_en.pdf
An Energy & Emissions Plan for Canada's Capital Region	2012	City of Ottawa, Ville de Gatineau and NCC	http://app06.ottawa.ca/calendar/ottawa/citycouncil/pec/2012/02-21/03-Document%204%20-%20CoF_Energy%20Plan_FINAL%5b1%5d.pdf
Regulatory Compliance Report Wastewater and Stormwater Systems 2011 Annual Summary Report	April 2012	City of Ottawa/ Stantec	http://app06.ottawa.ca/calendar/ottawa/citycouncil/occ/2012/06-27/ec/01-Document%201%20-%20Regulatory%20Compliance%20Report%5b1%5d.pdf

[i] https://documents.ottawa.ca/sites/documents/files/energy_evol_phase1_en.pdf

Appendix B

Technology Review
Summary Table

TECHNOLOGY REVIEW SUMMARY TABLE

CRITERIA		TECHNOLOGY 1 INTERNAL SEWER PIPE HEAT EXCHANGER (INSTALLED WITHIN PIPE)	TECHNOLOGY 2 INTEGRAL SEWER PIPE HEAT EXCHANGER (INTEGRAL TO PIPE)		TECHNOLOGY 3 EXTERNAL HEAT EXCHANGER	
TECHNOLOGY OVERVIEW	**MAJOR SEWAGE HEAT TRANSFER SYSTEM EQUIPMENT**	• Existing sewage collection piping. • Sewage heat exchanger, mounted inside sewage collection piping. • Water/glycol recirculation pump and associated closed loop piping.	TECHNOLOGY 2 INTEGRAL SEWER PIPE HEAT EXCHANGER (INTEGRAL TO PIPE)	• New sewage collection piping with integral sewage heat exchanger (water/glycol coil integral to sewer collection pipe wall). • Water/glycol recirculation pump and associated closed loop piping • Building corridor or below-grade shaft for closed loop piping manifolds and control valves.	• Existing sewage collection pipe • Sewage storage vessel (sump pit) • Mechanical screen (at sump pit) • Sewage recirculation pump (at sump pit) • Heat exchanger (in building)	• Existing sewage collection pipe • Sewage storage vessel (sump pit) • Sewage recirculation pump (at sump pit) • Macerator/grinder (in building) • Filter (in building) • Heat exchanger (in building) • Sludge discharge pump (at sump pit)
	SUPPLIERS AND PRODUCTS	Uhrig Group (Germany) • Therm-liner	Frank PKS NZ Ltd. (Germany) • Thermpipe	Rabtherm (Germany) • Rabtherm Energy System	HUBER Technology Inc: (Huntersville, NC) • ThermWin Heat Exchanger Noventa Energy Partners (Toronto, ON) (local distributer for Huber)	SHARC Energy Systems (Port Coquitlam, BC) • SHARC Series (medium to large scale) • PIRANHA Series (small scale - not reviewed)
	TYPICAL TECHNOLOGY APPLICATIONS	• Commercial buildings • District heating / cooling • Campuses (school, hospital, etc.)	• Commercial buildings • District heating / cooling • Campuses (school, hospital, etc.)		• Commercial buildings • District heating / cooling • Campuses (school, hospital, etc.) • Municipal sewage pumping stations • Municipal wastewater treatment plant	• Commercial buildings • District heating / cooling • Campuses (school, hospital, etc.)
	NOTABLE PROJECT EXAMPLES	• Europe: >80 installations • North America: No known installations • Bretten (Germany): 120kW heat recovery over 120m length pipe	• Europe: Widely used • North America: No known installations • Wimaria Stadium, Weimar (Germany): 22kW heat recovery over 36m length pipe	• Europe: Over 100 installations (Switzerland, Germany, Austia, France) • North America: No known installations • Medical Center, Leverkusen (Germany) 110 kW heat recovery	• Europe: Widely used • North America: under development with multiple Ontario municipalities • Wintower Building (Switzerland): 480kW heating, 840kW cooling • American Geophysical Union (Washington D.C.):480kW heating, 840kW cooling	Sharc • Europe: No known installations • Lake Louise Inn (Lake Louise, BC): 85% energy demand reduction
KEY TECHNOLOGY PARAMETERS	**SEWAGE FLOW REQUIREMENTS**	> 10 L/s for 400mm diameter sewer pipe (minimum flow varies with pipe diameter)	> 15 L/s (minimum flow varies with pipe diameter)	> 12 L/s (minimum flow varies with pipe diameter)	> 34 L/s	
	SEWAGE TEMPERATURE REQUIREMENTS	> 12 deg C (heating applications) < 20 deg C (cooling applications)	> 12 deg C (heating applications) < 20 deg C (cooling applications)		> 12 deg C (heating applications) < 20 deg C (cooling applications)	
	SEWAGE COLLECTION PIPE SIZE	400 mm to 3,250 mm	300mm to 1,800mm	800mm to 1,800mm	None	
	ENERGY RECOVERY / REJECTION POTENTIAL	< 450 kW (varies with pipe length and diameter)	< 540 kW	80 kW to 400 kW	250kW to 40MW	
	MAXIMUM ALLOWABLE DISTANCE FROM RECIEVER TO SEWER PIPE	< 200 m	< 500 m	< 200 m	< 200 m	
	FOOTPRINT / LAND USE REQUIREMENTS OF SEWAGE HEAT TRANSFER SYSTEM	• Building Mechanical Room: < 20 m^2	• Building Mechanical Room: < 20m^2 • Distribution Shaft / Corridor: 0.3 to 2 m diameter, 3 to 6m deep/long.		• Building Mechanical Room: 20 to 60 m^2 • Sewage Sump Pit: 1.5 to 10 m diameter, 4 to 8 m deep	
OPERATIONS AND MAINTENANCE REQUIREMENTS	**GENERAL REQUIREMENTS**	Medium to High: • Annual pressure washing/cleaning of heat exchanger submerged in sewage pipe. • Annual flushing of heat exchanger closed loop piping to remove scaling. • General maintenance of equipment (pumps, valves, controls, etc.).	Low: • Annual flushing of closed loop heat exchanger piping/coil. • General maintenance of mechanical equipment (pumps, valves, controls, etc.).		Medium to High: • General maintenance of mechanical equipment (pumps, screen/filter, heat exchanger, valves, controls, etc). • Periodic cleaning of heat exchanger to remove biofouling (automated process, may require occasional manual cleaning).	
	SOLID WASTE PRODUCTION / DISPOSAL REQUIREMENTS	Not Required.	Not Required.	Not Required.	Medium to High: • Raw sewage screened prior to entering sump pit. • Screened solids discharge to municipal sewer pipe	High: • Raw sewage filtered in mechanical room. • Filtered solids accumulate in Sump Pit. • Submersible pump discharges accumulated solids to municipal sewer pipe.
	OPERATION COMPLEXITY / EASE OF USE	Low to Medium: • Minimal mechanical equipment for sewage heat exchange process relative to other technologies. • Can operate unattended with periodic operator checks and scheduled maintenance. • No sewage pre-treatment required.	Low to Medium: • Minimal mechanical equipment for sewage heat exchange process relative to other technologies. • Can operate unattended with periodic operator checks and scheduled maintenance. • No sewage pre-treatment required.		Medium to High: • High number of mechanical components used for sewage heat exchange process relative to other technologies. • Requires solid waste management. • Sump pit may require odour control system. • Can operate unattended with periodic operator checks and scheduled maintenance.	
	ESTIMATED EQUIPMENT LIFESPAN	• Heat Exchanger Components: 10 to 20 years • Pumps: 10 years • Piping and Valves: 50 years	• Heat Exchanger (Custom Sewage Pipe): 30 to 50 years • Heat Exchanger (In Building): 10 to 20 years • Pumps: 10 years		• Sewage Pump(s): 10 years • Screen: 15 to 20 years • Piping and Valves: 50 years	• Sewage Pump(s): 10 years • Sludge Pump(s): 10 years • Macerator: 15 to 20 years
	REQUIRED ENERGY INPUTS	• Power Supply: Per site conditions • Recirculation Pump: 2.2 to 5.6 kW (3 to 7.5 HP)	• Power Supply: Per site conditions • Recirculation Pump: 2.2 to 5.6 kW (3 to 7.5 HP)		• Power Supply: Per site conditions • Sewage Pump(s): 3.7 kW per unit • Screen Auger: 1.1 to 2.2 kW	• Power Supply: Per site conditions • Sewage Pump(s): 3.7 kW per unit • Sludge Pump(s): 0.7 kW per unit • Macerator(s): 3.7 kW per unit • Filter Auger(s): 0.7 kW per unit

TECHNOLOGY REVIEW SUMMARY TABLE

OPINION OF PROBABLE COST (OPC) [3, 4]	• Small System (80 kW): $370,000, or $4,600/kW • Large system (450 kW): $1,200,000, or $2,600/kW	• Small System (80 kW): $250,000, or $3,100/kW • Large system (450 kW): $1,125,000, or $2,500/kW	• Small System (250 kW): $800,000, or $3,200/kW • Large system (1.5 MW): $2,700,000, or $1,800/kW
INSTALLATION CONSIDERATIONS	• Heat exchanger can be installed within sewer pipe without taking collection system offline. • Increased risk of sewage backup. • May require additional sewer maintenance holes for heat exchanger access.	• Requires replacement of sewage infrastructure piping (high impact on municipal infrastructure during construction).	• Requires two connections to existing sewage collection pipe: one to divert sewage to sump pit; one to return sewage and separated solids. • Well-suited to installation at existing pumping stations or wastewater treatment plants.
HEALTH, SAFETY AND ENVIRONMENTAL IMPACTS	• Remote inspection possible using CCTV. • Confined space entry and exposure to sewage in live piping required for heat exchanger maintenance. • All sewage remains within sewage collection piping.	• Remote inspection of piping possible using CCTV. • Confined space entry and exposure to sewage in live piping is least likely of all technologies since heat exchanger coils are not in direct contact with sewage. • All sewage remains within sewage collection piping.	• Building technicians exposed to sewage during routine maintenance and cleaning of mechanical equipment. • Odour control may be requied, depending on heat transfer systme location. • Regular hydrogen sulfide (H_2S) monitoring required.
SUMMARY OF ADVANTAGES	• High potential heat recovery from direct contact between inside the sewer pipe. • Heat exchanger and associated supply/return piping be installed inside sewer pipe without sewer shut down. • Does not require sewage pumping or pre-treatment. • Limited number of mechanical components (pumps, heat exchangers, valves, piping)	• Heat exchanger closed loop piping does not come in direct contact with sewage. • No increased risk of sewer backup. • Does not require sewage pumping or pre-treatment. • Limited number of mechanical components (pumps, heat exchangers, valves, piping)	• Minimal impacts on existing sewage collection infrastructure (i.e. pipe replacement not required, and minimal connections to existing piping) • Wide range of potential energy recovery/rejection. • Local manufacturers, distributors and engineering support. • Pre-treated sewage allows for lower risk of biofouling compared to Technology 1. • Technology can be integrated with existing pumping stations or wastewater treatment plants. • No size restrictions for sewer collection pipes.
SUMMARY OF DISADVANTAGES	• High risk of potential sewer backup from heat exchanger biofouling and ragging. • Biofouling of heat exchanger reduces heat transfer efficiency and requires manual cleaning (pressure washing). • No known North American distributor or installation support. • Additional heat exchanger required at mechanical room / building for distribution to receivers. • Not applicable for sewer pipes smaller than 400mm diameter.	• Integration with existing infrastructure requires replacement of sewage collection piping. • No known North American distributor or installation support. • Additional heat exchanger required at mechanical room / building for distribution to receivers • Not applicable for sewer pipes smaller than 300 mm diameter or larger than 1,800 mm diameter.	• High number of mechanical components, footprint, and operational complexity relative to other technologies. • Solid waste management system required (mechanical screen or grinder/filter). These components are high cost and maintenance compared to other equipment. • Odour control system may be required for sump pit, depending on application location. • Biofouling of heat exchanger reduces heat transfer efficiency (automated cleaning).

Notes:

1) Estimated life expectancy is based on typical mechanical equipment installations.

2) Low, Medium and High ratings are applied to criteria for qualitative comparision between technologies reviewed.

3) OPC values provided are order of magnitude costs for typical projects based on general information that is publicly available. A more detailed cost estimate is reocmmended when evaluating feasibility for specific projects.

4) Refer to Sections 4.1.5, 4.2.5 and 4.3.5 of Interim Report No. 1 for lists of assumptions and items included in the OPC for Technologies 1, 2 and 3 respectively.

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Appendix C

Uhrigh Therm-Liner Product Information

Description of the Heat Exchanger System

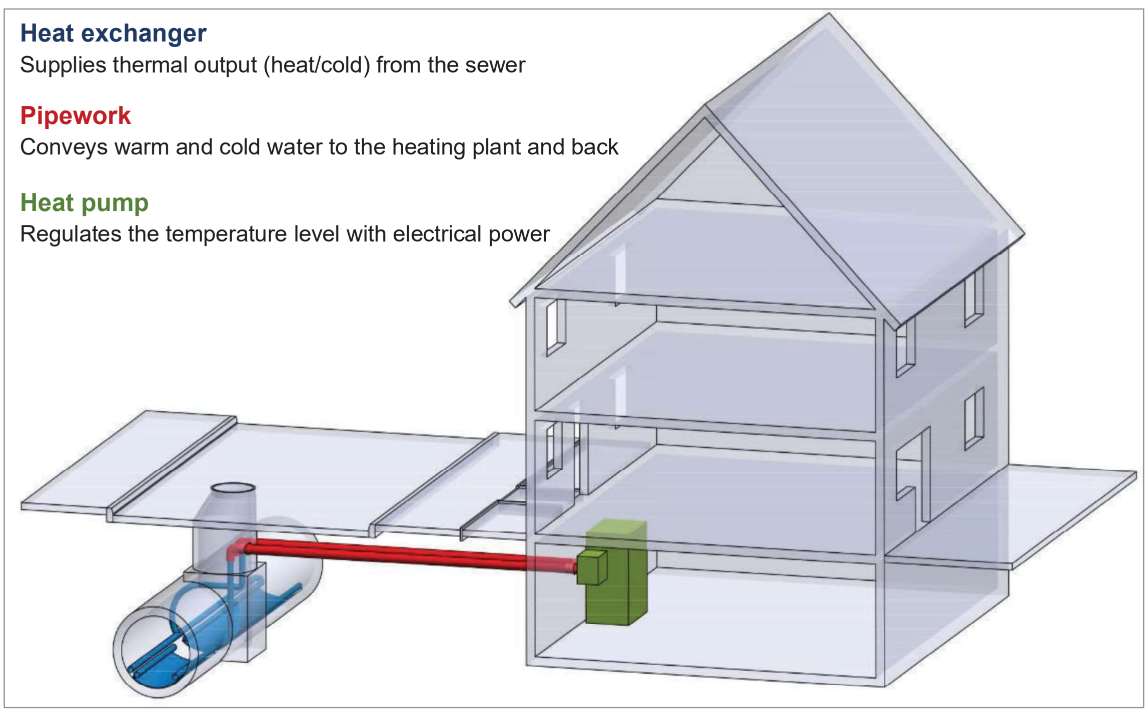
Energy from wastewater with UHRIG Therm-Liner

1. Energy from wastewater – operating principle

There is a massive energy potential in wastewater, which is available in our sewers all the time and in large quantities. Wastewater has an average temperature of 10 to 12°C in winter, and between 17 and 20°C in summer. This temperature represents heat or thermal energy that can be used to heat buildings in winter and cool them in summer. Energy from wastewater is a heat pump technology consisting of three components:

- Heat exchangers: These are mounted in the pipe so that warm wastewater flows across the heat exchanger and transmits thermal energy to the colder water in the heat exchanger.
- House connection: This pipe takes the energy obtained in the sewer to the heating plant.
- Heat pump: This makes the energy from the sewer usable with a low power input.

At good locations, energy from wastewater can incur production costs of around 7 cents pro kWh heating capacity. The heat production costs cover investment and operating costs for the heat exchangers, house connection and heat pump. Good locations are to be found in cities and conurbations, and also in smaller towns and villages that are close to a sufficiently large wastewater collector. Energy from wastewater is competitive with fossil fuels even without any subsidy.



2. Energy from wastewater - project development

If a new building is being constructed or an existing building refurbished, three questions arise as regards obtaining energy from wastewater:

- Is there a public sewer system nearby?
- How much water flows through the sewer?
- What is the temperature of the wastewater?

Using these three pieces of information, it is easy to calculate how much energy can be made available and at what price. Customers can then decide which source of energy they wish to use.

3. UHRIG Therm-Liner – operating principle

The Therm-Liner System is already operating in over 80 locations throughout Europe. Plant sizes vary. Wastewater energy can supply both individual buildings and whole districts. The Therm-Liner System is

- developed for retrofitting in existing and new sewers
- designed in such a way that it does not affect the actual operation of the sewer in any way
- always a custom solution matched precisely to the relevant sewer system
- easy to install, as the modules are positioned using the existing manhole structure
- capable of removal or expansion at any time
- patented and certified

We offer different Therm-Liners tailored to the sewer in question, e.g.:

Therm-Liner Form A

Therm-Liner Form B

4. Production und installation of UHRIG Therm-Liner

The heat exchanger elements are produced by us ready to install. They consist of austenitic stainless steel 1.4404 which, because of its excellent resistance to pitting and corrosion, is ideal for use in wastewater. The heat exchanger surface is pickled and passivated. The structure of the surface ensures turbulence of the wastewater, which reduces biofilm formation on the heat exchanger.

A mechanical coupling system with international approval and certification connects the heat exchanger elements in the sewer. The connection system guarantees secure installation and maximum flexibility. The connecting pipes are adapted to the structure of the sewer and manhole structure. The system meets all the sewer construction requirements of DWA-M 114.

After delivery to the site, installation is carried out by our team. After being brought in, the modules are installed in series and interconnected according to the "Tichelmann principle". A mechanical connection in the sewer and a run-up and run-down ramp fix the Therm-Liner System. The feed and return pipes with shut-off valves are taken upward out of the sewer via the manhole shaft or a cored hole. The system is filled, ventilated and then tested according to DIN EN 805 using the contraction method with 1.5 times operating pressure. The operating pressure for the entire system is generally set at 2.5 bar. Documentation and labelling are according to the SI system.

The Therm-Liner equipment is designed for a working life of up to 50 years. The actual operating duration and safety, however, depend on the subsequent system technology.

5. Contact partner

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Appendix D

PKS Thermpipe Product Information

PKS-THERMPIPE®

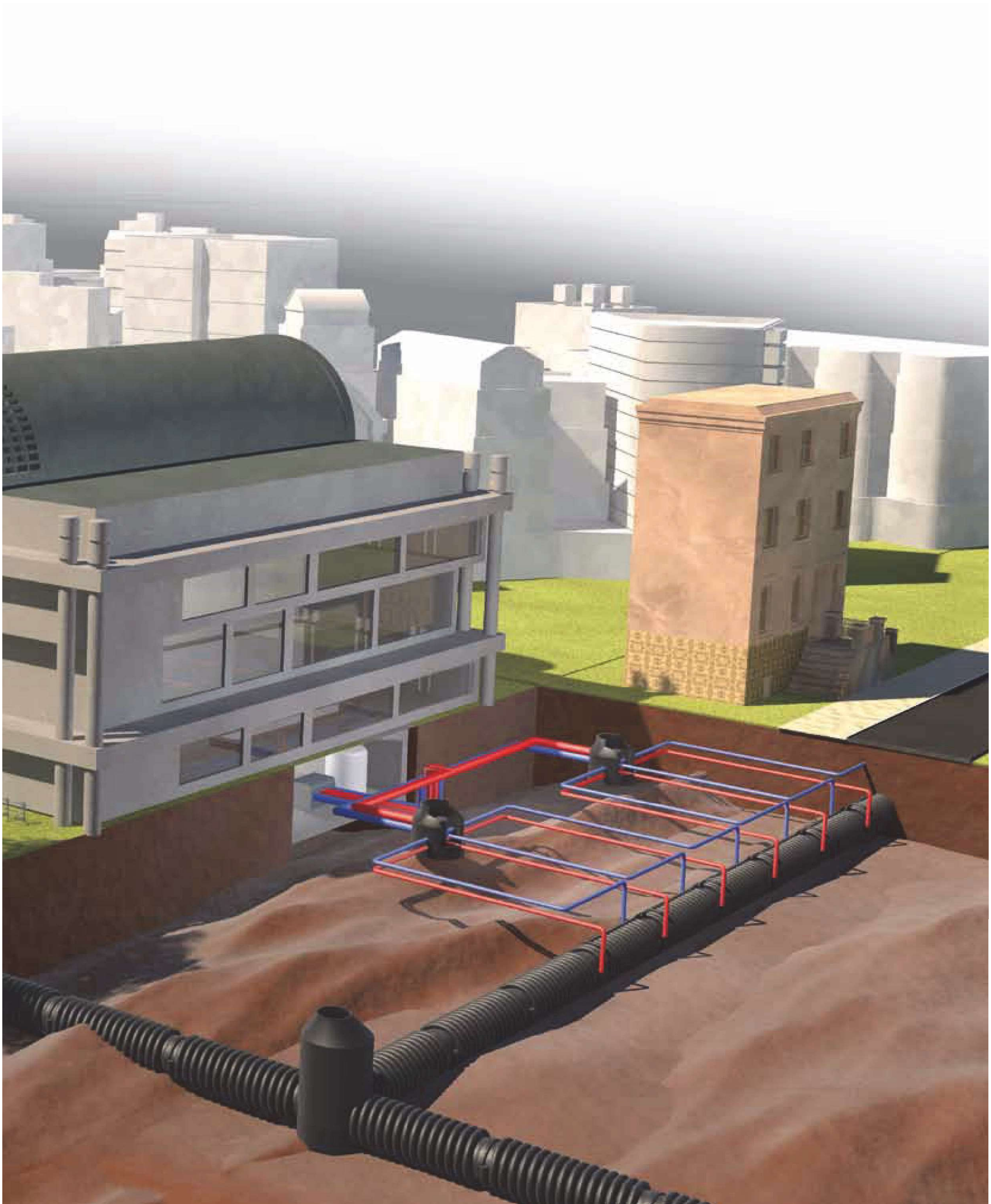
Geothermal and waste water warmth

FRANK
Der Vorsprung.

Energy recovery from the ground and waste water: a practical circuit

With the aim of conserving the environment, it is our task to handle the resources available to us as economically and efficiently as possible. Thanks to modern thermal insulation and the targeted use of energy, it has been possible to reduce heating energy consumption, for example, in Germany's residential sector by an average of 22% since 2002. But there is still an energy leak which has been given little attention to date: waste water. Originally a "waste product" of our society, this resource is disposed of by the cubic metre through the sewage system every day, whereby waste water harbours an enormous energy potential which should be no means be simply "thrown out with the bathwater": residual heat of 15 °C on average which can be used for cooling or heating buildings. The process of recovering waste water heat is quite simple: after all, waste water is always available wherever people live and work.

In addition to the waste water energy, the same system can also be used for the surrounding earth. Geothermal/ Waste water warmth is simply drained off from the sewage pipe and harnessed via a heat pump, for example. The energy can then be utilised directly on site without incurring any high losses associated with transport. Enabling up to 50% of the primary energy to be saved. A highly-efficient process!



Safe and durable

Our PKS sewage pipes made of polyethylene – the basis for energy recovery

PKS sewage pipes made of polyethylene (PE) offer maximum safety and durability. For more than 40 years, PE sewage pipes have proven their worth in the chemicals industry and in the municipal sector. And no wonder: after all, PE avails of the requisite properties which are indispensable for modern waste water systems: good chemical resistance as well as durability. Ideal for extreme loads: PE waste water systems are unbreakable and even capable of withstanding earthquakes. Thanks to the welding features displayed by PE, homogeneous waste water systems are possible from a single package principally dispensing with plug connections and sealing rings entirely. And root intrusions can be safely eliminated.

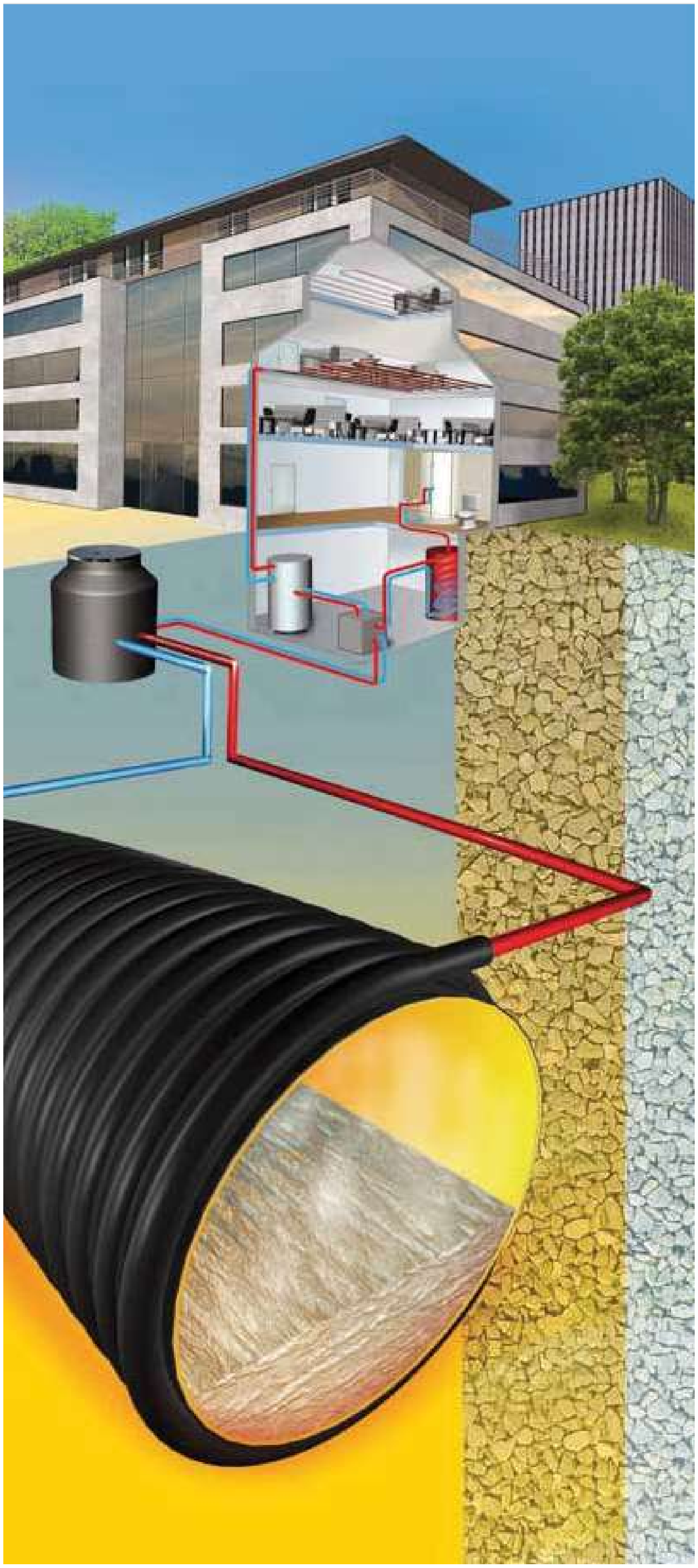
When compared to standard solid-wall pipes, the hollow, lightweight support pipes on the outside of the PKS sewage pipe ensure significant savings in terms of weight while guaranteeing easy handling during installation. PKS sewage pipes: the perfect basis for sustained energy recovery.

PKS sewage pipe in the production process

3-in-1 function

PKS sewage pipe + waste water heat + geo-thermics = PKS-THERMPIPE® system

The PKS sewage pipe forms the basis for the PKS-THERMPIPE® system. The system not only ensures safe waste water transport. As a "horizontal geothermal probe", the PKS-THERMPIPE® system has the additional task of deflecting thermal energy: waste water warmth and geothermal warmth. The advantage of utilising two heat sources at the same time is obvious. Apart from the sewage pipe, the waste water also heats up the surrounding earth which is repeatedly charged by the waste water energy along the same principle as a power pack. Otherwise lost within the earth, this energy is harnessed by the PKS-THERMPIPE® system. The conventional support pipe available on the outer pipe serves as a heat dissipater for both energy sources and through which a heat transfer medium flows. By additionally recovering the energy from the surrounding ground, the PKS-THERMPIPE® system is independent of diurnal lines or irregular waste water lines, thereby ensuring a constant supply of energy.



PKS-THERMPIPE®-System

How it works: geothermal probe with waste water turbocharger

The static and thermal design of the PKS-THERMPIPE® system depends on the project and is oriented towards the structural conditions on site, the available energy potential (waste water, geothermics) and the energy required by the units to be supplied. The system draws the lion's share of energy available from the ground. The number of PKS-THERMPIPE® pipes to be integrated depends on the requisite energy volume and the extraction outputs to be realised by the sub-systems comprising "waste water heat" and "geothermal heat". The PKS-THERMPIPE® pipes welded together are connected to the FRANK-PKS® distribution shaft using standard moulded parts and pipes made of PE-100 materials. The lines are directed from the shaft into the building, e.g. to a heat pump for energy realisation.

Reference values for extraction output by the PKS-THERMPIPE® system

DN	Q [W/m]	DN	Q [W/m]
300	350	1100	1130
400	450	1200	1220
500	550	1300	1320
600	640	1400	1420
700	740	1500	1520
800	840	1600	1610
900	930	1800	1810
1000	1030	-	-

Advantages of PKS-THERMPIPE® pipes

- Constant energy supply
  Use of waste water warmth PLUS continually available geo-thermal warmth
- Easy installation:
  no installations required inside the conduit
- High degree of tightness:
  no weak spots caused by plug connections
- Efficient utilisation:
  low pressure losses thanks to tightly-welded thermal conduction circuit
- Durable material: service life of all pipe components > 50 years
- Variable range of application:
  current range of application from DN 300 to DN 1800
- Consistent deflection of energy: consistent feeding of the heat pump
- No transport losses:
  heat is extracted from the waste water and pipeline zone on site
- Maintenance-friendly:
  low formation of sewer film

Planning with foresight for sustainable savings!

Plan the option of energy recovery when installing new sewage pipes and save up to 50% primary energy.
Have you already opted for a PKS sewage pipe when installing a new sewage system? Then make the most of your advantage now and keep your options open for energy recovery if new extensions are pending. After all, the energy cost benefits of PKS-THERMPIPE® pipes are unbeatable when it comes to new installations! At little extra expense, PKS pipes can be converted in the factory to highly-efficient PKS-THERMPIPE® pipes. Larger buildings in the vicinity or still planned which reveal higher energy requirements can be heated or cooled using energy from waste water or geothermal heat in future. See for yourself: compare the extra financial expense associated with energy recovery with the costs of conventional PKS pipes in the chart provided.

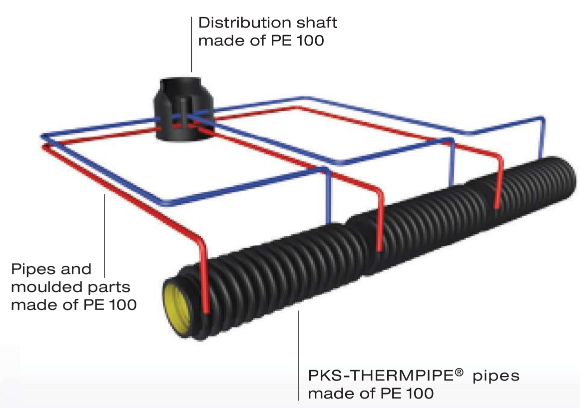
PKS-THERMPIPE® pipes and their energy utilisation costs*

DN [mm]	Costs [€/kW]
300	206
400	163
500	135
600	120
700	110
800	102
900	94
1000	86
1100	81
1200	77
1300	77
1400	74
1500	74
1600	72
1800	70

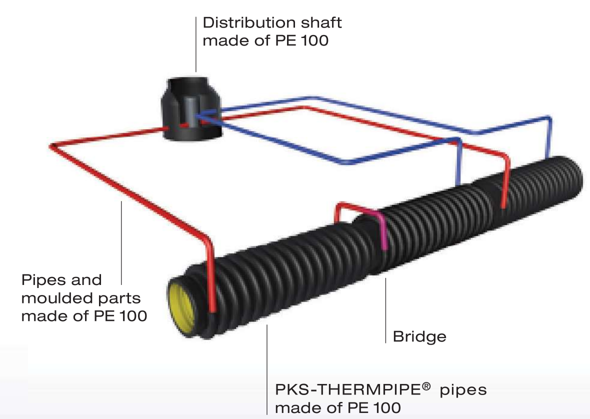
* Cost comparison: Additional costs compared to conventional PKS pipes

Higher energy efficiency thanks to variable installation

The individual 6-metre pipes are connected in parallel with the distribution shaft to achieve higher energy efficiency: low pressure losses are guaranteed; it is possible to connect and disconnect individual circuits.



Combinations of parallel and series switching are possible with small nominal widths: minimisation of installation costs owing to shorter mathematical constant and heat transfer pipelines.



Practical applications

Site report PKS-THERMPIPE®
Wimaria Stadion (Weimar)

Within the framework of a research project, a section (36 m) of an existing concrete duct was fitted with the PKS-THERMPIPE® pipe system in Weimar. The heat output comprises approx. 22 kW. The heat is used in a sports facility (for heating and warming service water). The existing gas heating system was extended to include the heat pump technology.
The pipes are installed at a depth of approx. 4.5 metres and transport the waste water generated by approx. 5,000 inhabitants in Thuringia's fourth-largest city.

The waste water volume is approx. 14 l/s at temperatures of 15 to 20 °C. Apart from the components already outlined which were installed in the ground, additional investments were also made in the area of the heating system. Along with an SWP 270 H high-temperature heat pump (heat output: 26.5 kW) and 2 multifunctional storage tanks (MFS 830 S) each with a capacity of 830 litres for drinking water supplies and a separating buffer storage tank of the same size, various measurement devices were also installed to document the efficiency of the plant.

Scope of supply

- 36 m PKS-THERMPIPE® DN 500 (6 pipes, 1 adapter incl. shaft connecting sleeve and wall collar)
- Electro-fusion coupler d 560 mm
- Type 1 distribution shaft with horizontal distribution trunk
- 300 m PE-100 pipe d 50 mm, SDR 11
- Electro-fusion moulded parts d 50 mm in SDR 11 for heat circuits

Services offered by FRANK

- Planning and design of the sewage pipe section
- Site support including training of installation personnel

External service

- Insulation design and optimisation of the system parameters by the Forschungsinstitut für Tief- und Rohrleitungsbau Weimar e. V. (FITR)

Responsibility and sustainability

How a "waste product" becomes an energy source

Global energy requirements are continually on the rise. Our modern society is no longer conceivable entirely without the free availability of energy - whether in private households, the commercial sector or industry. But the resources available are limited. For this reason, it is our task to utilise regenerative energies sustainably as well as the energy available to us in a more targeted fashion. Energy is often not fully used where it is applied. Resulting in unused residual energy. Or conversion into another form of energy demands energy losses which are too high. Larger buildings in particular such as residential and office complexes, hospitals, homes for the elderly, indoor swimming pools, sports facilities, commercial and industrial buildings could be heated and cooled using a particularly environmentally-friendly application of energy: geothermal heat and waste water energy. Geothermal heat is available everywhere and at all times. Waste water is always available wherever people live and work.

Using our PKS-THERMPIPE® system, we have succeeded in utilising energy where is is available: on site. Without any transport losses. And by dual utilisation of waste water AND geothermal heat, you are guaranteed constant and clean energy supplies.

At FRANK GmbH, we are delighted to be able to contribute towards conserving our environment in the form of our PKS-THERMPIPE® system.

... for official authorities

... for shopping centres

... for schools

... for swimming pools

... for hospitals

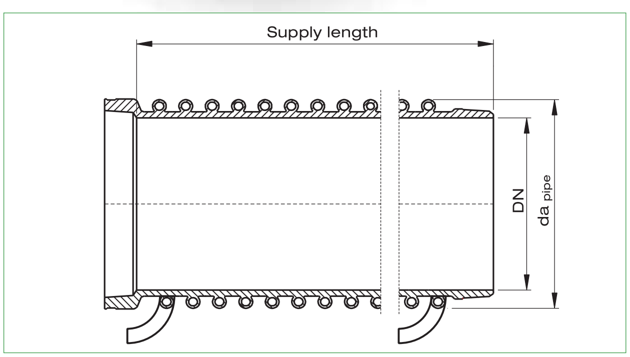
... for hotels ...

Prerequisites for utilising waste water warmth

1. Dense residential buildings or industry with a correspondingly high supply of waste water (dry weather flow ≥ 15 l/s).
2. Consumers with correspondingly high heat requirements (≥ 50 - 200 kW). These can include schools, kindergartens, official authorities and shopping centres, hospitals, hotels, swimming pools, larger residential complexes etc.
3. Relatively short distances (approx. 100 m, max. 500 m) between the heating system and the sewage conduit.
4. The system temperatures for heat utilisation (return pipe) are max. 50 °C (the lower the better).

Range of supply

	$SR_{24} \geq 4$ kN/m²		$SR_{24} \geq 8$ kN/m²		$SR_{24} \geq 16$ kN/m²		$SR_{24} \geq 31.5$kN/m²	
DN mm]	da_{pipe} [mm]	Weight [kg/6 m]	da_{pipe} [mm]	Weight [kg/6 m]	da_{pipe} [mm]	Weight [kg/6 m]	da_{pipe} [mm]	Weight [kg/6 m]
300	426	103	426	103	426	103	426	103
400	526	133	526	133	526	133	526	133
500	626	163	626	163	626	163	626	163
600	726	193	726	193	726	193	726	193
700	826	222	826	222	826	222	826	222
800	926	252	926	252	926	252	926	252
900	1026	282	1026	282	1026	282	1026	282
1000	1126	312	1126	312	1126	312	1132	399
1100	1226	342	1226	342	1226	342		
1200	1326	372	1326	372	1332	475		
1300	1426	402	1426	402	1432	513		
1400	1526	432	1526	432				
1500	1626	461	1626	461				
1600	1726	491	1732	628				
1800	1926	562						



PKS-THERMPIPE® pipes

Within the framework of static calculation to ATV-DVWK A 127, pipe rigidity (SR_{24}) is calculated in accordance with DIN 16961. The PKS-THERMPIPE pipe manufacturing process also enables the manufacture of other SR classes than those indicated here.

Project-related design and/or co-ordinated manufacturing guarantees the user a pipe system with economical dimensions and optimum rigidity.

- Standard length 6 m
- Special lengths on request
- Made of PE 100
- Form A:
  yellow interior with electro-fusion socket and spigot
  (DN 300 to DN 2400)
- Form B:
  yellow interior with extrusion-welding socket and spigot
  (DN 300 to DN 3500)

Prerequisites for PKS-THERMPIPE® pipes

1. Refurbishment / New installation
2. Collectors with no/few building connections (introductions poss. via shafts)
3. Waste water volume (15 l/s)
4. Bivalent heating system at consumer's

PKS-THERMPIPE® distribution shafts

The connection lines for the individual THERMPIPE brine circuit sections are combined at one or more central points in distribution shafts.
Fully prefabricated in the factory, the distribution shafts facilitate system connection and commissioning. All of the requisite shut-off and regulating valves are already pre-mounted. This facilitates flushing and ventilating as well as hydraulic adjustment of the system. High-quality balancing valves allow exact hydraulic adjustment at various lengths of the connection lines as well as ensuring optimum thermal utilisation of each pipe section.

The distribution shaft dimensions depend on the respective project. At increased static requirements - from pressing groundwater through to use by trucks - suitability is documented by verifiable statics.
The adaptable designs of the distributions therefore mean that a suitable solution can be found for any plant size.

- Shaft shell and base made of PE
- Shaft dimensions from DN 300 mm to 2000 mm
- Overall length or height from 3 to 6 m
- Passable/Navigable variants can be supplied.

Connecting line at distribution shaft in horizontal design

Distribution components in the distribution shaft

FRANK
Der Vorsprung.

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Appendix E

Rabtherm Energy System
Product Information

Heat recovery from raw sewage - An alternative for thermal energy supply in cities

Urs Studer

Rabtherm AG, Switzerland

Corresponding email: info@rabtherm.com

THE IDEA

- It is high time that we start recovering and re-using waste heat from industry and households. On a comprehensive view, waste heat could cover at least 30 % of our heating and cooling energy requirements. Today heat is being recovered from exhaust air and used on a very large scale. In many countries this is even governed by regulations. But what happens to waste water? Out of sight, out of mind.
- This was the starting point of the idea to utilize these resources, an idea resulting in the Rabtherm® Energy System. RABTHERM stands for heat recovery and utilization from untreated waste water. On leaving a house, the sewage has an average temperature of over 25°C and in the sewage system an annual mean of 15°C (summer 20°C, winter 10-12°C). Sewage is a continuously renewed source on a relatively high temperature level. With modern heat pumps one can transform this to a useful temperature of 65°C, high enough for hot water production and for the heating of newly constructed houses → heat pump COP's between 3.1 and 5.2, in special cases up to 6.2.
- The heat present in the waste water from residential buildings, trade and industry should therefore be utilized decentrally, i.e. locally, where it is generated, with a heat exchanger in the sewers and a heat pump. The temperature level is higher than that of most of the other natural renewable energy sources. The system can be used for heating and hot water in winter, and for cooling (air conditioning) and hot water in summer.
- The idea is not new but so far heat has been extracted practically only from purified waste water downstream of sewage works. However, since many sewage works lie at the periphery or outside residential areas, with large distances to the heat consumers, this strategy is uneconomic.
- Previous obstacles to the utilization of untreated water directly in the sewage system have been:
  - possible detriment to the biological purification stage in the sewage works, which are designed for a temperature of 8-13°C.
  - lack of a suitable heat exchangers which when installed in the drain channel, cannot lead to blockages.
  - → Today, these problems have been technically and economically solved, and the system is accepted by the authorities, i.e. Rabtherm®can now be marketed. The maximum cooling of the entire waste water on the way to the sewage works will in no case exceed 0.5 K.
- Contamination of the sewage channel and therefore the heat exchanger leads to a decrease in heat exchanger efficiency of up to 40%. (soiling with biomass film) Patented systems to solve this problem.

THE DEVELOPMENT

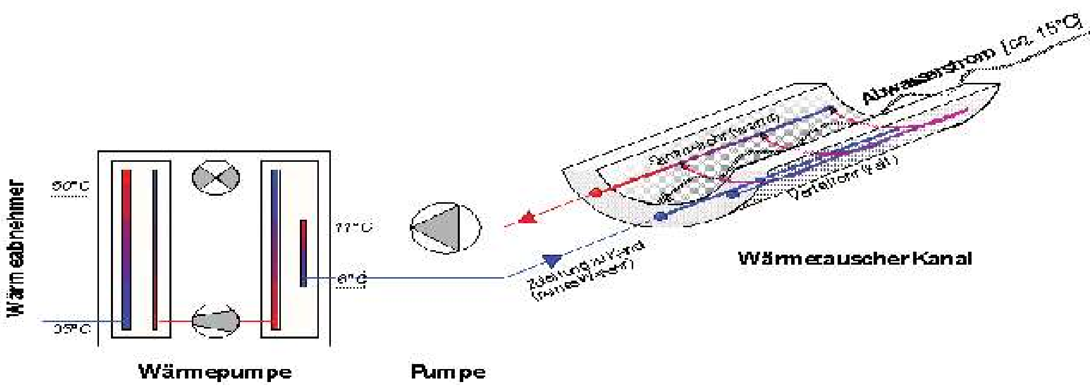
- The idea now had to be developed and brought to market in an economic manner.
- For this purpose, a trend analysis was required, e.g.
  - what is demanded by the energy market?
    → economical and/or ecological products
  - how are other technologies developing?
  - how fast is the political situation changing? (climatic changes, CO_2, fine dust)

  The trends were quite clear .
  - Electricity prices will drop .
  - Oil and gas prices have a tendency to rise .
  - Energy price surcharges or eco-taxes cannot be avoided sooner or later
- The expected result of the development process was that the local, decentralized utilization of the continuously available, renewable ambient energy by means of Rabtherm systems is
  - economic and
  - ecological / environmentally friendly.
- The goal was to develop a simple, robust and low-cost system. This required special efforts in the following areas:
  - Hydraulics, heat transfer
  - Materials
  - Joining technique
  - Design, installation

  The above objective has been achieved and led to patents. The know-how gained during this process represents a decisive lead over any competition.

THE PRODUCT (TECHNOLOGY)

- Working principle of the Rabtherm waste heat utilization system



Wärmeabnehmer .... user
Wärmepumpe .... heat pump
Pumpe .... circulation pump
Wärmetauscher Kanal .... heat exchanger sewage channel
Zuleitung zu Kanal (reines Wasser) .... connecting pipes (tap water)
Verteilrohr (kalt) .... distribution pipe (cold)
Sammelrohr (warm) .... collection pipe (hot)
Abwasserstrom [ca. 15°C] .... sewage

In the heat exchanger heat is extracted from the waste water and fed to the heat pump via the intermediate medium. The latter (pure water), circulating between heat pump (heat generation) and heat exchanger (heat utilization, heat extraction), is fed through the plastic pipe to the heat exchanger at the start of the cycle. The distributor pipe individually feeds each of the 1 to 3 m long heat exchangers. The intermediate medium warmed in the heat exchangers is then collected in the collector pipe and returned to the heat pump.

For summer cooling, the heat pump is hydraulically reversed, using the waste water as heat dump.

preassembled Rabtherm® - heat exchanger elements

- The specific extraction power of the heat exchanger is approx. 2-9 kW per metre heat exchanger (depending on the sewage flow rate, the flow speed or gradient and the degree of contamination). This rate can increase to 15 kW with pressure pipes. From 1 m3 of waste water (the contents of 5 bathtubs), the heat exchanger can extract 2-3 kWh of energy.
- Criteria for the application of Rabtherm systems.
  - sewage channel diameter > 400 to 500 mm
  - sewage flow average rate > 12 l/s
  - length of heat exchangers 9 m (min.) to 200 m (max.)
  - heating or cooling power output min. 80 kW
  - distance from sewage channel to user max. 150-300 m
  - heating temperature max. 70°C
- The heat exchanger is cemented into the sewage channel and is designed for a service life of at least 50 years.
  Corrosion, erosion / wear, leak tightness, channel maintenance and cleaning are some of the factors that because of the strict quality assurance criteria, had a decisive influence on choice of material, design, product (welding) and assembly / installation. Parallel to quality assurance, all possible damage repair scenarios have been established following the principles of "analysis-find-repair".
- The maintenance of the sewage channels with the integral heat exchanger requires no special effort. Blockage of the channels is impossible and they are cleaned with conventional equipment. The heat exchanger is dimensioned to withstand this treatment

Rabtherm Wülflingen (CH).

Trockenwetterrinnen Rabtherm Leverkusen (D) Dry weather channels.

THE MARKET

- After it had been recognized and proved that the system
  - makes good sense energetically, inasmuch as it has already been included in many urban energy plans
  - is economically feasible, in contrast to many other forms of alternative energy
  - brings ecological benefits with comparable or lower energy production costs than with energy from fossil fuels the question of markets and customers was considered.
- Who is interested in Rabtherm?
  - The heat consumer (user)
    . Rabtherm replaces the conventional heat energy supply with gas or oil by an environmental superior technology utilizing the waste heat from households that generates heat at economically comparable prices
    . The customer gets the same benefits (heat) at a comparable or better price, but in an ecological manner.
  - Who are the consumers?
    . Towns and cities with roughly 5'000 inhabitants upwards.
    . Communal co-operatives and consortia
    . Industrial enterprises with a significant fraction of consumption for space heating
    . Private building owners
    . The public sector
      . Rabtherm helps the public sector to
      . improve ecobalances
      . achieve energy policy goals
      . guarantee security of energy supply.
      → To supply 100 apartments with heat from waste water, the effluent from 300 apartments plus trade and infrastructure is required. To generate one kWh of heat, about 420 litres of waste water are needed.
      . Employment.
      . Rabtherm can generate around 30'000 man-years of work (up to 3'000 jobs).
- Who are our partners in the market?
  - Consulting engineers for the acquisition, study and planning of installations

- Contractors for the installation, maintenance and operation of installations. Contractors are e.g.
  - . Electricity utilities .
  - . Municipal works .
  - . Industrial enterprises

Contractors finance the construction of the installations and sell the energy generated. Electricity utilities and municipal works are highly interested in this lucrative second or additional source of income.

- What does Rabtherm cost?
  - Installations
    - . CHF 1'800.00 - 2'500.00 per connected residential unit (€ 1170-1620)
    - . CHF 500.00 -700.00 per kW of connected useful power (€ 325-455)
  - Heat exchangers
    - . CHF 1'600.00 - 2'100.00 per m of heat exchanger (€1070-1360) .
    - . The heat exchanger as an element, uninstalled, costs approx. 6-10% of the overall installation.
  - A sensitivity analysis predicts with high probability an improvement of profitability by over
  - 20%, influenced by
    - . the price of electricity
    - . the price of oil
    - . investment costs
    - . technological improvements (heat pump)

- How and where will Rabtherm® be employed?
  - The Rabtherm technology should be examined in the case of
    - . renovation of large sewage channels .
    - . renovation of large central heating or cooling works .
    - . new sewage channels .
    - . larger central heating or/and cooling works in the vicinity of larger sewage channels
- Market potential
  - Towns and cities
  - over 500’000 inhabitants 60 to 120
  - 200-500'000 inhabitants 27-60, equal to approx. 12'000 apartments
  - 100-200'000 inhabitants 20-27
  - 40-100'000 inhabitants 12-20
  - 15-40'000 inhabitants 5-12
  - 5-15'000 inhabitants 1- 5
    - . Switzerland 2500
    - . Germany 25000
    - . Europe 120000
    - . world 400000
- Existing and running installations 17 in Switzerland, Germany, Austria
- Installations in building or planning stadium over 100 in Switzerland, Germany, Austria, France, Ukraine, USA

ECOLOGY

- Rabtherm installations reduce the CO2 emissions over those from conventional plant by 50-80% (ecological benefit)Rabtherm installations reduce also the amount of primary / conventional energy.
- CO_2-output with the 17 running plants is reduced by 6000 tons.
- Rabtherm systems produce no fine dust like diesel engines and wood burning plants.

WHAT IS THE PRACTICAL SEQUENCE OF EVENTS IN THE PLANNING OF A HEAT UTILIZATION SYSTEM FROM UNTREATED SEWAGE?

- By means of a check list, a site can be roughly assessed for acceptance or rejection.
- Next the following procedure is scheduled .
  - Fundamental decision by the
    . sewage channel operator
    . sewage works operator
    . community
  - Analysis, site or feasibility study with data on the drainage system and heating furnaces. The studies contain the results of the local examination of sewage channel data (incl. condition) and furnace data, calculations of heating power and profitability, and cost estimates for the investments.
  - Clarification with the users or those to be connected .
  - Project with consulting engineers and contractor .
  - Execution and operation by contractors under long-term heat supply contracts.

Even with generally sinking heat demand, the Rabtherm technology, used in the district heating networks of city agglomerations, has an excellent chance of success, also in towns with an existing remote heating network.

ASSESSMENT / CONCLUSIONS

- The success of waste heat utilization from the public sewer system is based upon the following corner-stones

1. Profitability
2. Financing
3. Public interest
4. Ecology

- Profitability .
  - The heat production costs with a Rabtherm system are 5-20% lower than for conventionally generated heat.
  - The profitability increases when the installations are used in summer for cooling
  - Financing . by contracting
  - Public interest

- Compliance with goals of energy and environmental policies
- Creation of jobs
- Rabtherm Systems have an excellent outlook Future R&D can bring another 30% of improvement in quality, price and economy

RABTHERM PARTNERS

- engineers
- manufactoring companies
- concrete works
- contractors

have access to all the data, software and the latest research results.

GO WITH RABTHERM IN THE FUTURE
GOLD FLOWS CONSISTENTLY AND EVERYWHERE UNDER OUR FEET

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Appendix F

Huber Therm-Win Product Information

Heat Recovery from Wastewater
HUBER ThermWin

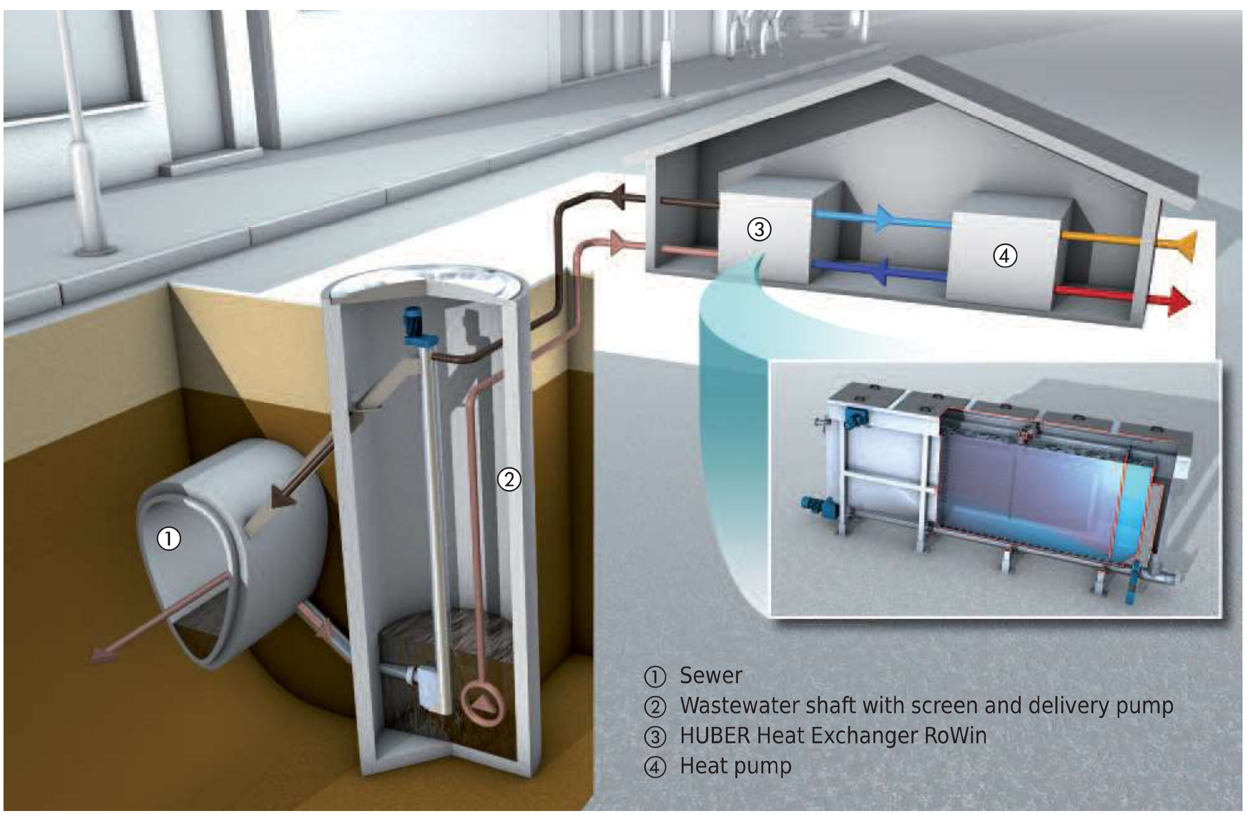
Recovery of thermal energy
from municipal and industrial wastewater

The streets are not paved with gold but …

… 'gold' is flowing under them. Hardly anybody seems to know about the fact that right below the ground, in sewers, there is a hidden and seldom used source of energy: domestic, municipal wastewater with a temperature of 12 °C to 20 °C. Even during winter the wastewater temperature hardly ever drops below 10 °C. This makes wastewater an excellent energy source for the operation of a heat pump. A heat exchanger is required to extract the heat energy contained within the wastewater. The heat exchanger transfers the thermal energy from the wastewater to the heat pump.

HUBER ThermWin system

The HUBER ThermWin system uses a heat exchanger installed above ground to extract the energy contained within wastewater. Via an intake structure a portion of the sewage flows from the sewer into a screen that retains coarse solids. The pre-screened wastewater is lifted and flows by gravity through the above ground installed heat exchanger. This creates continuously stable hydraulic conditions and ensures a controlled heat transfer within the heat exchanger where secondary circuit heating takes place. The secondary circuit is coupled with a heat pump. The cooled wastewater flows back to the sewer taking along the screenings.



HUBER Thermwin system for the recovery of thermal energy from wastewater

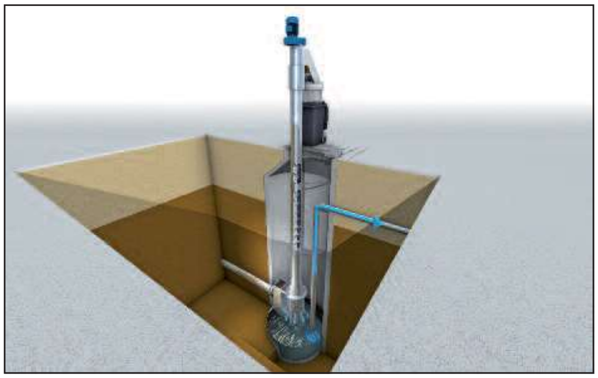
System components

1. Sewer

The HUBER Thermwin is independent of sewer shape and size. Even small flow rates are handled without problems due to the gravity system and intake near the sewer bottom.

2. Shaft with screen

The shaft is located directly at the sewer and has two functions. It serves as a sump for the pump feeding the heat exchanger and houses the HUBER Pumping Stations Screen RoK 4. This type of HUBER screen is well-proven worldwide and ensures pre-screening of the wastewater to protect the heat exchanger against coarse material. A vertical screw conveyor with brushes transports the separated solids upwards and at its top discharges them to the sewer.



3. Heat exchanger

The HUBER Heat Exchanger RoWin has been developed especially for wastewater applications. The tank is completely made of stainless steel and odour-tight and therefore can be installed even in residential areas. Automatic heat exchanger surface cleaning and a sediments removal screw guarantee continuous system operation with low maintenance requirements. Due to its modular design, the HUBER Heat Exchanger RoWin can be tailored to suit project-specific requirements.

4. Heat pump

A lot of households in Germany already have heat pumps that use regenerative energy sources, such as air or ground water. Generally the temperature of municipal sewage is relatively constant in the range of 10 °C to 20 °C throughout the year and therefore ideal to heat and cool buildings. Up to 5 kW eco-friendly energy can be generated by investing 1 kW electric energy.

Planning criteria

1. Wastewater supply

A continuous wastewater flow of approx. 5 l/sec is required to ensure efficient heat recovery.

2. Energy yield

The minimum output of useful heat from wastewater is approx. 40 kW. The wastewater temperature should not fall below 10 °C.

3. System requirements

The efficiency of heat pumps increases with decreasing temperatures of energy usage. Especially beneficial are new buildings with low temperature heating systems.

4. Locality

The connection from the heat station to the sewer system and building should be as short as possible to minimise investment and operating costs.

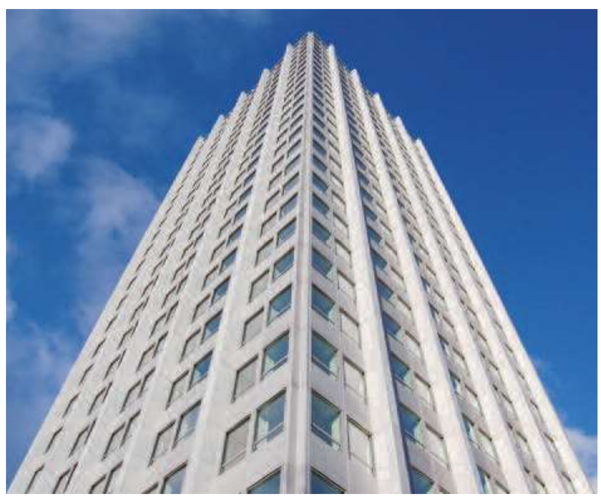
Applications

- Recovery of heat energy and/or hot water
- Heating and cooling
- For installation in nursing homes, hospitals, schools, sports halls, etc.
- Feeding recovered heat into local heat distribution networks
- Usage of an energy source available within city and town areas

Benefits

- Quick and easy installation
- Fast imlementation and utilisation, compact heat exchanger, easy maintenance, eco-friendly
- Climate-friendly due to CO_2 reduction
- Independence of gas or oil
- Independence of sewer geometry
- Cost-effectiveness

Heat station Straubing



Climatisation of the Winterthur Wintower building with the HUBER ThermWin® system

HUBER SE

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Phone: + 49 - 84 62 - 201 - 0 · Fax: + 49 - 84 62 - 201 - 810
info@huber.de · Internet: www.huber.de

Subject to technical modification
0,0 / 2 – 6.2011 – 9.2010

HUBER ThermWin

Appendix G

Sharc System Product Information

International Wastewater Systems

INFORMATION**BROCHURE**

President & CEO, Lynn Mueller

Index

"I never thought I would witness the effects of climate change on our planet during my lifetime, regrettably this is not the case. I've committed over twenty-five years in the sustainable energy business to make a change for the better.

International Wastewater Systems was founded in 2011 to help reshape the renewable energy landscape by focusing on a unique opportunity, wastewater heat recovery. Working with a team of conscientious and like minded individuals we are determined to make a real difference by decreasing greenhouse gas emissions and offering the best possible, cost effective, energy solutions for our clients."

The Ultimate Renewable Energy Source

International Wastewater Systems is a team of technical and engineering professionals with over 100 years of experience in the heating, ventilating and geo-exchange industries. We are committed to our environment and are committed to manufacturing quality products that positively impact our environment, saving resources and unnecessary expense for heating and cooling.

Using our innovative proprietary product, The Sewage SHARC, we can heat domestic hot water as well as heat & cool medium to large multi unit residential developments and commercial buildings. The SHARC can handle a wide spectrum of applications including condominiums, hospitals and office buildings with our scope extending to energy districts and supplemental use on large geothermal installations.

SHARC systems are 100% designed and manufactured in North America. They are custom tailored to your building specifications and work with new and retrofit applications. Each system includes detailed trending software to monitor all aspects of the system and its performance while ensuring optimal efficiency.

The thermo-mechanical methods used in our system are efficient, cost effective, scalable and reliable. Additionally, the system is an excellent solution for achieving green building points to meet sustainable design targets. We provide engineering assistance, feasibility studies, cost estimates as well as efficiency calculations proving our cost effectiveness. We also offer third party energy analysis studies to evaluate the capability of incorporating sewage heat recovery into your project.

Sewage SHARC

100% North American designed and manufactured

Scalable capacity flow: 4 inch (200 GPM) to 8 inch (1000 GPM) and multiples of those sizes to fit your requirements

Clog proof design

High quality material for long life cycle and reliable operation

Powder coated finish with stainless steel cover panels


Designed with reverse flow back flushing
Factory prewired DDC control system
Proprietary software and touch screen control
Custom tailored to building specifications
Shipped on heavy duty modular skids
Email alert system for warnings and alarms
Corrosion resistant coating and non-slip grating
Remote monitoring and data trending
Sewage SHARC

The SHARC can be integrated into a variety of different applications

Multi-Unit Residential
SAIL - Vancouver, BC

SAIL is a 172 unit condominium completed in Oct 2013.

SAIL achieved Residential Environmental Assessment Program (REAP) platinum build standards. Sewage heat recovery is used to pre-heat domestic hot water all year round. The SHARC system uses the sewage from the building itself before it leaves the property.

SHARC model	440
Sewage source	The building
Sewage quantity	25 GPM
SHARC HP* capacity	220,000 BTU/hr
Wet well capacity	3900 gallons

*SHARC HP - Model includes heat pump

Multi-Unit Residential
Seven35 - North Vancouver, BC

Seven35 is a 60 unit urban townhouse development completed in May 2012.

Seven35 received both LEED® Platinum and Built Green Gold certification, with the SHARC heat recovery system being the key sustainable feature. The SHARC system is used to heat domestic hot water.

SHARC model	440
Sewage source	The building
Sewage quantity	11 GPM
SHARC HP capacity	120,000 BTU/hr
Wet well capacity	2000 gallons

The SHARC can be integrated into a variety of different applications

Multi-Unit Residential
Canyon Springs -
North Vancouver, BC

Set in the heart of Lynn Valley Village on the North Shore of Vancouver, BC. Canyon Springs is a 108 unit residential building completed in fall 2014. Sewage heat recovery is used to heat domestic hot water all year round.

SHARC model	440
Sewage source	The building
Sewage quantity	15 GPM
SHARC HP capacity	120,000 BTU/hr
Wet well capacity	2570 gallons

Wastewater Treatment Plant
Sechelt, BC

Completed in August 2014 this SHARC system is used for building space heating and cooling as well as domestic hot water pre-heating.

The system consists of a primary loop that delivers heat to a few secondary circuits. Sewage is used as a heat source to boost the primary loop temperature. The SHARC contributed to LEED® Gold standards.

SHARC model	660
Sewage source	Wastewater tank
Sewage pumped through SHARC	350 GPM
SHARC HX* capacity	1,500,000 BTU/hr
Wet well capacity	Pre existing collection tank

*SHARC HX - Model includes heat exchanger only

The SHARC can be integrated into a variety of different applications

Multi-Unit Residential
Empire - Vancouver, BC

The Empire development comprises three buildings and a total of 160 units. Completion spring 2015.

The SHARC heat recovery system is the first stage heating source for building heating and domestic hot water preparation.

SHARC model	440
Sewage source	The building
Sewage quantity	20 GPM
SHARC HP capacity	300,000 BTU/hr
Wet well capacity	3500 gallons

Public Facilities
Gateway Theatre - Richmond, BC

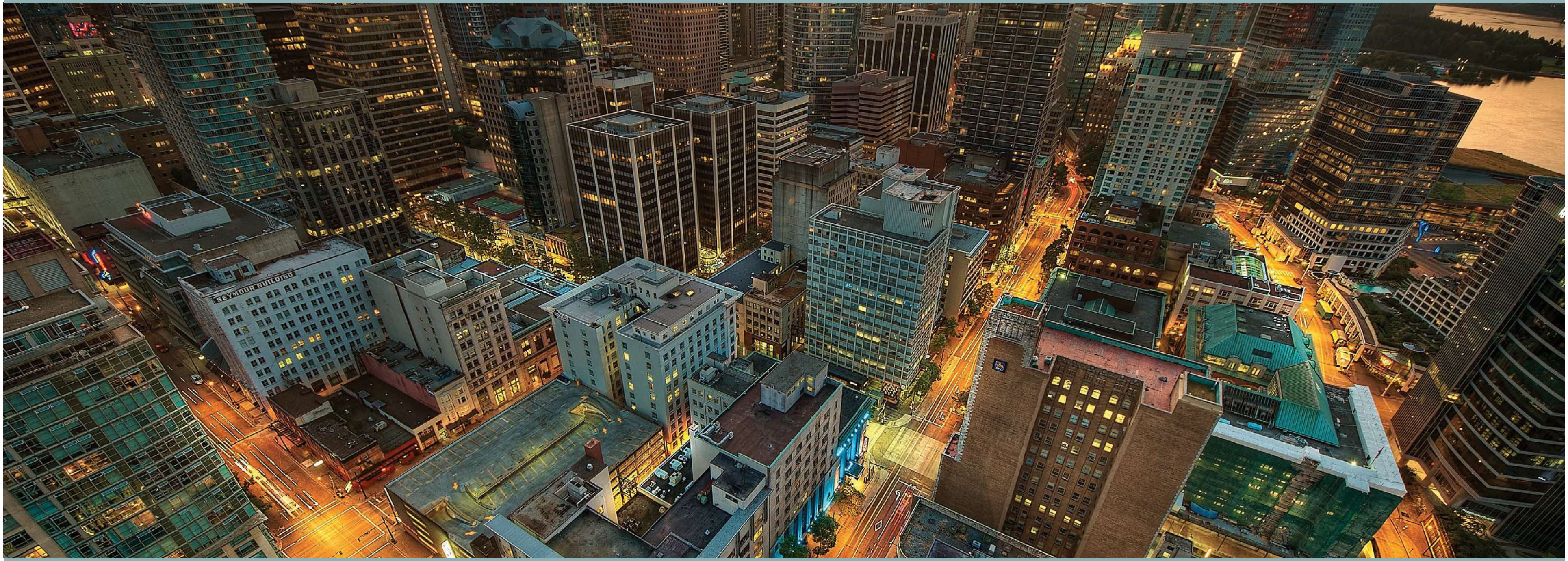
50,000 sqft municipal building. Retrofit completed April 2013. The Gateway theatre was built over an existing sewage lift station, which made the application of the SHARC sewage heat recovery system unique.

The HVAC system in the facility comprises water to air heat pumps connected in a water loop. The temperature of the water loop is kept within the working range by a boiler and a cooling tower.

SHARC model	660
Sewage source	City main, lift station
Sewage pumped through SHARC	200 GPM
SHARC HX capacity	750,000 BTU/hr
Wet well capacity	Pre existing

SHARC System Benefits:

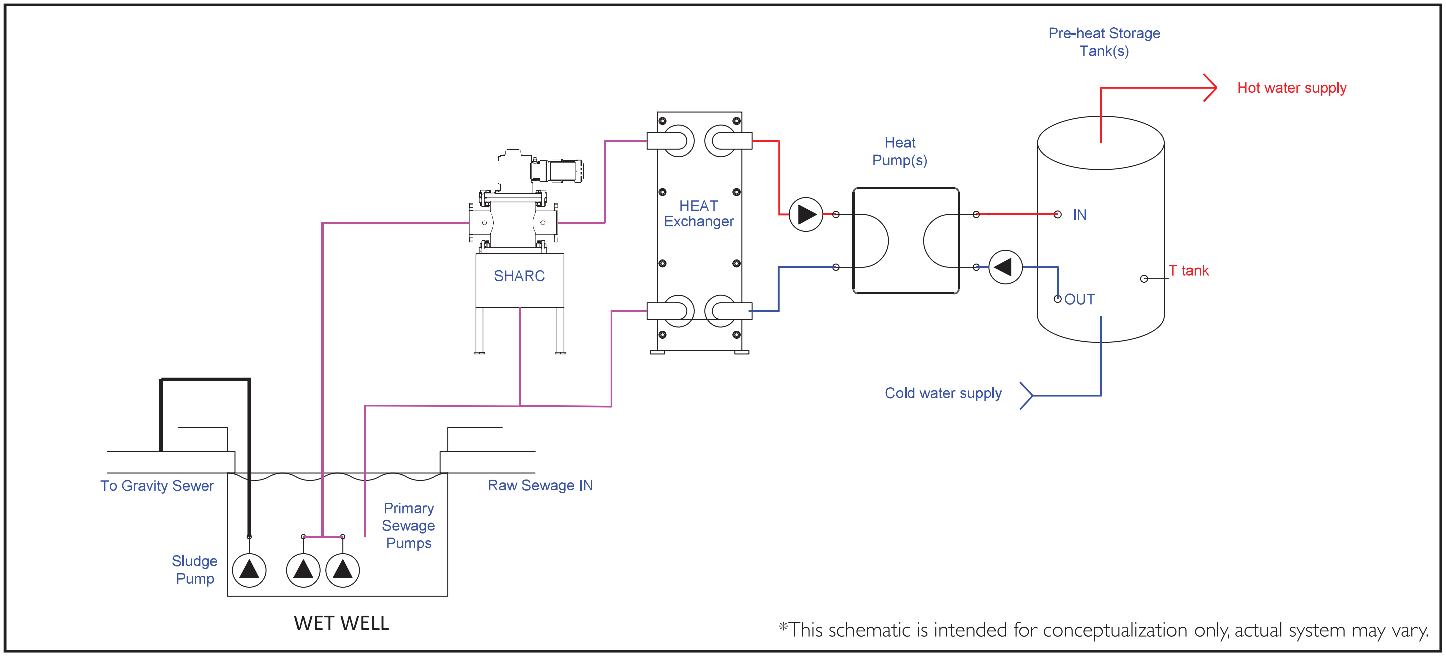
- √ Reduced CO_2 and GHG emissions
- √ Can be applied to new or existing infrastructure
- √ No need for unsightly rooftop equipment
- √ Easy to install
- √ Qualify for additional LEED® points
- √ Infinite energy supply
- √ Energy savings and primary energy cost reduction (30-85%)
- √ Trouble free operation and maintenance
- √ Long life-cycle
- √ Reliable technology



SHARC System Applications:

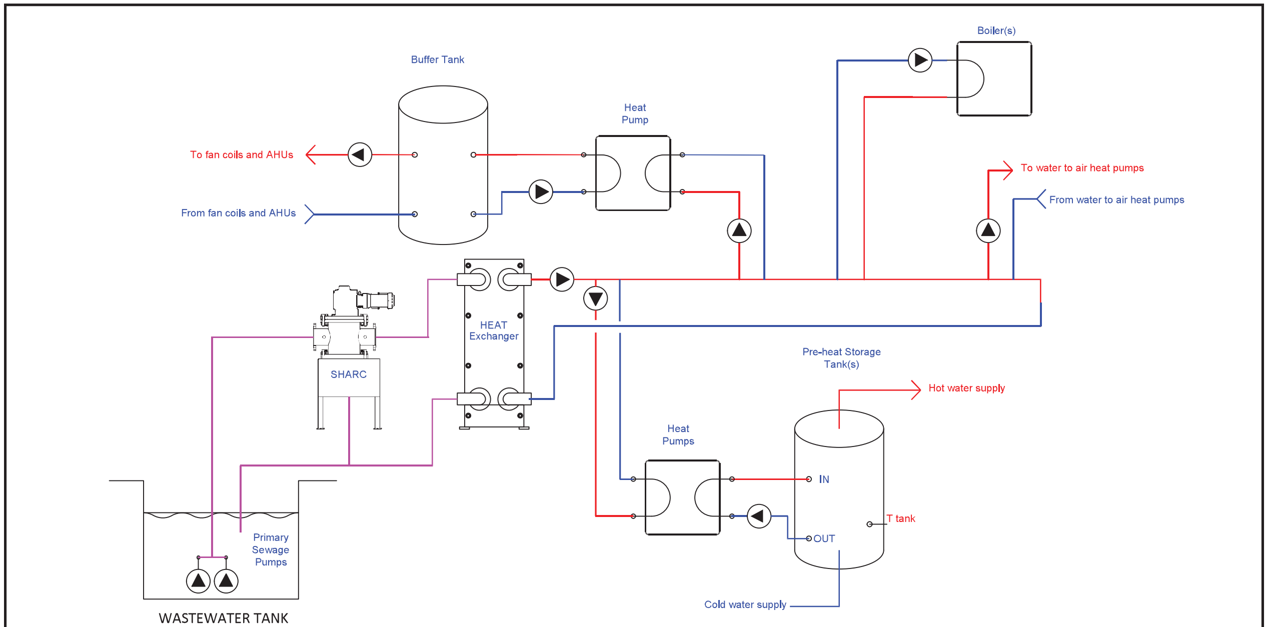
√ Apartments & Condominiums
√ Sports Facilities & Swimming pools
√ Educational Facilities
√ Hospitals & Long Term Care
√ Correctional Institutions
√ Industrial Wastewater
√ Wastewater Treatment Facilities
√ District Energy Systems

Domestic Hot Water Preparation



The sewage SHARC unit processes incoming raw sewage delivered by the primary sewage pump from a collection tank (wet well) piped to the SHARC system. The processed sewage is pumped through a heat exchanger where heat is extracted from the sewage water to process fluid in a heat pump loop. A heat pump in turn processes this fluid to heat domestic hot water in storage tanks. Processed sewage and separated solids rejoin with each other and can be sent back to the collection tank or out to the gravity sewer.

Domestic Hot Water Preheating, Space Heating and Cooling

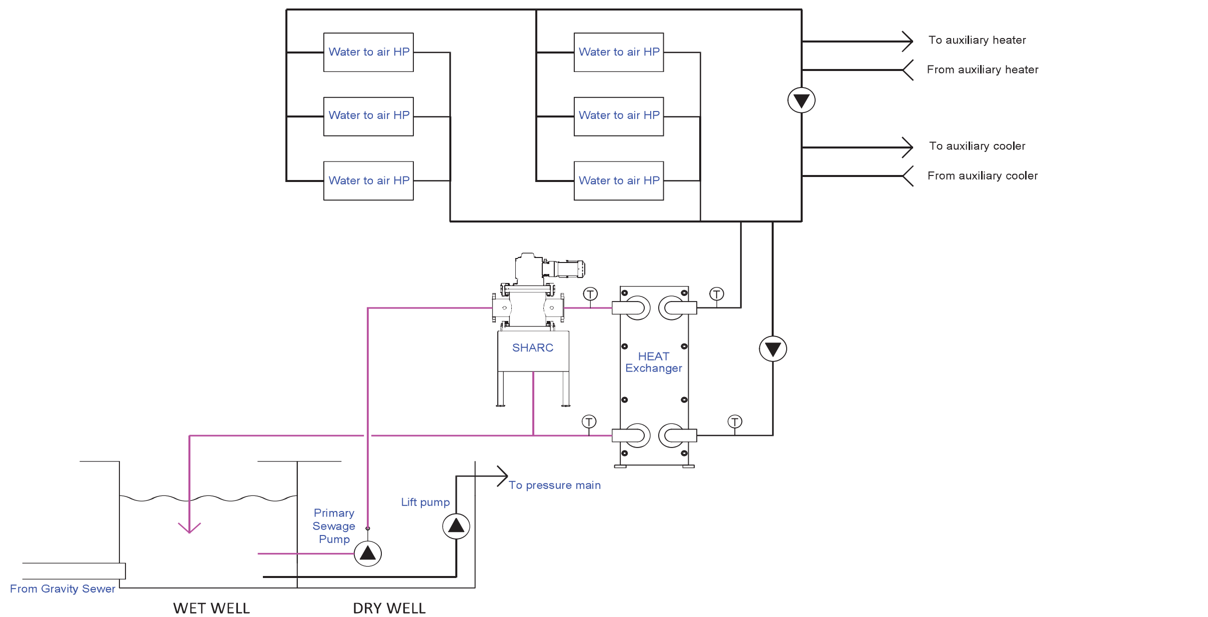


*This schematic is intended for conceptualization only, actual system may vary.

The system consists of a primary loop that delivers heat to secondary circuits. The SHARC sewage heat recovery system and a boiler are used as a heat source to boost the primary loop temperature.

Different loads can be connected to the primary circuit.The schematic depicts water to air heat pump units for space heating and cooling as well as water to water heat pumps for domestic hot water production, and a water to water heat pump used as a heating and cooling source for fan coils and air handling units.

Space Heating and Cooling in a Water Loop Heat Pump System

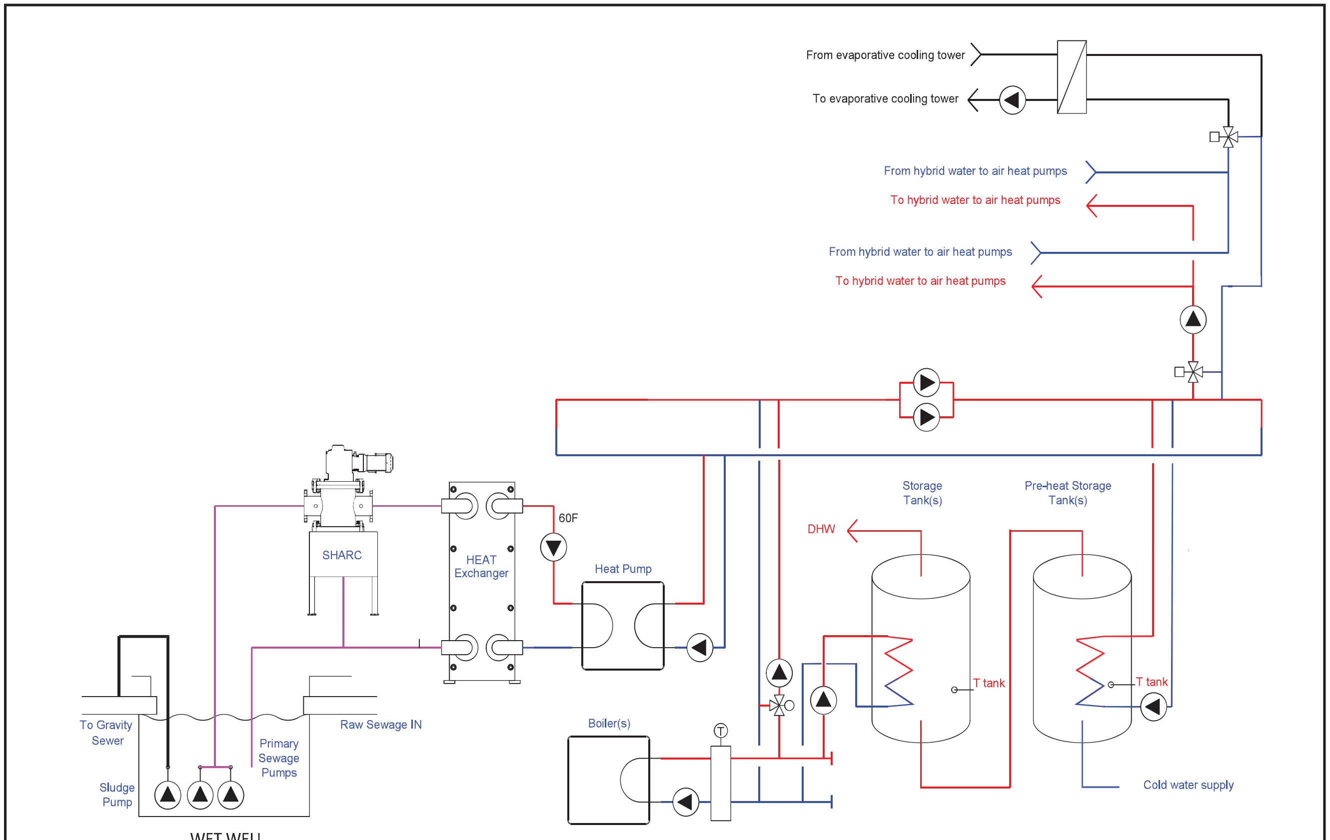


*This schematic is intended for conceptualization only, actual system may vary.

The SHARC sewage heat recovery system can be easily integrated into a closed-loop water source heat pump system.

The SHARC system works in combination with the existing boiler and cooling tower to keep the temperature of the water heat pump loop within the working range. Sewage is used as a heat sink to reject extra condensation heat and as a heat source to provide extra energy to the heat pumps.

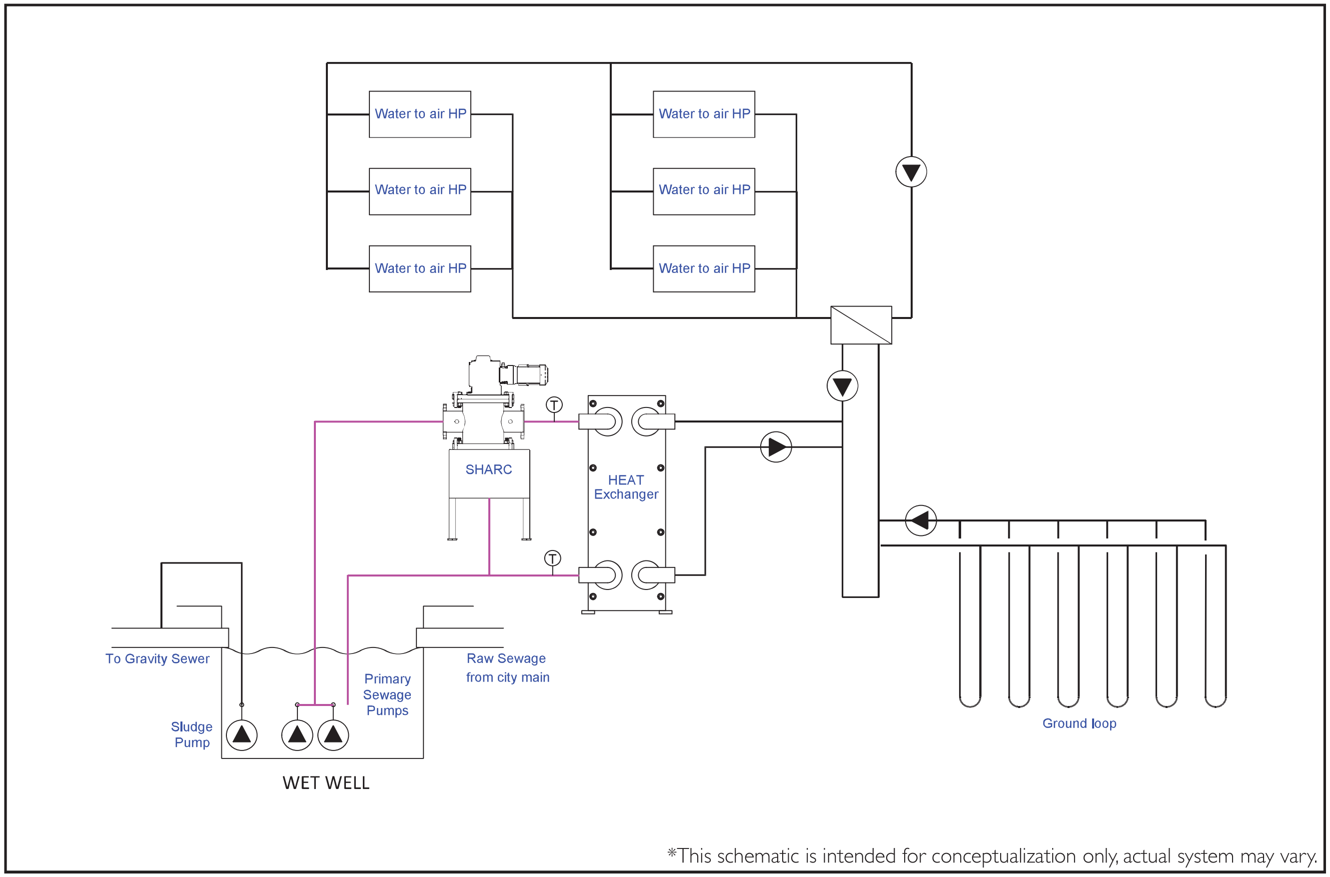
Domestic Hot Water and Space Heating



*This schematic is intended for conceptualization only, actual system may vary.

In this system the SHARC heat recovery system is the first stage heating source for building heating and domestic hot water preparation. Raw sewage is processed in the SHARC unit and then is pumped through a heat exchanger so that heat can be transferred to a water to water heat pump that maintains the minimum temperature of the primary loop.

Hybrid SHARC - Geothermal System



The SHARC system works with a geothermal loop to reject from or inject heat into the water heat pump loop. In combination with a geothermal system, sewage heat recovery can:

- Reduce drilling requirements 30-50%
- Reduce land mass requirements
- Reduce project pay back periods
- Improve loop temperatures
- Increase heating and cooling efficiency

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Appendix I

Archetype Report #1 –
OCH McCauley Place

Archetype Report #1 – OCH McCauley Place

Multi-unit Residential Building

Introduction

This archetype study is one of four undertaken within the City of Ottawa Sewer Waste Heat Scoping Study and provided as part of Sewer Waste Heat Scoping Study Final Report. It should be read within the context of the full report.

Key Archetype Parameters

Table 1: Key parameters of location, flow and temperature values used in the archetype study

Development type	Retrofit of a building in downtown, connecting to a medium sized sanitary line	
Archetype Study type	Social housing multi-unit residence	
Specific Location in Ottawa	Ottawa Community Housing (OCH) McAuley Place at 450 Laurier	
Flow Data	Modeled flow for the SAN38350 line	
Temperature Data	Synthetic, with reference to submersible probe data	
Sewer Lines	SAN38350 sanitary line flowing north along Lyon Street	
Sewer Line Width	675 mm	
Sewer Line Depth	3 m	
Key parameter	**Flow Model A[1]**	**Flow Model B[1]**
Average flow (L/s)	9	33
Minimum flow (L/s)	6	19
Max temperature	16.9 °C	
Minimum temperature	8.6 °C	

General Description

McAuley Place at 450 Laurier is an 11-storey multi-unit residential building (MURB) operated by Ottawa Community Housing (OCH). OCH is a leader in the City for decreasing the energy and carbon footprint of its portfolio, including through new buildings aiming for zero carbon and passive house standards. OCH was thus identified as a potential early adopter of a WET development. After review of their portfolio in collaboration with their Manager of Conservation and Sustainability, McCauley Place was selected due to the following considerations:

- It is situated near a medium-sized sanitary line. There were only a small number of OCH buildings that met this criterion because many buildings are located within residential areas where sanitary collector lines are smaller.
- The building is likely to undertake deep retrofits in a few years and building heating is provided centrally, without individual metering to each suite.

[1] Model A is called IMP2019 by the City and Model B is called CSO2020 by the City. Review of model accuracy and selection was out of scope but should be evaluated in future work.

This building may serve as an example for many MURBS and high-rise buildings in the downtown core, as well as MURBs elsewhere. Office buildings in the downtown core are also an opportunity to consider.

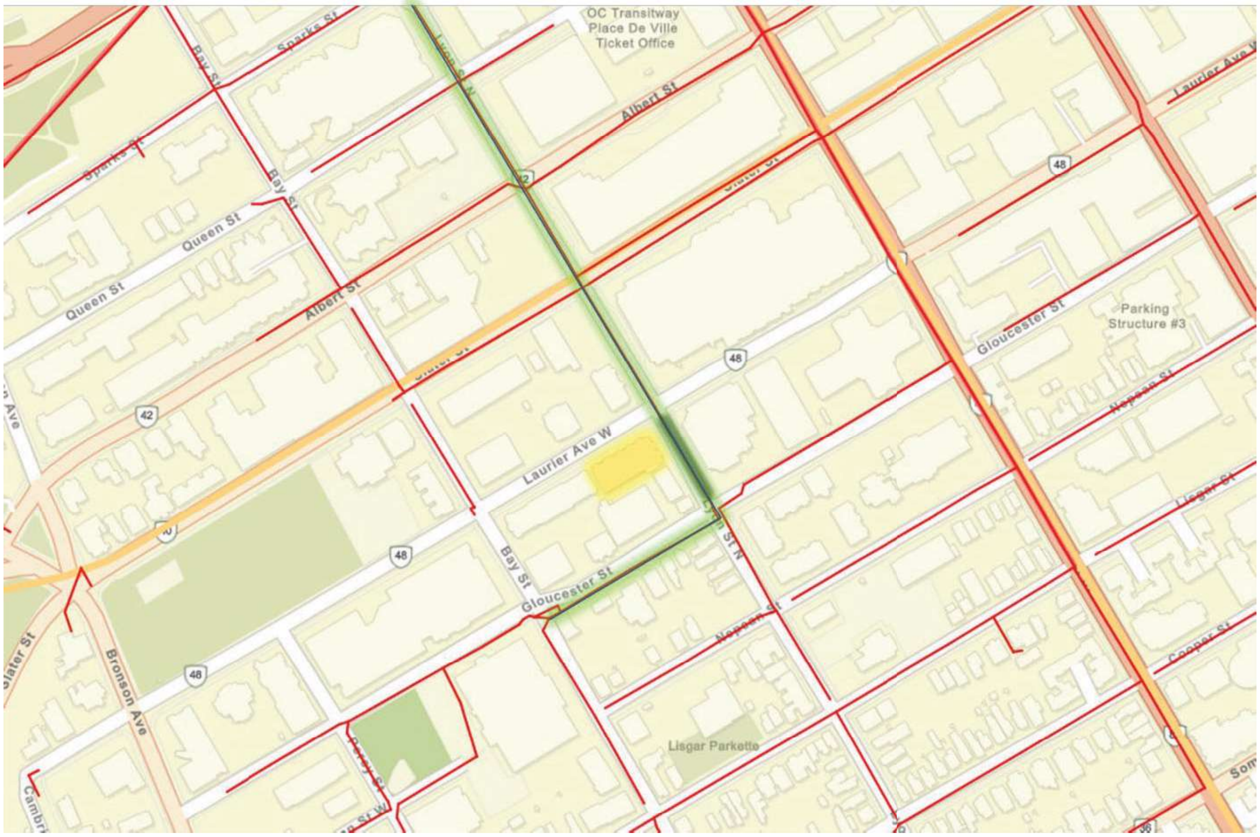

Figure 1: Map of the McAuley Place residential building (yellow highlight) and surrounding sanitary lines (red) and combined lines (orange). The sanitary line of interest is green highlight and the segment SAN38350 that was modeled is in dark green.

Analysis of Wastewater Heat Capacity

An hourly dry weather flow for the sanitary line was acquired from the City wastewater team – it is a modeled flow profile specific to the location. These low flow rates are near the minimum flows recommended by most suppliers, which means that the viability may be challenged, and thus the archetype is a “corner case” of the wide space of WET opportunities, and not an evaluation that is applicable to the broad range of opportunities that may exist. There is a high degree of uncertainty in the minimum flow data developed with this modeling and, in fact, two different models provide notable differences. The City indicated that the higher flow dataset (CSO2020), which was from the north (downstream) side of the intersection of Laurier and Lyon, was likely influenced by additional in-flow (which we guess is a large building). For this study, we are using two times the lower flow model as a compromise (thus 12 L/s) and to assess the minimum realistic size that could be pursued. The archetype was developed with Technology #1, which uses an in-sewer heat exchanger, that will run a fair distance along the bottom or the sewer pipe - this heat exchange could extend underneath both sides of the intersection and possibly access the larger flows.

Direct measurements of flow rates are recommended for feasibility assessment of a real project.

A synthetic hourly temperature profile was used - it was created from high quality submersible probe data from another location (Kanata West), where short-term weather-induced changes to temperature were removed to produce a “dry-weather” temperature profile (further rational on this approach is found in the main report). One point to mention here is that we have no dependable temperature data for *downtown* sanitary lines, and this synthetic model is from a suburban and low-density commercial inflow. There is reason to believe that sanitary sewage in some downtown lines may be warmer than the dataset used here, due to the high-density neighbourhoods and high domestic hot water use per linear length of sanitary line, but accurate estimates of warmer temperatures are not yet possible.

The hourly heat capacity of the sewer line (SAN38350) was then calculated using these temperature and flow profiles. The calculations assume a 2.4°C temperature drop in the wastewater from the heat exchange process for Technology #1; the requirement to maintain the wastewater temperature at the outlet of at least 5°C is achieved throughout the heating season without a need to constrain heat extraction. (see the project’s Final Report for further discussion on these parameters). The heat capacity in the line varies hour-by-hour, primarily due to flow variability, as shown in Figure 2. Sorting the hourly data of the sewer line by decreasing magnitude gives the heat capacity duration curve of the sewer line, as shown in Figure 3. The minimum heat capacity for the line during the October 29th -April 8th period was 110 kW. The non-smooth or stepped nature of the curves relate to the repeating daily profile of the modeled flow data.

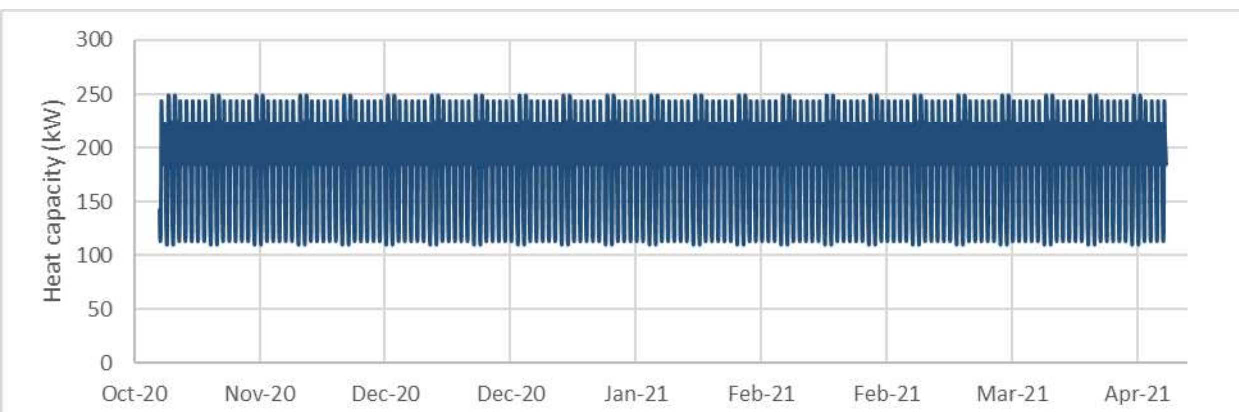

Figure 2 - Hourly WET heat capacity for the SAN38350 sanitation line

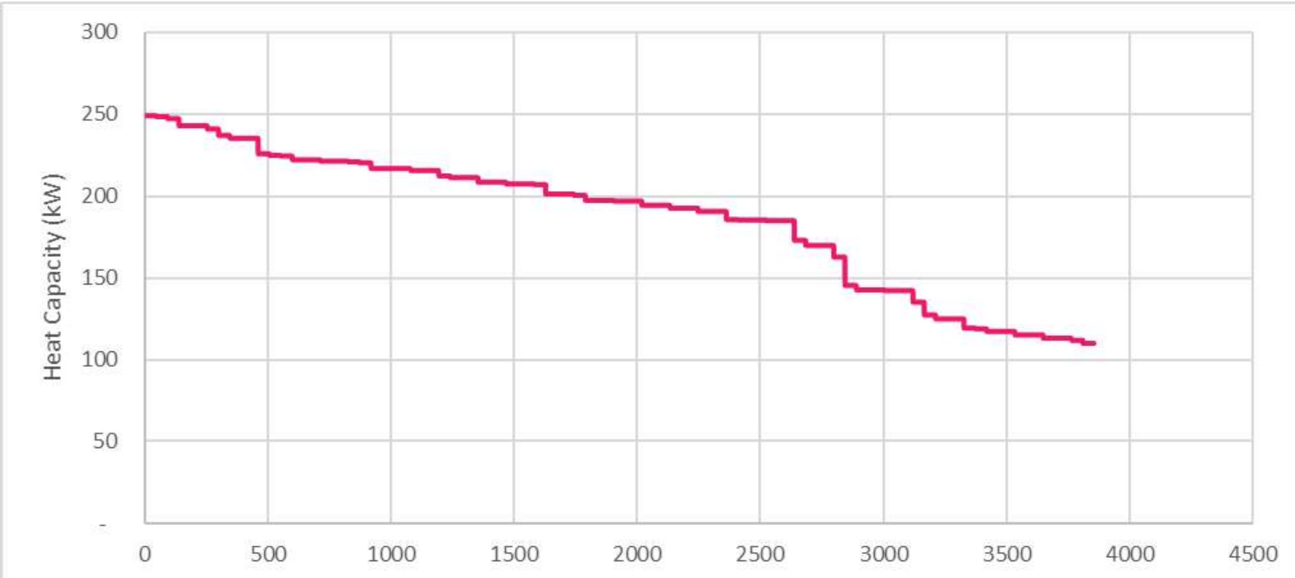

Figure 2 - Heat capacity curve of the SAN38350 sanitation line

Analysis of Building Heating

McAuley Place has a footprint of approximately 900 m^2, standing 11 storeys tall and constructed in 1992. To model the demand of this building, a scaled version of a similar Ottawa MURB building of 1993 construction was used. The modelled building was 8 storeys and had a relatively poor energy performance typical of MURB construction in the early nineties (for example, the energy use intensity of the model was 280 kWh/m^2, close to McAuley's 293 kWh/m^2). For this study, the model's energy demand was scaled to match the natural gas usage for McCauley Place. It is important to consider that retrofits of McCauley Place would reduce the energy demand, though this possible future impact is *not* included in the modelling presented herein. The hourly heating demand of the modeled MURB is compared with the thermal capacity of the WET system in Figure 4.

The two weeks of highest demand (January 13-27) are shown in Figure 5 below. In contrast to the office buildings of the March Road archetype of this project, MURBs are occupied during evenings and weekends, which drives their thermal demands during the cold winter nights. Usage patterns in this MURB model are much less regular than office buildings on a daily basis and are likely also strongly influenced by weather. In contrast, the wastewater heat capacity model is highly regular on a daily basis. Real data and other projects may find somewhat different hourly profiles.

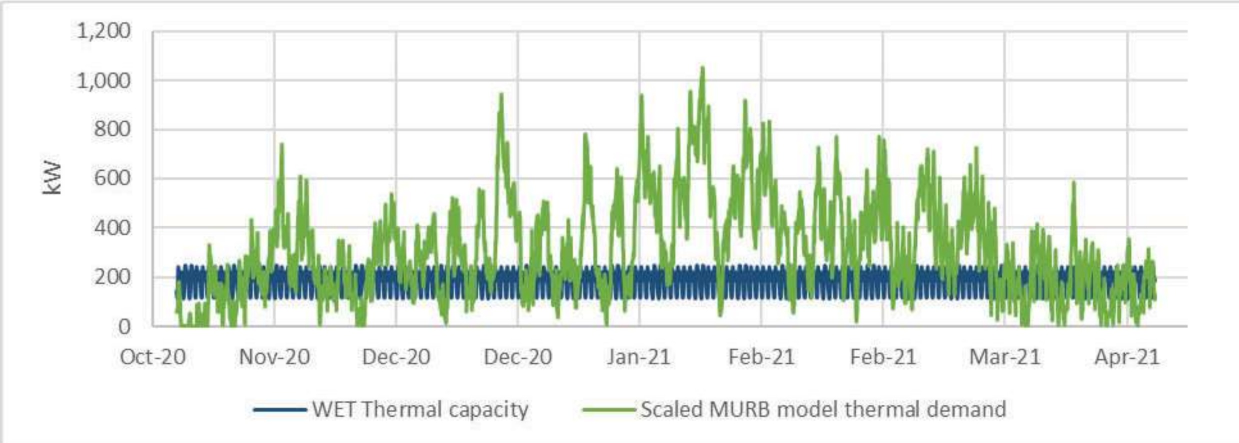

Figure 3 - WET system hourly heat capacity (blue curve) and heat demand trends for a scaled multi-unit residential building

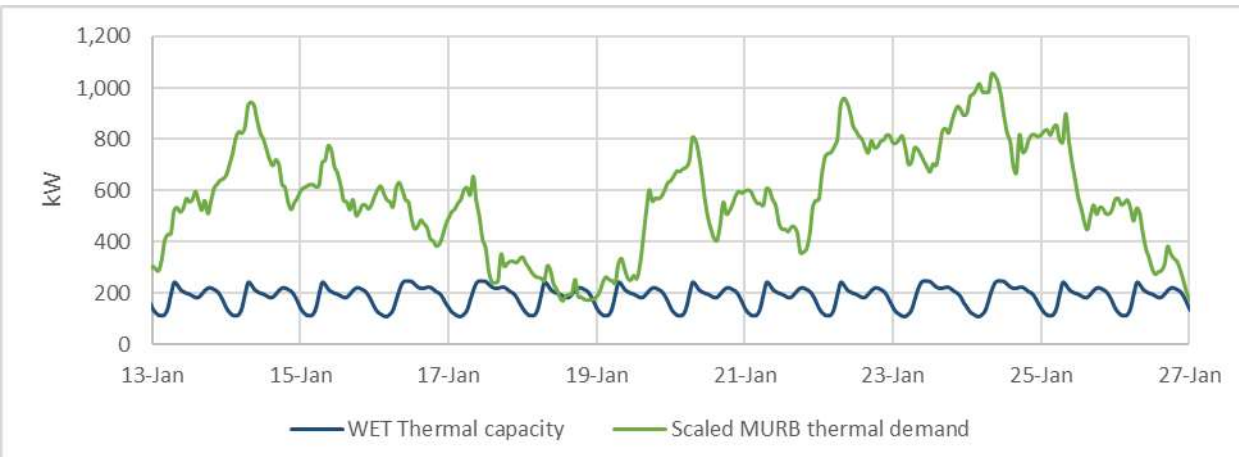

Figure 4 - Zoom in of two weeks during the highest heat demand of the winter

The thermal load duration curve for the scaled MURB building has been plotted against the simultaneous WET thermal capacity as a scatter plot in Figure 6 below. Periods where the scatter is under the load duration curve refer to instances when the WET heat capacity fell short of the thermal demand and auxiliary heating must be used.

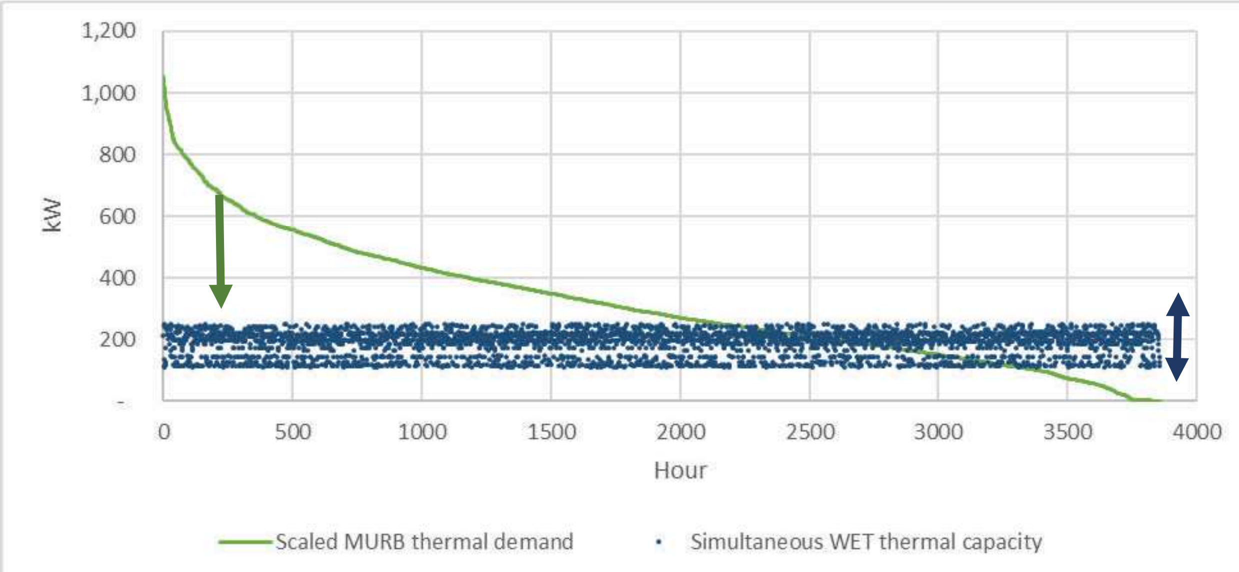

Figure 5 - Thermal load duration curve for MURB compared against the heat capacity of the WET supply

The thick arrows added to Figure 6 are to illustrate how these two curves *may* differ in reality. Firstly, the WET capacity (blue dots and blue arrow) may have different flow or temperature values than have been assumed in this modeling which would increase or decrease capacity. Second, the green arrow is included to indicate that energy retrofits at McCauley Place could be examined to lower the building's heating demand curve. The remainder of this report analyzes these load curves as shown.

The peak demand on the auxiliary system would be reduced to 905 kW from the original 1,054 kWh without the WET system. Thus, in the peak hour, the auxiliary supply would still supply 89% of the heat. This peak hour occurred at 4 AM on January 24^{th} which coincided with a relatively low heat capacity of 110 kW. The runtime of the auxiliary heat would be reduced to 3049 hours from the original 3830 hours of the original heating system without the WET supply.

The weekly percentage of energy provided by the auxiliary heating compared to the WET system is shown in Figure 7 below. The WET system covers much of the thermal demand during the colder seasons and, as a whole, it provides 41% of the heat.

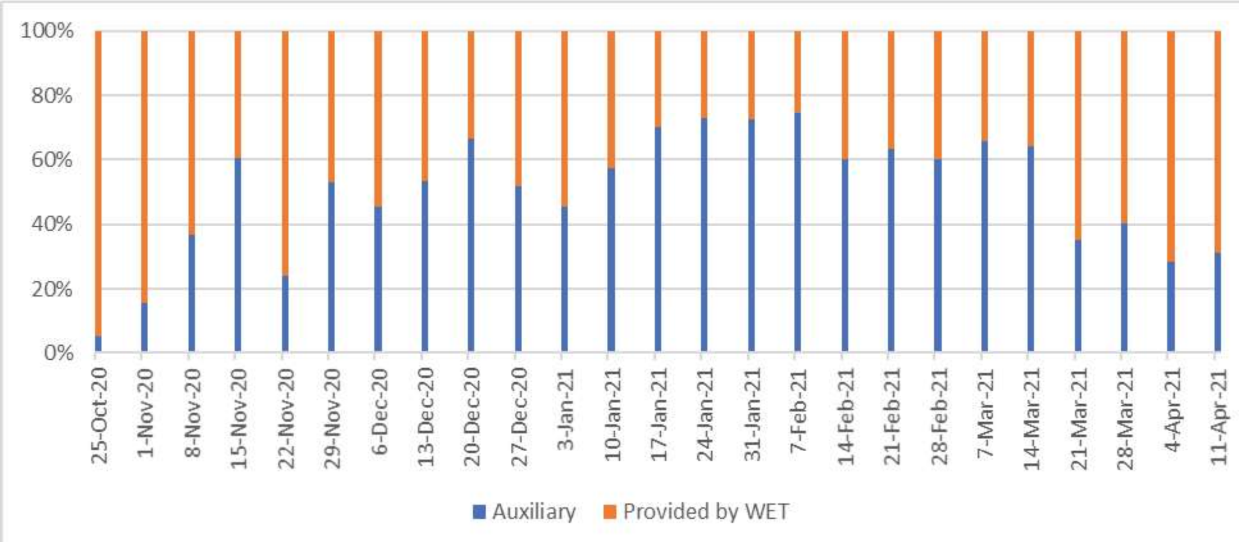

Figure 6 - Percent share of thermal supply for the auxiliary heating system

WET System Implementation

Because of the relatively low flow rates and because of the dense downtown area where the ability to locate additional civil infrastructure may be costly or prohibitive, we considered that heat exchangers installed within the sewage collection pipe (Technology #1) may be the most attractive for this potential project. An example of this technology is the Therm-Liner system provided by UHRIG Group, which consists of a custom heat exchanger designed to be installed within existing sanitary sewer lines via access maintenance holes. Fluid (e.g., water, glycol, etc.) is pumped in a closed loop from a mechanical room or building to the submerged heat exchanger tubes where it absorbs heat from sewage flowing through the sewer pipe. Heated fluid then returns to the mechanical room and passes through a separate heat recovery system for distribution to building loads. To our knowledge, this technology has not yet been used in Canada, however, UHRIG's Therm-Liner system has been installed in many deployments throughout Europe. Though the configuration is designed to be low profile and minimize collection of debris in the wastewater stream, there remain several operational and maintenance concerns related to sewer cleaning with this system in place. However, this technology is worth considering for this location due to the lack of available real-estate for installation of a wet well and lower installation and equipment maintenance costs.

The system envisioned for this archetype is a 100 m long in-sewer heat exchanger placed in the Lyon Street sewage collection line with underground piping connections that carry working fluid into a newly created mechanical room within the underground parking garage of McCauley Place. This room would house hydronic heat pumps and related monitoring equipment required to extract heat from the sewage heat exchanger and distribute it to the building heating system, either to the existing central distribution system or newly deployed distribution equipment. No costs for retrofits or additional in-building heating equipment are included in this concept, though they may be required. It was also assumed that auxiliary heat will be supplied to building loads via existing mechanical equipment.

A block flow diagram summarizing WET system components and equipment location is presented in Figure 8 below.

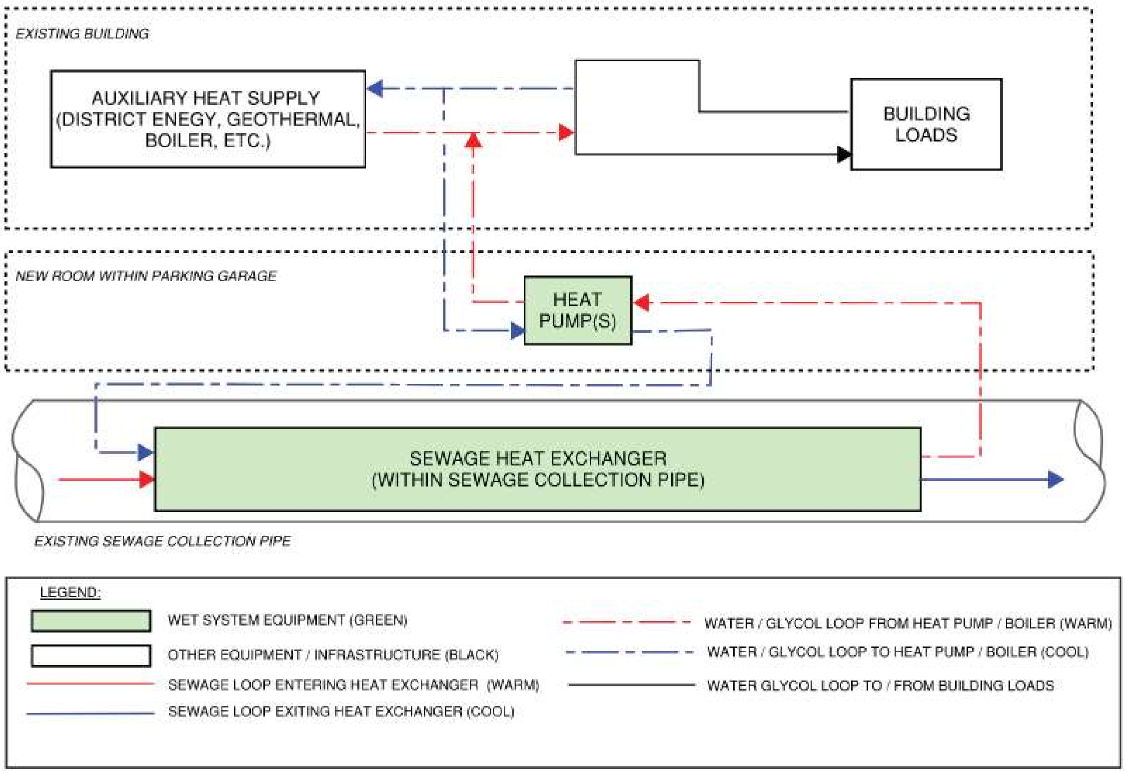

Figure 7 - WET System Concept Schematic

All required WET system components are summarized in Table 2 below. The information provided is based on high-level estimates and is subject to change based on concept development and optimization to suit a specific application.

Table 2: Summary of Wet System Components

Item	High-Level Description	
Sewage Heat Exchanger	Description: Sewer Diameter: Length: Min. Sewage Flow: Min. Sewage Temperature: Sewage Temperature Drop: Estimated Thermal Output:	Mounted in existing sewage collection pipe 675mm 100m 12 L/s 8.6 °C 2.4 °C 150 kW
Piping	Description: Max Length:	Piping from Building to Heat Exchanger Tie Points 200 m (total supply and return)
Heat Pump	Description: Quantity: Total Capacity:	Installed in Mechanical Building 2 150 kW
New Mechanical Room	Estimated Footprint Required:	32 m^2

Costs

High level opinions of probable costs have been prepared to install and operate the WET system concept described above to determine a levelized cost of heating (LCOH) for McAuley Place. This includes the WET system capital cost, utility costs, operations and maintenance costs, and equipment replacement costs. Based on these costs, and assuming a project life of 40 years and a real discount rate of 1%, the LCOH is estimated to be $0.12/kWh.

A summary of this financial analysis is presented in Table 3 below, followed by a list of assumptions associated with each line item.

Table 3: Levelized cost of heat from OCH McAuley Place

Capital Cost ($)			$952,000
Annual Utility Costs ($/year)			$17,000
Annual Operations and Maintenance Costs ($/year)			$3,000
Equipment Replacement Costs over Project Life ($)			Refer to the attached detailed table
Real Discount Rate (%)			1.0%
Project Lifetime (years)	20	30	40+
Levelized Cost of Heating ($/kWh)	$0.15	$0.14	$0.12

Assumptions:

1) Capital cost estimate includes:
    - WET system equipment (sewage heat exchanger and associated piping within sewage collection pipe)

- Building heat pumps.
- Up to 100 meters of supply and return piping between heat pump and heat exchanger tie point (200 linear meters of total pipe).
- Sewer line drain and bypass during construction based on an installation time of up to two weeks.
- 30% contingency allowance.
- 15% allowance for engineering and permitting.
- 10% cost allowance for commissioning.

Capital cost **does not** include:

- Proposed building architectural, civil, structural, mechanical, and electrical costs, unless otherwise specified above.
- Modifications to the existing parking garage to accommodate new mechanical equipment.

2) Annual operations and maintenance costs include:
    - Monthly maintenance labour associated with the new heat pumps, assuming one 8-hour visit per year.
    - Routine annual parts replacement.

3) Equipment replacement costs over the 40-year project life includes:
    - Installation of the WET system equipment at Year 0.
    - Inspection and cleaning the sewage heat exchanger once every 5 years (i.e., Years 6, 11, 16, 21, 26, 31, 36).
    - Replacement of the heat pumps every 20 years (Year 21).

In principle, a WET system can also provide cooling in addition to heating, and it is able to provide cooling at a higher efficiency than typical air conditioners or chillers and cooling towers because it is less work to reject heat into a moderate temperature liquid medium versus higher temperature ambient air. Its use will avoid the equipment costs, space requirements, maintenance and water consumption costs required for cooling towers. The WET system would need some added elements to output to a chilled water distribution loop. Defining the configuration and quantifying this benefit was beyond the scope of the present study but should be included in a full project evaluation.

Discussion and Conclusions

It is important to note that this brief exercise was a trial comparison of available sewer line data with an available building energy demand data; the implementation may not be optimal or indicative of the viability of other opportunities, but they are aimed to be illustrative of issues affecting viability.

The cost analysis indicates that the WET system, in this archetype, has a cost of heat of approximately $0.12/kWh over a 40-year project life. This is below or on par with *present* costs of electric resistance heating, though cheaper than future costs of electric heating. It is also comparable to LCOH of natural gas heating once the upcoming Federal carbon taxes are considered (see point 4 below).

We tested the impacts of larger flow rates using the City's other flow model. It would enable a larger WET system (of the order of 33-50% larger). This design change would produce more heat but also require added capital costs for the larger equipment - the net impact is to only slightly lower the LCOH of the WET system (of the order of $0.01/kWh); the most important effect is that it significantly reduces the required size and the use of the auxiliary system, which could improve the overall project performance.

It must be emphasized that this exercise indicative only, using one combination of flow, building, and system design – projects could have LCOH that differ by as much as ± 50% of this estimate. Each WET implementation will have unique design details; working with technology suppliers with site specific data to develop a design concept will help to improve and optimize system performance and costs. Additional deployment costs may exist that are not included herein, such as: additional building area, as the building will still need the existing heating equipment. Yet, there are several important factors as to why the levelized cost of heating is high for this example, which would not be universally high in an evaluation of other similar WET projects:

1. The heat capacity developed at this location are uncertain and on the small end for viable projects.
    - The sewage flow rates had a high degree of uncertainty and should be verified with field measurements.
    - The temperature profile of this type of downtown sanitary lines is not yet measured and may be higher than the available suburban collector profile used for analysis.
    - Larger flow rates will be more attractive for development.
2. This in-sewer heat exchanger technology (WET Technology #1) is a less *effective* heat exchanger than those of WET Technology #3.
    - Technology #3 can achieve a higher temperature drop in the same wastewater flow, allowing for higher heat delivery for the same flow (though this comes with higher capital costs, which would likely not be viable at this location).
    - Effectiveness decreases as biofilm from sewage builds up on the heat exchanger, which can be significant within the first few weeks of operation, if not addressed. Technology #3 suppliers use automated processes to regularly clean the sewage heat exchanger and maintain optimal performance. However, since frequent heat exchanger cleaning within the sewage collection pipe is not practical, Technology #1 suppliers account for biofilm buildup by applying a 40% correction factor to lower thermal output when developing the WET system concept. This correction factor is based on supplier experience with system installation, operation, and maintenance.
    - One attraction to WET Technology #1 is that it can be economic in moderate sized wastewater lines of this diameter or larger (675 mm or larger), such as do occur within the downtown core, whereas Technology #3 requires higher flow rates.
3. Cooling can be provided from the same WET system. Cooling is not presently provided to occupants of this OCH building but it can be considered to improve occupant comfort and health during increasingly intense summer heat waves. This WET system can provide the cooling supply for next to no additional cost, though equipment for the delivery of cooling to each unit would be an additional cost (as it would for any other cooling solution). Cooling would improve the WET economics by selling a second "product" using the same capital investment.
    - Applications with both heating and cooling should be investigated as a priority.

   - Levelized cost of heat appears to be a poor metric for a WET system.
4. It would be unfair to compare this all-in economic evaluation with the *operational* cost of alternative heating systems - full levelized costs of heating are rarely calculated for typical heating solutions such as natural gas – the full analysis should include cost to build and maintain the mechanical rooms, purchase of boilers, O&M of the equipment, and should include the carbon tax. For context, natural gas utility costs are around $0.04/kWh, and the full LCOH may be around $0.08 to $0.09/kWh[2]. These costs will be rising by $0.04/kWh by 2030 when the proposed Federal carbon taxes reach $170/tCO$_2$e).
   - All LCOH calculations will be very sensitivity to how the boundary of the project is defined.
   - WET system economics generally look at the all-in capital + operational costs. The same all-in economic evaluation should be developed for all other system options.
5. The building has a relatively poor envelope (poor TEDI) that requires more heat per square meter of space than most new construction.
   - Retrofitted, newer and new buildings are a better match and high-performance buildings with low TEDIs should be pursued as a priority.

The viability of a WET system at this location is uncertain and more work is required to clarify the potential. Additional investigations during pre-feasibility would include acquiring more data on the wasterwater heat capacity, including flow and temperature. Feasibility analysis will include: an improved understanding and of building's heat demands, investigations with the suppliers to develop more refined system sizes and more detailed evaluation of the potential retrofit measures. The assumed flow rates for this 675 mm pipe may be on the borderline for viability but flow rates and pipe sizes vary on a block-by-block basis in downtown and tend to increase within a block or two further north. Intensification and increases in the proportion of residential usage will increase flow rates with time.

[2] LCOH for natural gas systems are rarely reported, the numbers used here are approximate and derived from a small number of on-line references.

Appendix J

Archetype Report #2 –
March Road Pump Station

Archetype Report #2 – March Road Pump Station

Pumping Station & Office Building

Introduction

This archetype study is one of four undertaken within the City of Ottawa Sewer Waste Heat Scoping Study and provided as part of Sewer Waste Heat Scoping Study Final Report. It should be read within the context of the full report.

Key Archetype Parameters

Table 1:- Key parameters of location, flow and temperature values used in the archetype study

Development type	At a pumping station and with suburban residential and high-tech inflows
Archetype Study type	Heat supply to an office building, which could include a district energy system via a future technology park loop
Specific Location in Ottawa	March Road Collector, 305 Legget Drive, Kanata
Flow Data	March Road 2021 MHSA01106 from COVID study
Temperature Data	March Road 2021 MHSA01106 from COVID study (submersible probe)
Sewer Lines	SAN01146 flowing into the pumping station
Pipe Diameter	1050 mm
Average flow	90 L/s
Minimum flow	21 L/s
Pipe Diameter	1050 mm
Max temperature	16.5 °C (95th percentile)
Minimum temperature	8.2 °C

General Description

The City of Ottawa is rebuilding a new pumping station at this location (Figure 1). The opportunity to co-locate a WET system within a pumping station has a few potential advantages, in particular if the City were to become the owner/operator of the system and a vendor of heat: (i) the facility is already operated and maintained by the City; and (ii) some of the infrastructure required to support a WET system is already in place (e.g., wet well / pumping chamber). While the distance between this pumping station and existing buildings with significant heat demands may be 500 m or larger (which may be an uneconomic distance), this region has also been identified as having potential for a business park district heating system in the City of Ottawa Energy Evolution Final Report. Opportunities for construction of large new single office buildings are likely to also exist at this location. Furthermore, this archetype is also intended to generally capture certain conceptual opportunities for a WET system (suburban trunk line flows, pumping station use, and office building loads) and one or more of the attributes will apply to a number of other locations in Ottawa. This particular location was chosen in part because the City had directly measured high quality sanitary temperature and flow data covering the 2020-2021 heating season.

Figure 1 - Map of the March Road pumping station and its two incoming wastewater lines from the North and West and outgoing to the East. Right image is a zoom in of the area marked by the box on the left image. Cyan blue highlights the exact location measured by the flow probe.

To analyze how the heat capacity of the WET system compares against a generic office building, a 2-storey and a 9-storey office building energy model were used. The models were drawn from a previous building model from other J.L. Richards & Assocciates Limited projects. Due in part to the preferences of the City and the integration opportunity at a pumping station, we have selected to examine Technology 3 within this archetype, which would employ a wet well and specialty heat exchangers external to the sewage collection system. Because of the high-level and generic nature of this archetype assignment, we have not examined the specific configurations within the March Road pumping station – we assume that there is existing building capacity or building expansion already planned and funded to accommodate additional submersible pumps, which may or may not be true.

Analysis of Wastewater Heat Capacity

Using the flow and temperature data obtained from submersible probes in an accessible manhole (MSHA01106), the hourly heat capacity of the sewer line (SAN01146) was calculated. The calculations assume a 5 °C temperature drop in the wastewater from the heat exchange process but also imposes a constraint to maintain the wastewater temperature at the outlet of at least 5 °C to avoid icing (see the project's Final Report for further discussion on these parameters). The heat capacity in the line varies hour-by-hour, primarily due to flow variability, as shown in Figure 2 (blue curve). Sorting the hourly data of the sewer line by decreasing the magnitude gives the heat capacity curve of the sewer line, as shown in Figure 3 below; it can be observed that the minimum heat capacity for the line during the October 29th - April 8th period was 442 kW.

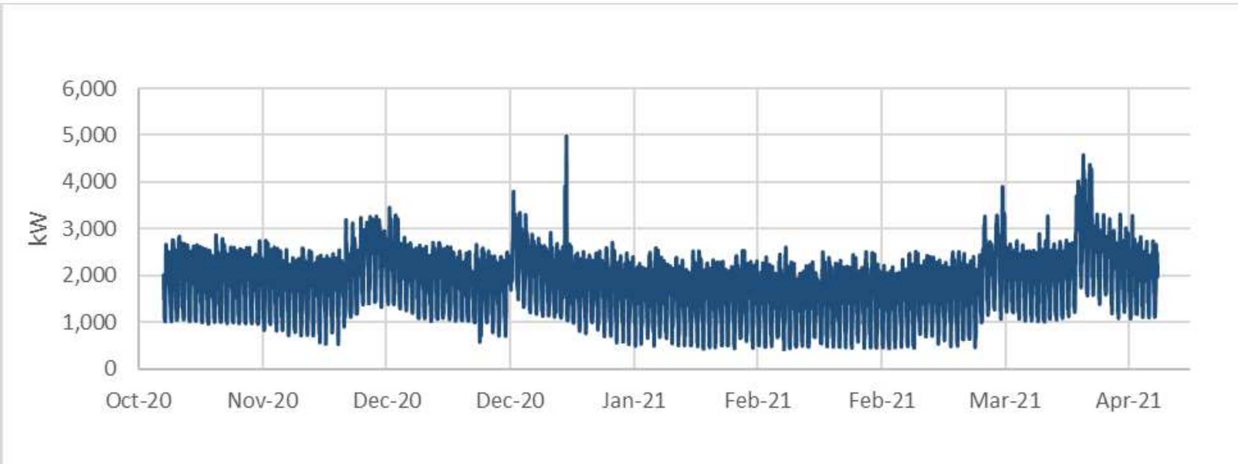

Figure 2 - March Road Pumping Station wastewater hourly heat capacity.

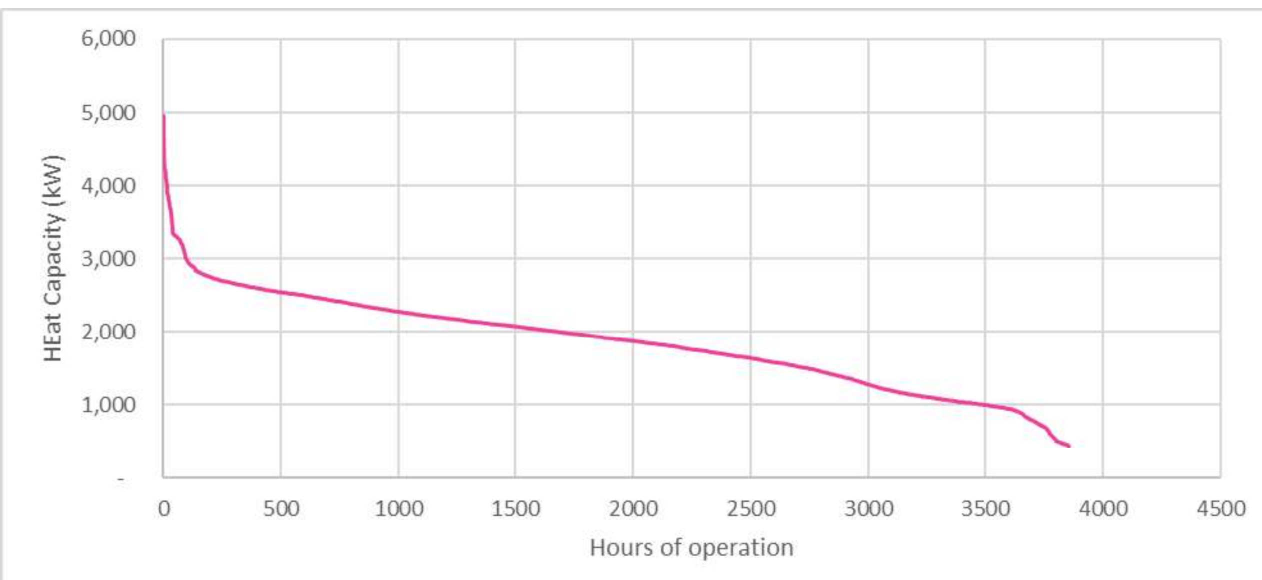

Figure 3 - Heat Capacity Curve of the March Road Pumping Station wastewater flow.

Analysis of Building Heating

Two different office building models were analyzed and compared with the thermal capacity of the WET system, as shown in Figure 4. The first model was of a 2-storey office building with basement having 1,910 m^2 of conditioned floor area which represents a contemporary office building built to current Ontario Building Code with an energy use intensity (EUI) of 135 kWh/m^2 per year. The second modelled building is a larger 9-storey office building with 39,162 m^2 of floor area representative of an existing Ottawa office building constructed in 2001 with an EUI of 396 kWh/m^2 per year. Another metric of energy performance is the Thermal Energy Demand Intensity or TEDI, a normalized measure of the space heating requirements, which comes to 54 kWh/m^2 for the 2-storey office and 85 kWh/m^2 for the 9-storey office building. For context, the Toronto Green Building Standard Tier 2 which will be in effect for new buildings in 2022 requires a TEDI value of 30 kWh/m^2 - thus a new building could be designed to be even more efficent than either of these currently used models. The 2-storey office building's heating demand never exceeded 105 kW, and thus never exceeded the capacity of the wastewater supply. It is clear that on occasion the 9-storey building's heating needs exceed the heat capacity of the wastewater. For the remainder of this study, we have focused on the 9-storey building.

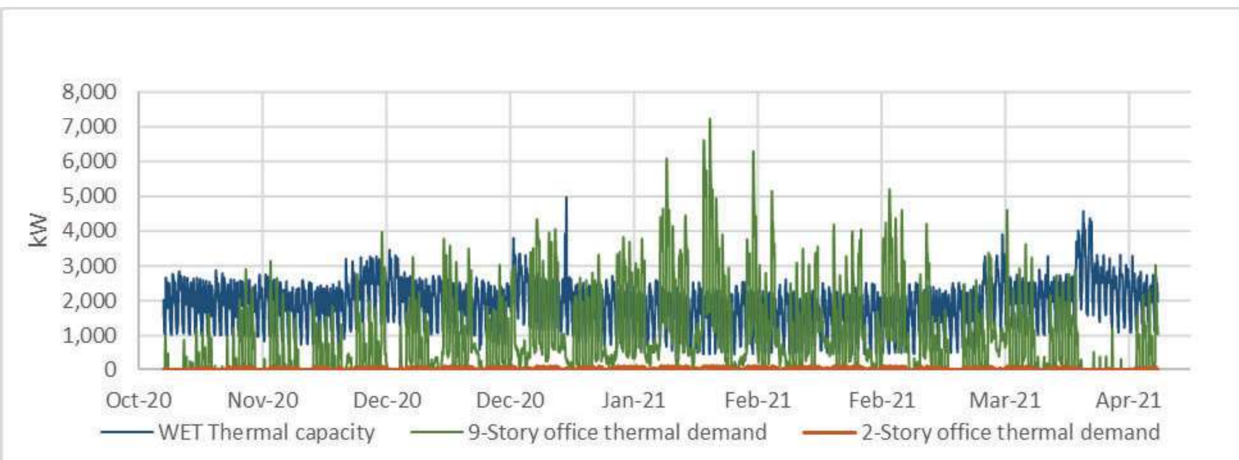

Figure 4 - WET system hourly heat capacity (blue curve) and heat demand trends for a 2-storey (orange curve) and 9-stoery (green curve) office buildings.

Two of the weeks in late January, when the thermal demand is the highest, are shown in Figure 5. Both the wastewater capacity curve and the building demand curve have daily patterns and both rise in the morning, however the building's heat demand (in this model) rises before the wastewater capacity does. During most nights, *the* heat capacity exceeds the building's demands, except for a small number of dates, such as the night of January 25-26th, where even at night the building requires more heat than can be obtained from the WET system. The strong peaks of heating demand in the morning is typical of gas-heated office buildings with poor envelopes - the heating schedule could likely change when using a heat pump to have a longer, more gradual, morning heating period, which would also smooth out the heating demand peaks in the morning, lowering the building's peak thermal demand. Improving the building envelope would also help with reducing the peak heating demand.

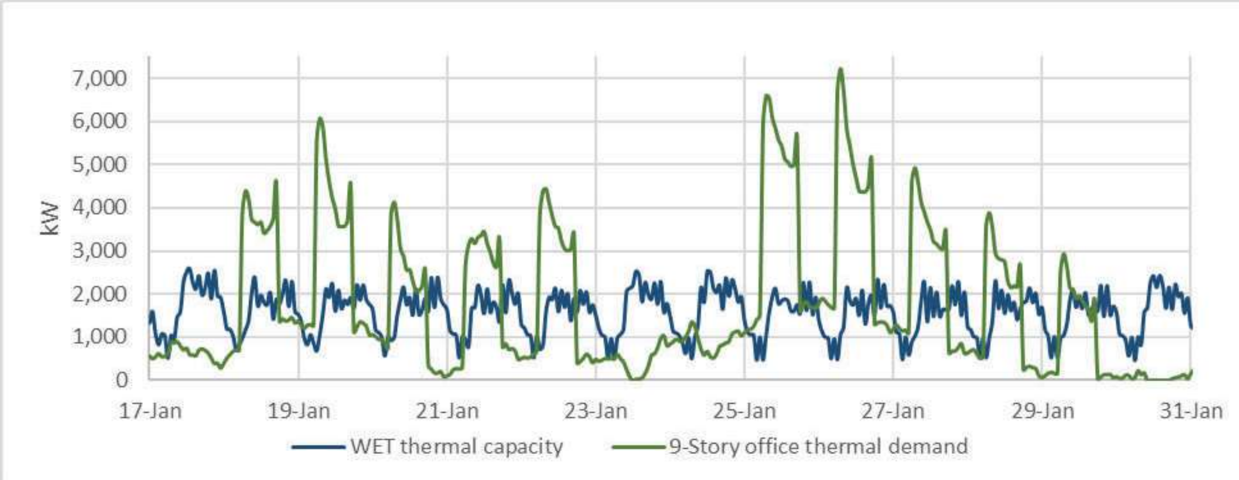

Figure 5 - Zoom in of two weeks during the coldest part of the winter.

The load duration curve for the 9-stoery office building is shown in Figure 6 with the simultaneous WET heat capacity (i.e., for that same hour of the year as the point on the green curve) is shown with blue dots. Periods where the blue dots are under the green load duration curve refer to instances when the WET heat capacity fell short of the thermal demand and auxiliary heating must be used. The thick green arrow on Figure 6 is to indicate that the heat demand of a potential building could be lower with improved building envelope, mechanical systems or controls, since the building model is representative of 2001 construction. The yellow line shows the capacity of the WET system if it were designed to a 1.4 MW heat capacity.

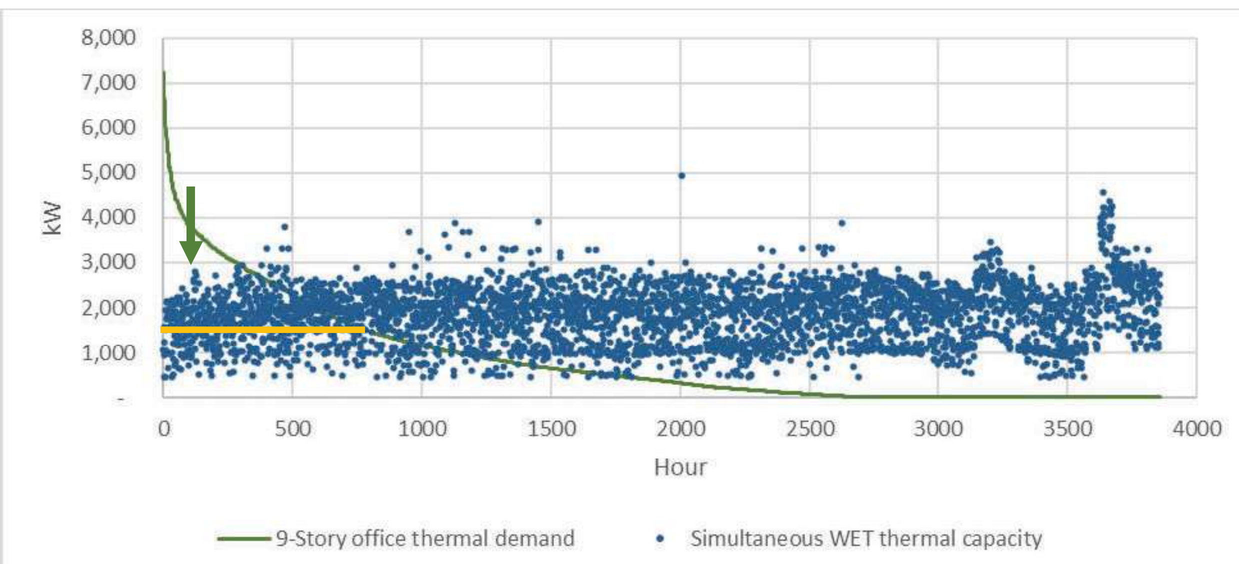

Figure 6 - Thermal load duration curve for the 9-storey office building compared against the heat capacity of the WET supply.

To see the effect that the WET system would have on the sizing of the mechanical system for the 9-storey office building, the load duration curve for the auxiliary heating system is shown below in Figure 7. The peak auxiliary load came to 6,237 kW, which is 93% of the buildings thermal demand of 7,236 kW during that particular hour. This event came during one of the buildings peak demand periods at 6 AM on January 26th. This coincides with one of the lower flows measured in the sanitary sewer, which correlates to 464 kW of available heating capacity. The flow data of the sewer line exhibited a short term variability (see oscillations in Figure 7) which might be possible to mitigate with a small amount of storage (such as a large wet well) – when we applied 3-hour averaging, the resulting minimum capacity was 615 kW, or 40% larger.

The weekly percentage of energy provided by the auxiliary heating compared to the WET system is shown in Figure 7. The WET system covers the majority (64%) of the thermal demand for the whole heating season.

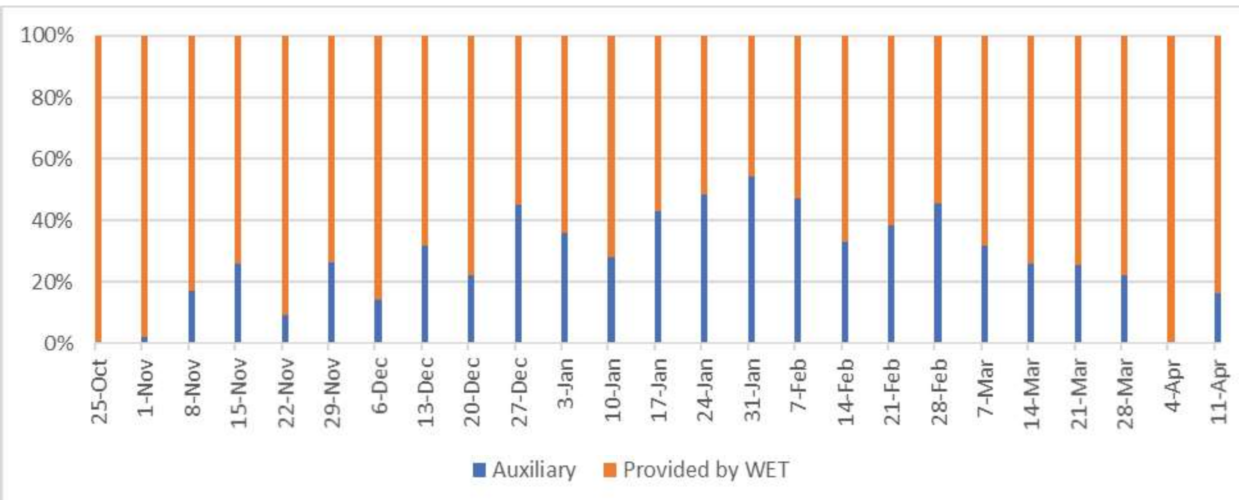

Figure 7 - Percent share of thermal supply for the auxiliary heating system.

WET System Implementation

As described above, the WET system considered for implementation at this site is based on Technology #3: diversion of sewage from the City's sewage collection system to a temporary tank or wet well, and pumping the sewage directly to a heat exchanger installed in a building mechanical room.

Based on the available sewage heat capacity, a 1.4 MW capacity WET system is proposed for this location. As noted previously, the WET system will require an auxiliary source of heat (e.g., boilers, geothermal, etc.) to meet the demands of the proposed 9-storey building.

The existing March Road pumping station Environmental Compliance Approval (ECA Number 0927-B9YTGT) indicates that the pumping station is not currently equipped with a mechanical screen at the wet well inlet. Thus, the WET system concept will be based on equipment supplied by SHARC. A description of this system is provided below, followed by a concept schematic (Figure 8). Alternative equipment concepts may be considered during design development if the City plans to install a screen at the pumping station wet well inlet in the future.

The WET system concept consists of new submersible sewage pumps installed within the existing pumping station. The submersible pumps convey the sewage to a macerator (i.e., grinder) followed by a filter unit designed to remove suspended solids from the macerated sewage. The filter unit uses a mechanical auger to press the macerated sewage through a fine screen filter. Filtered sewage is discharged to a heat exchanger for distribution of heat to various building loads via heat pump. The sewage discharge from the heat exchanger is combined with the solids collected by the filter and discharged back to the existing pumping station wet well.

For the purposes of this study, it is assumed that the submersible pumps associated with the WET system can be installed within the existing March Road pumping station wet well without additional structural or building modifications. The remaining WET system equipment will require installation within a classified area due to the potential presence and buildup of flammable and combustible gasses. One potential location for the equipment is within the existing pumping station, provided the existing building or a building expansion can accommodate the additional equipment. Alternatively, a dedicated building, or dedicated room within the proposed 9-storey building can be used. For the purposes of this study, it is assumed that the equipment will be installed in a classified dedicated room within the proposed 9-storey building. The location of the equipment can be optimized to suit more specific projects as necessary.

A block flow diagram summarizing WET system components and equipment location is presented in Figure 8 below.

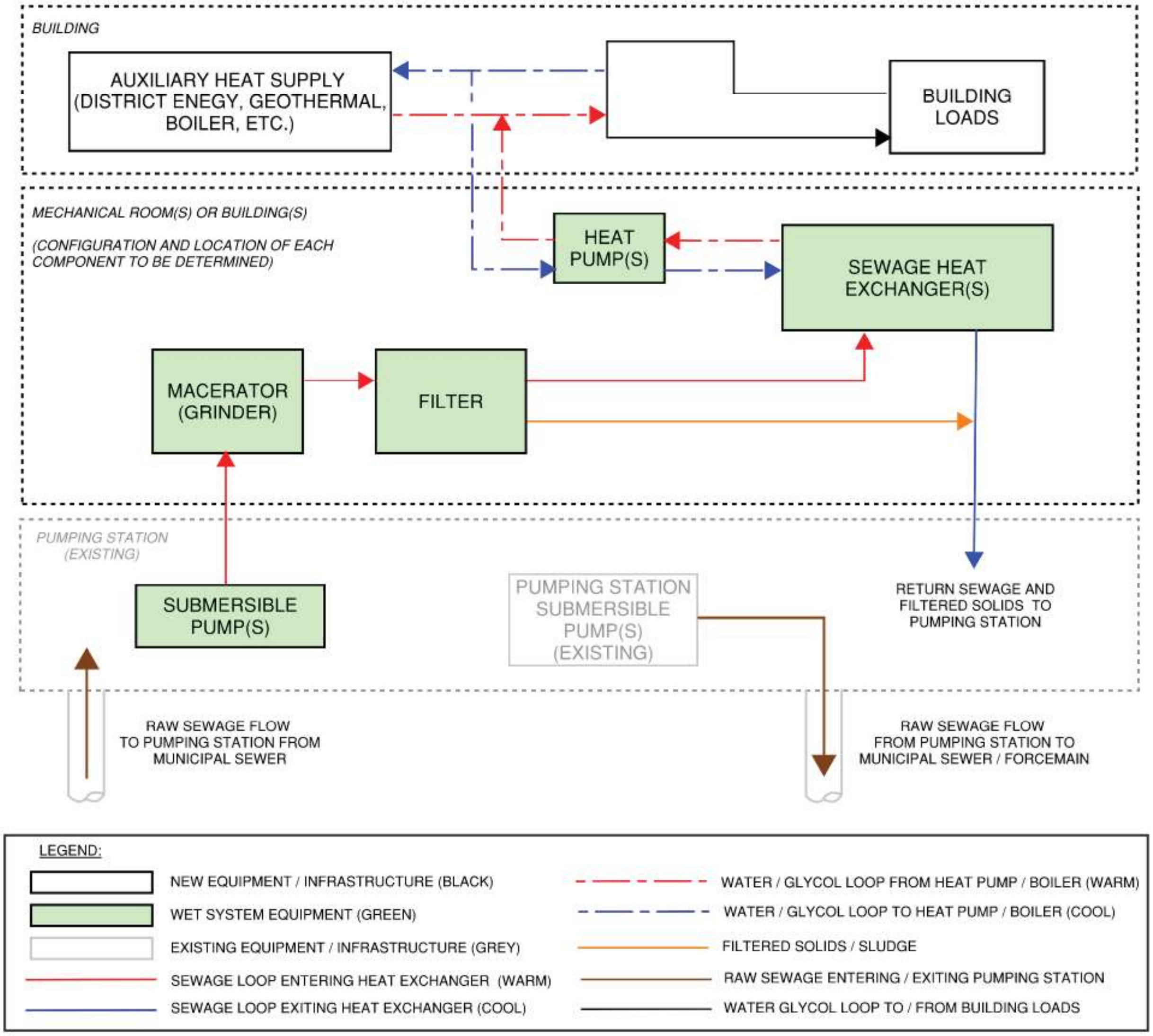

Figure 8: WET System Concept Schematic

A list of WET system components are summarized in Table 2 below. The information provided is based on high-level estimates and is subject to change based on concept development and optimization to suit a specific application.

Table 2: Summary of Wet System Components

Item	High-Level Description	
Submersible Sewage Pump(s)	Description: Quantity: Total Power:	Mounted in existing wet-well 2 15.0 kW
Piping	Description: Diameter: Max Length:	Piping between pumping station and Mechanical Building 200 mm 200 m
Macerator(s)	Description: Quantity: Total Power:	Skid-mounted within Mechanical Building 2 7.5 kW
Filter(s)	Description: Quantity: Total Power:	Skid-mounted within Mechanical Building 3 1.1 kW
Heat Exchanger(s)	Description: Quantity: Total Capacity:	Skid-mounted within Mechanical Building 2 1.4 MW
Heat Pump	Description: Quantity: Total Capacity:	Installed in Mechanical Building 3 1.4 MW
Mechanical Building	Footprint Required:	80 m^2

Costs

High level opinions of probable costs have been prepared to installand operate the WET system concept described above to determine a levelized cost of heating (LCOH) for a generic 9-storey office building. This includes the WET system capital cost, utility costs, operations and maintenance costs, and equipment replacement costs. Based on these costs, and assuming a project life of 40 years and a discount rate of 1%, the LCOH is estimated to be $0.18/kWh.

A summary of this financial analysis is presented in Table 3 below, followed by a list of assumptions associated with each line item.

Table 3: Summary of Financial Analysis (9-storey office model)

Capital Cost ($)	$5.1M		
Annual Utility Costs ($/year)	$105,000		
Annual Operations and Maintenance Costs ($/year)	$50,000		
Equipment Repacement Costs over Project Life ($)	Refer to the attached detailed table		
Real Discount Rate (%)	1.0%		
Project Lifetime (years)	20	30	40+
Levelized Cost of Heating ($/kWh)	$0.21	$0.20	$0.18

Assumptions:

1) Capital cost estimate includes:

- WET system equipment (skid-mounted macerator, heat exchanger, controls, etc.).
- Submersible pumps installed in existing pumping station wet well.
- Building heat pumps.
- Up to 200 meters of civil works / piping between the March Road pumping station and the proposed 9-storey building.
- 30% contingency allowance.
- 15% allowance for engineering and permitting.
- 10% cost allowance for commissioning.

Capital cost **does not** include:

- 9-storey building architectural, civil, structural, mechanical and electrical costs, unless otherwise specified above.
- Modifications to the existing March Road pumping station building and wet well.
- Modifications to any existing buildings to house WET system mechanical equipment.

2) Annual operations and maintenance costs include:
    - Daily maintenance labour, assuming 0.5 hours per day of maintenance, 365 days per year.
    - Monthly maintenance labour, assuming one 8-hour visit per month for one year.
    - Routine annual parts replacement.

3) Equipment replacement costs over the 40 year project life includes:
    - Installation of the WET system equipment at Year 0.
    - Replacement of submersible pumps every 10 years (Year 11, Year 21, Year 31).
    - Replacemement of the WET system equipment every 20 years (Year 21).

In principle, a WET system can also provide cooling in addition to heating, and it is able to operate at a higher efficiency than typical air conditioners or chillers and cooling towers because it is easier to reject heat into a moderate temperature liquid medium versus high temperature ambient air. It further reduces the equipment costs, space requiments, maintenance and water consumption costs required for cooling towers. The WET system would need some added elements to output to a chilled water distribution loop. Defining the configuration and quantifying this benefit was beyond the scope of the present study, but should be included in a full project evaluation.

Discussion and Conclusions

It is important to note that this brief exercise was a trial comparison of available sewer line data with available building energy demand data; certain implementations are far from optimal but they are illustrative of issues affecting viability.

The cost analysis indicates that the WET system, in this archetype, has a high cost of heat of $0.18/kWh over a 40 year project life. This is higher than *present* costs of electric resistance heating, though likely equivalent to it over such a long period. It is more expensive than using natural gas. Furthermore, additional deployment costs may exist that are included herein: additional building area, longer distances between buildings, safety and ventilation requirements, and the 9-storey building energy load we selected would still need a secondary source of heating. Yet, it is important to understand that there are several factors causing the proejc to be expensive here, but that other WET projects may be much more favourable:

1. The flow rates at this location are low, and thus the available heat is small relative to some of the fixed capital infrastructure costs of Technology #3.
   - There are economies of scale and larger installations should be pursued as a priority.
2. This office building archetype was mostly only daytime hours for five out of seven days a week , which doesn't take advantage of the continuous heat resource. The heat delivered relative to the capital investment is thus low and more expensive.
   - Heat demands that cover more hours of the day improve the economics, such as residential buildings and in particular buildings with 24-7 occupancy.
3. Cooling can be provided from the same WET system with minimal additional costs, which could significantly improve the overall return on investment by (a) selling a "second" product using the same capital investment and (b) replacing typical cooling equipment capital costs and O&M.
   - Applications with both heating and cooling should be investigated as a priority.
   - Levelized cost of heat may be poor metric for a WET system that can provide cooling too.
4. It would be unfair to compare this all-in economic evaluation with the simpler operational cost of alternative heating systems. Yet, full levelized costs of heating are rarely calculated for typical heating solutions such as natural gas – the full analysis should include cost to build and maintain the mechanical rooms, purchase of boilers, O&M of the equipment, etc. For context, natural gas utility costs are around $0.04/kWh, and the full LCOH may be around $0.08 to $0.09/kWh[1]. These costs will be rising by $0.04/kWh by 2030 when the proposed Federal carbon taxes reach $170/tCO$_2$e).
5. The building model is from a building with a poor building envelope (poor TEDI); because heat escapes rapidly, the operating schedule had heating only during times of occupancy and dramatic peak heating times in the mornings. This is a poor match for all heat pump solutions, including WET solutions, which have a higher capital cost per MW of peak heat capacity.
   - Newer and new buildings are a better match and high performance buildings with low TEDIs, and should be pursued as a priority.
   - This same size WET system could heat more than double the square footage of building space if it serviced new buildings built to new high performance standards.

This particular location for a WET system is not a foredrawn fail but a more comprehensive and specific set of factors for a new development that would need to be evaluated; for example, pursuing economies of scale, such as by coupling the WET system with geothermal systems and integration into a larger heat load or distric energy system for multiple new bulidngs. This location appears to have available lands for a geothermal system. Connecting multiple user types onto one DES is always advantageous to smooth out peak heating needs and, in particular, data centres, which are quite likley to be developed in Kanata North,– data centres need year-round cooling and thus would be delivering heat into the district energy loop during winter.

[1] LCOH for natural gas systems are rarely reported, the numbers used here are approximate and derived from a small number of on-line references.

Appendix K

Archetype Report #3 –
New Civic Hospital

Archetype Report #3 – New Civic Hospital

New Development Opportunity

Introduction

This archetype study is one of 4 undertaken within the City of Ottawa Sewer Waste Heat Scoping Study and provided as part of Sewer Waste Heat Scoping Study Final Report. It should be read within the context of the full report.

Key Archetype Parameters

Table 1: Key parameters of location, flow and temperature values used in the archetype study

Development Type	New Civic Hospital	
Architype Study Type	Wastewater resource analysis for potential new hospital	
Specific Location in Ottawa	West of Dows Lake (near Carling and Prince of Wales)	
Flow Data	CSO2020 Modeled flow	
Temperature Data	Synthetic, with reference to submersible probe data	
Sewer Line	SAN00987 sanitary called Mooney's Bay line	
Sewer Line Diameter	1050 mm	
Average Flow	68 L/s	85 L/s
Minimum Flow	31 L/s	58 L/s
Maximum Temperature (in winter)	16.9 °C	
Minimum Temperature	8.6 °C	

General Description

The Mooney's Bay trunk line collects sanitary wastewater starting in the Meadowlands/Viewmount neighbourhoods and flows north along the west side of Mooney's Bay, the Rideau Canal and Dow's Lake. It cuts straight through the parcel of land and proposed development plan for the new Ottawa Civic Hospital, which recently issued planning submission documents. As can be seen in Figure 2, the proposed new buildings are located on either side of this sanitary line. A WET system could be developed in, or adjacent to, underground levels of one of the new buildings and tap into a convenient location along the sanitary line.

The purpose of this study is to undertake a brief indicative look at the potential for this trunk line to support the heating needs of the new hospital development. Alternatively, or in addition, there are significant new developments in the neighbourhood north of Carling and west of the Trillium Line Light Rail corridor that could benefit from the development of a WET project on this trunk line. Sanitary flows will be higher for segments further north than the segment analysed here, as the outputs of the higher density area are added, including the additional flows of the potential new hospital.

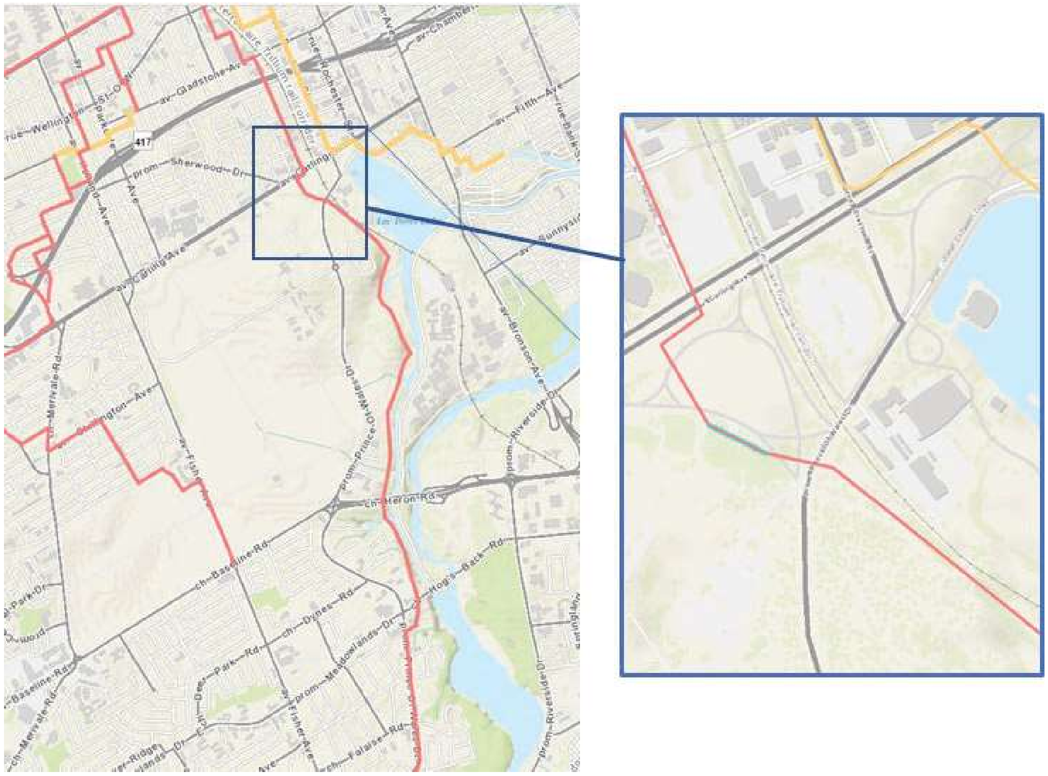

Figure 1 - Map of the configuration of Mooney's Bay trunk line and the SAN00987 segment (cyan highlight)

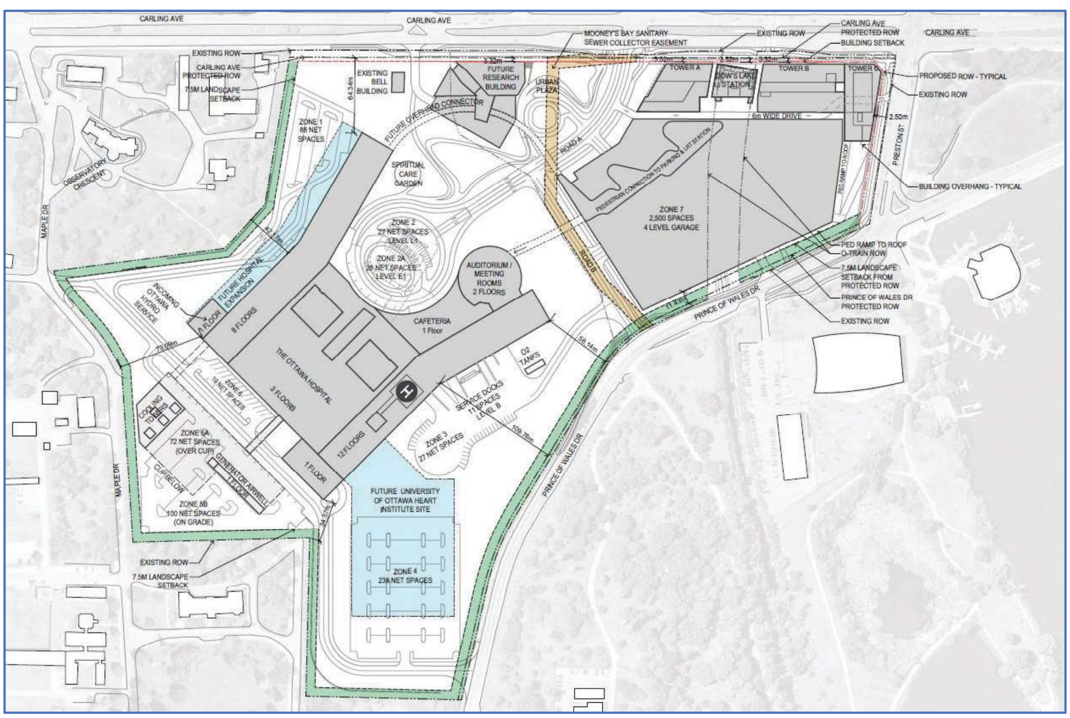

Figure 2 - Planning document showing proposed layout of buildings for the new Civic Hospital (retrieved from City of Ottawa website)

Analysis of Wastewater Heat Capacity

An hourly dry weather flow for the sanitary line was acquired from the City wastewater team – it is a modeled flow profile specific to the location. There is a high degree of uncertainty in the low flow data developed with this modeling and, in fact, two different modeling approaches they employ provide notable differences; we chose to use the lower flow dataset of Model A to be conservative. The City strongly recommends direct measurements during feasibility analysis.

The synthetic hourly temperature profile shown in Figure 3 was created from high quality submersible probe data from another location (Kanata West[1]), where short-term weather-induced changes to temperature were removed to produce a “dry-weather” temperature profile (this project’s main report provides further rational on this approach). In other parts of this Project, very similar temperatures and trends were observed on different sanitary lines where in-flows were somewhat similar to this line (a mix of residential and commercial from generally low-density zones), thus this temperature profile is anticipated to be reasonably indicative for the Mooney’s Bay trunk. Sanitary flow rate is the key factor for heat capacity and viability of a system, while sanitary temperature predominantly improves heat pump performance.

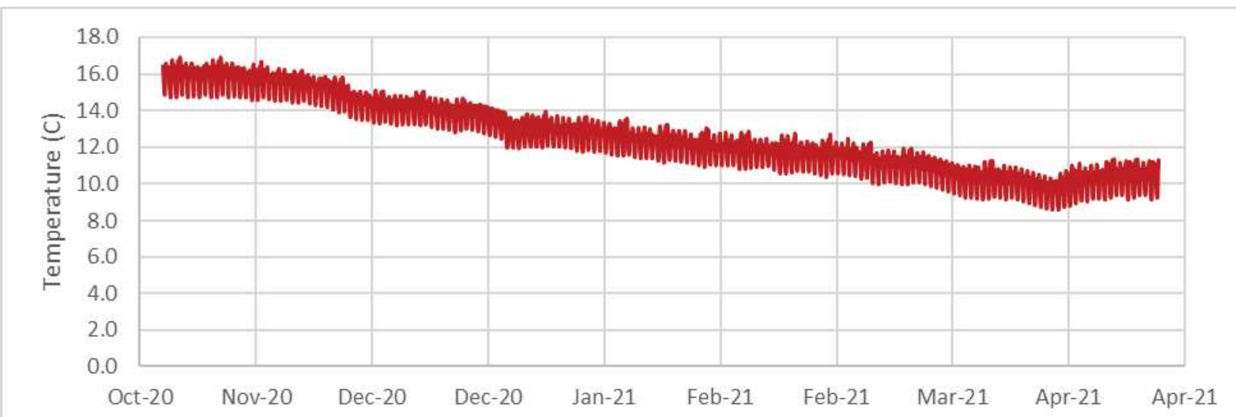

Figure 3 - Simulated temperature curve for the SAN00987 sanitary line

The hourly heat capacity of the sewer line was then calculated using these temperature and flow profiles. The calculations assume a 5 °C temperature drop in the wastewater from the heat exchange process but also imposes a constraint to maintain the wastewater temperature at the outlet of at least 5 °C to avoid icing (see the project’s Final Report for further discussion on these assumptions). The heat capacity in the line varies hour-by-hour, primarily due to flow variability, as shown in Figure 4.

Sorting the hourly data of the sewer line by decreasing magnitude gives the heat capacity duration curve of the sewer line, as shown in Figure 5. The blocky-ness of the curves relate to the fact that the data been created as a repeat of a single typical daily profile of the modeled flow data.

[1] Interestingly, this probe is part of the Wastewater COVID-19 Surveillance being undertaken by University of Ottawa, Children’s Hospital of Eastern Ontario and in partnership with the City of Ottawa. https://www.ottawapublichealth.ca/en/reports-research-and-statistics/Wastewater_COVID-19_Surveillance.aspx

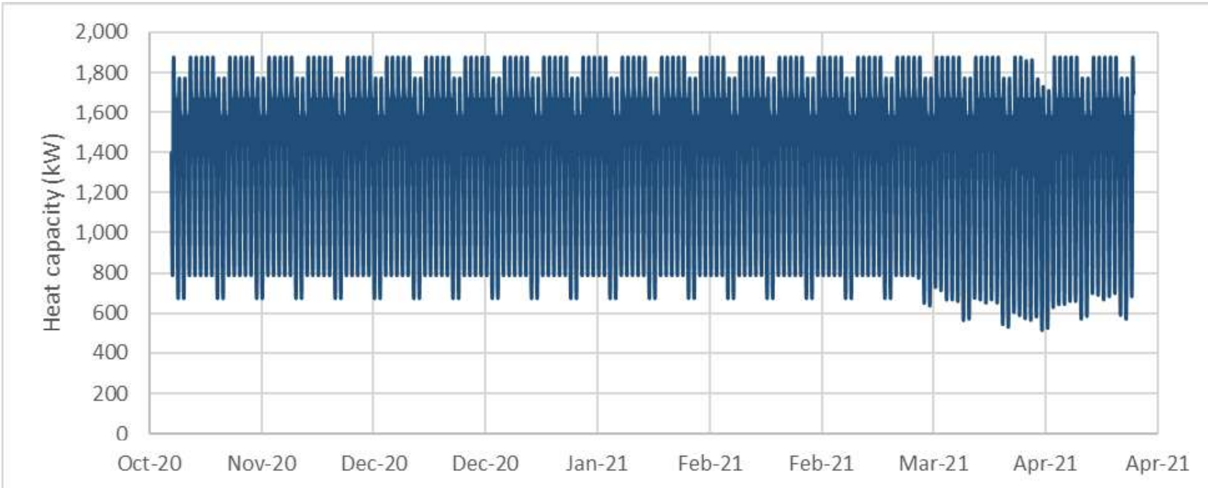

Figure 4 - Hourly WET heat capacity of the SAN00987 sanitary line

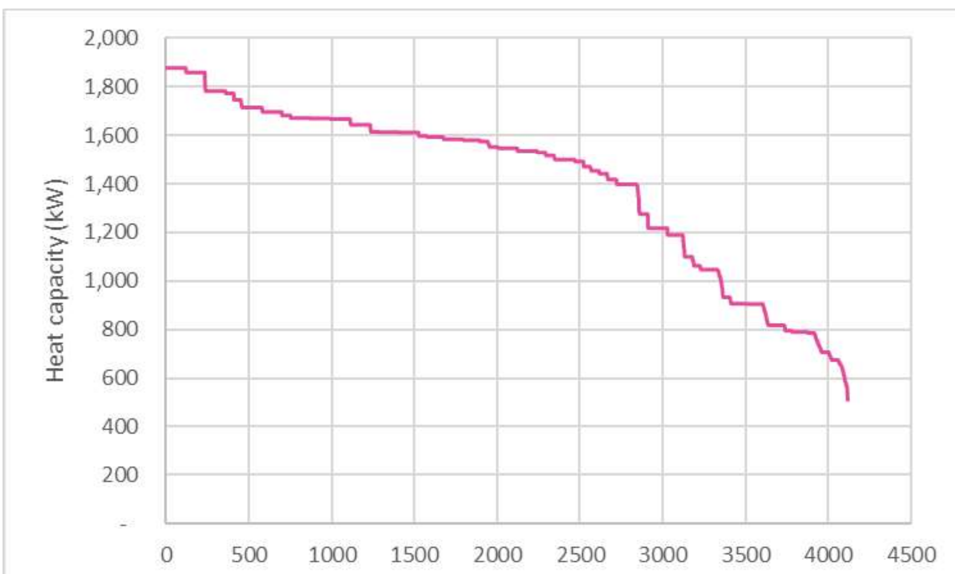

Figure 5 - Heat capacity curve of the SAN00987 sanitary line

The indicative calculations find that the minimum, always available, heat capacity of this sanitary line during the heating season is approximately 510 kW, while for a majority of the heating season the capacity is greater than 1.4 MW (for more than 2500 hours of the year). Heating capacities could be higher if flow values turn out to be larger, and the alternate flow data (IMP2019 model) were higher by more than 20%. Cooling capacities, though not evaluated herein, would typically be expected to be of a similar magnitude.

From publicly available information from the released planning documents, the new hospital is expected to be 2.5 million square feet and be built to high level of energy efficiency:

> *"The development is based on a hybrid of leading sustainability models, including the National Capital Commission's Sustainable Development Strategies, the One Planet Living framework, the Leadership in Energy and Environmental Design (LEED) rating system, and the WELL Building Standard."*

The New Civic Development website suggests "net-zero ready", without further the definition of whether it is net-zero energy or net-zero carbon. We suggest that net-zero *carbon* design targets should be seriously investigated. Hospitals are large consumers of energy, making net-zero energy hard to achieve (the amount of solar generation required to match facility consumption would likely exceed rooftop capacities). With purposeful selection of very low carbon heating, solar generation on a majority of the rooftops[2], and the low carbon intensity of the Ontario electricity grid, a very low operational carbon footprint could be achieved. Furthermore, reductions in carbon emissions are the important planetary issue, whereas *where* the energy is generated (on-site or purchased from external supplies) is of smaller importance and trying to generate all energy on-site can be a difficult design target.

There are, as of this moment, no examples of constructed net-zero carbon hospitals and no design information is yet available for this development. Working simply from the square footage of the facility and knowing that a purposefully designed low-energy building could reduce its heating demands by more than 50% compared with typical hospitals, we estimate that the Mooney's Bay sanitary line may be able to support between 5 and 60% of the hospital's energy needs. The sanitary outflow of the hospital will also provide a sizeable additional contribution to heat capacity that could be harvested separately or in combination with this WET system.

WET System Implementation

The most opportune time to evaluate and develop a WET system is during the planning stages of a new facility, when:

- the location of the WET system can be integrated into the site plan in an optimal way;
- design of the building's energy systems can be optimized for use of heating a cooling supply, including hybrid use of the WET thermal supply with other thermal equipment, and definition of working temperatures of internal distribution systems.

This enables the civil construction costs of the WET system to be much smaller given the already consumed civil works for the project.

The WET technology that may be most suitable for this archetype would be "Technology 3", which involves a wet well, filters and hydraulic pumps to move the wastewater through a heat exchanger specially

[2] Solar photovoltaic systems have relatively attractive paybacks, of the order of 10 years, especially when integrated directly into a project, and can be considered for immediate deployment as part of construction, avoiding the "ready" categorization.

designed for brown water; the technology and main suppliers are further described in the main report. This technology is suitable for flow rates > 30 L/s and with access to an existing wastewater pipe.

A hospital would typically be expected to have quite sizeable amounts of sanitary output itself, which should also be evaluated for harvesting of the waste heat, either as a separate system or integrating into the wet well of the above-described system. This wastewater flow may have stronger daily variations in flow rates and temperatures due to extreme proximity to the source and high daytime operations.

The WET system is expected to operate at an average coefficient of performance of over 4 most of the time (efficiency greater than 400%), which can result in utility costs that are comparable to natural gas heating, and become lower cost than natural gas if (i) carbon taxes rise to near or beyond the presently proposed rate of $170/tonne by 2030, and/or (ii) the facility's electricity consumption rates are low, such as under the "Class A Global Adjustment" Ontario electricity rate structure. A large hospital complex is likely to be in this rate category.

The WET system can also provide cooling at a higher efficiency than typical air conditioners or chillers plus cooling towers because it is easier to reject heat into a moderate temperature liquid medium than a high temperature ambient air. This benefit should be included in a full project evaluation. A WET cooling system also avoids the space, money, and water consumption required for cooling towers.

A WET system has analogies with a ground-source heat pump system (GSHP), as they both exchange thermal energy with underground infrastructure. The WET system *may* have lower costs to implement and higher operational efficiency than an equivalent-sized array of boreholes of a closed-loop GSHP system. Furthermore, a closed-loop GSHP has a design constraint of only being able to support equal heating and cooling (such that there is no change year-over-year of ground temperatures), while a WET system can support any combination of heating and cooling demands. If there are deep aquifers at the site, an open-loop geothermal system is an alternative option that may have capital costs similar to a WET system; a deep drilling test is required to determine feasibility. Finally, a WET system can be coupled with a GSHP system to fully cover the thermal needs of a facility.

Conclusions

The brief analysis of this study suggests that the flow rates in this sanitary line are modest but sufficient for the order of 1 MW of heating and cooling, which may provide a material percentage of a newly designed, highly energy efficient hospital.

These values should be understood as a rough indication of resource potential only, since flow rates are modeled and the temperature data is from another trunk line assumed, for this exercise, to be a reasonable proxy for this trunk line.

This WET system using City sewer flow can potentially be integrated with wastewater outflow of the hospital itself as well as the other low carbon thermal supplies. The New Civic Hospital Development project is reported to be in the second of five stages of the planning process, which is an excellent time to initiate investigations of a WET system. The very first step would be to deploy submersible temperature and flow probes in the Mooney's Bay wastewater line to confirm the thermal resource over the heating and cooling seasons.

J.L.Richards
ENGINEERS · ARCHITECTS · PLANNERS

Appendix L

Archetype Report #4 –
LeBreton Flats

Archetype Report #4 – LeBreton Flats
Heat Supply for a District Energy System

Introduction

This archetype study is one of four undertaken within the City of Ottawa Sewer Waste Heat Scoping Study and provided as part of Sewer Waste Heat Scoping Study Final Report. It should be read within the context of the full report.

Key Archetype Parameters

Table 1: Key parameters of location, flow and temperature values used in the archetype study

Development Type	District Energy System	
Archetype Study Type	Wastewater resource analysis for potential new district energy system	
Specific Location in Ottawa	LeBreton Flats (parcels West of Booth St)	
Flow Data	Modeled flow from the City's CSO2020 model.	
Temperature Data	Synthetic, with reference to submersible probe data	
Sewer Lines	West Nepean Collector (SAN01761)	Cave Creek Collector (SAN73141)
Sewer Line Diameter	1,650 mm	1,650 mm
Sewer Line Depth	12.5 m	6.1 m
Average Flow	691 L/s	157 L/s
Minimum Flow	371 L/s	72 L/s
Maximum Temperature (in winter)	16.9 °C	
Minimum Temperature	8.6 °C	

General Description

LeBreton Flats is the location of multiple major City of Ottawa sanitary trunk lines. It is also a region in the early stages of a massive, high-density urban development. Furthermore, the National Capital Commission (NCC), as the landowner and development coordinator of many parcels of LeBreton Flats, is in the process of redeveloping it in a manner that includes a broad set of community and sustainability goals. The NCC Master Concept Plan for LeBreton Flats includes the following sustainability strategy goal:

> *"A focus on transit and active mobility, as well as a commitment to zero carbon buildings, will ensure that LeBreton Flats will become one of the most sustainable communities in the country."*

The sum of these characteristics makes for a great synergy between LeBreton Flats and a wastewater energy transfer (WET) project.

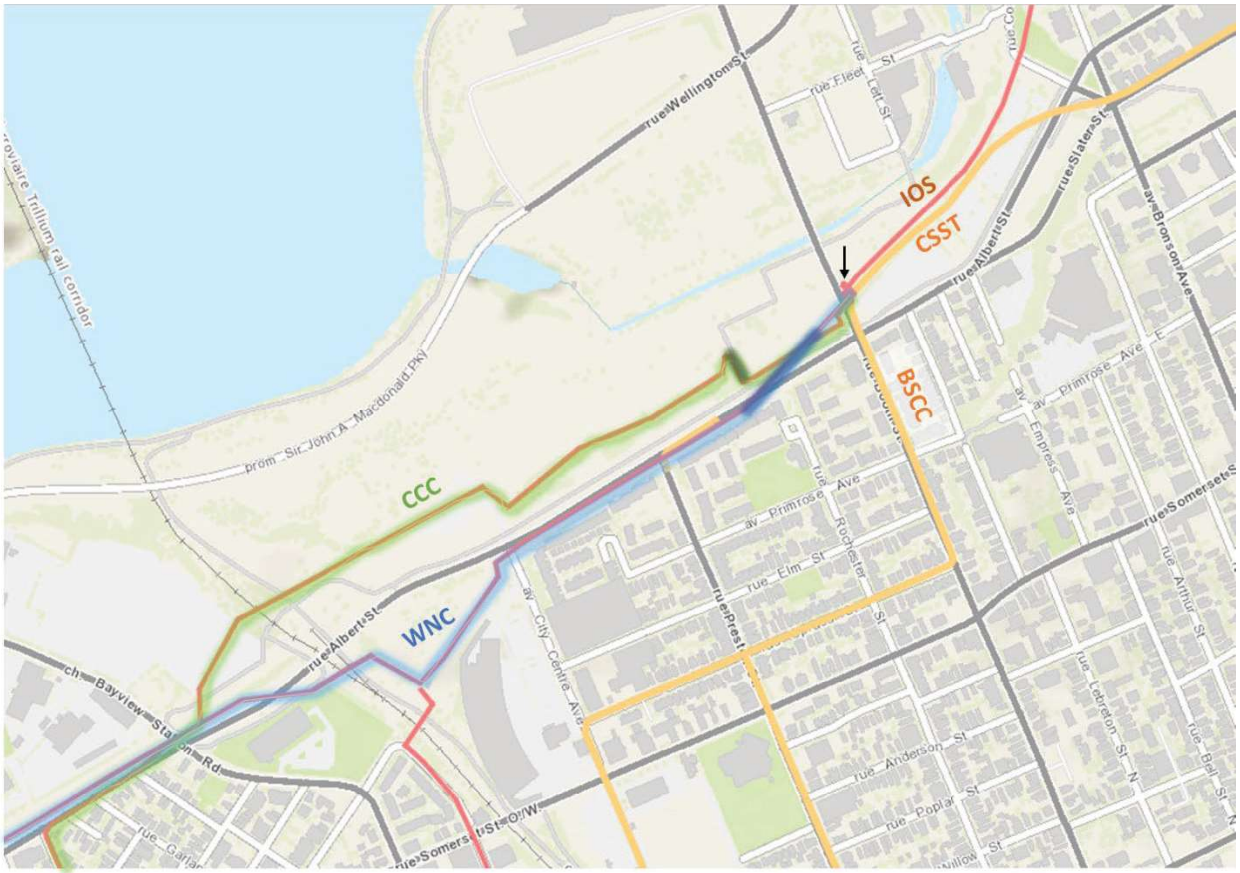

Figure 1 - Map of the wastewater trunk lines in LeBreton. The Cave Creek Collector (CCC) is highlighted in green and the West Nepean Collector (WNC) is highlighted in blue. Segments where the flow data was received are shown with a darker highlight. The arrow indicates a regulator station where the CCC, WNC and BSCC combine

The West Nepean Collector (WNC) and Cave Creek Collectors (CCC) are major wastewater trunk lines that flow west to east in the region of LeBreton Flats, as shown in Figure 1. The lines cross each other twice but, because they are at significantly different depths, they do not interact with each other until their junction at a major regulator station just east of Booth Street (black arrow in Figure 1); WNC is quite deep while CCC is shallower. These flows merge with the Booth Street Combined Collector (BSCC) at the regulator station and flow into the Interceptor Outfall Sewer (IOS) which continues to flow towards the northeast and under downtown. The newly built Combined Sewage Storage Tunnel (CSST) serves to reduce surcharging by detaining surges in wastewater flow during storm events.

The NCC reports that they are evaluating the development of a district energy system for the parcels of land in the large area to the west of Booth St. At a preliminary conversation, they expressed interest in understanding WET systems as a possible low carbon thermal supply into this future district energy. WET systems could also be developed for individual buildings along this high intensification corridor outside of the NCC managed lands. This archetype study examines the thermal heat capacity that may be available from these two sanitary lines.

Analysis of Wastewater Heat Capacity

The WNC has very high flow rates and, while the CCC flows are also substantial, though 5 times less than WNC. Both trunk lines are sanitary wastewater pipes, though both have some inputs from combined sewer lines and from stormwater in-flows. Our approach is to examine dry weather flows (i.e., when there is no stormwater flow), as a conservative evaluation of resource capacity. Sanitary flow rate is the key factor for heat capacity and viability of a system, while sanitary temperature improves heat pump performance. Temperatures are assumed to be the same between the two lines.

An hourly dry weather flow for the sanitary lines was acquired from the City wastewater team – it is a modeled flow profile specific to each of the locations. There is a high degree of uncertainty in the low flow data developed with this modeling and, in fact, two different modeling approaches the City provided notable differences; we chose to use the lower flow dataset in our analysis to be conservative. The City strongly recommends direct measurements during feasibility analysis.

The synthetic hourly temperature profile shown in Figure 2 was created from high quality submersible probe data from another location (Kanata West), where short-term weather-induced changes to temperature were removed to produce a “dry-weather” temperature profile (further rational on this approach can be found in “Sewer Waste Heat and Geothermal Energy Study - Final Report”).

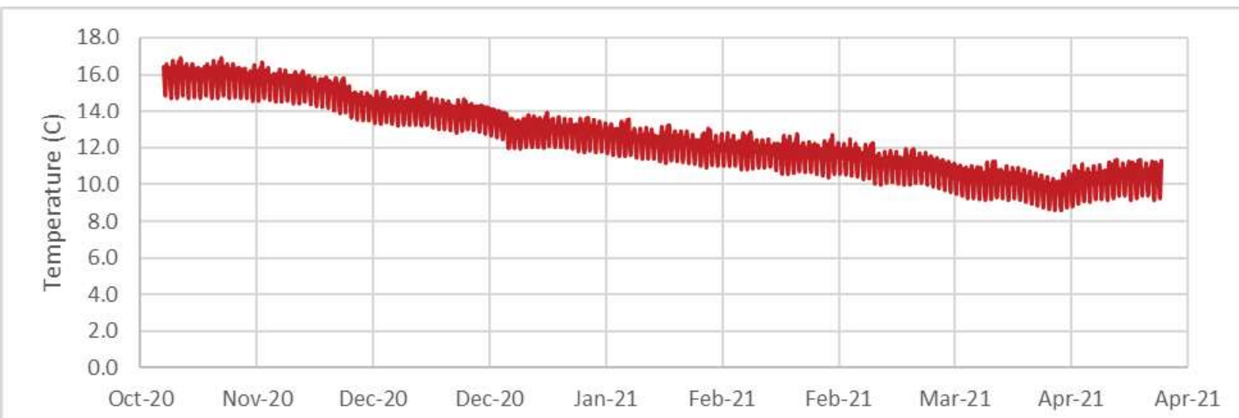

Figure 2 - Simulated temperature curve used in this study

The hourly heat capacities of the sewer lines were then calculated using hourly temperature and flow profiles. The calculations assume a 5°C temperature drop in the wastewater from the heat exchange process but also imposes a constraint to maintain the wastewater temperature at the outlet of at least 5°C to avoid icing. The latter constraint only comes into effect when the wastewater is lower than 10°C, which tends to be in the spring; note that since building heating demand peak in the winter, this constraint may be of minor consequence. Also note that spring runs-off tend to increase flow, which will boost heat capacity, but this effect is not captured in the dry-weather model used herein (for contrast see Archetype #2 which uses measured temperature and flow data). Overall, heat capacity in the line varies hour-by-hour, primarily due to flow variability, as shown in Figures 3 and 4.

Sorting the hourly data of the sewer line by decreasing magnitude gives the heat capacity duration curve of the sewer line, as shown in Figures 5 and 6. The blockiness of the curves relate to the repeating daily profile of the modeled flow data. The minimum heat capacities occur in the spring, when low wastewater temperatures means that the total heat capacity that can be drawn is constrained by our assumption that wastewater output should be kept above 5°C.

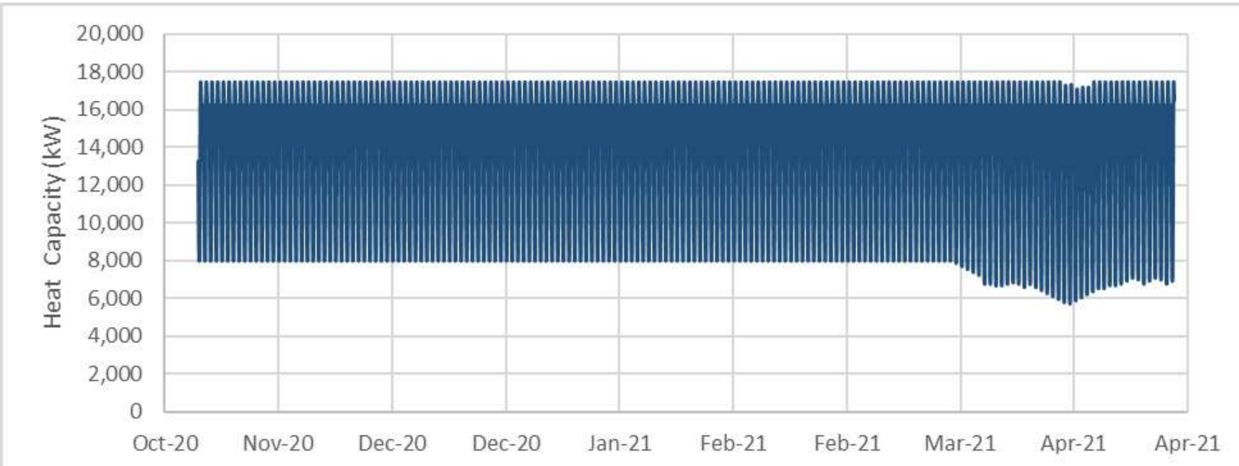

Figure 3 - Hourly WET heat capacity of the West Nepean Collector

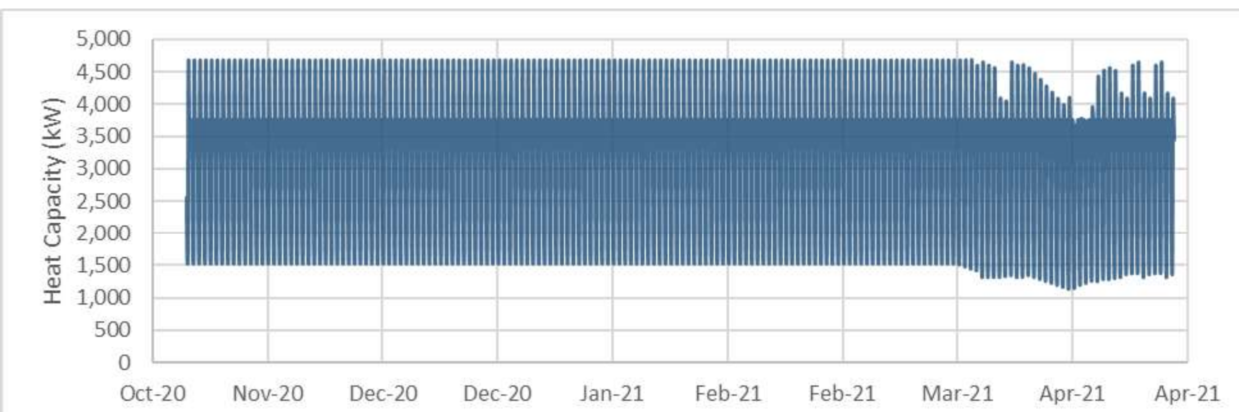

Figure 4 - Hourly WET heat capacity of the Cave Creek Collector

The indicative calculations find that the minimum heat capacity for the WNC during the October 29th to April 19th period was 5.7 MW, while the minimum heat capacity for the CCC during the same period was 1.1 MW. These minimum capacities occurred during March and April when the assumed constraint of staying above 5°C reduces harvested heat; for a majority of the heating season (more than 2500 hours) the heat capacities are 14 MW and 3 MW, respectively. These minimums occur at night, with higher values during the day. Buildings with high performance envelopes that can hold heat in (a form of thermal storage) can potentially be heated with consideration of the daily average values. A sizeable district energy system, as is possible at this location, may be likely to have other supplies which will be controlled to work together to meet the demand profile. In all cases, detailed hourly analysis would be required during design work.

Cooling capacities, though not evaluated herein, would typically be expected to be of a similar magnitude.

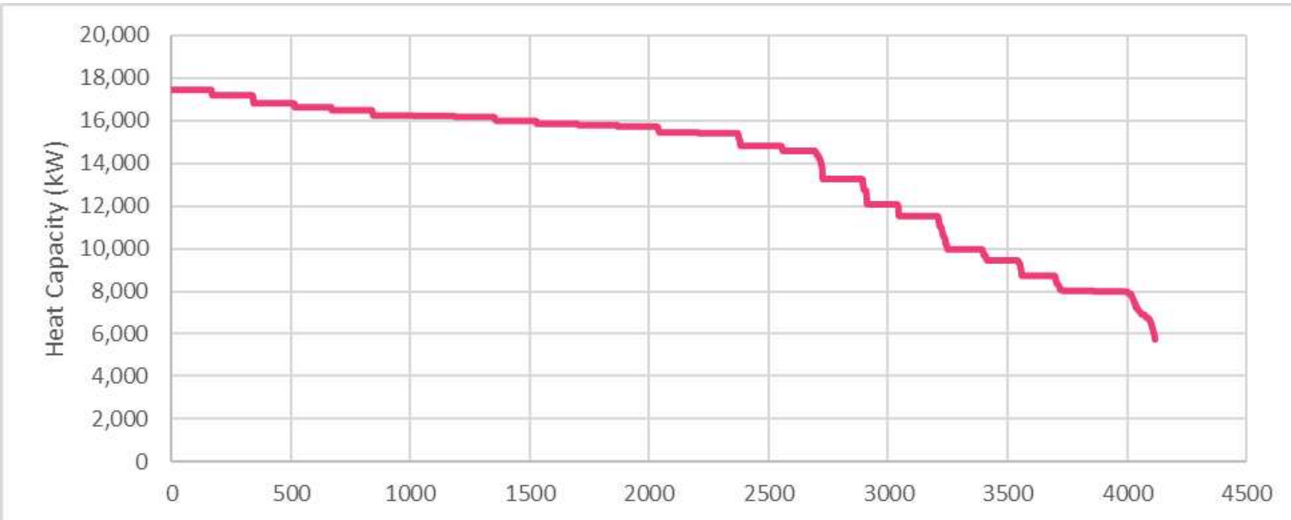

Figure 5 - Heat capacity duration curve of the West Nepean Collector wastewater flow

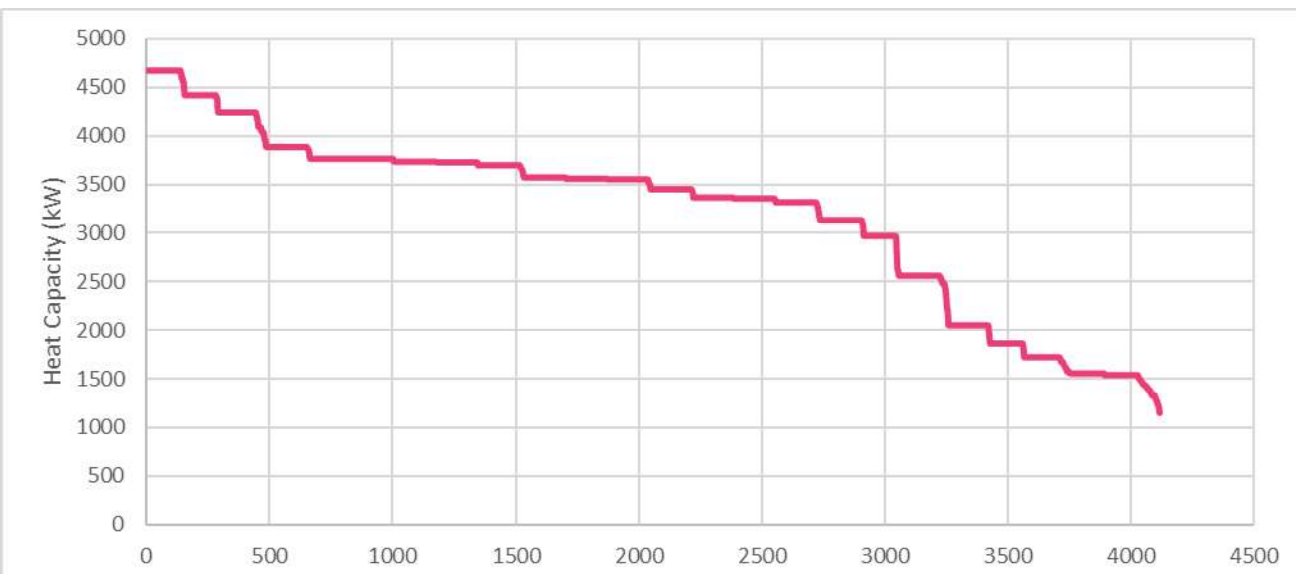

Figure 6 - Heat capacity duration curve of the Cave Creek Collector wastewater flow

WET System Implementation

The WET technology that would be most suitable for this archetype would be “Technology 3”, which involves a tapping off of the municipal line to direct wastewater into a wet well, with filters and hydraulic pumps to move the wastewater through a heat exchanger specially designed for brown water; the technology and main suppliers are further described in “Sewer Waste Heat and Geothermal Energy Study - Final Report”. This technology is suitable for flow rates > 30 L/s and has scalability to very large flow rates and heat delivery values.

The CCC and WNC may each be viable for supporting a WET system, either separately or in a combined manner, depending on many factors. A few examples of development timing and cost factors that are different between the two are:

- CCC, the shallower of the two lines, is being relocated to be aligned with the Albert St corridor (to reduce conflict with future building foundations and other building services in Lebreton Flats). This presents the opportunity to implement either: (i) specialized pipes that have embedded heat exchange tubes, as per Technology #2; or (ii) some advanced work in creating tie-ins and reserved zones for a WET system wet well as required for Technology #3.
- WNC, being deeper, would be more expensive to develop, but may be at a depth that coincides with depths of future underground parking levels of the buildings, in which case excavation costs are already partially committed; space allocation and civil works should be coordinated into planning and design of the buildings.
- The extensive sanitary output from the new developments at LeBreton will flow into the CCC and/or WNC, dependent on the grades, required slopes, capacities and civil site services design. Their wastewater is an additional thermal resource, representing new water flows, that could also be harvested by appropriate location of the tie-ins and the WET system.

The WET system is expected to operate with a coefficient of performance greater than 4.0 for most of the time (efficiency greater than 400%), which can result in utility costs that are comparable to natural gas heating and become lower cost than natural gas if carbon taxes rise to near or beyond the presently proposed rate of $170/tonne by 2030. The WET system can also provide cooling at a higher efficiency than typical air conditioners or chillers and cooling towers because it is easier to reject heat into a moderate temperature liquid medium (e.g. 15 – 20°C) versus high temperature ambient air (e.g. 25 – 35°C). A WET cooling system also avoids the space, operational and maintenance costs, and water consumption required by cooling towers.

A WET system has analogies with a ground-source heat pump system (GSHP), as they both exchange thermal energy with underground infrastructure. The WET system *may* have lower costs to implement and higher operational efficiency than an equivalent-sized array of boreholes of a GSHP system. Furthermore, a closed-loop GSHP has a design constraint of only being able to support equal heating and cooling (such that there is no long-term change in ground temperatures), while a WET system can support any combination of heating and cooling demands. If there are deep aquifers at the site, an open-loop geothermal system is an alternative option that may have capital costs similar to a WET system; a deep drilling test is required to determine feasibility. Finally, a WET system can be coupled with a GSHP system and other energy supplies, especially within the context of a large district energy system.

Multiple WET systems developed on the same trunk line have the potential to conflict with each other if the upstream WET system is drawing the maximum heat capacity from the wastewater flow. Partial use of heat capacities at two locations would be expected to work, as per energy balance principals. Furthermore, it was generally observed during the main part of this study that there is notable heat exchange between wastewater lines and their environment, wherein wastewater temperatures during the heating season tend to stabilize with ground temperatures. Some WET suppliers believed that this stabilisation occurred over very short distances (100s of meters). This effect may enable multiple WET systems along the same major trunk line - but these interactions need to be further investigated and quantified.

Conclusions

The flow rates in the WNC and CCC are both high. The brief indicative analysis of this study suggests that the minimum heat capacities for the WNC and the CCC were around 6 MW and 1 MW, respectively. These minimums occur during March and April, which is when building heating and cooling loads are low; for a majority of the heating season (more than 2500 hours) the heat capacities are 14 MW and 3 MW, respectively. These values are notable and could provide a percentage of the energy supply to a future district energy system at LeBreton Flats or other large facilities along this Albert Street corridor.

These values should be understood as a rough indication of resource potential only, since flow rates are modeled, and have a reasonable degree of uncertainty. Although the temperature data is from another trunk line, the temperatures observed during the study were reasonably consistent and assumed to be a reasonably proxy for the WNC and CCC trunk lines.

This WET system using City sewer flow can potentially be integrated with wastewater outflow of the LeBreton development itself. Consideration of WET system implementation is best started as early as possible for an optimal site services plan. One task that could be initiated immediately is to deploy submersible temperature and flow probes into these trunk lines to confirm the temperature and flow patterns of each line over both the heating and cooling seasons.

Appendix M

Open Loop Geothermal
Resource Scoping Study

JLR No.: 27623-020
Revision: 01

November 2, 2021

Open Loop Geothermal Resource Scoping Study

J.L.Richards
ENGINEERS · ARCHITECTS · PLANNERS

Value through service and commitment

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1.0 Introduction

J.L. Richards & Associates Limited (JLR) was retained by the City of Ottawa (the City) to provide a preliminary study for assessment of the geo-exchange open loop resources within the City of Ottawa. The scope of this project is being executed under Standing Offer for Professional Engineering Services 30717-92500-S01 - Category 1 - Planning, Feasibility, Pre-Engineering, Environmental Studies and Assessments (the SOA).

Increasing the use of geothermal heat pumps by buildings across the City is one of the potential means of achieving the City's greenhouse gas (GHG) emission reduction targets. The City's intention for this study is to provide a survey of the open loop geothermal resources that can help the stakeholders with reducing the risk of decisions in developing the geothermal projects. This study will provide the City with a scan of the available well records and explaining how the obtained information from these records can help with establishing a methodology for the assessment of different locations for open loop geothermal technology. The well records have been analyzed, categorized, and incorporated into an ArcGIS user interface.

2.0 Background

The City of Ottawa Energy Evolution Program has set a goal for the City to achieve carbon neutrality by 2050, and for City corporate operations to achieve carbon neutrality by 2040. One key need within this plan is for buildings and infrastructure to move to zero carbon energy using a range of viable technologies including air source heat pumps, ground source heat pumps, district energy systems, waste heat recovery, and renewable natural gas.

Ground source heat pumps can be used in different configurations such as open loop, horizontal closed loop, and vertical closed loop. In open loop configuration, the groundwater is directly used as a heat carrier. When productive aquifers are accessible, this type of geothermal technology is technically feasible and has generally lower costs than closed-loop systems. The common practice is to drill two wells: the extraction well, and the injection well. The extraction well pumps the groundwater towards the building where its energy is used, then the injection well injects the water back to the same aquifer with the same rate but at a slightly different temperature.

The purpose of this study is to evaluate potential locations of the open-loop geothermal projects within the boundaries of the City of Ottawa by using existing well data and reviewing information on geology and the yield of the aquifers. Specifically, the objectives and deliverables of this report are as follows:

- Explain geothermal heat pumps systems
- Describe critical parameters from the well data for open-loop geothermal systems
- Assess the available well data
- Categorize the wells based on their suitability to open loop systems
- Compile the data in ArcGIS user interface
- Evaluate how geological information further explains likelihood

3.0 Geothermal Heat Pumps

Geothermal heat pumps are systems that use a fluid to exchange heat to and from the ground along with a heat pump to provide heating and cooling to a building. The stable temperature of the earth below a certain depth is used as an energy source and sink. While the air temperature varies between -40°C in winter to 35°C in summer, the temperature of earth and underground water stays in the range of 6 to 10°C all year long. This relatively stable temperature provides an attractive source for extraction of heat in the winter and injecting of heat in the summer; it is accessed by burying pipes (horizontally or in vertical bore holes) and circulating a liquid through them. Two different types of such systems are closed loop and open loop. In both cases, a heat pump is used to exchange the heat between the building and the outside loop.

In **closed loop geothermal systems**, a mixture of antifreeze and water passes through the closed loop pipes that are buried in the ground. This heat transfer fluid does not interact directly with the ground or ground water. This system requires a long length of buried loop to ensure that sufficient heat transfer occurs between the ground and the circulating fluid. Two main variations of closed loop systems are horizontal and vertical. In **horizontal closed loop systems,** the pipes are laid horizontally in the ground which requires accessibility to a large area of space. This makes the horizontal variation difficult to adopt in dense city areas. **Vertical closed loop systems**, on the other hand, involve pipes which run vertically in several boreholes 30 to 150 m deep, but which can be as deep as 300 m. The two pipes are placed inside each borehole and are connected by a U-bend at the bottom; these pipes are then grouted in place with thermally conductive grout. This reduces the need for the accessible land, but it can still be challenging to locate several boreholes in a small site. It should be noted that since the piping in these vertical bore holes are grouted in place, the ground loop involves little to no maintenance and can be placed below parking lots or even installed underneath a building foundation. The limiting factor in the feasibility of closed loop geothermal systems is the availability of space for the ground loop installation, as well as the high cost of drilling. Closed loop systems also must be properly designed to avoid overheating or overcooling the ground over time; this can occur when the annual heating and cooling energy loads of a building are not balanced. A closed loop system can be expected to cause a seasonal variation in ground temperature (which will affect system efficiency at the end of a season); however, if not properly designed, the temperature may not recover after a full year cycle. The result over time can be the degradation of the system performance or system failure.

Open loop geothermal systems, also referred to as groundwater heat pump systems (GWHPs), directly use the ground water as a heat carrier. A well-doublet scheme is the most common installation method in which an extraction (supply) well pumps the groundwater up and to the building, and after passing through a heat pump, an injection (diffusion) well injects the water back into the same aquifer at the same rate; a schematic of the open loop system installation is shown in Figure 1. It is common for ground water to flow in a given direction, so to avoid a short circuit between the two wells, the rejection well is ideally installed “downstream” of the source well. This configuration ensures that the rejected water is not recirculated through the system and that the *source* water ground have the same temperature as the ground temperature throughout the year. This system inherently avoids long term ground temperature variation which occur in closed loop systems over the course of a season, and which may even change year-over-year if there are unbalanced heating/cooling loads (as discussed above).

When used in the larger systems (e.g., commercial buildings, universities, and hospitals), adequate control and monitoring measures are required. In such systems, water that is withdrawn from the extraction well, is pumped through several devices providing control and monitoring, as well as the heat exchanger and then returns to the aquifer through the injection well.

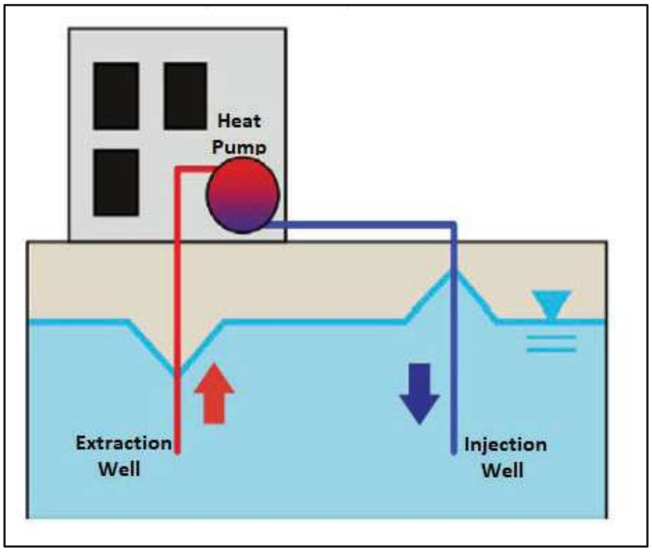


Figure 1: Schematic of an open loop geothermal installation

It should be noted the ground water piping loop runs from the source well through a closed heat exchanger, then to the rejection well with no exposure or interaction with the atmosphere or other water sources. This means that water quality is not affected and that there should be no environmental concerns. It also means that the pumping power is only required to overcome frictional losses in the pipes and heat exchanger, and is not affected by head loss (the inlet and outlet are at the same depth).

Due to the direct usage of underground water, which provides a constant temperature and high thermal conductivity, open loop systems offer a higher efficiency relative to closed loop systems. The system also requires fewer boreholes resulting in cost savings versus closed loop systems – often the open loop system can be half the capital expense of a closed loop system, though costs advantages do vary with ground conditions and system size. Hence, when there is enough groundwater, the feasibility study of an open loop geothermal system is highly recommended.

However, the design of the open loop geothermal system is dependent to the aquifer characteristics and the well yields. The limiting factor dictating the feasibility of an open loop geothermal system is the presence of sufficient ground water. In the absence of ground water, open loop systems cannot be relied upon and a closed loop system is a likely feasible alternative.

Implementation of a geothermal system is an iterative process that consists of pre-feasibility, feasibility, confirmation, design, and implementation steps. The feasibility stage starts when a client shows their desire for a geothermal system. In the feasibility stage, an initial evaluation from the site and geology will be undertaken, which may be followed by energy models on several geothermal options such as vertical closed loop, horizontal closed loop, and open loop.

Generally, conducting field tests by installing test wells is the most accurate method to obtain information about the aquifer such as porosity, conductivity, storage coefficient, and depth of water. However, performing these tests are expensive and could be economically infeasible in small geothermal projects. In the Ottawa area, drilling and pump testing a deep (180 m) test well for a commercial-sized open loop geothermal system can cost approximately $25,000.

Before incurring costs of this magnitude, a preliminary desktop study of published information and data about the local area and existing well records can be undertaken. The aim is to review if existing information indicates a likelihood of a suitable aquifer. If it looks sufficiently likely, then a test-well should be undertaken. Drilling a test well along with specific testing of the borehole (thermal conductivity test and/or water pump test) will show the detailed characteristics of the geology/hydrogeology and will help with a more detailed and accurate estimation of the costs of the project. Further explanations of these two steps are in the next section.

If an open-loop system is ruled out by either of these steps, then a closed loop system should be considered.

A common alternative heat pump solution to geothermal systems are air source heat pumps. These systems are considerably less expensive to install, but they have a lower efficiency due to their reliance on air as a heat source/sink. Seasonal variation of the air temperature hinders the performance of the heat pumps system. Hence, air source heat pumps often can't heat sufficiently in the coldest hours of the year, requiring additional back-up heating equipment. Cold climate air source heat pumps technologies are emerging but are still limited in their ability to heat in the coldest days of the year in Ottawa, typically requiring a resistive back-up heater.

4.0 Well Record Data

4.1 Ontario Well Records

The government of Ontario has collected the well record data from 1899 to present. As prescribed by Regulation 903, the well information is submitted by the well contractors and this provides a dataset that is stored and made publicly available in the Water Well Information System (WWIS). The data contains the geology, material properties and groundwater information, which is important in geotechnical and groundwater site assessments. The well data used in this study was downloaded on November 2020 from the Ontario well record database; more than 15,000 well records were reviewed and categorized, as further explained herein.

Figure 2 indicates the main parameters related to construction and performance of a typical well. By drilling a well, different layers of the underground are identified. The topsoil and other unconsolidated materials such as gravel, sand, silt and clay, make the overburden. The solid rock underlying these materials is called bedrock.

A water table describes the boundary between water-saturated ground and unsaturated ground. Below the water table, rocks and soil are full of water, but above the water table, water is unsaturated and is called the soil moisture.

Pockets of water existing below the water table are called aquifers. These aquifers exist in various layers of bedrock and are typically higher yield than the surface water or shallow aquifers in the upper water table (not shown in the schematic).

Parameters such as static water level and drawdown are explained later in this report.

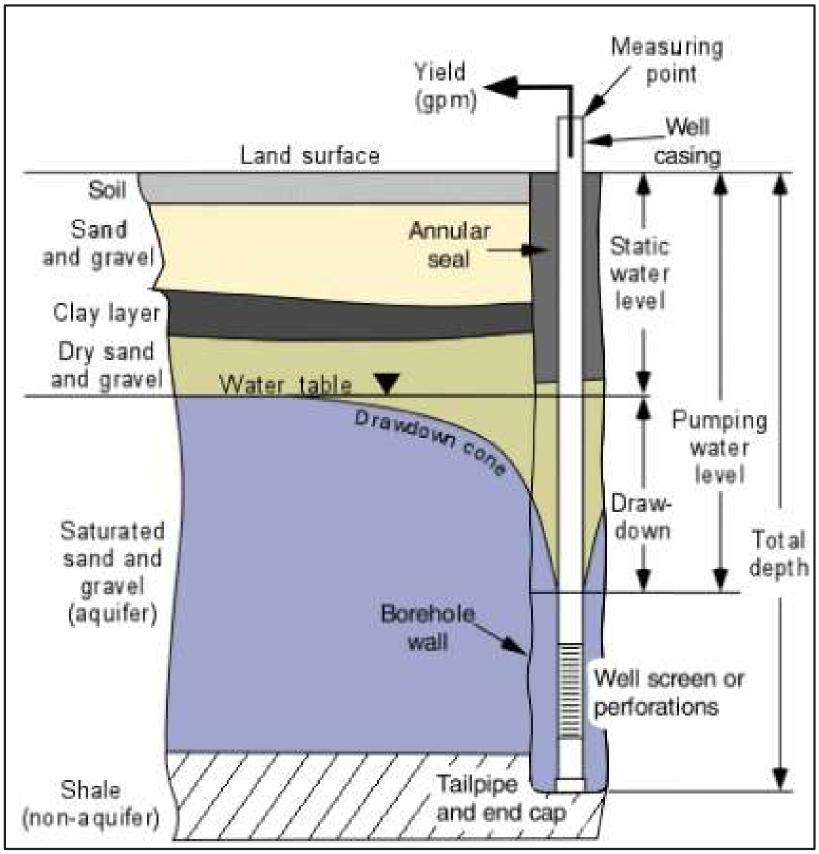
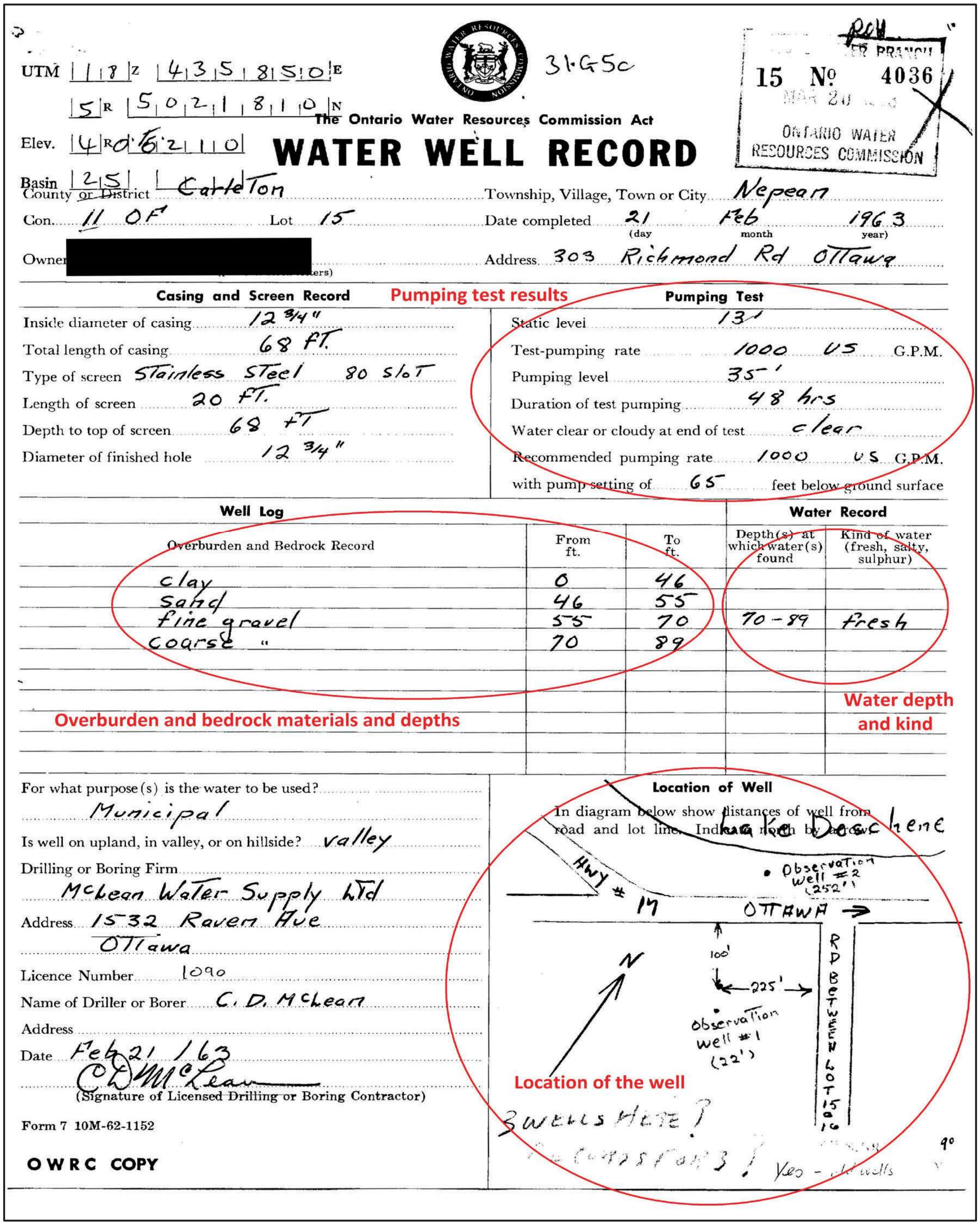


Figure 2: Main parameters related to construction and performance of a typical well

As shown in Figure 3, the Ontario water well records report the pumping test results, overburden and bedrock materials and depths, the depth at which the water is accessed and its quality, and the location of the well.

Generally, the important parameters that can be directly or indirectly extracted from the well records are: water flow rate, depth of water including static water level, pumping water level and drawdown level, depth of the well, and presence of sandstone, limestone, and granite (bedrock) and their depths.



UTM 1 18 Z 4 3 5 8 5 0 E
5 R 5 0 2 1 8 1 0 N
Elev. 4 R 0 6 2 1 1 0
Basin 2 5

31G5c

The Ontario Water Resources Commission Act

WATER WELL RECORD

15 № 4036
MAR 20
ONTARIO WATER RESOURCES COMMISSION

County or District Carleton — Township, Village, Town or City Nepean
Con. 11 OF — Lot 15 — Date completed 21 (day) Feb (month) 1963 (year)
Owner [redacted] — Address 303 Richmond Rd Ottawa

Casing and Screen Record		Pumping Test	
Inside diameter of casing	12 3/4"	Static level	13'
Total length of casing	68 FT.	Test-pumping rate	1000 US G.P.M.
Type of screen	Stainless Steel 80 slot	Pumping level	35'
Length of screen	20 FT.	Duration of test pumping	48 hrs
Depth to top of screen	68 FT	Water clear or cloudy at end of test	clear
Diameter of finished hole	12 3/4"	Recommended pumping rate	1000 US G.P.M.
		with pump setting of	65 feet below ground surface

Pumping test results

Well Log / **Water Record**

Overburden and Bedrock Record	From ft.	To ft.	Depth(s) at which water(s) found	Kind of water (fresh, salty, sulphur)
clay	0	46		
sand	46	55		
fine gravel	55	70	70 - 89	fresh
coarse "	70	89		

Overburden and bedrock materials and depths

Water depth and kind

For what purpose(s) is the water to be used? Municipal
Is well on upland, in valley, or on hillside? valley
Drilling or Boring Firm McLean Water Supply Ltd
Address 1532 Raven Ave Ottawa
Licence Number 1090
Name of Driller or Borer C. D. McLean
Address
Date Feb 21 / 63
C D McLean
(Signature of Licensed Drilling or Boring Contractor)

Form 7 10M-62-1152

OWRC COPY

Location of Well

In diagram below show distances of well from road and lot line. Indicate north by arrow.

Location of the well

Figure 3: A sample of an Ontario water well record

4.2 Well record parameters of use to this study

As a rule of thumb, around one to two gallons per minute (GPM) of water flow rate is required for each cooling ton of heat pump capacity. The required capacity of the heat pump system depends on the heating and cooling loads of the specific building. Generally, the heat pump is sized to fully meet the heating and cooling loads without auxiliary heat sources. This, however, should be evaluated or optimized on a case-by-case basis. Our judgment is that flow rates above 50 GPM represent locations with the highest potential for commercial-sized open loop systems. Though it should be noted that single family residential buildings do not require such high flow rates.

Surface water (found at shallow depths) is not commonly high enough yield for commercial applications (though may be sufficient for standalone drinking water wells or single-family open loop systems). Thus, an open loop geothermal system will typically use deeper aquifers, which will typically be within the bedrock layers, and often dependent upon the type of bedrock. Aquifers are commonly found in sandstone layers (and to a lesser extent limestone) since this type of stone is water permeable; they often have fissures and cracks that fill with water over time. Granite, on the other hand, rarely contains high yield aquifers. Therefore, if a drilled well record is deep (such that it has passed through overburden, limestone and sandstone layers and has reached the granite bedrock) it can provide significant information on the presence or absence of deep aquifers. If the well record shows the existence of the sandstone, there is a high probability of a sufficient aquifer. Hence, such location could be considered as a potential location for open-loop systems (though not guaranteed) and further investigations (such as test drilling) are warranted.

Drawdown is another important parameter to consider. As shown in Figure 2, this parameter is the difference between the pumping water level (i.e., the static level of the water inside the well after pumping) and the static water level (i.e., natural elevation of the water in the aquifer when no there is no pumping). Drawdown level is an indicator of the amount of available water in the vicinity of the well, and the smaller the drawdown, the higher the water yield and the reliability of good yield will be for that location.

It is important to note that the majority of the well records have a depth of less than 90 m. These records are not capable of providing relevant information for this study.

4.3 Evaluation of Potential for Open-loop Geothermal

A definitive evaluation of each well record was beyond the scope of the project and would need to be undertaken in the context of a known building heating and cooling load. The approach taken herein is to use the well record data to define the likelihood that a site would be a good candidate for open-loop geothermal system. Table 1 defines the categories of likelihood that were developed.

Table 1: Open loop geothermal suitability pick list

Likelihood Category	Description
Yes	Location with the highest potential
Potential	Likely to have a good potential, further investigation is warranted
Unlikely	Unlikely to be a promising location
No	Not suitable
N/A	Lack of information to decide

Based on the discussion in the previous section, technical criteria was developed to classify a given well to one of these categories, as detailed in Table 2. The analysis was undertaken on more than 15,000 wells.

Table 2: Technical criteria for selection from the picklist

Condition	Description	Likelihood Category
Flow ≥50 GPM	High capacity aquifer	Yes
Presence of granite in the materials without sandstone and limestone	Canadian shield	No
Presence of sandstone in the materials	Potential for high capacity aquifer after further investigation	Potential
Well depth ≥ 150 m and drawdown ≥ 60 m	Deep well and deep drawdown	No
Well depth ≥ 150 m and no presence of sandstone	Very low chance to access water	No
60 m ≤ Well depth ≤ 120 m and no presence of sandstone or limestone	Low chance to access water	Unlikely
depth ≤ 90 m	Not enough information	N/A

5.0 Presentation of the Results on ArcGIS

JLR analyzed the existing data in the Microsoft Access version of the Ontario Well database and extracted well locations and key parameters.This data was then transferred to the ArcGIS Online, which is a well-known geographic information system (GIS) for working with maps and geographic information developed by Esri. ArcGIS Online provides a user-friendly environment to filter potential locations and visualize relationships in the data. It gives access to all the data collected for each well including links to the well record detail sheets. The “shapefile” developed in this project show graphically the above mentioned data in a graphical format with access to underlying information. For example, by clicking on a well symbol, the information of the well record appears on the screen with a link to access the actual well record.

Figure 4 is a screenshot of the wells that show the highest potentials or “Yes” category. Similarly, the well records that show good potential, low potential, and no potential are shown by Figure 5.

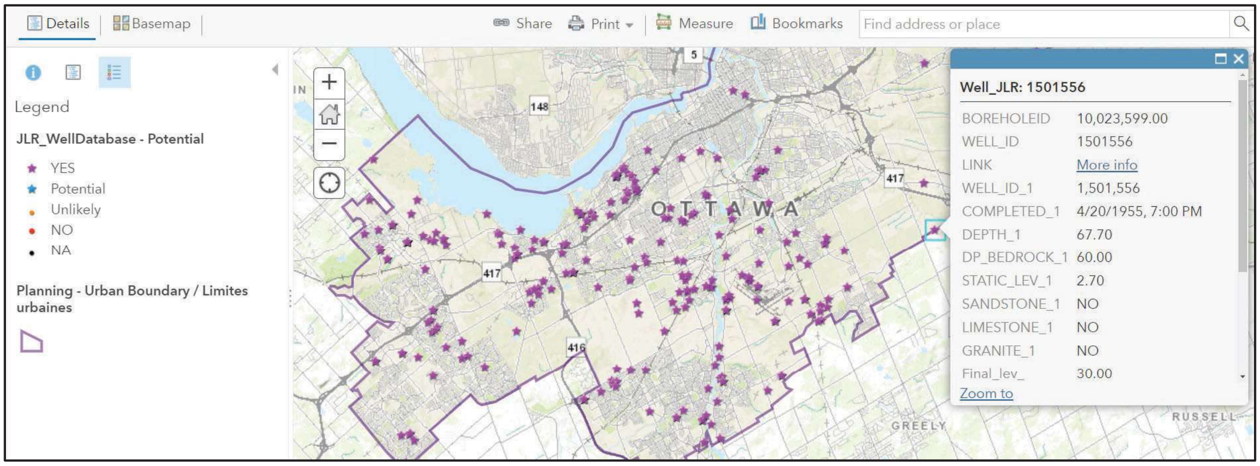


Figure 4: Map of the well records with the highest potential on ArcGIS

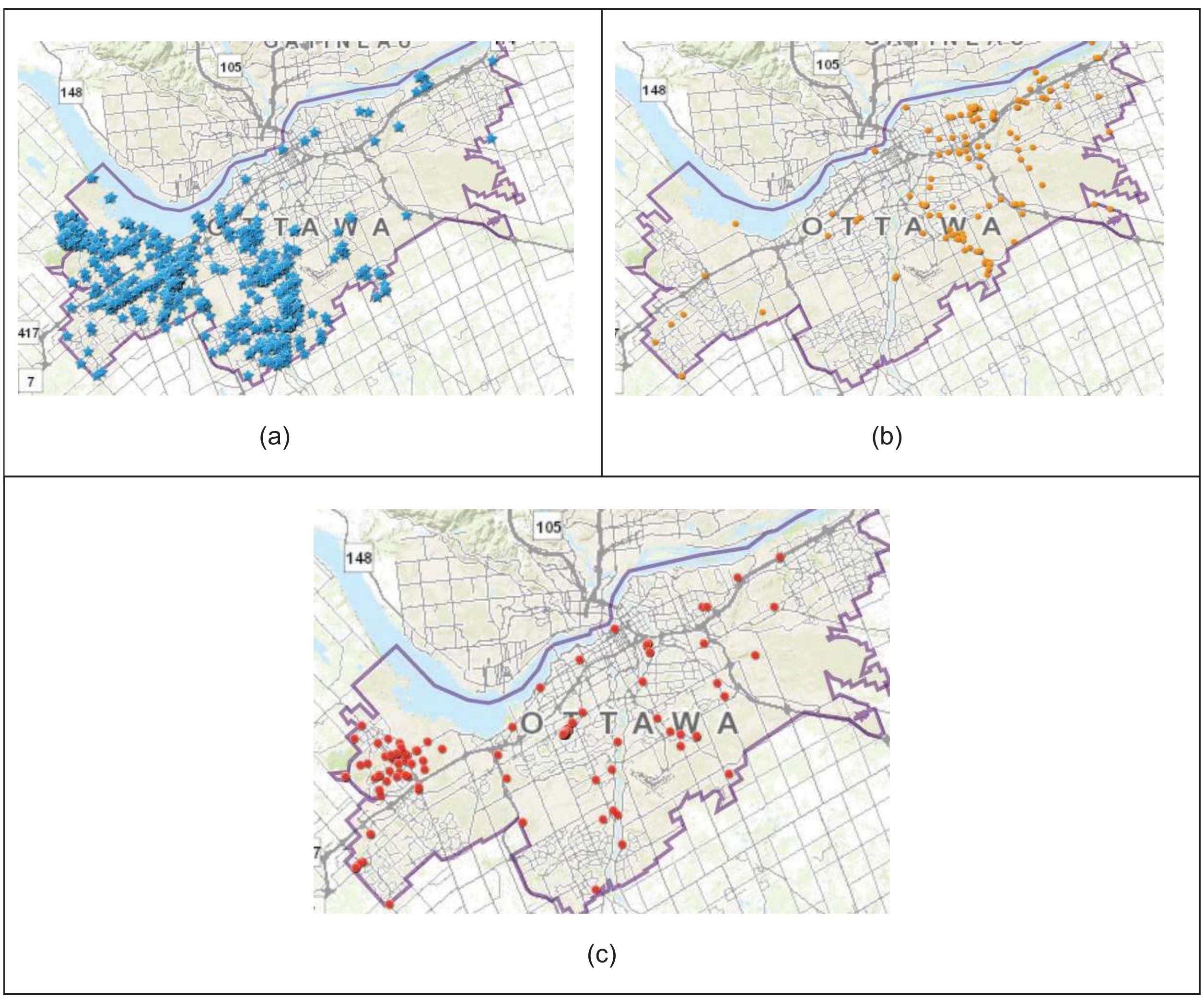


Figure 5: Map of the well records categorized as (a) “Potential”, (b) “Unlikely”, and (c) “No”

6.0 Evaluation of Geological Information

It should be noted that well records do not universally cover the City. There are areas in the City where there are few well records (such as downtown), since drinking water wells are not required in that area. There is a higher occurrence wells on the outer areas of the City (e.g. Kanata and Barrhaven); the magnitude of wells in these areas is/was due to the need of drinking water wells. The presence or lack of well records is in itself not an indication of groundwater, but merely an indication of available information.

As can be seen in Figure 4, the viable wells (classified as “Yes”) are concentrated in the western area of the City. This is further demonstrated when comparing the concentration of “potential” wells in the west side and “unlikely” wells in the east side as shown in Figure 5 (a) and Figure 5 (b) respectively.

To further investigate the geology of the region, a layer was added to the ArcGIS that can describe the surficial geology which is shown in Figure 6. The formations are categorized into different names including Billings, Bobcaygeon, Carlsbad, Covey Hill, Gull River, Lindsay, March, Nepean, Oxford, Queenston, Rockcliffe, and Verulam. The detailed description of these formations is out of the scope of this study but could be found in the documents of Ministry of Energy, Northern Development and Mines.

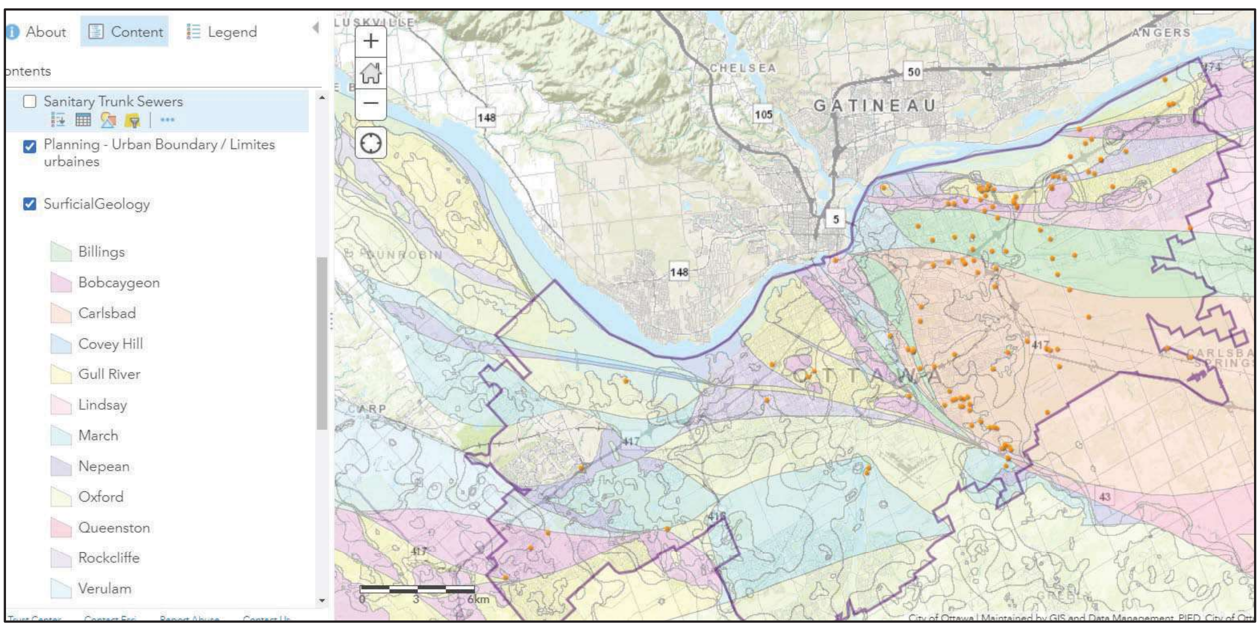


Figure 6: Layer of the surficial geology of the City of Ottawa

An interesting observation from Figure 5 (a) and Figure 5 (c) is the very close proximity between locations that do not show any potential (“No”, orange dots) and locations that do show a good potential (Yes”, purple dots). This is due to the occurrence of a complicated geology phenomenon of granite outcrops and fault lines.

The Nepean formation for example, which is located along the western margins of the Ottawa and St. Lawrence Basin, is sandstone bedrock; it has good potential for high yield aquifers and open loop geothermal projects. However, this formation lies directly over the Precambrian granite bedrock which has little to no potential for high yield aquifers. The granite layer can be variable with outcrops that can reach surface level. An example of such close proximity of “Yes” and “No” is observable in Figure 5 (a) and Figure 5 (c) in the northern area of Kanata where significant granite outcrops exist.

In addition, Figure 6 shows an extension of the Rockcliffe formation from the neighbourhood known as Rockliffe (west of downtown, near the Ottawa River) towards the West. Rockcliffe formation is mainly shale (with no potential for open loop systems), with lenses of sandstone (with high potential for open loop systems); these lenses explain the presence of the locations with no potential and high potential beside each other in this area.

There are also numerous fault lines in Ottawa. While one side of a fault line could contain a high yield aquifer in sandstone, the other side of the fault line may contain shale which is unsuitable for high yield aquifers. This is evident in Figure 6 where the Carlsbad and Billings formations of shale border the Nepean sandstone formation.

As shown in Figure 6, many of the locations that are unlikely to have a good potential, are in the Billings formation. The Billings formation outcrops east of Ottawa in a narrow band extending across Carleton and Russell Counties. The formation consists of brown shale that passes upwards into black fissile shale. This formation is known to contain brackish water and an underlying limestone formation that produces low rates of water that is not suitable for a geothermal system. It is also known to contain pockets of methane gas which can be hazardous when drilling. Another area in Figure 6 that indicates low potential is the area associated with the Carlsbad formation. These formations are mainly composed of grey shale that conformably overlies the Billings Shale and outcrops east of Ottawa in Carleton and Russell Counties.

Figure 7 contains all categories of well records as well as the geological information. An “unlikely zone” is shown with a hand-drawn red dashed line – this roughly aligns with the Billings and Carlsbad formations discussed above and where the majority of the “No” sites are located. The possibility of open-loop geothermal in this area is unlikely, though cannot be fully ruled out. Two zones with high variability - one in Kanata and one in Orleans - are also delineated with a hand-drawn yellow dashed line. These areas have particularly highly local variations in geology and intermingled both “YES” and “NO” sites.

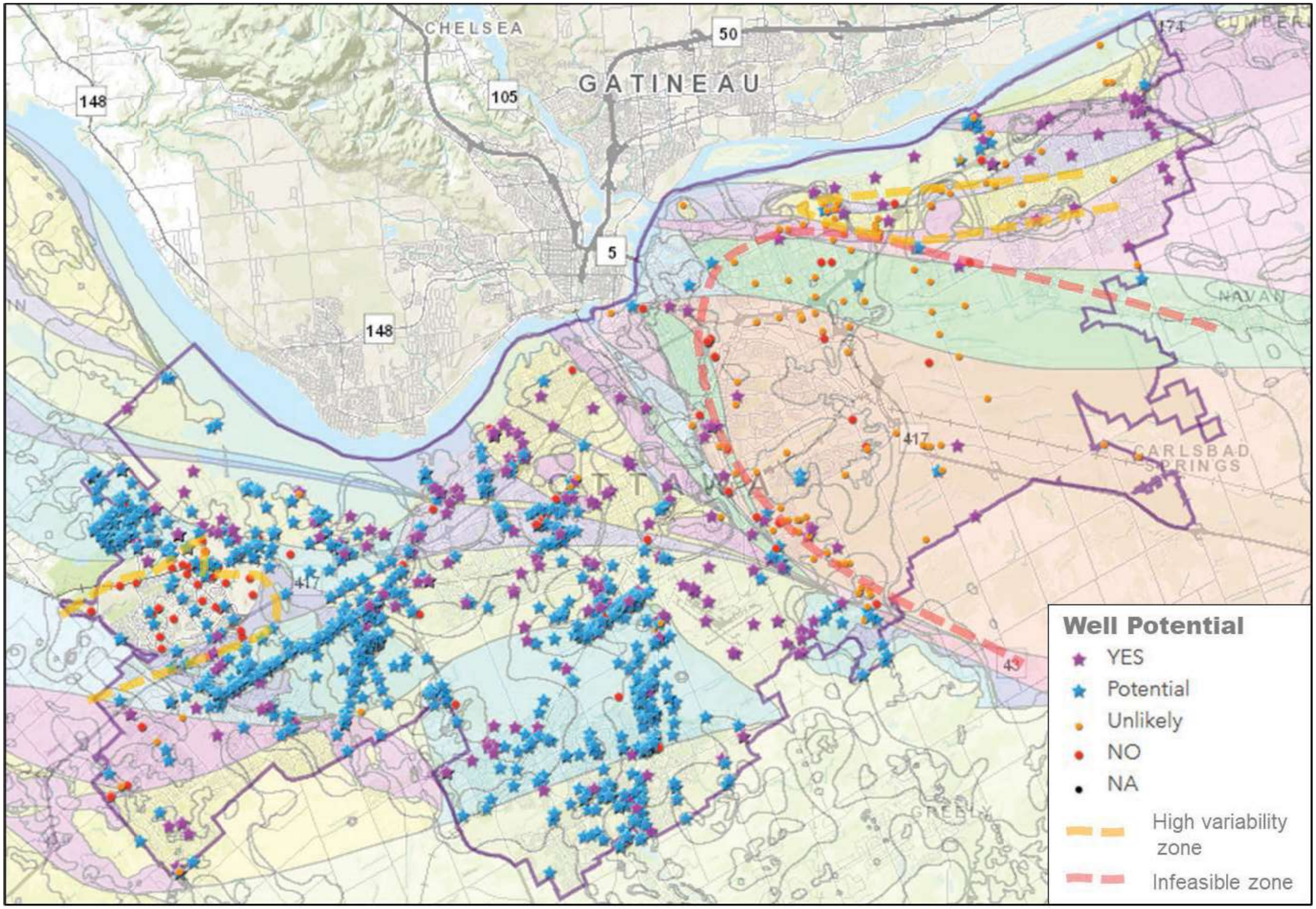


Figure 7: Map summarizing all well and geological information

7.0 Conclusions

The public well records were used to develop a map of the potential presence of deep aquifers for use in open-loop geothermal systems. Well records with depths of less than 90 m were ignored as not providing sufficient information on deep aquifers. For deeper wells, a range of categories were developed to describe the likelihood of there being a deep aquifer. For wells that recorded water flow rates, there were two categories: (i) high flow rates (categorized as "YES" sites), and (ii) where the well was ≥150 m and found only low flow capacities ("No" sites). Where flow measurements were not recorded, the underground geology provided in the well records was further used to predict the likelihood of an underground aquifer – these were labeled "Potential" when sandstone was found and "Unlikely" or "No" if no sandstone was found by 120 m or 150 m, respectively. In addition, if granite was encountered, the site was labeled as a "No".

These well records provide a sufficient distribution across the City to enable a rough sense of the probability of open-loop geothermal across the City. Well records categorizations were superimposed onto geological information to further complement the findings. The analysis identified: (i) one zone that will be infeasible for open-loop due to its geology, and which also had a large number of poor likelihood well records, and (ii) two zones that have high variability due to particularly mixed and locally-dependent geology. However, these finding must be clearly understood as only indicative of the probably that open-loop geothermal can be supported - geology can vary dramatically over short distances and there will be good and bad sites scattered throughout the City.

Further investigations are required for a developer to proceed. This is often a two-step process: pre-feasibilty would typically involve having a hydrogeologist undertake site-specific evaluation using similar process as herein but with added information and rigour (including consideration of the full three dimensional geological volume, aquifer shape and flow direction). Feasibility would involve engaging a geothermal consultant to develop drilling and testing specifications with which a driller can be contracted to drill a well and perform the testing. The findings presented in this study may influence a developer's interest in undertaking the pre-feasibility analysis, especially if other low carbon thermal energy supplies are available. Closed-loop geothermal can nearly always be developed if the open-loop option does not materialize.

8.0 Other Considerations

While this data is useful with providing information about the pumping test and geology of each location, several other factors such as hydraulic properties, water chemistry, and aquifer geometry should also be assessed. Some of the important factors are explained in this section:

- In addition to the well capacity and pumping costs, chemistry of the water needs further assessment. With an increase in the water temperature, smaller ranges of acceptable pH are expected as alkaline and acidic can dissolve the heat exchanger faster. A pH in the range of 6-8 is deemed to be reliable. Moreover, water hardness, and iron content should be tested and considered in any system design.

- A well can be used for both drinking water and open-loop geothermal systems. Dual use wells can aid the financial viability if a location required a drinking water well. The well however must have the capacity to meet both needs.
- Generally, it is more challenging to inject the water back into the aquifer than to extract it. If the material in which an open system is installed has higher percentage of void spaces (higher porosity), the reliability of the water injection to the aquifer increases. This is because materials with higher porosity can accept more water flow.
- In addition to high porosity, formations with high hydraulic conductivity (i.e., an indicator of aquifer’s ability to transmit water), are more suitable for open loop systems.
- In many cases, if a test drill shows insufficient aquifer yields for providing the heating and cooling demands, the same well could be converted into a closed loop borehole.

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