Sewer Heat Recovery

Exclusion Zone Guidance Methodology

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Important Note: This Guidance Note has been prepared by WSP on behalf of the Department for Energy Security and Net Zero for use by wastewater companies and heat network developers in the UK.

This Guidance Note provides ‘rules of thumb’ for establishing Exclusion Zones around sewer heat recovery projects. The guidance is based on analysis and modelling of limited third-party data sets (water company hydraulic models). Any limitations or inaccuracies in the third-party data may affect the guidance in this document.

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In addition to this Guidance Note, WSP has developed a **model** that calculates the temperature recovery downstream of sewage abstraction based on the sewer network topology, downstream sewage inflows and heat flux between the sewage, the in-sewer air and the surrounding ground. The model can be provided upon request from WSP free of charge (thomas.mills@wsp.com).

Contents

Guidance Note

Background

Sewer heat recovery represents a significant opportunity for the decarbonisation of heat in urban areas – particularly when combined with heat networks. The stable temperature of sewage (as compared to ambient air), and the correlation between population density, heat demand, and the scale of the sewer system means its potential as a heat source for low carbon heat networks is unique.

To date, uptake of sewer heat recovery projects in the UK has been limited. It is recognised, however, that as the number of sewer source heat pumps increases, there may be competition for the resource which, if left unchecked, could be detrimental. Specifically, the addition of new sewer heat recovery projects upstream of an existing one could lead to the sewage temperature at the original scheme being reduced to the extent that it has a significant negative impact on the efficiency of the heat pump.

Exclusion Zones

By establishing an 'Exclusion Zone' upstream of a sewer source heat pump, it is possible to safeguard performance in relation to the quality of the heat source, giving operators the surety required to make their investment. The size of the Exclusion Zone should not be fixed, however, since it depends on the scale of the proposed new heat abstraction (the required offtake) relative to the flow rate of the sewage (the available energy). Clearly, if there is a proposal to install a small sewer source heat pump on a large interceptor sewer with a very high sewage flow rate, any Exclusion Zone, if required, would be much smaller than if the proposed heat pump was larger and the sewage flow rate was lower. It is necessary, therefore, to assess each case on its own characteristics.

How was this guidance developed?

This guidance has been developed using evidence from a detailed modelling exercise that simulates the rate of sewage temperature recovery downstream of a notional heat abstraction. The model uses sewer network topology and dry weather flow rate profiles from detailed sewer system hydraulic models provided by several UK water companies. It calculates the rate at which sewage temperature would recover to within a given percentage of the pre-abstraction sewage temperature from a range of heat pump capacities, taking into account the downstream catchment characteristics and flow rate profiles. By repeating this exercise for a large number of notional heat pump capacities across a large number of notional heat abstraction sites, it is possible to statistically analyse the likelihood of sewage temperature recovery within a given downstream distance of a heat abstraction according to two key variables:

- Minimum (base) dry weather flow rate at the abstraction point
- Heat pump capacity

The relationship between these two variables can be described in a single metric by dividing the minimum (base) dry weather flow rate (l/s) by the heat pump capacity (MW). The resulting metric is referred to as the Demand Factor (l/s/MW).

Establishing whether a project is affected by an existing Exclusion Zone

If a sewer heat recovery project is being evaluated, it is necessary to first confirm whether there is an existing Exclusion Zone that covers the proposed project location. Since the application of any Exclusion Zone depends on the Demand Factor of the proposed project, the recommended process is as follows:

1. Establish contact with the sewer asset owner (i.e. the water company) to establish whether there is an existing sewer heat recovery project downstream of the proposed new project. If so, an Exclusion Zone may apply, and the extent/application will be determined by the location and Demand Factor of the proposed new project.
2. Confirm whether the proposed new project would have a direct cooling effect on the existing scheme. This is determined by the network topology and will require input from the water company, whose hydraulic models will confirm whether the outflow from the new project influences the inflow of the existing project, as shown in the following examples.

Figure 1 - Original project affected by new project

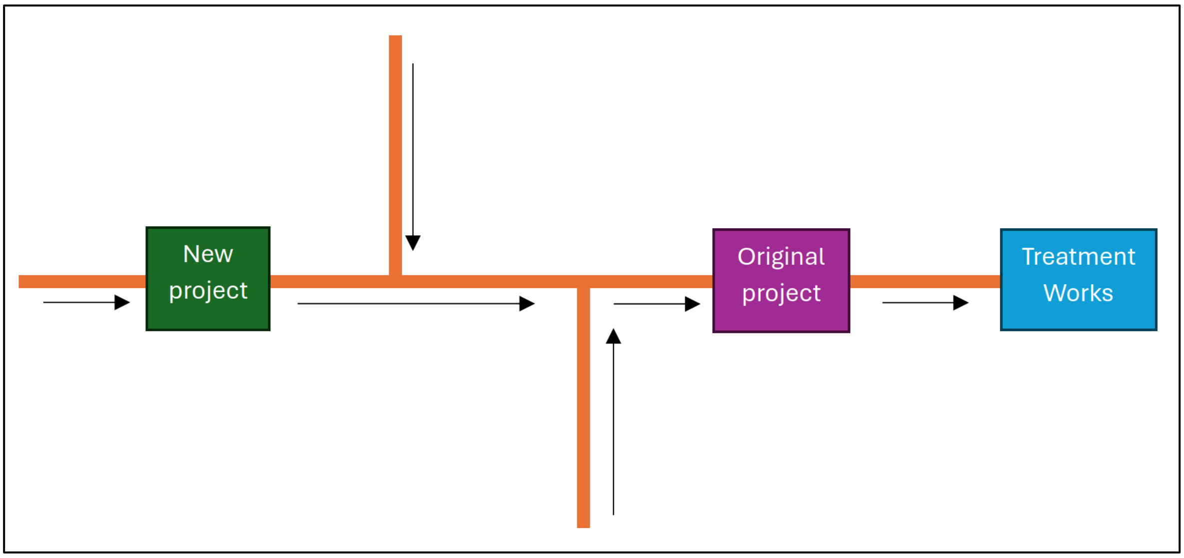
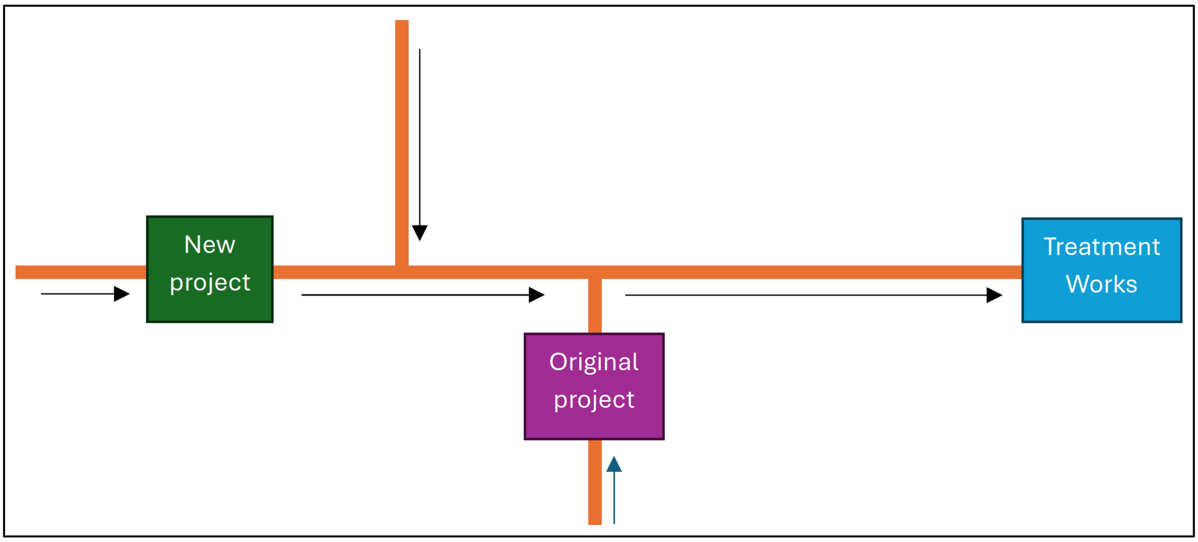


Figure 2 - Original project unaffected by new project



3. Confirm the minimum dry weather sewage flow rate[1] at the proposed site. This would ideally be sourced from one of:
    - Sewer flow and temperature monitoring over an extended period (preferred).
    - Water company hydraulic catchment models.
4. Establish the required/desired sewer source heat pump capacity. This may be based on:
    - The heat demand being met by the heat pump.
    - The heat available based on sewage flow rate data/modelling.
5. Calculate the Demand Factor.

$$DF\ (\mathrm{l/s/MW}) = a/b$$

Where:

- *a* is the minimum (base) dry weather sewage flow rate in litres per second (l/s).
- *b* is the heat pump capacity in MW.

It is recommended that new projects should seek to avoid cooling the sewage temperature of the downstream existing project by more than 1°C.

Use the Exclusion Zone Table in Figure 3 and the Demand Factor calculated at Step 5 to determine whether the proposed new project falls within the Exclusion Zone of the existing downstream project. Proceed accordingly.

[1] Note that sewer diameter is not a good indicator of sewage flow rate

Example 1

Project B is a proposed 800 kW sewer source heat pump project, which would be located 1.2 km upstream of existing sewer heat pump project, Project A.

It has been agreed by all parties that the new project should not cool the sewage entering the Project A site by more than 1°C below the sewage temperature upstream of Project B.

The Project B development team have accessed one year's worth of sewer flow rate monitoring at the proposed site. Following data analysis, it was determined that minimum dry weather sewage flow rate across the year is 275 l/s.

The Demand Factor for the project is calculated to be 344 l/s/MW (275 / 0.8). The Exclusion Zone Table (Figure 3) shows that for a project with a Demand Factor above 250 l/s/MW, **no Exclusion Zone is required**.

Example 2

Project B is a proposed 1,200 kW sewer source heat pump project, which would be located 1.2 km upstream of existing sewer heat pump project, Project A.

It has been agreed by all parties that the new project should not cool the sewage entering the Project A site by more than 1°C below the sewage temperature upstream of Project B.

The Project B development team have accessed one year's worth of sewer flow rate monitoring at the proposed site. Following data analysis, it was determined that minimum dry weather sewage flow rate across the year is 275 l/s.

The Demand Factor for the project is calculated to be 229 l/s/MW (275 / 1.2). The Exclusion Zone Table (Figure 3) shows that for a project with a Demand Factor of 200-250 l/s/MW, new projects must be 1.7km or more upstream of an existing project. Therefore, **Project B cannot proceed in this location unless a smaller heat pump is selected, or an agreement is reached with original project owner.**

Figure 3 - Exclusion Zone Table

<table>
<tr><th colspan="2" rowspan="2"></th><th colspan="6">Demand Factor of Upstream HP (l/s/MW)</th></tr>
<tr><th><50</th><th>50 - 100</th><th>100 - 150</th><th>150 - 200</th><th>200 - 250</th><th>250 - 300</th></tr>
<tr><td rowspan="3">Maximum permitted sewage temperature differential between heat recovery locations</td><td>1°C</td><td rowspan="3">Insufficient sewage flow</td><td colspan="3">Upstream WSHP installation prohibited</td><td>1700m</td><td rowspan="3">No Exclusion Zone Required</td></tr>
<tr><td>2°C</td><td rowspan="2"></td><td>900m</td><td colspan="2" rowspan="2"></td></tr>
<tr><td>3°C</td><td></td></tr>
</table>

Establishing an upstream Exclusion Zone with a Water Company

Once it is confirmed that a new sewer heat recovery project is going ahead (i.e. it is not affected by an Existing Exclusion zone), the project developer should establish their own upstream Exclusion Zone with the Water Company. This new Exclusion Zone should be incorporated into the Access Agreement between the project developer and the Water Company.

As described earlier in this guidance, the extent of the Exclusion Zone is defined by the Exclusion Zone Table and its application is determined by the Demand Factor of any potential future upstream project.

Further considerations

In the event that a new project falls within the Exclusion Zone of an existing project, there are a number of potential options for the new project:

1. Reduce the capacity of the heat pump.
2. Move the new project location outside of the Exclusion Zone.
3. Negotiate a compensatory payment to the original project to cover the loss in efficiency arising from the reduction in the sewage temperature.

In the event that there is more than one existing project downstream of a proposed new project, the cumulative impact of multiple projects must be considered, and the Exclusion Zone Table is not applicable.

Appendix 1 – Sewer Heat Recovery Technical Implications Note

Acronyms

Acronyms	Meaning
HNZ	Heat Network Zoning
WwTW	Wastewater Treatment Works
HNDU	Heat Network Delivery Unit
DESNZ	Department for Energy Security & Net Zero
SWH	Scottish Water Horizons
NWL	Northumbrian Water Ltd
TW	Thames Water
UU	United Utilities
ST	Severn Trent
GIS	Geographic Information System
SHRM	Sewer Heat Recovery Model
FOG	Fats, Oils and Greases
COP	Coefficient of Performance/Heat Pump Efficiency

Introduction

As part of its Net Zero commitment the UK Government is seeking to significantly increase the roll-out of heat networks across the UK. The anticipated introduction of a Heat Network Zoning (HNZ) policy in 2025 will see the introduction of powers to mandate connection to heat networks in areas where they have been identified as the lowest cost means of decarbonising building heat supply. With this policy, and the industry regulation that is expected to accompany it, the major barriers to heat network delivery will be removed and the pace of roll-out will intensify.

With increased heat network delivery comes an increased need for low carbon heat sources of suitable scale. Wastewater, when paired with a heat pump, is an attractive heat source for several reasons:

1. The stability of the temperature compared to other heat sources (e.g. ambient air and surface water).
2. It is intrinsically linked, both in terms of quantity and location, to areas of higher human population and therefore to areas of higher heat demand.
3. There are established technologies for wastewater heat recovery.

Wastewater can be recovered from the Wastewater Treatment Works (WwTW), either from the incoming sewage or from the final effluent. These opportunities are limited to locations close to a WwTW, which are typically some distance from urban centres. The available heat recovery will be significant, given the volume of sewage that flows through these facilities. Heat recovery from the final effluent offers a relatively low risk opportunity, since the treatment process is complete, meaning it is genuine waste heat; however, the temperature of the final effluent is generally cooler than the incoming sewage, since heat is lost in the treatment process. As such, the COP of heat pumps using heat from the final effluent would be lower than that of heat pumps using heat from raw sewage.

Heat can also be recovered from the sewers themselves. Given the extent of the sewer network within urban centres, this can be an attractive heat source, although only those with sufficiently high flow rates are suitable for heat network supply. It is this sewer heat recovery that is the focus of this Technical Note.

The Department for Energy Security & Net Zero (DESNZ) Heat Network Delivery Unit (HNDU) has funded several heat network development projects with sewer heat recovery as the proposed heat source and, through this work, several key issues have been identified. WSP was therefore appointed by DESNZ to assess the implications of sewer heat recovery, with particular focus on:

1. How to manage the risk of degrading heat quality at a particular abstraction point, should another heat recovery project be installed upstream; and

2. The impact of heat abstracted from one or more upstream sewer heat recovery projects on downstream WwTW processes.

In developing this Technical Note WSP has consulted with a number of stakeholders; specifically:

- Scottish Water Horizons (SWH) – non-regulated division of Scottish Water.
- Northumbrian Water Ltd (NWL) – North-East region water company.
- Thames Water (TW) – South-East region water company.
- United Utilities (UU) – North-West region water company.
- Severn Trent (ST) – Midlands region water company.
- Uhrig – manufacturer of ThermLiner sewer heat recovery system.
- Huber – manufacturer of ThermWin sewer heat recovery system.

The required outcomes for this exercise are:

1. A written document in the form of guidance to projects looking to negotiate Exclusion Zones that outlines the recommended steps to determine the requirement for, and extent of, Exclusion Zones.
2. An initial screening tool for high-level feasibility studies.
3. A more detailed tool that could determine more accurately the influence of individual and multiple heat abstraction projects.
4. Outputs to a user-friendly GIS layer to allow the data to be visualised.
5. Guidance on a standardised approach to investigating the potential for sewer heat abstraction for the supply to heat networks including recommendations on the data needed for high level and detailed modelling, including advice on the placement of monitoring equipment, use of the tool etc.
6. Details of the updates required to improve the accuracy of / maintain the tools.

This document and the detailed model that accompanies it address much of the scope; however, it does not yet provide, in full, definitive guidance on either a standardised approach to investigating the potential for sewer heat recovery (item 5), or on the steps to defining Exclusion Zones (item 1). These requirements will be discussed further with DESNZ and an approach for the next steps agreed.

Methodology

In evaluating the issues identified by DESNZ, the following methodology was used:

1. Meetings were held with heat recovery technology manufacturers, Huber and Uhrig, to establish the key operating principles for their technologies.
2. Workshops were held with water company technical teams to establish their perspectives on sewer heat recovery. These workshops focused on:
    - Existing UK sewer heat recovery projects.
    - The potential impact of different heat recovery technologies on the sewer system.
    - The potential impact of sewage cooling on the sewer system local to the heat abstraction location(s).
    - The potential impact of sewage cooling on the WwTW downstream of the heat abstraction location(s).
3. A Water Company Perspectives report was developed, summarising the key findings from the workshops. This was shared with DESNZ and is summarised in the next section of this Technical Note.
4. WSP was given access to NWL's hydraulic model covering Newcastle city centre. Modelled dry weather flow rates were assessed in the vicinity of known heat network projects (existing or in development) to identify preferred heat abstraction locations, which would also be selected as sites for the installation of monitoring equipment. To date, no monitoring equipment has been installed.
5. A detailed Sewer Heat Recovery Model (SHRM) was developed to quantify the impact of sewer heat abstraction on sewage temperature. The model uses a mass balance approach to calculate the cooling effect of sewer heat recovery and subsequent temperature recharge effect of downstream sewer connections. Heat flux from the sewage to the ground and the in-sewer air is also calculated. In calculating the heat flux, the model takes into account the shape of the sewer and the wetted perimeter based on the sewage depth.
6. The proposed heat recovery locations (point 4 above) and the downstream sewer system were replicated in the detailed model (point 5 above). Dry weather flow rate and sewage depth profiles and sewer type data were imported from the NWL hydraulic model for sewers ranging in diameter from 225mm to 2,750mm. Heat recovery was modelled using heat pump output profiles for the proposed heat network scheme, resulting in a modelled sewage temperature immediately downstream of the heat recovery location. Subsequent temperature change (from downstream sewer connections and heat flux) was modelled to evaluate the relationship between distance (from the abstraction point) and temperature recovery.

7. Based on initial model runs, it was determined that heat flux between the sewage and the ground / in-sewer air was of minimal consequence to the temperature change within the sewage when compared to the impact of sewage inflows. Consequently, when undertaking bulk abstraction modelling for Exclusion Zone data gathering, heat flux was excluded from the analysis. This is described in detail later in this Technical Note.
8. A second, bulk modelling approach was developed in which notional heat abstraction locations were analysed to evaluate how sewage temperature recovered for a range of heat abstraction capacities based on the downstream inflows. This modelling was done using data from the TW Beckton catchment model and the UU Sandon Dock and Davyhulme catchment models. The results were evaluated for patterns that could be used to establish guidance on the requirement for, and extent of, Exclusion Zones around a sewer heat recovery scheme.

The following sections describe the outcomes of this methodology.

Summary of Wastewater Industry Perspectives

Discussions with the water companies were held over video conference and focused on two key areas, as set out in the following sections. They are:

1. The impact of heat recovery on the sewer system local to, and downstream of, the abstraction point.
2. The impact of heat recovery on the WwTW.

Heat Recovery Impacts Local to and Downstream of the Abstraction Point

Sewer heat recovery requires the use of heat exchange equipment to transfer energy from the sewage to the heat pump circuit. The nature of the heat exchange depends on the technology that is used, but is based on one of two key design principles:

1. In-line heat exchange, where the heat transfer takes place via a heat exchange system installed within the sewer itself.
2. External heat exchange, where the sewage is pumped from the sewer to a heat exchange system situated outside the sewer.

Both of these systems will cool the sewage. One of them – the in-line heat exchanger system – will reduce the cross-sectional area of the sewer when installed as a retrofit to existing sewer mains. The other – the external heat exchanger system – will not affect the profile of the sewer.

Prior to discussion with the water companies, it was anticipated that the primary risks local to a heat abstraction location would arise from:

1. Changes to the characteristics of the sewage due to cooling, i.e. from the emulsification of Fats, Oils and Greases (FOG).
2. Reduction in sewer capacity from in-line heat exchange (where that technology is utilised)
3. Operational concerns such as ragging from the installation of equipment within a sewer.

Prior to meeting the water companies, the following questions were raised via a questionnaire issued in advance. Note that details of the Uhrig and Huber heat exchange technologies were shared along with the questionnaire:

- Does the cooling of sewage from sewer heat recovery pose a risk to conveyance within the network locally?
- Are there minimum limits on sewage temperature at the heat recovery location that, if followed, would negate or minimise these risks? For example, is there a wastewater temperature above which emulsification of FOG is of lesser concern?
- Of the heat exchange technology options, do you perceive any specific risks to the sewer system associated with their design?

Responses from NWL and UU in relation to the above questions were broadly consistent. Both had concerns about anything that reduces the capacity of the sewer system (i.e. the in-line heat exchange system), particularly in light of recently highlighted issues with the discharge of combined foul and storm water sewage via combined sewer overflows. TW noted that there are other examples of where water companies allow infrastructure (e.g. fibre optic cables) to be installed within the sewers, and that the risk is related to the percentage reduction in cross-sectional area.

Both companies observed that the external heat exchange system included screening prior to the sewage being pumped to the heat exchanger, and that this screening system would return rags to the sewer, potentially altering the way ragging occurs local to, and downstream of, the connection point. It has also been noted by DESNZ that in previous conversations with TW, concerns were raised over who would be responsible if a sewage leak occurred as a result of using the external heat exchange system, which could ultimately end up contaminating a water course. Sewage that leaves the sewer sits outside the water company regulated asset, which is not an issue with an in-line heat exchange system. Questions therefore exist around permitting for an external heat exchange system, and whether the water company would need to own or adopt the additional apparatus.

Regarding emulsification of FOG, both companies commented that the concentration of FOG varies across a catchment, with city centres and particularly areas with high numbers of restaurants and takeaways having higher FOG concentrations. Despite this, neither company stated that cooling the sewage would lead to issues with FOG. UU said they couldn’t see an immediate issue, but that it would be important to employ a watching brief in case unexpected issues should arise. They also noted that it may be the seasonal increase in temperature through the summer that keeps FOG ‘in balance’ and that permanently cooled sewage could theoretically lead to more FOG accumulation. NWL stated that they haven’t done any work in this area but noted that seasonal temperature fluctuations would obviously lead to cooling and that they were not aware of any increase in FOG issues as a result of this natural sewage cooling. TW noted that they have commissioned a desktop report that looks into the risks from FOG for different catchment characteristics and potential dT scenarios compared to measured flow and temp data. The results showed that the risks were very low.

In dialogue with SWH they stated that there had been no issues with FOG local to their heat recovery at Galashiels (which is a sewer heat recovery scheme just outside a WwTW). Furthermore, in discussion with Huber, when asked about their experience of FOG formation from cooling, they said they had not seen any issue on any of the projects they have been involved with.

Based on the responses from three water companies and Huber, it is concluded that the cooling of sewage local to a heat abstraction point is not expected to present any significant issues with emulsification of FOG. Nevertheless, it would be prudent to monitor conditions around any sewer heat recovery installation in any early-stage/pilot schemes – particularly in locations that are known to have a higher historic occurrence of FOG build-up.

It is also concluded that the in-line heat exchange system is unlikely to be acceptable to many UK water companies as things stand, given the potential for exacerbation of the capacity issues that are already causing a great deal of public concern and media attention. That is not to say that the external heat exchange arrangement is without issue (both UU and NWL mentioned ragging as a potential concern), but it appears much more palatable to the water industry at this point. SWH did say that they would like to see the in-line system deployed on a project, but that they found it to be too expensive compared to the external heat exchange system. It is also noted that new sewer pipes could be installed with in-line heat exchangers more easily, since they can be designed accordingly. Similarly, existing sewers could be retrofitted with the in-line system during a major diversion. However, since diversions and replacements represent a very small proportion of the total sewer infrastructure, it is unlikely to provide a significant contribution to UK sewer heat recovery.

Heat Recovery Impacts at the WwTW

The efficiency of the secondary treatment process - activated sludge - is heavily influenced by temperature in two ways:

1. It relies on the addition of air (oxygen) to the sewage, which is more efficient due to greater oxygen saturation levels in water/sewage at relatively lower temperatures.

2. The bacteria, particularly nitrifying bacteria, in the activated sludge process are sensitive to, and less effective at, lower temperatures. The populations can decay in prolonged lower temperatures.

Overall, like most biochemical processes, WwTW perform best with a fixed temperature and quality of feed. Of course, neither of these things are fixed; however, the concern is that performance could be further reduced by the action of heat recovery.

Prior to meeting the water companies, the following questions were raised via a questionnaire issued in advance.

- Does the cooling of sewage entering the WwTW pose a risk to the treatment process? If so, what are the risks and what are the temperature requirements associated with avoiding them?
- Is there a minimum wastewater temperature entering the WwTW that must be adhered to when designing wastewater heat recovery on the upstream sewer network?
- Do you have any operational experience of issues associated with reduction in sewage temperature? Natural seasonal variation, trade or other impacts.

Responses from NWL and UU in relation to the above questions were also broadly consistent. They both noted that the temperature plays an important role in the efficiency of the treatment process. Both companies stated that 8°C is an important threshold for the incoming sewage, with UU confirming that it is the temperature used in the design of the WwTW process. NWL stated that on nitrifying works, if the sewage temperature drops below 8°C, it ‘can cause significant issues’.

Further discussion with UU confirmed that when sewage temperatures are lower, more electrical energy is required for the blowers, which increases the concentration of dissolved oxygen (and therefore the concentration of bacteria) in the activated sludge. When asked whether it would be possible to assess the required electrical input as a function of WwTW inlet temperature, UU said this data was not available (i.e. it is not specifically monitored). Conversely, UU also noted that there could be some benefit from cooling the sewage because cooled water (sewage) can hold more dissolved oxygen than warmer water, so the aeration efficiency of the process increases.

While there do appear to be some competing effects of cooling the sewage influent, and none of the water companies were able to quantify the anticipated loss in efficiency resulting from cooling the sewage as it enters the WwTW, all of them identified system efficiency loss as a concern. It is therefore concluded that sewer heat recovery must not cool the sewage below 8°C as it enters the WwTW, and ideally should not cool the sewage below 10°C. It was generally agreed that the scale of wastewater catchments compared to the scale of demand on a heat network is such that a single, or small numbers of schemes are unlikely to have a significant impact on the WwTW inlet temperature; however, water companies would want to be satisfied of the impact of any scheme before agreeing to proceed. TW also noted that smaller rural WwTW are most commonly effected by lower temperatures so would make sewer heat recovery less likely in these catchments, even if there was demand from a heat network.

It was also highlighted in the discussions that the majority of annual heat demand occurs in the colder months when the sewage temperature is already low, increasing the risk of impacting on the wastewater treatment process.

When we discussed these matters with SWH, they described their existing heat recovery schemes at Galashiels and Stirling. Galashiels is a sewer heat recovery scheme immediately adjacent to the Galafoot WwTW, albeit taking heat from a small proportion of the sewage flowing into the works (so with minimal impact on temperature). SWH are planning another sewer heat recovery scheme in Edinburgh. The Stirling scheme recovers heat from the WwTW pre-primary sedimentation with, according to SWH, minimal impact on the wastewater treatment process. They have another, similar scheme at Dalmarnock.

While SWH have the most experience with wastewater heat recovery of the three companies we have spoken to, they are also the most comfortable with the risks to the treatment process, although SWH are not a regulated water business (Scottish Water is the regulated business). The two key observations made in the discussion were:

1. That the biggest issues they have had to date have been related to a particular heat recovery technology. The technology referred to is neither the Uhrig nor the Huber system, and no longer has a presence in the UK.
2. That as far as the core (wastewater treatment) business goes, they ‘haven’t seen any negatives’.

While this does not negate the legitimate concerns of the other water companies, it does perhaps provide some confidence that, designed correctly, heat can be recovered from sewage upstream of, or even at, the WwTW without significantly impacting on the core process.

The Impact of Heat Flux on Sewage Temperature Recovery

As a sewage system is primarily comprised of buried pipework containing both sewage and air, it was seen as necessary to evaluate the importance of heat flux:

- From the sewage to the soil surrounding the pipe, and the in-sewer air within the pipe, when the sewage temperature exceeds that of the soil and air.
- From the soil and in-sewer air to the sewage when the sewage temperature falls below that of the soil and air.

The following section describes the overall process WSP applied to assess the importance of heat flux in the estimation of sewage temperature downstream of a heat abstraction location. It describes:

- The heat flux calculation methodology.
- The way this methodology was used to assess the impact of heat flux on sewage temperature recovery.
- The key results and conclusions.

Heat Flux Calculation Methodologies

Total heat flux between the sewage, in-sewer air and the surrounding ground was calculated for each 100m section of piping defined in the model. This was achieved by splitting the pipe into 10 x 10m sections and calculating the heat flux and temperature drop across each section.

The flux (W) and temperature drop (K) across each section are estimated using the following methodology, which was published by the University of Sheffield[2]:

$$Heat\ Flux = \left[\frac{1}{R_{EA}}(T_{Start} - T_{Air}) + \frac{1}{R_{ES}}(T_{Start} - T_{Air})\right] L$$

$$T_{End} = T_{start} - \left[\frac{Heat\ Flux}{m_{flow}C}\right]$$

Where:

- T_{End} and T_{start} are the temperatures at the end of each pipe section (K).
- L is pipe section length (m).
- R_{EA} and R_{ES} are the sewage to sewer air thermal resistivity and sewage to surrounding soil thermal resistivity (W/m·K).
- m_{flow} is the sewage mass flow rate (kg/s); and

[2] Abdel-Aal, M., 2018. Modelling the potential for multi-location in-sewer heat recovery at a city scale under different seasonal scenarios.

- C is the specific heat capacity of the sewage (4180 J/Kg·K)[3].

This approach required both R_{EA} and R_{ES} to be estimated. R_{EA} was estimated using the Flinspach[4] Approach. R_{ES} was estimated using 2 methods:

- Where pipe material was known, resistivity was based on both pipe material and thickness, where thicknesses were assigned lower-normal values to ensure realistic worst-case heat flux effects.
- Where pipe material was unknown, resistivity was based on generic values provided by the University of Sheffield.

Modelling the Impact of Heat Flux

The impact of heat flux on the sewage temperature was estimated using the following process:

1. Sewers with average abstraction point flow rates between 60 l/s and 1,050 l/s were selected from the data within the TW hydraulic catchment model. These flow rates are generally representative of the lower to mid-range of sewer capacities that might be suitable for sewer heat recovery to supply a heat network. To stress test the importance of heat flux two more sewers with average flow rates of 24 l/s and 28 l/s from the NWL model were also analysed.
2. Each network was modelled using the detailed SHRM (which utilises the heat flux calculation methodology described above), with heat pump sizes assigned based on the minimum hourly abstraction point flow rate and a flow/return temperature differential of 4°C. Hourly terminal node temperature time series were calculated for 'heat flux calculations on' and 'heat flux calculations off' scenarios. The 'distance to recover to within x°C of pre-abstraction temperature' outputs were recorded for temperatures between 1°C and 4°C for each scenario.
3. The significance of heat flux at each flow rate was evaluated by (a) assessing the correlation between hourly terminal node temperatures calculated with and without heat flux calculations active, and (b) assessing whether recovery distance results altered with the inclusion/exclusion of the calculations.

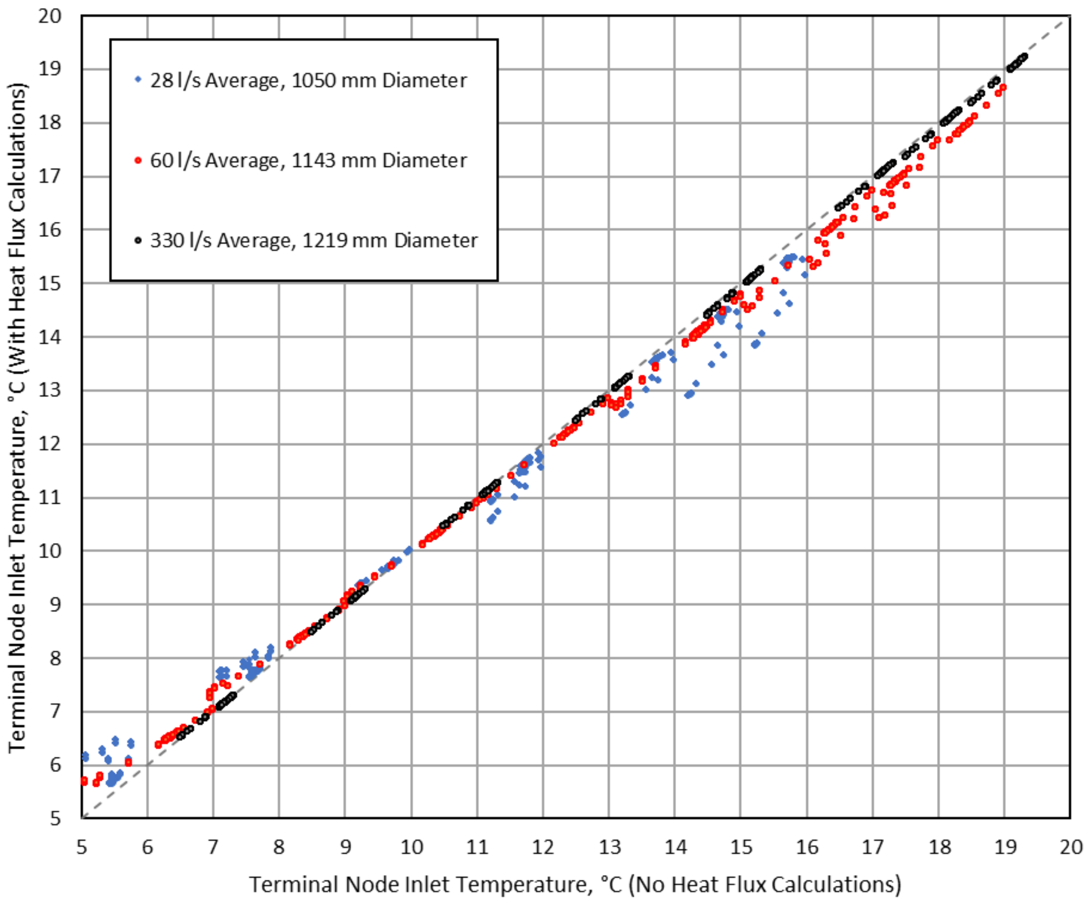
[3] Specific heat capacity of wastewater is assumed equal to that of water, as is typical in associated studies. This is because untreated sewage is almost entirely water by composition.
[4] Flinspach, D., 1973. Warmelastplan neckar plochingen bis mannheim stand (German Language).

Results

The inclusion of heat flux calculations was seen to have almost no effect on terminal node temperature for any sewers with average flow rates exceeding 300 l/s, and minimal effect on sewers falling into the 50-100 l/s range (see Figure 4 - Comparison of modelled terminal node temperatures, with and without the inclusion of heat flux calculations, for selected sewers with average flow rates between 28-330 l/s.). Sewers with average abstraction point flows exceeding 330 l/s were seen to exhibit near perfect correlation between 'heat flux included' and 'heat flux excluded' terminal node temperatures, so are not presented graphically.

Whilst the inclusion of heat flux calculations was seen to influence terminal node temperatures by more than 1°C for sewers with average sewage flow rates below 30 l/s, their low average and near-zero minimum flow rates make them unsuitable for sewer heat recovery schemes.

Figure 4 - Comparison of modelled terminal node temperatures, with and without the inclusion of heat flux calculations, for selected sewers with average flow rates between 28-330 l/s.



Furthermore, the inclusion of heat flux calculations altered heat recovery distance results in only one instance, which concerned a sewer with average flow rate 24 l/s – this network was included only as part of the stress test and does not represent a suitable abstraction location.

Figure 4 also shows that the direction of flux is from sewage to ground during any times at which the sewage exceeds 10ºC. As 10ºC has been suggested as a minimum permissible sewage temperature for abstraction, the ground should not be thought of as a source for heat recovery after abstraction.

Conclusions

As a result of this analysis, it was determined that heat flux between the sewage, the ground and in-sewer air is of little consequence to the sewage temperature recovery in the context of establishing rules of thumb for Exclusion Zones. As such – and owing to the computational burden from including heat flux in the bulk data analysis described in the following section – it has been excluded from further analysis.

The Case for, and Extent of, Exclusion Zones

Introduction

The purpose of an Exclusion Zone would be to prevent a sewer heat recovery scheme from being negatively impacted by other schemes being developed upstream, thus lowering the sewage temperature and reducing the efficiency (COP) of the heat pump on the original scheme.

It is noted that when this was discussed with both Huber and Uhrig, neither of them had any experience of this being an issue in the (mainly European) cities where they have multiple installations, although it was noted by both that this may change as uptake increases.

As described in the preceding section, heat flux between the sewage, the ground and in-sewer air is of little consequence to the sewage temperature recovery in the context of establishing rules of thumb for Exclusion Zones. The variables that have a significant impact on sewage temperature recovery downstream of an abstraction are therefore concluded to be:

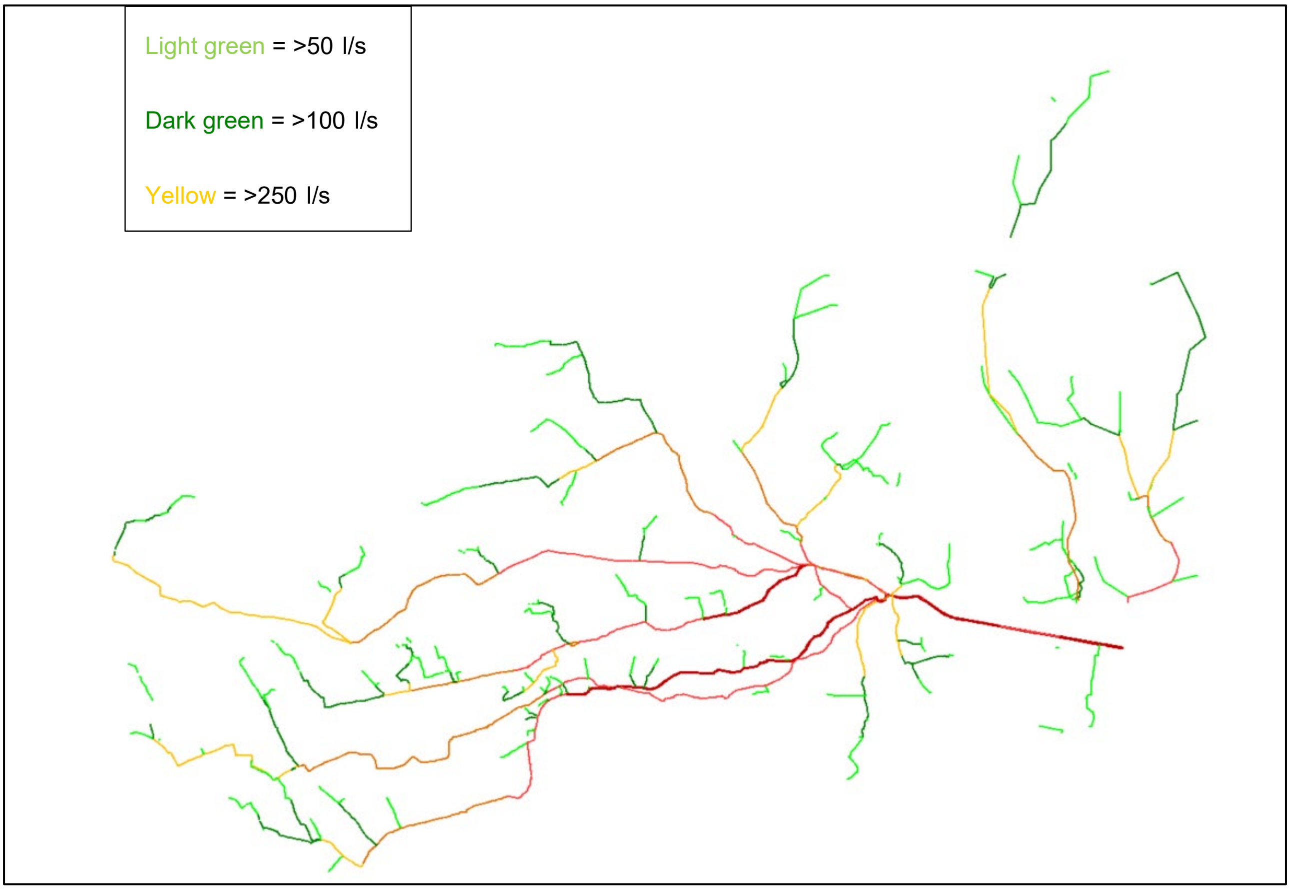
1. The sewage flow rate at the point of abstraction.
2. The sewage temperature at the point of abstraction.
3. The quantum of heat abstracted from the sewage.
4. The location, flow rate and temperature of inflows downstream of the abstraction.

Methodology

In order to test the case for, and extent of, Exclusion Zones, the variables above were tested for notional heat abstraction locations on the TW Beckton, UU Sandon Dock and Davyhulme sewer models using WSP’s SHRM, as described in Point 8 of the Methodology section above. A more detailed description of this process is as follows:

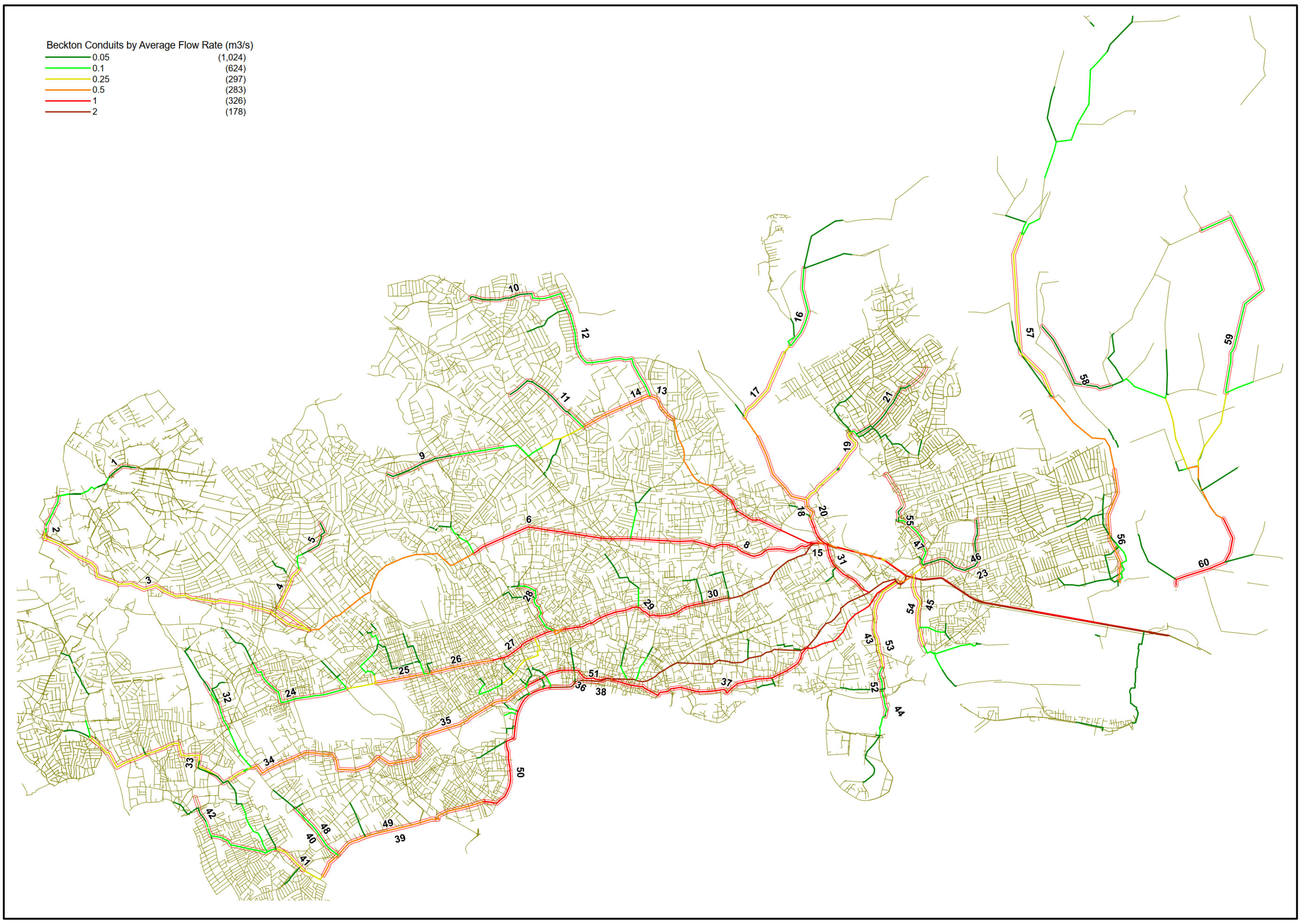
- The catchment models were interrogated to identify all sewers with an average dry weather flow rate of 50 l/s or more. Sewers with lower flow rates are assumed to be unsuitable for heat supply to heat networks. The following map shows a sample of the output of this process from the TW Beckton catchment.

Figure 5 - Beckton catchment sewers above 50 l/s flow rate



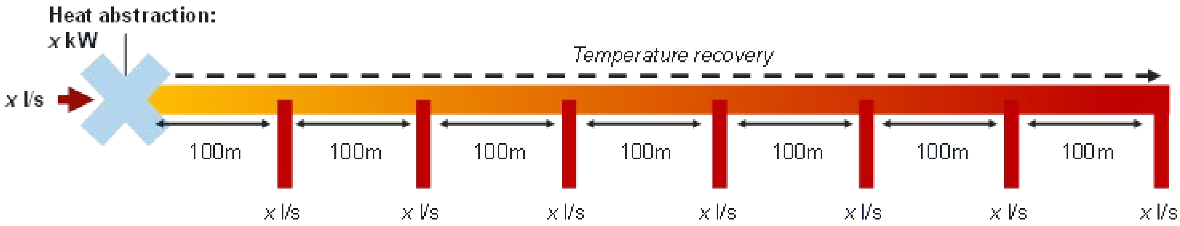
- Notional abstraction locations were selected across the sewers with dry weather flow rates above 50 l/s. Because the natural topology of the sewer network is for the flow rate to increase as it moves from the head of the system towards the WwTW, the abstraction locations have been positioned at the top (upstream) end of each pipe. The positions of the modelled abstraction locations for the example TW Beckton catchment are shown in the following image.

Figure 6 - Beckton catchment modelling locations (each number identifies a modelling location)



- For each abstraction location the following information was exported from the sewer model:
    - Dry weather flow rate and velocity profile at the abstraction location.
    - Sewer size, shape and material at the abstraction location.
    - Dry weather flow rate and velocity profile at 100m intervals downstream of the abstraction location.
- For each abstraction location a range of heat recovery capacities were modelled against the dry weather flow rate profiles to evaluate:
    - How the different capacities reduced the sewage temperature at the abstraction point.
    - How the sewage temperature recovered at 100m intervals downstream of the abstraction point taking into account the sewage inflows (see Figure 7).

Figure 7 - Sewage temperature recovery diagram



- Note that this analysis does not take into account absolute temperature values within the sewage. It is concerned only with the change in temperature based on upstream sewage flow rates and the quantum of heat abstraction, and then the downstream temperature recovery based on sewage inflows.
- The results were analysed across the full set of modelled heat abstraction locations to determine the trends between downstream temperature recovery and abstraction point flow/abstraction characteristics.

Results

The results were analysed several different ways to look for rules of thumb that could be used to define Exclusions Zones related to sewer heat recovery. The following chart, which presents results from the sample Beckton catchment data analysis, can be read as follows:

- Each row represents a single modelling location. The number in the left-hand column is the sewer diameter (mm) at the modelled abstraction point.
- Each column shows the modelled heat pump capacity. So, for each modelling location, 10 different heat pump capacities were assessed. A nominal COP of 3.2 has been used to calculate the quantum of energy abstracted from the sewage for each heat pump capacity.
- The model calculates the distance within which the sewage temperature has recovered to within 2°C (variable within the model) of the pre-abstraction sewage temperature for that modelling location.
    - Where the cell is black, it means there is insufficient energy in the sewage to meet the modelled heat pump capacity.
    - Where the cell contains ‘NR’ it means the temperature has not recovered to within 2°C of the pre-abstraction temperature within the downstream distance modelled.
    - Where the cell is green with a ‘0’ it means the quantum of heat abstraction is insufficient to reduce the sewage temperature by more than 2°C.
    - Where the cell contains a number, that is the distance at which the sewage recovers to within 2°C of the pre-abstraction temperature.

Figure 8 - Sewer diameter / heat pump capacity temperature recovery model results - 2°C temperature recovery

Sewer Nominal Diameter (mm)	HP Output Capacity (kW)									
	50	100	250	500	750	1,000	1,500	2,000	2,500	3,000
525	0	0	0	800	NR					
915	0	0	0	0	0	0	200	NR	NR	NR
930	0	0	600							
953	0	0	500	NR						
1,017	0	0	0	0	200	800	NR			
1,067	0	0	400							
1,080	0	0	0	1200	NR	NR				
1,200	0	0	0	0	0	900	NR	NR		
1,219	0	0	0	300	1600	NR				
1,219	0	0	0	300	1600	NR				
1,219	0	0	0	300	1600	NR				
1,250	0	0	0	0	0	0	1200	NR	NR	
1,275	0	0	0	900	NR					
1,372	0	0	0	0	0	0	0	0	NR	NR
1,372	0	0	0	0	0	0	0	0	NR	NR
1,380	0	0	100							
1,385	0	0	0	0	NR	NR				
1,450	0	0	0	0	0	0	0	0	0	0
1,676	0	0	0	0	0	0	0	0	0	0
1,716	0	0	0	0	0	0	0	0	0	0
1,750	0	0	800							
1,829	0	0	0	0	0	0	0	0	0	1900
1,829	0	0	0	0	0	0	0	0	0	1900
1,830	0	0	0	0	0	0	0	1100	NR	NR
1,830	0	0	0	0	0	0	0	1100	NR	NR
1,905	0	0	0	0	0	0	0	0	0	0
2,134	0	0	0	0	0	0	0	0	0	0
2,134	0	0	0	0	0	0	0	0	0	0
2,134	0	0	0	0	0	0	0	0	0	0
2,250	0	0	0	0	0	500	NR	NR		
2,250	0	0	0	0	0	500	NR	NR		
2,286	0	0	0	0	0	0	0	0	0	0
2,438	0	0	0	0	800	NR	NR			
2,438	0	0	0	0	800	NR	NR			
2,542	0	0	0	0	0	0	0	0	0	0
2,591	0	0	0	0	0	0	0	0	0	0
2,667	0	0	0	0	0	0	0	0	0	0
2,667	0	0	0	0	0	0	0	0	0	0
3,048	0	0	0	0	0	0	0	0	0	0

The modelling shows there is no correlation between sewer diameter and temperature recovery, which is influenced by the weak correlation between sewer diameter and sewage flow rate.

The following chart can be read the same way as the chart above, except the sewer diameter in the left-hand column is replaced with the maximum continuously available dry weather flow rate (or base dry weather flow rate) for each location (l/s), as taken from the water company hydraulic model dry weather flow rate profiles.

Figure 9 – Maximum continuously available dry weather flow rate / heat pump capacity temperature recovery model results - 2°C temperature recovery

Available Flow Rate (l/s)	HP Output Capacity (kW)									
	50	100	250	500	750	1,000	1,500	2,000	2,500	3,000
14	0	0	600							
15	0	0	100							
21	0	0	800							
22	0	0	400							
28	0	0	500	NR						
38	0	0	0	900	NR					
39	0	0	0	800	NR					
51	0	0	0	1200	NR	NR				
53	0	0	0	300	1600	NR				
61	0	0	0	0	NR	NR				
81	0	0	0	0	200	800	NR			
83	0	0	0	0	800	NR	NR			
83	0	0	0	0	800	NR	NR			
104	0	0	0	0	0	900	NR	NR		
109	0	0	0	0	0	500	NR	NR		
109	0	0	0	0	0	500	NR	NR		
110	0	0	0	0	0	300	NR	NR		
141	0	0	0	0	0	0	1200	NR	NR	
166	0	0	0	0	0	0	200	NR	NR	NR
182	0	0	0	0	0	0	0	1000	1000	1000
187	0	0	0	0	0	0	0	1100	NR	NR
187	0	0	0	0	0	0	0	1100	NR	NR
246	0	0	0	0	0	0	0	0	1700	NR
259	0	0	0	0	0	0	0	0	NR	NR
306	0	0	0	0	0	0	0	0	0	1900
377	0	0	0	0	0	0	0	0	0	0
452	0	0	0	0	0	0	0	0	0	0
464	0	0	0	0	0	0	0	0	0	0
484	0	0	0	0	0	0	0	0	0	0
496	0	0	0	0	0	0	0	0	0	0
577	0	0	0	0	0	0	0	0	0	0
626	0	0	0	0	0	0	0	0	0	0
681	0	0	0	0	0	0	0	0	0	0
708	0	0	0	0	0	0	0	0	0	0
771	0	0	0	0	0	0	0	0	0	0
777	0	0	0	0	0	0	0	0	0	0
983	0	0	0	0	0	0	0	0	0	0
1,157	0	0	0	0	0	0	0	0	0	0
1,369	0	0	0	0	0	0	0	0	0	0

The results show a clear trend between the sewage base dry weather flow rate, the heat pump capacity, and sewage temperature recovery within the modelled downstream sewer system. It shows that systems with a higher base dry weather flow rate can support larger heat pump capacity.

This relationship is somewhat intuitive since the sewage flow rate is the driving factor for its energy content. The higher the base flow rate, the larger the heat pump capacity it can support without exceeding (in this case) 2°C reduction in sewage temperature. The uniformity of the green 'zero' cells is therefore entirely predictable.

What is perhaps more interesting is the presence, or absence, of trends in the distance within which the temperature recovers to within 2°C, i.e. the pattern within the cells containing numbers in each column, as shown in the following image.

Figure 10 – Trends within temperature recovery distance

Available Flow Rate (l/s)	HP Output Capacity (kW): 50	100	250	500	750	1,000	1,500	2,000	2,500	3,000
14	0	0	600							
15	0	0	100							
21	0	0	800							
22	0	0	400							
28	0	0	500	NR						
38	0	0	0	900	NR					
39	0	0	0	800	NR					
51	0	0	0	1200	NR	NR				
53	0	0	0	300	1600	NR				
61	0	0	0	0	NR	NR				
81	0	0	0	0	200	800	NR			
83	0	0	0	0	800	NR	NR			
83	0	0	0	0	800	NR	NR			
104	0	0	0	0	0	900	NR	NR		
109	[illegible]	[illegible]	[illegible]	[illegible]	0	500	NR	NR		
109	[illegible]	[illegible]	[illegible]	[illegible]	0	500	NR	NR		
110	[illegible]	[illegible]	[illegible]	[illegible]	0	300	NR	NR		
141	0	0	0	0	0	0	1200	NR	NR	
166	0	0	0	0	0	0	200	NR	NR	NR
182	0	0	0	0	0	0	0	1000	1000	1000
187	0	0	0	0	0	0	0	1100	NR	NR
187	0	0	0	0	0	0	0	1100	NR	NR
246	0	0	0	0	0	0	0	0	1700	NR
259	0	0	0	0	0	0	0	0	NR	NR
306	0	0	[illegible]	[illegible]	[illegible]	0	0	0	0	1900
377	0	0	[illegible]	[illegible]	[illegible]	0	0	0	0	0
452	0	0	[illegible]	[illegible]	[illegible]	0	0	0	0	0
464	0	0	0	0	0	0	0	0	0	0
484	0	0	0	0	0	0	0	0	0	0
496	0	0	0	0	0	0	0	0	0	0
577	0	0	0	0	0	0	0	0	0	0
626	0	0	0	0	0	0	0	0	0	0
681	0	0	0	0	0	0	0	0	0	0
708	0	0	0	0	0	0	0	0	0	0
771	0	0	0	0	0	0	0	0	0	0
777	0	0	0	0	0	0	0	0	0	0
983	0	0	0	0	0	0	0	0	0	0
1,157	0	0	0	0	0	0	0	0	0	0
1,369	0	0	0	0	0	0	0	0	0	0

Weak/no correlation

Discontinuous

Analysis of this data shows that, within the cases in which the sewage temperature is recovered to within 2°C of the pre-abstraction temperature, there is a weak correlation between the recovery distance and the base sewage flow rate.

As the correlations are weak and often discontinuous, the data presented in Figure 10 above cannot be used directly as a rule of thumb for exclusion zone extent. However, by following the 3-stage process of:

1. Combining the Available Flow rate and HP output Capacity into one composite variable, the ‘Demand Factor’.
2. Calculating Demand Factor and Recovery distance for each model run.
3. Grouping model runs into statistical ranges based on Demand Factor, then assessing the probability of recovering sewage temperature to within a predefined dT as a function of both distance from initial abstraction and Demand Factor range.

A statistical rule of thumb can be derived. This process is described in greater detail below.

The Demand Factor

Neither the abstraction rate from the sewer or the sewer flow rate are independently sufficient to predict temperature recovery distance - they must be considered in combination. The following observations were made when investigating the relationship between the two variables.

- Across all modelled scenarios, as sewer flow rate increases relative to heat pump output (or heat pump output decreases relative to sewer flow rate), temperature recovery distance tends to decrease.
- For a single sewer, as heat pump output increases relative to sewer flow rate (or sewer flow rate falls relative to heat pump output), temperature recovery distance always increases.
- A very low sewer flow rate relative to abstraction rate results in failure to recover to the required dT within 2.5 km.
- Exclusion Zones are generally not required when sewer flow rate is high relative to abstraction rate (the abstraction rate is too low to drop sewage temperature below the dT recovery threshold).

The above observations can be explained by thinking of sewage flow as the heat supply, and the heat pump abstraction as heat demand; the sewage flow relative to heat pump capacity is a proxy for the strain placed on the supply by the demand, which is in turn related to the magnitude of sewage temperature reduction at the point of abstraction.

The ‘Demand Factor’ captures this relationship between the supply energy (sewage base flow rate) and the energy demand (heat pump capacity). Therefore, the lower the Demand Factor, the higher the proportion of the available energy that is required for the heat pump.

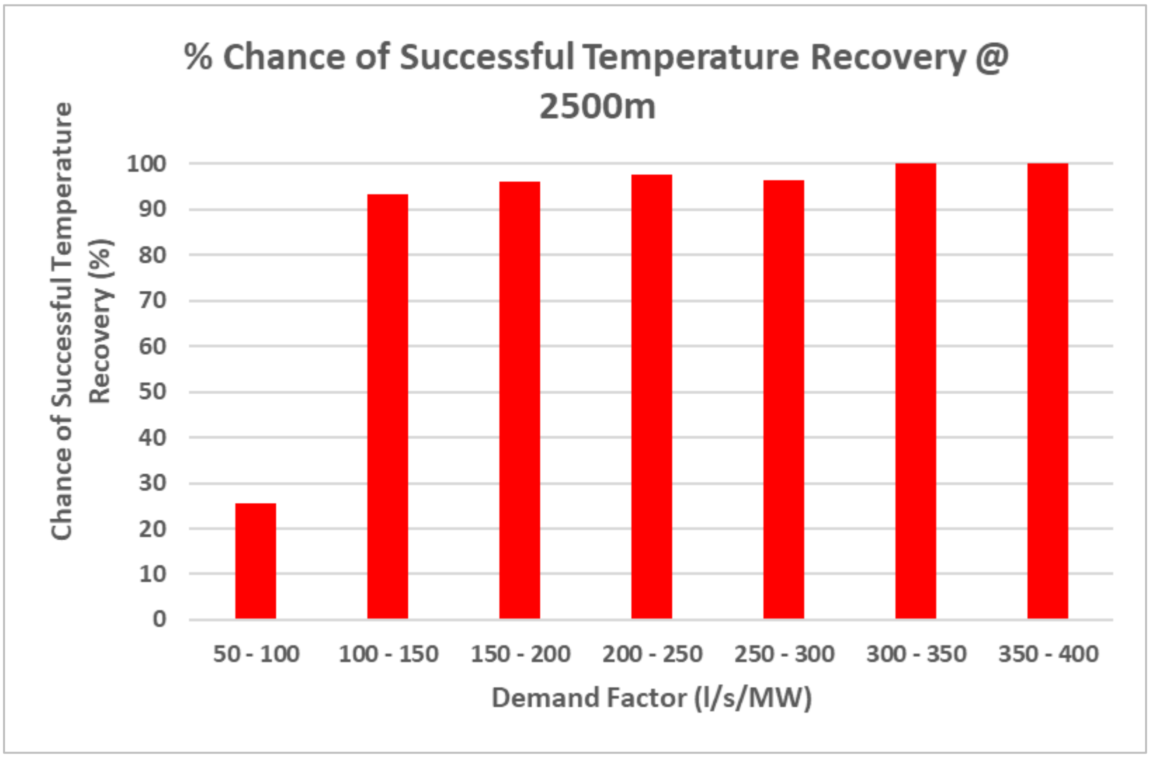
$$Demand\ Factor\ (l/s/\ MW)\ =\ sewage\ base\ flow\ rate\ (l/s)\ /\ heat\ pump\ output\ (MW)$$

Statistical Grouping of Demand Factors, and Analysis

The result set generated from each model run was placed into a group determined by its associated demand factor e.g. result sets for all model runs with demand factors between 50 – 100 l/s/MW were grouped together. The probability of recovering sewage temperature to within a predefined dT relative to abstraction temperature, at a given distance, was assessed for each demand factor range.

As an example, the following chart shows how model iterations with a demand factor between 50 - 100 l/s/MW have a ~30% probability of recovering to within 2°C of the pre-abstraction temperature within the modelled downstream sewage network (up to 2.5km), and those with a demand factor between 100-150 l/s/MW have a ~96% probability of achieving the same recovery.

Figure 11 - Demand Factor and % chance of temperature recovery to within 2°C



This approach can then be used to evaluate the likelihood of different Demand Factor groups recovering to within the required temperature differential (relative to the pre-abstraction temperature) at all evaluated distances. To determine this, we:

- Grouped evaluated locations based on their Demand Factors
- Determined the % of locations within each Demand Factor group that were able to recover to within the desired temperature differential between heat recovery locations, in 99% of timesteps at all evaluated distances

The results of this analysis, for differentials of 1°C and 2°C, are shown overleaf.

Figure 12 - Percentage of evaluated locations achieving the desired temperature recovery differential for ≥99% of timesteps, within Demand Factor groups

Maximum permitted sewage temperature differential between heat recovery locations (°C)	Demand Factor (l/s/MW)	Distance From Abstraction (m) 0	100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400	2500
1	50 - 100	0%	1%	1%	1%	1%	1%	1%	1%	1%	1%	2%	2%	2%	2%	2%	3%	3%	3%	3%	3%	3%	3%	3%	4%	6%	6%
	100 - 150	0%	3%	3%	3%	5%	5%	5%	5%	5%	5%	7%	7%	8%	11%	11%	13%	13%	13%	13%	13%	13%	13%	13%	13%	15%	15%
	150 - 200	0%	0%	4%	6%	6%	6%	6%	6%	10%	12%	13%	19%	21%	21%	23%	27%	27%	29%	29%	33%	33%	33%	33%	33%	33%	33%
	200 - 250	22%	29%	32%	41%	49%	54%	54%	54%	56%	66%	68%	68%	71%	73%	78%	78%	83%	83%	83%	85%	85%	85%	85%	85%	85%	85%
	250 - 300	93%	93%	93%	93%	93%	93%	93%	93%	93%	93%	93%	93%	93%	93%	93%	93%	93%	93%	93%	93%	93%	93%	93%	93%	93%	93%
	300 -350	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
2	50 - 100	0%	1%	3%	4%	5%	5%	7%	7%	10%	11%	14%	17%	19%	20%	21%	21%	22%	23%	23%	24%	24%	24%	24%	24%	25%	25%
	100 - 150	48%	49%	54%	66%	66%	70%	72%	75%	80%	85%	87%	87%	89%	90%	90%	90%	92%	92%	92%	93%	93%	93%	93%	93%	93%	93%
	150 - 200	94%	94%	94%	94%	94%	94%	94%	94%	94%	94%	94%	94%	94%	94%	96%	96%	96%	96%	96%	96%	96%	96%	96%	96%	96%	96%
	200 - 250	98%	98%	98%	98%	98%	98%	98%	98%	98%	98%	98%	98%	98%	98%	98%	98%	98%	98%	98%	98%	98%	98%	98%	98%	98%	98%
	250 - 300	96%	96%	96%	96%	96%	96%	96%	96%	96%	96%	96%	96%	96%	96%	96%	96%	96%	96%	96%	96%	96%	96%	96%	96%	96%	96%
	300 -350	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

By analysing the data in this way, it is possible to identify some indicative rules of thumb for the establishment of Exclusion Zones based on the model data that was analysed, for example:

1. Locations with a Demand Factor below 50 l/s/MW do not have enough energy within the sewage for the required heat pump capacity.
2. Locations with a Demand Factor of 300 l/s/MW and above will never cool the sewage by more than 1°C in >1% of timesteps.
3. >80% of locations with a Demand Factor of 250 - 300 l/s/MW recover to within 1°C of the pre-abstraction temperature at all distances from abstraction for >99% of timesteps.
4. >80% of locations with a Demand Factor of 200 - 250 l/s/MW recover to within 1°C of the pre-abstraction temperature within 1.6km in >99% of timesteps.
5. <80% of locations with a Demand Factor <200 l/s/MW recover to within 1°C of the pre-abstraction temperature within 2.5km downstream in >99% of timesteps.
6. >80% of locations with a Demand Factor above 150 l/s/MW cool the sewage by less than 2°C at all distances from abstraction in >99% of timesteps.
7. ~80% of locations with a Demand Factor of 100 l/s/MW - 150 l/s/MW recover to within 2°C of the pre-abstraction temperature within 0.8km in >99% of timesteps.
8. All locations with a Demand Factor <100 l/s/MW fail to recover to within 2°C of the pre-abstraction temperature within 2.5km downstream >99% of timesteps.

Based on the data analysed and the statements above, the following indicative rule of thumb table has been developed for Exclusion Zone definition. It is noted that this is a preliminary output. If more data is secured from other water company catchment models, further analysis can be undertaken to strengthen the recommendations around Exclusion Zones.

Figure 13 - Exclusion Zone rules of thumb based on analysed data

<table>
<tr><th colspan="2" rowspan="2"></th><th colspan="6">Demand Factor of Upstream HP (l/s/MW)</th></tr>
<tr><th><50</th><th>50 - 100</th><th>100 - 150</th><th>150 - 200</th><th>200 - 250</th><th>250 - 300</th></tr>
<tr><td rowspan="3">Maximum permitted sewage temperature differential between heat recovery locations</td><td>1°C</td><td rowspan="3">Insufficient sewage flow</td><td colspan="3">Upstream WSHP installation prohibited</td><td>1700m</td><td></td></tr>
<tr><td>2°C</td><td></td><td>900m</td><td colspan="3" rowspan="2">No Exclusion Zone Required</td></tr>
<tr><td>3°C</td><td></td><td></td></tr>
</table>

Further Considerations

The preceding sections present a methodology for identifying rules of thumb related to sewer heat recovery Exclusion Zones. It is important to note, however, that the confidence within the conclusions is limited by the volume of data that is analysed. It is therefore recommended that efforts continue to access more water company model data with which rules of thumb can be developed further. Indeed, by evaluating data from different water companies and different locations, it may be that rules of thumb could be refined based on additional, location-specific characteristics. It may be that catchment characteristics in very large cities mean Exclusion Zone rules of thumb differ slightly from those relevant to smaller towns and cities.

Other points of consideration based on the work undertaken to date include:

- The results will be conservative due to the non-inclusion of wet weather flow; however, it would be impossible to define meaningful rules of thumb taking into account the influence of rainfall on sewer heat recovery potential.
- Before rules of thumb can be finalised, the threshold criteria for Exclusion Zones must be defined, for example:
  - What is an acceptable temperature threshold for cooling of sewage in relation to an existing project? Figure 10 presents results for values of 1°C, 2°C and 3°C.
  - What is an acceptable threshold for the percentage of time that sewage temperature should recover to the required temperature delta? Analysis to date has been based on temperature recovery for 99% of modelled time steps.
  - How should the cumulative effect of multiple schemes be accounted for? Is the purpose of the Exclusion Zone to ensure that the first heat recovery scheme's source temperature is not degraded by subsequent upstream projects? If so, all Exclusion Zones should be referred back to the initial project and would change as more upstream schemes are added.

On the matter of the cumulative effect of multiple schemes, it is proposed that there are a number of potential approaches, as follows:

1. Exclusion Zones are related to the nearest downstream heat recovery project only. This approach provides no theoretical limit to the cumulative impact of multiple upstream heat recovery projects on an initial first user scheme installed further downstream.
2. Exclusion Zones are related to the nearest downstream heat recovery project, but also to the initial first user scheme, ensuring that the cumulative impact on the first user does not exceed a defined threshold. Where a proposed scheme is expected to exceed this threshold impact on the first user, it could either:

- Be rejected upon application; or
- Approved if the proposed scheme operator pays the first user a fee to compensate for the reduction in heat pump COP. This may still be more attractive to an alternative heat source for the proposed scheme operator.

It is recommended that this workstream continues with the aim of establishing Exclusion Zone threshold criteria and increasing the volume of data on which rules of thumb can be based.

The Impact of Sewer Heat Recovery on WwTWs

As described in the Summary of Water Company Perspectives section, the importance of limiting sewage cooling on the wastewater treatment process was emphasised by all the water companies that were engaged. Two of the companies we spoke to identified 8°C as an important design threshold temperature below which the wastewater treatment process would suffer significant issues. It was also noted that any reduction in the sewage temperature would have some impact on the process, although none of the companies we spoke to were able to quantify the efficiency loss, stating that a watching brief would be required.

With regard to Exclusion Zones, it is proposed that they are not necessary for regulating the temperature of sewage as it enters the WwTW. Rather, it is the total quantum of heat recovered across the catchment relative to the volumetric flow of sewage into the WwTW that is the key factor in determining the change in inflow temperature. To model this to a high degree of accuracy, it would be necessary to take into account the time in transit from the heat recovery location(s) to the WwTW, such that the downstream impact of multiple heat recovery projects can be simulated. For the purposes of guideline development, however, an alternative is proposed in which the available heat is calculated using the volumetric flow rate and a threshold (minimum) permissible sewage temperature into the WwTW.

To quantify the available heat a tool has been developed to calculate the quantum of energy that could be recovered in cooling the WwTW inflow to a defined temperature. The methodology leverages the fact that WwTW intake temperature is influenced by the total quantum of heat abstracted from the sewer network it serves, i.e. the location of abstraction is of little significance[5]. From this, it can be approximated that:

$$T_{inflow,abstraction} = \frac{T_{Inflow,no\ abstraction} * \dot{m}_{inflow} * C - \dot{Q}_{abstraction}}{\dot{m}_{inflow} * C}$$

Where:

- C is the specific heat capacity of the sewage (4180 J/Kg/K).
- $T_{inflow,abstraction}$ and $T_{Inflow,no\ abstraction}$ are the temperature of the inflow to the WwTW with and without abstraction (K)
- $\dot{m}_{inflow}$ is the mass flow rate into the WwTW (Kg/s)
- $\dot{Q}_{abstraction}$ is the abstraction rate (J/S or W)

In operating the tool, the user must provide intake flow rate and sewage temperature profiles for the modelled year. The user may then vary the minimum allowed inflow temperature to determine:

[5] *There will be an additional heat flux effect (heat transfer between the sewage and air/ground) with a small dependency on abstraction location. However, for reasons outlined in the methodology section, it is expected that the contribution of this effect to WwTW intake temperature will be very slight.*

- The minimum continuously available heat abstraction (in kW) based on the sewage inflow profile and the permissible sewage temperature reduction.
- The peak available abstraction capacity (in kW) based on the sewage inflow profile and the permissible sewage temperature reduction.
- The total annual abstractable heat (in kWh) based on the sewage inflow profile and the permissible sewage temperature reduction.

To provide an example of the calculation, dry weather inflow data from the Thames Water Beckton WwTW was input into the model with sewage temperature set to a constant 14°C (which is reasonable as an average sewage temperature across a year), and the minimum allowed inflow temperature set to 10°C (representing the nominal minimum temperature limit). The projected annual available heat was ~1,900GWh, with 160MW of source heat available as a baseline. This provides an indication of the scale of sewer heat abstraction that could be possible across a catchment before problematically impacting the wastewater treatment process. It is noted, however, that this will vary significantly depending on the size of each catchment.

It is also important to note that it would be very difficult to control the heat offtake on multiple heat recovery schemes to a minimum permissible downstream WwTW inflow temperature. It is therefore suggested that the available heat is limited according to pre-defined conditions, which could vary diurnally or seasonally, but could more conservatively simply be based on the maximum continuously available WwTW inflow rate. When the scale of the heat recovery is such that it will not make a significant difference to the WwTW inflow temperature, conditions/limitations should not be required; however, as more schemes are added and the cumulative impact on the WwTW inflow temperature becomes more pronounced, assessment will be required prior to new heat recovery schemes getting the go-ahead.

It is anticipated that water companies will have high-quality sewage inflow data for their treatment works, and this should be evaluated prior to any upstream heat offtake development to evaluate the impact on the WwTW, taking into account any existing heat recovery projects on the same catchment. It is also proposed that water companies may require a mechanism through which they can prevent heat recovery schemes from operating if conditions at the WwTW require it (e.g. if the inflow temperature at the WwTW has dropped to 10°C).

Conclusions and Next Steps

Conclusions

They key conclusions from this exercise are summarised as follows:

- Water company attitudes to sewer heat recovery vary somewhat; however, the majority of those we spoke to are primarily concerned about the impact of cooling the sewage on the wastewater treatment process.
- Water companies were also concerned about anything that would reduce the cross-sectional area of existing sewer mains, given the known issues with system capacities and the discharging of raw sewage to water courses during heavy rainfall events. It has also been noted that solutions involving the diversion of sewage out of water company regulated assets (sewers) for heat exchange raises concerns about permitting and the ownership of risk.
- Based on discussions with water companies, it is concluded that sewer heat recovery must not cool the sewage below 8°C as it enters the WwTW, and ideally should not cool the sewage below 10°C. This is to maintain the efficiency of treatment process.
- Analysis shows that there is a weak correlation between the diameter of the sewer and the sewage flow rate within it. As such, sewer diameter is not a good indicator of the potential heat recovery at a given location.
- Sewage flow rate is the key factor in determining the available heat recovery. The relationship between sewage flow rate (l/s) and the required heat abstraction (MW) are the key factors in determining the extent to which a sewage will be cooled in a heat recovery project. This relationship is simplified via a single composite variable – the Demand Factor (l/s/MW), which is the ratio of sewage base flow rate (l/s) to the required heat pump output (MW).
- Regarding sewage temperature recovery downstream of a heat abstraction, analysis shows that heat flux between sewage, the ground and in-sewer air is of minimal significance compared to the changing mass balance due to sewage inflows in the downstream sewer network.
- Through analysing large sets of sewage flow rate data from water company hydraulic models, trends between the Demand Factor and the rate of temperature recovery downstream of a notional heat abstraction can be seen. These trends indicate the probability of the sewage temperature recovering to within a given delta of the pre-abstraction temperature based on the Demand Factor and can be used to inform the development of Exclusion Zones.
- An Exclusion Zone should be established according to the Demand Factor of a potential future heat recovery project upstream of an existing one. Unless, and until, there is a proposal for a new heat recovery project upstream of an existing one, there is no justification for an Exclusion Zone around the original scheme, since it would be entirely arbitrary.

- Further development of guidance is required around the threshold criteria for Exclusion Zones; specifically:
    - What is an acceptable temperature threshold for cooling of sewage in relation to an existing heat recovery project?
    - What is an acceptable threshold for the percentage of time that sewage temperature should recover to the required temperature delta?
    - How should the cumulative effect of multiple schemes be accounted for? Is the purpose of the Exclusion Zone to ensure that the first heat recovery scheme's source temperature is not degraded by subsequent upstream projects? If so, all Exclusion Zones should be referred back to the initial project and would change as more upstream schemes are added.
    - How should the total sewer heat recovery across a catchment be limited, i.e. based on the flow rate and temperature of the inflows at the WwTW?

Next Steps

The proposed next steps are:

- Work with water companies to access more hydraulic model data with which to perform further analysis of the relationship between Demand Factor and sewage temperature recovery. This will inform the further development of Exclusion Zone guidelines.
- Where sewer monitoring equipment has been installed (i.e. through heat network project development activities), review the data alongside the corresponding water company hydraulic model to evaluate the accuracy of the modelled data. Consider installation of monitoring equipment under this scope of work, budget allowing, but noting that the bulk data analysis described above is more valuable to the development of rules of thumb.
- Once the above is complete, develop finalised guidelines on the use of Exclusion Zones around sewer heat recovery. DESNZ to publish.
- Consider how Exclusion Zones would be identified and implemented, i.e. is this something that would be overseen by the water companies, or by another party (e.g. DESNZ) on behalf of the water companies?
- DESNZ to continue engagement with water companies to discuss the commercial, regulatory and other non-technical implications of sewer heat recovery.

This publication is available from: https://www.gov.uk/government/collections/heat-networks, https://www.gov.uk/government/publications/sewer-heat-recovery-exclusion-zone-guidance-methodology

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