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Vulnerability of a water distribution network from a hydraulic point of view

A case study in Lille Skensved, Denmark

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Abstract

As the global population continues to grow and the demand for clean drinking water increases, the importance of a functioning water distribution network becomes evident. In the design and planning phase of a distribution network, a hydraulic model is a helpful tool for predicting consequences of an action and defining vulnerable parts of a network. This study attempts to set up a reliable and calibrated hydraulic model of a water distribution network in Lille Skensved, Denmark, using MIKE+ (EPANET) software. The study focused on investigating and determining critical parameters within the network to evaluate the vulnerability of the water distribution network in Lille Skensved.

Calibration of sensitive parameters can improve the results to a certain extent if the functional input data does not fulfill the desired quality. The hydraulic model constructed for the water utility of Lille Skensved was calibrated using field measured data for a 1-week period. Following adjustments of sensitive parameters, high similarities between simulated and measured values were achieved for 3 measurement stations. Despite this, significant deviations were detected in the measurement station located in the eastern part of the system.

Simulations were executed for 2 separate scenarios. Differences in the result of the vulnerability were found between the two scenarios. Furthermore, the generated results showed high redundancy in the network as well as certain degree of robustness.

Lastly, the simulated results were compared to future renovation projects of the water utility. The authors concluded that this vulnerability function is a solid aid and serves best as a support tool in decisions about renovation, since the model displayed some uncertainties. Furthermore, it was deduced that a vulnerability analysis is useful for initial screening of the performance of a network.

Sammanfattning

I takt med att den globala befolkningen fortsätter att växa och efterfrågan på rent dricksvatten ökar blir vikten av ett fungerande dricksvattennätverk uppenbart. I design- och planeringsfasen av ett distributionsnät är en hydraulisk modell ett användbart verktyg för att förutsäga konsekvenser av en åtgärd och för att definiera sårbara delar av ett nätverk. Denna studie försöker skapa en tillförlitlig och kalibrerad hydraulisk modell av ett vattendistributionsnät i Lille Skensved, Danmark, med hjälp av MIKE+ (EPANET) programvara. Studien fokuserade på att undersöka och bestämma kritiska parametrar inom nätverket för att utvärdera sårbarheten hos vattendistributionsnätet i Lille Skensved.

Kalibrering av känsliga parametrar kan förbättra resultaten till viss del om indata inte uppfyller önskad kvalitet. Den hydrauliska modellen som konstruerades för vattenverket i Lille Skensved kalibrerades med hjälp av fältmätdata under en 1-veckorsperiod. Efter justeringar av känsliga parametrar uppnåddes stora likheter mellan simulerade och uppmätta värden för 3 mätstationer. Trots detta upptäcktes betydande avvikelser i mätstationen i den östra delen av systemet. Simuleringar utfördes för 2 separata scenarion. Skillnader i resultatet av sårbarheten hittades mellan de två scenarierna. Dessutom visade de genererade resultaten hög redundans i nätverket samt en viss grad av robusthet.

Slutligen jämfördes de simulerade resultaten med framtida renoveringsprojekt av vattenverket. Författarna drog slutsatsen att denna sårbarhetsfunktion är ett solitt hjälpmedel och fungerar bäst som ett stödverktyg vid beslut om renovering, eftersom modellen visade vissa osäkerheter. Vidare drogs slutsatsen att en sårbarhetsanalys är användbar för den inledande screeningen av ett nätverks prestanda.

Contents

1. INTRODUCTION

1.1 Background

As the global population continues to grow and the demand for clean drinking water increases, the importance of a functioning water distribution system becomes evident as a critical infrastructure. The design of a water distribution system may vary depending on living standards and conditions, but the fundamental principles remain the same. In modern urban societies, a water distribution system is essential for maintaining and developing the needs of the population, including private consumption, hospitals, agricultural production, and industrial needs. High demand and high needs put significant stress on distribution systems, and actively managing the combined resilience and vulnerability of a heterogeneous distribution system, whether it is an older system or a newer one, can be a challenging task.

Determining a water distribution networks openness to failure requires a clear definition of used terms. Hashimoto et al. was one of the first to introduce vulnerability within hydraulic applications in 1982, as describing the overall performance of the distribution system and defining the term as "*the extent of failure of the system in question"* and system resilience as "*the rate of recovery from failure"*. Several years later, a new resilience index was presented by Todini (2000) as "*the essential capability of the system to overcome failures*". Nowadays, many different useful and supportive tools and methods exist in this process of determining vulnerability, resilience, and sensitive parameters of a network with these definitions in mind. This could be e.g., building case specific hydraulic models based on geospatial data and information systems, yielding index data to quantify vulnerability and resilience. Moreover, previously published graph theory (Wagner 2003) has advanced into more complex networking theories (Antionetta et al. 2018). For this specific case study, the method used will be based on a hydraulic approach; pipe-node topology representation of the water supply (Yazdani & Jeffrey 2011) and using the mathematical tools within EPANET engine with MIKE+ as built-on package code. Nevertheless, predicting an accurate outcome of the response of a water distribution system to a pipe break is, whichever used method, challenging.

This case study is based off the water distribution network of a small town called Lille Skensved (1.16 km^2) located in Køge municipality, southwest of Copenhagen. The water distribution has a total length of about 42 km of varying materials and dimensions. One of the top consumers connected to the supply network is one of the largest gelatin factories in the world.

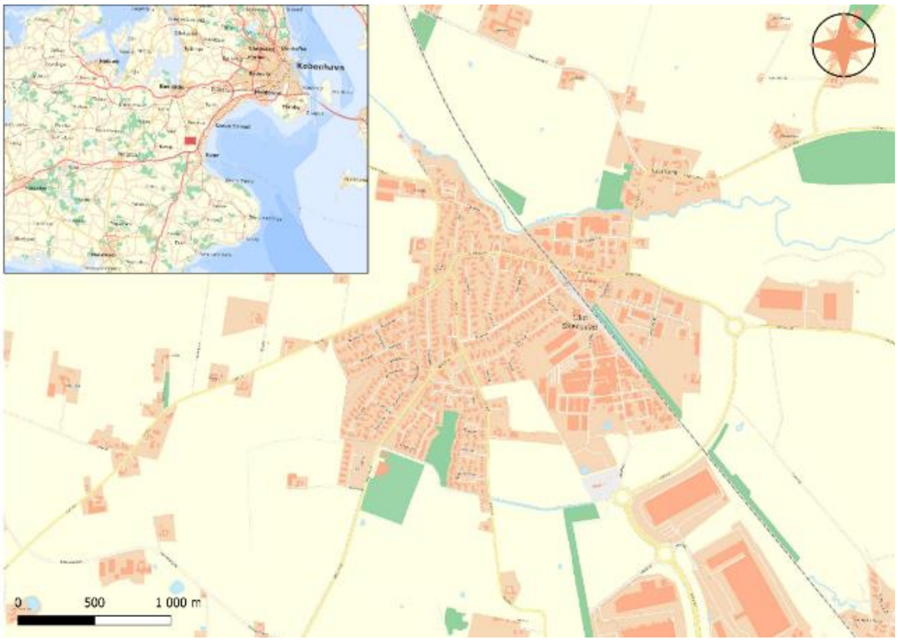


Figure 1. Case study area – Lille Skensved

In this case study, the functional behavior, critical segments, and vulnerable pipes of the water distribution system in Lille Skensved will be analyzed, as well as the effectiveness of planned reconstructions in addressing system deficiencies. It will be evaluated whether the results of this case study will be used to support decision-making by the water utility in developing a renovation plan and identifying vulnerable and sensitive parts of the distribution network.

The study will begin with a literature review of published papers and journals on various methods and hydraulic approaches for conducting a vulnerability or criticality analysis of a water supply network and applied software. Data collection and raw data treatment will be the first step in setting up the hydraulic model, to the extent allowed by Ramboll GDPR. The model will then be calibrated, and sensitive parameters will be evaluated before running both functional and vulnerability analyses. The workflow for this thesis is outlined in Figure 2.

The aim of this thesis is to set up a hydraulic model to evaluate the vulnerability of the water distribution network in Lille Skensved using MIKE+ in 2 different scenarios – normal operating conditions and in a scenario where the distribution system runs on a backup pump. The vulnerability analysis will examine various parameters, including pipe criticality, node reachability, and system-wide indexes. The network in the model will also be modified to observe how the vulnerability of the network changes. More specifically, the vulnerability is termed as hydraulic vulnerability in this report which means that it is based on parameters such as flow, pressure, and demand. Importantly, it solely focuses on this type of vulnerability entailing that all future references to vulnerability or criticality in this report are connected to hydraulic metrics. For instance, there is a need for determining the vulnerability of a network due to earthquakes and other disasters (Christodoulou et al. 2018). While this is important, this report once again will only analyze the hydraulic vulnerability of the water distribution network.

This work progressed based on following research topics:

- How is a reliable and calibrated hydraulic model set up, in this case for Skensved water utility?
- How is a vulnerability analysis performed in MIKE+ and how are the results interpreted?
- How does the vulnerability vary in different scenarios?
- How can the results of the vulnerability analysis be useful for future renovation plans by the water utility?

1.2 List of terminology

Vulnerability	The collective analysis of the indexes, node reachability and pipe criticality generated in Mike+ programming
Pipe criticality	Numerical representation of the importance of each individual pipe in the network based on the parameters flow, pressure, demand and length
Node reachability	The probability of one node being connected to one source
Node connectivity	The probability of all nodes being connected to one source
Reliability	A probabilistic measure of a system remaining functional at any given time (Gunawan et al. 017)
*Resilienc*y	Capability of overcoming stress or failures to the network (Todini 2000)
Robustness	Capability of sustaining supply of water in the network during malfunctions (Gunawan et al. 2017)
Redundancy	Alternate pathways for the water to travel in an event of disruption (Dave & Layton 2020)
Looped network	One source distributes water through interconnected pipes resulting in flow being able to travel to the same location in multiple ways (Todini 2000)
Branched network	One source distributes water through independent pipes stretching out in several separate directions (Todini 2000)
Functional analysis	Analysis of functional parameters, e.g., pressure, flow
Control pressure	Target pressure controlled by pump
Service pressure	Pressure at demand point
Hydraulic head	Datum, sea level to Hydraulic grade line
Pressure	Pipe elevation to Hydraulic grade line

2. METHODOLOGY

2.1 Work progress

The present study was initiated by Ramboll and commenced with a comprehensive review of existing literature on vulnerability studies and relevant published papers to inform the selection of appropriate methodology and identification of necessary data. The majority of the duration of the project was devoted to establishing the hydraulic model, a process which entailed the collection and processing of data and the calibration of the model through the adjustment of sensitive parameters to ensure its reliability. Once the model had been successfully established, the vulnerability analysis could be carried out and the results evaluated.

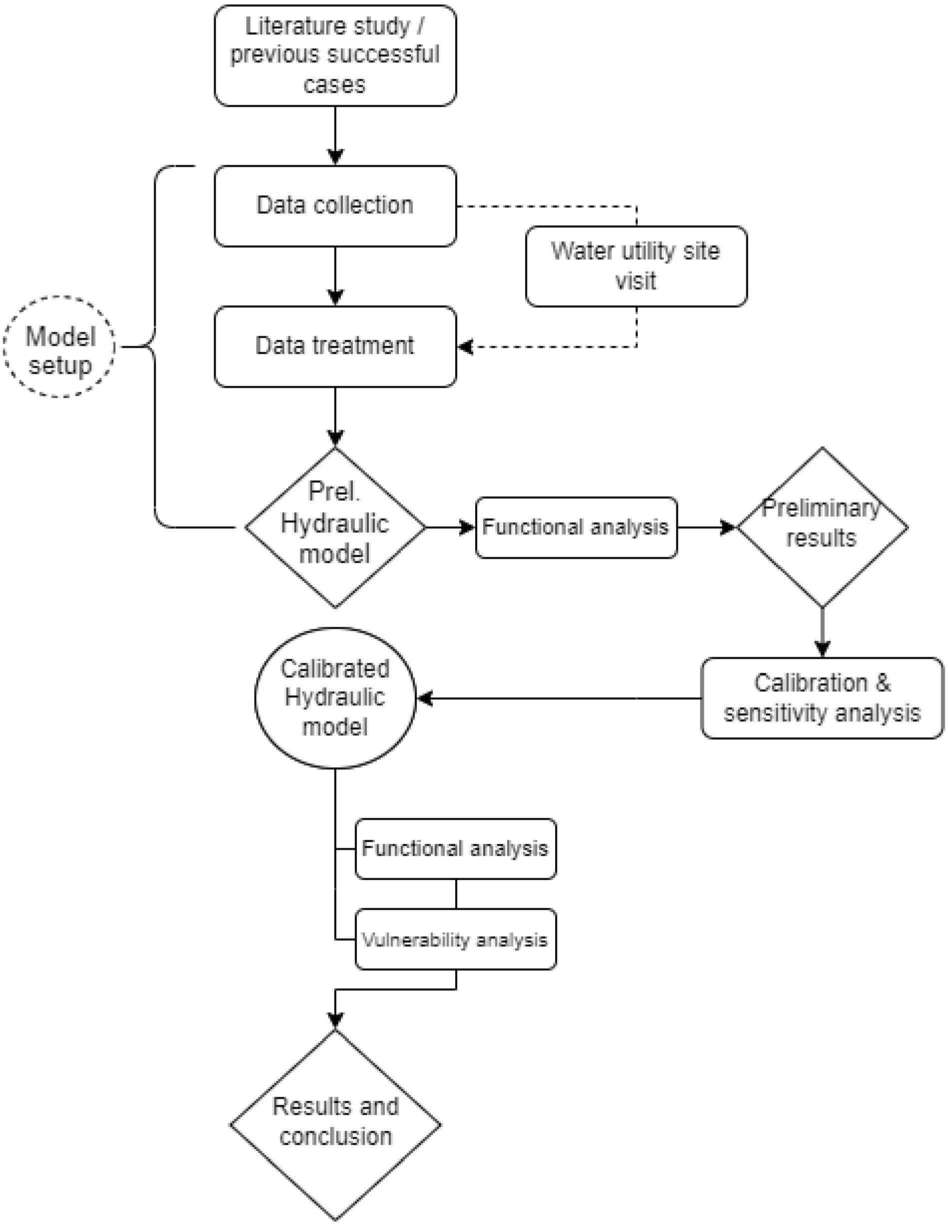


Figure 2. Overview of the case study as generalized workflow chart.

2.2 Literature study

To understand how a water distribution network can be vulnerable, the crucial elements of a network must be specified. A water distribution network is intricate in its nature with many components. The ambition of a water distribution network is for all separate parts of the network to function properly and cooperate with each other (Tornyeviadzi et al. 2022). Pipes, pumps, and valves are the transporting substance of water distribution network and collectively named links (Desta et al. 2022). If for instance a pipe were to become damaged and thus unusable, the overall capacity and performance of the network would be affected. Naturally, certain pipes have more water flowing through them than others making them more hydraulically important. In other words, these pipes could be regarded as more critical from a hydraulic point of view (Marlim et al. 2019).

While links are necessary in a water distribution system, connections between them are equally important. These connections are as a group called nodes. Tanks, reservoirs and junctions comprise this group (Desta et al. 2022). If a node were to become incapacitated, affected consumers could be without water (Tornyeviadzi et al. 2022). Nodes can be viewed as more or less critical based on probabilistic measures. (Agathokleous et al. 2022). In summary, links and nodes are the essence of a water distribution system and the need for every component functioning for the benefit of the entire system is imperative.

Vulnerability is a broad term which according to Fragidiakis & Christodoulou covers three main topics: components, topology and hydraulics. Initially, components entail mechanical parts such as valves, tanks and pipes. Secondly, topology refers to the number of nodes connected in the system as well as elevations of the nodes. Lastly, parameters such as flow and pressure are considered hydraulic properties (Fragiadikis & Christodoulou 2014).
Wagner, Shamir & Marks conduct a simple way of calculating the reachability and connectivity for nodes. They describe how a modern water distribution network with both a looped and branched topology can be explained in terms of water supply to nodes. Reduced to simply determining whether a demand node can access water, this analysis provides an overview of the general state of water availability in the network (Wagner et al. 1988). Subsequently, Wagner et al continues with a simulation method of analyzing the reliability of two water distribution methods. This model introduces a flexibility by accounting for all nodes despite some being below the service pressure. However, a drawback of these studies is the application of the methods being limited to small networks (Wagner et al. 1988).

Terms such as reliability, redundancy and resilience have emerged in recent years as useful metrics when evaluating the vulnerability of a water distribution network. Todini introduced a resilience index which can be used to evaluate the reliability of a water distribution network. The Todini index describes the intrinsic capability of the system to overcome failures, but still being able to supply demands at nodes (Todini, 2000). The introduced resilience index stating the internal energy through the pipes of a system would meet the minimum requirements for pressure and flow at a given node (1). The proposed resilience index by Todini bases its idea of all the energy going into a network is equal to the internal energy lost due to friction and the energy required to supply water at a demand point. Theoretically, it is a proportion that should vary between 0 and 1.

$$TI = \frac{\sum_{j=1}^{n_n} d_j(h_j - h_{aj})}{\sum_{i=1}^{n_0} q_l h_l + \left(\frac{1}{\gamma_w}\right)\sum_{k=1}^{n_p} P_k - \sum_{j=1}^{n_n} d_j h_{aj}} \tag{1}$$

Whereas,
n_n is the number of nodes in the network, d_j is demand at node j, h_j is hydraulic head at node j and h_{aj} is minimum required hydraulic head at node j. Furthermore, n_0 is number of reservoirs in the network, $q_i$is outflow from reservoir i, h_i is hydraulic head at reservoir i, n_p is the number of pumps in the system, P_k is power of pump k and lastly γ_w is water specific weight. In case there's no additional pumps present in the system, the energy provided by the pump is removed from the denominator.

From Todini's introduced equation the total index value will either be positive or negative depending on the nominator $\sum_{j=1}^{n_n} d_j(h_j - h_{aj}) < 0$ or $\sum_{j=1}^{n_n} d_j(h_j - h_{aj}) > 0$. This means that there are nodes of energy shortage and surplus of energy respectively. In the case of negative resilience index, the minimum service pressure exceeds the given pressure at node and calls for operational problems within the system. It is therefore desirable to obtain a positive index value.
Similarly, Gunawan et al. attempted to combine the reliability, resilience, robustness and redundancy of the parameters into a joint assessment of the performance of a water distribution network. They continue with joining structural and hydraulic quantifiers and highlight the importance of using several metrics when evaluating the performance of a drinking water network (Gunawan et al. 2017). In this report, the main parameters of interest are the redundancy robustness of the network. To clarify the definition, the redundancy means how many alternate pathways water can reach a specific consumer. Furthermore, robustness entails to what degree the network is still able to supply water to consumers despite a malfunction of for instance a pipe (Gunawan et al. 2017).

Moreover, pipe criticality analysis is an integral part of network vulnerability assessment. Such an analysis is performed by Prasad. First, a process of shutting down one pipe at a time in the network is conducted. For each shutdown sequence, using Wagner´s theory on accounting for all nodes despite pressure level, two indexes representing the supply to, and pressure decrease of each node respectively can be calculated (Prasad 2021). Marlim, Jeong & Kang develop thus further by identifying critical pipes through using multiple criticality indexes (Marlim et al. 2019). Albeit these methods seem time-consuming and somewhat inefficient.

While the studies above contain useful results, the proposed method is a holistic approach which attempts to cover all vital parts of a drinking water network. By using a function within MIKE+, network vulnerability analysis, an extensive depiction of the topological and hydraulic state of the distribution network can be viewed. In addition, the analysis is fully automated which increases efficiency. Importantly, the study will attempt to analyze how the parameters robustness and redundancy are linked to the vulnerability of the network.

2.3 Vulnerability modelling & applied software

To begin, several methods of assessing vulnerability exist, in particular *topological* and *hydraulic* modelling. It should be noted that these two methods can often be combined when investigating a distribution network. Nonetheless, a comparison below will describe how they differ in technique and outcome.

Hoese describes how a *topological* method searches for the connectivity of the nodes in a network and ranks the nodes based on number of connections. Thus, this method does not account for actual flow and instead relies on the probability that a strongly connected node likely will have high flow passing through. Furthermore, the evaluation of the vulnerability is based on the nodes with highest rank and uses them as the center of the investigation (Hoese 2022).

Hydraulic modelling solely uses parameters such as flow, demand and pressure according to Hoese. This method is a direct measure of the performance of a system. In addition, Gunawan et al reveal in a study how many different parameters have an impact on the vulnerability of a water distribution network. Due to this, a more holistic result is achieved through a combination of the two methods (Gunawan et al. 2017).

2.3.1 MIKE+ methodology

MIKE+ is a hydraulic modelling program which uses EPANET as its engine to for instance simulate and calculate flow in pipes, pressure at nodes, simulating shutdown scenarios, tracking chemical pollutants in the system and simulating maintenance requirements. The model uses retrieved data and applies it to the appropriate components in the model. In this report, the function of use will be network vulnerability analysis. Below is an introduction to the various components of a network vulnerability analysis.

The hydraulic analysis is executed out by closing each pipe, one by one, and evaluating the hydraulic impact of the closed pipe. The analysis generates further two indexes. Namely, Todini index and node connectivity. These indexes are network-wide and provide an overview of the network condition. However, they refrain from detailing any specific tendencies of the network. Furthermore, the analysis also generates parameters specific to each element of the network. These are pipe criticality and node reachability. The following chapters will further explain these indexes and parameters.

2.3.1.1 Node reachability & connectivity

Node reachability describes the probability where one given node is connected to at least one source. For example, if a node is to achieve a 100 % reachability, then this node is connected during the entire duration of the vulnerability analysis, which occurs primarily for nodes within looped networks. Furthermore, connectivity defines as the probability where every node is connected to at least one source. The definition - if connected to a source – does not necessarily mean enough pressure is provided, though instead that the node in question is functional and connected to the network. There could be scenarios where a given node is connected to a water source through a fully functional flow path, but if the system has insufficient pressure levels, it may be the demand is not filled at the given node due to the insufficient pressure.

Whether the pressure levels are insufficient or not for a node to also meet its required demand, are further determined when accounting for critical parameters and determining the total pipe criticality. Node reachability and connectivity are, though, first indicators of how well a system operates.

2.3.1.2 Todini Index

Combined with the node connectivity and pipe criticality indexes, the Todini index is calculated and is one of the parameters in terms of evaluating a systems vulnerability. Todini index reveals the margin of capacity for the entire network. The closer the value is to 1, the closer the entire network is operating to its minimum demand (DHI 2022).

2.3.1.3 Pipe criticality

The pipe criticality index creates a rating of each link based on flow, pressure, demand, and pipe length. In addition, one parameter of study can be added to the pipe criticality analysis at the discretion of the modeler. Below the integral parameters of the pipe criticality index are described. The pipe criticality is the emphasis of the analysis as it is most intricate in its yield of results. Lastly, these parameters are probabilistic measures based on the flow and pressure generated by a standard hydraulic simulation in MIKE+.

P1	Flow that cannot be transmitted or delivered through a given pipe
P2	Number of nodes where service pressure is below minimum service pressure
P3	Total water demand that cannot be delivered due to insufficient service pressure
P4	Total length of pipes where service pressure is insufficient

$$Pipe\ criticality_{pipe,i} = Average\ of\ (P1 + P2 + P3 + P4\ _{pipe,i}) \qquad (2)$$

Pipe criticality is defined as the average of the four parameters P1-P4 (2). These parameters are measured in percentage terms. The four parameters as well as the criticality can be viewed in both table and map view for every link. In addition to the percentage terms, the actual value of each parameter is also presented in a tabular view. In addition to these parameters, the function allows the user to define another parameter, P5, which adds flexibility to the modelling of the vulnerability analysis. This parameter is not used in this work.

3. HYDRAULIC MODEL SETUP & PRELIMINARY RESULTS

3.1 Overview of Lille Skensved water distribution network

Lille Skensved is a small community in the region of Sjælland, about 40 km south of Copenhagen. Lille Skensved has about 1600 inhabitants as of 2022 and is part of Køge municipality. and its own water distribution network which supplies the entire population with water. The town of Lille Skensved is also home to both large as well as several smaller industries.

Figure 3. Lille Skensved (Dataforsyningen, 2022)

The water utility of Lille Skensved distribution system has given the authors further approval to use the GIS (geographic information system) data for the distribution system solely for this thesis purpose. The data for the outlaying framework is extracted from Ramboll's GIS-library and used as the base of the model in form of geospatial vector data format (points and polylines). The GIS-data can be viewed for potential new connecting costumers on the water utility of Lille Skensved's website (including valves, boreholes etc.).

Figure 4. Polylines (pipes) and points (junctions) imported.

Furthermore, distribution pipes and transmission pipes have been inserted in the model whilst majority of minor branch pipes (connecting to private consumers within private cadasters) are excluded in the model.

Even though the main topology consisting of lines and points was imported directly from given GIS data, there were still missing components in the system. Valves, pumps, booster pump station and backup pump needed to be obtained. A site visit to Skensved waterworks was carried out where the chairman of Skensved waterworks provided useful data regarding pump models, booster station, which valves were closed and more besides. This could subsequently be imported into the hydraulic model.

While pipelines as well as junctions can be imported directly, importing valves requires some additional exertion. Point/node data can be geocoded into a direct discrete location of a junction/node and link data is fundamentally imbued with length of the polyline. These 2 would be considered. Even though a valve could be considered a discrete location in GIS format, it’s modelled as a link between 2 nodes in MIKE+ and thus require some attention and additional coding. Below is an overview of the water supply system. The waterworks is in the northern part of the village (marked light blue, Figure 5). The system goes all the way from Vikestrup, to Assendrup in the south-eastern direction to Ølsemagle in the western outermost parts. A booster pump/station (marked green) is in connection to Assendrup to elevate the pressure at the outermost demand points due to higher altitude. Furthermore, a backup pump is present in the central part of the system, connected to a nearby reservoir (marked yellow in Figure 5). This is operating in case of disruption or disturbance at the waterworks.

Figure 5. Overview of the water distribution system. Valves (red), waterworks (light blue), booster pump (green) and backup pump (yellow) are marked.

3.2 Topography

The topography is at a relatively even level throughout the study area. Figure 6 displays the topography variation in SW/SE/NW direction respectively. In the southwestern part of the distribution network, the height difference is most prominent with an increase of about 10-15 meters. From the waterworks to the outermost demand points, there is a total elevation difference of 30 meters. This is also the reason why a booster pump has been established in connection to the southwestern outlying parts to be able to supply sufficient service pressure. The newly built residential area in the eastern part is located at a lower level, and thus a pressure increase could be expected in these parts of the system.

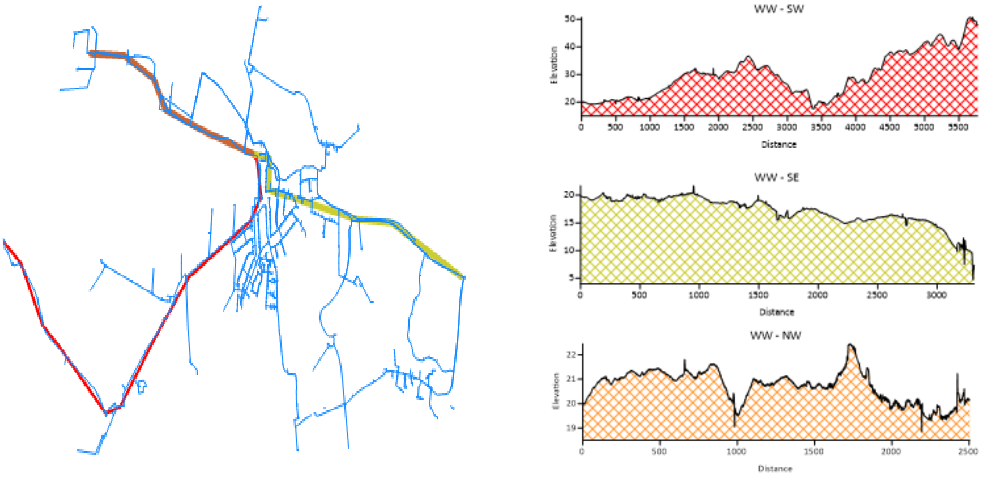


Figure 6. Topography of Lille Skensved in 3 directions: Waterworks – SW direction (red), waterworks – SE direction (yellow) and waterworks – NW direction (orange).

3.3 Pipes

In this chapter the physical characteristics of pipe dimensions, construction year, material and roughness are presented. Pipes are the link in between 2 nodes and where water is transported between different locations. During this transportation, loss of energy within pipes are due to friction between water and the surface of a pipe. In this paper, the Darcy-Weisbach formula has been applied for calculations of head losses (Abdulameer et al 2022).

Pipes are all assumed to be constructed according to Danish standards of 1,2 m below the surface. The topography/terrain is extracted as a raster layer from SCALGO Live, and further interpolated so each node is assigned corresponding surface elevation. The actual of each node is then submerged 1,2 m below the terrain according to Danish standards (Miljøministeriet 2020).

3.3.1 Pipe dimensions

The dataset consisting of dimensions is relatively complete for the distribution system. It is mainly minor consumer branch pipes that are lacking data, connecting further into larger distribution pipes. Therefore, these pipes are assumed to be a continuation of the distribution pipes and thus have the same material and dimension.

Figure 7. Overview of the different dimensions of the water distribution system.

In Figure 7 above, an illustration of what material is used throughout the system in Lille Skensved is shown. Pipes outgoing from the waterworks is of Ø140 and the main dimension of transmission pipes throughout the system is of Ø110. The transmission pipes reaching out from the water works to the residential area and expanding industries to the east is of Ø160.

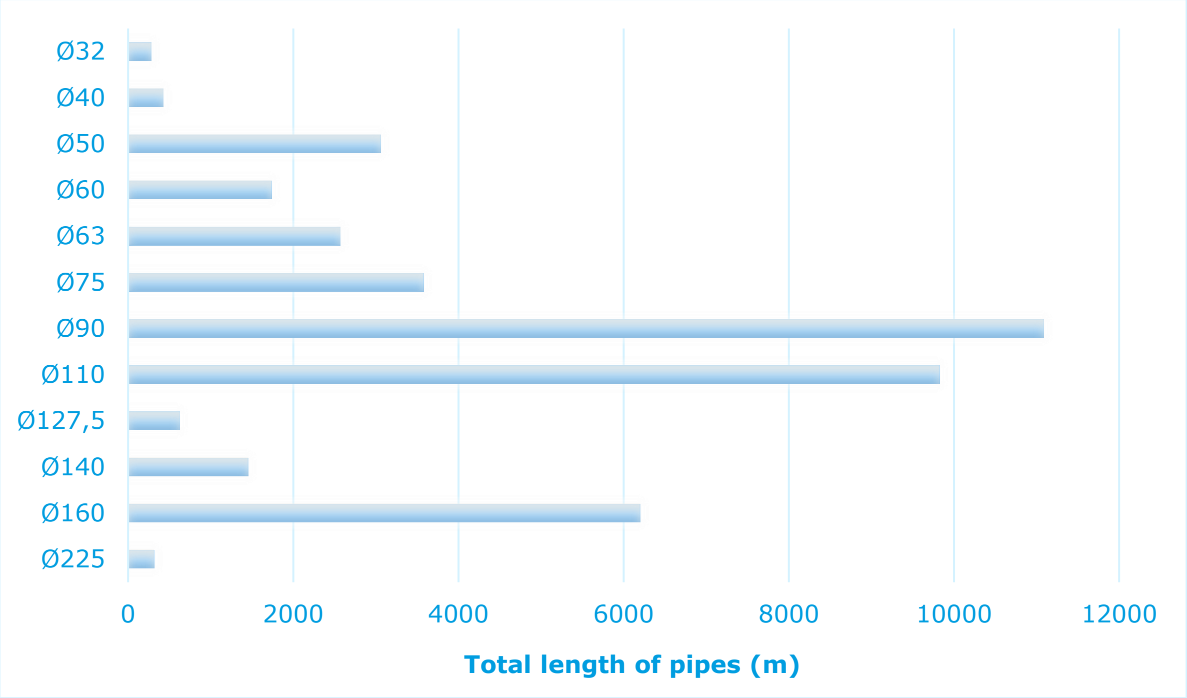


Figure 8. The dimensions of the water distribution network in Lille Skensved in relation to the total length of each individual dimension.

3.3.2 Pipe material

The water supply system of Lille Skensved consists of: PE, PEM, PVC, PEL and PEH as of known materials. The distribution network consists mainly of PVC and most of the system is not yet renewed. Newer installed pipes are of PE type. Around the central parts of Lille Skensved as well as around the waterworks, the dominating material for existing pipes is PVC. The eastern part of the distribution system is extended in recent days with a newly built residential area which is why here PE is the most prominent material. PEM, PEL and PEH are varieties of PE. The M signifies medium density, L signifies low density whereas H means a high-density pipe (Holm & Holm n.y.).

PVC (Polyvinyl chloride) and PE (Polyethylene) are thermoplastic material designed to transport large amounts of water effectively with a low amount of resistance to maintain high velocity and flow. These materials are of great character of being resistant to chemicals and other detrimental factors (DRTS 2018).
In recent years, PE has become the most popular material when choosing materials for water supply pipes. This is due to one of the main differences between PE and PVC that is the flexibility of the pipes; PE pipes are more flexible and can be bent to a much tighter diameter without breaking. This makes them easier to install for putting down pipes around corners. PVC pipes are more rigid and are more prone to breaking if they are bent too sharply (DRTS 2018). Further, the durability is another factor that is differentiating PE from PVC and making it a more prominent choice of material. PE pipes are generally more resistant to corrosion and less likely to be damaged by exposure to chemicals or UV radiation. PVC pipes, on the other hand, are more prone to corrosion and may need to be replaced more frequently in certain environments. The cost aspect is also beneficial for PE (it's generally cheaper choice of material) even though it's a more expensive pipe since the expected product lifetime is longer. Figure 9 shows the distribution of the different materials around the system.

Figure 9. Overview of the different materials of the water distribution system.

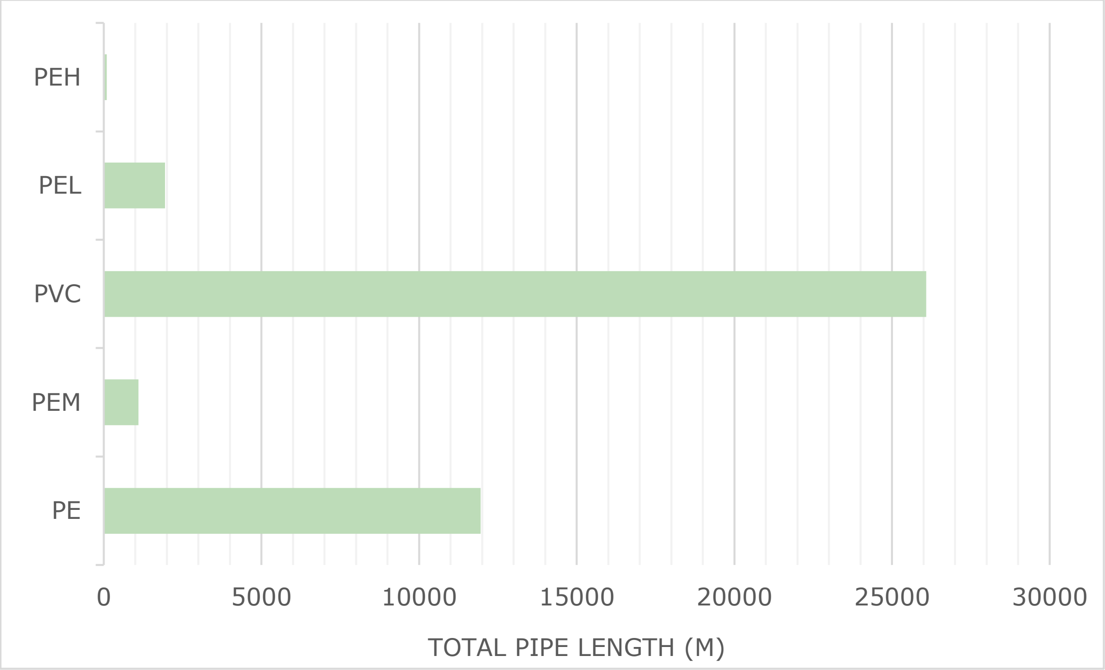


Figure 10. Material of the water distribution network in relation to the total length.

3.3.4 Pipe construction year

The dataset extracted on the construction dates of the pipes in the water distribution network is largely complete, with only a small amount of missing data. As shown in Figure 11, the majority of the pipes in the distribution network were constructed between 20 and 40 years ago. This is likely due to PVC being a popular choice for pipe construction material during that time period, as described in more detail in the section on pipe material. A small portion of the network has been constructed more recently.

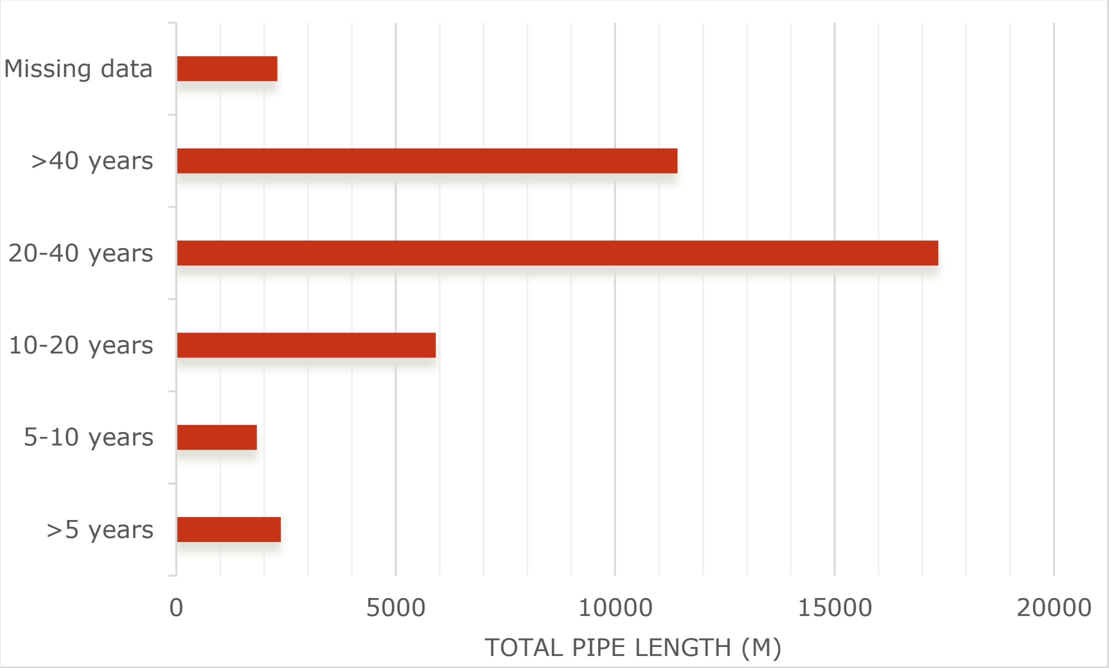


Figure 11. Construction year of pipes in the water distribution system of Lille Skensved in relation to the total length of each construction date interval.

3.3.5 Pipe roughness

The roughness of a pipe is an integral part of modelling a drinking water network and is linked to pressure head drops in the system (Kaltenbacher et al. 2022). To clarify, the interior wall of the pipe is a surface which has a certain level of roughness. This affects the flow in the pipe, particularly along the edges of the pipe (Vasudevan 2018).

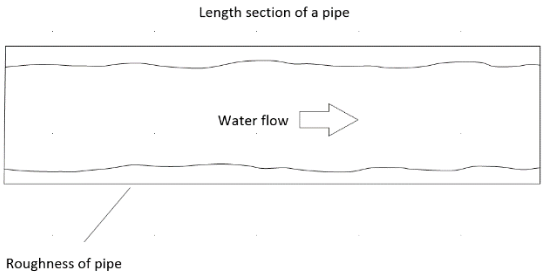


Figure 12. Roughness of pipes.

The material of the pipe has a significant impact on the roughness of the pipe (Marusic-Paloka & Pazanin 2020). In other words, the thickness of the roughness layer which is shown in Figure 12 above varies depending on the type of pipe. The roughness of polyethene (PE) and polyvinyl chloride (PVC) pipes is typically very smooth, with a ranging roughness value of

0.0015-0.01 (linearly interpreted for given intervals) (Engineeringtoolbox 2003). Since the roughness values for plastic material varies, assigned roughness values has been based on construction year. For missing data, roughness values of 0.01 was applied.

Table 1. Applied roughness for varying construction year.

Construction year (interval)	**Roughness**
>40 years	0.01
20-40 years	0.007875
10-20 years	0.00575
5-10 years	0.00363
<5 years	0.0015
Missing data	0.01

3.4 Valves

The network has a total of 131 valves divided into mains and minor shut-off valves. In the water distribution system, there are disconnected valves which do not function as intended, according to the chairman of Lille Skensved. In this study, it is assumed all valves are working and they are all fixed open, shut-off valves.

Three isolation valves are present at the outskirts of the system, each connected to a different external water distribution system. These valves are intended to activate if for example substantial water loss were to occur in Lille Skensved. On the contrary, in the event of a water loss in the opposite direction; water can be transported into the affected system from Lille Skensved as well. Apart from these, several other valves are present in the system highlighted in the figure below.

Figure 13. Valves present in the water distribution network.

3.5 Waterworks & booster station

3.5.1 Waterworks flow scheme

Initially, drinking water is pumped from 4 boreholes outside of town and transported to the waterworks. Methane is naturally produced by sub surficial bacteria as well as decay of organic matter and dissolves in groundwater when it migrates upwards towards the surface. High concentration of methane in a water distribution system can cause water hammer issues, pressure surge as well as health related problems (KnowyourH2O 2016). Therefore, it is of importance to release the water of methane and simultaneously enrich the water with oxygen.

Figure 14. Waterworks at Lille Skensved.

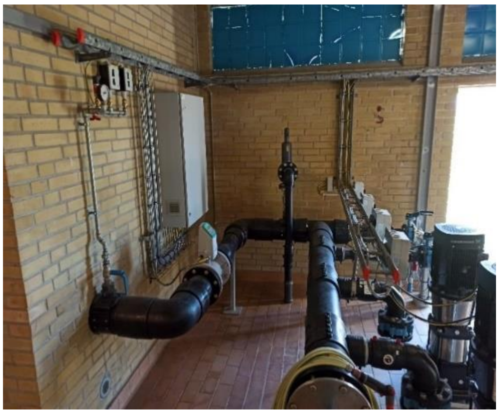


Figure 15. Waterworks at Lille Skensved.

This process is done in Skensved water works through letting the incoming groundwater fall from a height onto a staircase-like structure to prolong the time the groundwater is in direct contact with air and thus increasing. Thereafter, the water proceeds into small basins for sedimentation and finally accumulates into a 250 m^3 tank. The cleaned water is further pump,3ed out to consumers by 4 Grundfos pumps. This pumping scheme consists of two models; two pumps are of a newer model and two an older variety. Three outgoing pipes from the water works transmit the aired and water to the consumers. In addition, one booster station is positioned to supply an area of significantly higher elevation with water. The activation of the pumps is a function of demand meaning that periods of low demand entail fewer active pumps. On the other hand, times of high demand can require all four pumps working simultaneously. The tank is used as a buffer; it is used/drained in high-demand periods, and refilled during low demand hours (e.g., nighttime). A schematic picture of the component scheme within the waterworks can be seen in Figure 16.

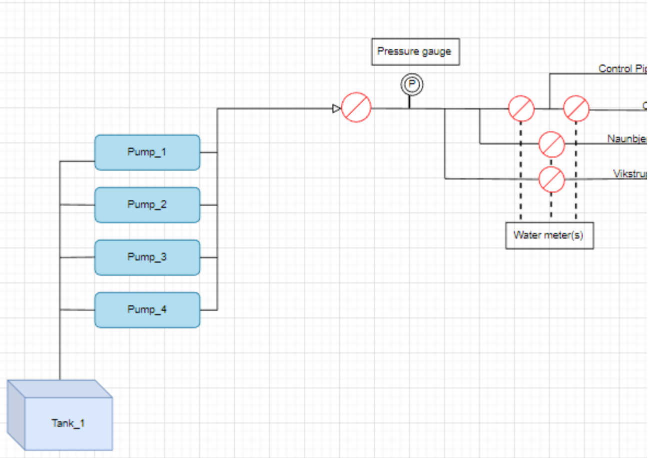


Figure 16. Schematic picture of the waterworks of Lille Skensved. Water-meters and pressure gauge marked in red.

Figure 17. Main transmission pipes of Lille Skensved waterworks.

3.5.2 Pumps

The waterworks consists of 4 parallel connected pumps. There are currently 2 newer models of Grundfos CR 45-2 A-F-A-HQQE, 2 older models of submersible SP 17-7 - 12A00007, and the booster pump is of model CRE5-5-A-A-A-Q-HQQE. The waterworks of Lille Skensved are planning to replace the older 2 models with the same newer models within the near future, and thus the newer pumps and their respective pump curves have been implemented in the hydraulic model. The CR 45 pumps are vertical, multistage centrifugal pumps with discharge and ports on the same level (Grundfos 2022).

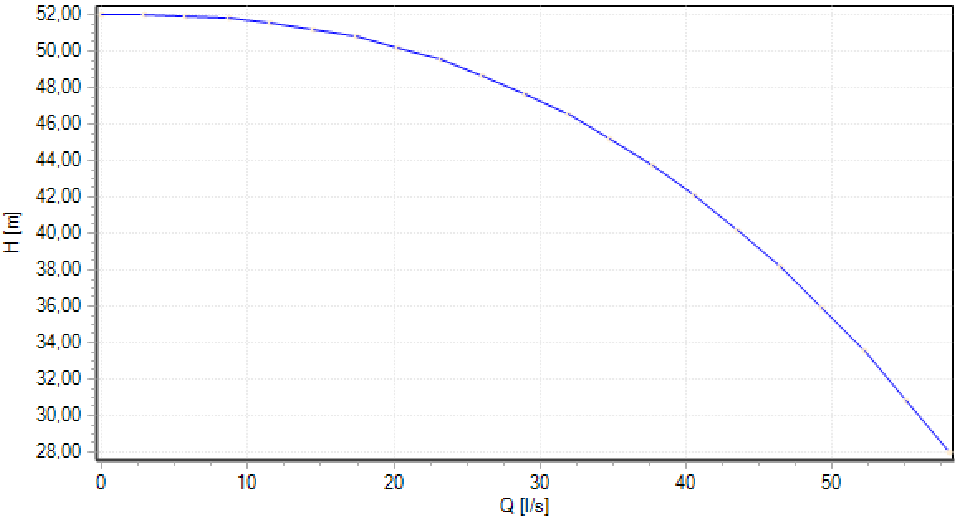


Figure 18. Pump curve, Grundfos CR 45-2-A-F-A-HQQE (Grundfos, 2022).

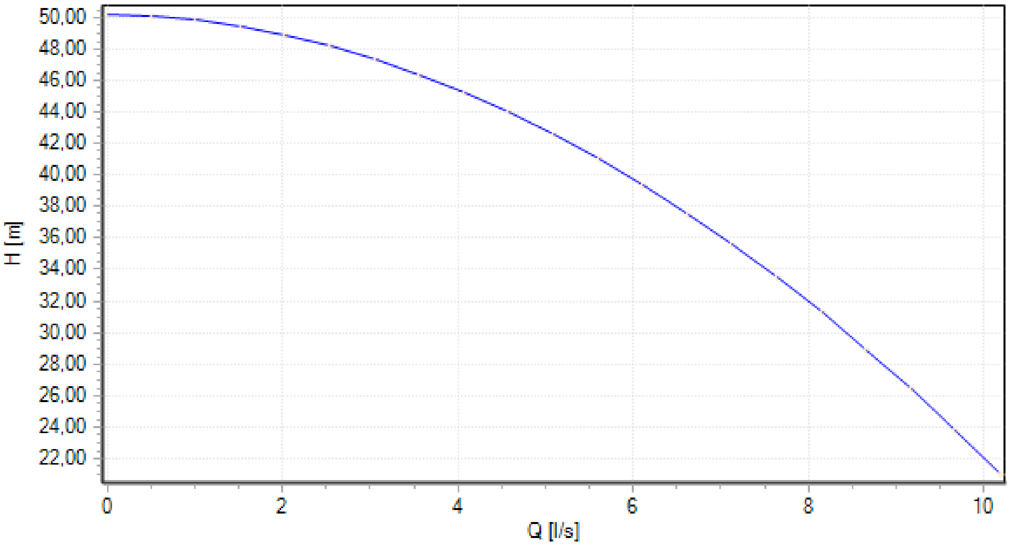


Figure 19. Pump curve, Grundfos CRE5-5-A-A-A-Q-HQQE (booster pump) (Grundfos, 2022).

The combined performance of the pumps with (the same inlet and outlet as they are in parallel operation) will yield a higher total accumulated flow with the same differential head as shown in the figure below (Pumpindustry 2013).

Figure 20. Pump curve, 4 parallel connected CR 45-2 A-F-A-HQQE.

Furthermore, the operating pump schemes are of variable type and set to variable speed drive. (Pumpfundamentals 2015). 2 pumps are set to active, whilst the other 2 pumps are inactive. Note that the 2 inactive pumps schedule is only operating when flow demand increases above the capacity of the 2 active pumps.

3.5.3 Service pressure from waterworks

The water works service pressure is set to 3.8 bar service pressure, meaning the pump system is set to target 3.8 bar going out of the waterworks. This is assumed to be the same for both the booster station as well as the backup pump due to no further information about the targeted service pressure.

Figure 21. Waterworks at Lille Skensved

Figure 22. 4 parallel pumps at Lille Skensved waterworks.

Figure 23. Booster station pump.

Figure 24. Incoming raw water line.

3.6 Consumers & consumption data

3.6.1 Consumer demand allocation

From Ramboll FAS database, information about every connected consumer could be extracted. This includes the address of every water meter as well as the consumption. Using this information, every consumer could be allocated and geocoded into the hydraulic model using Google's API (Google maps). Geocoding is the process of taking an address or name of a place and converting it into a latitude-longitude coordinate. This process can be done manually but processing a lot of information would be, especially for our case work, very time consuming. The geocoded locations of every water meter would then be imported to the hydraulic model. In this model setup, we would exclude branch pipes and thus only include transmission and distribution pipes. Every demand allocation would therefore be aggregated to the nearest node on a distribution pipe (see Figure 25 below). The consumption for a single, blue-marked house represents the actual consumer, distributing its fluctuating pattern-depending demand to the nearest node.

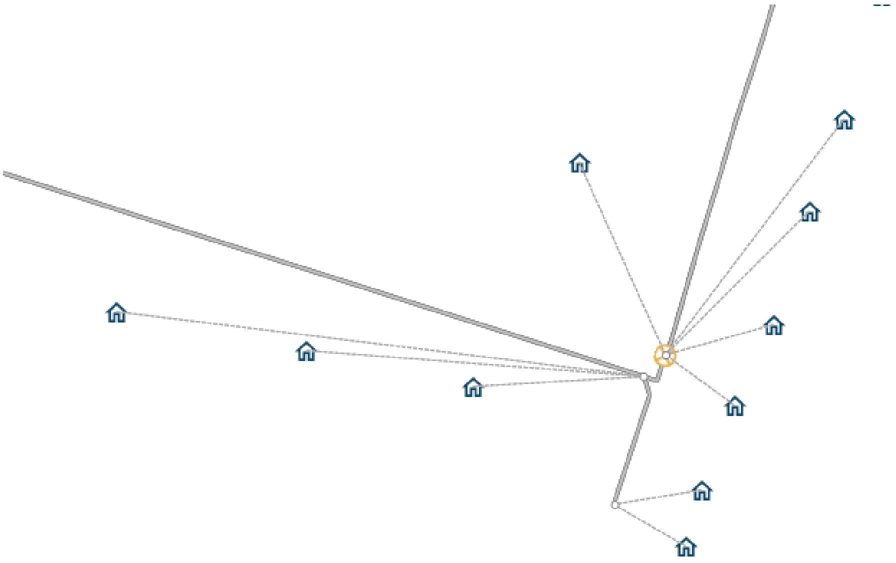


Figure 25. Allocated demands and aggregated demands to nearest node. Blue-marked houses represents a demand allocation.

3.6.2 Annual consumption data

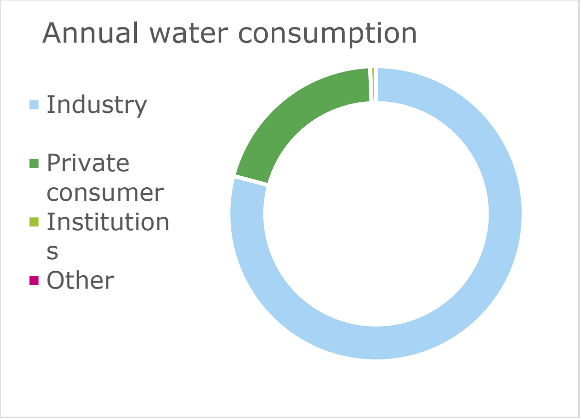
The consumption data used for every consumer was extracted from Ramboll FAS. This is the billing system the water utility of Lille Skensved uses for correct billing from respective consumer. This data was extracted and imported as demand allocations into the hydraulic model. The data is further distributed as the average flow per day with fluctuation according to specific consumer type / consumption pattern.

3.6.3 Hourly consumption data

Consumption data was also extracted in more detail from every single water meter from a period of (1/2)-2 years (depending on individual logger data). Data from every individual meter time stamped every hour, was extracted for every consumer/meter. This was not used in the original model setup, but later used in the calibration process of the hydraulic model and explained further in the Calibration & sensitivity analysis chapter.

3.6.4 Consumer types

Lille Skensved waterworks serves a diverse range of consumers through its distribution network, including large industries, local farmers, and private consumers. Initial data on annual consumption for each connected user in 2021 was obtained from Ramboll's billing system, Ramboll FAS, and further categorized into four categories: industry, private consumers, institutions, and other. This categorization is based on the classification of each user in Ramboll FAS.



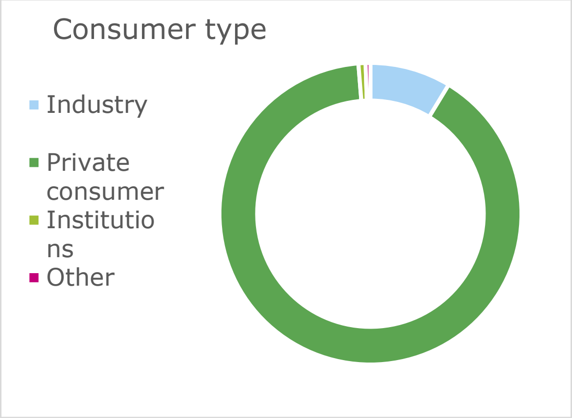


Figure 26. Annual water consumption proportion.

Figure 27. Proportion of consumer type

Most of the water usage comes from industries around the system as shown in Figure 26 and Figure 27 above, even though many of the consumers are private consumers. Only a minor part of the consumers is categorized as 'other' (agriculture, minor stores, etc.) and has an equal proportion of the total annual consumption of the distribution system. It is important to make as realistic categorization of every user as possible for the hydraulic model to simulate the real-time flow and pressure as the demand pattern would show as a sensitive parameter when calibrating the model.

Moreover, Figure 28 displays the top 10 largest consumers of Skensved water distribution network put into comparison with the remaining consumers interconnected around the network. As shown in the figure, the top 10 consumers account for >60% of the total water consumption in the distribution network. This is discussed further in *Calibration* chapter.

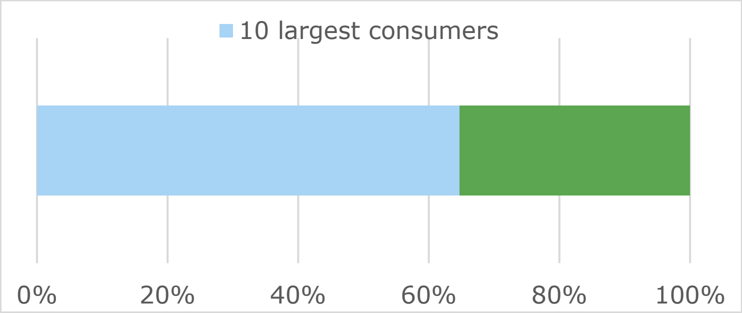


Figure 28. Top 10 annual consumers connected to the water distribution system of Lille Skensved in comparison to the remaining consumers.

3.6.5 Demand patterns

Initially, standardized patterns were imported to respective category. They are each set for 1 week period (168 h). These standardized patterns are Miljøstyrelsen's standard pattern for a water distribution system when setting up a hydraulic model. The input pattern data into MIKE+ is formatted as normalized values of flow data - the y-axis has a scale factor parameter of the average flow value and x-axis represents the time steps. Thus, the normalized flow character of each category will have different fluctuations depending on when the demand is at its highest respectively lowest value.

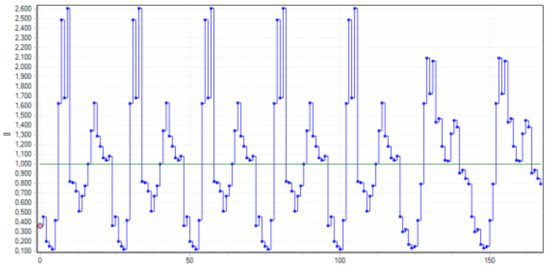


Figure 29. **<u>Consumer patter</u>: Private consumer. Y-axis scale factor (unitless) and X-axis hours (h) from Monday 00:00.**

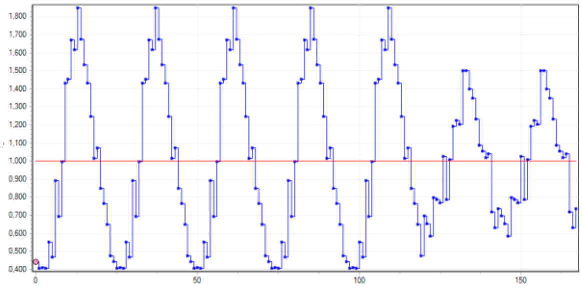


Figure 30. **<u>Consumer pattern:</u> Industry. Y-axis scale factor (unitless) and X-axis hours (h) from Monday 00:00.**

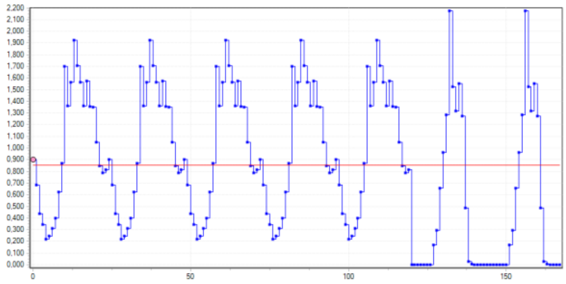


Figure 31. **<u>Consumer pattern</u>: Institution. Y-axis scale factor (unitless) and X-axis hours (h) from Monday 00:00.**

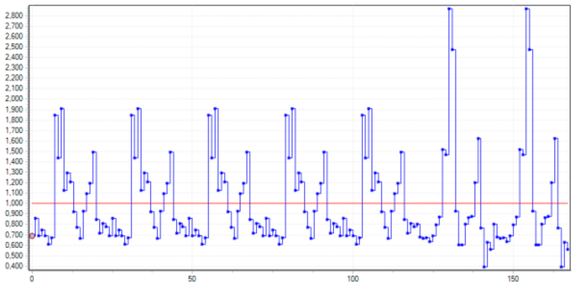


Figure 32. **<u>Consumer pattern:</u> Other (agriculture etc.). Y-axis scale factor (unitless) and X-axis hours (h) from Monday 00:00.**

3.7 Vulnerability analysis setup

The evaluation of the vulnerability of the water distribution system in Lille Skensved is executed in MIKE+ and run as a network vulnerability analysis within the program. This type of analysis is hydraulic and is based on the control pressure. In other words, the result is mainly dependent on the control pressure input to the simulation. The minimum service pressure is the pressure that the network should uphold in the event of a pipe burst for instance (Wu & Walski 2006). According to the Guaranteed Standards Scheme, the absolute minimum water service pressure a utility is required to uphold is 7 meters water column (Ofwat 2017).

In addition to the minimum service pressure, the second parameter is the time level of the simulation. The time period can be decided specifically by the modeler for a certain number of hours. In contrast to that, an extended period simulation can be run. As previously mentioned, this analysis generates values on the following system-wide indexes: Todini, node connectivity and pipe criticality. Admittedly, these values alter depending on the length of the selected time level as well as if an extended period simulation is chosen. Therefore, it is important to assign a specific time for the simulation.

Regarding the time level in the figure below, the values of the indexes are dictated by the time level. First and foremost, the difference between selected time level and extended period simulation is important to distinguish. For a selected time level, the network vulnerability is calculated for the selected time slot within the extended period simulation of the functional analysis. If the time level is decided to 10 this means that the vulnerability indexes and parameters are calculated for that specific hour within the hydraulic simulation. Meanwhile, an extended period simulation accounts for every time step of the functional analysis. As a result, this type of simulation gives an average value of the network vulnerability. In contrast to this, the selected time level approach can choose to analyze the network vulnerability during a time slot of peak flow for instance. Therefore, it is fair to assume that the selected time level method can be used to calculate network vulnerability in the worst-case scenario. Table 2 shows what values are used for the vulnerability simulation in both scenarios.

Table 2. Input values for vulnerability simulation

Minimum service pressure	Selected time level
15 m	9 am

Several scenarios will be tried and analyzed. First, a simulation is done with the network running at normal conditions. Namely, all components of the network are fully functioning and representative of reality. Following this, additional scenarios will be investigated.
In case of emergencies, the water distribution network has a backup pump present in the center of the network. Thus, a scenario will be tested when the normal pump station is shut down and the network instead is supplied by this lone pump as well as the booster station. The newly activated pump is located within the red circle.

Figure 33. Scenario with new pump.

3.8 Preliminary functional results

In this chapter, the initial functional result of the hydraulic model is displayed. This result is before any modification in terms of calibration is done. In Figure 34 the hydraulic head [m] is shown. Eastern part of the system is shown a higher-pressure level and the south-eastern part is at lower pressure. Figure 35 shows the absolute flow for the distribution network. Higher flow (>0,38 l/s) can be observed around the waterworks going in the direction of the central parts of Lille Skensved.

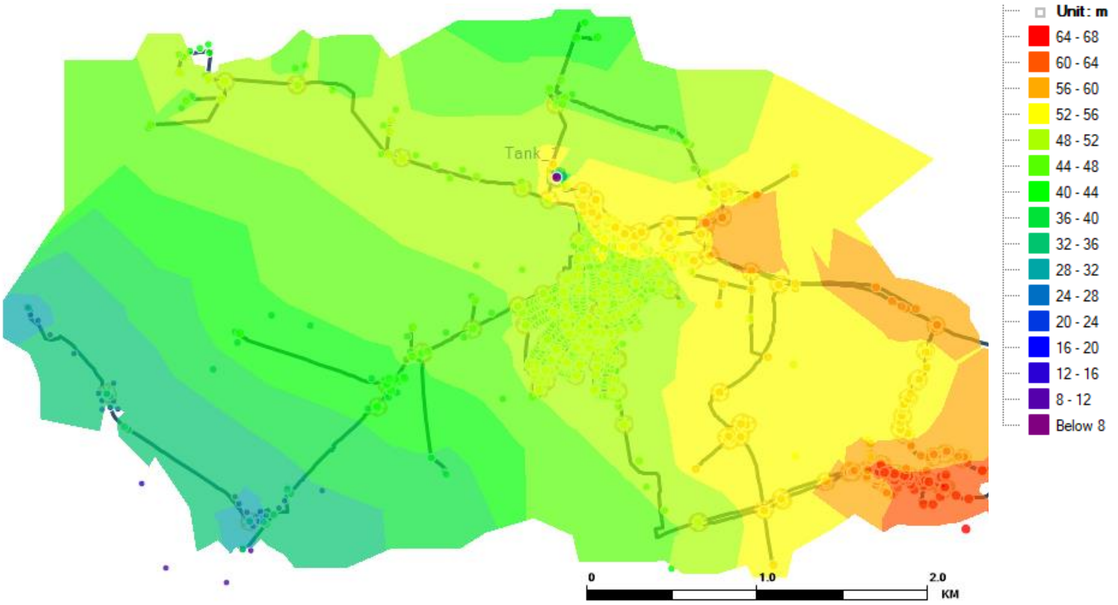


Figure 34. Heatmap of the pressure zones (m)

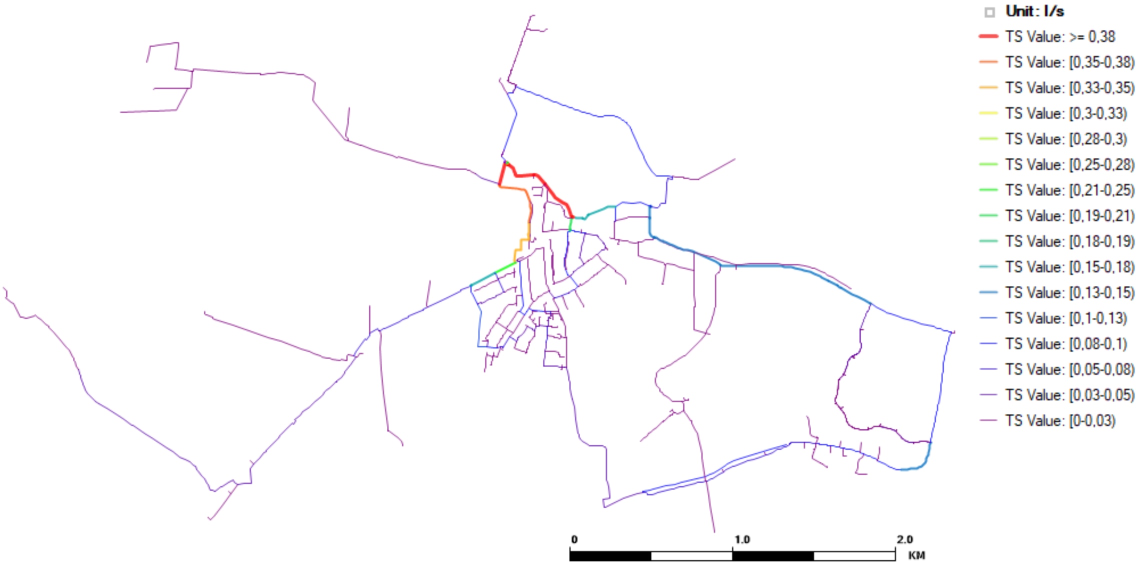


Figure 35. Flow (absolute) through links in the distribution network (l/s).

4. CALIBRATION & SENSITIVITY ANALYSIS

4.1 Pressure & flow data collection for calibration

It was not possible to obtain both flow and pressure data from the same locations due to practical considerations. Pressure loggers were placed at four different measurement stations (located at private residences) connected to the distribution system in the outermost parts of the system. For privacy reasons, the specific locations of the loggers have not been disclosed, but they have been identified as stations 1-4 in the corresponding area (see Figure 36). These measurements, being located further out in the system and therefore more sensitive to variations in the network, are expected to provide valuable results (Todini 2000). The pressure loggers were set up and logged pressure data for a period of one week in late November. In the hydraulic model, a measurement station was set up at the location of each measurement station.

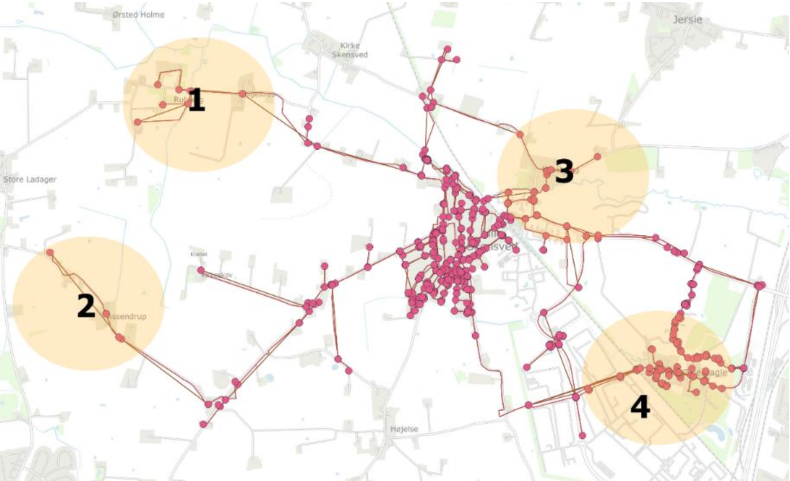


Figure 36. Location of the 4 measurement stations where the pressure loggers has been setup

During the same time, flow data was also collected. This data was obtained from permanent flow meters installed at the waterworks. This data was used as calibration data for flow. Figure 37 below shows the location of the water meters and the measurement stations used in the hydraulic model.

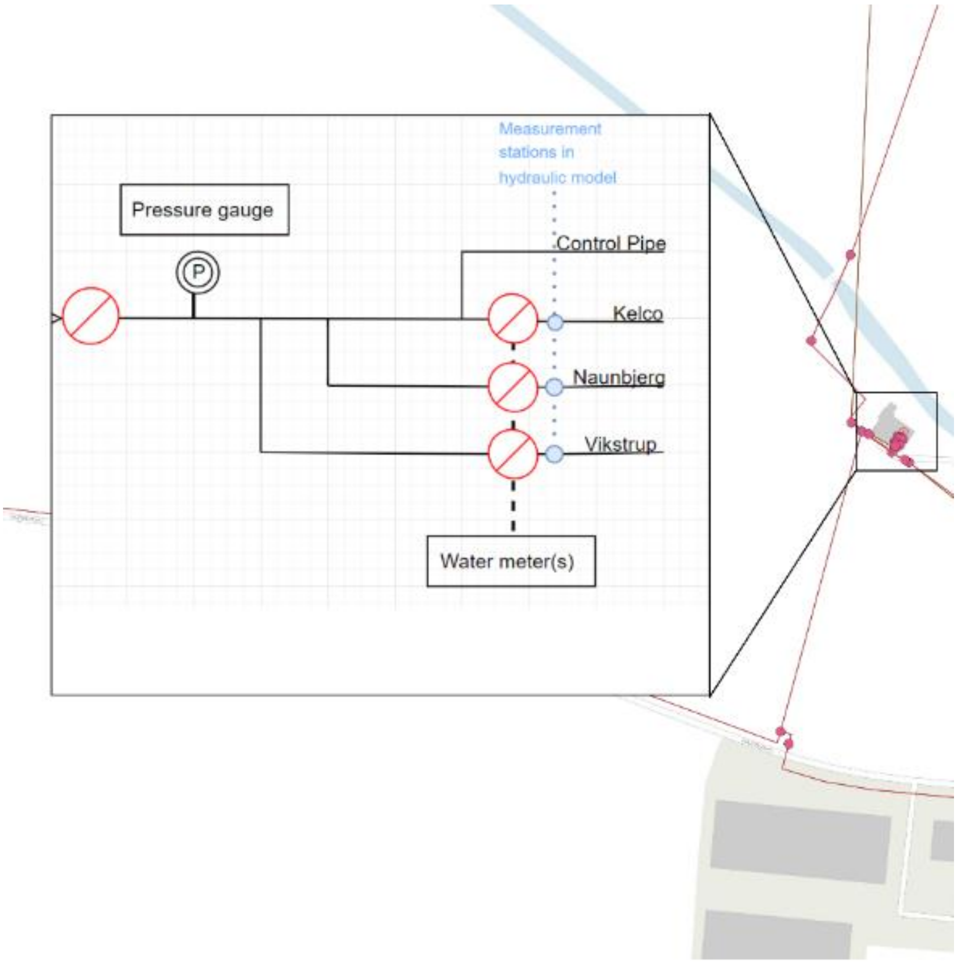


Figure 37. Water meters' location whereas flow data was extracted and measurement station placement in hydraulic model

4.2 Initially computed in comparison to measured flow

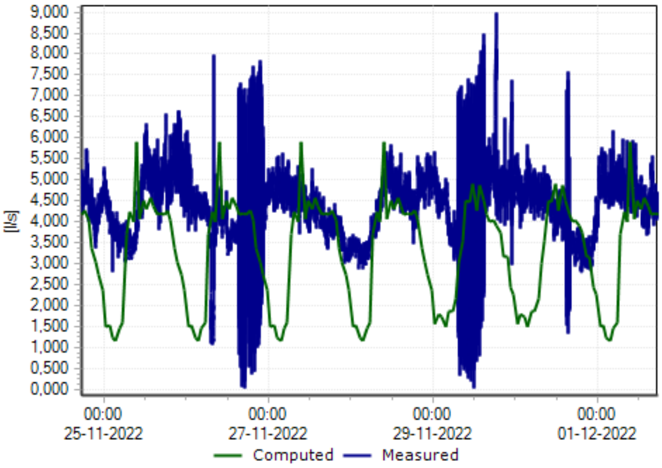


Figure 38. Simulated and measured flow, pipe 1

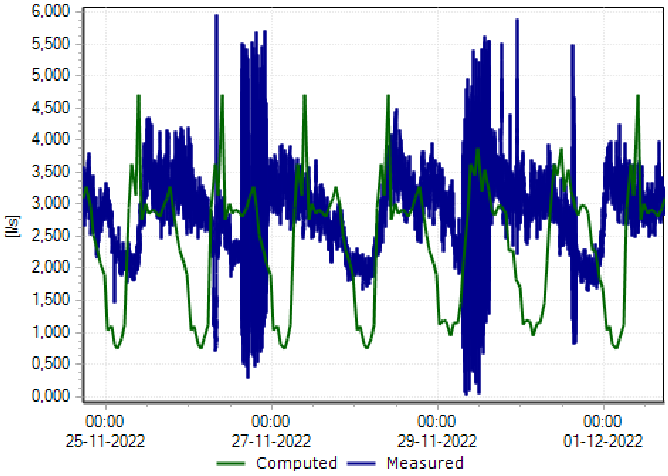


Figure 39. Simulated and measured flow, pipe 2.

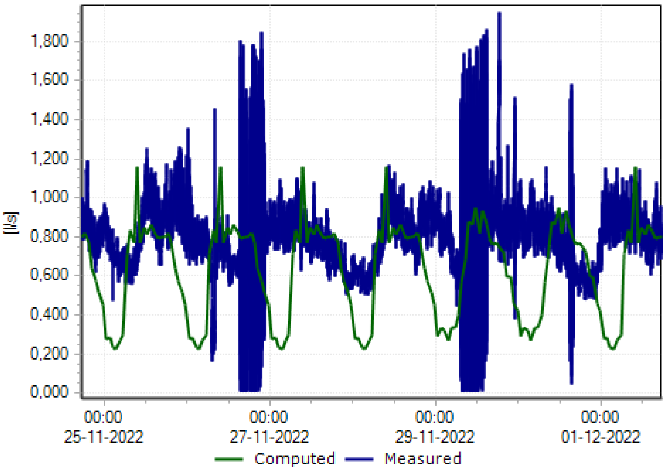


Figure 40. Simulated and measured flow, pipe 3.

The figures 38-40 above demonstrate the measured flow versus the actual flow out of the three main pipes of the waterworks. The mean values for each comparison are displayed on the right side. The data for this comparison was collected over a period of 168 hours in November. It is evident that there are significant differences in the fluctuation of the pipes. Pipe 1 exhibits particularly large variations, with a noticeable discrepancy between measured and computed values. Pipe 2 and pipe 3 also show differences between measured and computed values, but the measured values for these two pipes appear to have a more consistent behavior throughout the week. It is worth noting that there are large fluctuations in flow, ranging from as high as 16 liters per second to 0 liters per second (accumulated flow for pipes 1-3), that occur during nighttime and span across all three pipes.

4.3 Initially computed in comparison to measured pressure.

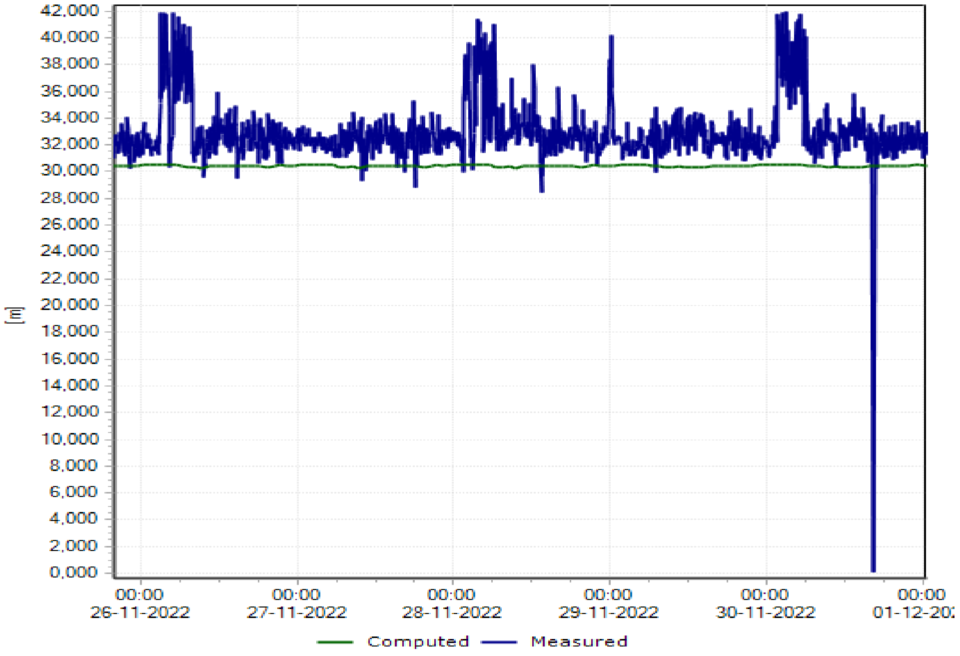


Figure 41. Simulated and measured pressure, station 1.

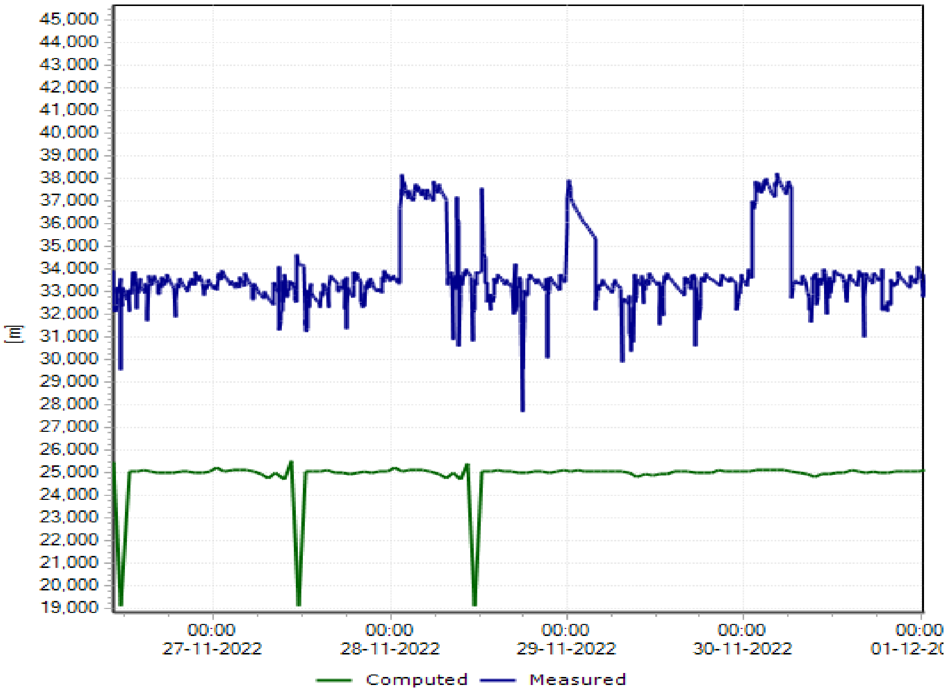


Figure 42. Simulated and measured pressure, station 2.

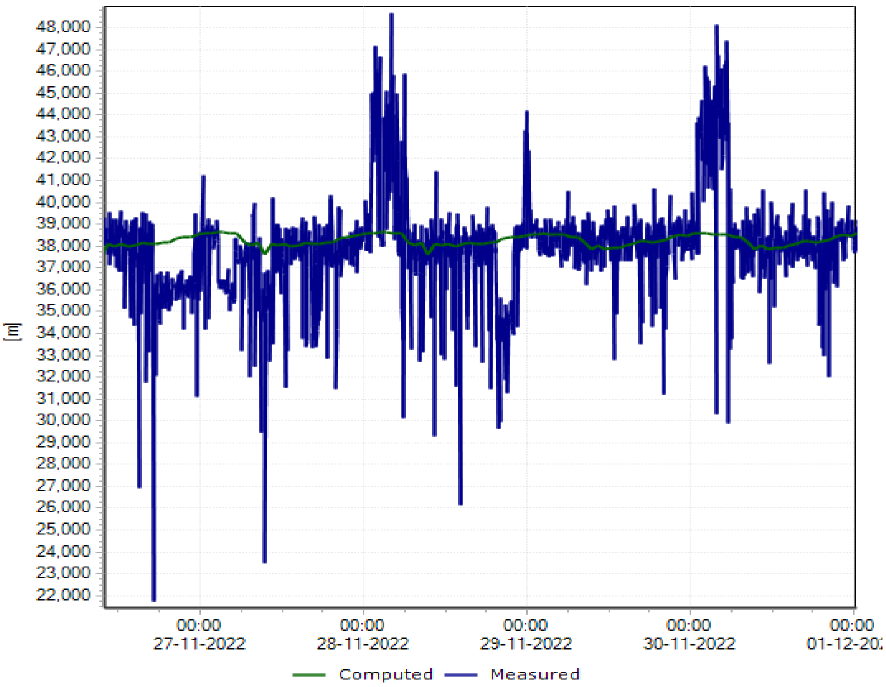


Figure 43. Simulated and computed pressure, station 3.

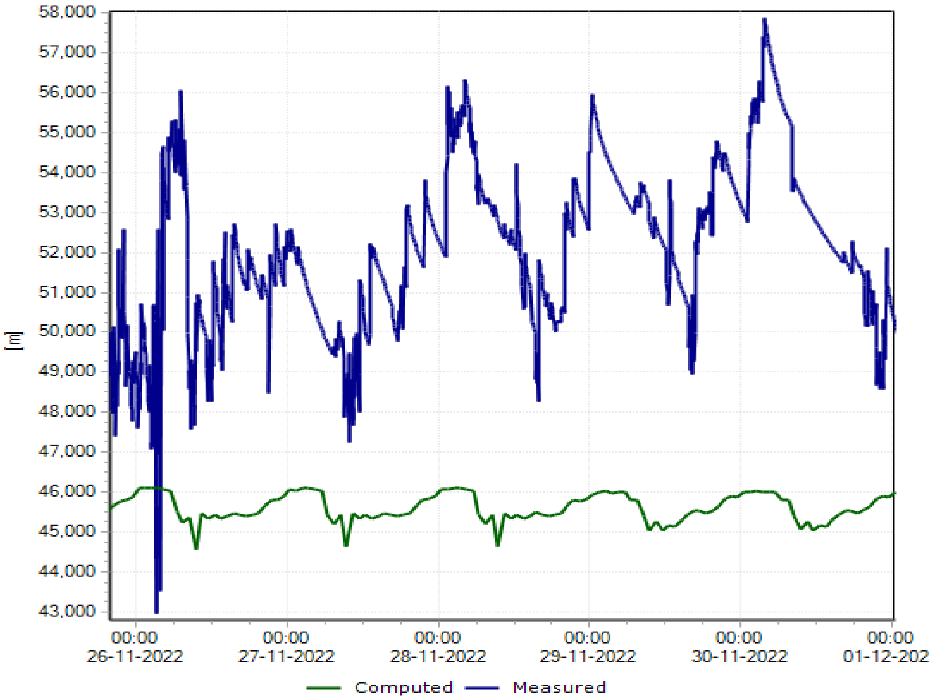


Figure 44. Simulated and computed pressure, station 4.

The figures 41-44 above demonstrate the measured flow versus the actual flow out of the three main pipes of the waterworks. The simulated pressure exhibits greater deviation compared to the flow data. At measurement station 1, there is a relatively similar pattern between the two datasets, with minor deviations. However, the result data from station 2 exhibits more variation, with the mean differing by approximately 0.9 bar. In contrast, the measured and computed pressure at station 3 have a similar oscillating pattern, with only minor fluctuations. The mean values are also nearly identical. Significant differences can be observed at measurement station 4, where the overall deviation is more pronounced, with significant spikes in the measured pressure and fewer fluctuations in the computed data. It is worth noting that the measured pressure at each station is taken from private residences, which may result in minor fluctuations in pressure due to private water usage.

4.4 Sensitivity analysis

Calibration of a water distribution network can prove difficult according to Sanz and Perez. Since a real network is unpredictable, modelling in a similar fashion is challenging to achieve (Sans & Perez 2014). Nonetheless, Sans and Perez suggest some parameters of focus for an effective calibration. Namely roughness of pipes, demand patterns and pump adjustments.

Regarding calibrations of the imbalance of flow, the demands can be investigated. More specifically, the demand patterns which decide the consumption through a multiplier. These multipliers can be altered at the discretion of the modeler. Since the factories consume significantly more water than household do, a change in the factory pattern can be impactful (Sans & Perez 2014).

Furthermore, the pressure deviations between measured and computed values can be managed through changes in the pump setup. The control pressure of the pumps can be changed and thereby affecting the pressure at every node in the network as well (Sans & Perez 2014).

Given this information, it was decided to calibrate and monitor the results in successive steps to determine the most sensitive parameters. Initially, the roughness of the pipes was altered from the original presented roughness values in Table 1. Applied roughness for varying construction year. Calculations of Zhao et al generated a roughness of PVC pipes of 0,01 mm. (Zhao et al. 2022). However, Marusic-Paloka & Pazanin state that the roughness of a PVC pipe is 0,12 mm (Marusic-Paloka & Pazanin 2020). Therefore, a value ranging within this interval seems reasonable.

4.5 Further data treatment of sensitive parameters

In 2014, Sans and Perez emphasized the importance of using accurate demand patterns to ensure accurate results in their work. In this chapter, the authors implemented a comprehensive approach to demand patterns by using hourly demand values and creating individual patterns for each consumer connected to the distribution system. The data was processed in two steps. First, the authors focused on implementing a representative usage pattern for the locations with the highest demand, which accounted for more than 60% of the total yearly demand (as shown in Figure 27). It was also done for the remaining consumers. The process is described below.

It was required some additional data processing to treat the data in order to implement it into the hydraulic model (workflow in Figure 45). The code loops through the dataset for each individual device (logger), calculating the accumulated consumption for every hour and every day of the week (a total of 168 points) and then dividing it by the total number of data points for each day and hour to get the average consumption for each day and hour. The data was then normalized for the 168-hour period using the average consumption for each accumulated data point of the week. It is worth noting that the extracted hourly raw data was not uniform, resulting in variations in the time period of data collected for each logger. Results from top 10 consumer is presented in **Error! Reference source not found.**, yielding consumer specific patterns.

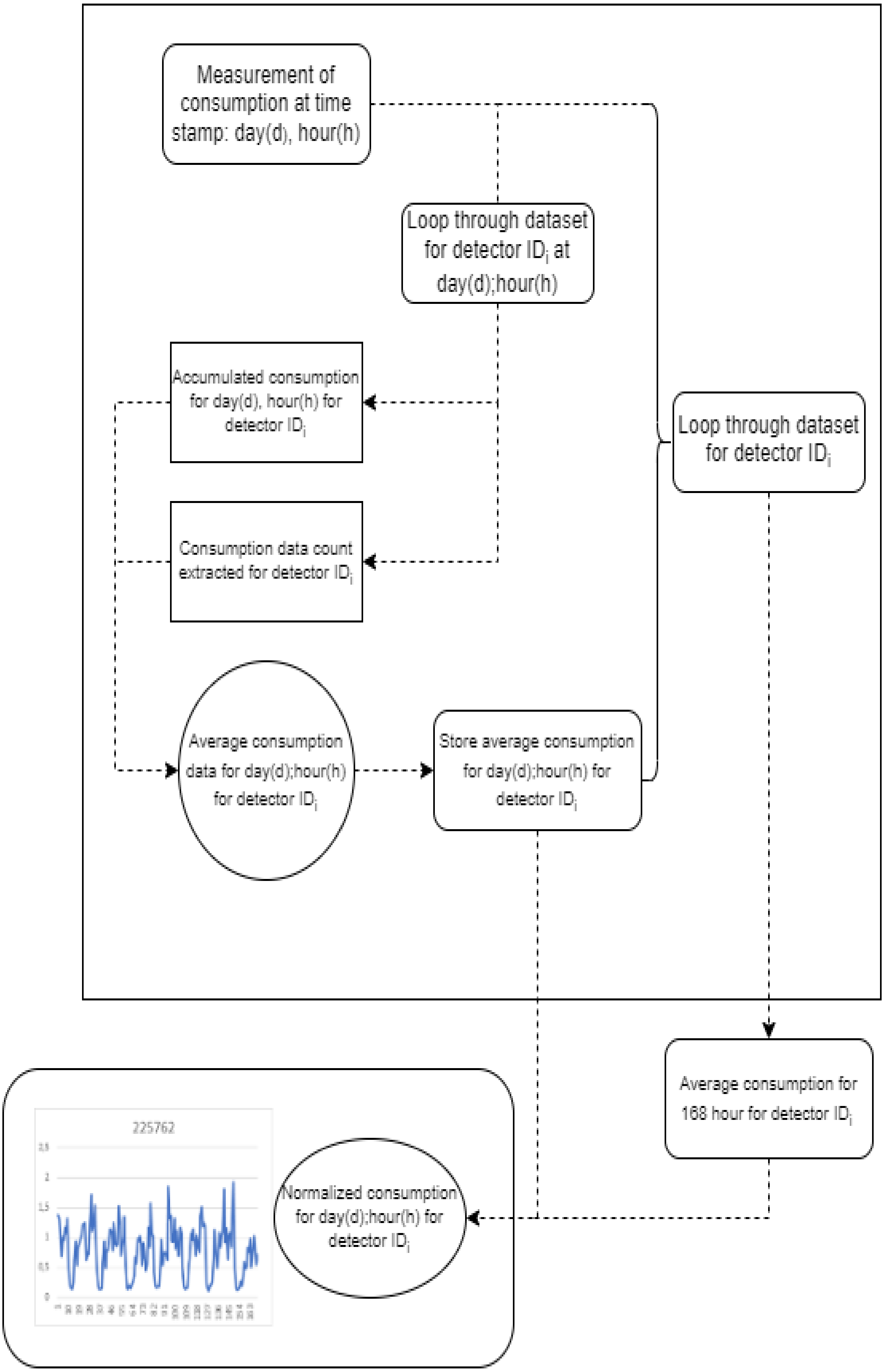


Figure 45. Schematic workflow of data treatment and processing of demand patterns.

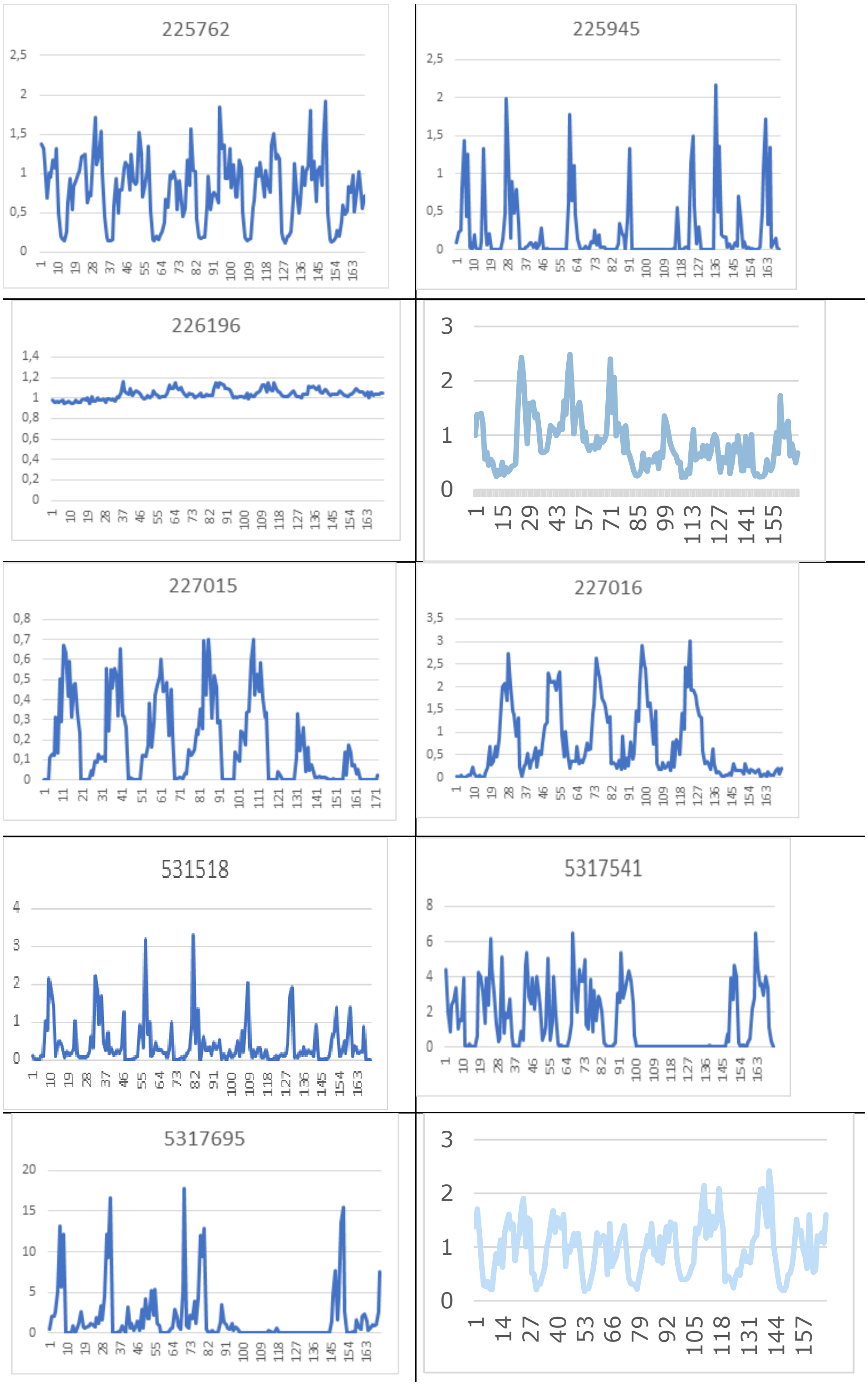
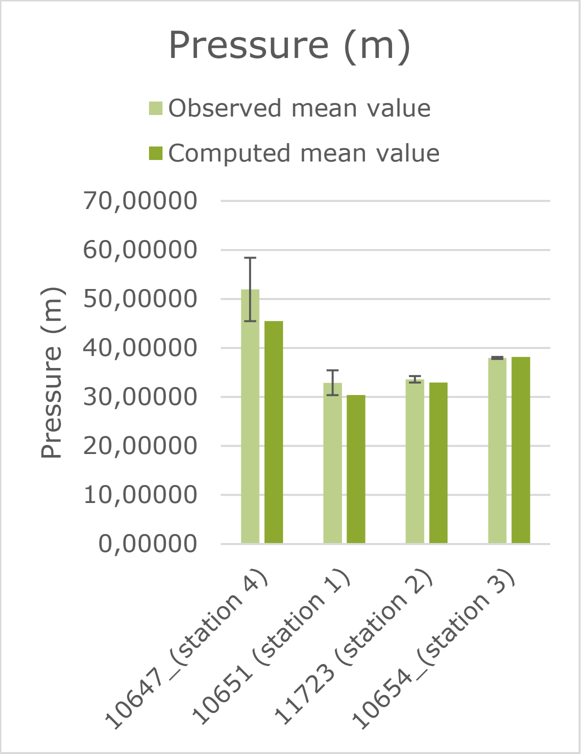


Figure 46. Normalized values for the top 10 consumers in the water distribution network. Y-axis is a multiplying scale factor (unitless) and the X-axis displays the hours (h) from start (Monday 00:00). ,

4.6 Calibrated results



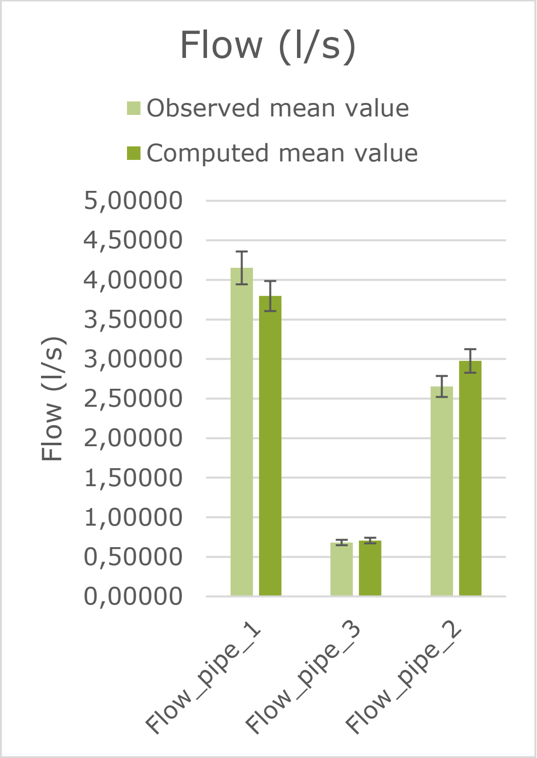


Figure 47. Observed and computed mean values after calibration, pressure (m).

Figure 48. Observed and computed mean values after calibration, flow (l/s).

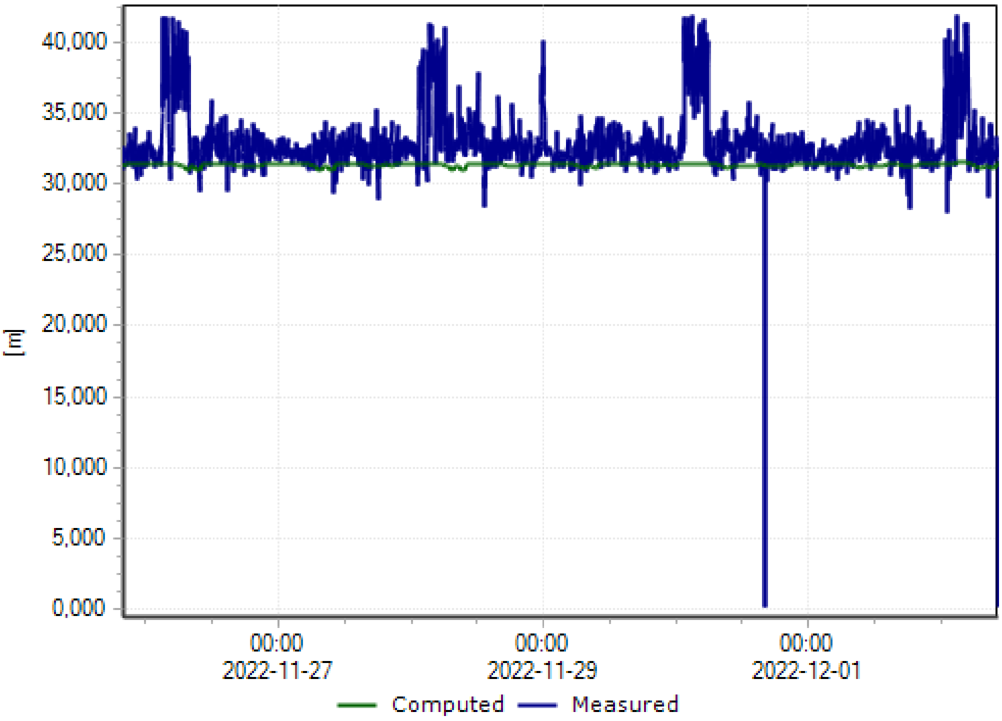


Figure 49. Station 1 - measured vs computed puressure.

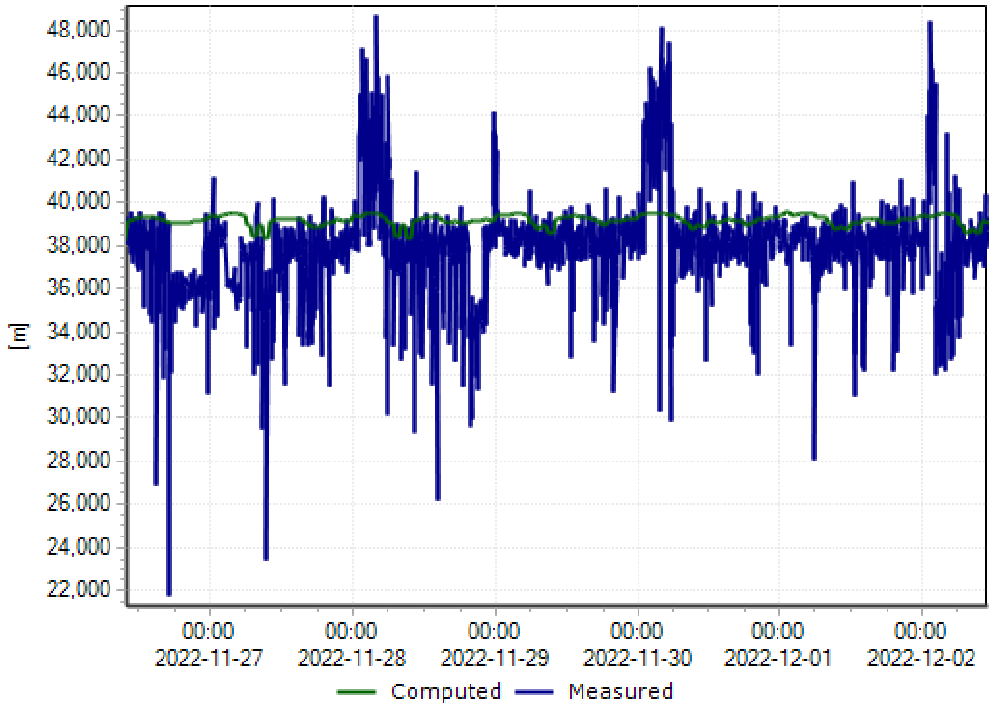


Figure 50. Station 2 – measured vs computed puressure.

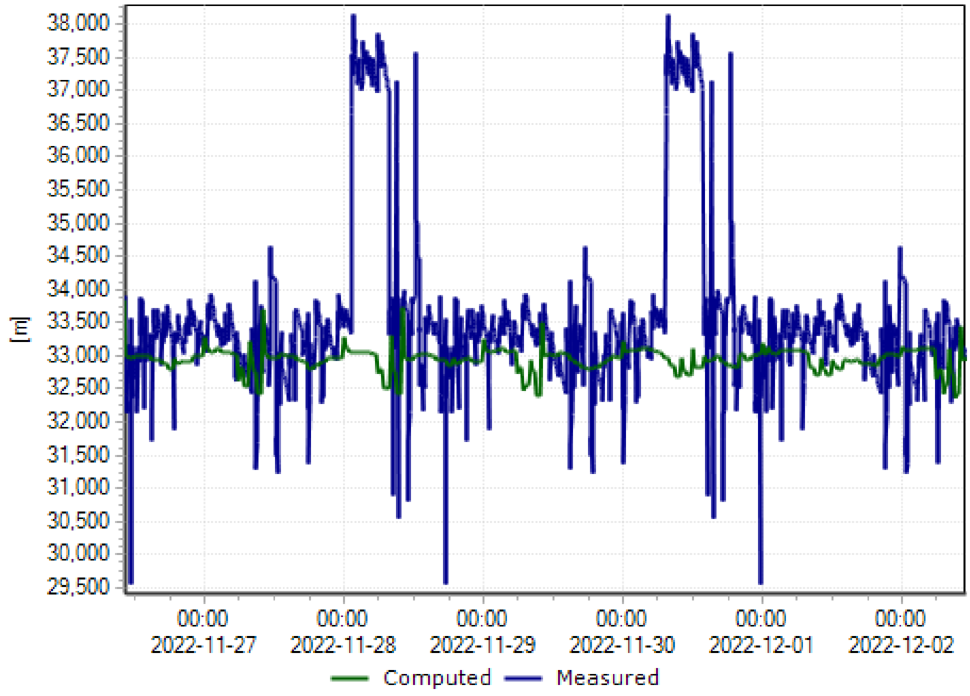


Figure 51. Station 3 – computed vs measured pressure.

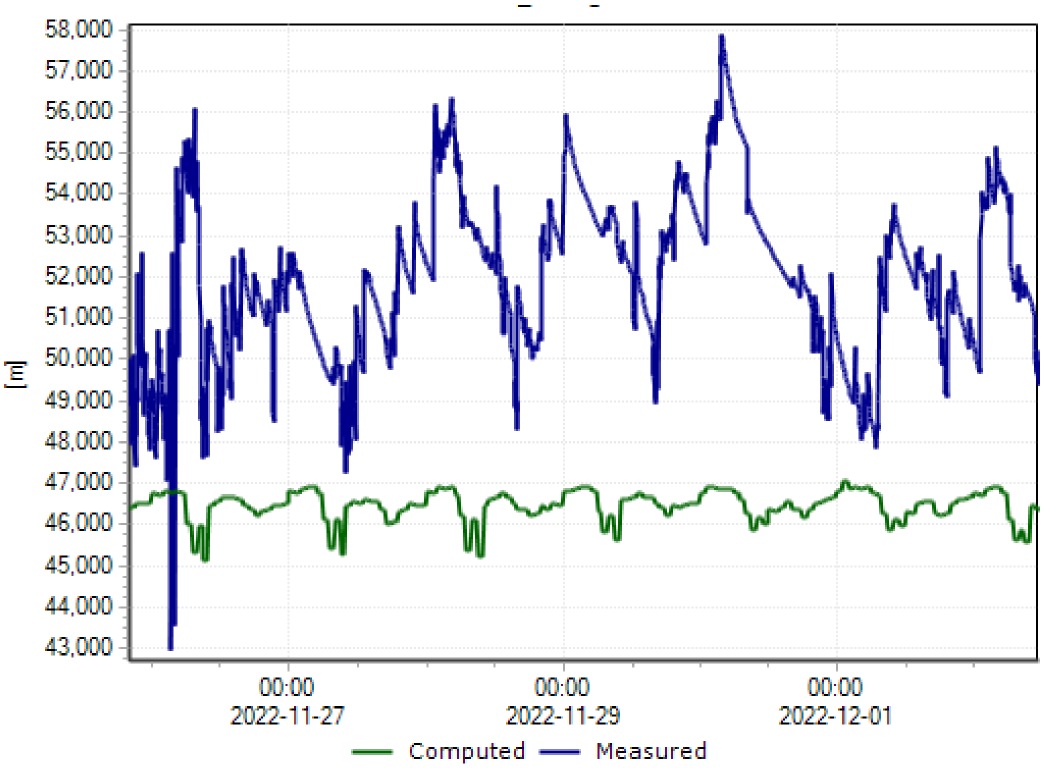


Figure 52. Station 4 - measured vs computed puressure.

The final calibrated model results are shown in figures 49-52 for pressure at locations 1-4. The comparison between simulated and measured values for pressure reveals that the difference is more significant in the eastern part of the system at station 4. However, it should be noted that the pressure fluctuations are higher in the measured values than in the simulated values. At station 4, there is a notable difference in pressure level, as the mean value differs by almost 0.7 bars. For stations 1-3, the main observation is a high-pressure spike occurring during the night. This pattern is also present in the measured and simulated flow values for pipes 1-3. The mean flow values for the simulated values are very close to the measured values, with the exception of the oscillating pattern observed at night. It is worth noting that this calibration period covers a period of one week, and local deviations may occur within this time frame. In order to further calibrate the model and make it more representative of measured values, a longer calibration period may be necessary.

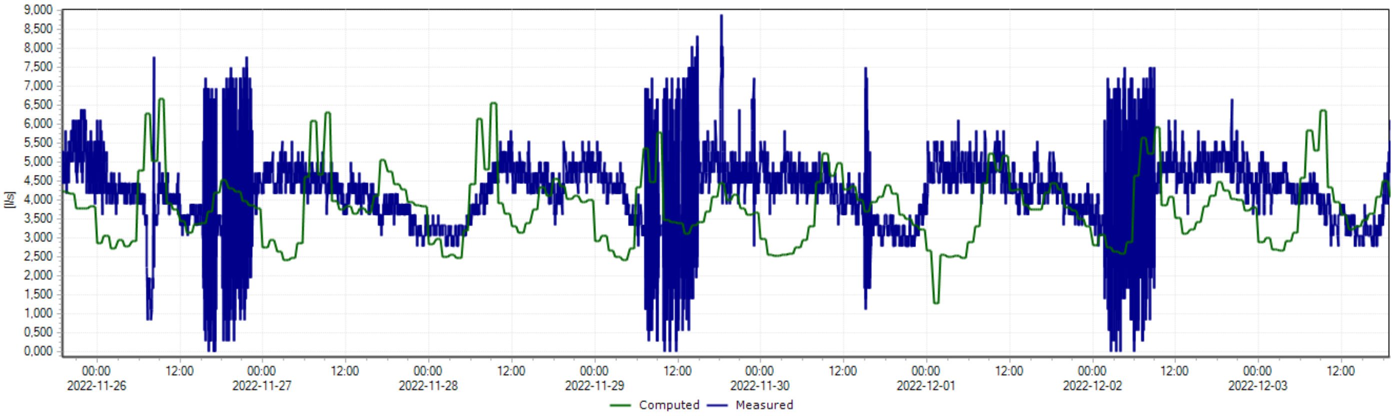


Figure 53 53. Simulated and measured flow values after calibration, pipe 1. Y-axis displays the flow (l/s) and the date on the X-axis.

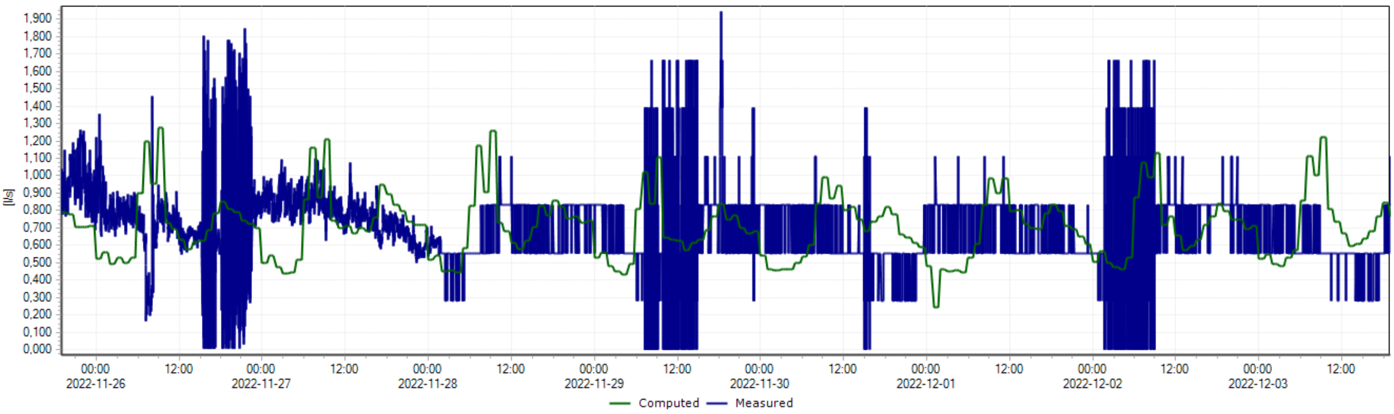


Figure 54 54. Simulated and measured flow values after calibration, pipe 2. Y-axis displays the flow (l/s) and the date on the X-axis.

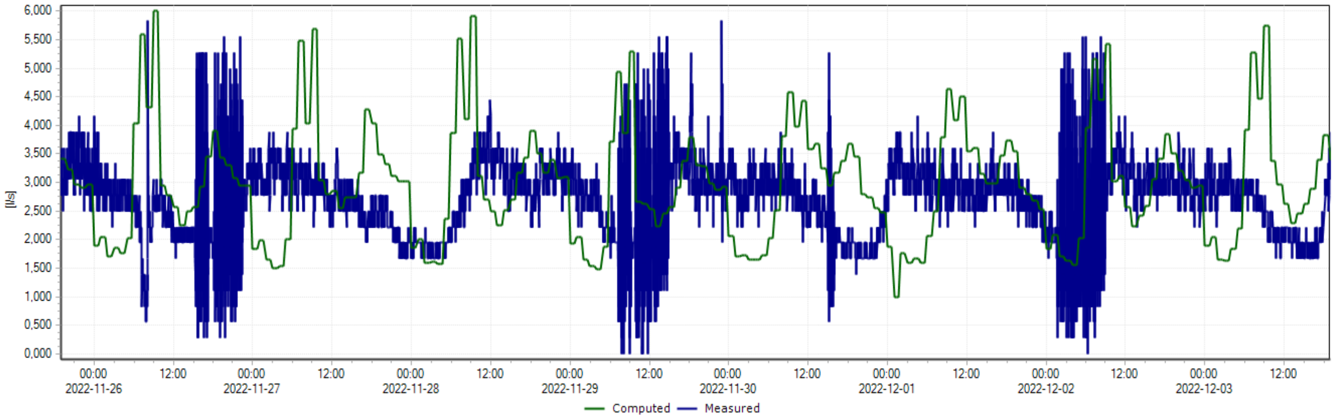


Figure 55 55. Simulated and measured flow values after calibration, pipe 3. Y-axis displays the flow (l/s) and the date on the X-axis.

5. LIMITATIONS

When creating a model based on real network, some simplifications are needed for the model to run properly. Therefore, below the necessary simplifications and limitations are listed based on each category of data.

- All elements are assumed to be active
- Incompressible fluid and one-dimensional flow.

5.1 Pipes

- All pipes are assumed to be fully functional.
- Age of pipes are assumed to affect the roughness.
- All links with missing data assumed same dimensions and construction year as neighboring pipes.
- Branch pipes excluded - demand allocations connect to nearest node.
- Standard Dimensional Ratio 17 (pressure stage).
- Flow is modeled as absolute, thus direction of pipe within the hydraulic model is irrelevant

5.2 Valves

- Every valve is intact and properly operating.
- All valves initially open.

5.3 Pumps

- Pumps are configured as variable speed drive (controlled by a control pressure at designated node).
- Booster pump & back-up pump assumes same control pressure as waterworks.

5.4 Tank

- Tank level assumed to be at constant Hydraulic gradient level (HGL).

5.5 Pressure loggers

- Assumed they were properly operating for the whole period of data collection for calibration purposes.

5.6 Consumer types

- The assigned consumer type according to Ramboll FAS.

6. RESULTS

6.1 Functional analysis

In this chapter it is presented the functional results of the hydraulic model.

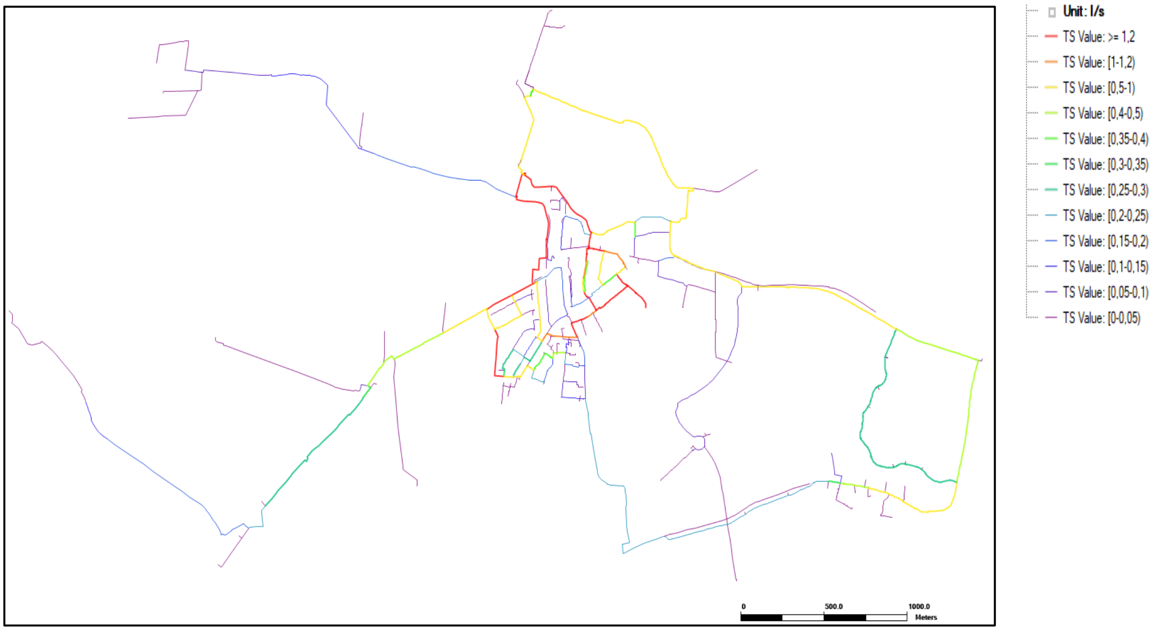


Figure 5656. Velocity (maximum).

In figure above, the maximum velocity is displayed. Maximum velocity is chosen due to high velocity in pipes causing higher stress of the pipes.

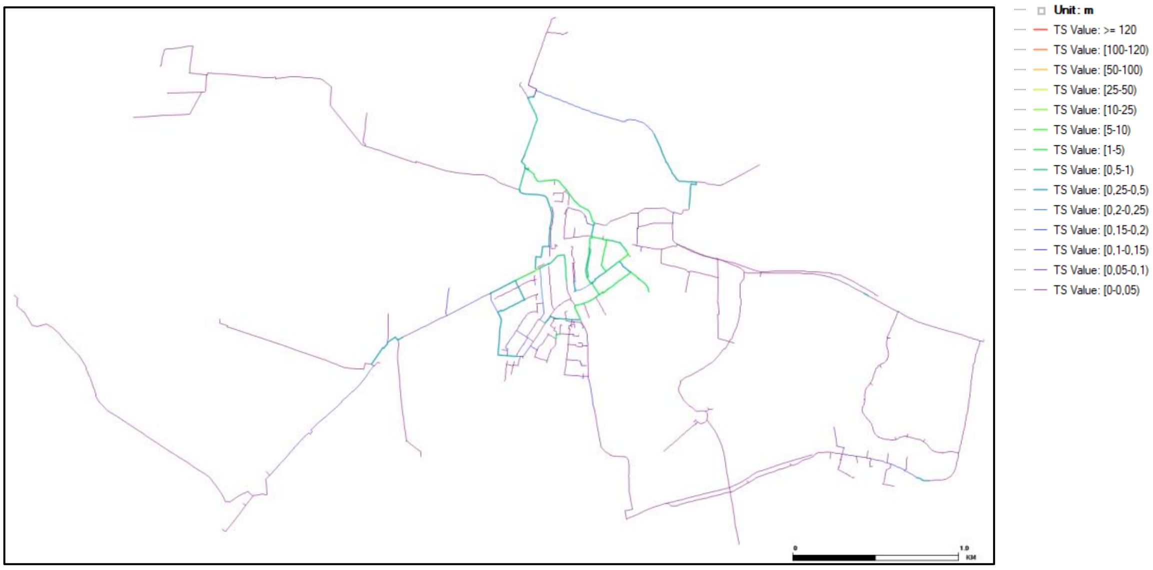


Figure 57 57. Head loss (m).

Head loss in the pipes of the water distribution system can be seen above.

The flow directions around the waterworks are displayed in figure 58 below. We can see a higher flow going through both pipe 1 and 2 towards the central parts of the town. Flow can also be seen connecting back to the central parts from pipe 3, creating several loops within the system (see figure 62).

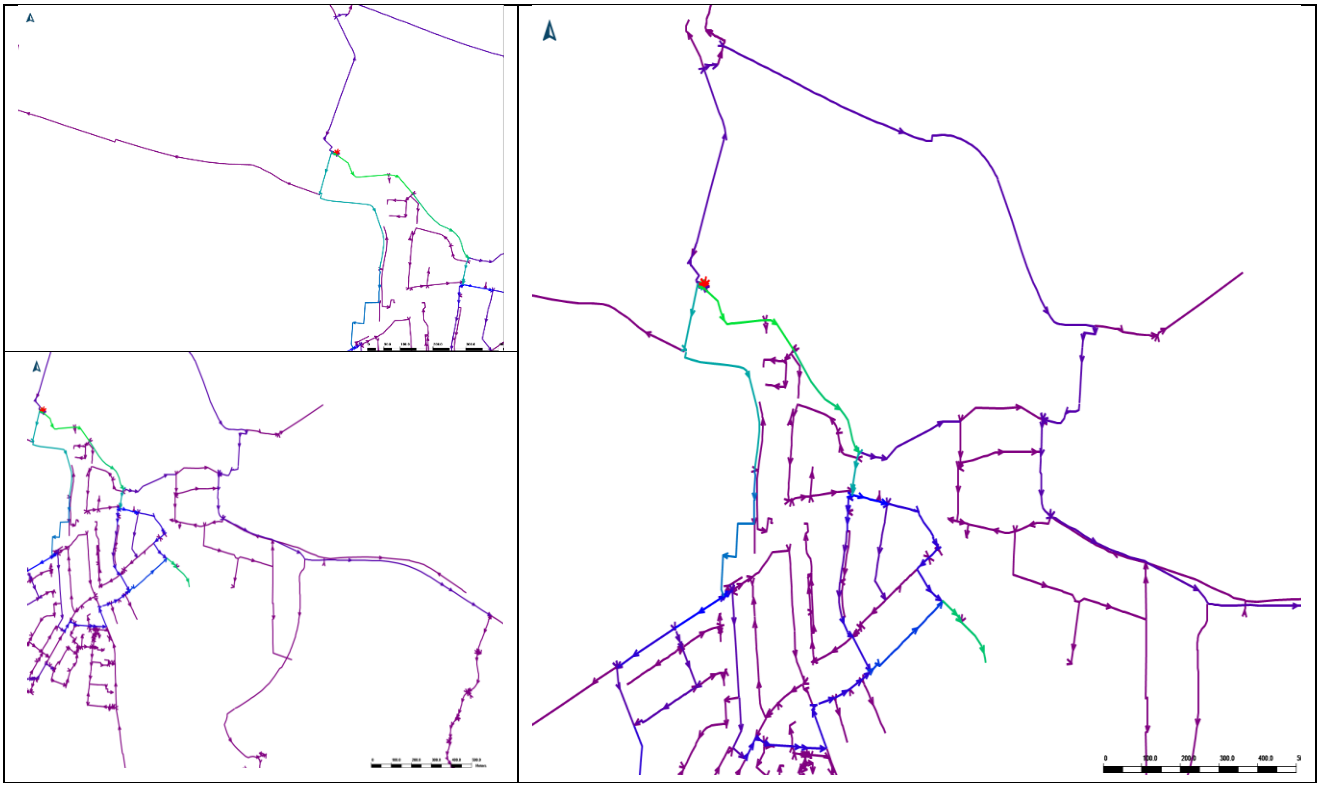


Figure 5858. Flow directions around the waterworks (absolute)

Figure 59 visualizes how the demand is distributed in the system. It is clear the major demand is located in the central parts of Lille Skensved.

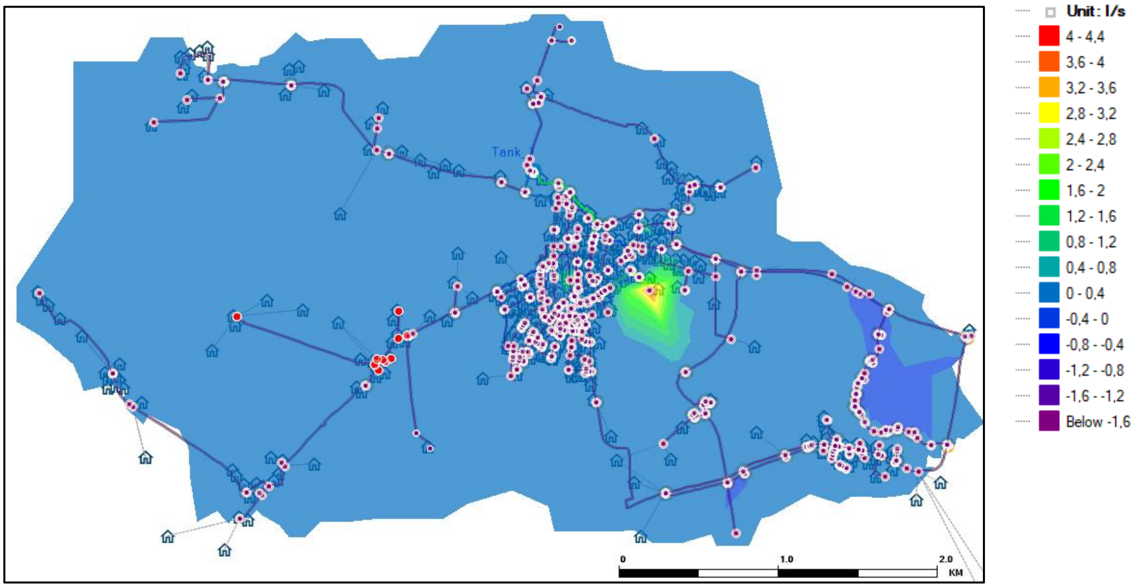


Figure 5959. Water demand distribution (l/s).

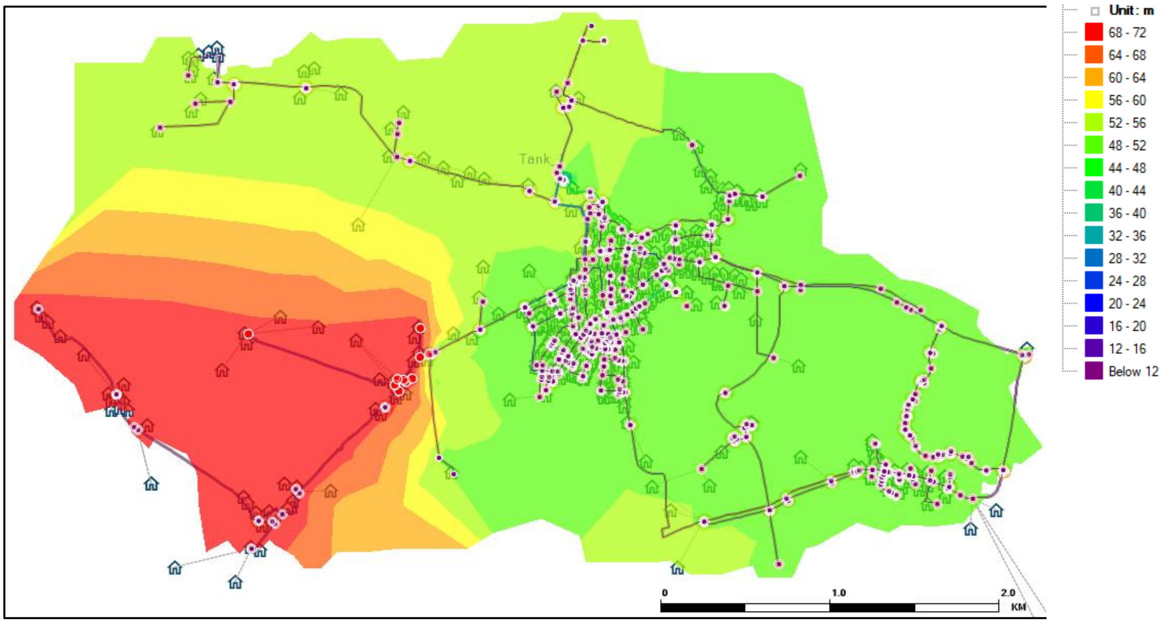


Figure 6060. Heatmap of the hydraulic head (m).

From figure 60 and figure 61 a heatmap of the hydraulic head (m) and the pressure (m) distribution over the waterworks. The western part of Assendrup can clearly observed a high hydraulic head due to its higher elevated area.

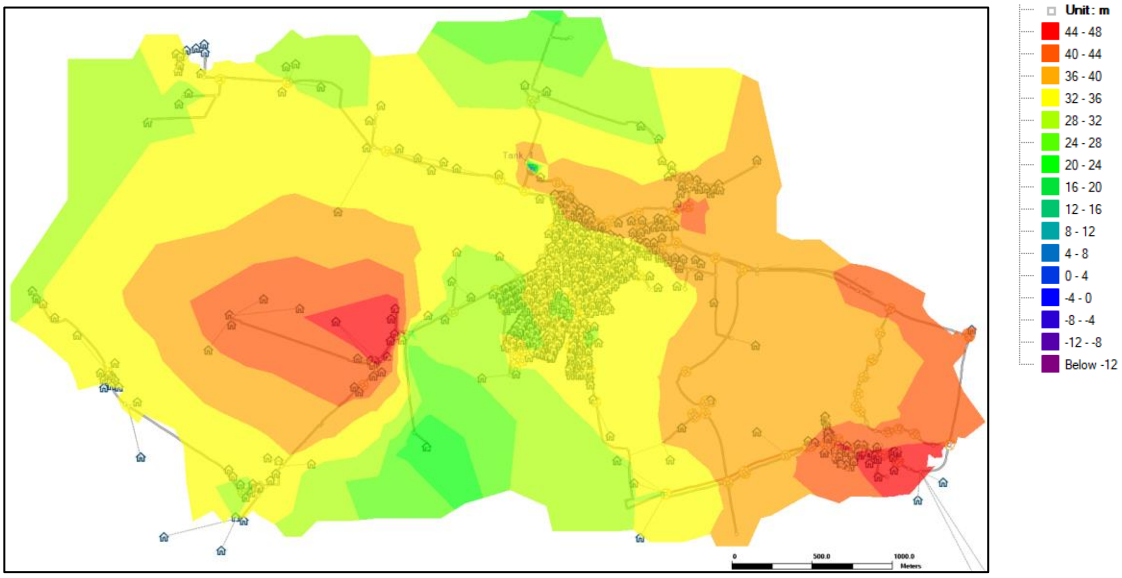


Figure 6161. Heatmap of the pressure (m)

Figure 6262. Water distribution network loops within the distribution network (marked yellow).

As visualized in figure 62, much of the water distribution system is within a loop (marked yellow). Outer parts of the distribution system - Assendrup and Vikstrup - are branched in outgoing tree formation.

6.2 Vulnerability analysis

This analysis was conducted following a validated and calibrated model. Therefore, the network vulnerability results should be reliable. Below, the results of the different scenarios of the vulnerability analysis are shown and compared.

6.2.1 Scenario 1 – normal operating conditions.

6.2.1.1 Indexes

The table below presents the indexes of the system. The connectivity index indicates the accessibility of the network for water distribution and that the system has functioning flow paths. The positive value of the Todini index can indicate a well-functioning system if the value is positive however, it is not necessarily the case.

Table 3. Network-wide indexes.

Todini index	Connectivity index
1.777	0.997

6.2.1.2 Pipe criticality & node reachability

Node reachability measures the accessibility of each individual node in the network. The average node reachability in this case is 0.991 and interestingly, no nodes have a reachability value of 1. In addition, the nodes adjacent to the water tank which are placed before the pumps, received a reachability of 0.172. The schematic map below illustrates the pipe criticality in the network at 9am. The red pipes, representing the highest criticality, lead to the largest factory. Other pipes with high criticality include transmission pipes from the water works and several major distribution pipes. The highest criticality is concentrated to the middle of the network.

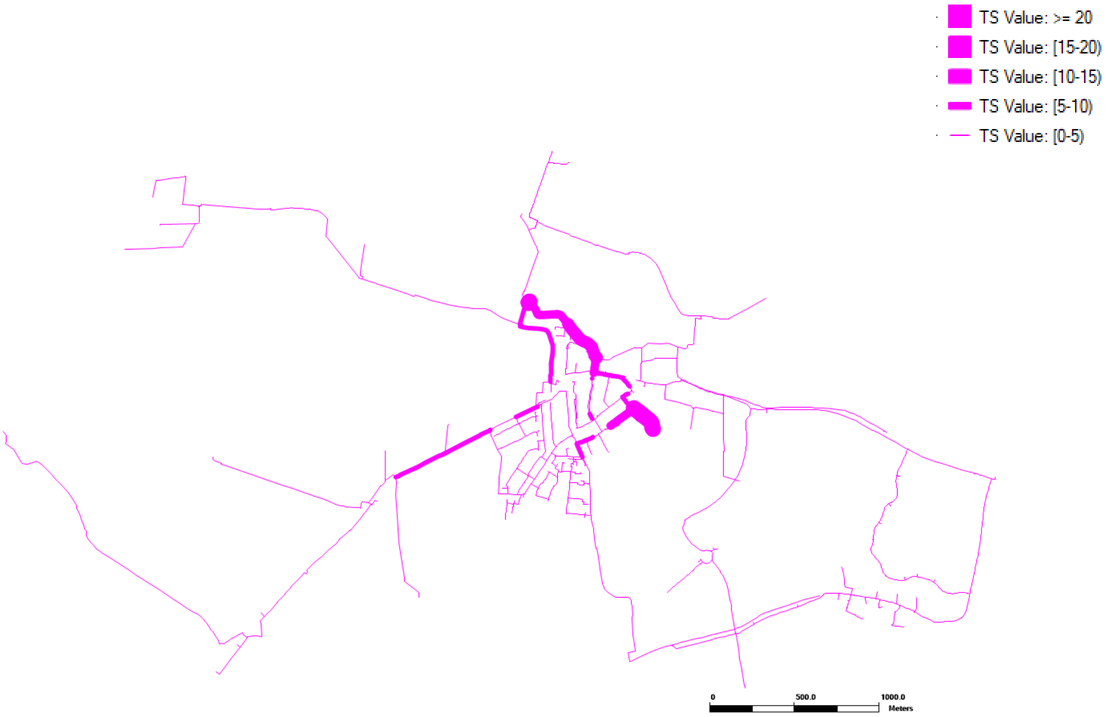


Figure 6363. Pipe criticality (%) for hour 9 – visualized as graduated size.

Figure 63 and figure 64 show the overall pipe criticality of the network. Figure 63 is intended to give an overview of the criticality whereas figure 64 has a more specified depiction of the critical pipes.

Figure 6464. Pipe criticality for hour 9.

The table below shows the ten highest values of pipe criticality in the network. The following analysis will present all parameters within the pipe criticality for these pipes.

Table 4. 10 highest values of pipe criticality

Pipe ID	Criticality (%)
Pipe_229_1	37.5
Pipe_634_1	37.4
Pipe_84_1	37.4
Pipe_83_1	37.3
Pipe_110_1	15.6
Pipe_3	13.8
Pipe_4	13.8
Pipe_566_1	13.8
Pipe_85_1	13.8
Pipe_440_1	13.0

The table above shows the four most critical pipes, marked in red in both Table 4 and Figure 6464, which make up the connection to the major consumer in the network. The pipes marked in green are part of the green trail emerging from the water works, although pipes within the water works are excluded from this table. These pipes display a criticality of around 80%, which is still noteworthy. It is important to note that the pipe criticality is the average of four separate parameters, which may result in significant variations within the pipe criticality for different pipes. Table 5 presents all four parameters for the pipes in the previous table.

As mentioned previously, the parameters which constitute the pipe criticality cover separate hydraulic aspects. Firstly, P1 states the amount of undeliverable flow through that pipe if it were to close. Secondly, P2 is number of nodes are affected by insufficient pressure for each pipe. Furthermore, P3 is related to P2 by showing the unattainable demand due to insufficient pressure per pipe. Lastly, P4 is the length of pipe which is affected by insufficient pressure.

Table 5. All parameters in criticality pipe criticality.

Pipe ID	P1(%)	P2(%)	P3(%)	P4(%)	C(%)
Pipe_229_1	74.52	0.41	74.52	0.41	37.47
Pipe_634_1	74.51	0.27	74.51	0.26	37.39
Pipe_84_1	74.51	0.27	74.51	0.26	37.39
Pipe_83_1	74.44	0.14	74.44	0.26	37.32
Pipe_110_1	62.47	0.00	0.00	0.01	15.62
Pipe_3	55.38	0.00	0.00	0.01	13.85
Pipe_4	55.38	0.00	0.00	0.01	13.85
Pipe_566_1	55.37	0.00	0.00	0.01	13.85
Pipe_85_1	55.37	0.00	0.00	0.01	13.84
Pipe_440_1	52.16	0.00	0.00	0.01	13.04

As seen in Table 5 above, there is variation in the values of the parameters depending on the pipe. It is evident that parameter P1 significantly influences the criticality of all ten pipes. However, there is a significant difference in the remaining parameters. For example, P3 significantly contributes to the criticality of the four most critical pipes but has no impact on the other pipes. Given that P2 and P3 are related, it is reasonable that the green pipes have a value of zero for both parameters. It is noteworthy that P2 has a minimal impact on the criticality of any of the pipes, with more than half of the pipes in the entire network having a value of zero for both P2 and P3. The table below presents excerpts from the results of the simulation, focusing on parameters P2 and P3.

Table 6. Highest values of P2 from simulation.

Pipe ID	P1(%)	P2(%)	P3(%)	P4(%)	C(%)
Pipe_385_1	2.08	3.54	2.08	15.62	5.83
Pipe_384_1	2.02	3.27	2.02	14.53	5.46
Pipe_12	2.00	3.13	2.00	13.83	5.24
Pipe_10	2.00	3.00	2.00	11.99	4.75
Pipe_458_1	2.00	2.86	2.00	11.98	4.71
Pipe_459_1	1.66	2.59	1.66	11.41	4.33
Pipe_460_1	1.35	2.04	1.35	8.61	3.34
Pipe_573_1	1.34	1.91	1.34	8.44	3.26
Pipe_657_1	0.31	1.91	0.31	1.55	1.02
Pipe_68_1	1.31	1.77	1.31	8.28	3.17
Pipe_67_1	1.22	1.64	1.22	7.98	3.01
Pipe_575_1	0.28	1.64	0.28	1.35	0.89

Table 7 below presents the values of parameter P3 in order of the ten highest values. The four highest values correspond to the pipes with the highest overall criticality, which are connected to the largest consumer.

Notably, many of the pipes appear in both in Table 6 and Table 7.

Table 7. Highest simulated values for P3.

Pipe ID	P1(%)	P2(%)	P3(%)	P4(%)	C(%)
Pipe_229_1	74.52	0.41	74.52	0.41	37.47
Pipe_634_1	74.51	0.27	74.51	0.26	37.39
Pipe_84_1	74.51	0.27	74.51	0.26	37.39
Pipe_83_1	74.44	0.14	74.44	0.26	37.32
Pipe_73_1	5.44	0.14	5.44	0.04	2.77
Pipe_385_1	2.08	3.54	2.08	15.62	5.83
Pipe_384_1	2.02	3.27	2.02	14.53	5.46
Pipe_12	2.00	3.13	2.00	13.83	5.24
Pipe_10	2.00	3.00	2.00	11.99	4.75
Pipe_458_1	2.00	2.86	2.00	11.98	4.71
Pipe_459_1	1.66	2.59	1.66	11.41	4.33
Pipe_460_1	1.35	2.04	1.35	8.61	3.34

To emphasize the results of the individual parameters, schematic maps of each parameter is presented below.

Figure 6565. P1 (%) – scenario 1.

Figure 65 shows the intensity of parameter P1 with increasing thickness as the value grows. To repeat, most of the flow in centered around the water works and the largest consumer. Similarly, the following figures have the equivalent structure for the remaining parameters.

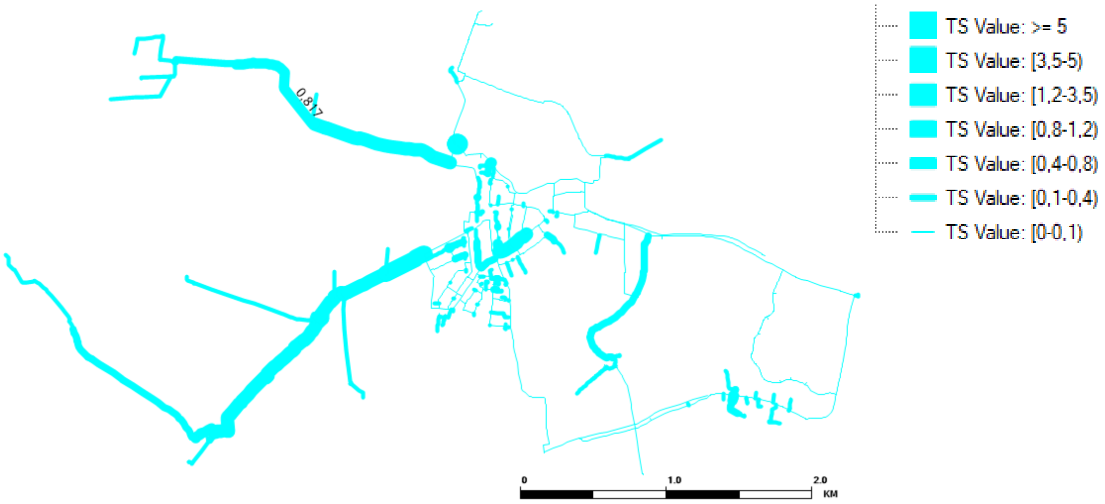


Figure 6666. P2 (%) – scenario 1.

Clearly, figure 66 and figure 67 have similarities in terms of where the highest values occur. Since these parameters both are related to consumers in the network, it seems to be reasonable.

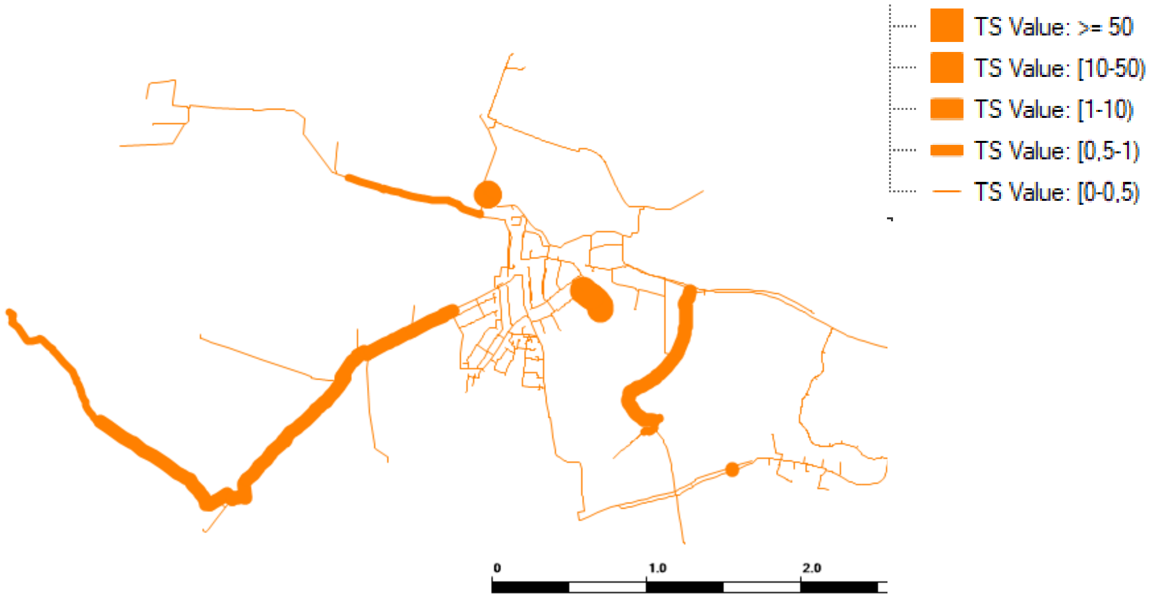


Figure 6767. P3 (5) – scenario 1.

Lastly, figure 68 also appears to produce results alike the other parameters. The two arms stretching out to the left from the city center experience some of the highest values of all parameters except P1.

Figure 6868. P4 (%) – scenario 1.

Table 8 below shows the two most critical pipes in the network. Pipe 33 conveys drinking water from the reservoir to the pumping station, and pipe 37 carries that water from the pumping station to the entire drinking water system.

Table 8. Criticality parameters for pump site.

Pipe ID	P1(%)	P2(%)	P3(%)	P4(%)	C(%)
Pipe_33	100.00	39.37	100.00	100.00	84.84
Pipe_37	100.00	39.37	100.00	100.00	84.84

To summarize the first scenario, some pipes are highly critical in the network. There is a clear path of critical pipes from the pump site to the factory. It is important to note that the most critical pipes may not be the most critical in all aspects. The following scenario will analyze and compare the results of the network vulnerability based on changes in the pump setup.

6.2.2 Scenario 2 – system running on backup pump.

In this next scenario, results of the network vulnerability for the pump scenario are presented.

6.2.2.1 Indexes

Table 9. Network-wide indexes.

Todini index	Connectivity index
1.527	0.999

As in the first scenario, the Todini index has a positive value. The index is slightly lower than in the first scenario, while the connectivity index is slightly higher than in scenario 1 as can be seen above in Table 9.

6.2.2.2 Pipe criticality and node reachability

The average node reachability in this scenario is .993, which exceeds the value from the first scenario. In fact, many nodes have a node reachability value of 1 in this case. As can be seen in the figure below, the location of critical pipes has changed substantially. Naturally, the pipes surrounding the pump have become increasingly critical whereas the pipes around the original location of the pumps are minimally critical. However, the pipes leading to the largest factory are equally critical in this scenario.

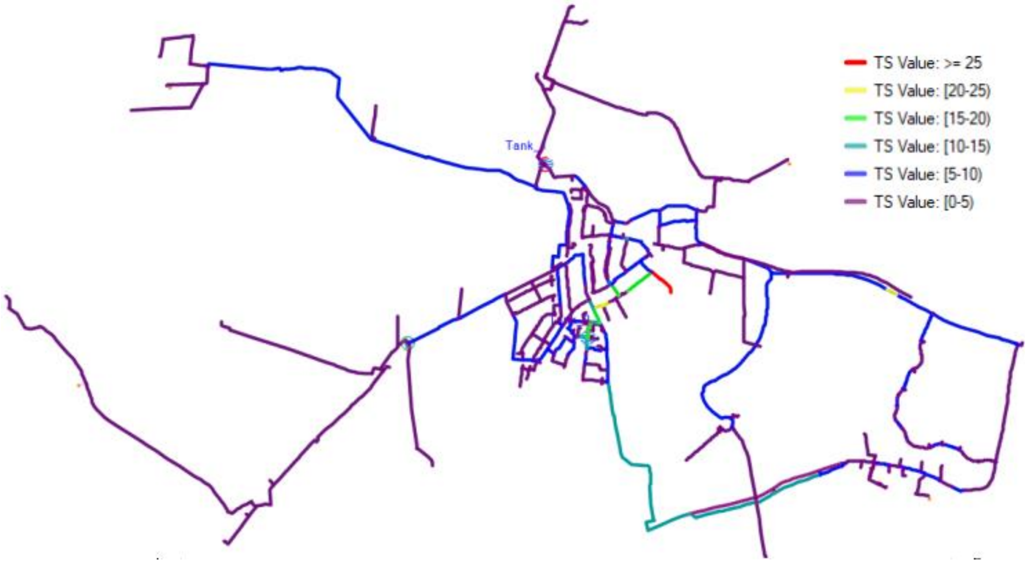


Figure 6969. Pipe criticality after change of pump location.

Shown below are the ten highest values of the pipe criticality. Apart from the pipes to the largest consumer, the criticality is overall lower in this scenario compared to the first. Furthermore, the criticality seems to be spread out more evenly among more pipes as opposed to a few highly critical pipes.

Table 10. Ten highest values of pipe criticality

Pipe ID	C(%)
Pipe_229_1	37.5
Pipe_84_1	37.4
Pipe_634_1	37.4
Pipe_83_1	37.3
Pipe_470_1	13.5
Pipe_13	12.8
Pipe_141_1	12.3
Pipe_14	12.3
Pipe_464_1	12.2
Pipe_159_1	12.2

The following table expresses the difference in the two scenarios regarding how many critical pipes exceed values of specific percentages. To depict this clearly, five values of criticality were selected.

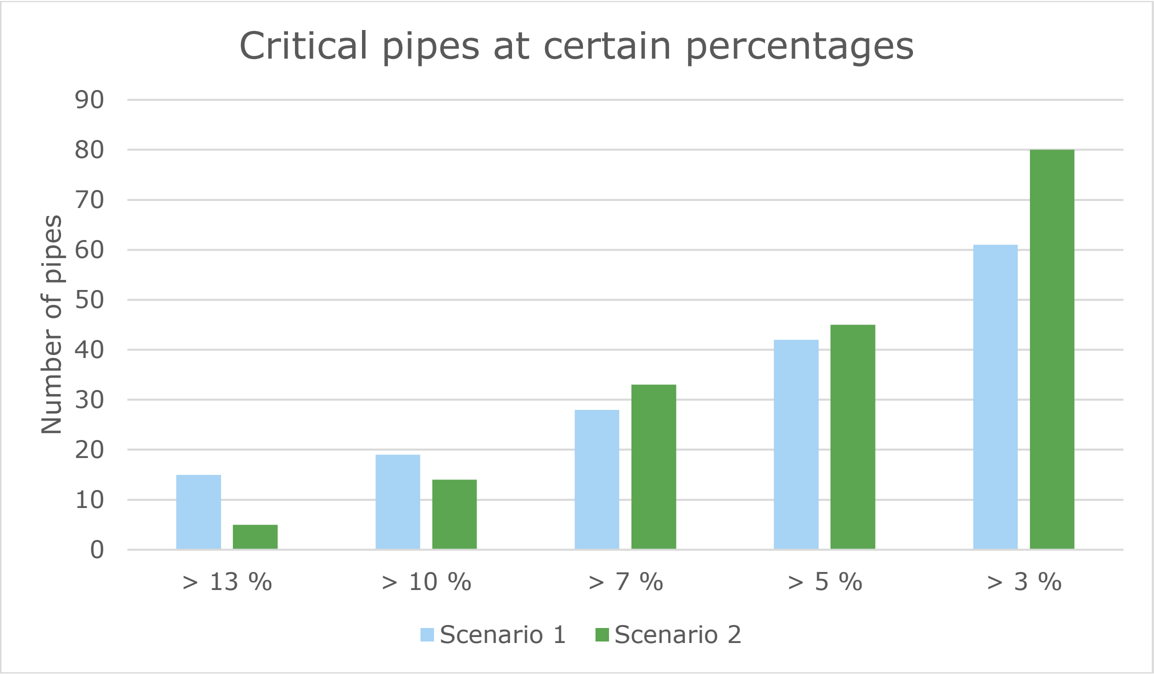


Figure 7070. Pipes at different critical stages

In figure 70 above, there appears to be a difference in the breakdown of critical pipes. Scenario 2 has a considerably larger number of pipes above the value of 3 percent criticality than scenario 1. On the other hand, scenario 1 dominates at higher critical values. The breaking point seems to be between 7 and 10 percent.

Again, the figures below show the intensity of the values of parameters P1 to P4. Some changes can be detected for each parameter.

Figure 7171. P1 (%) - scenario 2

In figure 71 the flow unable of being transmitted through each closed pipe has altered appearance compared to scenario 1. However, there are minimal changes for parameter P2 in figure 72.

Figure 7272. P2 (%) - scenario 2

Furthermore, high values of P3 are distinguishable in the long stretch of pipes in the low left corner as well as around the factory. One additional section of pipes to the right is also critical based on parameter P3 as can be seen in figure 73.

Figure 7373. P3 (%) - scenario 2

Lastly, parameter P4 in figure 74 has high values on left side of the network.

Figure 7474. P4 (%) - scenario 2

To conclude the results section, some differences in the pipe criticality and node reachability is evident in the two scenarios. Most notably, large changes in parameter P1 were clear which has a significant impact on the overall criticality. Following this, a discussion of the results will be conducted.

7. DISCUSSION

To begin, discovering where the most critical sections of pipe in the area proved to be a daunting task since the network vulnerability is dependent on several different factors. In addition, the demands alter throughout the day which entails varying results dependent on the time. Nonetheless, results of the vulnerability have been achieved with sufficient quality to make conclusive deductions.

When the pump location changed to the city center and the vulnerability analysis was run again, the criticality of the pipes changed drastically. Instead of having three or four heavily critical pipes, many more pipes increased slightly in criticality whereas the most critical pipes decreased in criticality. One would argue that since the city center has a looped structure, especially compared to where the water works lies currently, this contributes to a high redundancy. In addition, the results of parameter P3 also shows how high the redundancy in the network is since many pipes in the network have a value of zero. Granted, the pipes in the branched sections to the left have a significant value of P3 indicating that these consumers would not have their demand met in the event of a pipe burst in this section. However, the node reachability indicates that these consumers still would get access to water despite it being at an insufficient pressure. This suggests a high degree of robustness in the network entailing that the network can manage a pipe malfunction well.

Continuing with the backup pump, the node reachability increased compared to scenario one with some nodes even having a perfect reachability. Most of the consumers are concentrated in the city center. Therefore, the water generally has a shorter path to travel which minimizes the vulnerability. Possibly, that location is more appropriate for a network of this shape. A drawback of scenario two however, is the presence of only one pump. If it were to malfunction, there would be no alternative. This scenario is however, only used in special cases where the waterworks needs to be closed off. More importantly, the pipes in the city center are not intended as transmission pipes. This could entail that during a longer period, the pipes could be subject to high stress due to for instance unsuitable pipe dimensions and unforeseen velocities.

Generally, within the four parameters of criticality there appears to be one of them which dominates the criticality. P1 seems to be a huge contributor to the overall criticality as a comparison between the two schematic maps show below, with the left being the overall criticality and right being P1. On the other hand, the three remaining parameters have high values in for instance the branched sections to the left in the network. As mentioned previously, the parameters each have on specific area of focus. P2 refers to number of consumers affected by insufficient pressure. Based on this parameter, the most affected are the ones in the branched sections in the left part of the network. Despite this, these pipes are not high in overall criticality.

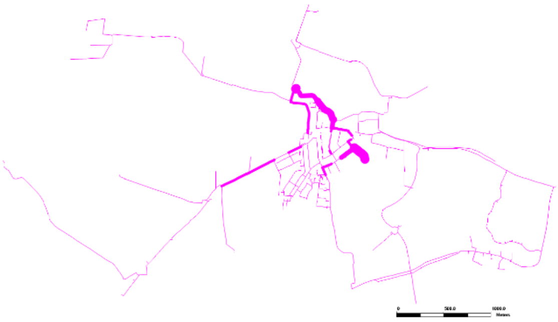


Figure 75. Criticality C(%)

Figure 76. Parameter P1(%)

Regarding the criticality, this type of analysis presents results using only hydraulic metrics. Were it to incorporate other metrics such as sensitive users in for instance hospitals, which may not be the largest water consumers but are nonetheless very important, the results of the analysis could potentially be different. Possibly, an additional parameter could be added to the analysis which would account for sensitive consumers.

Since simplifications have been made in the model, the maximum value of P2 in the network is 39 % at the pipe emerging from the water works as opposed to 100 % for P1, P3 and P4 at the same pipe. This is due to the model including all nodes in the network in the analysis, even nodes without consumers connected to it. Therefore, the result of this parameter can be misleading for the overall criticality.

In the results for both scenario 1 and 2, the calculated values is 1,777 and 1,527. This could be interpreted as the system having enough surplus energy to meet its demand of assigned minimum service pressure for both cases. Importantly, the Todini index changes depending on the time period as well as the minimum service pressure input. Therefore, it is necessary to be decisive when calculating this index. The index gives an overall evaluation of how the reliability of the water distribution network is operating under these circumstances, and its availability to potential actions and changes.

Renovation suggestions & ideas for water utility of Lille Skensved

One of the main challenges faced by the water utility of Lille Skensved is the direction and volume of flow in the three main transmission pipes. Currently, parts of the network are not restricted in any direction and are connected in a loop (Figure 62). Additionally, the amount of water entering each direction is for the water utility currently unknown, apart from the outgoing flow rate from the waterworks. If the direction and volume of water flowing through each pipe are not known, it can lead to unnecessary stress on certain transmission lines. This means that the water could flow at an unknown proportion to a demand point in the central parts of Lille Skensved through various pathways. While this lack of knowledge about the flow proportion in the three main transmission lines is not ideal, the many flow paths does offer some benefits in terms of resilience and redundancy. Todini (2000) argued that the resilience of the system can be enhanced through more even distribution of flow among all pipes, rather than allowing flow to concentrate in a spanning tree.

According to the results of scenario one, the P1 index is higher for transmission pipe two, indicating that there is a greater flow through this pipe, which results in a higher proportion of water that cannot be delivered through this pipe in relation to the total flow and thus will be redistributed to the remaining two transmission pipes. Although the calculated P1 index value for pipe one is not significantly different from pipe two, the reasoning of Todini suggests that from a redundancy perspective, it may be beneficial to keep the loop open in order to keep the flow evenly distributed.

The water utility in Skensved has expressed interest in its upcoming renovation plans, which include renovation of pipes as depicted in the figure (marked in red). This is consistent with the findings of the hydraulic calculations, which indicate that neither of the pipes presents a high level of criticality, meaning that they can be closed off without significantly impacting the system or causing significant pressure losses. The majority of the flow seems to be concentrated in the outskirts of the system towards a high-demand point.

Figure 7777. Water utility of Lille Skensved's future plans in renovation of pipes marked in red. Criticality results of scenario 1 displayed in purple.

This part of the system (figure 77), located in the central parts of Lille Skensved, is part of a looped system. The indexes for undelivered water and the total length of pipes with pressure below the required service level are low, as seen in figure 73, due to the presence of alternative routes. The criticality index for these pipes is not significant. However, it is important to note that other practical considerations, such as the construction year and material of the pipes, should also be taken into account when developing a renovation plan.

The vulnerability analysis can be a useful tool for the water utility of Lille Skensved when making decisions. To consider all factors that may impact the system can be challenging although, this vulnerability tool can act as an indicator for the initial impacts of a particular action. However, it is important to note that this tool should rather be used as a support mechanism, as opposed to being the sole basis for the decision making. Utilizing the Todini index in a similar manner can also provide insight into the efficiency of the network, as one of the advantages of this index is that it does not require any previous statistical data to calculate the index itself. When combined with other previously discussed parameters, the vulnerability analysis and Todini index can provide an initial indication of how the resilience of the water distribution system may be affected by a particular action in the design and planning stages of reconstruction.

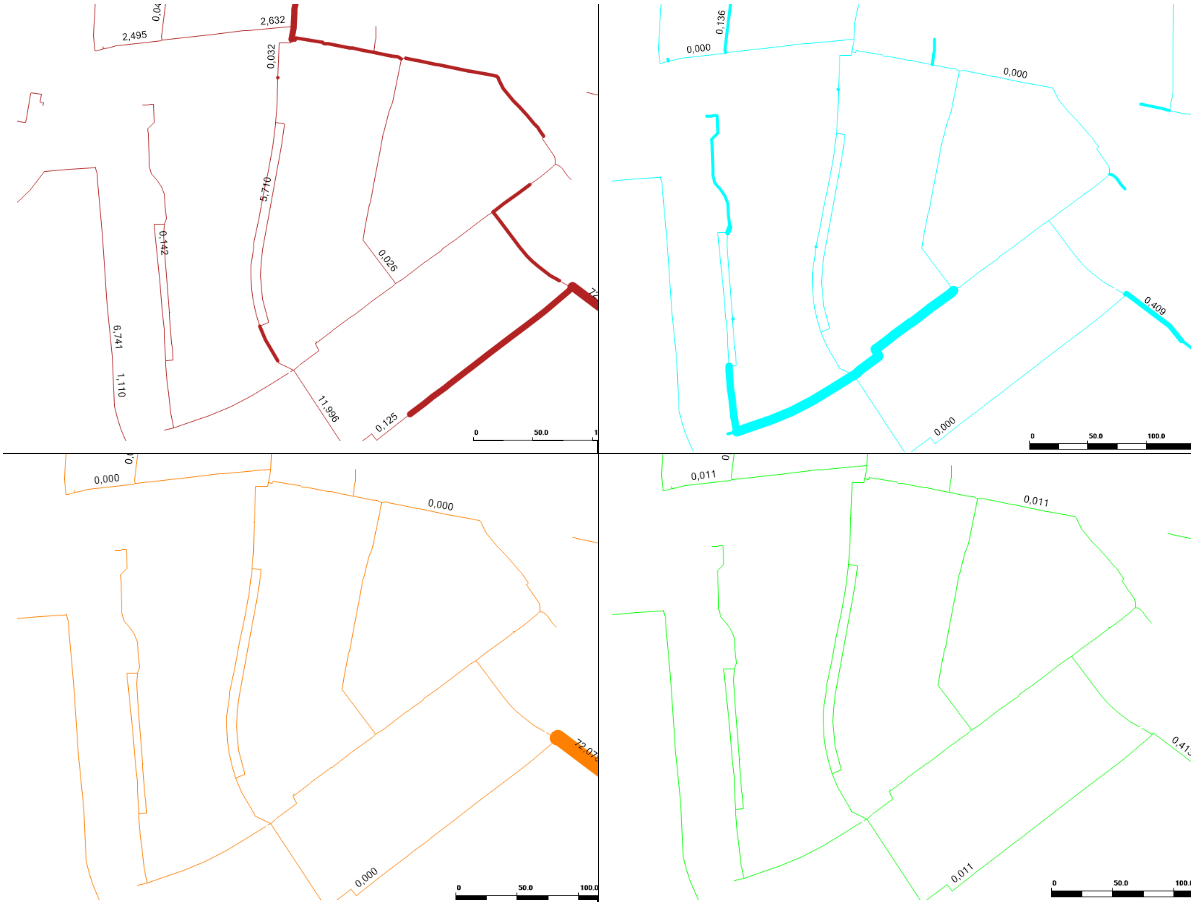


Figure 7878. P1, P2, P3 and P4 for the area of interest of renovation for the water utility of Lille Skensved, scenario 1, normal operating conditions.

Evaluations of limitations and improvements of the hydraulic model

Establishing a robust hydraulic model can be a complex undertaking. A substantial amount of data is required to construct such a model, and assumptions may need to be made due to the absence or unavailability of certain information, which can introduce uncertainty into the model. Calibrating the model to better align with reality is a crucial aspect, and the incorporation of more data over an extended period of time would enhance the calibration process. In the present case, the model was calibrated using field data collected over a one-week period, which may not be adequate for achieving an optimal hydraulic model. This could imply that the data used for calibration does not accurately represent the normal operating conditions of the network, as there are observable variations in pressure and flow during nighttime in the measured data. A longer calibration period of six months or more would produce a model that is more representative of reality and has a higher level of accuracy in simulated values.

The consumer water usage patterns are a vital consideration in the process of calibrating the model. In this model, standardized patterns from Miljøstyrelsen were applied to pre-categorized consumer allocations, and only the top 10 consumer demand patterns were implemented. Due to technical limitations, the same implementation was not applied to the remaining consumers, which would have led to a higher degree of accuracy in replicating the actual demand patterns for each allocation. The utilization of standardized patterns entails a degree of uncertainty in the model. Furthermore, having more data would enable the creation of an hourly consumption pattern for each consumer, which would provide an even more precise representation, instead of utilizing a 168-hour pattern.

The model constructed also has some uncertainties regarding the input data. The tank level is assumed to be constant, which has an impact on pump regulations. There were no real-time control conditions implemented for the pumps, which may result in unrealistic operating conditions. Improving operational factors would reduce these uncertainties and enhance the simulated values in comparison to measured flow, which would lead to a higher level of reliability and broader use of the hydraulic model for different purposes beyond vulnerability analysis.

8. CONCLUSION

Firstly, it can be concluded that the main difference in vulnerability between the two scenarios is an alteration in critical pipes. Moreover, the pipes that are intended by the water utility to be renovated have a low criticality. Therefore, they can be renovated while only slightly affecting the network.

Based on the results of the pipe criticality, it can be concluded that from a hydraulic point of view the results show a clear representation of the network. However, there is room for improvement in the model. Firstly, the parameter P2 should be adjusted to only account for nodes in the network which are connected to consumers. Secondly, the analysis can be expanded to a fifth parameter which accounts for how sensitive consumers in the network are to loss of water based on societal importance.

The water utility of Lille Skensved could use the resulting parameters of the network vulnerability as a supporting tool in the decision making of renovations. Instead of the vulnerability analysis being the only deciding tool for a renovation plan, it should be used to get an initial screening of the critical parts of the vital infrastructure. The concluding results shows the planned segments renovations is not critical from a vulnerability aspect. Still, some uncertainties exist, and the calibrated model does not yield perfect correlating results between measured and flow, especially in the low-laying eastern part of the system (which reflects the credibility of the whole hydraulic model). Even though the calibrated values are not perfect, the results could be seen as first indicators of a consequence within a distribution system in a design and planning phase.

In conclusion, a network vulnerability analysis is a powerful tool which has many applications. It is important to remember its limitations and if evaluating the renovation plan of a water distribution network, to use this analysis as a complement to other areas of investigation.

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10. APPENDIX

10.1 Appendix A

Simulated result data.

Pipe ID	Q	P1 (%)	Σ	P2 (%)	Σ	P3 (%)	Σ	P4 (%)	C (%)	Pipe ID	Q	P1 (%)	Σ	P2 (%)	Σ	P3 (%)	Σ	P4 (%)	C (%)
Pipe_1	1.698	34.935	0	0.000	0.000	0.000	4.513	0.011	8.736	Pipe_48_1	0.516	10.625	0	0.000	0.000	0.000	4.513	0.011	2.659
Pipe_10	0.097	2.000	22	2.993	0.097	2.000	5088.886	11.991	4.746	Pipe_490_1	0.002	0.036	7	0.952	0.002	0.036	241.038	0.568	0.398
Pipe_100_1	0.189	3.898	0	0.000	0.000	0.000	4.513	0.011	0.977	Pipe_491_1	0.001	0.012	2	0.272	0.001	0.012	65.871	0.155	0.113
Pipe_101_1	0.073	1.500	0	0.000	0.000	0.000	4.513	0.011	0.378	Pipe_492_1	0.001	0.018	1	0.136	0.001	0.018	14.842	0.035	0.052
Pipe_102_1	0.002	0.043	0	0.000	0.000	0.000	4.513	0.011	0.013	Pipe_493_1	0.001	0.014	1	0.136	0.001	0.014	6.740	0.016	0.045
Pipe_103_1	0.805	16.561	0	0.000	0.000	0.000	4.513	0.011	4.143	Pipe_494_1	0.002	0.048	1	0.136	0.002	0.048	23.324	0.055	0.072
Pipe_104_1	0.002	0.033	1	0.136	0.002	0.033	60.287	0.142	0.086	Pipe_495_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_105_1	0.002	0.047	2	0.272	0.002	0.047	63.318	0.149	0.129	Pipe_496_1	1.278	26.290	0	0.000	0.000	0.000	4.513	0.011	6.575
Pipe_106_1	0.403	8.292	0	0.000	0.000	0.000	4.513	0.011	2.076	Pipe_497_1	0.042	0.864	3	0.408	0.042	0.864	1010.140	2.380	1.129
Pipe_107_1	0.000	0.003	0	0.000	0.000	0.000	4.513	0.011	0.004	Pipe_498_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_108_1	0.097	1.990	0	0.000	0.000	0.000	4.513	0.011	0.500	Pipe_499_1	0.000	0.009	1	0.136	0.000	0.009	107.422	0.253	0.102
Pipe_109_1	0.001	0.017	0	0.000	0.000	0.000	4.513	0.011	0.007	Pipe_49_1	0.001	0.017	1	0.136	0.001	0.017	62.041	0.146	0.079
Pipe_11	0.250	5.137	0	0.000	0.000	0.000	4.513	0.011	1.287	Pipe_5	0.250	5.138	0	0.000	0.000	0.000	4.513	0.011	1.287
Pipe_110_1	1.652	33.992	0	0.000	0.000	0.000	4.513	0.011	8.501	Pipe_500_1	0.005	0.105	0	0.000	0.000	0.000	4.513	0.011	0.029
Pipe_111_1	0.000	0.002	0	0.000	0.000	0.000	4.513	0.011	0.003	Pipe_501_1	1.237	25.458	0	0.000	0.000	0.000	4.513	0.011	6.367
Pipe_112_1	0.014	0.287	6	0.816	0.014	0.287	306.904	0.723	0.529	Pipe_502_1	0.459	9.454	0	0.000	0.000	0.000	4.513	0.011	2.366
Pipe_113_1	0.014	0.287	6	0.816	0.014	0.287	307.496	0.725	0.529	Pipe_503_1	0.002	0.041	0	0.000	0.000	0.000	4.513	0.011	0.013
Pipe_114_1	0.100	2.058	0	0.000	0.000	0.000	4.513	0.011	0.517	Pipe_504_1	1.829	37.641	0	0.000	0.000	0.000	4.513	0.011	9.413
Pipe_115_1	0.002	0.036	0	0.000	0.000	0.000	4.513	0.011	0.012	Pipe_505_1	0.002	0.049	1	0.136	0.002	0.049	6.591	0.016	0.062
Pipe_116_1	0.003	0.063	0	0.000	0.000	0.000	4.513	0.011	0.018	Pipe_506_1	0.009	0.188	4	0.544	0.009	0.188	208.492	0.491	0.353
Pipe_117_1	0.002	0.038	0	0.000	0.000	0.000	4.513	0.011	0.012	Pipe_507_1	0.000	0.005	1	0.136	0.000	0.005	141.917	0.334	0.120
Pipe_118_1	0.002	0.040	1	0.136	0.002	0.040	115.090	0.271	0.122	Pipe_508_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_119_1	0.005	0.100	3	0.408	0.005	0.100	119.656	0.282	0.222	Pipe_509_1	0.001	0.025	0	0.000	0.000	0.000	4.513	0.011	0.009
Pipe_12	0.097	2.002	23	3.129	0.097	2.002	5867.851	13.827	5.240	Pipe_50_1	0.002	0.041	2	0.272	0.002	0.041	70.261	0.166	0.130
Pipe_120_1	0.010	0.199	7	0.952	0.010	0.199	408.498	0.963	0.578	Pipe_510_1	0.003	0.070	0	0.000	0.000	0.000	4.513	0.011	0.020
Pipe_121_1	0.011	0.234	8	1.088	0.011	0.234	420.623	0.991	0.637	Pipe_511_1	0.023	0.466	0	0.000	0.000	0.000	4.513	0.011	0.119
Pipe_122_1	0.465	9.566	0	0.000	0.000	0.000	4.513	0.011	2.394	Pipe_512_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003

Pipe_123_1	0.013	0.277	11	1.497	0.013	0.277	542.306	1.278	0.832	Pipe_513_1	0.432	8.898	0	0.000	0.000	0.000	4.513	0.011	2.227
Pipe_124_1	0.012	0.257	10	1.361	0.012	0.257	536.139	1.263	0.784	Pipe_514_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_125_1	0.013	0.277	11	1.497	0.013	0.277	544.203	1.282	0.833	Pipe_515_1	0.777	15.990	0	0.000	0.000	0.000	4.513	0.011	4.000
Pipe_126_1	0.528	10.866	0	0.000	0.000	0.000	4.513	0.011	2.719	Pipe_516_1	0.228	4.694	0	0.000	0.000	0.000	4.513	0.011	1.176
Pipe_127_1	0.001	0.022	1	0.136	0.001	0.022	4.943	0.012	0.048	Pipe_517_1	0.003	0.061	2	0.272	0.003	0.061	425.938	1.004	0.350
Pipe_128_1	0.001	0.022	1	0.136	0.001	0.022	5.162	0.012	0.048	Pipe_518_1	0.000	0.008	1	0.136	0.000	0.008	101.714	0.240	0.098
Pipe_129_1	0.089	1.827	0	0.000	0.000	0.000	4.513	0.011	0.459	Pipe_519_1	0.001	0.018	1	0.136	0.001	0.018	5.556	0.013	0.046
Pipe_13	2.478	50.987	0	0.000	0.000	0.000	4.513	0.011	12.749	Pipe_51_1	0.002	0.045	1	0.136	0.002	0.045	45.520	0.107	0.083
Pipe_130_1	0.075	1.552	0	0.000	0.000	0.000	4.513	0.011	0.391	Pipe_520_1	0.616	12.681	0	0.000	0.000	0.000	4.513	0.011	3.173
Pipe_131_1	1.815	37.335	0	0.000	0.000	0.000	4.513	0.011	9.336	Pipe_521_1	0.002	0.048	0	0.000	0.000	0.000	4.513	0.011	0.015
Pipe_132_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003	Pipe_522_1	0.003	0.066	0	0.000	0.000	0.000	4.513	0.011	0.019
Pipe_133_1	0.996	20.493	0	0.000	0.000	0.000	4.513	0.011	5.126	Pipe_523_1	0.002	0.037	0	0.000	0.000	0.000	4.513	0.011	0.012
Pipe_134_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003	Pipe_524_1	0.000	0.004	1	0.136	0.000	0.004	10.515	0.025	0.042
Pipe_135_1	0.001	0.012	0	0.000	0.000	0.000	4.513	0.011	0.006	Pipe_525_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_136_1	0.006	0.117	0	0.000	0.000	0.000	4.513	0.011	0.032	Pipe_526_1	0.000	0.007	1	0.136	0.000	0.007	11.481	0.027	0.044
Pipe_137_1	1.007	20.718	0	0.000	0.000	0.000	4.513	0.011	5.182	Pipe_527_1	0.803	16.527	0	0.000	0.000	0.000	4.513	0.011	4.135
Pipe_138_1	0.004	0.077	0	0.000	0.000	0.000	4.513	0.011	0.022	Pipe_528_1	0.772	15.886	0	0.000	0.000	0.000	4.513	0.011	3.974
Pipe_139_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003	Pipe_529_1	0.265	5.443	0	0.000	0.000	0.000	4.513	0.011	1.363
Pipe_14	2.382	49.011	0	0.000	0.000	0.000	4.513	0.011	12.255	Pipe_52_1	0.001	0.020	2	0.272	0.001	0.020	45.126	0.106	0.105
Pipe_140_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003	Pipe_530_1	0.002	0.034	1	0.136	0.002	0.034	500.305	1.179	0.346
Pipe_141_1	2.394	49.249	0	0.000	0.000	0.000	4.513	0.011	12.315	Pipe_531_1	0.025	0.506	0	0.000	0.000	0.000	4.513	0.011	0.129
Pipe_142_1	0.002	0.050	0	0.000	0.000	0.000	4.513	0.011	0.015	Pipe_532_1	0.008	0.163	0	0.000	0.000	0.000	4.513	0.011	0.043
Pipe_143_1	0.004	0.081	0	0.000	0.000	0.000	4.513	0.011	0.023	Pipe_533_1	0.001	0.020	1	0.136	0.001	0.020	29.919	0.071	0.062
Pipe_144_1	0.000	0.006	0	0.000	0.000	0.000	4.513	0.011	0.004	Pipe_534_1	0.305	6.275	0	0.000	0.000	0.000	4.513	0.011	1.571
Pipe_145_1	1.369	28.178	0	0.000	0.000	0.000	4.513	0.011	7.047	Pipe_535_1	0.002	0.034	1	0.136	0.002	0.034	55.332	0.130	0.083
Pipe_146_1	0.000	0.007	0	0.000	0.000	0.000	4.513	0.011	0.004	Pipe_536_1	0.001	0.025	1	0.136	0.001	0.025	5.834	0.014	0.050
Pipe_147_1	0.002	0.042	1	0.136	0.002	0.042	114.046	0.269	0.122	Pipe_537_1	0.520	10.707	0	0.000	0.000	0.000	4.513	0.011	2.680
Pipe_148_1	0.003	0.071	2	0.272	0.003	0.071	126.645	0.298	0.178	Pipe_538_1	0.002	0.045	0	0.000	0.000	0.000	4.513	0.011	0.014
Pipe_149_1	0.002	0.032	1	0.136	0.002	0.032	84.092	0.198	0.100	Pipe_539_1	0.000	0.005	0	0.000	0.000	0.000	4.513	0.011	0.004
Pipe_150_1	0.003	0.058	2	0.272	0.003	0.058	96.921	0.228	0.154	Pipe_53_1	0.005	0.113	3	0.408	0.005	0.113	208.477	0.491	0.281
Pipe_151_1	1.876	38.609	0	0.000	0.000	0.000	4.513	0.011	9.655	Pipe_540_1	0.387	7.967	0	0.000	0.000	0.000	4.513	0.011	1.994
Pipe_152_1	0.000	0.004	0	0.000	0.000	0.000	4.513	0.011	0.004	Pipe_541_1	0.009	0.179	0	0.000	0.000	0.000	4.513	0.011	0.048
Pipe_153_1	0.002	0.041	1	0.136	0.002	0.041	62.679	0.148	0.092	Pipe_542_1	0.005	0.106	0	0.000	0.000	0.000	4.513	0.011	0.029

Pipe_154_1	0.002	0.041	1	0.136	0.002	0.041	65.607	0.155	0.093	Pipe_543_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_155_1	0.277	5.693	0	0.000	0.000	0.000	4.513	0.011	1.426	Pipe_544_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_156_1	0.001	0.020	1	0.136	0.001	0.020	38.681	0.091	0.067	Pipe_545_1	0.282	5.794	0	0.000	0.000	0.000	4.513	0.011	1.451
Pipe_157_1	0.001	0.022	1	0.136	0.001	0.022	44.558	0.105	0.071	Pipe_546_1	0.781	16.076	0	0.000	0.000	0.000	4.513	0.011	4.022
Pipe_158_1	0.001	0.022	1	0.136	0.001	0.022	6.536	0.015	0.049	Pipe_548_1	0.299	6.149	0	0.000	0.000	0.000	4.513	0.011	1.540
Pipe_159_1	2.380	48.964	0	0.000	0.000	0.000	4.513	0.011	12.244	Pipe_549_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_160_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003	Pipe_54_1	0.002	0.036	7	0.952	0.002	0.036	241.008	0.568	0.398
Pipe_161_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003	Pipe_550_1	0.433	8.907	0	0.000	0.000	0.000	4.513	0.011	2.229
Pipe_162_1	0.000	0.000	1	0.136	0.000	0.000	16.178	0.038	0.044	Pipe_551_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_163_1	0.000	0.000	1	0.136	0.000	0.000	7.266	0.017	0.039	Pipe_552_1	0.281	5.773	0	0.000	0.000	0.000	4.513	0.011	1.446
Pipe_164_1	0.004	0.081	3	0.408	0.004	0.081	113.104	0.267	0.209	Pipe_553_1	0.143	2.946	0	0.000	0.000	0.000	4.513	0.011	0.739
Pipe_165_1	2.372	48.808	0	0.000	0.000	0.000	4.513	0.011	12.205	Pipe_554_1	0.151	3.104	0	0.000	0.000	0.000	4.513	0.011	0.779
Pipe_166_1	0.382	7.863	0	0.000	0.000	0.000	4.513	0.011	1.968	Pipe_555_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_167_1	0.001	0.014	1	0.136	0.001	0.014	5.564	0.013	0.044	Pipe_556_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_168_1	0.001	0.014	1	0.136	0.001	0.014	6.130	0.014	0.045	Pipe_557_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_169_1	0.566	11.655	0	0.000	0.000	0.000	4.513	0.011	2.916	Pipe_558_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_170_1	0.000	0.010	1	0.136	0.000	0.010	5.359	0.013	0.042	Pipe_559_1	0.151	3.104	0	0.000	0.000	0.000	4.513	0.011	0.779
Pipe_171_1	0.000	0.010	1	0.136	0.000	0.010	5.680	0.013	0.042	Pipe_55_1	0.002	0.032	1	0.136	0.002	0.032	42.279	0.100	0.075
Pipe_172_1	0.627	12.898	0	0.000	0.000	0.000	4.513	0.011	3.227	Pipe_560_1	0.001	0.029	1	0.136	0.001	0.029	20.354	0.048	0.061
Pipe_173_1	0.002	0.032	0	0.000	0.000	0.000	4.513	0.011	0.011	Pipe_561_1	0.001	0.011	1	0.136	0.001	0.011	57.332	0.135	0.073
Pipe_174_1	0.002	0.047	3	0.408	0.002	0.047	80.557	0.190	0.173	Pipe_562_1	0.149	3.064	0	0.000	0.000	0.000	4.513	0.011	0.769
Pipe_175_1	0.002	0.047	3	0.408	0.002	0.047	66.115	0.156	0.164	Pipe_563_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_176_1	1.396	28.718	0	0.000	0.000	0.000	4.513	0.011	7.182	Pipe_564_1	0.001	0.019	1	0.136	0.001	0.019	4.884	0.012	0.046
Pipe_177_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003	Pipe_565_1	0.349	7.183	0	0.000	0.000	0.000	4.513	0.011	1.798
Pipe_178_1	0.001	0.029	1	0.136	0.001	0.029	65.260	0.154	0.087	Pipe_566_1	1.477	30.397	0	0.000	0.000	0.000	4.513	0.011	7.602
Pipe_179_1	0.543	11.179	0	0.000	0.000	0.000	4.513	0.011	2.797	Pipe_567_1	0.244	5.029	0	0.000	0.000	0.000	4.513	0.011	1.260
Pipe_180_1	0.000	0.005	0	0.000	0.000	0.000	4.513	0.011	0.004	Pipe_568_1	0.000	0.007	0	0.000	0.000	0.000	4.513	0.011	0.004
Pipe_181_1	0.573	11.795	0	0.000	0.000	0.000	4.513	0.011	2.951	Pipe_569_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_182_1	0.001	0.020	0	0.000	0.000	0.000	4.513	0.011	0.008	Pipe_56_1	0.541	11.128	0	0.000	0.000	0.000	4.513	0.011	2.785
Pipe_183_1	0.003	0.068	0	0.000	0.000	0.000	4.513	0.011	0.020	Pipe_570_1	0.001	0.013	1	0.136	0.001	0.013	42.734	0.101	0.065
Pipe_184_1	0.001	0.029	0	0.000	0.000	0.000	4.513	0.011	0.010	Pipe_571_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_185_1	0.001	0.024	0	0.000	0.000	0.000	4.513	0.011	0.009	Pipe_572_1	0.051	1.047	10	1.361	0.051	1.047	2618.269	6.170	2.406
Pipe_186_1	0.002	0.045	0	0.000	0.000	0.000	4.513	0.011	0.014	Pipe_573_1	0.065	1.344	14	1.905	0.065	1.344	3580.392	8.437	3.257
Pipe_187_1	0.735	15.128	0	0.000	0.000	0.000	4.513	0.011	3.785	Pipe_574_1	0.000	0.005	1	0.136	0.000	0.005	10.510	0.025	0.043

Pipe_188_1	0.001	0.029	0	0.000	0.000	0.000	4.513	0.011	0.010	Pipe_575_1	0.014	0.283	12	1.633	0.014	0.283	572.846	1.350	0.887
Pipe_189_1	0.166	3.416	0	0.000	0.000	0.000	4.513	0.011	0.857	Pipe_576_1	0.000	0.005	1	0.136	0.000	0.005	13.184	0.031	0.044
Pipe_190_1	0.002	0.031	0	0.000	0.000	0.000	4.513	0.011	0.010	Pipe_577_1	0.001	0.019	1	0.136	0.001	0.019	38.469	0.091	0.066
Pipe_191_1	0.008	0.159	5	0.680	0.008	0.159	387.038	0.912	0.477	Pipe_578_1	0.766	15.771	0	0.000	0.000	0.000	4.513	0.011	3.945
Pipe_192_1	0.005	0.099	3	0.408	0.005	0.099	269.714	0.636	0.310	Pipe_579_1	0.717	14.759	0	0.000	0.000	0.000	4.513	0.011	3.692
Pipe_193_1	0.005	0.110	4	0.544	0.005	0.110	311.856	0.735	0.375	Pipe_57_1	0.552	11.366	0	0.000	0.000	0.000	4.513	0.011	2.844
Pipe_194_1	0.005	0.110	4	0.544	0.005	0.110	269.730	0.636	0.350	Pipe_580_1	0.827	17.020	0	0.000	0.000	0.000	4.513	0.011	4.258
Pipe_195_1	1.236	25.441	0	0.000	0.000	0.000	4.513	0.011	6.363	Pipe_581_1	0.001	0.020	0	0.000	0.000	0.000	4.513	0.011	0.008
Pipe_196_1	0.000	0.003	0	0.000	0.000	0.000	4.513	0.011	0.004	Pipe_582_1	0.001	0.012	0	0.000	0.000	0.000	4.513	0.011	0.006
Pipe_197_1	0.520	10.697	0	0.000	0.000	0.000	4.513	0.011	2.677	Pipe_583_1	0.712	14.651	0	0.000	0.000	0.000	4.513	0.011	3.665
Pipe_198_1	0.438	9.021	0	0.000	0.000	0.000	4.513	0.011	2.258	Pipe_584_1	0.795	16.360	0	0.000	0.000	0.000	4.513	0.011	4.093
Pipe_199_1	0.004	0.072	5	0.680	0.004	0.072	178.240	0.420	0.311	Pipe_585_1	0.919	18.916	0	0.000	0.000	0.000	4.513	0.011	4.732
Pipe_2	1.698	34.935	0	0.000	0.000	0.000	4.513	0.011	8.736	Pipe_586_1	0.002	0.044	1	0.136	0.002	0.044	24.168	0.057	0.070
Pipe_200_1	0.004	0.081	6	0.816	0.004	0.081	183.380	0.432	0.353	Pipe_587_1	0.001	0.019	1	0.136	0.001	0.019	35.563	0.084	0.065
Pipe_201_1	0.380	7.817	0	0.000	0.000	0.000	4.513	0.011	1.957	Pipe_588_1	0.151	3.104	0	0.000	0.000	0.000	4.513	0.011	0.779
Pipe_202_1	0.001	0.012	0	0.000	0.000	0.000	4.513	0.011	0.006	Pipe_589_1	0.762	15.670	0	0.000	0.000	0.000	4.513	0.011	3.920
Pipe_203_1	0.001	0.026	1	0.136	0.001	0.026	150.894	0.356	0.136	Pipe_58_1	0.000	0.003	1	0.136	0.000	0.003	62.320	0.147	0.072
Pipe_204_1	0.003	0.059	2	0.272	0.003	0.059	165.220	0.389	0.195	Pipe_590_1	0.764	15.730	0	0.000	0.000	0.000	4.513	0.011	3.935
Pipe_205_1	0.033	0.679	0	0.000	0.000	0.000	4.513	0.011	0.172	Pipe_591_1	0.001	0.018	2	0.272	0.001	0.018	213.945	0.504	0.203
Pipe_206_1	0.007	0.136	0	0.000	0.000	0.000	4.513	0.011	0.037	Pipe_592_1	0.000	0.008	1	0.136	0.000	0.008	71.017	0.167	0.080
Pipe_207_1	0.000	0.004	0	0.000	0.000	0.000	4.513	0.011	0.004	Pipe_593_1	0.151	3.104	0	0.000	0.000	0.000	4.513	0.011	0.779
Pipe_208_1	0.236	4.858	0	0.000	0.000	0.000	4.513	0.011	1.217	Pipe_594_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_209_1	0.002	0.041	0	0.000	0.000	0.000	4.513	0.011	0.013	Pipe_595_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_210_1	0.005	0.097	0	0.000	0.000	0.000	4.513	0.011	0.027	Pipe_596_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_211_1	0.323	6.653	0	0.000	0.000	0.000	4.513	0.011	1.666	Pipe_598_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_212_1	0.003	0.053	0	0.000	0.000	0.000	4.513	0.011	0.016	Pipe_599_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_213_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003	Pipe_59_1	0.001	0.012	2	0.272	0.001	0.012	273.511	0.645	0.235
Pipe_214_1	0.000	0.002	1	0.136	0.000	0.002	47.060	0.111	0.063	Pipe_6	0.151	3.104	0	0.000	0.000	0.000	4.513	0.011	0.779
Pipe_215_1	0.001	0.023	2	0.272	0.001	0.023	61.323	0.145	0.115	Pipe_600_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_216_1	0.651	13.398	0	0.000	0.000	0.000	4.513	0.011	3.352	Pipe_601_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_218_1	0.047	0.958	4	0.544	0.047	0.958	1919.699	4.524	1.746	Pipe_602_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_219_1	0.048	0.988	6	0.816	0.048	0.988	2092.423	4.931	1.931	Pipe_603_1	0.151	3.104	0	0.000	0.000	0.000	4.513	0.011	0.779
Pipe_220_1	0.037	0.753	1	0.136	0.037	0.753	759.508	1.790	0.858	Pipe_604_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003

Pipe_221_1	0.042	0.864	3	0.408	0.042	0.864	982.797	2.316	1.113	Pipe_605_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_222_1	0.021	0.425	9	1.224	0.021	0.425	2902.071	6.838	2.228	Pipe_607_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_223_1	0.022	0.458	10	1.361	0.022	0.458	3642.038	8.582	2.715	Pipe_608_1	0.151	3.101	0	0.000	0.000	0.000	4.513	0.011	0.778
Pipe_224_1	0.024	0.493	11	1.497	0.024	0.493	3807.632	8.972	2.863	Pipe_609_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_225_1	1.722	35.428	0	0.000	0.000	0.000	4.513	0.011	8.860	Pipe_60_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_226_1	0.006	0.130	3	0.408	0.006	0.130	334.136	0.787	0.364	Pipe_610_1	0.151	3.104	0	0.000	0.000	0.000	4.513	0.011	0.779
Pipe_227_1	1.234	25.395	0	0.000	0.000	0.000	4.513	0.011	6.351	Pipe_611_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_228_1	0.003	0.068	0	0.000	0.000	0.000	4.513	0.011	0.020	Pipe_613_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_229_1	3.622	74.521	3	0.408	3.622	74.521	175.393	0.413	37.466	Pipe_614_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_230_1	0.248	5.110	0	0.000	0.000	0.000	4.513	0.011	1.280	Pipe_615_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_231_1	0.000	0.000	0	0.000	0.000	0.000	0.000	0.000	0.000	Pipe_616_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_232_1	0.386	7.950	0	0.000	0.000	0.000	4.513	0.011	1.990	Pipe_617_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_233_1	0.291	5.981	0	0.000	0.000	0.000	4.513	0.011	1.498	Pipe_618_1	0.151	3.101	0	0.000	0.000	0.000	4.513	0.011	0.778
Pipe_234_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003	Pipe_619_1	0.003	0.067	2	0.272	0.003	0.067	540.263	1.273	0.420
Pipe_235_1	0.004	0.073	4	0.544	0.004	0.073	120.102	0.283	0.243	Pipe_61_1	0.001	0.012	2	0.272	0.001	0.012	335.355	0.790	0.271
Pipe_236_1	0.002	0.041	1	0.136	0.002	0.041	170.623	0.402	0.155	Pipe_620_1	0.002	0.033	1	0.136	0.002	0.033	6.148	0.014	0.054
Pipe_237_1	0.235	4.827	0	0.000	0.000	0.000	4.513	0.011	1.209	Pipe_621_1	0.003	0.067	2	0.272	0.003	0.067	546.633	1.288	0.424
Pipe_238_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003	Pipe_622_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_239_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003	Pipe_623_1	0.001	0.011	1	0.136	0.001	0.011	8.196	0.019	0.044
Pipe_240_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003	Pipe_624_1	0.525	10.800	0	0.000	0.000	0.000	4.513	0.011	2.703
Pipe_3	1.448	29.797	0	0.000	0.000	0.000	4.513	0.011	7.452	Pipe_625_1	0.011	0.224	0	0.000	0.000	0.000	4.513	0.011	0.059
Pipe_32_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003	Pipe_626_1	0.009	0.188	0	0.000	0.000	0.000	4.513	0.011	0.050
Pipe_33	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003	Pipe_627_1	0.012	0.250	0	0.000	0.000	0.000	4.513	0.011	0.065
Pipe_33_1	0.000	0.008	0	0.000	0.000	0.000	4.513	0.011	0.005	Pipe_628_1	0.000	0.009	0	0.000	0.000	0.000	4.513	0.011	0.005
Pipe_34	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003	Pipe_629_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_34_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003	Pipe_62_1	0.092	1.886	0	0.000	0.000	0.000	4.513	0.011	0.474
Pipe_35	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003	Pipe_630_1	0.001	0.019	1	0.136	0.001	0.019	216.728	0.511	0.171
Pipe_354_1	1.873	38.538	0	0.000	0.000	0.000	4.513	0.011	9.637	Pipe_631_1	1.976	40.658	0	0.000	0.000	0.000	4.513	0.011	10.167
Pipe_355_1	0.005	0.095	0	0.000	0.000	0.000	4.513	0.011	0.027	Pipe_632_1	0.332	6.838	0	0.000	0.000	0.000	4.513	0.011	1.712
Pipe_356_1	0.004	0.076	0	0.000	0.000	0.000	4.513	0.011	0.022	Pipe_633_1	0.190	3.916	0	0.000	0.000	0.000	4.513	0.011	0.982
Pipe_358_1	0.891	18.332	0	0.000	0.000	0.000	4.513	0.011	4.586	Pipe_634_1	3.621	74.513	2	0.272	3.621	74.513	112.038	0.264	37.391
Pipe_359_1	0.002	0.034	1	0.136	0.002	0.034	444.347	1.047	0.313	Pipe_635_1	0.001	0.015	1	0.136	0.001	0.015	65.937	0.155	0.081
Pipe_35_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003	Pipe_636_1	0.793	16.310	0	0.000	0.000	0.000	4.513	0.011	4.080
Pipe_36	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003	Pipe_637_1	0.687	14.137	0	0.000	0.000	0.000	4.513	0.011	3.537
Pipe_360_1	0.008	0.174	1	0.136	0.008	0.174	75.054	0.177	0.165	Pipe_638_1	0.990	20.369	0	0.000	0.000	0.000	4.513	0.011	5.095

Pipe_361_1	0.003	0.059	3	0.408	0.003	0.059	119.407	0.281	0.202	Pipe_639_1	0.121	2.488	0	0.000	0.000	0.000	4.513	0.011	0.625
Pipe_362_1	0.249	5.133	0	0.000	0.000	0.000	4.513	0.011	1.286	Pipe_63_1	0.525	10.796	0	0.000	0.000	0.000	4.513	0.011	2.702
Pipe_363_1	0.000	0.009	0	0.000	0.000	0.000	4.513	0.011	0.005	Pipe_640_1	0.402	8.277	0	0.000	0.000	0.000	4.513	0.011	2.072
Pipe_364_1	0.002	0.042	1	0.136	0.002	0.042	5.326	0.013	0.058	Pipe_641_1	0.000	0.009	0	0.000	0.000	0.000	4.513	0.011	0.005
Pipe_365_1	0.092	1.886	0	0.000	0.000	0.000	4.513	0.011	0.474	Pipe_642_1	0.000	0.009	1	0.136	0.000	0.009	39.650	0.093	0.062
Pipe_366_1	0.001	0.028	1	0.136	0.001	0.028	51.590	0.122	0.079	Pipe_643_1	0.001	0.010	1	0.136	0.001	0.010	23.828	0.056	0.053
Pipe_367_1	0.002	0.041	2	0.272	0.002	0.041	66.501	0.157	0.128	Pipe_644_1	0.001	0.015	1	0.136	0.001	0.015	6.517	0.015	0.045
Pipe_368_1	0.387	7.958	0	0.000	0.000	0.000	4.513	0.011	1.992	Pipe_645_1	0.092	1.886	0	0.000	0.000	0.000	4.513	0.011	0.474
Pipe_369_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003	Pipe_646_1	0.002	0.039	1	0.136	0.002	0.039	7.156	0.017	0.058
Pipe_37	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003	Pipe_647_1	0.001	0.021	1	0.136	0.001	0.021	7.144	0.017	0.049
Pipe_370_1	0.002	0.031	1	0.136	0.002	0.031	262.785	0.619	0.204	Pipe_648_1	0.518	10.667	0	0.000	0.000	0.000	4.513	0.011	2.669
Pipe_371_1	0.002	0.031	1	0.136	0.002	0.031	258.715	0.610	0.202	Pipe_649_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_372_1	0.287	5.905	0	0.000	0.000	0.000	4.513	0.011	1.479	Pipe_64_1	0.006	0.123	0	0.000	0.000	0.000	4.513	0.011	0.033
Pipe_373_1	0.000	0.008	1	0.136	0.000	0.008	17.467	0.041	0.048	Pipe_650_1	0.001	0.015	1	0.136	0.001	0.015	55.844	0.132	0.075
Pipe_374_1	0.001	0.022	3	0.408	0.001	0.022	46.453	0.109	0.140	Pipe_651_1	0.001	0.020	1	0.136	0.001	0.020	11.487	0.027	0.051
Pipe_375_1	0.752	15.478	0	0.000	0.000	0.000	4.513	0.011	3.872	Pipe_652_1	0.515	10.587	0	0.000	0.000	0.000	4.513	0.011	2.649
Pipe_376_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003	Pipe_653_1	0.001	0.015	1	0.136	0.001	0.015	31.239	0.074	0.060
Pipe_377_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003	Pipe_654_1	0.014	0.279	5	0.680	0.014	0.279	200.563	0.473	0.428
Pipe_378_1	0.000	0.006	0	0.000	0.000	0.000	4.513	0.011	0.004	Pipe_655_1	0.004	0.082	3	0.408	0.004	0.082	107.977	0.254	0.207
Pipe_379_1	0.003	0.060	2	0.272	0.003	0.060	94.118	0.222	0.153	Pipe_656_1	0.001	0.022	1	0.136	0.001	0.022	5.787	0.014	0.048
Pipe_37_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003	Pipe_657_1	0.015	0.314	14	1.905	0.015	0.314	656.428	1.547	1.020
Pipe_38	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003	Pipe_658_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_380_1	0.004	0.081	3	0.408	0.004	0.081	104.421	0.246	0.204	Pipe_659_1	0.000	0.009	1	0.136	0.000	0.009	16.212	0.038	0.048
Pipe_381_1	0.139	2.870	0	0.000	0.000	0.000	4.513	0.011	0.720	Pipe_65_1	0.282	5.794	0	0.000	0.000	0.000	4.513	0.011	1.451
Pipe_382_1	0.734	15.107	0	0.000	0.000	0.000	4.513	0.011	3.780	Pipe_660_1	0.000	0.005	1	0.136	0.000	0.005	15.340	0.036	0.045
Pipe_383_1	0.001	0.011	1	0.136	0.001	0.011	33.200	0.078	0.059	Pipe_664_1	0.010	0.202	1	0.136	0.010	0.202	32.071	0.076	0.154
Pipe_384_1	0.098	2.017	24	3.265	0.098	2.017	6167.164	14.532	5.458	Pipe_665_1	0.151	3.104	0	0.000	0.000	0.000	4.513	0.011	0.779
Pipe_385_1	0.101	2.081	26	3.537	0.101	2.081	6628.849	15.620	5.830	Pipe_666_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_386_1	1.030	21.194	0	0.000	0.000	0.000	4.513	0.011	5.301	Pipe_667_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_387_1	0.001	0.015	1	0.136	0.001	0.015	10.760	0.025	0.048	Pipe_669_1	0.151	3.104	0	0.000	0.000	0.000	4.513	0.011	0.779
Pipe_388_1	0.001	0.015	1	0.136	0.001	0.015	35.144	0.083	0.062	Pipe_66_1	0.428	8.799	0	0.000	0.000	0.000	4.513	0.011	2.202
Pipe_389_1	0.540	11.102	0	0.000	0.000	0.000	4.513	0.011	2.778	Pipe_670_1	0.353	7.255	0	0.000	0.000	0.000	4.513	0.011	1.816
Pipe_39	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003	Pipe_671_1	0.151	3.104	0	0.000	0.000	0.000	4.513	0.011	0.779

Pipe_390_1	0.002	0.046	2	0.272	0.002	0.046	86.408	0.204	0.142	Pipe_672_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_391_1	1.729	35.574	0	0.000	0.000	0.000	4.513	0.011	8.896	Pipe_673_1	0.151	3.101	0	0.000	0.000	0.000	4.513	0.011	0.778
Pipe_392_1	0.002	0.036	0	0.000	0.000	0.000	4.513	0.011	0.012	Pipe_675_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_394_1	0.000	0.001	1	0.136	0.000	0.001	6.516	0.015	0.038	Pipe_678_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_395_1	0.000	0.008	1	0.136	0.000	0.008	4.741	0.011	0.041	Pipe_679_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_396_1	0.000	0.010	1	0.136	0.000	0.010	6.877	0.016	0.043	Pipe_67_1	0.059	1.220	12	1.633	0.059	1.220	3386.713	7.980	3.013
Pipe_397_1	0.001	0.028	1	0.136	0.001	0.028	10.647	0.025	0.054	Pipe_680_1	0.151	3.104	0	0.000	0.000	0.000	4.513	0.011	0.779
Pipe_398_1	0.006	0.121	4	0.544	0.006	0.121	1381.266	3.255	1.010	Pipe_681_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_399_1	0.003	0.067	2	0.272	0.003	0.067	551.335	1.299	0.427	Pipe_682_1	0.007	0.149	1	0.136	0.007	0.149	34.725	0.082	0.129
Pipe_39_1	0.001	0.018	0	0.000	0.000	0.000	4.513	0.011	0.007	Pipe_687_1	0.014	0.281	0	0.000	0.000	0.000	4.513	0.011	0.073
Pipe_4	1.448	29.797	0	0.000	0.000	0.000	4.513	0.011	7.452	Pipe_688_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_40	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003	Pipe_68_1	0.064	1.307	13	1.769	0.064	1.307	3512.665	8.277	3.165
Pipe_400_1	0.006	0.121	4	0.544	0.006	0.121	1381.273	3.255	1.010	Pipe_690_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_401_1	0.010	0.216	5	0.680	0.010	0.216	1823.814	4.298	1.352	Pipe_692_1	0.001	0.013	1	0.136	0.001	0.013	216.609	0.510	0.168
Pipe_402_1	0.011	0.229	6	0.816	0.011	0.229	2612.268	6.156	1.857	Pipe_69_1	0.003	0.054	1	0.136	0.003	0.054	943.139	2.222	0.617
Pipe_403_1	0.001	0.018	1	0.136	0.001	0.018	6.137	0.014	0.047	Pipe_7	0.249	5.133	0	0.000	0.000	0.000	4.513	0.011	1.286
Pipe_404_1	0.001	0.014	1	0.136	0.001	0.014	67.945	0.160	0.081	Pipe_702_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_405_1	0.001	0.022	1	0.136	0.001	0.022	13.919	0.033	0.053	Pipe_703_1	0.000	0.008	0	0.000	0.000	0.000	4.513	0.011	0.005
Pipe_406_1	0.007	0.142	1	0.136	0.007	0.142	36.353	0.086	0.126	Pipe_704_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_407_1	0.002	0.038	1	0.136	0.002	0.038	26.207	0.062	0.068	Pipe_705_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_408_1	0.841	17.313	0	0.000	0.000	0.000	4.513	0.011	4.331	Pipe_706_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_409_1	0.018	0.366	0	0.000	0.000	0.000	4.513	0.011	0.094	Pipe_70_1	0.004	0.081	3	0.408	0.004	0.081	984.335	2.319	0.722
Pipe_410_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003	Pipe_713_1	0.005	0.095	0	0.000	0.000	0.000	4.513	0.011	0.026
Pipe_411_1	0.533	10.969	0	0.000	0.000	0.000	4.513	0.011	2.745	Pipe_714_1	0.016	0.332	0	0.000	0.000	0.000	4.513	0.011	0.086
Pipe_412_1	0.001	0.022	0	0.000	0.000	0.000	4.513	0.011	0.008	Pipe_716_1	0.001	0.020	1	0.136	0.001	0.020	130.408	0.307	0.121
Pipe_413_1	0.003	0.055	0	0.000	0.000	0.000	4.513	0.011	0.016	Pipe_717_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_414_1	0.373	7.681	0	0.000	0.000	0.000	4.513	0.011	1.923	Pipe_718_1	0.019	0.389	0	0.000	0.000	0.000	4.513	0.011	0.100
Pipe_415_1	0.001	0.022	0	0.000	0.000	0.000	4.513	0.011	0.008	Pipe_719_1	0.001	0.018	1	0.136	0.001	0.018	44.856	0.106	0.070
Pipe_416_1	0.005	0.095	0	0.000	0.000	0.000	4.513	0.011	0.026	Pipe_71_1	0.616	12.671	0	0.000	0.000	0.000	4.513	0.011	3.170
Pipe_417_1	0.085	1.754	0	0.000	0.000	0.000	4.513	0.011	0.441	Pipe_721_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_418_1	1.826	37.566	0	0.000	0.000	0.000	4.513	0.011	9.394	Pipe_722_1	0.000	0.002	1	0.136	0.000	0.002	142.439	0.336	0.119
Pipe_419_1	0.725	14.915	0	0.000	0.000	0.000	4.513	0.011	3.731	Pipe_723_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_41_1	0.004	0.080	0	0.000	0.000	0.000	4.513	0.011	0.023	Pipe_72_1	0.006	0.121	4	0.544	0.006	0.121	1823.465	4.297	1.271
Pipe_42	0.014	0.286	0	0.000	0.000	0.000	4.513	0.011	0.074	Pipe_733_1	0.249	5.133	0	0.000	0.000	0.000	4.513	0.011	1.286

Pipe_420_1	0.701	14.420	0	0.000	0.000	0.000	4.513	0.011	3.608	Pipe_735_1	0.000	0.005	0	0.000	0.000	0.000	4.513	0.011	0.004
Pipe_421_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003	Pipe_736_1	0.000	0.005	1	0.136	0.000	0.005	117.172	0.276	0.106
Pipe_422_1	0.001	0.025	1	0.136	0.001	0.025	7.126	0.017	0.051	Pipe_737_1	0.250	5.138	0	0.000	0.000	0.000	4.513	0.011	1.287
Pipe_423_1	0.115	2.361	0	0.000	0.000	0.000	4.513	0.011	0.593	Pipe_739_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_424_1	0.002	0.041	1	0.136	0.002	0.041	14.468	0.034	0.063	Pipe_73_1	0.265	5.443	1	0.136	0.265	5.443	17.839	0.042	2.766
Pipe_425_1	0.789	16.233	0	0.000	0.000	0.000	4.513	0.011	4.061	Pipe_741_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_426_1	0.000	0.003	0	0.000	0.000	0.000	4.513	0.011	0.004	Pipe_743_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_427_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003	Pipe_74_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_428_1	0.003	0.054	3	0.408	0.003	0.054	316.836	0.747	0.316	Pipe_752_1	0.354	7.282	0	0.000	0.000	0.000	4.513	0.011	1.823
Pipe_429_1	0.001	0.024	1	0.136	0.001	0.024	24.273	0.057	0.060	Pipe_753_1	0.059	1.216	3	0.408	0.059	1.216	2393.622	5.640	2.120
Pipe_42_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003	Pipe_754_1	0.059	1.216	3	0.408	0.059	1.216	1617.120	3.811	1.663
Pipe_430_1	0.280	5.752	0	0.000	0.000	0.000	4.513	0.011	1.441	Pipe_755_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_431_1	0.230	4.737	0	0.000	0.000	0.000	4.513	0.011	1.187	Pipe_756_1	0.010	0.205	1	0.136	0.010	0.205	8.742	0.021	0.141
Pipe_432_1	0.758	15.604	0	0.000	0.000	0.000	4.513	0.011	3.904	Pipe_757_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_433_1	0.004	0.080	2	0.272	0.004	0.080	156.692	0.369	0.200	Pipe_758_1	0.034	0.696	1	0.136	0.034	0.696	67.542	0.159	0.422
Pipe_434_1	0.282	5.794	0	0.000	0.000	0.000	4.513	0.011	1.451	Pipe_759_1	0.034	0.696	1	0.136	0.034	0.696	11.324	0.027	0.388
Pipe_435_1	0.413	8.499	0	0.000	0.000	0.000	4.513	0.011	2.127	Pipe_75_1	0.805	16.556	0	0.000	0.000	0.000	4.513	0.011	4.142
Pipe_436_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003	Pipe_760_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_437_1	0.000	0.001	0	0.000	0.000	0.000	4.513	0.011	0.003	Pipe_761_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_438_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003	Pipe_762_1	0.019	0.399	0	0.000	0.000	0.000	4.513	0.011	0.103
Pipe_439_1	0.000	0.004	1	0.136	0.000	0.004	6.513	0.015	0.040	Pipe_763_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_43_1	0.000	0.003	0	0.000	0.000	0.000	4.513	0.011	0.003	Pipe_76_1	0.804	16.542	0	0.000	0.000	0.000	4.513	0.011	4.138
Pipe_440_1	1.837	37.789	0	0.000	0.000	0.000	4.513	0.011	9.450	Pipe_771_1	0.431	8.864	0	0.000	0.000	0.000	4.513	0.011	2.219
Pipe_441_1	0.001	0.013	1	0.136	0.001	0.013	5.601	0.013	0.044	Pipe_772_1	0.004	0.087	0	0.000	0.000	0.000	4.513	0.011	0.024
Pipe_442_1	1.077	22.170	0	0.000	0.000	0.000	4.513	0.011	5.545	Pipe_773_1	0.034	0.696	1	0.136	0.034	0.696	33.447	0.079	0.401
Pipe_443_1	0.001	0.028	1	0.136	0.001	0.028	5.750	0.014	0.052	Pipe_774_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_444_1	0.841	17.313	0	0.000	0.000	0.000	4.513	0.011	4.331	Pipe_775_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_445_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003	Pipe_776_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_446_1	0.015	0.316	1	0.136	0.015	0.316	175.895	0.414	0.296	Pipe_777_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_447_1	0.004	0.077	1	0.136	0.004	0.077	189.395	0.446	0.184	Pipe_778_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_448_1	0.001	0.014	1	0.136	0.001	0.014	4.974	0.012	0.044	Pipe_779_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_449_1	0.432	8.898	0	0.000	0.000	0.000	4.513	0.011	2.227	Pipe_780_1	0.025	0.521	2	0.272	0.025	0.521	385.501	0.908	0.556
Pipe_44_1	0.082	1.689	0	0.000	0.000	0.000	4.513	0.011	0.425	Pipe_781_1	0.025	0.521	2	0.272	0.025	0.521	281.781	0.664	0.494
Pipe_45	0.000	0.002	1	0.136	0.000	0.002	757.395	1.785	0.481	Pipe_782_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_450_1	0.518	10.667	0	0.000	0.000	0.000	4.513	0.011	2.669	Pipe_783_1	0.025	0.521	2	0.272	0.025	0.521	1227.044	2.891	1.051

Pipe_451_1	0.001	0.022	1	0.136	0.001	0.022	20.865	0.049	0.057	Pipe_784_1	0.432	8.898	0	0.000	0.000	0.000	4.513	0.011	2.227
Pipe_452_1	0.036	0.739	0	0.000	0.000	0.000	4.513	0.011	0.188	Pipe_785_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_453_1	0.241	4.950	0	0.000	0.000	0.000	4.513	0.011	1.240	Pipe_786_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_454_1	2.379	48.941	0	0.000	0.000	0.000	4.513	0.011	12.238	Pipe_787_1	0.015	0.316	1	0.136	0.015	0.316	260.784	0.615	0.346
Pipe_455_1	0.003	0.052	0	0.000	0.000	0.000	4.513	0.011	0.016	Pipe_78_1	1.722	35.428	0	0.000	0.000	0.000	4.513	0.011	8.860
Pipe_456_1	0.001	0.030	2	0.272	0.001	0.030	226.224	0.533	0.216	Pipe_79_1	0.000	0.010	1	0.136	0.000	0.010	78.755	0.186	0.085
Pipe_457_1	0.001	0.014	1	0.136	0.001	0.014	4.547	0.011	0.044	Pipe_8	0.249	5.133	0	0.000	0.000	0.000	4.513	0.011	1.286
Pipe_458_1	0.097	1.997	21	2.857	0.097	1.997	5083.303	11.978	4.708	Pipe_803_1	0.049	0.999	0	0.000	0.000	0.000	4.513	0.011	0.252
Pipe_459_1	0.081	1.659	19	2.585	0.081	1.659	4841.088	11.408	4.328	Pipe_80_1	0.001	0.015	2	0.272	0.001	0.015	93.907	0.221	0.131
Pipe_45_1	0.001	0.011	1	0.136	0.001	0.011	6.050	0.014	0.043	Pipe_817_1	0.014	0.281	0	0.000	0.000	0.000	4.513	0.011	0.073
Pipe_46	0.000	0.002	1	0.136	0.000	0.002	756.273	1.782	0.481	Pipe_819_1	0.151	3.104	0	0.000	0.000	0.000	4.513	0.011	0.779
Pipe_460_1	0.066	1.354	15	2.041	0.066	1.354	3654.254	8.611	3.340	Pipe_81_1	0.001	0.015	2	0.272	0.001	0.015	93.723	0.221	0.131
Pipe_461_1	0.015	0.305	4	0.544	0.015	0.305	1020.869	2.406	0.890	Pipe_821_1	0.046	0.944	0	0.000	0.000	0.000	4.513	0.011	0.239
Pipe_462_1	0.003	0.071	2	0.272	0.003	0.071	65.721	0.155	0.142	Pipe_82_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_464_1	2.380	48.964	0	0.000	0.000	0.000	4.513	0.011	12.244	Pipe_830_1	0.014	0.280	0	0.000	0.000	0.000	4.513	0.011	0.073
Pipe_465_1	2.321	47.758	0	0.000	0.000	0.000	4.513	0.011	11.942	Pipe_839_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_466_1	0.777	15.977	0	0.000	0.000	0.000	4.513	0.011	3.997	Pipe_83_1	3.618	74.438	1	0.136	3.618	74.438	111.131	0.262	37.319
Pipe_467_1	0.199	4.100	0	0.000	0.000	0.000	4.513	0.011	1.028	Pipe_841_1	0.125	2.567	0	0.000	0.000	0.000	4.513	0.011	0.644
Pipe_468_1	0.522	10.736	0	0.000	0.000	0.000	4.513	0.011	2.687	Pipe_842_1	0.247	5.088	0	0.000	0.000	0.000	4.513	0.011	1.275
Pipe_469_1	0.002	0.044	1	0.136	0.002	0.044	33.470	0.079	0.076	Pipe_843_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_46_1	0.515	10.587	0	0.000	0.000	0.000	4.513	0.011	2.649	Pipe_844_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_470_1	2.623	53.967	0	0.000	0.000	0.000	4.513	0.011	13.494	Pipe_845_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_471_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003	Pipe_846_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_472_1	0.012	0.256	0	0.000	0.000	0.000	4.513	0.011	0.067	Pipe_847_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_473_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003	Pipe_84_1	3.621	74.513	2	0.272	3.621	74.513	112.026	0.264	37.391
Pipe_474_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003	Pipe_85_1	1.448	29.787	0	0.000	0.000	0.000	4.513	0.011	7.449
Pipe_476_1	0.000	0.009	1	0.136	0.000	0.009	167.406	0.394	0.137	Pipe_86_1	0.000	0.010	0	0.000	0.000	0.000	4.513	0.011	0.005
Pipe_477_1	0.000	0.009	1	0.136	0.000	0.009	188.451	0.444	0.149	Pipe_87_1	0.003	0.053	2	0.272	0.003	0.053	834.327	1.966	0.586
Pipe_478_1	0.001	0.012	2	0.272	0.001	0.012	273.523	0.645	0.235	Pipe_88_1	0.003	0.053	2	0.272	0.003	0.053	834.441	1.966	0.586
Pipe_479_1	0.001	0.025	1	0.136	0.001	0.025	38.486	0.091	0.069	Pipe_89_1	0.404	8.321	0	0.000	0.000	0.000	4.513	0.011	2.083
Pipe_47_1	0.516	10.612	0	0.000	0.000	0.000	4.513	0.011	2.656	Pipe_9	1.704	35.059	0	0.000	0.000	0.000	4.513	0.011	8.767
Pipe_480_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003	Pipe_90_1	0.162	3.333	0	0.000	0.000	0.000	4.513	0.011	0.836
Pipe_481_1	0.004	0.075	2	0.272	0.004	0.075	168.561	0.397	0.205	Pipe_91_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003

Pipe_482_1	0.005	0.113	3	0.408	0.005	0.113	170.124	0.401	0.259	Pipe_92_1	0.009	0.191	0	0.000	0.000	0.000	4.513	0.011	0.050
Pipe_483_1	0.002	0.049	1	0.136	0.002	0.049	11.923	0.028	0.065	Pipe_93_1	0.000	0.007	0	0.000	0.000	0.000	4.513	0.011	0.004
Pipe_484_1	0.002	0.032	5	0.680	0.002	0.032	202.709	0.478	0.305	Pipe_94_1	0.124	2.559	0	0.000	0.000	0.000	4.513	0.011	0.642
Pipe_485_1	0.002	0.036	7	0.952	0.002	0.036	220.713	0.520	0.386	Pipe_95_1	0.000	0.000	0	0.000	0.000	0.000	4.513	0.011	0.003
Pipe_486_1	0.001	0.031	4	0.544	0.001	0.031	170.950	0.403	0.252	Pipe_96_1	0.237	4.872	0	0.000	0.000	0.000	4.513	0.011	1.221
Pipe_487_1	0.002	0.032	5	0.680	0.002	0.032	193.975	0.457	0.300	Pipe_97_1	0.329	6.763	0	0.000	0.000	0.000	4.513	0.011	1.693
Pipe_488_1	0.001	0.016	3	0.408	0.001	0.016	147.457	0.347	0.197	Pipe_98_1	0.001	0.016	0	0.000	0.000	0.000	4.513	0.011	0.007