Universidad de Valladolid

ESCUELA DE INGENIERÍAS INDUSTRIALES

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Grado en Ingeniería Mecánica

Status description and evaluation of the complete water supply system of Hinnerup

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Aarhus Universitet

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TFG REALIZADO EN PROGRAMA DE INTERCAMBIO

TÍTULO: Status description and evaluation of the complete water supply system of Hinnerup

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FECHA: 20/06/23

CENTRO: AU Engineering

UNIVERSIDAD: Aarhus Universitet

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RESUMEN

El trabajo realizado evalúa el estado de la planta de abastecimiento de agua de Hinnerup en todas sus fases: abstracción (incluyendo una evaluación del estado de los acuíferos), tratamiento, almacenamiento y distribución. Además, se espera un crecimiento de la zona urbana en los próximos años, con lo que se evalúa la posibilidad de mantener el suministro de calidad para la nueva cantidad que hay que abastecer, de nuevo en todas las fases del proceso. Para ello, se realiza una pertinente estimación del consumo en esta nueva zona urbana; así como una evaluación del punto de conexión de la misma y de la compatibilidad con el sistema existente. Por último, se realiza una evaluación de riesgos con el fin de determinar la vulnerabilidad del suministro de agua potable de la zona abastecida por esta planta, concluyendo en que el riesgo es bajo.

PALABRAS CLAVE

Abstracción, tratamiento, distribución, futuro, seguridad.

ABSTRACT

The conducted report assesses the status of the Hinnerup water supply plant in all its phases: abstraction (including an assessment of the state of the aquifers), treatment, storage and distribution in the water supply area. Moreover, an urban area growth is expected in the upcoming years. Hence, the quality provided must still accomplish certain parameters in all the phases of the process. On this purpose, a justified estimation of the consumption in this new urban area is conducted, as well as an assessment of its connection point and compatibility with the existing system. Lastly, a risk assessment is performed in order to determine the vulnerability of the water supply system, concluding that the risk in general terms is low.

KEYWORDS

Abstraction, treatment, distribution, future, security.

Department of Construction and Building Design

Status description and evaluation of the complete water supply system of Hinnerup

6th semester, Diploma Engineering Project, Spring 2023

International Study Programme, Urban Water

Project linked course, BTFMWS Water Supply Engineering

Course supervisors:
Civil engineer M.Sc.Eng. Peder Maribo

Assistant professor Emilie Johanne Bihsberg Møller

Aarhus, 30.05.2023

1. Abstract

The aim of the report is to conduct an analysis of Hinnerup waterworks, a private cooperative waterworks located in the Municipality of Favrskov. The primary focus of the report is to thoroughly assess the current state of the waterworks, examining the processes involved from water abstraction (or even groundwater infiltration) to distribution. Not only the current functioning has been checked, but also hypothetical situations are posed to determine how well prepared is the current system for different possible situations.

The waterworks obtains it raw water from an unprotected aquifer, which renders it vulnerable to substance infiltration even if it is an unlikely event to take place. According to its historical and current composition, standard treatment is sufficient to meet the DW criteria: aeration and sand filtration are the steps followed. Afterwards, the water is stored and distributed. The conditions of the clean water tanks and the piping system are subject to further investigation to ensure that the water quality maintains the quality acquired in the treatment process. On the distribution, key aspects like the pressure provided by the pumps, flow and residential time should be compared with the adequate values. Furthermore, this report addresses the implementation of a new urban area in accordance with the projected population growth in the forthcoming years.

The methods followed to manage the data include procedures learnt in the BTFMWS Water Supply courses and software to simulate distribution networks: EPANET and MIKE+. Data regarding abstraction and distribution is mainly provided by Hinnerup waterworks: the SCADA monitoring system generates reports that can be used to verify the correct functioning of the system. The conclusions obtained match the requirements of a safe water supply process.

The findings and recommendations presented herein serve to improve the understanding and preparedness of the waterworks for several circumstances, guaranteeing at all times the delivery of safe and reliable water to the consumers.

2. Foreword

The project is offered as part of the 6th semester of the Diploma Engineering education of Aarhus University, within the study programme Urban Water – Water Supply. The project focusses on intake resource, treatment, and supply of drinking water. Elements of resource analysis, water treatment and supply network analysis as well as planning are the main elements of this project which have been obtained though the project-linked course BTFMWS Water Supply.

The project group was intended to play the role of consulting engineers hired by the waterwork of Hinnerup to make a status description and evaluation of the complete water supply system within the area of Hinnerup town.

The study and investigations being made draws extensively from the materials provided by the course supervisors and the lectures of project-linked modules. Additionally, the project group had the valuable opportunity to visit the Hinnerup Waterwork facility and closely observe each step of the water treatment process. This visit has allowed the project group to directly interact with the operator and seek clarification on various aspects of the operation. Additionally, in order to facilitate discussions and evaluations on the subject, the project group have conducted further research, with these being referred to in the report.

The project consist of the following parts:
1) Main report
2) Appendix
3) A compressed zip file containing hydraulic model simulations

Furthermore, the members of the project group wish to be individually graded in relation to the evaluation on the quality of the report. The specific organization and split of work within the project group is stated in the table below. The specific organization and split of work are described in relation and accordance to the Table of Content.

Group no: 2
Members of the group by name:
Dimitris Kounadis Rasmussen
Clara Covadonga de las Heras López
Arne Kattert
Cato Wachshofer

Overview table stating the specific organization and split of work within the group, in relation and accordance to the Table of Content:

(next page)

Author(s):	Responsibly for the section(s)
The whole group (all members)	1 Abstract 2. Foreword 3. Table of content 4. Report objectives 10. Risk assessment on the water supply process (and all the subsections within) 11. Report conclusion 12. References Appendix 10 (and all the subsection within)
Dimitris Kounadis Rasmussen & Clara Covadonga de las Heras López	5. Introduction (and all the subsections within) 6. Intake resource (and all the subsections within) 8. Status of current distribution network (and all the subsections within) 9. Future distribution system (and all the subsections within) Appendix 5 (and all the subsections within) Appendix 6 (and all the subsections within) Appendix 8 (and all the subsections within) Appendix 9 (and all the subsections within)
Arne Kattert & Cato Wachshofer	7. Treatment Within this section 7, each subsection is further divided between the two stated authors. On each subsection headline, the author is stated with this note: “[name]“ hereby specifying the author. Appendix 7.0 (and all subsection within)

Hand-in deadline: 30-05-2023
Members and signatures:

Name	*Place and date*	*Signature with student ID*
Dimitris Kounadis Rasmussen	Aarhus, 30-05-2023	201911314
Clara Covadonga de las Heras López	Aarhus, 30-05-2023	202209911
Arne Kattert	Aarhus, 30-05-2023	202209916
Cato Wachshofer	Aarhus, 30-05-2023	202209913

3. Table of content

4. Report objectives

The goal of this report is to describe the status of the complete water supply system of Hinnerup and evaluate this in relation to the current situation and in the light of a future planned urban expansion in the northern part of Hinnerup. The complete water supply system deals with the abstracted groundwater resource over to the treatment facility and lastly the supply within the distribution network. Hinnerup Waterwork (Hinnerup Vandværk a.m.b.a.), which is a private cooperative waterwork company, is in charge of the raw water abstraction, the treatment process and the distribution of clean water to Hinnerup town. Based on the described status and evaluation of the complete supply system, a risk assessment of the current supply has been prepared.

5. Introduction

5.1 Area of Hinnerup

Hinnerup is located in East Jutland in the municipality of Favrskov, approx. 15 km North-West of Aarhus. The town of Hinnerup has a population of 8.164 people and the waterwork is in charge of the supply of 2.722 properties with a total water quantity of approx. 380.000 m^3 in 2021. (Favrskov Vandforsyningsplan (2020-30), 2020).

The area of Hinnerup can be characterized by a very variable terrain with an elevation difference of up to 50 meters within the main area of Hinnerup. In addition, the town of Hinnerup is surrounded by land fields which indicates the presence of agricultural activities in the area of Hinnerup. In figure 5.1 below, a terrain model for the area can be view.

Figure 5.1 Terrain model of Hinnerup town, (SCALGO Live, 2023)

5.2 Present situation

In figure 5.2 below, an overview of the whole distribution network can be viewed. Hinnerup waterwork is located at Herredsvej 10, with 4 local intake wells (DGU no. 79.605, 79.681, 79.848, 79.803) abstracting the daily needed demand to be treated at the waterwork. In addition, a new intake well 79.1731 have been established in recent years, due to an increasing tendency of water consumption in coherence with the population growth. The waterwork is currently abstracting water from all 5 intake wells. All references and data about intake well and boreholes are collected from GEUS' public national borehole database Jupiter (GEUS: JUPITER, 2023).

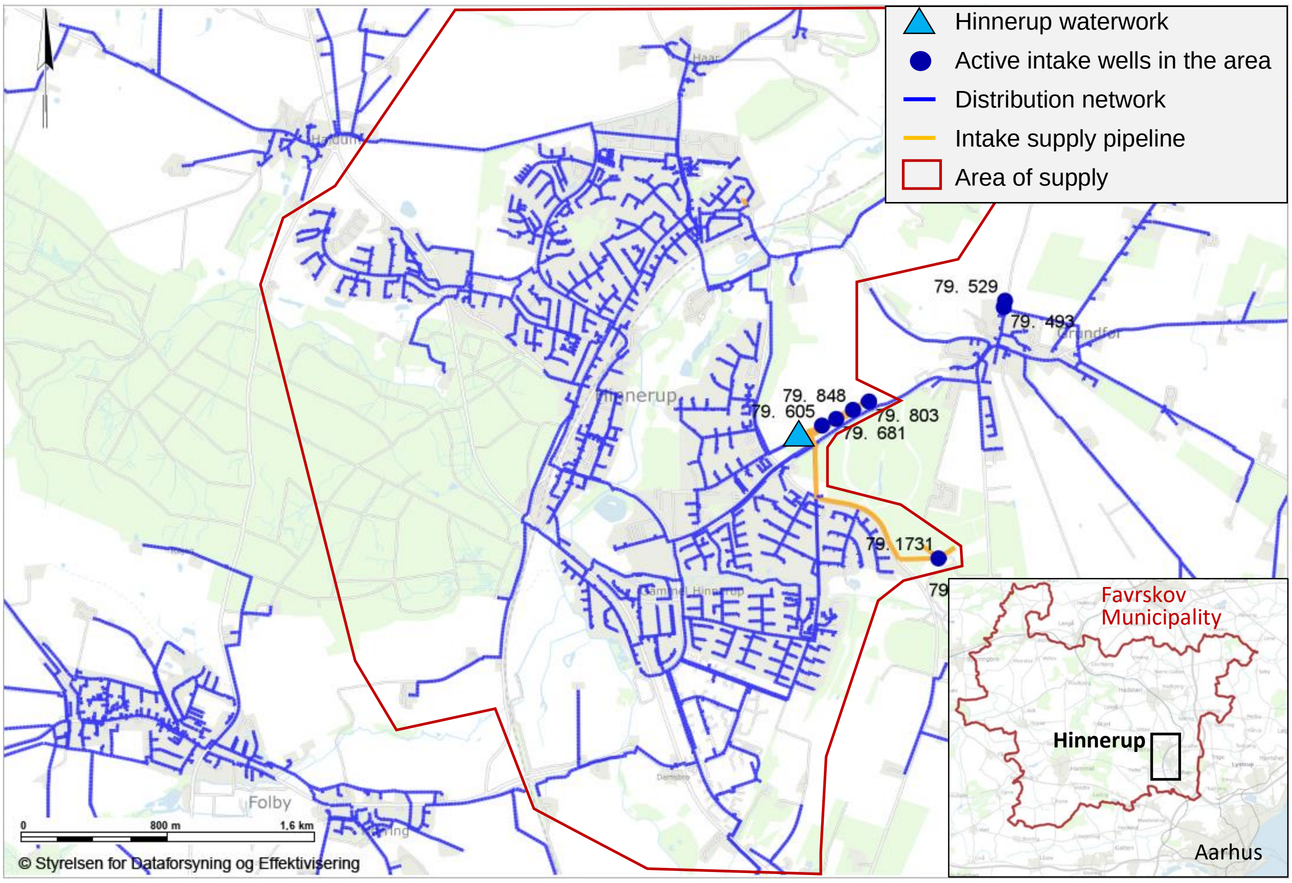
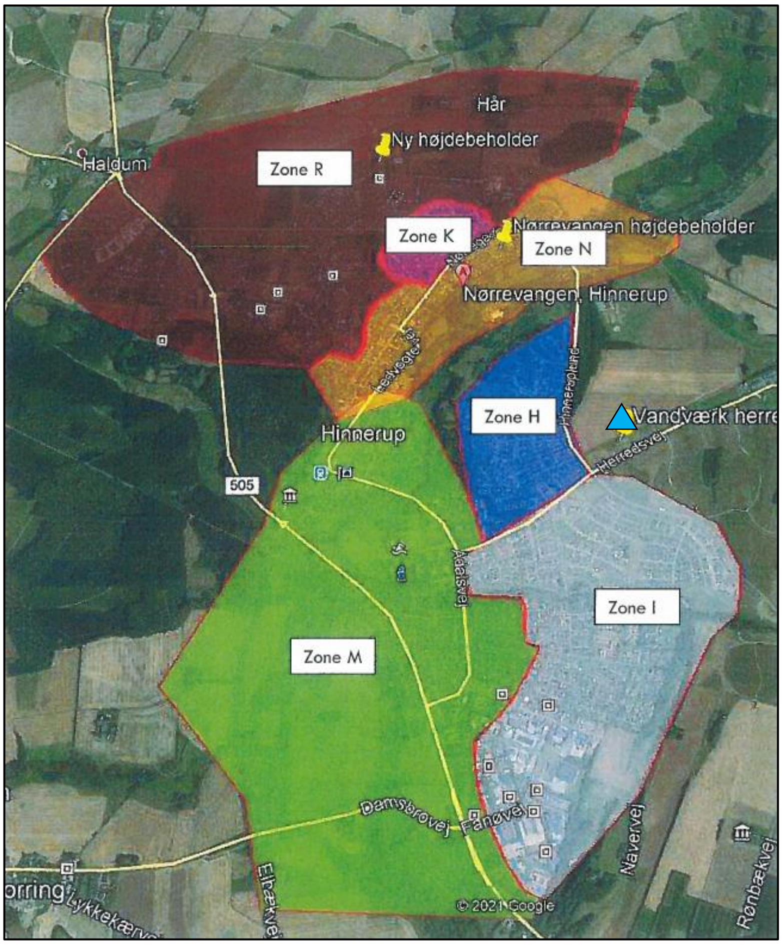


Figure 5.2 Overview of supply network, waterwork and active intake wells, (Favrskov Vandforsyningsplan (2020-30), 2020).

From Hinnerup waterwork, water is supplied to 6 different supply zones. The 6 zones can be viewed on figure 5.3 below. Initially, 4 zones are being supplied directly from the waterwork, these being the Industrial area (zone I), Hinnerup Lund (zone H), Hinnerup Midt (zone M) and Nørrevangen (zone N). At Nørrevangen, a reservoir is supplying the remaining zones Kildevangen (zone K) and Rylevej (zone R). The structure and sections of the distribution network is further explained in section 8.0. A simplified diagram overview of the complete supply system of Hinnerup can be viewed in figure 5.4.



Zone I	Industrial area
Zone H	Hinnerup Lund
Zone M	Hinnerup Midt
Zone N	Nørrevangen
Zone K	Kildevangen
Zone R	Rylevej

Figure 5.3 Overview of the 6 different supply zones, Appendix 5.2.

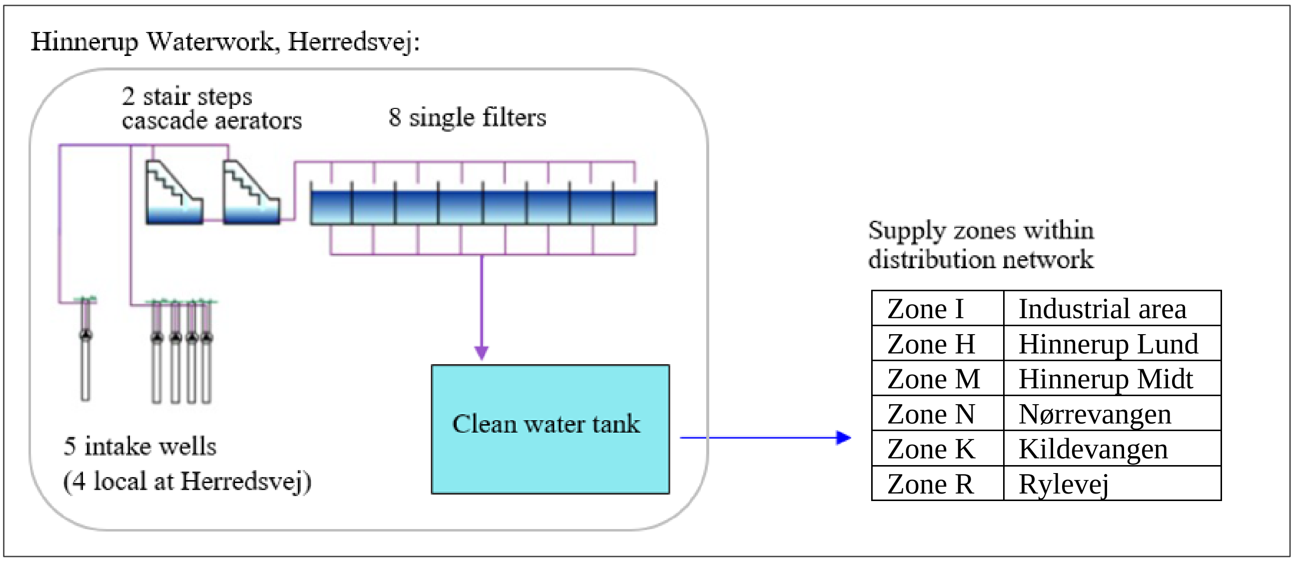


Figure 5.4 Simplified diagram overview of the complete supply system of Hinnerup.

5.2.1 Abstraction and consumption

The following subsection provides an overview of the general abstraction and consumption within the supply area of Hinnerup. An increase in the yearly abstraction can be seen within recent years.

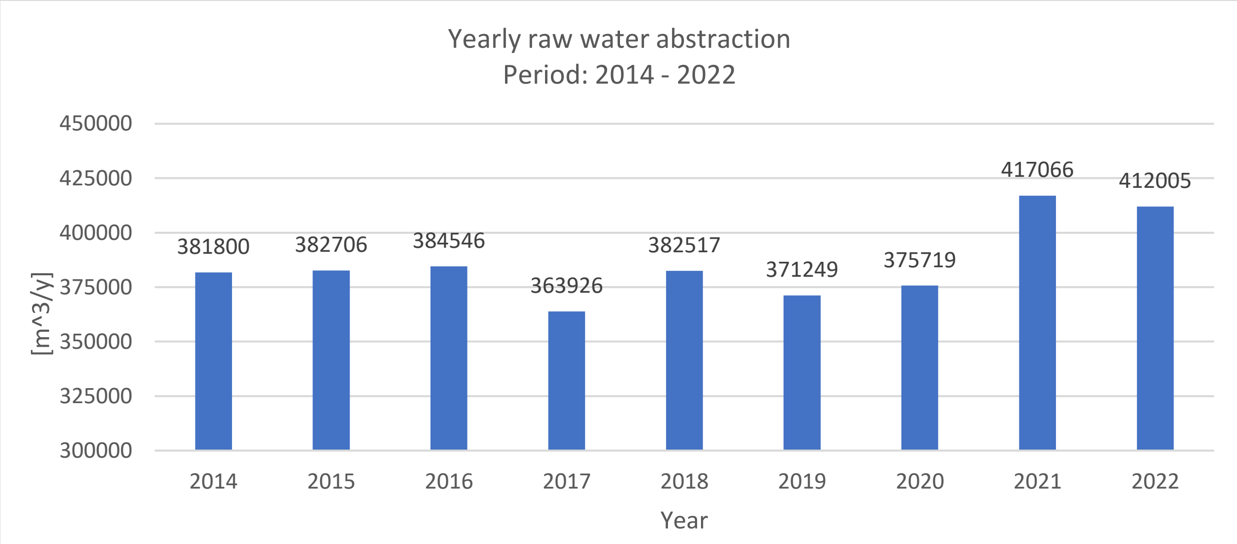


Figure 5.5 Yearly raw water abstraction, (GEUS: JUPITER, 2023).

When looking at the water being distributed to the area of Hinnerup, figure 5.6 and 5.7 below provides information regarding the total amount of distributed water from Hinnerup Waterwork into the distribution network. The total amount of distributed water is equal to the consumption of the 4 initial zones directly connected to the waterwork. Table 5.1 shows the total distribution of each year.

	2018	2019	2020	2021
Total yearly distribution [m^3]	364.514	343.685	356.361	376.561

Table 5.1 Total amount of distributed water from Hinnerup waterwork into the distribution network. Appendix 5.1.

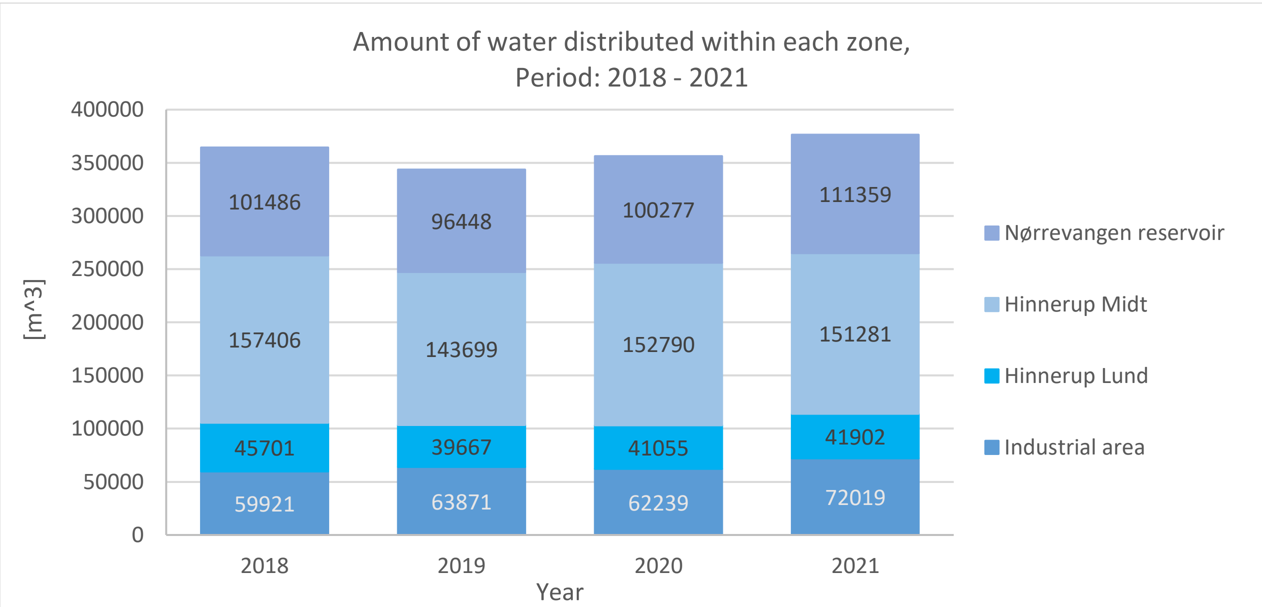


Figure 5.6 Total yearly distribution of each zone separately. Appendix 5.1.

As mentioned, from Nørrevangen reservoir water is then further distributed out to the zones Kildevangen and Rylevej. The noted distributed quanities of these two zones in figure 5.9 below, should not be seen as an additional water-amount in the network. The distrubtion network are to be further expained in section 8.0.

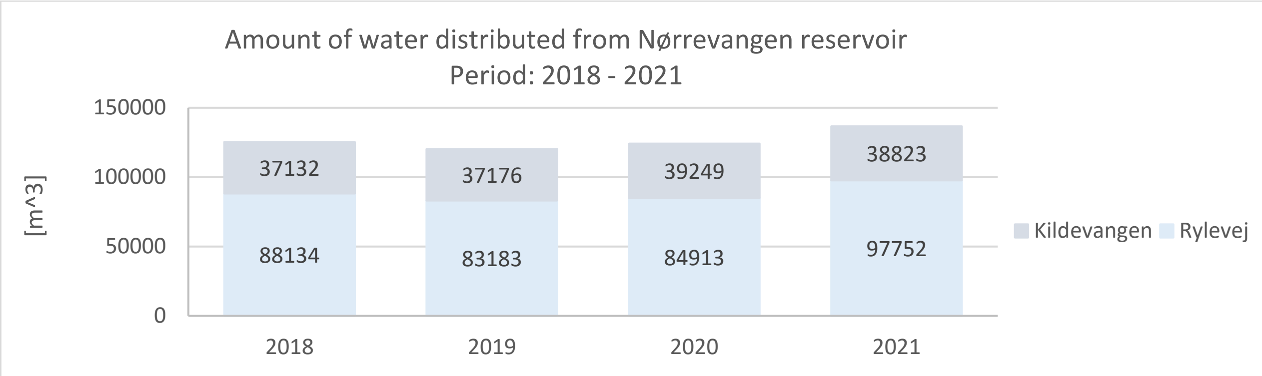


Figure 5.7 Amount of water distributed from Nørrevangen reservoir. Appendix 5.1.

Lastly, figure 5.10 below shows a comparison between the quantities of water being abstracted and distributed from 2018 to 2021.

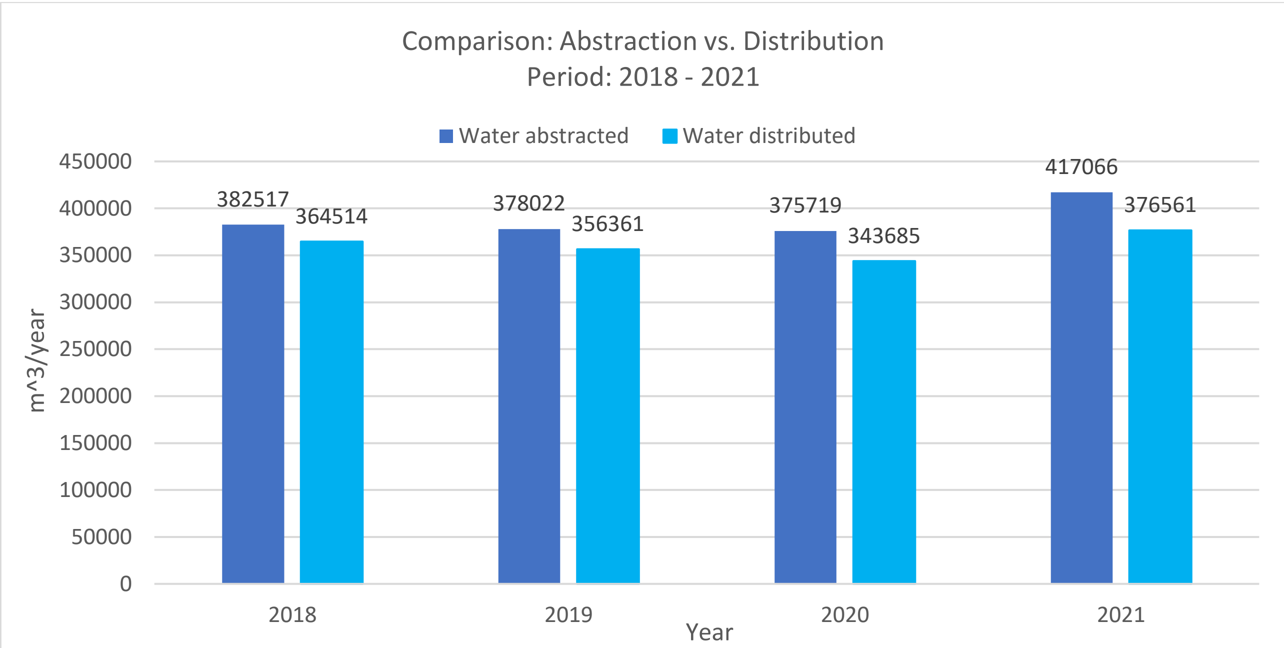


Figure 5.8 Comparison between abstracted and distributed quantities of water from 2018 to 2021. Appendix 5.1.

It can be concluded that more water is being abstracted than distributed. This is not an inconvenience given that there is plenty of storage space in both the clean water tank at the waterwork and the reservoir at Nørrevangen. In addition, it also indicates that supplying a larger population in the future is a viable option.

5.3 Future plan for urban expansion

Hinnerup is a town in growth and within the last 13 years there have been an increasement in the population of approx. 17% according to Denmark' Statistics, which can be viewed in Appendix 5.3. The yearly increasement over the last 13 years is visualized in figure 5.11 below, with data provides by Denmark' Statistics. The increasement is measured within the postcode 8382 Hinnerup, stretching across both the area of Hinnerup and parts of the neighboring Aarhus area.

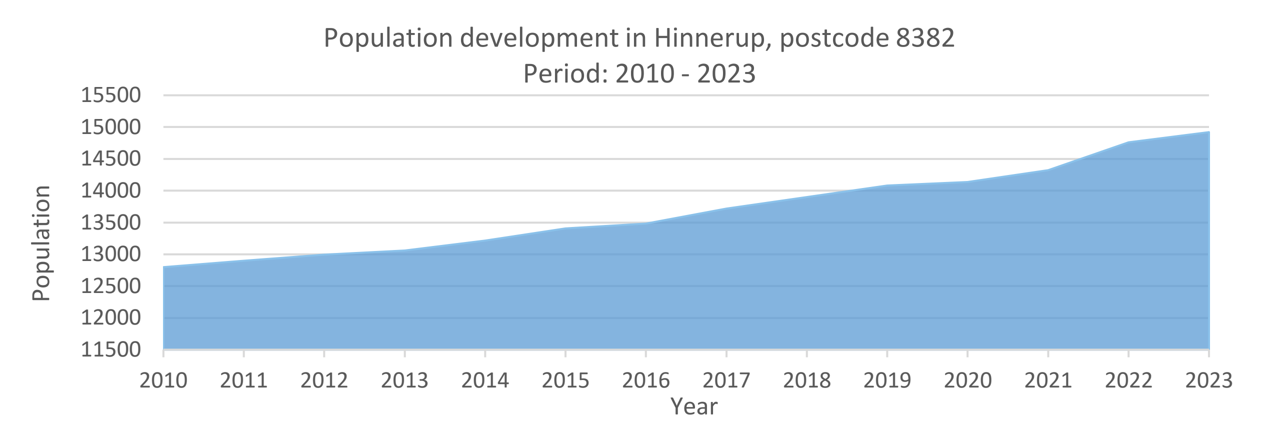


Figure 5.9 Development in the population of Hinnerup with postcode 8382, Denmark' Statistics. Appendix 5.3.

During recent years, new residential areas have been built, and the prediction for the close future is a continuous growth of among 1000 to 1500 people over the next 10 to 15 years focusing on the northern part of the town. Figure 5.10 below provides an overview of the planned urban expansion within the next 30 years according to Favrskov Municipality Plan 2021-32 (Favrskov Municipality, 2023). Following the planned urban expansion of the town of Hinnerup, increasing demands of distributed water are set to follow.

The increasing demand are set to impact the whole supply system of Hinnerup, from the intake wells to the treatment facility and lastly the distribution network. A determination of the actual impact has been stated in section 9, based on an estimation of the future demand. The section investigates whether the urban expansion results in any kind of challenges regarding capacity and overall sufficient operation of the whole supply system.

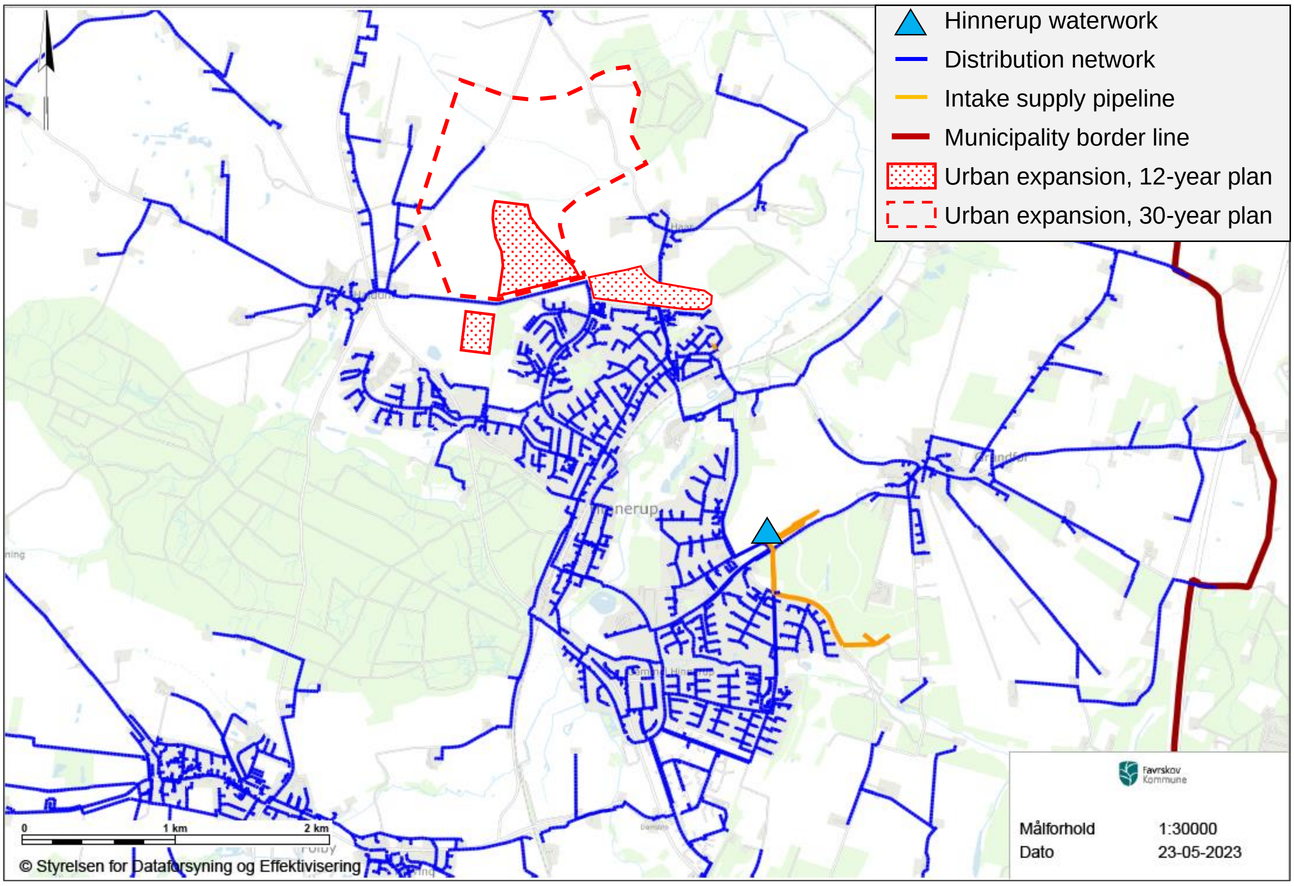


Figure 5.10 Overview of planned urban expansion of Hinnerup, Favrskov Kommune - Kommuneplan 2021-32. (Favrskov Municipality, 2023).

6. Intake resource

The following section is the first of the four main sections of this report, as described in section 5. The goal of the following section 6.0 is to investigate the status of the waterwork' current intake resource in terms of size, geology, water quality, groundwater formation and vulnerability. Based on these investigations, an evaluation of the intake resource is described in subsection 6.7.

6.1 Abstraction and recharge area

The following subsection investigates the location and size of the abstraction area of the intake resource. In section 6.2, the identified abstraction area is then being put in relation to the geological condition, hereby identifying whether the intake aquifer can be seen as a protected groundwater resource.

In figure 6.1 below, the abstraction area has been calculated and mapped based on provided data by Tillie Madsen, associate professor at Aarhus University. The map-based calculations can be found in Appendix 6.1. In addition, the calculated abstraction area is compared with the abstraction area provided by the Danish Environment Agency. Both areas of abstraction can be viewed in figure 6.1 below. Recharge areas within the abstraction area is commented on in section 6.2.

The EPA identifies the total abstraction area to approximately 2,47 km^2, consisting of two overlapping abstraction areas. The four intake wells at Herredsvej have an abstraction area of 2,0 km^2 and the remaining 0,93 km^2 is connected to the new intake well 79.1731 at Rønbækgård. For the noted total abstraction area provided by the EPA, the overlapping area have been taken into account. The calculated abstraction area is roughly estimated to be approx. 1,62 km^2 for the intake wells at Herredsvej and 0,44 km^2 for intake well B10 at Rønbækgård.

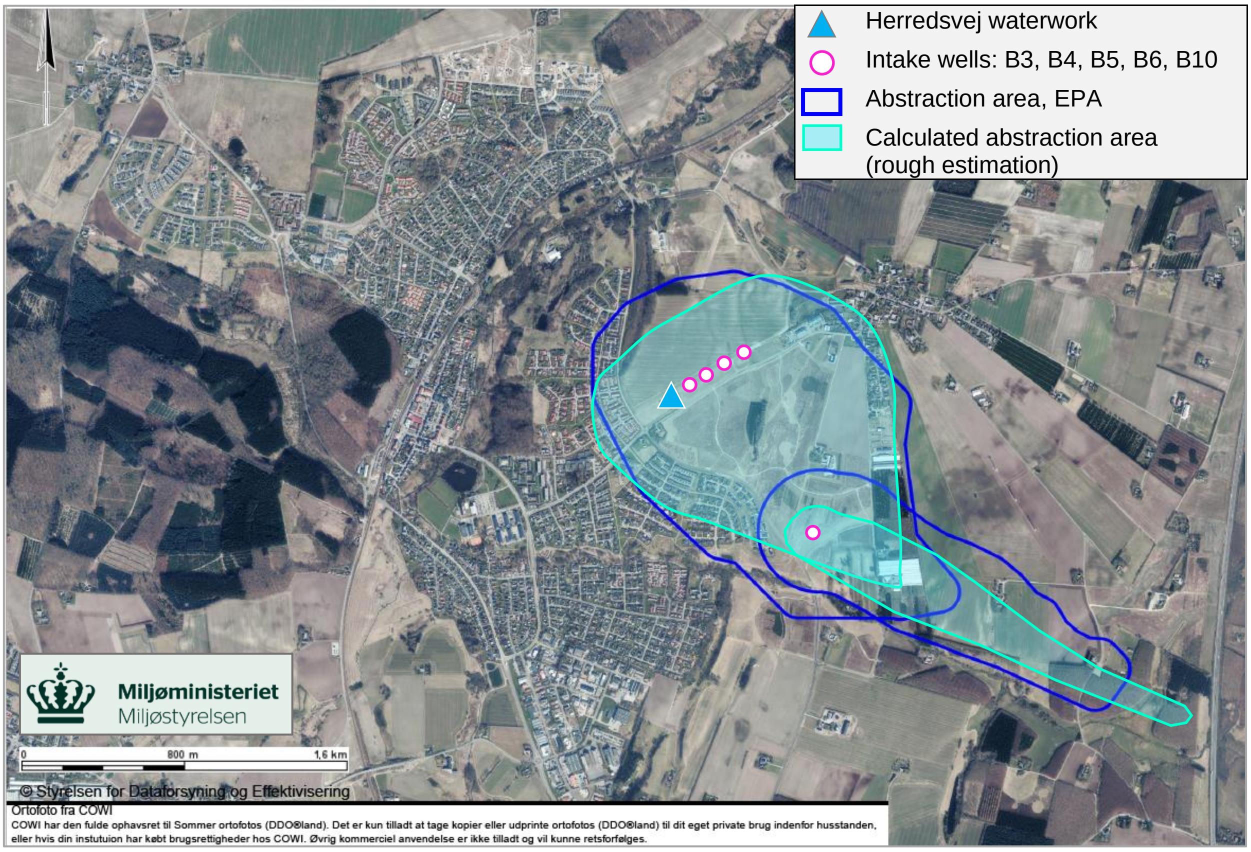


Figure 6.1 Overview of abstraction areas, waterwork and intake wells. (Danish Environmental Agency, 2023).

6.2 Geological conditions of the intake aquifer

The following section investigates the geological conditions within the abstraction area, hereby estimating whether unfavorable geological conditions are present within the abstraction area. Information about the geological conditions of the intake aquifer is provided by three TEM/SkyTEM profile plots: Cross section 1, 2 and 3. An overview of the location of the three cross sections can be viewed in Appendix 6.2.

An initial estimation of the aquifer conditions is presented in table 6.1 below, based on determination of the redox water type. The algorithm for redox water type determination can be found in Appendix 6.3. The noted values in table 6.1 are from most recent samples and a complete overview of the chemical composition of the water can be found in table 6.2, subsection 6.3.1.

Chemical components		*Intake wells*				
		B3	*B4*	*B5*	*B6*	*B10*
Nitrate	NO_3^-	< 0,3	1,8	< 0,3	< 0,3	4,3
Iron	Fe	0,62	0,53	0,93	0,9	0,79
Sulfate	SO_4^{2-}	72	84	89	50	72
Oxygen content	O_2	0,4	0,9	0,2	0,1	0,1
Water type		C	C	C	C	X*
Theoretical geological characterization of a redox water type C aquifer		Aquitard thickness within 5-15 meters or higher. Vulnerability to nitrate: limited to some, depending on clay thickness and the presence of pyrite of lignite.				

Commented on in Appendix 6.3

Table 6.1 Redox water type determination for each intake well. Most recent concentrations are noted. (GEUS: JUPITER, 2023).

In comparison to the actual geological conditions of the abstraction area, shown on the profile plots of the three cross sections below, the geophysical survey indicates an unconfined aquifer, because of the clay layers not being evenly present in the area. Local recharge areas may be present within the abstraction area based on the survey. The exact location of the recharge areas should not be considered significant, as it is rather the abstraction area as a whole that should be considered vulnerable against surface infiltration.

Looking at cross section 1, the intake aquifer can be identified within the sand layer above the tertiary clay layer. The tertiary clay layer is identified by a resistivity of 1-20. A thin clay layer is only present in the western direction of the cross section, hereby leaving the East side unprotected from surface infiltration. The area surrounding well 79.856 could therefore be interpretated as a potential recharge area, where the water table indicates groundwater flow towards well 79.1731. The diameter of this recharge area may be around 2 km or more.

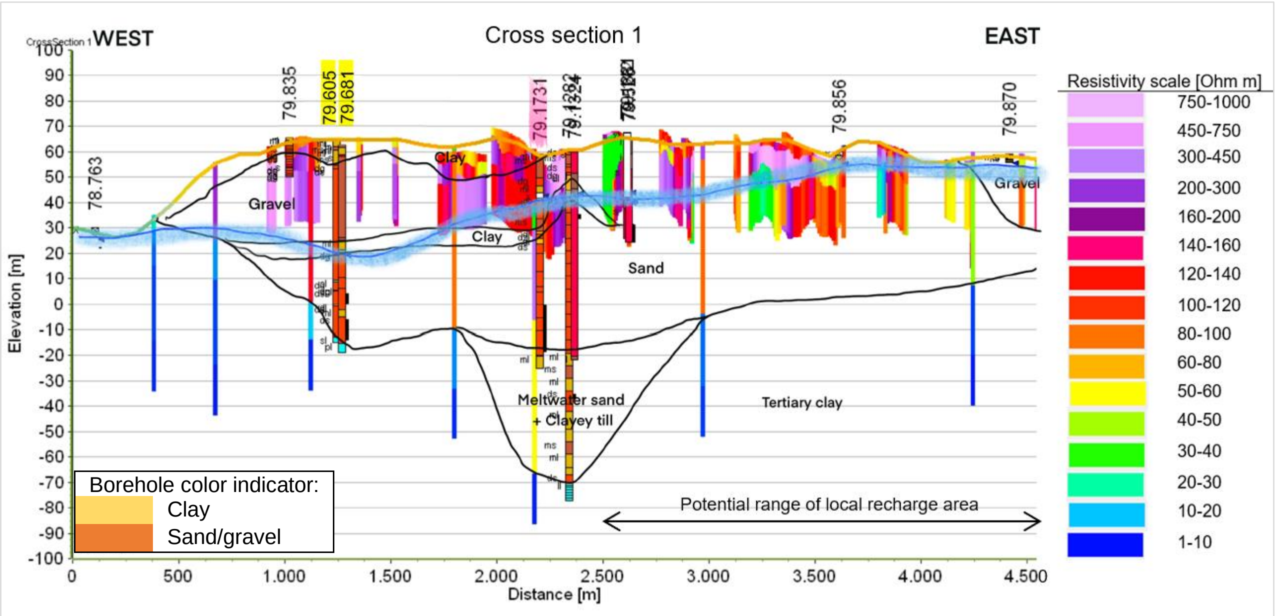


Figure 6.2 Geological conditions within the range of cross section 1.

Looking at cross section 2, the intake aquifer can be located within the range of 1.400 - 2.200 meters and within the saturated zone of the sand and gravel layer. Layers of clay above the aquifer is only present locally around the 4 intake wells just beneath the surface, as wells as a small bed of clay inside the aquifer. Two local recharge areas may be present, one on each side of the 4 intake wells at Herredsvej. Thus, the interpretated water table suggests that the water infiltrating on the western side of the cross section, may flow away from the aquifer, due to the groundwater divide located at well 79.436.

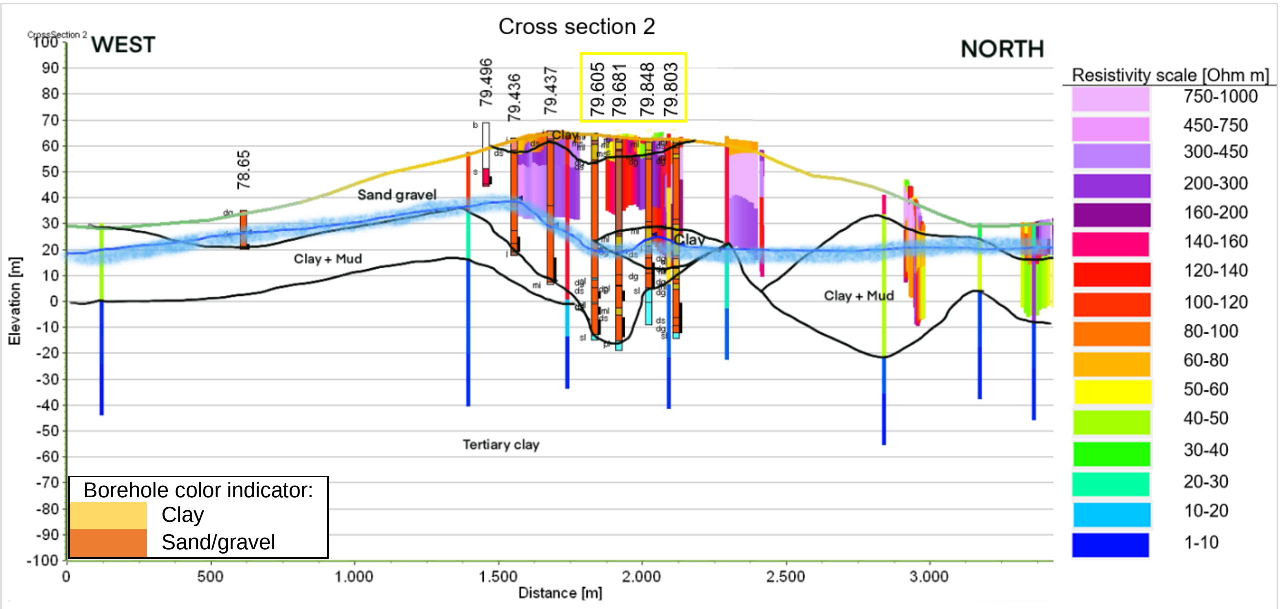


Figure 6.3 Geological conditions within the range of cross section 2.

Lastly, looking at cross section 3, a more evenly presence of clay may be the case here, as close to surface clay layers can be interpretated on both the northern and southern side of well 79.1731. The intake aquifer has been located above the tertiary clay layer and could be interpretated as more protected based on the cross section. There is no clear sign of a local recharge area within the profile range of cross section 3.

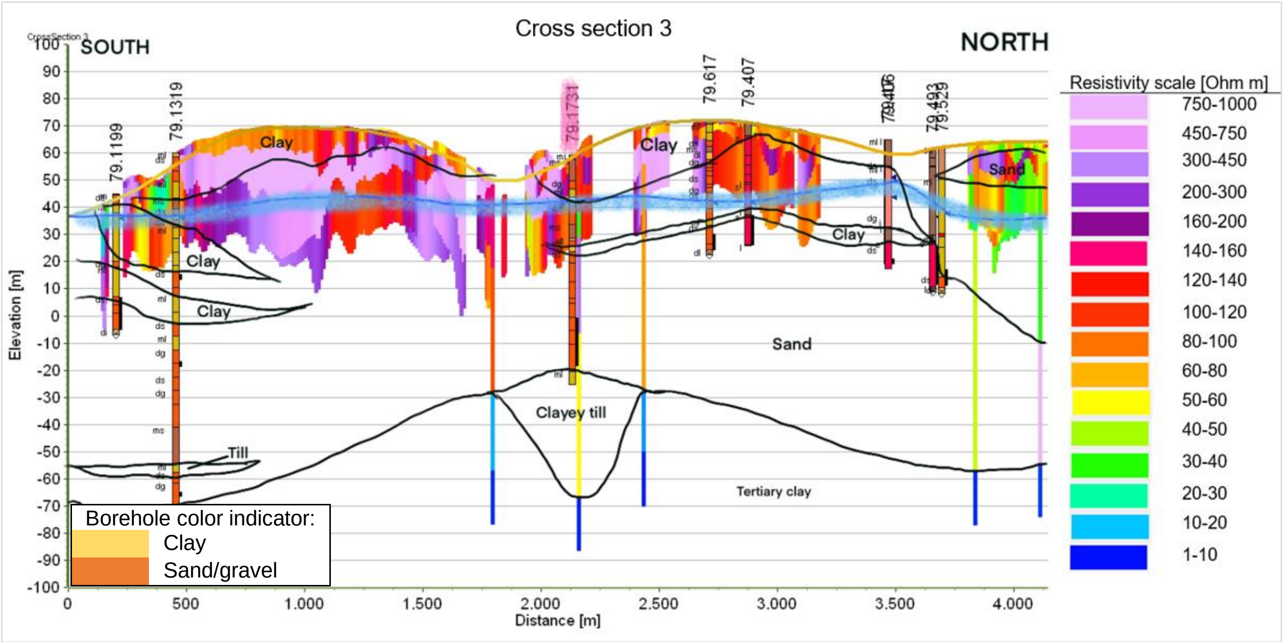


Figure 6.4 Geological conditions within the range of cross section 3.

A more detailed description of the local geology surrounding the 5 intake wells, is provided by GEUS (GEUS: JUPITER, 2023) and can be viewed on the figures below. These local geophysical surveys provide additional information regarding the depth of the different layers as well as information about the presence of calcareous conditions.

In general, only thin layers of clay is present within the local geology of the intake wells. The thickness various between a few meters and up to 10 meters of clay, as the case for well B5 and B6. It is not certain to state whether these thicker layers of clay provide an actual protection of the intake aquifer. In addition, the geological conditions can be viewed as calcareous, which is the case for all 5 intake wells. Also, meltwater sand / gravel is present within the sand layers and with clayey till being present within the layers of clay.

To summarize, both the cross sections and the local geology of the wells indicate a less protected aquifer and with the redox water type also considered, the vulnerability should be within concern.

Well B3
DGU no. 79.605

Terrain surface			Layer:	Note:
0	-	0,5	Soil	Soil
0,5	-	3,0	Clay	Clayey till non-calcareous
3,0	-	4,5	Sd	Clayey sand calcareous
4,5	-	10,5	Clay	Clayey till calcareous
10,5	-	12,0	gl	Meltwater gravel calcareous
12,0	-	56,0	Sd	Meltwater sand calcareous
56,0	-	56,7	Clay	Sea wind mergel strongly calcareous
56,7	-	65,4	Sd	Meltwater sand calcareous
65,4	-	66,0	Clay	Meltwater clay calcareous
66,0	-	78,0	Sd	Meltwater sand calcareous
78,0	-	80,0		Clay strongly calcareous

Figure 6.5 Local geological conditions, well B3. (GEUS: JUPITER, 2023)

Well B4
DGU no. 79.681

Terrain surface			Layer:	Note:
0	-	1,6	Clay	Soil content non-calcareous
1,6	-	4,5	Clay	Clayey till non-calcareous
4,5	-	38,0	Sd	Clayey sand calcareous
38,0	-	43,0	Clay	Clayey till calcareous
43,0	-	65,6	gl	Meltwater gravel calcareous
65,6		68,5	Clay	Clayey till calcareous
68,5	-	78,5	Sd	Meltwater sand Calcareous
78,5	-	82	Clay	Kerteminde mergel calcareous

Figure 6.6 Local geological conditions, well B4. (GEUS: JUPITER, 2023)

Well B5
DGU no. 79.848

Terrain surface			Layer:	Note:
0	-	5	Clay	Clayey till non-calcareous
5,0	-	7,0	Sd	Clayey sand non-calcareous
7,0	-	33,5	gl	Meltwater gravel weakly calcareous
33,5	-	42,5	Clay	Clayey till calcareous
42,5	-	56,5	Sd/gl	Meltwater sand/gravel weakly calcareous
56,5	-	71,0	Clay	Sea wind mergel strongly calcareous

Figure 6.7 Local geological conditions, well B5. (GEUS: JUPITER, 2023)

Well B6
DGU no. 79.803

Terrain surface			Layer:	Note:
0	-	0,3	Soil	Soil
0,3	-	1,5	Clay	Clayey till non-calcareous
1,5	-	6,0	Sd	Meltwater sand non-calcareous
6,0	-	7,5	Clay	Clayey till non-calcareous
7,5	-	33,0	gl	Meltwater gravel non-calcareous
33,0	-	45,0	Clay	Clayey till calcareous
45,0	-	46,5	gl	Meltwater gravel calcareous
46,5	-	49,0	Clay	Meltwater clay calcareous
49,0	-	50,0	gl	Meltwater gravel calcareous
50,0	-	54,0	Clay	Clayey till calcareous
54,0	-	56,0	gl	Meltwater gravel calcareous
56,0	-	58,0	Clay	Clayey till calcareous
58,0	-	75,0	Sd/gl	Meltwater sand/gravel non-calcareous to calcareous
75,0	-	77,0	Clay	Sea wind mergel weakly calcareous

Figure 6.8 Local geological conditions, well B6 (GEUS: JUPITER, 2023).

Well B10
DGU no. 79.1731

Terrain surface			Layer:	Note:
0	-	0,2	Soil	Soil
0,2	-	2,0	Clay	Clay -
2,0	-	10,0	Sd	Clayey sand non-calcareous
10,0	-	13,0	gl	Meltwater gravel weakly calcareous
13,0	-	16,0	Clay	Clayey till strongly calcareous
16,0	-	18,0	-	no data
18,0	-	19,0	Clay	Meltwater clay strongly calcareous
19,0	-	26	Sd	Meltwater sand non-calcareous
26,0	-	31,0	Sd	Clayey sand strongly calcareous
31,0	-	32,0	Clay	Meltwater clay strongly calcareous
32,0	-	34,0	gl	Meltwater gravel strongly calcareous
34,0	-	36,0	Clay	Meltwater clay strongly calcareous
36,0	-	80,0	Sd	Meltwater sand weakly calcareous
80,0	-	85,0	Clay	Clayey till strongly calcareous

Figure 6.9 Local geological conditions, well B10. (GEUS: JUPITER, 2023)

6.3 Chemical quality of the raw water

In the following subsection, the chemical quality of the raw water is going to be investigated. The quality is investigated based on raw water samples provided by Jupiter. Most recent samples from each well have been used to state the current quality of the intake resource. In addition, historical trends for key water contaminants have been visualized. These should serve the purpose of reviewing if there are any changes in the quality of the raw water, hereby indicating potential future challenges with contaminants.

6.3.1 Major chemical components

The major chemical components are noted for each of the 5 intake wells in table 6.2 below. Exceeding concentrations, in relation to the drinking water criteria (abbreviated as DW criteria) are highlighted with **bold font**.

Chemical component		*Concentration* [mg/L]					*DW criteria* (Jupiter)
		DGU no. 79.605 B3	*DGU no. 79.681 B4*	*DGU no. 79.848 B5*	*DGU no. 79.803 B6*	*DGU no. 79.1731 B10*	[mg/L]
	Date of sample:	12/05-20	07/05-19	10/11-20	22/01-21	24/08-22	
pH		7,5	7,5	7,5	7,4	7,6	
Ammonia	NH_4^+	0,023	0,039	0,027	**0,095**	0,028	0,05
Calcium	Ca^{2+}	92	95	100	69	95	-
Carbon (NVOC)	-	0,85	0,58	0,92	0,51	1,1	4
Carbon dioxide, agg.	CO_2	3	< 2	3	< 2	< 2	-
Chloride	Cl^-	23	28	35	23	33	250
Fluoride	F^-	0,21	0,18	0,21	0,26	0,16	1,5
Hydrogen carbonate	HCO_3^-	203	219	220	189	209	-
Potassium	K^+	1,4	1,4	1,6	2,2	1,3	-
Iron	Fe	**0,62**	**0,53**	**0,93**	**0,9**	**0,79**	0,2
Magnesium	Mg^{2+}	2,8	2,8	3,2	3,9	3	-
Manganese	Mn	**0,25**	**0,23**	**0,27**	**0,17**	**0,17**	0,05
Methane	CH_4	< 0,005	< 0,005	< 0,005	< 0,005	< 0,005	-
Sodium	Na^+	14	14	14	15	15	175
Nitrate	NO_3^-	< 0,3	1,8	< 0,3	< 0,3	4,3	50
Nitrite	NO_2^-	< 0,001	0,019	< 0,001	< 0,001	0,09	0,1
Phosphor, total-P	P	0,023	< 0,01	0,032	0,072	0,066	-
Sulfate	SO_4^{2-}	72	84	89	50	72	250
Oxygen content	O_2	0,4	0,9	0,2	0,1	0,1	-

Table 6.2 Most recent concentrations of major chemical components. Exceeding values highlighted with bold font. (GEUS: JUPITER, 2023).

There is a total of three components exceeding the drinking water criteria:

1) Ammonia.............. (well B6 exceeding)
2) Iron........................ (all intake wells exceeding)
3) Manganese............ (all intake wells exceeding)

Normal treatment is sufficient for these components and will be analyzed further in section 7.

6.3.2 Content of contaminants

Focused contaminants with noted values taken from the most recent samples, can be viewed in table 6.3 below. Historical trends for the trace of nitrate, fluoride, nickel and arsenic can be viewed on figure 6.10 to 6.13.

Focused contaminants		*Concentration*					*DW criteria (Jupiter)*
		DGU no. 79.605 B3	*DGU no. 79.681 B4*	*DGU no. 79.848 B5*	*DGU no. 79.803 B6*	*DGU no. 79.1731 B10*	
Nitrate	NO_3^-	< 0,3	1,8	< 0,3	< 0,3	4,3	50 [mg/L]
Fluoride	F^-	0,21	0,18	0,21	0,26	0,16	1,5 [mg/L]
Nickel	Ni	1,3	1,0	0,36	0,71	0,12	20 [µg/L]
Radon	Ra	-	-	-	-	-	100 [Bq/L]
Pesticides {sum}	-	< 0,39*	< 0,33*	< 0,39*	< 0,39*	< 0,5*	0,5 [µg/L]
PFAS {sum}	-	< 0,001	< 0,001	< 0,001	< 0,001	-	0,1 [µg/L]
Arsenic	As	1,6	1,1	1,8	3,1	2,9	5 [µg/L]
Lead	Pb	-	-	-	-	-	5 [µg/L]
E. coli	-	-	-	-	-	-	None (0,0)

worst-case scenario, to be described below

Table 6.3 Most recent concentrations of focused contaminants. (GEUS: JUPITER, 2023).

Measurements on PFAS is only available in the most recent sample of each intake well. For the concentration of pesticides, the noted values are for the *worst-case scenario*. The worst-case scenario for each intake well is the sum of all measured types of pesticides with a detection value of "< 0,01". For example, the pesticides concentration for intake well B3 is the result of 39 different types of pesticides, all with a detection value of 0,01 µg/L; equal to 0,39 µg/L. The amount of different pesticides types measured does not exceed 50 in total for any well at any point. In relation to the worst-case scenario analogy, this will result in a concentration of 50 times 0,01 µg/L; equal to 0,50 µg/L. Hereby not exceeding the DW criteria.

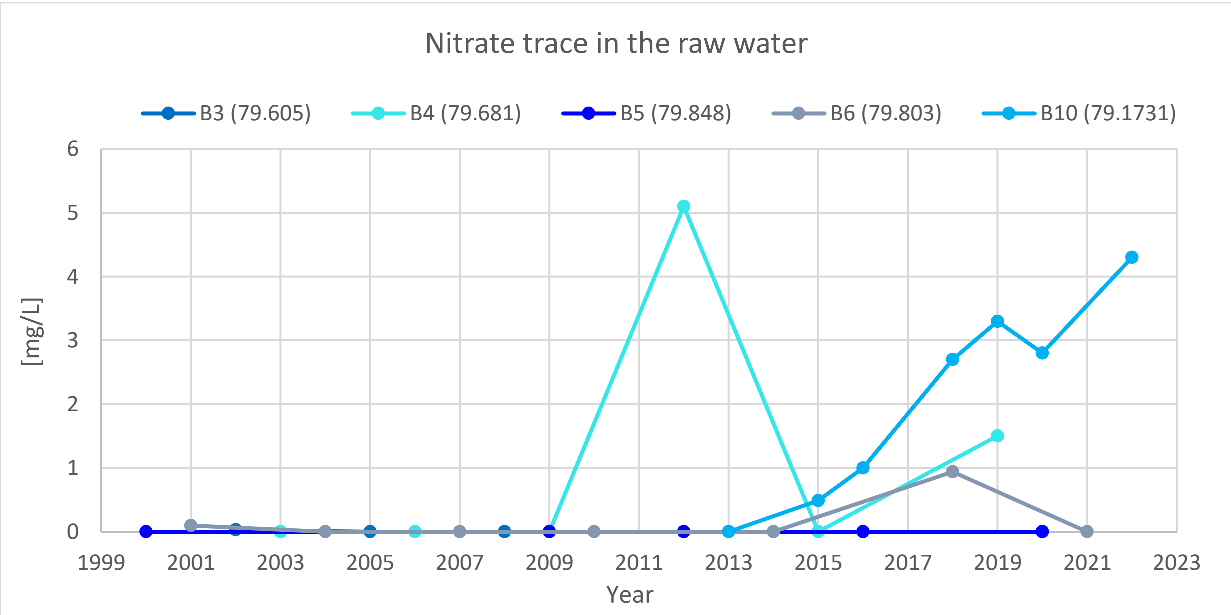


Figure 6.10 Nitrate trace in the raw water over a 10–20-year period. (GEUS: JUPITER, 2023).

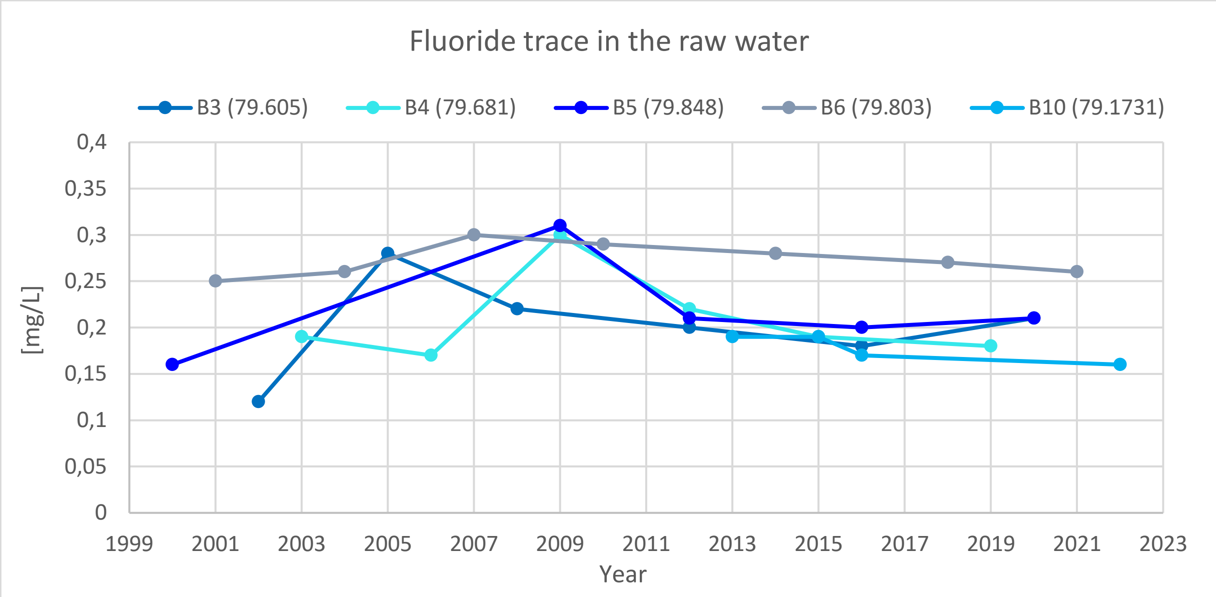


Figure 6.11 Fluoride trace in the raw water over a 10–20-year period. (GEUS: JUPITER, 2023).

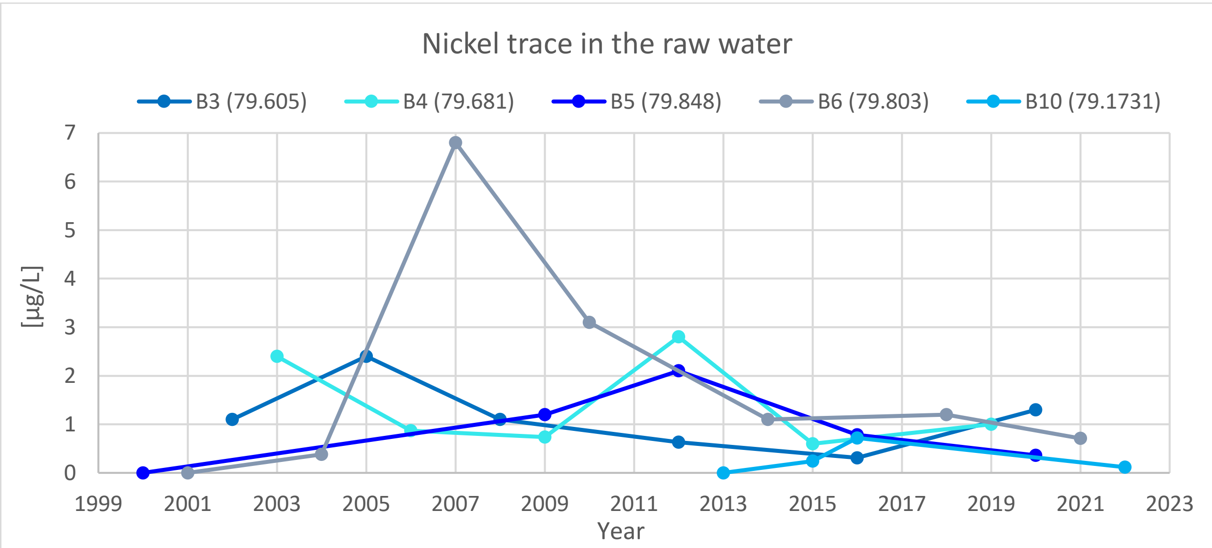


Figure 6.12 Nickel trace in the raw water over a 10–20-year period. (GEUS: JUPITER, 2023).

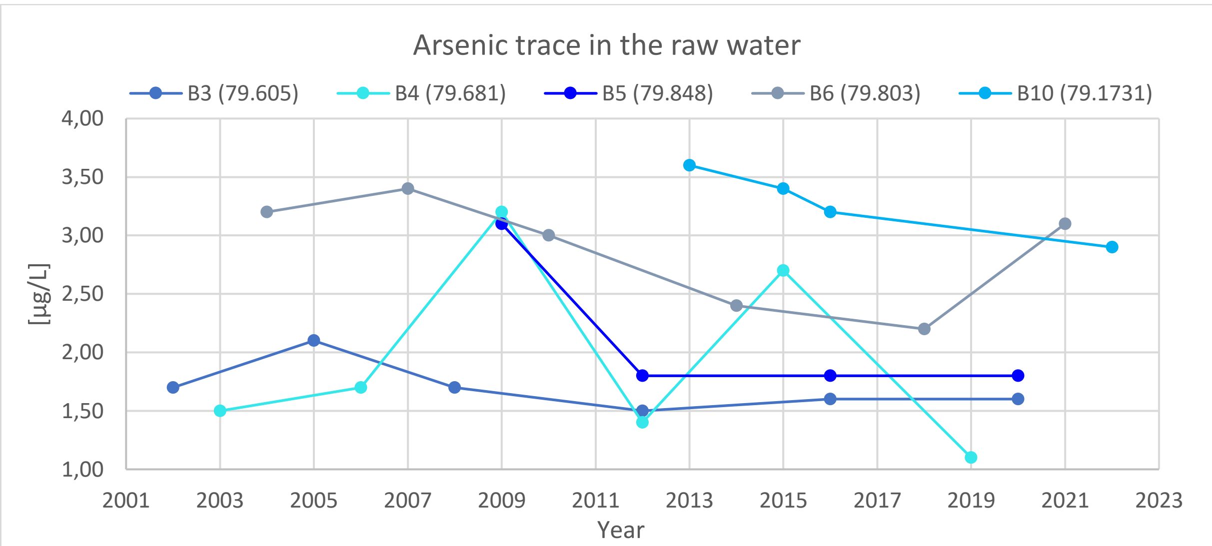


Figure 6.13 Arsenic trace in the raw water over a 10–20-year period. (GEUS: JUPITER, 2023).

For the case of fluoride, nickel and arsenic, the graphs do not indicate any clear overall increasing or decreasing trend over the 10–20-year data period. Each component various in concentration throughout the period and is rarely constant. Looking at nitrate, one peak measurement can be seen for intake well B4. In addition, an increasing trend can be viewed for intake well B10 from 2013 to 2022. This could perhaps indicate limited to some impact from agricultural activity around the area of well B10 within recent years.

In section 6.2, a potential recharge area was identified in the East direction of cross section 1 (figure 6.2) around well 79.856 with groundwater flow towards well B10. Therefore, is it possible that the increasing nitrate concentration at well B10, originates from agricultural activity around well 79.856, with nitrate infiltrating through the surface within the local recharge area. Attention should be paid in this area so that the nitrate concentration does not reach critical levels.

6.4 Main processes in the formation of the raw water

Main processes in the formation of the raw water have been identified and described in the sections below, based on investigation of the following conditions:

1. pH
2. Degree of hardness
3. Degree of ion exchange
4. Degree of weathering

These results have then been placed in relation to the geological conditions of the abstraction area. Results of investigation:

		B3	B4	B5	B6	B10
Ph	[-]	7,5	7,5	7,5	7,4	7,6
Degree of ion exchange, I	[-]	0,94	0,77	0,62	1,01	0,70
Degree of weathering, F	[-]	1,45	1,38	1,46	1,21	1,45
Degree of hardness,	[°dH]	13,49	13,91	14,70	10,53	13,96

Table 6.4 - Results of chemical analysis parameters.

6.4.1 Calcite dissolution

The pH-levels indicate buffered water (7,0-8,0) and the presence of the acid-neutralizing mineral calcite. Calcite mineral is present when there are calcareous conditions in the soils of the intake aquifer. In section 6.2, the presence of calcareous conditions has been identified for all 5 intake wells, based on investigation of local geological surveys (figure 6.5 - 6.9). With buffered water, higher concentrations of calcium and hydrogen carbonate is expected, as result of calcite mineral dissolution. In the samples, concentration of calcium and hydrogen carbonate can be viewed within expected levels, given the pH-value of 7,4-7,6.

In addition, the extent of the following reactions:

- Biodegradation
- Nitrification
- Pyritoxidation

can be considered more limited because there is a typical / medium degree of hardness. If the mentioned reactions above had been at greater extent, this would inevitably have resulted in a high formation of acids making the water hard because of the high carbonate buffer capacity that is present through calcite. The fact that both pH and hardness is seen in aspiring conditions tells that the groundwater formation is very balanced, not producing more acids than what is in favor for the hardness within calcareous aquifer conditions. (Loren Ramsay, 2014)

6.4.2 Ion exchange

Calculations of the degree of ion exchange indicates both *no ion exchange* (0,6 < I < 0,9) and *ion exchange* (0,9 < I < 2,0) within the abstraction area, which is the case for the intake wells at Herredsvej regarding well B3, B4, B5 and B6. Intake well B10 is categorized by *no ion exchange*.

	Typical conditions: no ion exchange 0,6 < I < 0,9	High conditions: ion exchange 0,9 < I < 2,0
Covered wells:	B4, B5, B10	B3, B6
Interpretation:	• Limited presence of protecting clay layers. • Risk of vulnerable groundwater. • Possible limited CEC = limited release of sodium.	• Protecting clay layers is present. • Can indicate less vulnerable groundwater. • High CEC = higher release of sodium.

Note: Cation-exchange-capacity, CEC.

Table 6.5 Interpretation of the investigated degree of ion exchange

No ion exchange is the result of limited presence of clay layers within the abstraction area, with the groundwater not passing by or through clay layers on its way to the intake aquifer, hereby not releasing sodium in the process. Even though ion exchange is identified for well B3 and B6, the calculated value is close to fall within the range of no ion exchange, especially in the case of well B3. This forms a general picture of limited presence of protecting clay layers within the area of abstraction, thereby identifying the intake resource as vulnerable. (Loren Ramsay, 2014).

6.4.3 Pyrite oxidation

Pyrite oxidation could be considered an undergone process, as the degree of weathering can be viewed just above the typical range (1,0-1,3) which is the case for 4/5 of the intake wells with exception of B6 (F=1,21). The pyrite mineral is typically seen in greater amount in clayey till and meltwater sand, which is in accordance with the geological characteristics of the abstraction area.

The presence of pyrite mineral and pyrite oxidation is in favor of the intake aquifer as nitrate and oxygen are being consumed with pyrite oxidation, thereby acting like a buffer against intruding nitrate (Loren Ramsay, 2014). This could thus be the explanation for the low concentration of nitrate and oxygen content that are present in the samples. However, the low concentrations of nitrate could also be the result of low agricultural impact, hereby questioning the extent of pyrite oxidation. Beside nitrate concentration, other indicators of pyrite oxidation can be:

	Indicators of pyrite oxidation:	Status:
a)	Sulfate conc. above 30 mg/L	Yes (cf. table 6.2)
b)	Hardness increase	No (cf. table 6.4)
c)	pH lowering	No (cf. table 6.4)
d)	Ion exchange is usually low	Yes (cf. table 6.5)
e)	Possible increase in iron concentration	No clear trend (cf. section *7.*)
f)	Possible increase in nickel concentration	No significant, generally low conc. (cf. figure 6.12)

Table 6.6 Indicators of pyrite oxidation

To summarize, even though there are indicators of pyrite oxidation, the presence of a well buffered water and a balanced hardness in a calcareous conditioned aquifer, indicates that pyrite oxidation can only be present in limited or some extent. The presence of pyrite oxidation is also in accordance with redox water type C aquifers, which was identified for 4/5 of the intake wells in table 6.1.

6.5 Vulnerability to contamination

The intake resource should be considered vulnerable when geological conditions and groundwater formations doesn't provide protection and buffering of the resource. Such conditions have already been identified for the area in section 6.2, as well as the presence of limited pyrite oxidation to consume future infiltrating nitrate in subsection 6.4.3. Beside nitrate, several contaminants could infiltrate from surface. Following parameters should be considered problematic, as standard water treatment is not efficient for these.

Potential contaminants:	Status based on groundwater samples:	Can infiltrate from surface:
Nitrate……………………………	Increasing concentrations detected, B10, cf. figure 6.10	……Yes
Pesticides………………………	Insignificant concentrations detected, cf. table 6.3	……Yes
PFAS…………………...........	Concentrations below detection value, cf. table 6.3	-
Arsenic………………...........	Concentrations below DW criteria, cf. figure 6.13	……No
Fluoride……………............	Concentrations below DW criteria, cf. figure 6.11	……Yes
Nickel………………………….	Concentrations below DW criteria, cf. figure 6.12	……No
Natural organic matter.....	Insignificant concentrations detected, cf. table 6.2	……Yes
Radon…………………………….	No data, cf. table 6.3	-

Table 6.7 Overview of potential contaminants

As the status describes, there is currently only one sign of contamination for the intake resource, this being increasing concentrations of nitrate for the case of well B10. However, figure 6.14 below identifies the nitrate vulnerability zones indicating the risk of future contamination from infiltrating contaminants, which could be caused by agricultural activity.

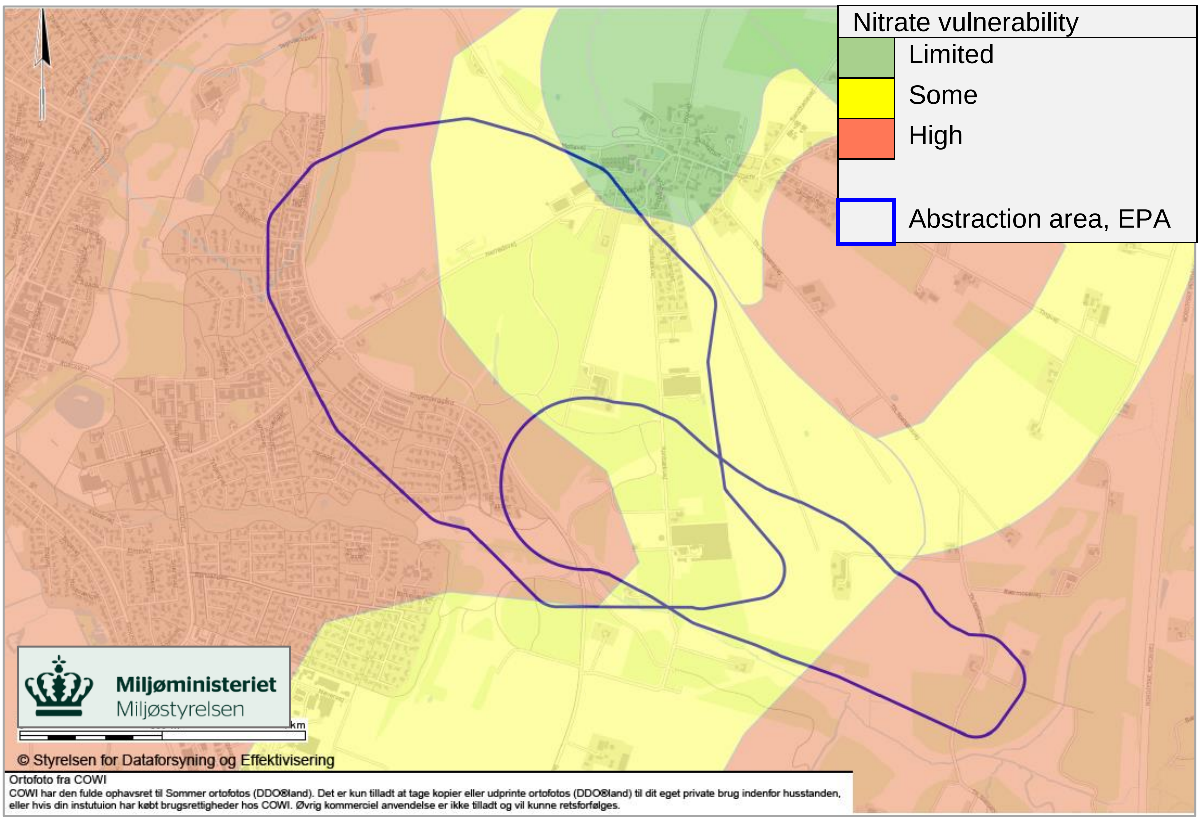


Figure 6.14 Nitrate vulnerability zones, (Danish Environmental Agency, 2023).

Based on figure 6.14 and in relation to the earlier described geological conditions of the abstraction area in section 6.2, this groundwater resource should be considered unprotected and agricultural activity should be monitored to prevent future contamination. Action have already been taken and *close to drilling protection zones* have been pointed out, which can be viewed on figure 6.15 below.

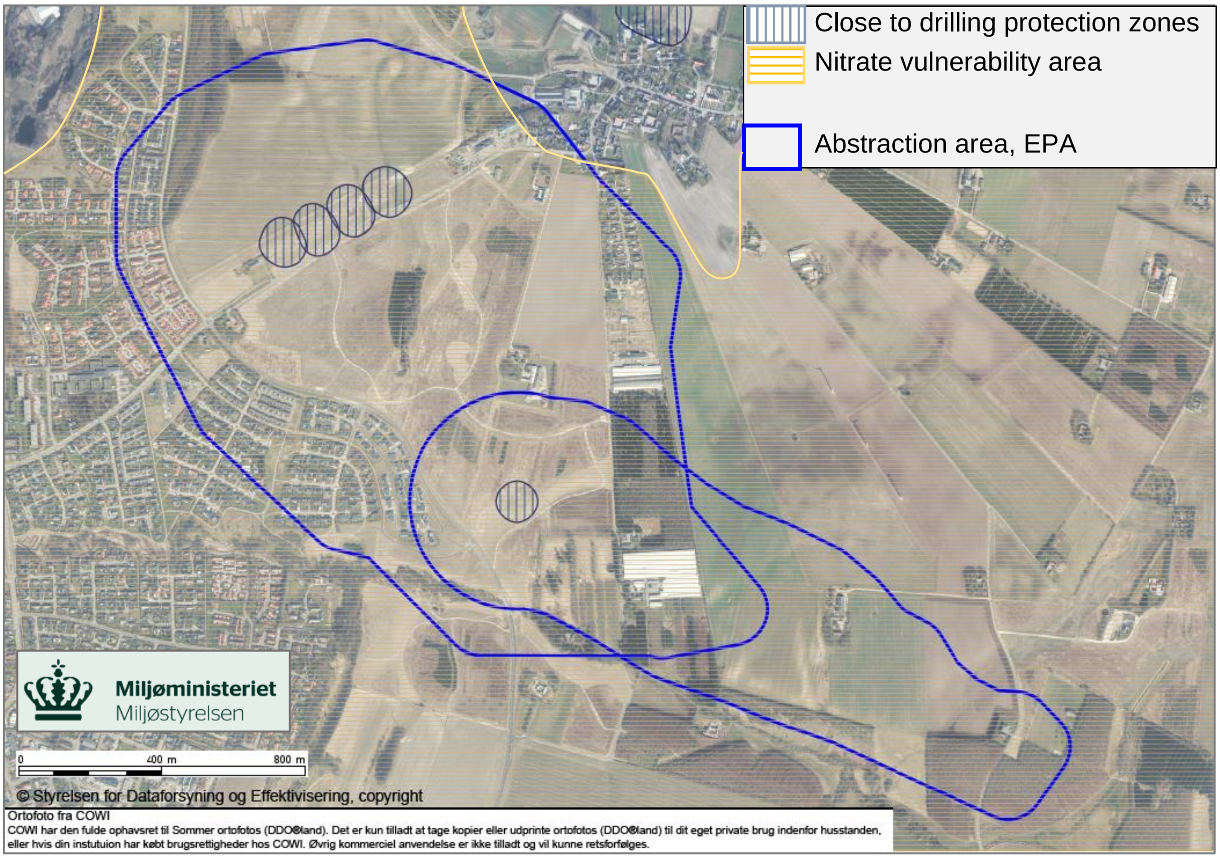


Figure 6.15 - Close to drilling protection zones. (Danish Environmental Agency, 2023).

6.7 Evaluation of intake resource

The intake recourse is currently supplying a very well quality of raw water with only iron, manganese and ammonia as exceeding parameters (table 6.2). The intake aquifer can be characterized as a well buffered water resource with an ideal pH and a balanced/medium hardness (table 6.4), which is the result of calcareous conditions being present for this aquifer (figure 6.5 - 6.9). In addition, no exceeding contaminants have been identified within the abstraction area and with nitrate and pesticides having insignificant concentrations (table 6.3). Based on the chemical composition of the raw water, redox water type C have been determined, indicating limited to some vulnerability against future contamination (table 6.1).

Furthermore, the analysis of provided geophysical surveys indicates an unconfined aquifer, because of the clay layers not being evenly present in the area (subsection 6.2). Several local recharge areas can be identified within the abstraction area with water flow routes leading directly to the aquifers, hereby indicating a significant threat for surface infiltration of contaminants. The vulnerability of the area is also in accordance with detected nitrate vulnerability zones provided by the Danish Environment Agency, where the whole area of abstraction is being categorized as some to high vulnerability (figure 6.14).

Even though redox water type C indicates the possible presence of the mineral pyrite, which would consume infiltrating nitrate when oxidized, the current extent of pyrite oxidation has been estimated as being limited (subsection 6.4.3). Special attention should be paid to the parameter nitrate as well as other contaminants that could infiltrate from surface. The overall conditions of the intake resource calls for the need of monitoring of agricultural activities within the area of abstraction.

7. Treatment

The quality of water can vary from region to region, depending on factors such as geological conditions, land use, and population density. These differences require different treatment processes to bring the water to a safe and acceptable standard. Some regions may require more intensive treatment due to higher levels of pollutants or the need to remove specific contaminants, while others may require fewer complex processes.

This section demonstrates the treatment process of water at the Hinnerup Waterworks to ensure safe consumption. It explains all the treatment steps involved in this process. Furthermore, calculations are utilized to examine the adequacy of the applied methods in achieving the desired quality standards.

The intention behind the calculations is to determine a calculated value from the available data that can be considered as a threshold for the treatment process. By comparing the calculated threshold values with the actual measurement results from the Hinnerup Waterworks, it can be assessed whether the applied treatment process is effective. If the actual values fall within the defined limits, it indicates that the applied methods are sufficient to prepare the water for safe consumption.

The approach taken in interpreting the data from the five different wells involves the consideration of worst-case scenarios. This means that calculations and analyses are based on the data that would result in the most challenging conditions for the treatment processes. For example, the maximum oxygen demand or highest levels of other constituents are taken into account to ensure that the treatment processes are effective and appropriate under any circumstances. This approach is essential for ensuring the safety and reliability of the water supply.

7.1 Review on the quality of the produced water [Cato]

The information from section 6 provides important insights into the water. It is classified as Water Type C and is referred to as buffered water. Particularly noteworthy is that in section 6.7, no alarming main processes or values were identified that deviate significantly from the norm. Thresholds are reference values that indicate the levels at which water quality is considered sufficient. When water quality parameters exceed these thresholds, it indicates the need for additional treatment measures. See table 7.1 below.

	B3	B4	B5	B6	B10	Threshold	Units	Comments
Iron	**0,62**	**0,53**	**0,93**	**0,9**	**0,79**	<0,2	mg/l	Values exceed the drinking water criteria
Manganese	**0,25**	**0,23**	**0,27**	**0,17**	**0,17**	<0,05	mg/l	Values exceed the drinking water criteria
Ammonia	0,023	0,039	0,027	**0,095**	0,028	<0,05	mg/l	Value B6 exceeds the drinking water criteria
Ph	7,5	7,5	7,5	7,4	7,6	7,0 - 8,5	[-]	typical value
Degree of ion exchange	0,94	0,77	0,62	1,01	0,70	typical 0,6 - 0,9	meq/l	> 0,9 ion exchange
Degree of weathering	1,45	1,38	1,46	1,21	1,45	typical 1,0 - 1,3	[-]	> 1,3 weathering
Degree of hardness	13,49	13,91	14,70	10,53	13,96	8,4 - 14	°dH	Water is medium hard and for B5 hard water

Table 7.1 Overview of the five borings and their different parameter as well as their respective thresholds. Marked in bold are the exceeding values.

Upon reviewing the current data, delving into the historical records of the elevated values aids in obtaining a more comprehensive understanding. The trace of ammonia, iron and manganese in the groundwater over a period of 10-20 years can be viewed below. For some years with more than one value available, the highest value has been used.

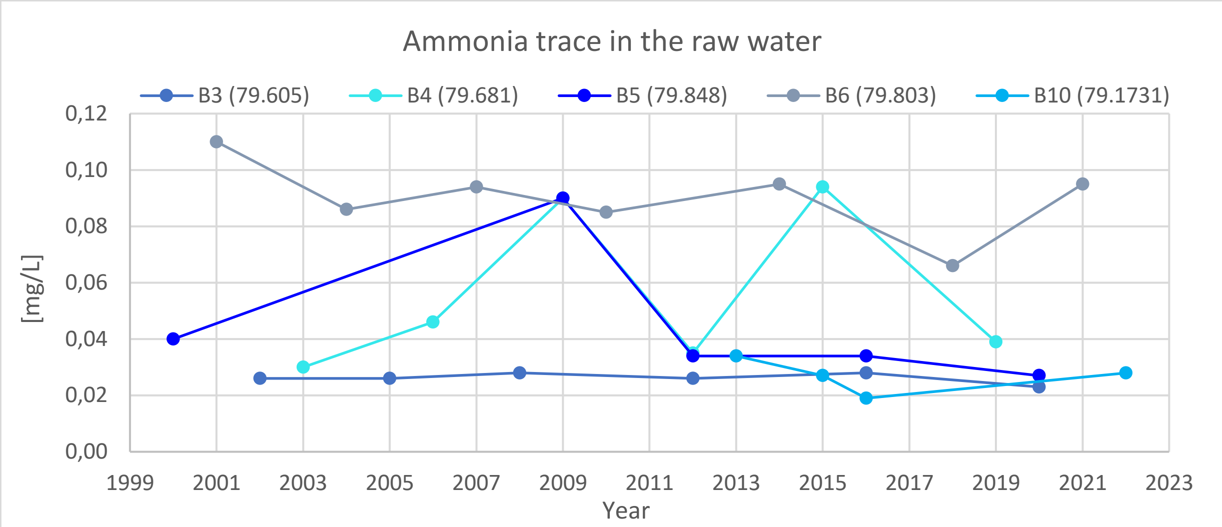


Figure 7.1 Ammonia trace in the raw water over a 10–20-year period. (GEUS: JUPITER, 2023).

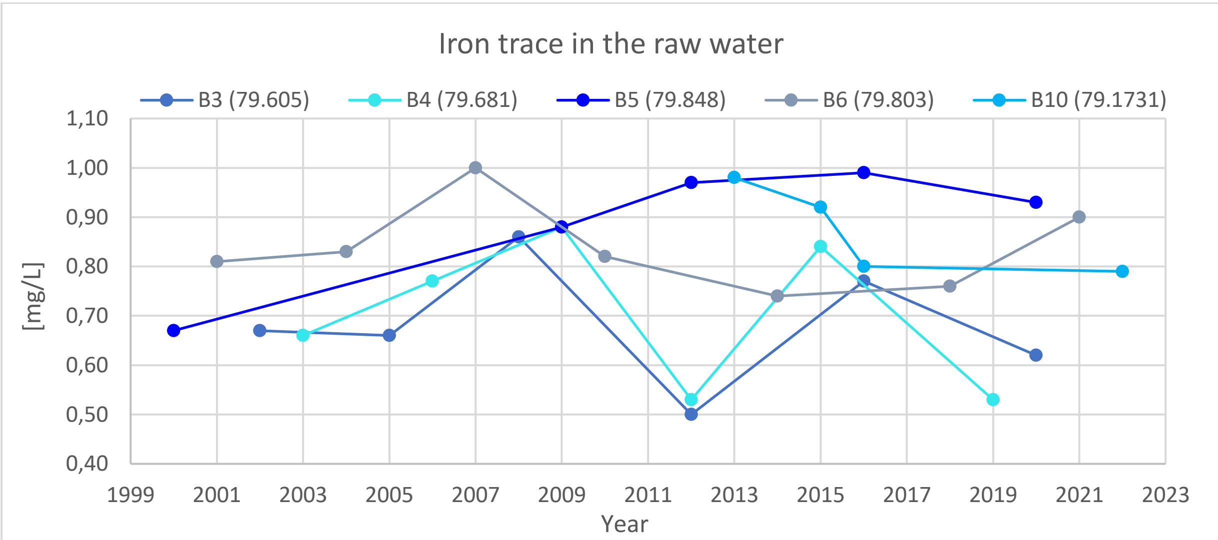


Figure 7.2 Iron trace in the raw water over a 10–20-year period. (GEUS: JUPITER, 2023).

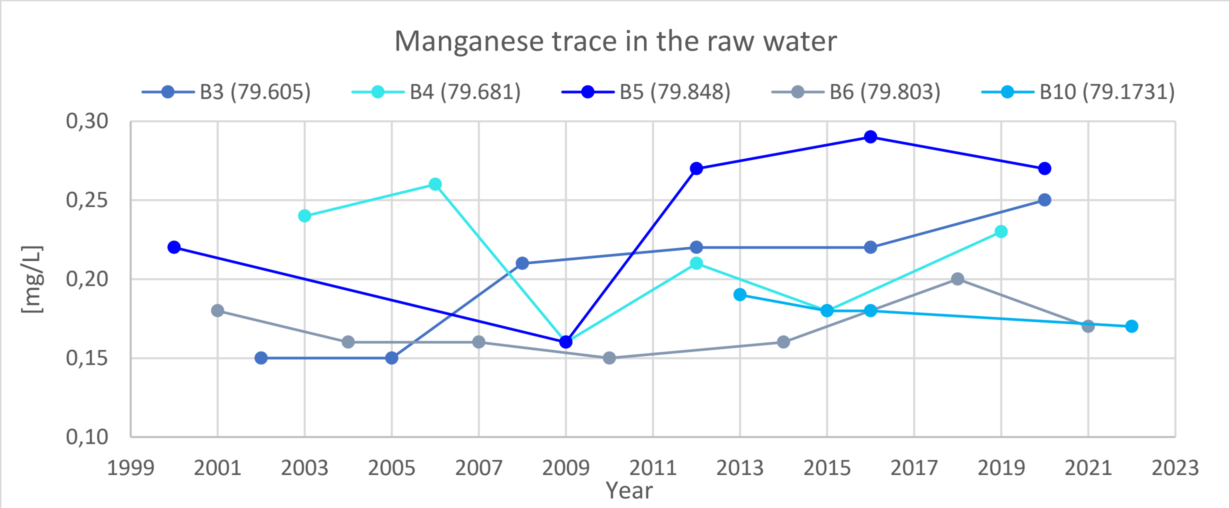


Figure 7.3 Manganese trace in the raw water over a 10–20-year period. (GEUS: JUPITER, 2023)

The graphs do not indicate any clear overall increasing or decreasing trend over the 10–20-year data period. Each component various in concentration throughout the period and is rarely constant. However, for well B3 (79.605) and B5 (79.848) we see an increase in iron and manganese.

		value before	*value after*	*increasement*
Manganese	B3 (79.605)	0,15 mg/L (2002)	0,25 mg/L (2020)	67%
Manganese	B5 (79.848)	0,16 mg/L (2009)	0,27 mg/L (2020)	69%
Iron	B5 (79.848)	0,67 mg/L (1999)	0,93 mg/L (2020)	39%

Table 7.2 This table is showing the actual increasement of the exceeding values of Manganese from B3 and B5 and also of Iron from B5.

Yet, these increasements can be difficult to interpret, as they can just be periodic peaks stretching over a longer period for then to decrease again as the general picture indicates. In the case of manganese and iron for well B5, this decrease can be seen to have started, as both values peaked in 2016.

Additionally, both iron and manganese has been exceeding the drinking water criteria through the whole period. Furthermore, regarding ammonia, there seem to be a significantly large difference between the ammonia conc. form intake well B6 compared to its neighbor wells; B3, B4 and B5.

7.2 The treatment facilities

7.2.1 Overall structure [Arne]

At Hinnerup Water works the water undergoes standard treatment. Figure 7.4 gives a better understanding of the order of the different treatment processes.

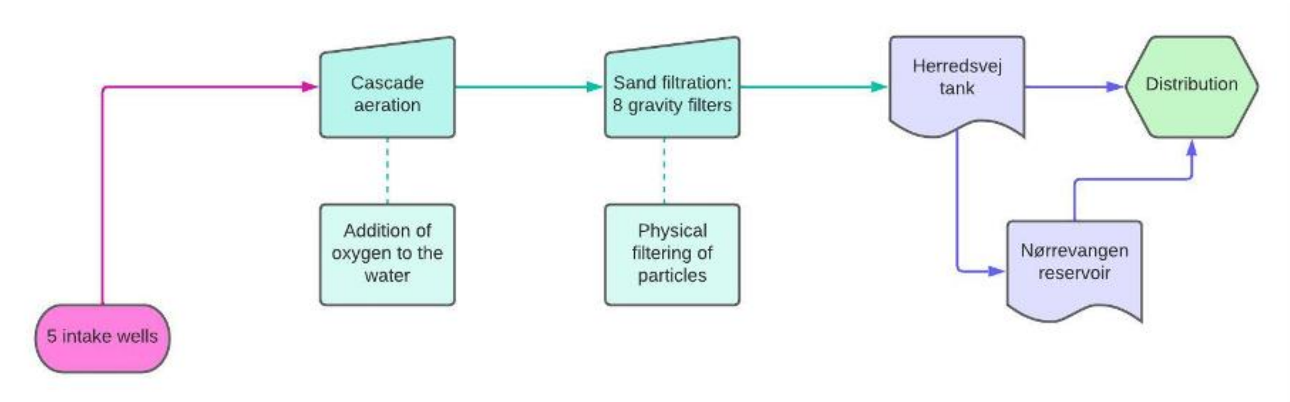


Figure 7.4. Overview diagram of the standard treatment and the way to the distribution system in Hinnerup.

The Raw water supply comes from five different boreholes with the DGN numbers: 79.848; 79.681; 79.803; 79.605 and 79.1731 which are already described in more detail in section 6.3. In Hinnerup the water gets treated in two separate sets each having a cascade aeration and four sand filters. First the Raw water of the five wells gets separated into the two different systems. In the beginning stands the cascade aeration with three steps which can be seen in figure 7.5. Each of the two cascades aerations are in a single room.

Figure 7.5 Picture taken from one of the two cascade aerators in Hinnerup during the visit in the waterwork on the third of May.

After that the aerated water is directly divided into four different flows and headed into the next room in which the two filter sets with each four filter per sides are located in. The sand filters have a channel in the middle from where the water, which can be seen in the figure 7.6. From the channel the water can flow over the edges into the sand filter.

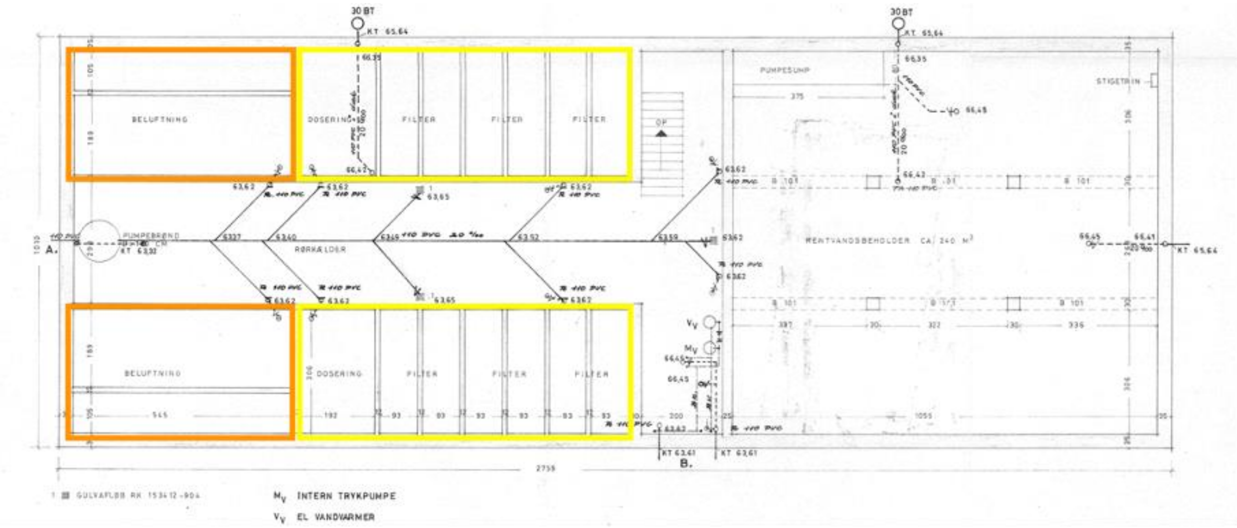


Figure 7.6 Schematic drawing of the floor plan in the Hinnerup waterworks. The orange marked areas are the Cascade aeration. In yellow the Sand filters can be seen. The drawing is from 1973. Since then, the "Dosering" has now also been converted into a sand filter. Provided by the waterworks.

When the water ran through the four filters it is collected and both filter sets are pumped through the pipes into the clean water tank. Here the water is stored before being supplied within the network. All the different pipes and steps can also be seen in the pipe and process diagram in figure 7.7.

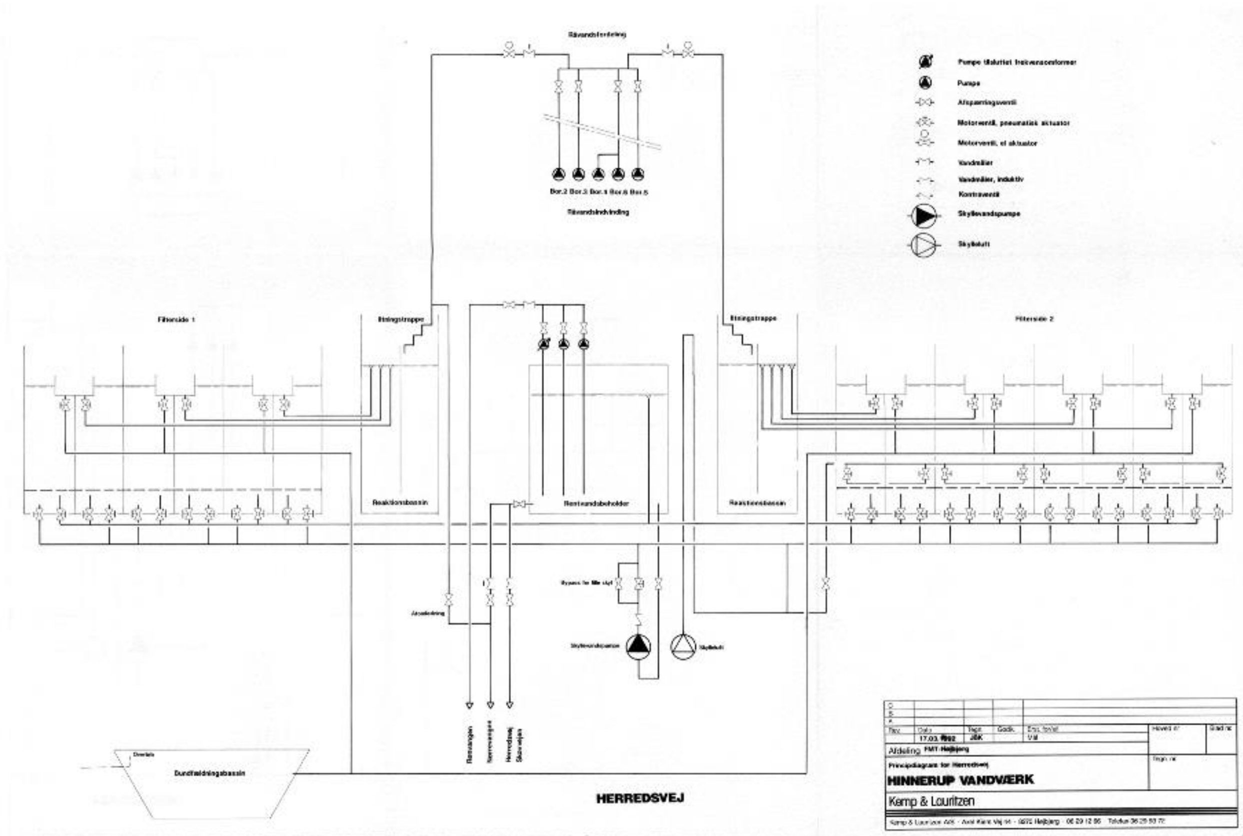


Figure 7.7. Pipe and process Diagram of the waterwork in Hinnerup from 1992 provided by the water-works.

7.2.2 Cascade Aeration. [Cato]

The initial stage of the treatment process, as previously discussed in the preceding subsection, involves aeration. In this step, a specific quantity of 5,8214 mgO_2/L must be introduced into the water to effectively reduce manganese, iron, and ammonium concentrations to their respective DW criteria values.

The required oxygen demand can be observed in table 7.2, and all relevant calculations and formulas utilizing the data from the table are provided in the Appendix 7 (formula 7.1). As the waterwork combines multiple boreholes and divides them into two separate flows, an average value was derived to ensure meaningful calculations.

In the Appendix 7., formula 7.2 contains the calculation for the efficiency of the cascade. Cascade aeration facilitates the removal of gases in the Hinnerup cascade with an efficiency of 36%.

Concentration [mg/L]	79.605	79.681	79.803	79.848	791.731	Average Concentration [mg/L]	Theoretical oxygen demand [mgO_2 /L]	Required oxygen demand [mgO2 /L]
Mn^{2+}	0,25	0,23	0,17	0,27	0,17	0,218	0,29	0,1056
Fe^{2+}	0,62	0,53	0,9	0,93	0,79	0,754	0,14	0,0632
NH_4^+	0,023	0,039	0,095	0,027	0,028	0,0424	3,5	0,1526
Residual oxygen								5,5
Total oxygen demand								**5,8214**

Table 7.3 with the concentrations of Manganese, Iron and Ammonium from each borehole and the respective required oxygen demand. Calculations were made with formula 7.1., Appendix 7.

7.2.3 Filter design [Arne]

As previously mentioned, Hinnerup is equipped with eight individual single-media sand filters. These filters utilize quartz sand, and their primary purpose is to remove oxidized manganese and iron, which have been treated in the reaction basins. Ammonia, on the other hand, is oxidized by the biofilm present within the filter. The filter design employed in Hinnerup is straight forward, as depicted in figure 7.8, which provides a top-down view. Each filter is separated by a channel into two distinct filter areas. Combined, these two filter areas have a total size of 5.69 m^2, with each section measuring 3.05 by 0.93 meters. Detailed dimensions can be found in figure 7.6 of subsection 7.2.1.

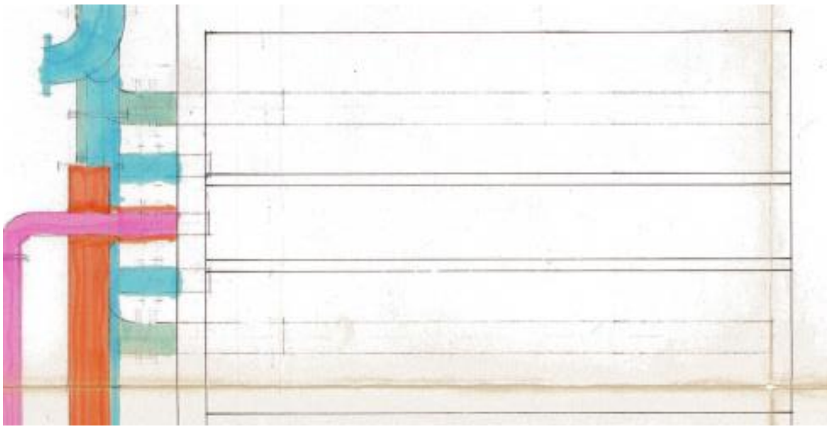


Figure 7.8 The top view of one of the eight sand filters in Hinnerup showcases color-coded pipes entering and exiting the filter. The raw water flow is indicated by the color red, the clean water flow is marked in blue, the backwash water is represented by green, and the pink pipe is used for air ventilation during the backwashing process. Excerpt from drawing provided by the waterworks.

Figure 7.9 and 7.10 provide a comprehensive cross-section view of the filter's construction. The filtration process begins with approximately one meter of quartz sand. Following that, a layer of gravel is added to ensure uniform drainage of the filtered water without any accumulation. Within the figures 7.9 and 7.10, various pipes are depicted in different colors, each serving a specific purpose. The blue pipes transport the drained water to the clean water tank. The green pipes are dedicated to the backwash water, while the red pipe facilitates the entry of aerated water from the cascades. In the drawing, the pink pipes represent the air supply during the backwashing of the filters.

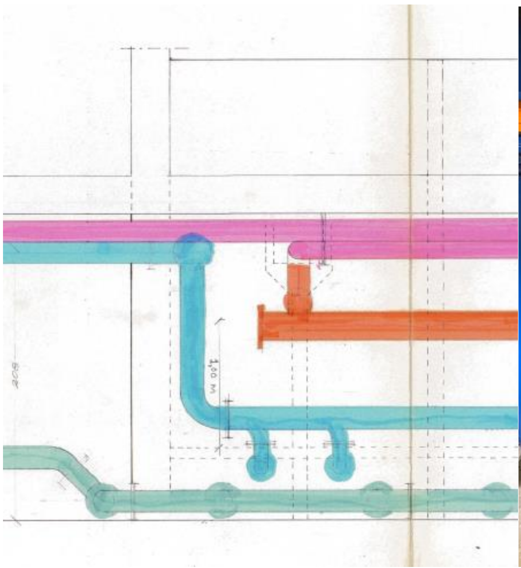


Figure 7.9 (left) and 7.10 (right) shows the filter configuration. The left image is a drawing based on the provided data, featuring a transparent wall that allows for a clear view of the filter. On the right, an actual photograph taken during the visit to Hinnerup Waterworks on May 3rd showcases the real-life appearance of the filter setup.

7.2.4 Filter velocity and filter operation time. [Cato]

	Filtration Method	Filter velocity	Time between backwash
Calculated		0,34592 mm/s	16,78 days

Reality	single Filter, 1-media	0,34592 mm/s	14 days

Table 7.4. presents the key parameters regarding filtration at the Hinnerup Water Treatment Plant, both from real-world measurements and calculated from a dataset.

Based on the data provided in Appendix 7.6., it can be observed that a single filter is utilized, filled with a medium, namely quartz sand.

The filter velocity in table 7.3 was determined using the continuity equation (Appendix 7, Formula 7.3). At the Hinnerup water treatment plant, the filters undergo a backwashing process one after another every two days. In total each filter is backwashed every 14 days. In the initial phase, an air-blower with a capacity of 2895 liters per minute is utilized to blow air for a duration of eight minutes. Subsequently, a combination of air and water is blown for approximately two minutes. The backwash pump employed during this phase has a capacity of 30 cubic meters per hour. Afterward, water is pumped for a period of 30 seconds using the same pump with a capacity of 30 cubic meters per hour. The final step involves the use of a high-yield water pump with a capacity of 125-130 cubic meters per hour, pumping water alone for approximately two minutes. The calculation (Appendix 7, Formula 7.4) show that the required 16,78 days to ensure sufficient filter performance are significantly exceeded. This suggests that the time between backwash cycles is sufficient for optimal filter effectiveness.

7.2.5. Treated water quality [Cato]

	Before Treatment	After Treatment	Drinking Water Criteria
Iron	0,93 mg/l	0,023 mg/l	0,2 mg/l
Manganese	0,27 mg/l	< 0,002 mg/l	0,05 mg/l
Ammonia	0,095 mg/l	< 0,005 mg/l	0,05 mg/l

Table 7.5. Exceeding values before and after treatment plus the drinking water criteria.

Table 7.5 compares the values that exceeded the limits as per section 7.1, both before and after the treatment, with the drinking water criteria. The key finding from table 7.5 is that after the treatment, the values meet the drinking water criteria. This means, on one hand, that the treated water from the tanks can be directed into the distribution system. On the other hand, it indicates that the standard treatment process at the Hinnerup waterwork is efficient and sufficient in ensuring clean drinking water.

7.3 Risk assessment of the present production [Arne]

7.3.1 Risks of water contamination [Arne]

Waterworks are one of the most important parts of a country's critical infrastructure. The fact that running drinking water is always available at any time with virtually no limit is the normal state of affairs for the population. With an output of 417,066 m^3/year it quickly becomes clear that if contamination occurs in the waterworks, many households will be supplied with contaminated water very quickly. But what are the potential risks at the Hinnerup waterworks? This question will be discussed in more detail in this subsection.

Structural hazards can also pose risks in terms of water pollution. In Hinnerup, all necessary precautions have been taken for this purpose. The two process chains in Hinnerup, in which the aeration and filtration take place, are structurally very well separated, and secured from each other, so that no cross-contamination can take place. The cascade ventilation is each in its own enclosed space and the four sand filters are protected behind a glass front together in one room. The arrangement can be seen on the schematic figure 7.11. Unfortunately, it is not possible to see the exact measures just mentioned.

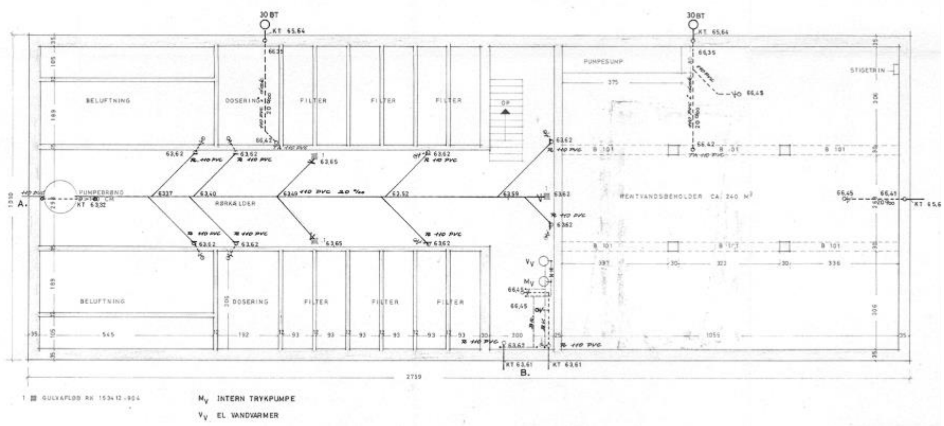


Figure 7.11 Schematic drawing of the floor plan in the Hinnerup waterworks. The drawing is not quite up to date, the "Dosering" has now also been converted into a sand filter.

Another structural hazard could be the aeration holes for the cascade aeration outside of the building. These need to be secured to prevent contamination. Here the aeration holes are secured so nothing from the outside can contaminate the water (Municipality Hinnerup, 2022).

Inadequate treatment is another risk factor that can lead to water contamination. Since there is only aeration and filtration here, the risks here are rather low. However, there is a distinctive feature in the clean water tank. In Hinnerup, the clean water tank is usually kept as full as possible, however this could lead to a water age that exceeds the maximum recommended three days, which increases the risk of germ growth (Slavik, 2020).

This is a rather unusual approach, but the head of the facility prefers to have a little more water in reserve in case of an emergency and is willing to take this risk, since there did not occur any problems with bacterial growth yet. Another source of deterioration in water quality could be sand filters. It is essential that these are regularly flushed back. Otherwise, the filters may become clogged, or the filter function may weaken. Since the facility operates 24/7, they cannot backwash a whole filter set at once. Therefore, they backwash one of the eight filters every second day, ensuring that every filter gets backwashed at the 14-day mark, and they can start with the first one again. (Hinnerup Vandværk, 2022)

Finally, aging infrastructure can also be a risk factor for water contamination. The treatment infrastructure in Hinnerup is relatively old, regarding. Waterworks being built in 1973. During this time, there were always various updates of the distribution networks, but the cascades and six out of the eight filters are still the same from the very beginning. However, with the use of a cascade system and sand filters that are regularly backwashed and checked, the waterworks are doing well. Additionally, the operation of the waterworks is under constant surveillance through the utilization of state-of-the-art technology. This allows for real-time monitoring of the entire system, ensuring its smooth operation. In addition, the network infrastructure is regularly renewed and expanded as necessary to accommodate the growing demand and maintain the efficiency of the water supply.

To guarantee the delivery of the highest quality water, comprehensive testing and analysis are conducted on a regular basis. These tests assess various parameters and characteristics of the water, ensuring that it meets the strictest quality standards. Through this rigorous monitoring process, the waterworks can assure its members that they consistently receive the clearest and cleanest water product.
By employing advanced technology, regular network maintenance, and stringent water quality monitoring, the waterworks remains committed to providing a reliable and pristine water supply to its members. (Hinnerup Vandværk a.m.b.a., 2023)

In conclusion the risks of water contamination in Hinnerup are managed through a combination of measures including monitoring and management of the raw water source, securing the treatment process, proper treatment procedures, and infrastructure updates. It is quite hard to find exact data about the ranking from high to low risks in waterworks since it really depends on the respective situation. However, it is important to remain vigilant and continue to assess and manage these risks to ensure the safety and quality of the drinking water supply.

7.3.2 Supply failure. [Arne]

Ensuring a reliable and uninterrupted water supply to consumers, especially during emergency situations, is of paramount importance for the water work in Hinnerup. The security of supply plays a crucial role in assessing the resilience and preparedness of waterworks in both extraction and distribution processes. To evaluate the security of supply, several key parameters are taken into consideration, as outlined in this subsection.

In case of an emergency the Hinnerup waterwork is one of 17 waterworks in that area, that has an emergency connection to another two waterworks enhancing the security of supply. That being Grundfør and Søften which can be seen on figure 7.12. This connection serves as a backup, enabling water transfer from one facility to another in case of any disruptions or contamination. (Favrskov Municipality, 2023)

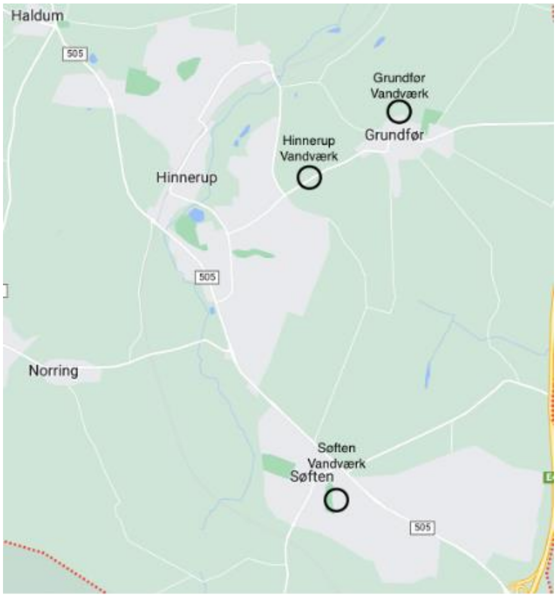


Figure 7.12. Map of the area around Hinnerup waterwork which also shows Grundfør and Søften Waterworks which are the emergency connections for Hinnerup. (Google Maps, 2023).

But according to the Commune the evaluation regarding whether the emergency connections are capable of meeting the water consumption needs of each individual waterworks.

Hinnerup, on the other hand, has additional Recovery Boreholes. Waterworks that have additional recovery boreholes demonstrate an added layer of security. These contingency measures ensure alternative sources of water in the event of groundwater contamination or any unforeseen circumstances affecting the primary extraction source.

Power supply failure is also a significant risk associated with supply failures in the waterworks system in Hinnerup. The treatment processes rely mostly on electrical power to operate, and a longtime power outage would disrupt the treatment process and affect the ability to pump water into the distribution system. (Favrskov Municipality Nature and Environment, 2023) If only short power loses occur most of the treatment processes would still taking place. While the recently installed solar panels could run the

whole facility in the best-worst-case scenario, when the sun is out, and a power supply failure happens. Hinnerup currently has no backup power source in case of brownouts.
Discussions are underway to acquire a generator for such scenarios. (Kommune, 2022) Although it is somewhat unusual for critical infrastructure not to be supplied during brownouts, a generator could be essential during major supply problems or blackouts. Furthermore, many of the processes in Hinnerup run on gravitational power, meaning that if there is a power shortage for a short time, much of the facility can still run for a good amount of time.

Furthermore, waterworks must be adequately secured against vandalism and burglary. Implementing appropriate security measures in Hinnerup like such as locks, surveillance systems, and restricted access helps safeguard the infrastructure, preventing unauthorized access or tampering that could compromise the supply.

Last but not least coming to the capacity of the clean water tank. Hinnerup has a clean water tank which ensures that even during peak demand periods or temporary interruptions, there is an adequate reserve of treated water available for distribution to consumers. In the event of an emergency, the clean water tank can continue to supply the municipality with water for two hours. In the matter of fact, the main operator from the facility mentioned that the Waterwork always tries to have a good buffer for emergencies, which sometimes could lead to a relatively high-water age. By evaluating and fulfilling these parameters, waterworks can enhance their security of supply, ensuring that consumers have access to a reliable and uninterrupted water source, even in emergency situations. These measures contribute to the resilience and preparedness of waterworks, fostering a robust and dependable water supply system for the community (Favrskov Municipality Nature and Environment, 2023)..

7.4 Estimate of maximum production capacity and increasement of maximum capacity to accommodate future conditions [Arne]

With the increasing population in the upcoming years, it is very important to know if and if so, how the capacities of the Hinnerup Water works could be increased as well in this section the focus is on that. Starting with the aeration in the beginning of the treatment process.

The effectiveness of a cascade aeration system relies on the height of each step and the number of steps involved. In general, a cascade with three to four steps and a drop of 30 to 50 cm per step can process 50 m^3 of water per hour for each meter of edge, resulting in an oxygen concentration of approximately 7 mg of dissolved oxygen per liter of water after the aeration process. The recent water analysis conducted at the Hinnerup waterworks indicated an oxygen concentration of 10.6 mg/L, which confirms this expectation. Upon reviewing the initial step of the treatment process, namely cascade aeration, it can be calculated with the formula 7.5 that the cascades have the capacity to handle a significantly larger volume of water of 272,5 m^3, considering that the typical average oxygen concentration is around 10.5 mg/L. Detailed measurements and data can be found in figure 7.13.

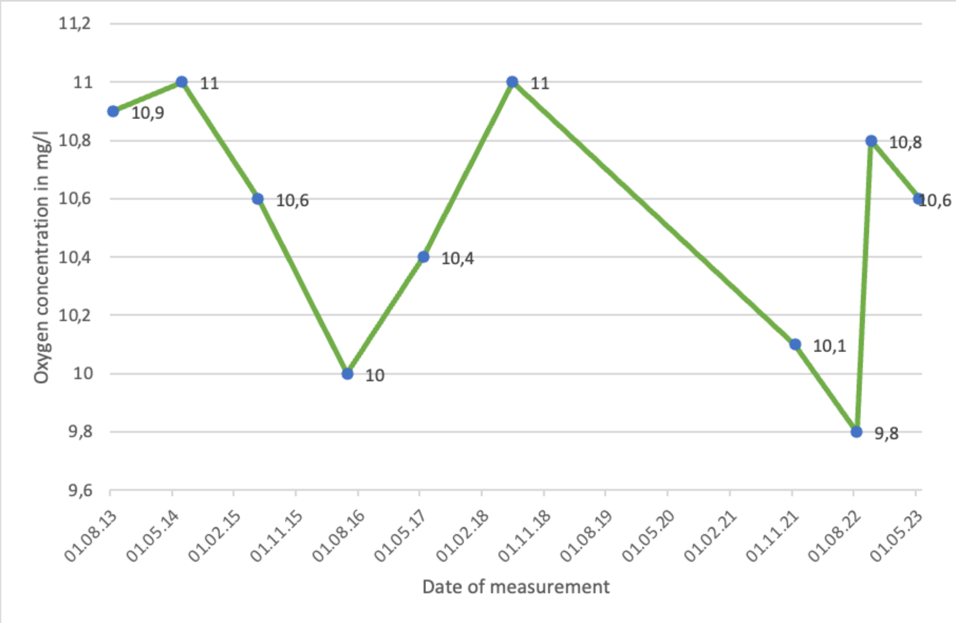


Figure 7.13 The oxygen concentration in the water at the Hinnerup waterworks after aeration consistently measured by Eurofins from 2013 to 2023 (eurofins, 2023)

Coming to the filters: With the calculations about the backwash intervals in subsection 7.2.6 of 16,78 days and the actual 14 days which are operated in Hinnerup is a slight difference, submitting not really a possible optimization. This seems to be an accurate calculation since the filters usually getting back-washed a little earlier than needed to prevent the growth of iron stone (Karlsen & Sørensen, 2014)

The Hinnerup waterworks has an overall filter capacity of 250 m^3/h (Kommune, 2022), which is around two times higher than the in calculated current maximum daily distribution of 129,00 m^3/h found in sub-section 8.2.4. If the flow rate were to increase, the backwash time interval would decrease, resulting in more frequent emptying of the clean water tank. This would put strain on the pumps, which may not be efficient enough to handle the increased demand.

In 2021, the Hinnerup Waterwork had an intake of 417,066 m^3/year. According to the report, the maximum outtake from all five boreholes is 445,000 m3/year. From this there is not more capacity from the boreholes, and they would need a sixth one. However, this information does not align with the fact that approximately 2,720 consumers (properties) are currently supplied with approximately 355,000 m^3 of water per year. The municipality suggests that the discrepancy could be attributed to variations in the meters, which are regularly cleaned and inspected (Kommune, 2022). But with knowing that due to its proximity to Aarhus, Hinnerup is anticipated to experience a substantial population growth in the coming decades which is already explained in more detail in section 5.3. Over the next 10-15 years, it is projected that 1000-1500 new households will be established in the northern part of the town. Now knowing that the Waterwork could potentially have around five times more capacity and the 1000-1500 households only being around 50 % of the current population, it ought to be possible to supply the coming populations.

Also, another important point to consider is the increasing significance of water conservation and efficiency. Compared to a few decades ago, toilets, for instance, consumed significantly more water. (Bundesinnenministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz, 2023)) This trend continues today. During a visit to the Hinnerup waterworks, the operator also mentioned that in the past, fewer households consumed roughly the same amount of water as the current population does.

8. Status of current distribution network

In this section, the status of the current distribution network is described and evaluated. Initially, a structural explanation of the distribution system is described in section 8.1., following a statement of the current water consumption within the distribution network in section 8.2. The current water consumption is stated based on recent consumption data, and daily and hourly consumption variation for each zone has been determined. Finally, a series of MIKE+ and EPANET simulations have been carried out in subsection 8.4., to state pressure and residence time conditions within the distribution network.

8.1. Structure and sections

An overall layout drawing of the current distribution system is provided by the Waterwork and can be found in Appendix 8.1. The layout drawing provides information regarding elevation of the supply zones, pipes, the waterwork supply structure and the tank and reservoir. In addition, the type of pipe network system is described for each of the supply zones. The layout drawing is the basis for the following description of the structure and sections of the current distribution system.

8.1.1 Distributed zones and connections

The following description corresponds to Herredsvej waterwork, where water is initially supplied to 4 zones:

Industrial area………………	Zone I	Pressurized supply by 3 pumps placed in parallel.
Hinnerup Lund………………	Zone H	Pressurized supply by 2 pumps placed in parallel.
Hinnerup Midt………………	Zone M	Gravitational supply.
Nørrevangen reservoir…	Zone N	Gravitational supply.

From Nørrevangen reservoir two more zones are supplied directly from the reservoir:

Kildevangen…………………..	Zone K	Pressurized supply by 3 pumps placed in parallel.
Rylevej…………………………..	Zone R	Pressurized supply by 3 pumps placed in parallel.

The following figure 8.1. shows schematically the flow distribution system, and the way each of them are provided.

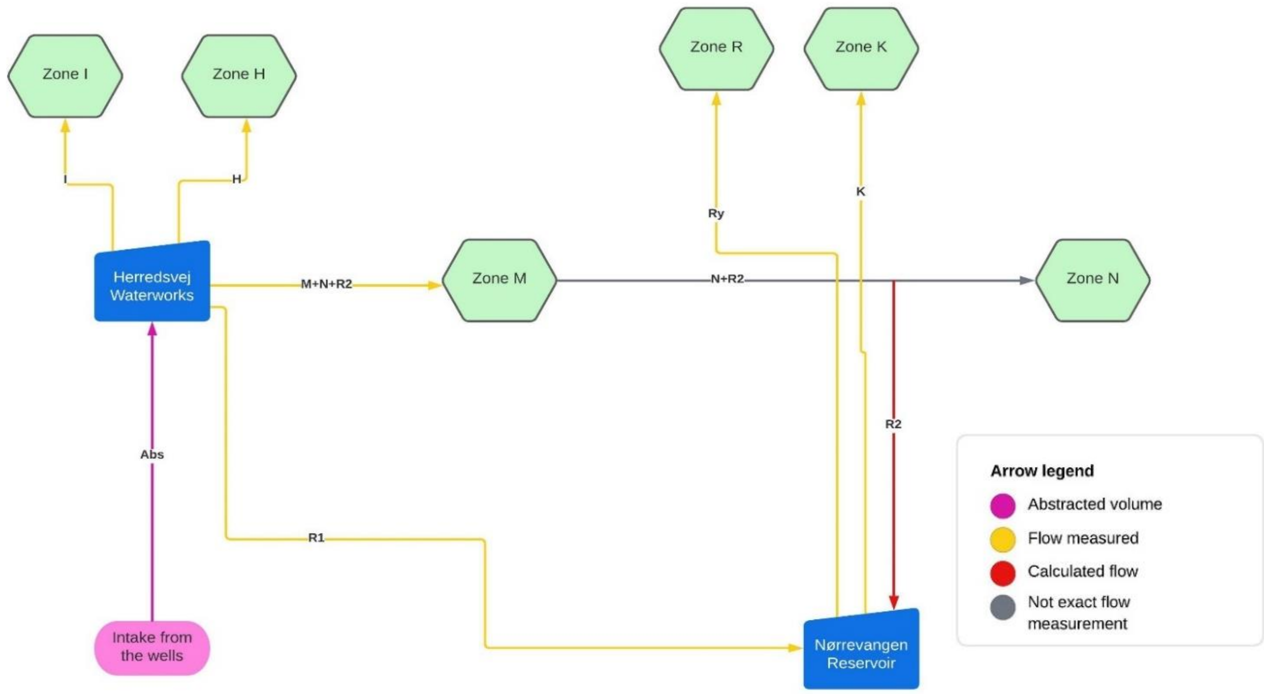


Figure 8.1. Overview diagram of the complete distribution network and denomination of the flows.

Within supply zone M, water is further supplied to a smaller household area; zone N, while some water gravitates to the Nørrevangen reservoir. This secondary gravitational supply to the reservoir (R2) is smaller than the primary supply (R1) directly from the waterwork. According to the Waterwork's yearly report anno 2021, the secondary supply line to the reservoir (R2) constituted to 18,5% of the total output of the reservoir to zone R and K combined. The yearly report can be found in Appendix 8.2. Informations about the pump properties and tank/reservoir capacities of Herredsvej waterwork and Nørrevangen reservoir can be viewed in subsection 8.1.2.

Figures 5.6 and 5.7 in section 5 quantify the amount of distributed water to each zone. The largest amount is being consumed by the zones M and N, followed by Zone R and I. There is no noticeable disparity in the distributed water within one zone over the considered period.

8.1.2 Properties of pumps, tanks and reservoir

In this section, further technical details about the elements in the supply system can be found. These define the limits for the waterworks in terms of supply, giving an idea of how exploited the current resources are. The provided information about the pumps has been obtained from the visit made to the waterworks.

Herredsvej waterwork					
	Pump group	Type	Capacity	Pcs.	Total capacity
Industrial area	(1)	Grundfos CR 30-30	30,0 m^3/h	3	90,0 m^3/h
Hinnerup Lund	(2)	Grundfos CRE 32-20	32,0 m^3/h	2	64,0 m^3/h
Clean water tank*				1	240,0 m^3

Nørrevangen reservoir					
	Pump group	Type	Capacity	Pcs.	Total capacity
Rylevej	(1)	Grundfos CR 20-07	21,0 m^3/h	3	63,0 m^3/h
Kildevangen	(2)	Grundfos CR 30-50	30,0 m^3/h	1	30,0 m^3/h
		Grundfos CRE 10-06	12,1 m^3/h	2	24,2 m^3/h
Reservoir*				1	175,0 m^3

the noted capacities can be found in Appendix 8.3.

Table 8.1. Overview of pumps and storage elements.

Regarding the distribution system, it is highly automated: there are several sensors and actuators in the different parts of the distribution system that activate and stop the pumps. In the case of the clean water tank, it detects when the level is too low and it makes the abstraction pumps work. It is the same with the distribution network: when the pressure drops due to consumption, the distribution pumps are activated and water is pumped.

8.1.3 Pressure levels

The supplied zones have different terrain elevations according to their geography, what is decisive for determining the hydraulic head needed to supply the zone, meaning the features of the pump to use. The energy transmitted to the water flow, which is the pressure should always be high enough to carry the water to the most critical point of each zone. The system characteristic is determined by friction loss, local head loss in components and the geodetic lift.

The table below compares the supply height with the terrain elevation. The column *Lowest pressure in the pipes*, compares the pipes' elevation shown in Appendix 8.1 with the highest terrain elevation for each zone. This pressure must be a positive value, meaning that water can flow to the desired supply zones following the natural tendency to be transmitted from higher energy zones to lower energy zones.

Terrain levels in different zones can be found in Appendix 8.1. It is visible that, in all cases, water flow is guaranteed: the pressure value is always positive, hence there is not a problem. There are, as well, two pressure-reducing valves in certain points of the network. Their purpose is to lower the pressure on the going-through flow. This means that if the water was given the necessary pressure and not more, a valve would not be needed and the extra energy would be saved.

Zone Name		Highest terrain level	Pipe Level [m]	Lowest pressure level in pipe [mWC]
Industrial area	Zone I	59	97,7	38,7
Hinnerup Lund	Zone H	62	92,5	30,5
Hinnerup Midt	Zone M	40	65,0	25
Nørrevangen Reservoir	Zone N	39	65,0	26
Rylevej	Zone R	60	100,5	40,5
Kildevangen	Zone K	78	83,1	5,1

Table 8.2. Terrain levels for the different pressure zones.

8.1.4 Network type

As mentioned, the pipe network system consists of 6 different pressure zones. The pipes are made of either PVC or PE with different diameters on each zone: 250 mm, 200 mm, 180 mm, 160 mm, 125 mm and 110 mm.

The network system within each pressure zone can be classified in 3 different ways:

1- Dead-end network.
2- Gridiron network.
3- Combination of both systems.

Predictably, each of them implies various advantages and disadvantages. Let us examine what they entail.

	Advantages	Disadvantages
Dead-end network	- Simplicity: one-way flow of water. - Reduced risk of contamination coming from other areas.	- Risk of stagnant water, leading to bacterial growth and accumulation of sediments and contaminants. - Sensibility to pipe bursts: water flow in one way all the time.
Grid iron network	- High reliability: alternative routes for the water. - Unlikelihood of stagnant water. - Expansion flexibility: easier connections.	- Complex maintenance: it requires more coordination. - Increased water loss, coming from a higher number of pipelines and connections. - Greater energy consumption coming from pumping.

Table 8.3. Comparison between grid iron network and dead-end network.

The utilization of these distinct systems is contingent upon the specific attributes of each zone, encompassing factors such as size, available resources and hydraulic conditions. The following table classifies the distribution network on each supply zone of Hinnerup. See Appendix 8.5 for further description.

Industrial area, Zone I	Mostly dead-end network.
Hinnerup Lund, Zone H	Dead-end network
Hinnerup Midt, Zone M	Combination: dead-end and gridiron network
Rylevej, Zone R	Dead-end network
Kildevangen, Zone K	Dead-end network

Table 8.4. Distribution network analysis divided in zones.

8.1.5 System security

Regarding the system security, a valve system has been constructed which allows the zones to be supplied in different ways depending on the item that fails, making the system redundant. More specifically, at the Nørrevangen reservoir where Rylevej and Kildevangen are supplied by one pump group each. In case of failure from any of the two pump groups, there is a bypass pipe connecting both that enables the working pump group to supply both zones. Furthermore, valves in the distribution network, of which plenty can be found, can help when contamination events take place, allowing to interrupt the flow and narrow down the problem to a specific area.

In case of needed reparation of any pump, it is convenient to interrupt the connection between the supply areas and the pump group. For that purpose, there are two valves (one for each pump group) that are manually activated and prevent backflow from happening.

8.2. Present water consumption.

The following section studies the present water consumption conditions of the zone and its variation among different periods. This analysis holds significant importance: the maximum value of consumption in a day is used for dimensioning the reservoirs, tanks, abstraction, and treatment facilities. The distribution systems must ensure the maximum hourly consumption value. These quantities in relation to the system capacity provide insights into the potential expansion of the waterworks and other related factors.

It is relevant to know if the data measured in the waterworks is consistent with the theoretical values studied in (Winther, 2010) referring to daily and hourly variations or, on the contrary, there is any discrepancy that could mean measurement errors or consumption anomalies that would be subject to further study. This comparison can be made with the different factors defined to analyze variation.

The following subsections presented aim to comment the conclusions obtained from the various periods analyzed. For daily and hourly analysis, the results are shown all together in table 8.5.

8.2.1. Seasonal consumption: analysis.

Let us examine how the consumption is dependent on the month or season of the year. Seasonal variation affects the overall consumption throughout each month resulting in a decrease or increase in the hour variation of each day. It has been studied for 4 different years and the results are shown in figure 8.2. below.

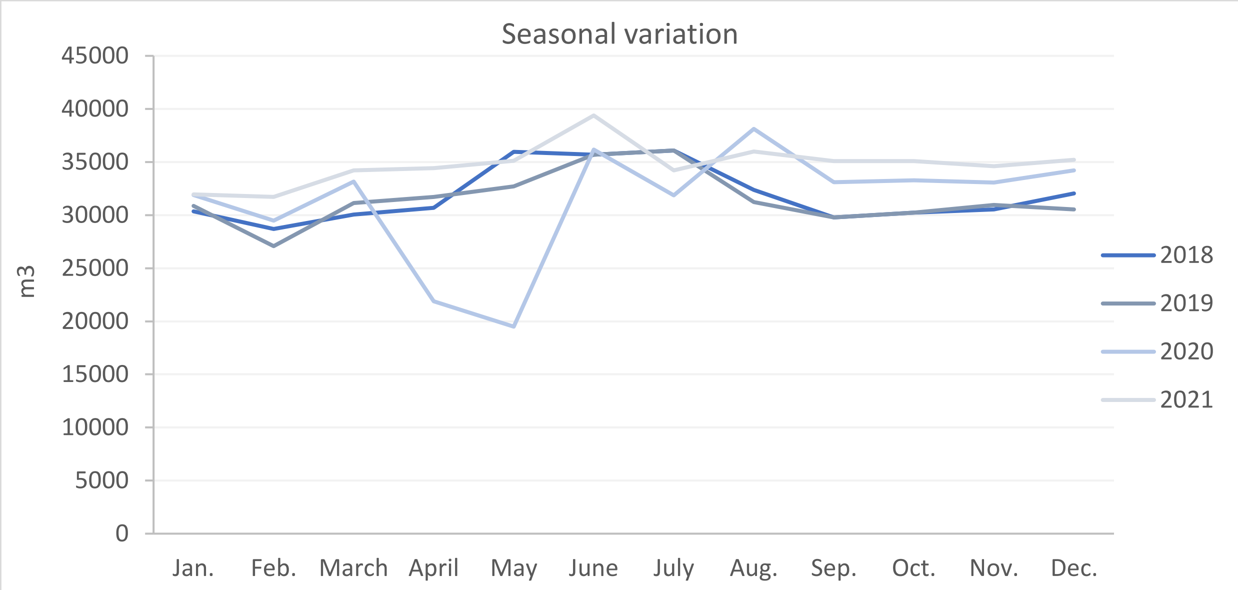


Figure 8.2. Analysis of the consumption throughout the months within 4 different years.

As a conclusion, seasonal variation is presented indicating a higher consumption in the summer period compared to the rest of the year. This is a coherent behavior considering factors like outdoor water use and recreational activities. Furthermore, there is one variation to highlight: in March and April 2020 the consumption was significantly below the usual levels. This drawdown in consumption can be attributed to the COVID-19 Pandemic, with the strict measures affecting business, educational institutions and industries that were either closed or operating with limited capacity for a period. It also involved a huge reduction in tourism and travel.

Though the overall consumption of each month is seasonally dependent, the hour-factor for each hour of the day can be considered much more constant, as the hourly consumption pattern does not depend that much on the season. Therefore hour-factors, based on data from a given month, are representative for determining the general consumption in the system.

8.2.2. Daily consumption: analysis.

This section intends to analyze in 24-hour periods the whole zone consumption [m^3/day], with a basis on the data for each single zone, found in Appendix 5.1. To reach proper conclusions, the parameters studied are the average daily consumptions and the maximum consumption day for each zone. This maximum daily consumption value is relevant for dimensioning the abstraction infrastructure, treatment facilities and tanks.

Not only is the raw amount relevant, but also the relation between the maximum value and the average one. This is defined as the $f_{day,max}$. See Appendix 8.4 for more details. In table 8.5, the separate result for each zone can be seen.

8.2.3. Hourly consumption: analysis.

The following section aims to examine the flow values [m^3/h] within the different hours in a day: both for individual zones and as a zone combination. For this intention, the maximum day hour factor ($f_{hour,max}$) is defined in the same way as the $f_{day,max}$.

The data available covers a 6-day period, meaning that 6 different maximum hour factors have been obtained for each zone. Out of this 6 possible $f_{hour,max}$, the highest one has been used: it poses a more critical situation in terms of water supply. Further explanation on this process is given in Appendix 8.4. The results are shown in subsection 8.2.4.

As further verification for these, there is another data source providing information about the hourly flow (see Appendix 8.2). However, it does not provide values for the average hourly consumption, so it is not enough to obtain the maximum hourly consumption factor. Nonetheless, the calculated values for the maximum hourly consumption can be checked. See figure 8.3 below.

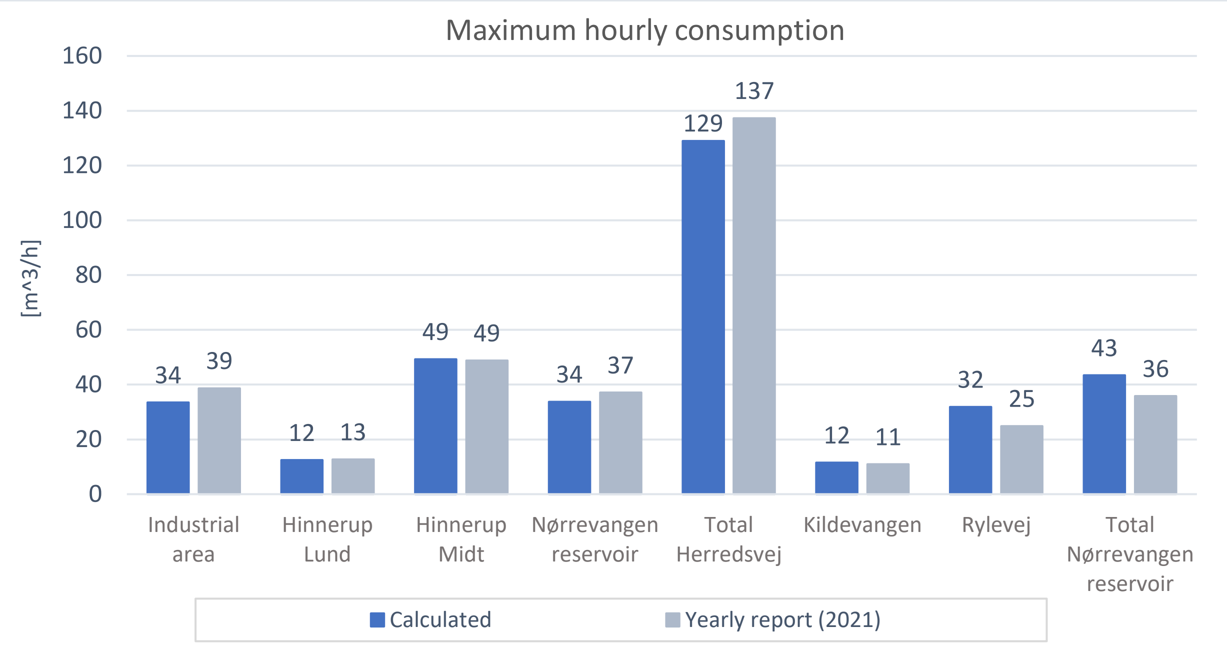


Figure 8.3. Comparison between the result obtained on the data analysis made and the existing data for 2021.

As a comment, the results are significantly similar, meaning that the calculations made have got to the correct results: it could not really be expected to get the exact same results, but it is coherent to get similar values when comparing real data from one year to theoretical and estimated yearly calculations.

8.2.4. Result presentation.

The following table aims to present all the results obtained regarding present consumption.

	Q_{year} [m^3/y] Yearly report	Period [days]	Q_{mean} [m^3/d]	f_{day}	$Q_{max\ day}$ [m^3/d]	f_{hour}	$Q_{max\ hour}$ [m^3/h]	
							Calculated	Yearly report
Herredsvej Waterwork								
Industrial area	72.019	250	288,1	1,31	376,6	2,14	33,5	38,7
Hinnerup Lund	41.902	365	114,8	1,23	141,5	2,11	12,4	12,7
Hinnerup Midt	151.281	365	414,5	1,35	559,7	2,11	49,3	48,8
Nørrevangen reservoir	111.359	365	305,1	1,25	380,3	2,13	33,8	37,1
Total	376.561	-	1.122,4	-	1.458,2	-	129,0	137,3
Nørrevangen reservoir								
Kildevangen	38.823	365	106,4	1,23	131,1	2,11	11,5	10,9
Rylevej	97.752	365	267,8	1,35	361,7	2,11	31,9	24,9
Total	136.575	-	374,2	-	492,8	-	43,4	35,8

Table 8.5. Consumption data per zone analyzed in different time periods.

To conclude this section, a comparison with the data provided in (Winther, 2010): Variation in consumption standard factors} can be made to check whether the obtained values are coherent. See table 8.6. below.

Category	Day factor (f_{day})	Hour factor (f_{hour})
Holiday homes, caravan parks	2,0-4,0	2,0-3,0
Rural area with farming and agriculture	2,0-3,0	2,0-2,5
Villages, primarily sustained by small industries and shops	1,5-2,0	1,7-2,0
Larger cities with a varied mix of industries, offices etc.	1,3-1,5	1,5-1,7
Obtained factors	**1,23-1,35**	**2,11-2,14**

Table 8.6. Comparison of the range of the results obtained with the established values.

It is challenging to classify the zones among one of the studied types. According to the features of the zones, it could be named as a village, but since some of the houses may be holiday homes, there is an acceptable range of variation for the obtained factors. Consequently, the results obtained show an acceptable similarity to the expected ones.

8.3. Waterworks capacity in relation to maximum daily consumption.

Maximum daily consumption of the full distribution system is to be placed in relation to the treatment facility capacity as well as the abstraction demand. It shows how demanded the current infrastructure is. Figure 8.4 below compares the supply pumps' capacity (see Appendix 8.3.) with the calculated value for the maximum hour consumption on each zone, thus knowing whether there is any pump under excessive usage and more prone to collapse.

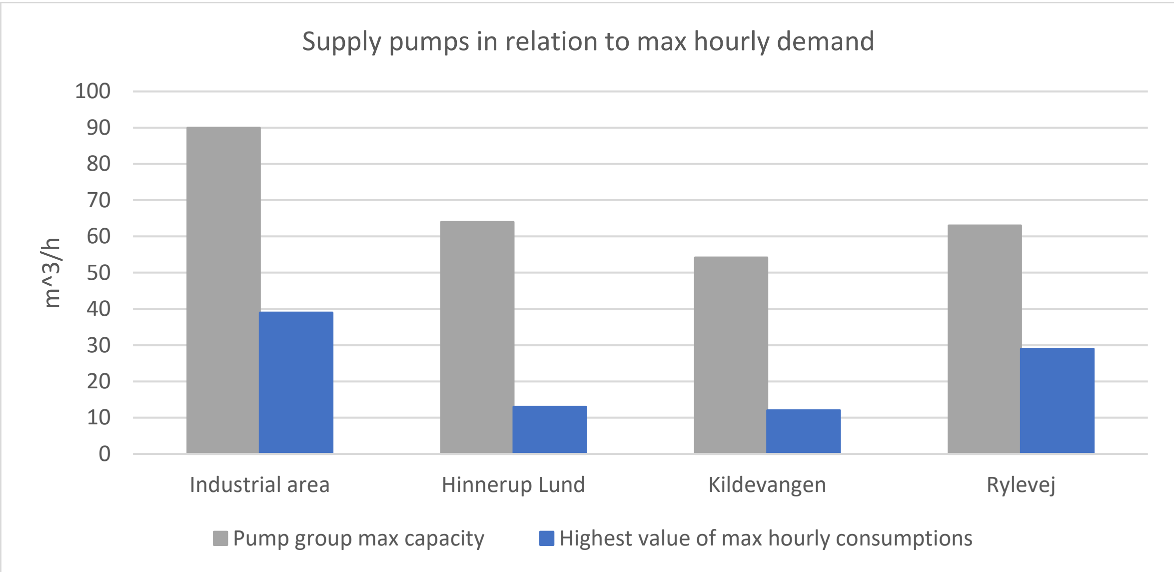


Figure 8.4. Maximum usage of the existent pumps with the assessed requirements.

It can be observed that none of them has to perform at more than the 50% of the total capacity. This means that not all the pumps among one same zone will be required to work at the same time, thus if one of them needs to be repaired the supply won't necessarily be completely interrupted. Consequently, the infrastructure can handle a larger volume of water without encountering any issues, which is a positive result.

8.4 Consumer pressure in the network

A status of consumer pressure during the hour of maximum demand are presented and evaluated in the following subsection. The status is based on the results prepared with the use of the hydraulic modeling system MIKE+ EPANET. Consumer pressure have been investigated for each zone separately. For each zone, consumer pressure during maximum hour demand has been modeled for 2 scenarios:

1) Flow evenly distributed within the zone. Most critical discharge point is identified.
2) 50% of maximum hour demand distributed to the most critical discharge point.

In table 8.7 below, consumer pressure is presented within each zone. In addition, the following results are included in Appendix 8.0, resulted from the simulated hydraulic models:

- An overview of the model parameters
- A sensibility assessment of the model parameters
- Map overview of consumer pressure at different points in relation to the elevation for each zone.
- Profile plot for each zone visualizing the change in pressure when the water is moving from the main supply pipe to the identified critical discharge point of the zone.
- Overview of velocity and pump operation within each zone.

It should be noted that the presented results in table 8.7 below, is based on a simplified hydraulic modeling, with no pressure requirements being specified within the distribution system. Therefore, the presented pressure values are based on a pump efficiency of 100% within each zone, hereby providing the highest possible pressure. For further explanation see Appendix 8.Z

		Max hour demand of zone [m^3/h]	Min. pressure [mWc]	Max. pressure [mWc]	Pressure req* [mWc]
Hinnerup Lund	Zone H				
	Scenario (1)	12,7	29,90	47,26	20-50
	Scenario (2)	12,7	29,77	-	
Industrial area	Zone I				Min 20 with considera-tion for fire hydrants.
	Scenario (1)	38,7	54,08	67,96	
	Scenario (2)	38,7	48,44	-	
Hinnerup Midt	Zone M				
	Scenario (1)	48,8	16,75	38,81	
	Scenario (2)	48,8	8,47	-	Max 50 with considera-tion for con-venient tap-ping at the tap.
Kildevangen	Zone K				
	Scenario (1)	10,9	51,89	72,36	
	Scenario (2)	10,9	51,74	-	
Rylevej	Zone R				
	Scenario (1)	24,9	83,34	138,72	
	Scenario (2)	24,9	0,00*	-	

see explanations below

Table 8.7 Minimum and maximum consumer pressure for each zone during the hour of maximum demand

The required pressure within the distribution network should not be below 20 mWc with consideration for fire hydrants and not more than 50 mWc with consideration for convenient tapping at the tap. (Winther, 2010).

Rylevej, scenario 2, reaches a min. pressure of 0,00 at the most critical discharge point due to elevation difference, long supply distance and high friction loss coursed by a pipe diameter of 50 mm. The critical discharge point is only supplying 8-9 households and the scenario should therefore only be seen possible in case of fire in the area within the same hour of maximum demand for the zone. A simulation error control regarding the scenario 2 result can be found in Appendix 8.7.3.

8.5 Max residence time of the water in the network

A status of max residence time of the water within the distribution network, over a time period of 72 hours, are presented and evaluated in the following section. The status is based on the results prepared with the use of the hydraulic modeling system MIKE+ EPANET. Max residence time of the water have been investigated for each zone separately.

Hourly variations patterns for each zone have been considered and is based on the consumption data of January. Analyses indicate that water demand in Hinnerup is lowest during winter. With lower demand, the flow supply is smaller, hereby decreasing the velocity and thus increasing the residence time of the water in the network.

An overview of the model parameters as well as a sensibility assessment of these are described in Appendix 8.8.1. and 8.8.2. In addition, map overview of max residence time within each zone, as well as graphical view of max residence time, can also be found in Appendix 8.8.3 and 8.8.4.

In the table 8.8 below, the maximum residence time of the water is presented for each zone separately.

		Average hour demand of zone [m^3/h]	Min. residence time [hh]	Max. residence time [hh]	Req. for max residence time
Hinnerup Lund	Zone H	4,5	3-4	13	Max 72 hours (Anders Hahn Kristensen, 2014)
Industrial area	Zone I	7,4	5-10	27	
Hinnerup Midt	Zone M	19,2	5-10	31	
Kildevangen	Zone K	4,5	2-3	21	
Rylevej	Zone R	9,8	5-10	+72	

Table 8.8 Minimum and maximum residence time for each zone during month of lowest consumption.

High exceeding water age of +72 hours can be seen within Rylevej due to a pipe diameter of 160 mm at the critical discharge point. This results in a very low velocity because of the limited applied node demand. A map overview of the maximum residence time for the zone of Rylevej can be viewed in Appendix 8.8.3.

8.6 Evaluation on distribution network

For the current distribution network, consumer pressure can be seen to have a high degree of diversity (table 8.1) This is firstly due to the highly changing terrain elevation within each zone. Secondly, each zone has different groups of pumps, each of them with their unic operational specifications.

Thirdly, due to the simplification of the network model, no pressure requirements are being specified within each distribution zone. Therefore, the presented pressure values are based on a pump efficiency of 100% within each zone, hereby providing the highest possible pressure. Further requirements regarding pressure should be specified within each hydraulic model of each zone to state the impact of these. With pressure requirements being specified, it would be expected that the pressure will see a drop within each zone. This could create a challenge with regards to the minimum pressure within Hinnerup Midt, where the minimum pressure is below 20 mWc for scenario 1 (subsection 8.4) with the maximum hour demand flow being evenly distributed in the zone. However, as described in Appendix 8.7, scenario 1 is only distributing the flow between the dead-end-nodes of the zone, hereby increasing the overall flow within the network. Less flow could potentially create a small increase of the minimum pressure as less friction would be expected.

Looking at Rylevej, zone R, the minimum pressure reaches 0 mWc in the case of scenario 2. The pressure of 0 mWc is seen at the most critical discharge point due to elevation difference, long supply distance and high friction loss coursed by a pipe diameter of 50 mm. The critical discharge point is only supplying 8-9 households and scenario 2 should therefore only be seen possible in case of fire in the area within the same hour of maximum demand for the zone.

When it comes to the maximum residence time, the whole distribution network is within the requirement of a maximum 3-day residence time of the water. The criteria is only being exceeded in the case of a smaller area in the zone of Rylevej (Appendix 8.8.3), which is due to the combination of low flow and large pipe diameter.

Lastly, looking at the velocity within the distribution network, this is an area of high concern (Appendix 8.7.5). The velocity within each zone during the hour of maximum consumption, is not more than 0,6 m/s at any point in the network, and with velocities going as low as 0,05 m/s. This is more than far from the EU standard regarding an economical velocity of 0,8-1,4 m/s (Winther, 2010).

9. Future distribution system

The following section will investigate whether supply can be achieved within the area of the planned urban expansion as it has been described in subsection 5.2. A growth of 1000 to 1500 households is expected to take place, meaning that the existing water infrastructure must adapt to accommodate the increasing demand. The demand requirements for the supply of the future urban area will be estimated in order to determine the most convenient way to connect the new urban area to the existing distribution network. In addition, investigation will be prepared with the use of the hydraulic model tool MIKE+ EPA-NET.

9.1. Assessment of future water consumption

This section intends to quantify approximately the raw amount of water per year needed to supply the new urban area. On this purpose, the method used for analyzing the current consumption has been used again. By estimating the consumption per capita and predicting that the new buildings will mainly be households (in terms of seasonal and daily variations behave in the same way as the majority of the present zone), a realistic prediction has been conducted. See Appendix 9.1. The result is a flow for water distribution of 180675 m^3/year.

In order to check if this value is proportionally similar to the data available, the table presented below facilitates a comparison between the current annual consumption per household (see Appendix 8.1.1. for data) and the estimations that have been conducted.

	Present yearly consumption (2021 report)	Future yearly consumption for new urban area
Total yearly [m^3]	376.561	180.675
Households	2.722	1.500
Consumption per house per year [m^3]	138	120,45

Table 9.1. Consumption comparison of current data with predicted values for the future urban area.

The annual consumption per house estimated is lower than the known one. One reason why this occurs ought to be that in the current supply zone of Hinnerup there is one Industrial zone in which the specific quantities and usage are not determined. On the contrary, the expected zone for the future is merely residential, so the consumption value would reasonably be lower. This difference could be avoided if more data about the exact number of households per zone was available, allowing to make a comparison with an area without industry. However, for the purpose needed (checking the estimation made), the difference would not be so significant, so the approach has been simplified.

9.2. Evaluation of point of connection for the new supply network zone

This subsection aims to conduct an evaluation regarding the most optimal point of connection for the new supply area to the existing one. Several technical factors must be considered, including:

1. **Hydraulic capacity**, considering adequate flow rates and pressure levels.
2. **Geographic location** and physical proximity of the new supply zone to the existing system.
3. **Water quality**. The treatment plant must be able to deal with the increase in water demand.
4. **Infrastructure compatibility**, examining the condition of pipes, valves and pumps.
5. **Regulatory compliance**, setting the limits of abstraction or other instructions.

9.2.1 Hydraulic capacity

Assessing the hydraulic capacity of the existing system is crucial to ensure that it can accommodate the additional water demand from the new supply zone without compromising the overall system performance. On this purpose, several factors are relevant. First to mention, the prognosis of consumption in this new supply area is based in knowledge of similar areas.

In first place, the main pipes supplying the zone to which it will be connected should have enough pressure and flow to supply the new critical point. If the current system could not guarantee an effective supply in the worst day at the worst hour, further adjustments should be made. Dimensioning the new zone involves finding proper values for day and hour factors, which give an idea of the relationship between the highest consumption and the average one in a defined period.

For this aim, the same maximum hour and daily factors previously calculated for the present consumption will be used. The most similar zone in these terms is Hinnerup Midt (Zone M): the flow volume is similar and in both cases the zone is merely (or mostly composed of households. Furthermore, the active period for both zones is 365 days.

	Total consumption [m^3/year]	Active days
Zone M	151.281	365
Future urban area (F)	180.675	365

Table 9.2. Consumption quantity comparison between Hinnerup Midt and the Future Urban Area.

The purpose of the table presented below is to determine the values for the projected maximum daily and hourly flow rates. Both values are crucial for assessing whether the existing tanks, pumps, and pipes can effectively handle the anticipated increase in flow. See calculations in Appendix 9.2.1.

	Q_{year} [m^3/y] Yearly report	Q_{year} [m^3/y] Estimation	Q_{mean} [m^3/d]	$Q_{max\ day}$ [m^3/d]	f_{day}	$Q_{max\ hour}$ [m^3/h]	f_{hour}
Zone M	151.281	-	414,5	559,7	1,35	49,3	2,11
Future urban area (F)	-	180.675	594	668,5	1,35	58,8	2,11

Table 9.3. Estimated values for the future urban zone, in relation to Hinnerup Midt.

Considering the value obtained for the maximum hourly flow, the maximum flow velocity within a supply pipe can be estimated as well. In order to provide the best pipe connection possible, the same pipe diameter as Rylevej's supply pipe (geographical connection explained in subsection 9.2.2.) has been assumed to use. This is a 160 mm diameter of PVC. The maximum hourly flow estimation is of 58,8 m^3/h and leads to a maximum flow velocity of 0,59 m/s which is acceptable and close to the range of the economical flow velocity, being 0,8-1,4 m/s (Winther, 2010). Thus, the expected flow in the future urban area is, in this first approach, well managed.

For further conclusions, it is necessary to evaluate the connection point for additional conclusions regarding the compatibility with the current network. Refer to the sections below for more details.

9.2.2. Geographical location and connection to the existent network

The new supply zone is predicted to be in a Northern-West zone of Hinnerup, close to Rylevej and Kildevangen. Given the physical proximity of the area to Zones R and K and the data for pressure given by the pumps (section 8.1.3.), the most convenient connection is to Rylevej zone, which is supplied by Nørrevangen reservoir. Hence, the pipe that used to supply only Rylevej will now have to deliver both flows: Rylevej and the future urban zone. Considering the connection of the new supply area, the updated amounts to supply are the ones shown in the table below.

	Q_{year} $[m^3/y]$ Yearly report	Q_{year} $[m^3/y]$ After implementation of Zone F	$Q_{max\ day}$ $[m^3/d]$	f_{day}	$Q_{max\ hour}$ $[m^3/h]$	f_{hour}
Kildevangen (K)	38.823	38.823	132,8	1,25	11,7	2,11
Rylevej (Ry+F)	97.752	278.427	1.030,2	1,35	90,8	2,11

Table 9.4. Estimated water consumption after implementing the future urban area.

On the aim of giving a more graphic and clear sight on the description, the following figure 9.1 simplifies the analysis and the different flows to consider for this future system.

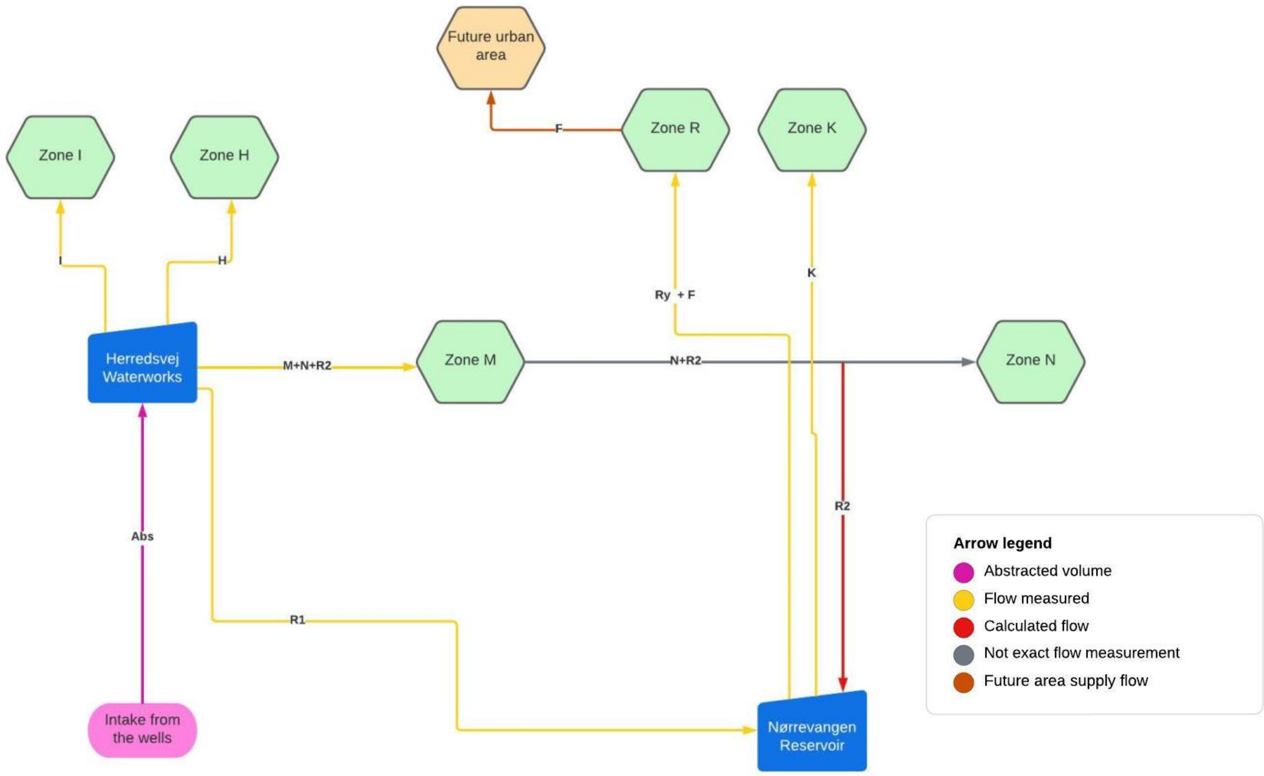


Figure 9.1. Flow diagram for the future distribution system.

Considering the approach already made to determine the consumption in the present, it can be said that the consumption amount is measured in the outflows from Herredsvej Waterworks. The resulting quantities can be seen in the table below, along with the day and hour factors.

	Q_{year} Yearly report [m³/year]	Q_{year} After implementation of Zone F [m³/year]	$Q_{max\ day}$ [m³/d]	f_{day}	$Q_{max\ hour}$ [m³/h]	f_{hour}
Zone I (I)	72.019	72.019	376,6	1,31	33,5	2,14
Zone H (H)	41.902	41.902	141,5	1,23	12,4	2,11
Zone M (M+N+R2)	151.281	151.281	559,7	1,35	49,3	2,11
Nørrevangen Reservoir (R1)	111.359	292.034	997,4	1,25	88,6	2,13
Total distribution flow	376.561	557.236	2.075,2		183,8	

Table 9.5. Estimated impact of the future urban area on the existing supply system.

The total sum of flow for Herredsvej distribution to manage is 557.236 m³. Considering this information, and the data regarding pump capacity (section 8.1.2.) we can reach the following conclusions. See Appendix 9.2.2. for calculations.

9.2.2.a. From Herredsvej to Nørrevangen.

The flow R1 will increase an estimated quantity of 180.675 m³. However, it flows by gravity to Nørrenvangen Reservoir. In this sense, there is not any pump in this part of the network to observe, so no capacity is challenged.

The maximum expected flow for this pipe is 88,6 m³/h, which according to the pipe dimensions means a velocity of 0,87 m/s (see Appendix 9.2.2.) contained in the economical flow velocity interval (Winther, 2010). Thus, the pipe is totally compatible with the expected performance.

9.2.2.b. From Nørrevangen to the New Urban Area.

The pump group providing Rylevej (the previous flow, according to figure 8.1., was *Ry*) must now provide *Ry+F*. See calculations in Appendix 9.2.2. The pump group is not able to provide this new zone in the maximum consumption time, increasing from the current performance of 46% of the total capacity to the impossible value of 144%. The comparison is shown in the figure 9.2.

For this issue, several solutions can be considered.

- The bypass pipe in Nørrevangen that could be used on this purpose as well. Nevertheless, this technical installation should be studied to the details, to see if it is a realistic approach and possible to make the two individual pump groups work as a whole group providing two different zones. In terms of capacity, it would mean a performance of 77,47% of the whole system. Moreover, it would be more susceptible to failure: the supply would not be guaranteed.
- The installation of a new pump with a capacity of, at least, 30 m³/h. In this way, the pump groups would still be working as two individual groups. The maximum performance required would be considerably high: 97,63%. Thus, a special performance mode could be studied, using the second pump group as well (the one currently supplying Kildevangen). This scenario is not very secure in terms of supply, given that a 1,1-1,5 capacity requirement factor is used in Hinnerup Waterworks, according to (Favrskov Vandforsyningsplan (2020-30), 2020).

Figure 9.2 below compares, in terms of pump performance, the current scenarios as well as the possibilities mentioned for the future. The third columns are, as, it can be observed, a non-suitable scenario. Further study would be, without a shadow of a doubt, needed to find the most convenient solution for this issue.

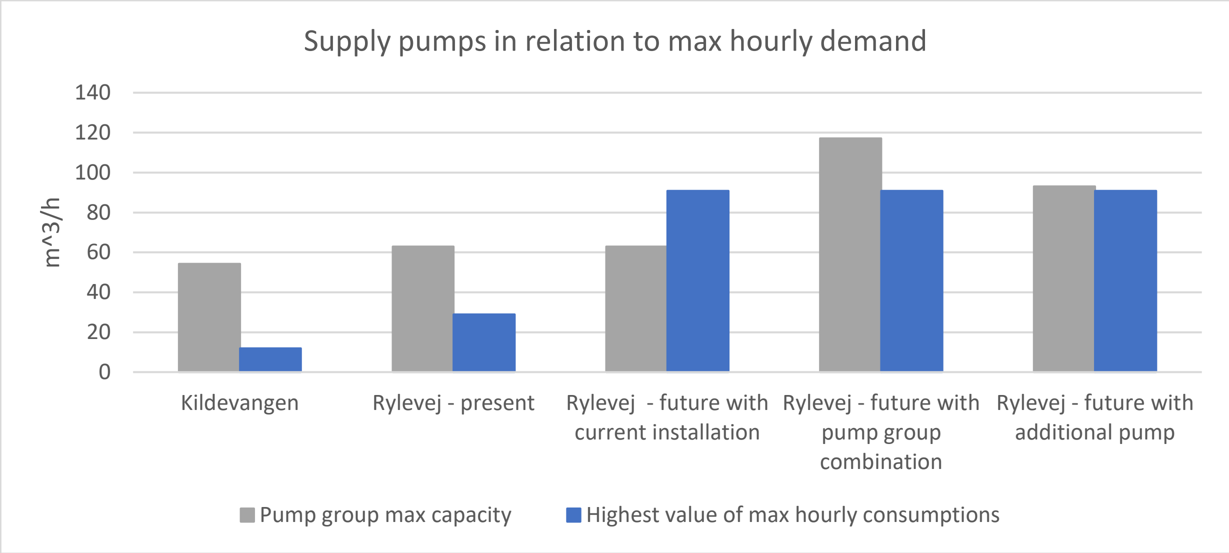


Figure 9.2. Evaluation of the different possible scenarios to supply Nørrevangen after the implementation of the future urban area.

9.2.3. Water quality.

This section intends to check whether the current treatment plan can successfully treat the predicted amount of water.

In first place, the oxygen requirements must be the same: the water is to extract from the same wells as it is already being pumped up, so the concentrations of different constituents considered are the ones known in the present time. There is not any way of predicting changes on them, but as studied in section 7.1., historically there are not any trends that can need of special treatment. After the abstraction the water flow goes through the cascade aeration process, exactly in the same way as before. The cascade aeration capacity was already estimated in section 7.5 with a quantity of 272,5 m^3/h. The maximum hourly flow estimated is 183,3 m^3/h, so the cascade aeration step is not expected to have any problem with the flow increase.

Given that the planned scenario is the worst possible to happen in terms of quantities to supply, the sand filtration step must be studied for the maximum daily flow (2.075,2 m^3/day). The overall filter capacity (Kommune, 2022) is 250 m^3/h, which would be translated into 6.000 m^3/day against the maximum expected daily consumption of 2.075,2 m^3/day. This means that in terms of capacity, the filters are proved to successfully work. When handling this larger quantity, backwash is needed every 11,79 days (see Appendix 9.2.3.). The current functioning times involve backwash every 14 days, so the procedure must be revised and properly adjusted to the new requirements.

In conclusion, in terms of water quality, no alarming parameters have been observed that determine the need to adapt the treatment plant.

9.2.4. Infrastructure compatibility.

In first place, the abstraction pumps must be able to pump up as much water as needed. In the most comfortable scenario, the 5 existing wells would do it. This is subject to further study. See Appendix 9.2.4.a. for calculations.

- The total abstraction capacity of the pumps is 3082 m^3/day.
- The estimated maximum daily distribution is 2075,2 m^3/day.

In terms of capacity, the abstraction does not suppose any problem, so the pump infrastructure is well prepared for the future consumption.

The flow velocity in the pipes of the network is also a matter of importance. To check the compatibility, the maximum hourly flow should be studied. See calculations in Appendix 9.2.4.b, and results in table 9.6 below.

Time	Flow	Outside diameter [m]	Inside diameter [m]	Highest max hourly flow value [m^3/h]	Flow velocity [m/s]
Present	Ry	0,2	0,188	31,79	0,32
Future	Ry + F	0,2	0,188	90,8	0,91
Future	F	0,16	0,154	58,8	0,59

Table 9.6. Flow velocity in the distribution pipes after the implementation of the new urban area.

As a conclusion, the values obtained are still far from the optimal velocity (Winther, 2010), which is the most convenient one. Hence, there is no way for the velocity to be too high for the network supply. Even if it is out of the optimal range in some cases, since the values obtained are not too high, the pressure losses will not be so either.

9.2.5. Regulatory compliance.

During the evaluation process, it is crucial to consider permits, environmental impact assessments and legal requirements to ensure adherence to applicable guidelines. Now, the annual limit of extraction is 445.000 m^3. Considering that the predicted abstraction volume is of 600.533 m^3, it is of fundamental importance to obtain the required permissions and carry out environmental research on the impact of this increase of the abstraction. Nevertheless, this extraction permit is renewed every year according to the needs of the zones and guaranteeing the supply.

9.3 Assessment of consumer pressure and residence time regarding the network of future urban area

The following subsection will investigate consumer pressure and residence time within the area of the planned urban expansion. On figure 9.3, the area of the planned urban expansion can be viewed. The investigation will be prepared with the use of the hydraulic model tool MIKE+ EPANET. A description of the use of the model can be found in Appendix 8.0.

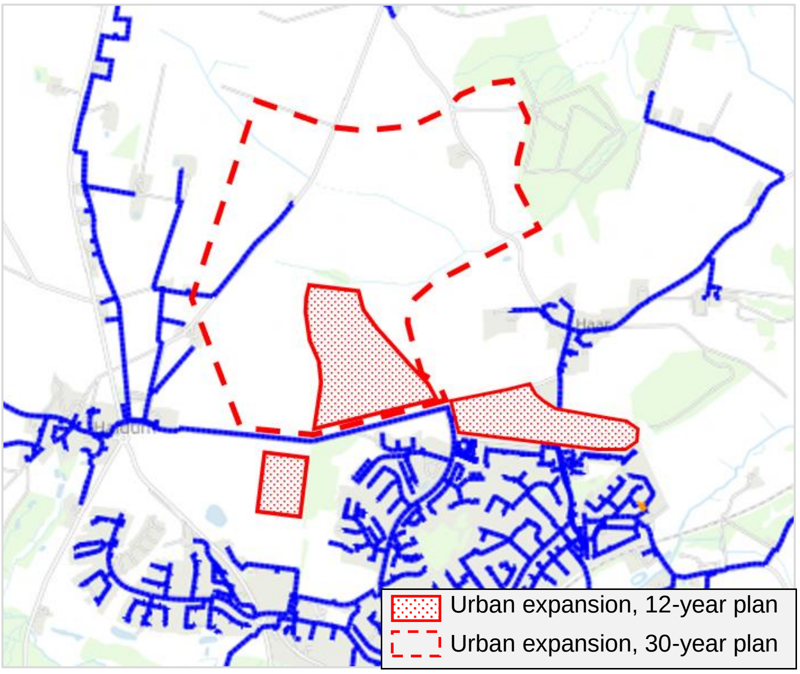


Figure 9.3 Area of planned urban expansion

The following consumption parameters is the basis for the preparation of the hydraulic modeling.

Future urban expansion area: zone F		
To be supplied from / connected with	Zone R	
Future yearly estimated consumption of zone F	180.675	[m^3/year]
Estimated maximum hour consumption of zone F	58,8	[m^3/h]
Flow demand at inlet pipe to zone F	16,3	[L/s]

Table 9.7 Consumption parameters for new area, zone F.

The model will investigate whether sufficient supply can be achieved in relation to:

1. Consumer pressure at critical discharge point, scenario 1
2. Maximum residence of the water within the new zone F

A description of scenario 1 can be found in Appendix 8.2.

The potential most critical discharge point of the new zone has been identified on figure 9.4 below. Furthermore, in the hydraulic model, each identified point will be supplied by a 63 mm pipe, thereby enforcing increased friction loss to these points.

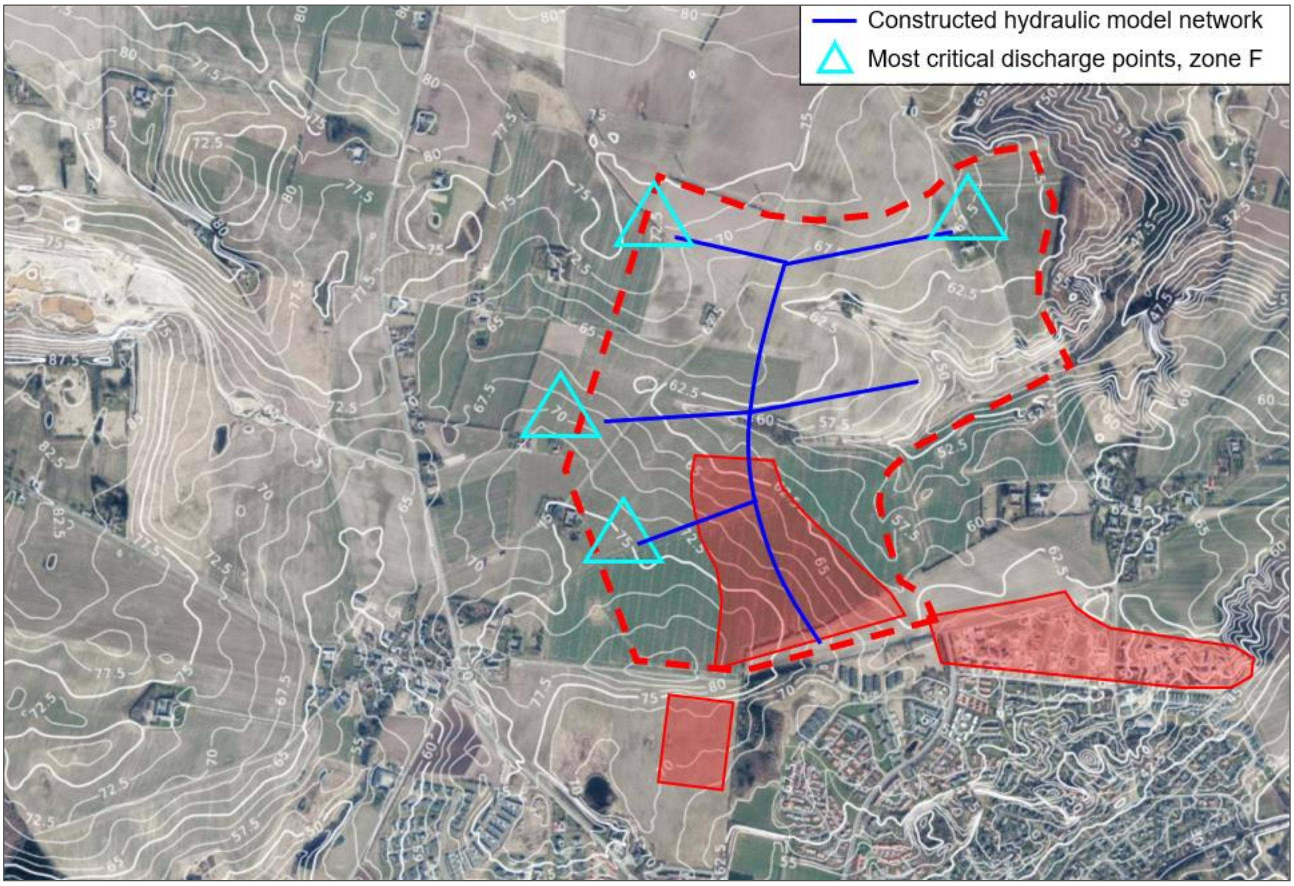


Figure 9.4 Overview of constructed hydraulic model network and identified most critical future discharge points, Scalgo LIVE.

Based on the described parameters and conditions of the new area in figure 9.4 and table 9.7, an overview of the specific hydraulic model inputs can be found in Appendix 9.3. The results of the investigation is presented in subsection 9.3.1 below.

9.3.1 Consumer pressure at critical discharge points in future supply area

The following subsection presents the results of the hydraulic modeling for the investigation of sufficient distribution to future zone F in relation to consumer pressure at critical discharge points. On figure 9.5 below, the pressure levels resulted from the model simulation can be viewed within 48 to 74 mWc. Sufficient supply to the future area can be considered achievable.

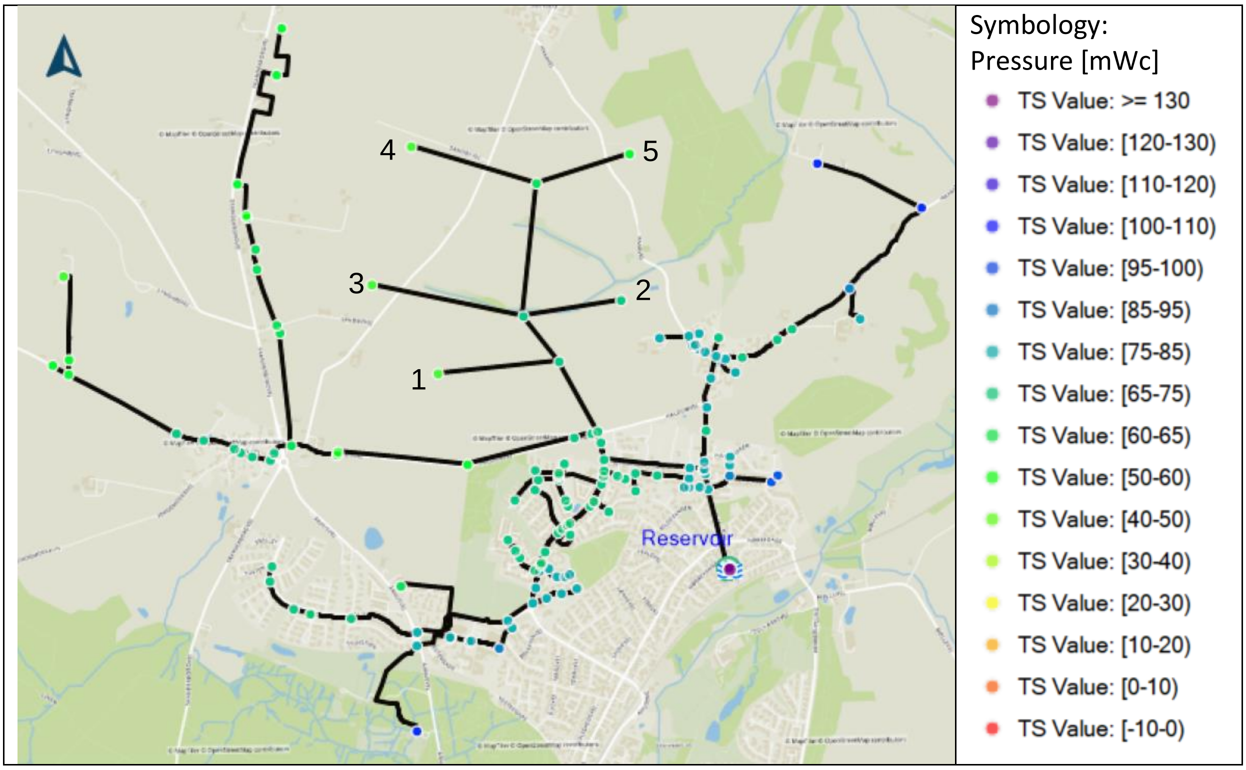


Figure 9.5 Consumer pressure at critical discharge points for future zone F and current zone R when zone F is connected. Result of hydraulic modeling.

Type	Node Water Demand [L/s]	Elevation of critical discharge point, cf. figure 9.4 [m]	Node pressure at critical discharge points [mWc]
Dead-end-node 1	3,26	75	48,10
Dead-end-node 2	3,26	50	74,28
Dead-end-node 3	3,26	70	49,85
Dead-end-node 4	3,26	72,5	48,87
Dead-end-node 5	3,26	67,5	56,48
Total demand	*16,3*		

New pump operation	Pump flow [L/s]
Pump 1, zone R	7,74
Pump 2, zone R	7,74
Pump 3, zone R	7,74

Table 9.8 Flow demand and consumer pressure at critical discharge point for future zone F. Overview of updated pump operation at Nørrevangen Reservoir for the pump group supplying Rylevej.

9.3.2 Maximum residence time in the future supply area

The following subsection presents the results of the hydraulic modeling for the investigation of maximum residence time for the future area, zone F. Looking at figure 9.6 and 9.7 below, maximum residence time of the water can be viewed to approx. 8 ½ hours. The parameters for the hydraulic model simulation can be found in Appendix 9.3. The noted maximum residence time of 8 ½ hours should not be considered as more than a rough estimation. Further studies should be carried out as a result of future indication of cadastral boundaries in the area of the planned urban expansion. As a result of cadastral boundaries, the future pipeline network will be significantly larger, whereby the residence time of the water could be seen to increase further, as the water must be distributed to several pipeline routes and points.

Lastly, in relation to the current estimated residence time of Rylevej, which can be viewed in Appendix 8.8, the impact of the connection of the future area, is not viewed to be significant and the residence time within the zone of Rylevej can be seen to be unchanged overall. This is to be expected, as more water is being introduced to the zone of Rylevej through the main pipeline, due to the connection of the future area.

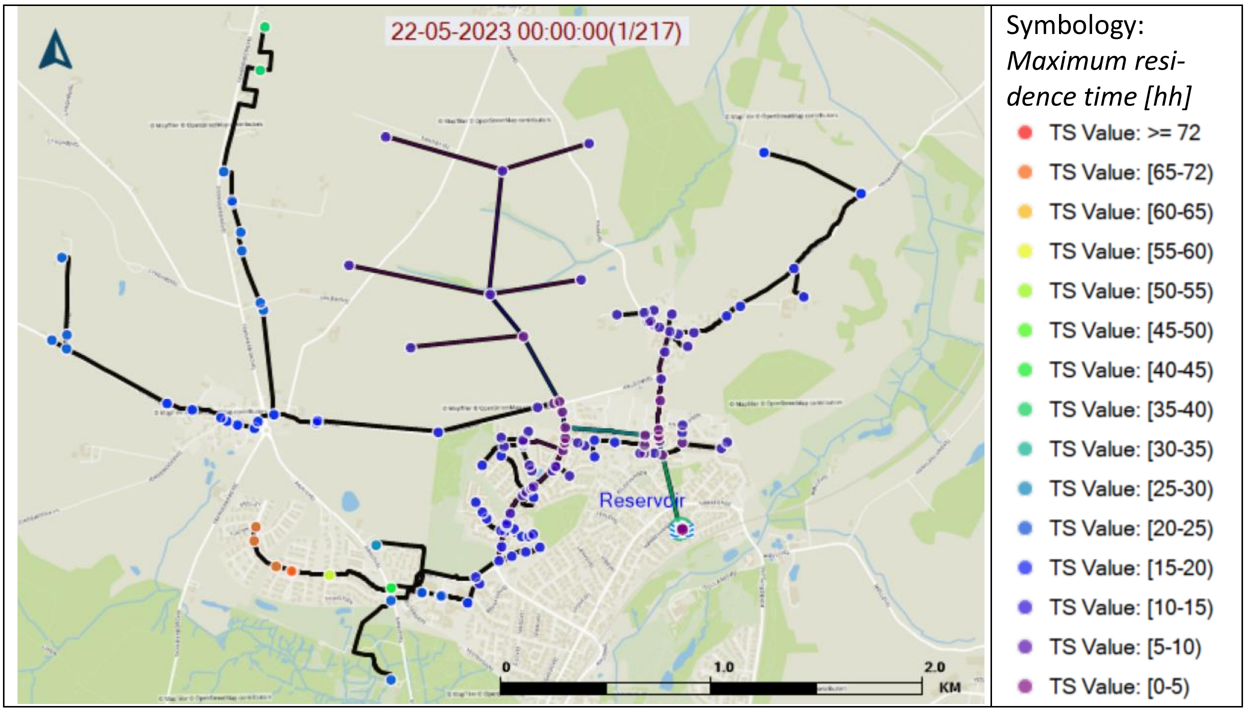


Figure 9.6 Maximum residence time of future zone F and current zone R.

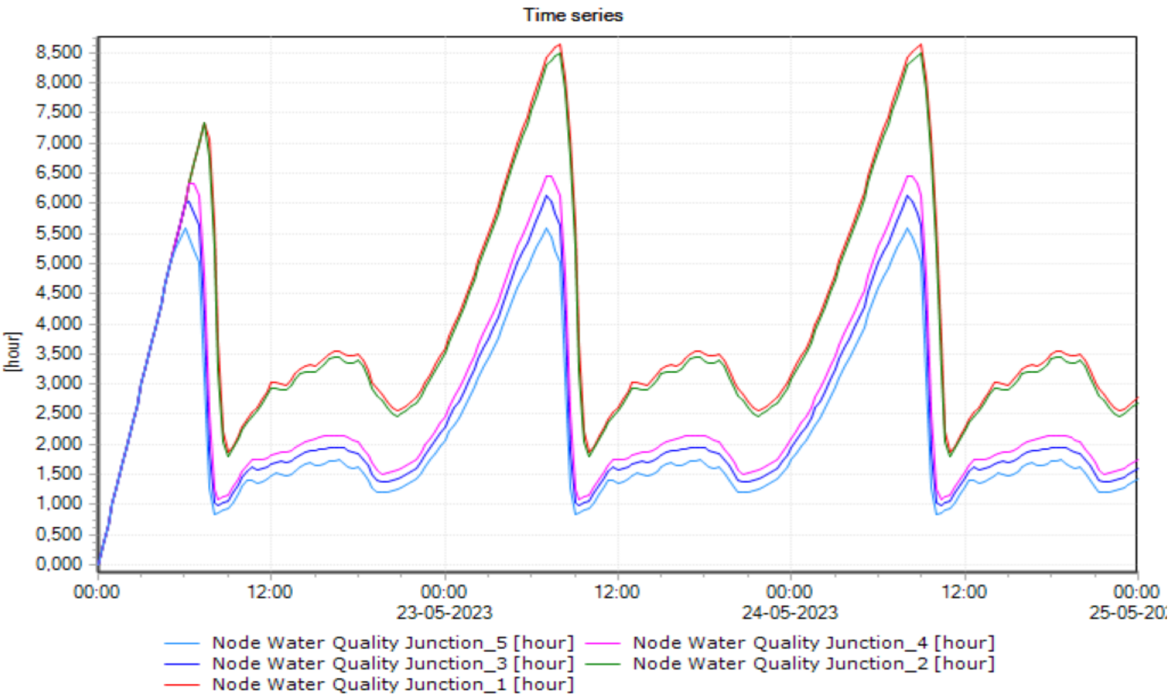


Figure 9.7 Graphical view of maximum residence time of critical discharge points within the future zone F

10. Risk assessment on the water supply process

The goal of this optional part in the report is to assess the potentially dangerous situations that can take place in the whole waterworks and analyze how they would affect the distribution process. The focus is not set on one specific part of the process, but it is approached as a whole.

As a critical infrastructure facility, the Hinnerup water supply plant plays a vital role in providing clean and safe drinking water to the aimed zones. On this purpose, there are several ways to procede. The one that will be presented in this section is known as HACCP (Hazard Analysis and Critical Control Point). It is a systematic approach to food safety management with the aim of preventing, reducing or eliminating hazards that can damage food and involve health risks.

More specifically, focusing on the control of water quality, the DDS (Documented Drinking water Safety) Plans (Comité, 2006) establish some guidance on ensuring drinking water quality. The main focus is prevention of risks rather than reacting when the damage has already happened and learning from experience.

The starting point is the water quality targets, which in this case corresponds to the DW criteria. There are recommendations to carry out a risk assessment simplifying the procedure in relation to the main processes taking place in a waterworks (abstraction, treatment, storaging and distribution). Hence, all potential hazards can be identified separately.

Summarizing, the purpose of this section is to focus on the risks deemed to be the most significant and establish appropriate monitoring and verification plans that successfully maintain the hazardous situation under control. The method to follow cathegorises each of the identified hazardous event according to their likelihood to happen and the severity of their consequiences (WHO, 2005). This assessment must be justified clearly and it is specific for each water supply system:

	Main indicator	Description
Likelihood		
A	Almost certain	Almost certain. Weekly or constantly
B	Likely	Monthly
C	Possible	Sometimes annually
D	Unlikely / Rare	Less often than annually
Severity		
1	Insignificant / Minor	No detectable impact / Minor impact causing dis-satisfaction but not likely to threaten the supply
2	Moderate	Major impact possibly resulting in an alteration in the supply
3	Major	Supply interruption, but manageable to be re-stored
4	Catastrophic	Water can not be supplied securely, alternative options have to be used

Table 10.1. Definition of the different categories of likelihood and severity for the risk assessment.

In coherence with the above-presented classification, the following qualitative risk assessment matrix can be used to categorize the risks. The color pattern defines four different risk levels that involve attention in different ways. In coherence, each risk level is defined:

- E: Extreme risk. Immediate action required.
- H: high risk. Management attention needed.
- M: Moderate risk. Management responsibility must be specified.
- L: Low risk. Manage by routine procedures.

With this definition, they are displayed in the risk-assessment matrix. See Table 10.2. below.

	Severity			
Likelihood	Insignificant / Minor (1)	Moderate (2)	Major (3)	Catastrophic (4)
Almost certain (A)	H	E	E	E
Likely (B)	M	H	E	E
Moderate (C)	L	M	H	E
Unlikely / Rare (D)	L	L	M	H

Table 10.2. Graphical display of the risk levels in the risk matrix.

In the before-presented sections of the report, a detailed description for the processes happening in Hinnerup waterworks has already been made. With the objective of identifying the most critical scenarios, the following subsections are to analyze the potential risky situations on each subprocess.

10.1. Risk analysis.

In first place, the situations are shown in the following table with a short title regarding each risk identified. This table 10.3. below shows them in their correspondent place according to their severity and likelihood to take place. Since some of them are related to specific parts of the water supply process, but others are hazardous for the whole process. For further argumentations on each of them, they will be described in different sections.

	Severity			
Likelihood	Insignificant / Minor (1)	Moderate (2)	Major (3)	Catastrophic (4)
Almost certain (A)				
Likely (B)	- Aging infrastructure	- Aquifer contamination by infiltration of substances		
Possible (C)		- Water loss - Power failure	- Contamination being introduced in the pipes	
Unlikely / Rare (D)	- Air contamination from the outside - Backwash error - Pump failure in Nørrevangen	- Pump failure in the abstraction wells - Old water - Clean water tank sensor error	- Access to the clean water tanks - Backflow event - Pump failure in Herredsvej - Transport of pathogenes to wellfield	- Emergency system not working - Vandalism - Cyber attacks

Table 10.3. Risk assessment on Hinnerup Waterworks.

It is visible that some of the gaps on the table are blank: the water supply plant is effectively working and there are not frequent hazardous events taking place. Nonetheless, this is a positive conclusion, meaning that the current situation in the waterworks guarantees a secure supply.

As said before, the following subsections intend to classify the risk according to the process they are related to.

10.1.1. Abstraction.

As it has been explained in Section 6. regarding Hydrogeology and water abstraction, boreholes are drilled to the target aquifers and water is obtained from them to be later treated. Let us see what potential threats related to water supply can be found in this step.

10.1.1.a. Transport of pathogens to wellhead.

The quality of the primary raw water depends in a big extent on the abstraction well and the state of the same. The risk analyzed in this section refers to the potential movement or introduction of disease-causing microorganisms. These can enter the well in several ways: surface water runoff, infiltration of contaminated groundwater or improper maintenance or construction of the well.

Several security actions can be considered on this purpose, mainly involving quality controls on the existing installation. All the abstraction wells have a proper well construction including casing, sealing and wellhead security (Favrskov Vandforsyningsplan (2020-30), 2020). A yearly inspection takes place and checks in detail the installation: alarms, locks, pumps, ventilation and hygiene (Hinnerup Vandværk, 2022). Hence, vandalism is prevented. In the case of having this event taking place, the alarms in the abstraction wells would be activated and the pumps would stop the intake. Then, from the clean water tanks, it is affirmed by the waterwork that there is enough water to guarantee the supply up to 3 to 5 hours, so the problem should be fixed within that time to ensure the supply.

A different preventive measure which can be taken by the producer is the restriction of water intake in periods of poor quality (e.g. after heavy rainfall) (Havelaar, 2003). Furthermore, bacteriological monitoring of the abstracted water for fecal index bacteria remains important to safeguard water quality. This could be observed in trends for the concentration of different substances from groundwater samples.

Taking the above-mentioned factors into account, in the scale regarding likelihood and severity, the considered level is:

Likelihood	D
Severity	3

10.1.1.b. Pump failure in the abstraction wells.

The pumps in charge of the abstraction are automatically activated when the water level in the tank is detected too low. There are sensors in charge of sending signals to the pumps and activating them, alternatively, to fill up the tank.

Whilst the maximum capacity of all the abstraction pumps in 33 m^3/h, they don't perform at their highest capacity all the time, but at a performance level of 65%. According to (Favrskov Vandforsyningsplan (2020-30), 2020), 3 out of the 5 wells can guarantee the supply if one or even two reach failure. This enables to fix the problem without having to interrupt the water supply. Figure 10.1 below shows the abstraction pumps' operation within one day. For further information about the data, see Appendix 10.1.

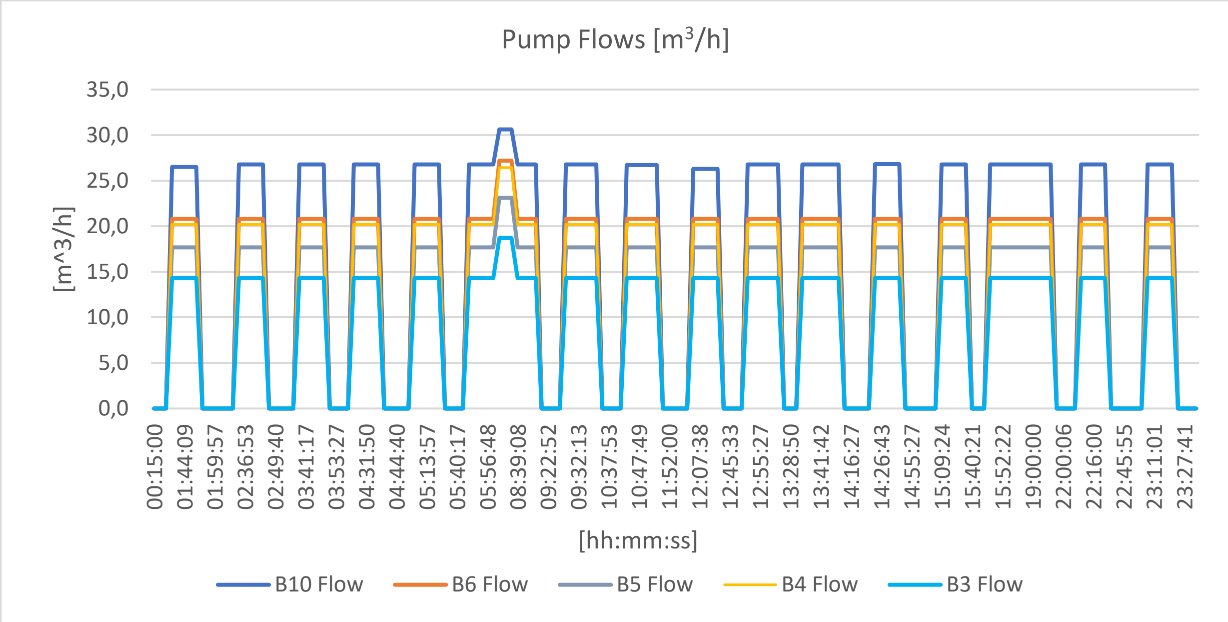


Figure 10.1. Abstraction pumps flow during a 24h period.

As a further comment, they are all working at the same time but not at full capacity (which, as seen in section 6.2, is 33 m^3/h for all of them). In the case of having more than two pumps reaching failure at the same time, the situation would be the same as in the previous section: the clean water tanks can provide the area for 4-5 hours.

Likelihood	D
Severity	2

10.1.1.c. Aquifer contamination by infiltration of substances.

Harmful substances for human consumption can be introduced into the intake area and therefore contaminating the source of water. The aquifer's vulnerability to pollution has been already assessed over section 6. The intake resources are not protected against surface pollutants, so agricultural activity should be monitored in the several local recharge areas located within the abstraction area. Currently, there are some protection zones close to the drillings (see figure 6.16), meaning that some control actions are already being executed.

Farming areas are the main source for pesticides and other contaminants, which as can be seen in figure 6.1 is mostly the abstraction area for Hinnerup borings. Thus, bans that prevent substances from being applied in that zones are the most effective way for preventing aquifer contamination.

When considering the risk of substances infiltrating into groundwater, a specific substance to focus on is pesticides: their specific characteristics, widespread use and impact on environment and human health make them so alarming. The EPA has a recent Agreement on the Pesticides Strategy 2017-2021 coming after the previous plan (2013-2016) based on targeted and sustained efforts to decrease pesticide utilization in Denmark (Stockmarr & Thomsen, 2014). They include the pesticides authorisation scheme, a framework with a high degree of compliance with EU requirements (Ministry of Environment and Food of Denmark, 2017). Not only do they need to be authorised by the EPA, but they are also tested under the Danish Pesticide Leaching Assessment Programme (PLAP). In case of being assessed not to be used, the authorisation would be lapsed. If they finally start being used, their effect is followed for 4 years by several means including groundwater monitoring, that has been enhanced in the previous years. Thus, it can be concluded that if a responsible use of pesticides is made, there must not be a problem in the abstraction area for Hinnerup.

The tool for checking water composition in the aquifers is groundwater monitoring, for which companies like the national groundwater monitoring (GRUMO) and more specifically, GEUS provides an annual control regarding groundwater chemical components and scientifically based advice regarding monitoring, considering the field work taking place in the different zones. This is of fundamental importance to document positive and negative development in groundwater quality.

There are, as well, specific action plans and control measures regarding Nitrate and Pesticides (Favrskov Municipality, 2023). Hence, it is proved that this area has a tough surveillance guaranteeing security in this sense. Nevertheless, in case of accident, the aquifer is vulnerable to substance infiltration, and this is the justification for the grade of likelihood determined (B).

Summarizing, the categorization of this risk is the following:

Likelihood	B
Severity	2

10.1.2. Treatment.

The water treatment part has already been described in section 7., providing an overview on the status of the treatment plant and analysing the vulnerability and the existing control and action measures. For this reason, this subsection will not be as descriptive as the previous one, but it will refer to the already made analysis.

As a comment regarding the whole treatment process, since there is more than one treatment line (there are 8 filters working in parallel), the supply security is enhanced. This makes it less likely that when there is any kind of issue, the overall supply has to be challenged.

10.1.2.a. Air contamination from the outside.

Air contamination can enter the treatment plant through the ventilation holes, coming from events from agriculture or industry. This air is used both in aeration and the filter backwash, so if it happened, the water would not be guaranteed to be safe.

As prevention measures for this event, the holes in the wall for ventilation are protected. (Hinnerup Vandværk, 2022). Depending on the size-filtrating net, the protection level would be higher or lower. There is not a specific measure control for it further than visual inspection (Comité, 2006). However, according to historical trends and the existing protection, it is rare.

Likelihood	D
Severity	3

10.1.2.b. Aging infrastructure

Risk already described in section 7. There is regular maintenance, so of course the waterworks is getting old, but for the moment it is not compromising for water quality.

Likelihood	B
Severity	1

10.1.2.c. Backwash error.

Backwashing is a crucial event in sand filtration to guarantee an optimal filtration process. It is described in section 7.2.2., and knowing the procedure, the potential breakdown points can be identified.

The failure of any of the pumps would provoke a less effective backwash. This effect could be visible at human sight by observing the water surface if it is not working at all. However, if the flow is lower than expected but it is still working, it would not be so noticeable. In this case the SCADA system must provide information about the state of all the different pumps, so the personnel should notice it.

The source of backwash water should be at the needed level all the time, and not having enough would also provoke and ineffective backwash event. Nonetheless, the clean water tank is proved to always have enough water in its regular functioning. Only in an abstraction failure event, it is susceptible to be emptied.

Agitation of filter media (sand grains) must be controlled by the air and water pressure to keep the filter bed expansion ought to be between 10-40 %, otherwise it has different downsides (Maribo, 2023). There is a control system for the filters: once every 60 days, 2 filters are taken out for random sample control and manually rinsed to compare the colour of the rinse with pictures hanging on the wall, which are retaken and compared every 4 months (Favrskov Vandforsyningsplan (2020-30), 2020).

Considering the existing control methods, it is rare having an error happening. If it did, the consequences would not compromise the supply nor the consumers' health because the water quality before filtration is already acceptable. Hence, the parameters are:

Likelihood	D
Severity	1

10.1.3. Storaging.

As described in section 8.1., there are two different places for water storaging: the clean water tank in Herredsvej and Nørrevangen Reservoir. The quality reached in the treatment must be now conserved until the water reaches its destination. The following events are to analyze how the supply could be threatened in this step of the water supply process.

10.1.3.a. Access to the clean water tanks

No person without authorization must enter the clean tank installation. Secured from the access by animals and to prevent unauthorized access, sabotage and tapping and tampering. According to the personnel in the waterworks, this event is extremely unlikely to happen. However, it could potentially harm consumers: it is the last point before distribution, so no contamination has the chance to get removed at this point. As a preventive action against this possible hazardous event, there are alarms and locks to access the area of the clean water tanks. According to the personnel, if an alarm is activated the pumping is stopped. Furthermore, if the pumps are stopped the supply is interrupted as well. This is the justification for the decided score:

Likelihood	D
Severity	1

10.1.3.b. Old water

The water must not stay longer than 3 days in the system to prevent microbial pathogens from growing. For prevention, there is a circulating system inside the clean water tank. This ensures that the water will not stay in the tank for more than 5 hours: during the peak consumption times, it will predictably stay in the distribution system for less time than in hours with less consumption. However, if the system is working normally, it would never be a threat.

Likelihood	D
Severity	2

10.1.3.c. Clean water tank sensor error

The system is considerably automatized: sensors and actuators decide when the pumps start and stop working. Therefore, if they fail, they can compromise the supply. When the tank empties, the abstraction pumps start working. Hence, if they stopped sending the required signals when the pumps need to work, the tank would eventually empty.

As a control action, the SCADA system gets notified with how the elements are working, so the personnel would notice and get the required reparation. Nevertheless, informatic errors can get complicated. Considering this argumentation, the assessment is shown below:

Likelihood	D
Severity	2

10.1.4. Distribution.

The last step in the water supply process. Depending on the display of the distribution network, its reliability is determined. Let us evaluate the specific risks for this step.

10.1.4.a. Backflow event.

This phenomenon can take place when the connected distribution systems have pressure differences. Backflow events happen due to the hydraulic gradient: water naturally flows from higher pressure areas to areas of lower pressure. This pressure difference is typically caused by pumps, elevated storage tanks or gravity. At certain moments when the flow is interrupted and pumps stop the supply, the pressure difference disappears. Nevertheless, in Hinnerup distribution system there are flowmeters for every household being supplied. All the flowmeters have as well a non-return valve ensuring that water will not flow back to the pump. Furthermore, there are two manual valves that can be closed when repairing or replacing components of the distribution network.

To summarize, in a regular distribution process, backflows are successfully prevented from happening. As the waterworks personnel have stated, only damages in pipes could cause backflow events. The potential hazards arising from backflow events include contamination being spread over the network. In the event of being caused by pipe damages, harmful pathogens could enter the system and pollute the water. An early-detection system is crucial on this purpose to close the needed valves and locate efficiently the problem.

Likelihood	D
Severity	3

10.1.4.b. Contamination being introduced in the pipes.

In the distribution network, contamination has a different impact depending on of its stricture (see subsection 8.1.3.). Possible sources of contamination include pipe burst, having pollutants coming from the ground, and reparations: hygiene measures are to be taken and new materials must follow specific procedures to prevent contamination events.

In a dead-end network, the contamination is easier to locate and to remove, so the consequences are minor than in grid-iron networks: the paths are redundant, so the pollution can spread faster throughout the network. This has a more severe consequence in terms of ability to stop it. In both cases, the supply for certain zones would have to be interrupted, so this event compromises the supply. In consequence, the assessment is shown below:

Likelihood	C
Severity	3

10.1.4.c. Pump failure at Nørrenvangen.

In the case of having a pump failing at Nørrevangen, there is a bypass pipe connecting both pump groups that gives a higher level of security to the distribution network: the supply can be guaranteed. It would make the pumps work at a higher capacity, but it would prevent the system from totally failing. The distribution system security is already described in subsection 8.1.5.

The consumption for both zones R and K and pumps capacity were already studied along Section 8. The following graph (figure 10.2) intends to prove if a single pump group could currently handle the water distribution of both zones: it would need to successfully provide the sum of the maximum hourly flow of Rylevej and Kildevangen. See Appendix 10.2:

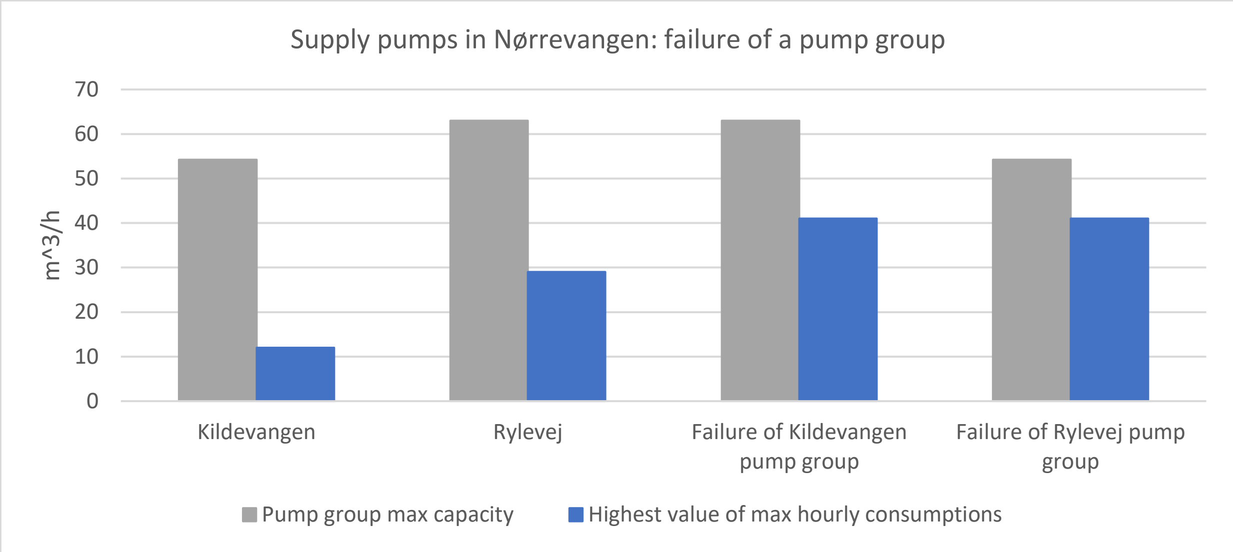


Figure 10.2. Pump capacity vs. Maximum hourly flow to provide in different scenarios.

To sum up, it is proved that one pump group is sufficient to supply the present zone that Nørrevangen reservoir is supplying. The respective performances required would be 65% and 75%. Hence, the consequence of a pump failure would not be so severe here.

Likelihood	D
Severity	1

10.1.4.d. Pump failure in Herredsvej.

This scenario is similar to the previously studied one. However, there is not knowledge about any bypass pipe in Herredsvej Waterworks. Therefore, if a pump needs reparation, the supply would need to be interrupted until it is fixed. The probability is not high, but the consequences would be more severe than in the case of the supply pumps distributing water from Nørrevangen reservoir.

Likelihood	D
Severity	3

10.1.4.e. Water loss.

Water loss refers to the overall reduction in the amount of water within a water supply system. It is calculated as the difference between the amount of water pumped out and the amount of water sold (Møller, 2023). It is useful to effectively be able to evaluate the causes and impacts within the system with the aim of enhancing the overall sustainability of the system. This can also cause service disruption, reduced efficiency, and potential effects on water availability for consumers.

In the calculations regarding future water distribution (Section 9), a 10% out of the estimated distribution has been estimated for the extraordinary consumption. It includes the firefighting reserve and the water losses, which all together must not exceed the 10% of the water consumption value (Dansk standard, 1988).

Nonetheless, the water losses themselves must not be greater than 10% of the total consumption, imposing a penalty tax if they do. Nonetheless, Denmark's limit for losses is considerably lower than other countries (Danish Environmental Agency, 2018), that loose from 30 to 60% of the treated water before it reaches costumers.

The sources of water loss can include leaks, unauthorized usage and system inefficiencies. Considering the above-mentioned factors, water losses are inevitable but well-handed and controlled, thus the assessment for this risk is:

Likelihood	A
Severity	1

10.1.5. Whole process.

10.1.5.a. Power failure

This scenario poses a risk for the waterworks because it heavily relies on electricity to operate essential components and processes: pumping, treatment, monitoring and control systems need electric supply for functioning. According to the personnel of the waterworks, the frequency for it to happen is once or twice a year, with a duration of a few minutes. Hence, until the moment it does not suppose a very severe problem because the supply is not affected.

If a power failure event is detected early, certain supply areas can be closed for a determined amount of time, thus preventing a general power failure to happen. However, if such a circumstance was to materialize, the waterworks facility lacks an emergency generator.

As mentioned in subsection 7.4.2., there are two emergency connections for the waterworks ensuring approximately 50% of the consumption to be supplied, hence enhancing the system's resilience and ability to respond to crisis. Therefore, the supply is not fully compromised.

Likelihood	C
Severity	2

10.1.5.b. Emergency system not working.

As just mentioned in the previous subsection, in Hinnerup they lack an emergency generator that provides electrical power when power failure takes place. They do have solar panels that can provide the needed power when it has happened before, given that it has only had a duration of several minutes. Nonetheless, it should be bear in mind that this event is possible to happen, and it would compromise the whole distribution network.

As explained in subsection 7.4.2., there is an emergency supply relying on two proximal waterworks. But in the worst case (if there was a general failure), the supply would be interrupted. This justifies the categorization decided for this event:

Likelihood	D
Severity	4

10.1.5.c. Vandalism or sabotaging

Acts of vandalism or sabotaging can have severe consequences on the water supply system, meaning a threat to public safety. They can disrupt the functioning of the water supply system, compromise water quality and lead to service interruptions or potential safety hazards. The relevance given, of course, depends on the likelihood for it to take place. In Hinnerup Waterworks, according to the personnel, never has such event taken place, so it is extremely unlikely for it to happen.

However, since the severity can potentially be very high, there are security measures: the waterwork, wells and clean water tank are all secured with locks and alarms (Favrskov Vandforsyningsplan (2020-30), 2020). Moreover, every intake well has an individual alarm and lock. If the alarm is activated, all the pumps stop working. Accessing the waterworks without authorization is not very likely either: the installation is secured with 2 access codes and 3 locks. Taking it all into account, the categorization is:

Likelihood	D
Severity	4

10.1.5.d. Cyber, SCADA and Communications Issues. - questions

The connection between a SCADA system and a company's intranet may not be protected, allowing unknown connections to partners or other organizations. Nevertheless, in the case of Hinnerup there are security measures like passwords and codes that need to be typed in for accessing the software regarding water management. Furthermore, there is an employee trained about information technology security to assess the utility's cyber vulnerabilities and develop mitigation issues. Intrusion-detection software allows network administrators to determine if individuals are seeking unauthorized access to the system and their target.

Even if it has never happened, manipulating the system could have fatal consequences on the supply. Given that it is a primarily supply system, the security level should be very high. Summarizing, the assessment is shown below:

Likelihood	D
Severity	4

10.2. Conclusion on risk assessment.

As it can be seen in the qualitative risk assessment matrix, there are not so many extreme risks for the waterworks to handle nor frequents hazardous events taking place. Therefore, the report concludes that the present situation in the waterworks guarantees a secure water supply. The existing preventive measures, periodic maintenance and monitoring and control systems are successfully mitigating the risks and maintaining water quality.

11. Report conclusion

Looking back at the main report objective, regarding a description of the status of the complete water supply system in Hinnerup and evaluating on this both in a current perspective and in the light of the future planned urban expansion of the town, it can be concluded that this main objective has been met. In continuation of this, several main findings can be presented in relation to the main elements of the water supply system, these being; the abstracted groundwater resource, the treatment facility and lastly the supply within the distribution network.

Regarding the current groundwater resource, the intake recourse is currently supplying a very ideal quality of raw water with no trace of contaminants and with the quality being suitable for standard treatment within the treatment facility. However, analysis of geophysical surveys indicates an unconfined aquifer, due to the clay layers not being evenly present within the area of abstraction. Several local recharge areas have been identified within the area, and with the EPA categorizing the whole abstraction area as some to high vulnerability, the threat for surface infiltration of contaminants is significant. Furthermore, the current extent of pyrite oxidation has been estimated as being limited, resulting in an aquifer with almost no nitrate-consuming capacity to withstand potential agricultural spray agent impact in the future. Therefore, the overall conditions of the intake resource calls for the need of monitoring of agricultural activities within the area of abstraction, so that the current ideal raw water quality can be maintained for the future to come.

Looking at the treatment facility the cascade aeration system and overall filter capacity at the Hinnerup waterworks are well-equipped to handle the current intake and have the potential to handle flow rates increased by around two times. Optimizing the backwash time do not seem to be necessary, and future considerations should be made to accommodate any changes in flow rates and ensure the efficiency and effectiveness of the water treatment processes. The only aspect that may require attention in this scenario is the pumps, but with water-saving strategies, it is possible that significant increases in pump capacity may not be necessary.

Furthermore, the investigation has provided a comprehensive assessment of the current distribution network, including its structure, sections, system security, network types and water consumption analysis. The findings suggest the need for further evaluation and potential improvements in terms of network reliability, security measures and understanding consumption patterns for efficient resource management and optimization of the usage of energy. With the use of hydraulic modeling tools, consumer pressure, velocity and residence within the current network have been stated.

Consumer pressure can be seen to have a high degree of diversity and with pressure level slightly exceeding the lower and upper requirements of consumer pressure within a supply network. However, these results should not cause concern at this point, due to the result being prepared based on a simplified hydraulic network model with no pressure requirements being specified within the distribution area. Therefore, the presented pressure values are based on a pump efficiency of 100% within each zone, hereby providing the highest possible pressure. Further requirements regarding pressure should be specified within each hydraulic model of each zone to state the impact of these.

When it comes to the maximum residence time, the whole distribution network is within the requirement of a maximum 3-day residence time of the water. The criteria is only being exceeded in the case of a smaller area in the zone of Rylevej which is due to the combination of low flow and large pipe diameter. Additionally, the velocity within the distribution network, this is an area of high concern. The velocity within each zone during the hour of maximum consumption, is not more than 0,6 m/s at any point in the network, and with velocities going as low as 0,05 m/s. This is more than far from the EU standard regarding an economical velocity of 0,8-1,4 m/s.

Also, the addition of a new planned urban expansion area has been analyzed in terms of geographical location, connection-point to the existing network, infrastructure compatibility, consumer pressure and water quality regarding the maximum residence time of the water. In some cases, further studies and adjustments should be made in terms of pump capacity, pipe connections and treatment procedures. Overall, the analysis suggests that the existing water infrastructure can adapt to the future demand in the new urban area.

Based on an interpretation of the most critical discharge points within the future planned area, hydraulic modeling has stated the consumer pressure and residence within acceptable range, when taking into consideration, that the hydraulic model has been provided with point specific pressure-requirements.

Further studies should be carried out as a result of future indication of cadastral boundaries in the future planned area. With cadastral boundaries being introduced, the future pipeline network will be significantly larger, whereby the residence time of the water could be seen to increase further, as the water must be distributed to several pipeline routes and points.

Lastly, considering the risk assessment procedure carried out on the whole supply system, the potential risks have been evaluated along with the necessary control and action measures that ensure a secure supply for the areas of Hinnerup waterworks.

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APPENDIX document

Table of content

NOTE:

Page number within each Appendix can be viewed on the bottom right corner of the page.

Page number in accordance with the table of content presented above for the whole Appendix document, can be viewed on the top right side of the page.

Appendix 5.0

Table of content

5.1. SCADA Datafiles

Below, the yearly overview on abstraction and distribution from 2014 to 2021 and the analysis per months on the distribution over the different zones.

5.1.1. Year 2014

Årsresultat 2014	
Energiforbrug Herredsvej	
KWh/år	141999
Kwh gns/mdr	11833,25
Energiforbrug Nørrevangen	
KWh/år	57911
KWh gns/mdr	4825,916667
Total energiforbrug	
KWh/år	199910
Gns KWh/mdr	16659,16667
Udpumpet	
Udpumpet Nørrevangen m3/år	102761
Gns udpumpet Nørrevangen m3/mdr	8563,416667
Udpumpet Herredsvej m3/år	337816
Gns udpumpet Herredsvej m3/mdr	28151,33333
Total udpumpet m3/år	440577
Total gns udpumpet m3/mdr	36714,75
Oppumpet	

Total oppumpet m3/år	381800
Total gns oppumpet m3/mdr	31816,66667
Diff. Total op- og udpumpet	-58777
Energifaktor	
Energifaktor Herredsvej KWh/m3	0,371919853
Energifaktor Nørrevangen KWh/m3	0,563550374
M3 iflg årsopgørelse	327373

2014	Serie 1	Serie2	Serie1	Serie 2	Serie3	Serie4
m3	Kildevangen	Rylevej	Industriområde	Hinneruplund	Hinnerup midt	Nørrevangen
Jan	3017	5189	4697	3855	10620	8753
feb	2630	4623	4275	3417	9203	7790
mar	3070	5426	4889	3910	10694	9002
apr	3063	6105	4787	3781	10607	9509
maj	3221	6840	5117	3949	11007	10315
jun	3369	6740	4071	5093	11165	10315
jul	3174	5414	4784	3613	10164	9110
aug	3164	5315	4850	3922	10283	8944
sep	2999	4998	4462	3708	10401	8530
okt	3029	5013	4625	3724	10765	8605
nov	2919	5045	4681	3733	11401	7636
dec	3119	5279	5019	3991	12557	7487
i alt	36774	65987	56257	46696	128867	105996
Total Nørrevangen/år		102761				
Gns Nørrevangen/mdr		8563,4167				

Total Herredsvej/år		337816				
Gns Herredsvej/mdr		28151,333				
Total udpumpet/m3 år		440577				
Gns udpumpet/m3/mdr		36714,75				

5.1.2. Year 2015.

Energiforbrug Herredsvej	
KWh/år	45939
Kwh gns/mdr	3828,25
Energiforbrug Nørrevangen	
KWh/år	48207
KWh gns/mdr	4017,25
Total energiforbrug	
KWh/år	94146
Gns KWh/mdr	7845,5
Udpumpet	
Udpumpet Nørrevangen m3/år	98313
Gns udpumpet Nørrevangen m3/mdr	8192,75
Udpumpet Herredsvej m3/år	337555
Gns udpumpet Herredsvej m3/mdr	28129,58333
Total udpumpet m3/år	435868
Total gns udpumpet m3/mdr	36322,33333

Oppumpet	
Total oppumpet m3/år	382706
Total gns oppumpet m3/mdr	31892,16667
Diff. Total op- og udpumpet	-53162
Energifaktor	
Energifaktor Herredsvej KWh/m3	0,120037313
Energifaktor Nørrevangen KWh/m3	0,490342071
M3 iflg årsopgørelse	

Udpumpet m3 total						
2015	Serie 1	Serie2	Serie1	Serie 2	Serie3	Serie4
m3	Kildevangen	Rylevej	Industriområde	Hinneruplund	Hinnerup midt	Nørrevangen
Jan	2956	5298	4905	3782	12596	7328
feb	2543	4672	4366	3338	11437	6600
mar	2933	5378	4902	3847	12536	7531
apr	2982	5263	5072	3720	12345	7405
maj	3074	5365	5150	3874	12582	7522
jun	3083	5356	4893	3813	12165	7431
jul	2855	4691	4413	3465	11188	6780
aug	3169	5544	5111	3868	12575	7665
sep	2892	5213	4743	3654	12185	7133
okt	2886	5285	4985	3712	12303	7216
nov	2865	5335	5121	3608	12122	7186
dec	3146	5529	5620	3843	12383	7536
i alt	35384	62929	59281	44524	146417	87333

Total Nørrevangen/år		98313				
Gns Nørrevangen/mdr		8192,75				
Total Herredsvej/år		337555				
Gns Herredsvej/mdr		28129,583				
Total udpumpet/m3 år		435868				

5.1.3. Year 2016

Energiforbrug Herredsvej	
KWh/år	32093
Kwh gns/mdr	2674,416667
Energiforbrug Nørrevangen	
KWh/år	58641
KWh gns/mdr	4886,75
Total energiforbrug	
KWh/år	90734
Gns KWh/mdr	7561,166667
Udpumpet	
Udpumpet Nørrevangen m3/år	93599
Gns udpumpet Nørrevangen m3/mdr	7799,916667
Udpumpet Herredsvej m3/år	338743
Gns udpumpet Herredsvej m3/mdr	28228,58333
Total udpumpet m3/år	432342

Total gns udpumpet m3/mdr	36028,5
Oppumpet	
Total oppumpet m3/år	384546
Total gns oppumpet m3/mdr	32045,5
Diff. Total op- og udpumpet	-47796
Energifaktor	
Energifaktor Herredsvej KWh/m3	0,083456856
Energifaktor Nørrevangen KWh/m3	0,626513104
M3 iflg årsopgørelse	

Udpumpet m3 total						
2016	Serie 1	Serie2	Serie1	Serie 2	Serie3	Serie4
m3	Kildevangen	Rylevej	Industriområde	Hinneruplund	Hinnerup midt	Nørrevangen
Jan	3017	5536	5116	3734	12514	7435
feb	2704	5079	4449	3442	11669	6875
mar	2924	5519	4733	3623	12388	7398
apr	2912	5628	4854	3641	12296	7416
maj	3231	5897	4932	4023	13160	7941
jun	3182	5769	5020	3967	12752	7766
jul	2601	4689	4120	3153	10608	6530
aug	2992	5492	4879	3659	12338	7443
sep	2923	5431	4795	3612	11448	8183
okt	2899	6130	5056	3629	12134	7914
nov	2769	6275	5158	3491	11976	7624

dec			5655	3744	12306	8144
i alt	32154	61445	58767	43718	145589	90669
Total Nørrevangen/år		93599				
Gns Nørrevangen/mdr		7799,9167				
Total Herredsvej/år		338743				
Gns Herredsvej/mdr		28228,583				
Total udpumpet/m3 år		432342				
Gns udpumpet/m3/mdr		36028,5				

5.1.4. Year 2017

Energiforbrug Herredsvej	
KWh/år	127033
Kwh gns/mdr	10586,08333
Energiforbrug Nørrevangen	
KWh/år	66309
KWh gns/mdr	5525,75
Total energiforbrug	
KWh/år	193342
Gns KWh/mdr	16111,83333
Udpumpet	
Udpumpet Nørrevangen m3/år	116650

Gns udpumpet Nørrevangen m3/mdr	9720,833333
Udpumpet Herredsvej m3/år	346854
Gns udpumpet Herredsvej m3/mdr	28904,5
Total udpumpet m3/år	463504
Total gns udpumpet m3/mdr	38625,33333
Oppumpet	
Total oppumpet m3/år	363926
Total gns oppumpet m3/mdr	30327,16667
Diff. Total op- og udpumpet	-99578
Energifaktor	
Energifaktor Herredsvej KWh/m3	0,349062722
Energifaktor Nørrevangen KWh/m3	0,568444063
M3 iflg årsopgørelse	

Udpumpet m3 total						
2017	Serie 1	Serie2	Serie1	Serie 2	Serie3	Serie4
m3	Kildevangen	Rylevej	Industriområde	Hinneruplund	Hinnerup midt	Nørrevangen
Jan	2894	5855	5451	3698	12357	8001
feb	2667	5548	4631	3182	11243	7052
mar	2991	6734	5289	3824	12540	7998
apr	2999	6941	4801	3534	12224	8137
maj	3231	8335	5157	3932	14031	9457
jun	3049	6758	4961	3808	12818	8207
jul	2710	6002	4153	3102	11200	7231
aug	2924	6984	5169	3631	12187	8029

sep	2835	6869	4949	3429	11953	7824
okt	2878	7014	5032	3464	12306	8016
nov	2805	7028	5008	3518	12251	7939
dec	3093	7506	5270	3643	12643	8574
i alt	35076	81574	59871	42765	147753	96465
Total Nørrevangen/år		116650				
Gns Nørrevangen/mdr		9720,8333				
Total Herredsvej/år		346854				
Gns Herredsvej/mdr		28904,5				
Total udpumpet/m3 år		463504				
Gns udpumpet/m3/mdr		38625,333				

5.1.5. Year 2018

Energiforbrug Herredsvej	
KWh/år	134066
Kwh gns/mdr	11172,16667
Energiforbrug Nørrevangen	
KWh/år	70371
KWh gns/mdr	5864,25
Total energiforbrug	
KWh/år	204437
Gns KWh/mdr	17036,41667

Udpumpet	
Udpumpet Nørrevangen m3/år	125266
Gns udpumpet Nørrevangen m3/mdr	10438,83333
Udpumpet Herredsvej m3/år	364514
Gns udpumpet Herredsvej m3/mdr	30376,16667
Total udpumpet m3/år	489780
Total gns udpumpet m3/mdr	40815
Oppumpet	
Total oppumpet m3/år	382517
Total gns oppumpet m3/mdr	31876,41667
Diff. Total op- og udpumpet	-107263
Energifaktor	
Energifaktor Herredsvej KWh/m3	0,350483769
Energifaktor Nørrevangen KWh/m3	0,561772548
M3 iflg årsopgørelse	

2018	Serie 1	Serie2	Serie1	Serie 2	Serie3	Serie4
m3	Kildevangen	Rylevej	Industriområde	Hinneruplund	Hinnerup midt	Nørrevangen
Jan	2890	6893	5006	3427	12693	8030
feb	1718	6862	4354	3023	12853	7328
mar	1991	8521	2685	5407	12433	8128
apr	3188	6900	3319	5213	12757	8170
maj	3711	8582	5606	3779	15090	9930
jun	3800	7915	5857	3828	14759	9571

jul	4036	8139	6237	3917	14410	9823
aug	3390	7235	5440	3493	13243	8594
sep	3028	6500	5255	3370	11949	7702
okt	3066	6767	5072	3291	12304	7955
nov	2979	6893	5089	3308	12515	7987
dec	3335	6927	6001	3645	12400	8268
i alt	37132	88134	59921	45701	157406	101486
Total Nørrevangen/år		125266				
Gns Nørrevangen/mdr		10438,833				
Total Herredsvej/år		364514				
Gns Herredsvej/mdr		30376,167				
Total udpumpet/m3 år		489780				
Gns udpumpet/m3/mdr		40815				

5.1.6. Year 2019

Energiforbrug Herredsvej	
KWh/år	130638
Kwh gns/mdr	10886,5
Energiforbrug Nørrevangen	
KWh/år	67970
KWh gns/mdr	5664,166667
Total energiforbrug	

KWh/år	198608
Gns KWh/mdr	16550,66667
Udpumpet	
Udpumpet Nørrevangen m3/år	124162
Gns udpumpet Nørrevangen m3/mdr	10346,83333
Udpumpet Herredsvej m3/år	356361
Gns udpumpet Herredsvej m3/mdr	29696,75
Total udpumpet m3/år	480523
Total gns udpumpet m3/mdr	40043,58333
Oppumpet	
Total oppumpet m3/år	378022
Total gns oppumpet m3/mdr	31501,83333
Diff. Total op- og udpumpet	-102501
Energifaktor	
Energifaktor Herredsvej KWh/m3	0,345583061
Energifaktor Nørrevangen KWh/m3	0,547429971
M3 iflg årsopgørelse	

Udpumpet m3 total						
2019	Serie 1	Serie2	Serie1	Serie 2	Serie3	Serie4
m3	Kildevangen	Rylevej	Industriområde	Hinneruplund	Hinnerup midt	Nørrevangen
Jan	3165	6953	4968	3437	12538	8170
feb	2842	6060	4315	3003	10980	7204

mar	3273	6952	5073	3393	12571	8243
apr	3352	7463	5012	3391	12658	8732
maj	3318	7281	5216	3410	13452	8580
jun	3800	7915	5857	3828	14759	9571
jul	4036	8139	6237	3917	14410	9823
aug	3166	7224	5046	3378	12375	8296
sep	3028	6500	5255	3370	11949	7702
okt	3066	6767	5072	3291	12304	7955
nov	3224	6766	5099	3329	12279	8014
dec	2979	6893	5089	3308	12515	7987
i alt	39249	84913	62239	41055	152790	100277
Total Nørrevangen/år		124162				
Gns Nørrevangen/mdr		10346,833				
Total Herredsvej/år		356361				
Gns Herredsvej/mdr		29696,75				
Total udpumpet/m3 år		480523				
Gns udpumpet/m3/mdr		40043,583				

5.1.7. Year 2020

Energiforbrug Herredsvej	
KWh/år	130076
Kwh gns/mdr	10839,66667
Energiforbrug Nørrevangen	

KWh/år	61259
KWh gns/mdr	5104,916667
Total energiforbrug	
KWh/år	191335
Gns KWh/mdr	15944,58333
Udpumpet	
Udpumpet Nørrevangen m3/år	120359
Gns udpumpet Nørrevangen m3/mdr	10029,91667
Udpumpet Herredsvej m3/år	343685
Gns udpumpet Herredsvej m3/mdr	28640,41667
Total udpumpet m3/år	464044
Total gns udpumpet m3/mdr	38670,33333
Oppumpet	
Total oppumpet m3/år	375719
Total gns oppumpet m3/mdr	31309,91667
Diff. Total op- og udpumpet	-88325
Energifaktor	
Energifaktor Herredsvej KWh/m3	0,346205542
Energifaktor Nørrevangen KWh/m3	0,508969001
M3 iflg årsopgørelse	

Udpumpet m3 total						
2020	Serie 1	Serie2	Serie1	Serie 2	Serie3	Serie4

m3	Kildevangen	Rylevej	Industriområde	Hinneruplund	Hinnerup midt	Nørrevangen
Jan	3238	6980	5341	3364	12494	8230
feb	2888	6343	4858	3154	11684	7470
mar	3424	7444	5633	3589	12678	8625
apr	2702	5704	3865	2343	8162	5666
maj	2013	4372	3410	2087	7326	5026
jun	3430	8233	6249	3667	12923	10484
jul	2987	6748	5080	3286	12738	7969
aug	3650	8444	6787	3975	14475	9631
sep	3098	7187	5575	3508	12813	8210
okt	3192	7156	5677	3555	12782	8235
nov	3145	7113	5567	3505	12768	8217
dec	3409	7459	5829	3634	12856	8685
i alt	37176	83183	63871	39667	143699	96448
Total Nørrevangen/år		120359				
Gns Nørrevangen/mdr		10029,917				
Total Herredsvej/år		343685				
Gns Herredsvej/mdr		28640,417				
Total udpumpet/m3 år		464044				
Gns udpumpet/m3/mdr		38670,333				

5.1.8. Year 2021

Energiforbrug Herredsvej	
KWh/år	135604
Kwh gns/mdr	11300,33333
Energiforbrug Nørrevangen	
KWh/år	66745
KWh gns/mdr	5562,083333
Total energiforbrug	
KWh/år	202349
Gns KWh/mdr	16862,41667
Udpumpet	
Udpumpet Nørrevangen m3/år	136575
Gns udpumpet Nørrevangen m3/mdr	11381,25
Udpumpet Herredsvej m3/år	376561
Gns udpumpet Herredsvej m3/mdr	31380,08333
Total udpumpet m3/år	513136
Total gns udpumpet m3/mdr	42761,33333
Oppumpet	
Total oppumpet m3/år	417066
Total gns oppumpet m3/mdr	34755,5
Diff. Total op- og udpumpet	-96070
Energifaktor	
Energifaktor Herredsvej KWh/m3	0,325137988
Energifaktor Nørrevangen KWh/m3	0,488705839

M3 iflg årsopgørelse	

2021	Serie 1	Serie2	Serie1	Serie 2	Serie3	Serie4
m3	Kildevangen	Rylevej	Industriområde	Hinneruplund	Hinnerup midt	Nørrevangen
Jan	3219	7200	5486	3610	11801	8014
feb	2967	7079	5510	3512	10402	9452
mar	3363	7852	6000	3654	12452	8826
apr	3313	8218	5879	3587	12704	9009
maj	3370	8107	6035	3639	13064	9033
jun	3712	9269	7072	3947	14573	10114
jul	3175	8057	5982	3428	12204	9275
aug	3326	8415	6360	3422	12375	10304
sep	3147	8288	6208	3323	13186	8938
okt	3090	8352	6068	3206	13300	8982
nov	3000	8314	5617	3197	12654	9549
dec	3141	8601	5802	3377	12566	9863
i alt	38823	97752	72019	41902	151281	111359
Total Nørrevangen/år		136575				
Gns Nørrevangen/mdr		11381,25				
Total Herredsvej/år		376561				
Gns Herredsvej/mdr		31380,083				
Total udpumpet/m3 år		513136				
Gns udpumpet/m3/mdr		42761,333				

5.2 Handlings- og strategiplan Højdemåler

See next page

HINNERUP VANDVÆRK

06-08-2020

Handlings- og strategiplan Højdebeholder

Journalnr.: Hinnerup
Rev.: 1.0
Initialer: JK
Sag nr.:

Vand og Teknik A/S
Michael Drewsens Vej 23
8270 Højbjerg

Partially translated and reduced for usage as background information in BTFPM1&2 at CAE Urban Water Specialization. Modified by Peder Maribo.

Hinnerup Vandværk

HANDLINGS- OG STRATEGIPLAN

INDHOLD

1. INDLEDNING - introduction

Hinnerup Vandværk has requested Vand og Teknik A/S to produce a action- and strategy plan to qualify the considerations about the establishment of a new clean water resservoir. This is to ensure that the citizens of Hinnerup can have a stable and secure water supply in the future.

[Rapporten er udarbejdet med baggrund i udleveret materiale og gennemgang af anlægget, samt de oplysninger der er fremkommet under møder og drøftelser pr telefon.

Nærværende handlings- og strategiplan indeholder en kort beskrivelse af status på distributionsanlægget og de enkelte anlæg og tiltagsområder.]

2. FREMTIDIG KAPACITET - Future capacity

2.1. Kalkulation af kapacitetsbehov vandværk

Yearly intake pt approximately. .... 345.000 m^3

Udvidelser over de næste 10 år (YY husstande).........................

Fremtidig årlig udpumpning..

Svarende til en gennemsnitlig udpumpning pr. dag på omkring....

Maksimalt døgnforbrug er normalt omkring 30 % højere end gennemsnitdøgnet, der regnes med en maksimal døgnindvinding på..

Nødvendig behandlingskapacitet ved ca. 22 timers drift ....

Maksimal udpumpning pr. time skal normalt være min. 10-12 % af maksimal døgnudpumpning svarende til......................................

Nødvendig beholdervolumen indregnes som XX% af maksdøgn behovet ....

2.2. Kalkulation af kapacitetsbehov Højdebeholder - volume of new øtorage tank

yearly intake approx. .... 120.000 m³

Udvidelser over de næste 10 år (YY husstande).........................

Fremtidig max årlig udpumpning...

Svarende til en gennemsnitlig udpumpning pr. dag på omkring....

Maksimalt døgnforbrug er normalt omkring 30 % højere end gennemsnitdøgnet, der regnes med en maksimal døgnindvinding på... [data removed]

Maksimal udpumpning pr. time skal normalt være min. 10-12 % af maksimal døgnudpumpning svarende til......................................

Nødvendig beholdervolumen indregnes som XX% af maksdøgn behovet .... [Data removed]

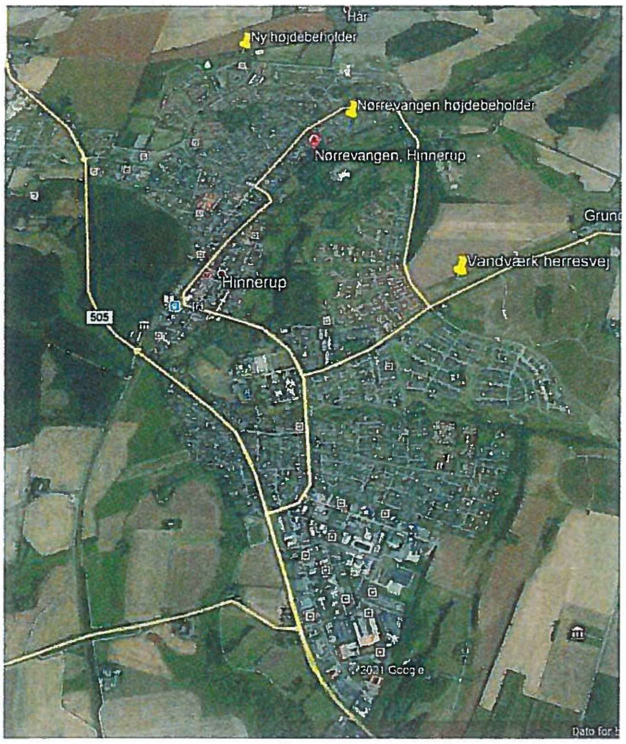
* Det bør overvejes om man bør etablere et større beholderanlæg end normalt, i tilfælde at der skulle ske noget med den nye transportledning fra vandværket og højdebeholdren.

3. EKSISTERENDE ANLÆG - existing waterworks

3.1. Vandværk skolevej 6

Hinnerups waterworks i located on Herresvej in Hinnerup in level 68. The raw water i withdrawn by 4 local borings and one newer boring in another wellfield. The water is aerated at two older cascades, after which it is filtered in single sand filters (8 seperate filter cells). From there the water is led to an underground storage tank madeinconcrete. The tank has a total volume of 200 m3.

Water is pumped to 4 pressure zones. Some water is pumped/gravitates to the storage tank at Nørevangen, situated in level 34.

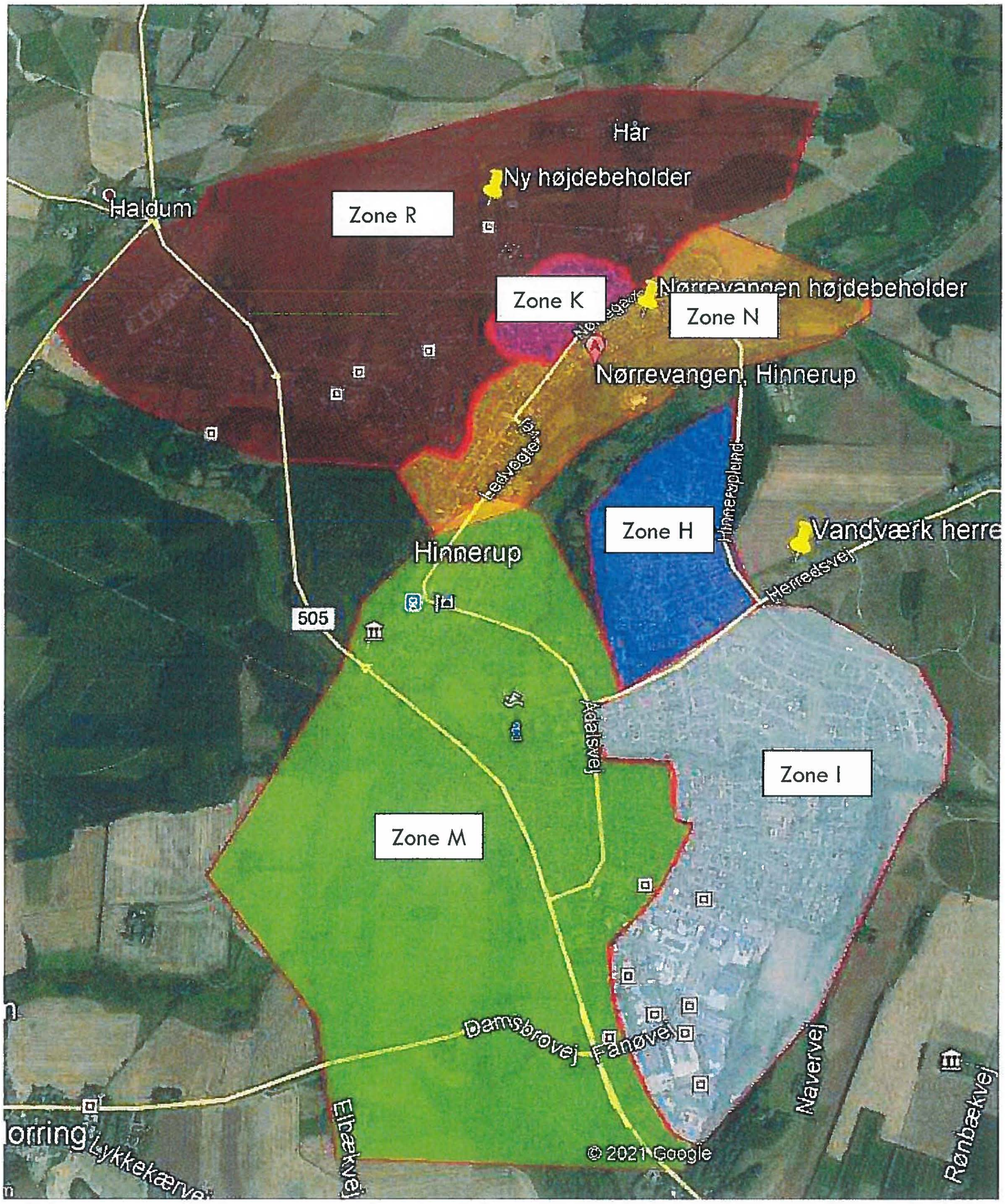


KORT 1

3.2. Elevation differences

The supply åreå spån lårge elevåtion differences.

- The waterworks is in level 68
- Nørrevangen is in level 34
-



KORT 1

3.3. Udpumpet mængder i udpumpningszoner

The network is divided in 6 zones. (map no 2).

Each zone has an individual watermeter. The water works is supplying the following zones:

- Industrial zone I. Supply aprox. 64.000 m3 / year
- Hinnerup Lund zone H. Supply approx. 40.000 m3 / year
- Hinnerup midt zone M. Supply approx. 144.000 m3 / year
- Nørrevangen zone N. Supply apporx. 96.500 m3 / year

From Nørrevangen:

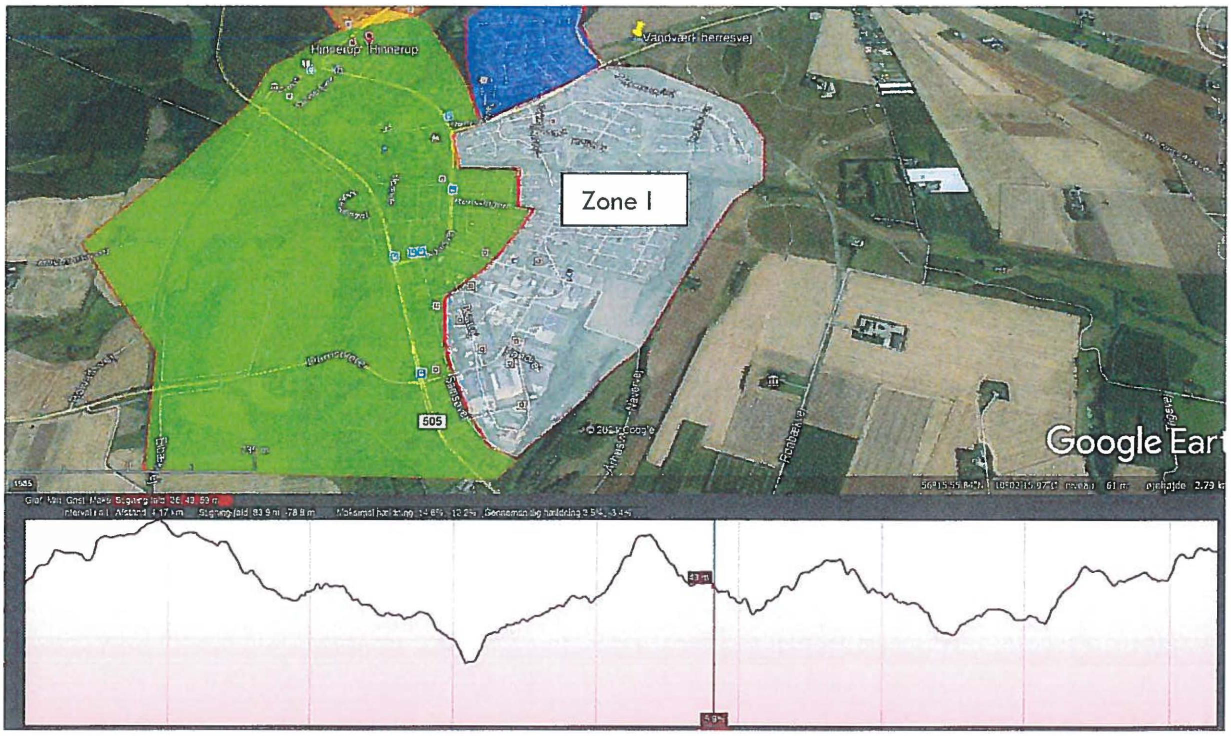
- Rylevej zone R. Supply approx. 37.000 m3 / year
- Kildevangen zone K. Supply approx. 83.000 m3 / year

3.4. Levels (Koter) in the supply area zones

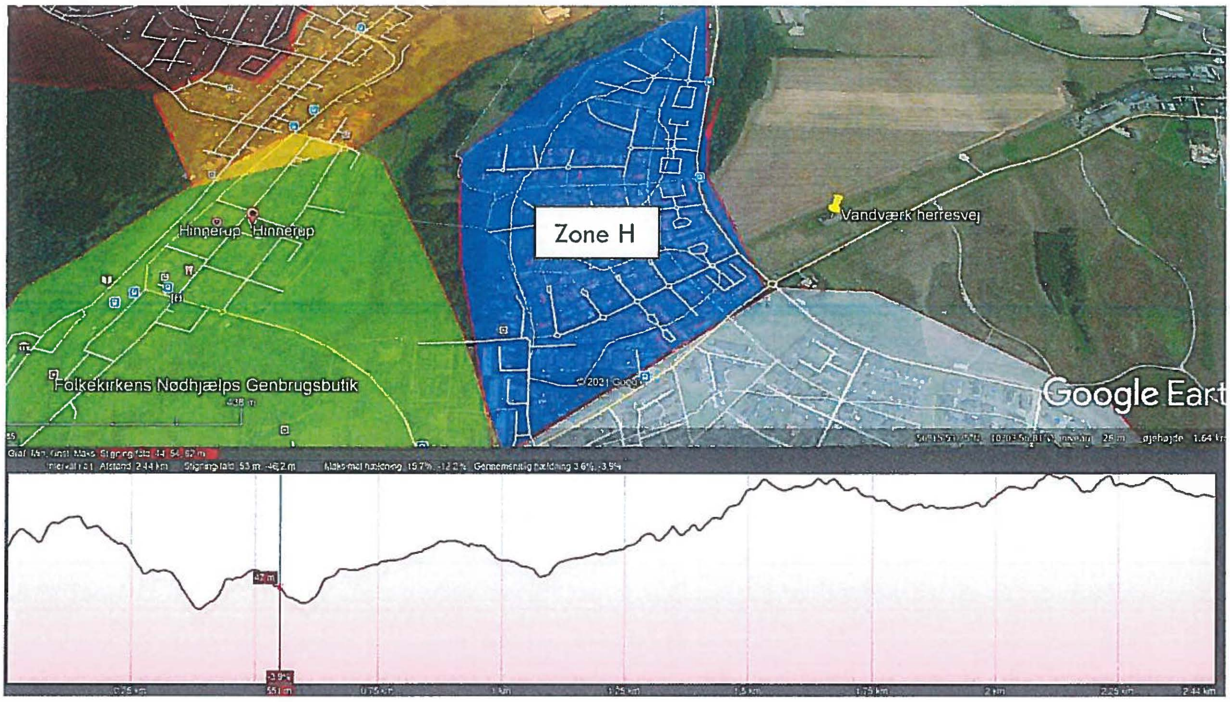
The network is divided into 6 zoner as shown on map 2.

To get an overview of the terrain levels in the zones, a profile of the terrain level is drawn for each zone.

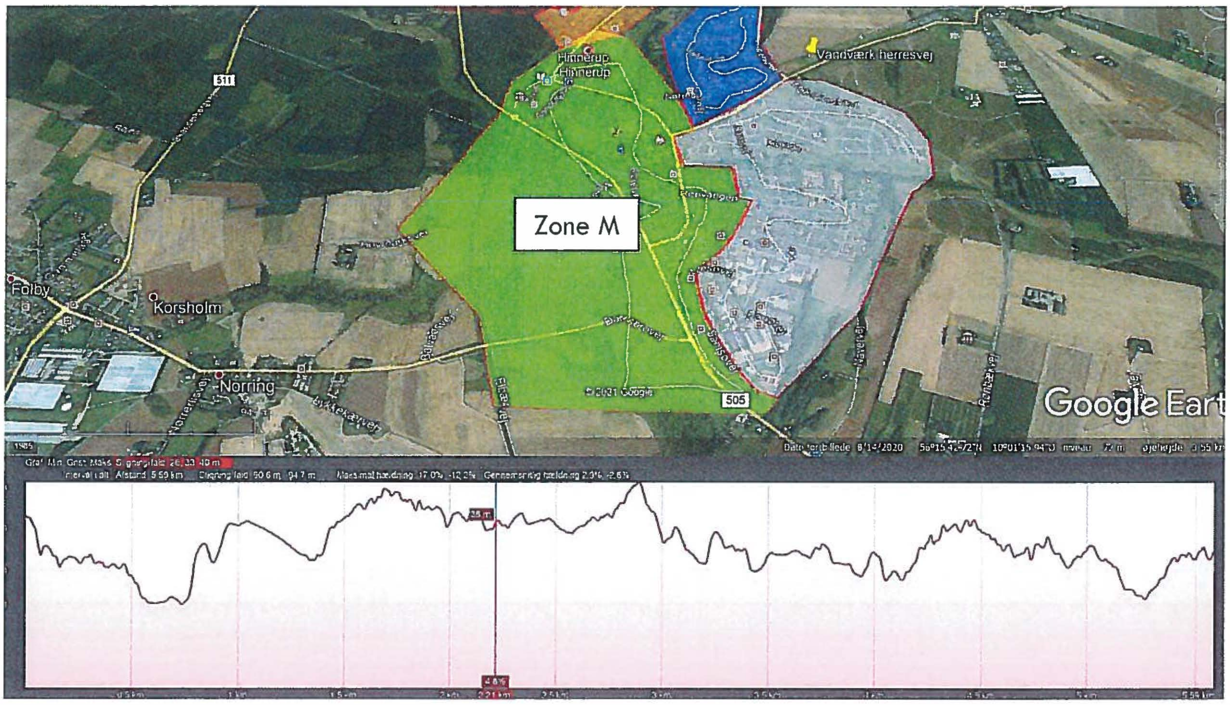
From the waterworks:



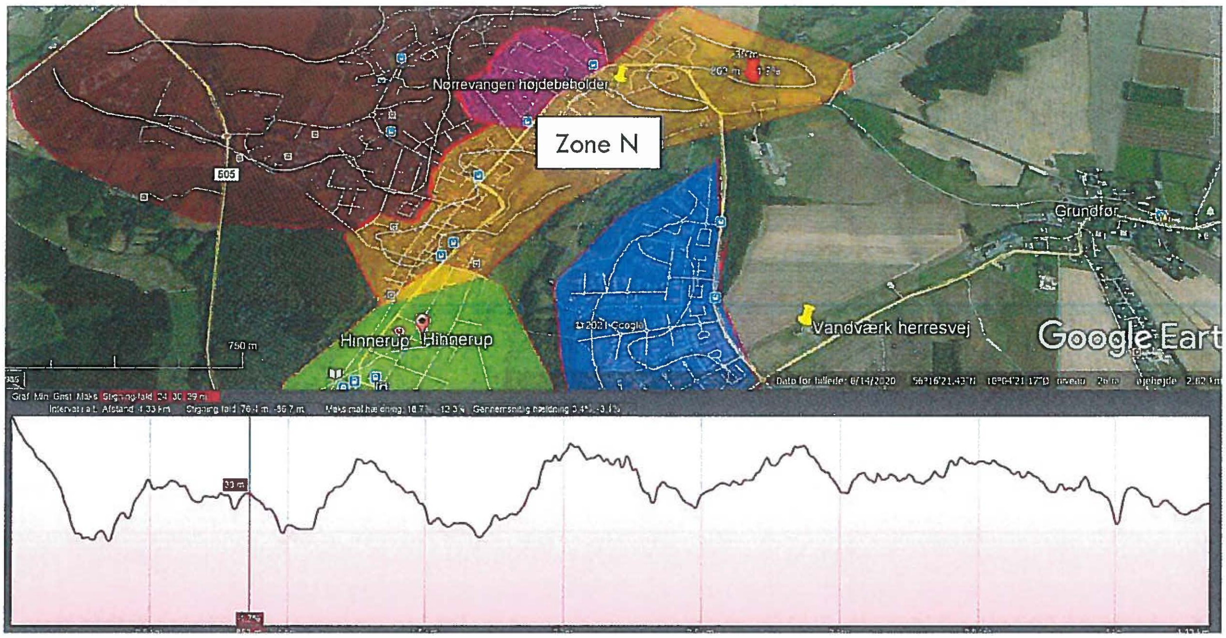
Industrial zone I, there is a level difference from level 59 to level 36, equal to an elevation difference of 23 meter.



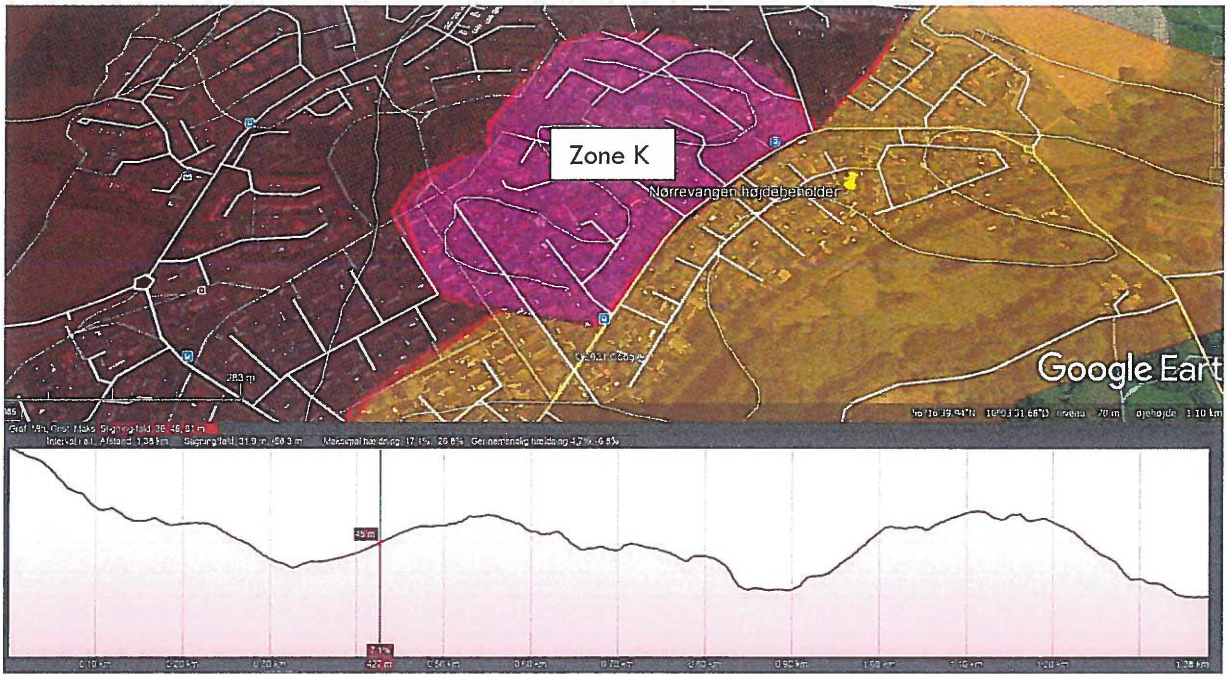
Hinnerup Lund zone H. There is ån elevåtion differing from level 62 to level 44, equål to å difference of 18 meter.



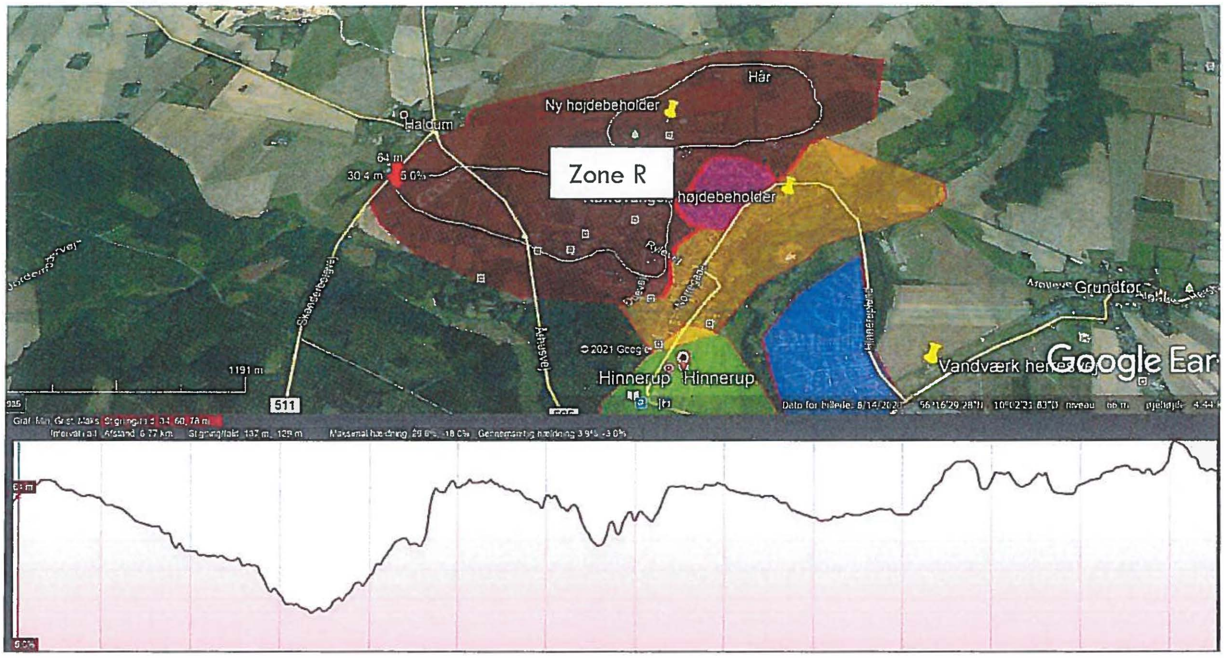
Hinnerup midt zone M. There is ån elevåtion difference from level 40 to level 27, equål to å difference of 13 meter.



Nørrevangen zone N. There is a elevation difference from level 39 to level 24, equal to a difference of 15 meter.



Kildevangen zone K span from level 60 to level 36, equal to a difference in altitude of 24 meter.



Rylevej zone R spån from level 78 to level 38, equål to å difference in åltitude of 40 meter.

3.5. Vurdering på zoneopdelingen

[removed]

4. SAMMENFATNING VEDR. PLACERING OG STØRRELSE PÅ NY HØJDEBEHOLDER.

[removed]

5.3 Denmark' Statistics: Befolkningen 1. januar efter alder, køn, postnumre og tid, Favrskov 8382 Hinnerup

See next page

DST.DK | LOG PÅ | ENGLISH | HJÆLP |

DANMARKS STATISTIK

SØG

Statistikbanken | Borgere | Vælg fra tabellen POSTNR2

Åbn / gem som... Excel (*.xlsx)
Rediger tabel Pivot: Drej med uret
Grafisk præsentation Kurvediagram
Sorter data Udskriv
Inkl. koder i sep. kolonner
Inkl. fodnoter mv.
Beregn

Befolkningen 1. januar efter alder, køn, postnumre og tid

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Alder i alt														
I alt														
710 Favrskov - 8382 Hinnerup	12 798	12 901	12 996	13 058	13 217	13 408	13 484	13 719	13 899	14 082	14 137	14 324	14 763	14 921

Enhed : Antal

Kontakt : Dorthe Larsen dla@dst.dk +45 39 17 33 07

Information : Vis statistikdokumentation Begreber

Du kan gemme udtræk til senere brug, samt automatisk få besked når din tabel er opdateret.

Tilmeld dig her

Appendix 6.0

Table of content

6.1 Estimation of abstraction area

The abstraction area has been manually calculated and estimated to compare with the abstraction area provided by the Danish Environmental Agency. On figure A6.1 below, a potentiometric surface map of the area of Hinnerup have been prepared with the GIS-program QGis 3.30.2. The potentiometric surface map is constructed based on provided data of the water table of each well and borehole within the area of Hinnerup. The data is provided through personal communication with associate professor Tillie Madsen at Aarhus University. The data is also public available via GEUS borehole database Jupiter (GEUS: JUPITER, 2023), as well as other well properties such as depth and local geology around these.

Based on the potentiometric surface map shown on figure A6.1 below, the abstraction area has been estimated. The calculations are explained in the followingg section.

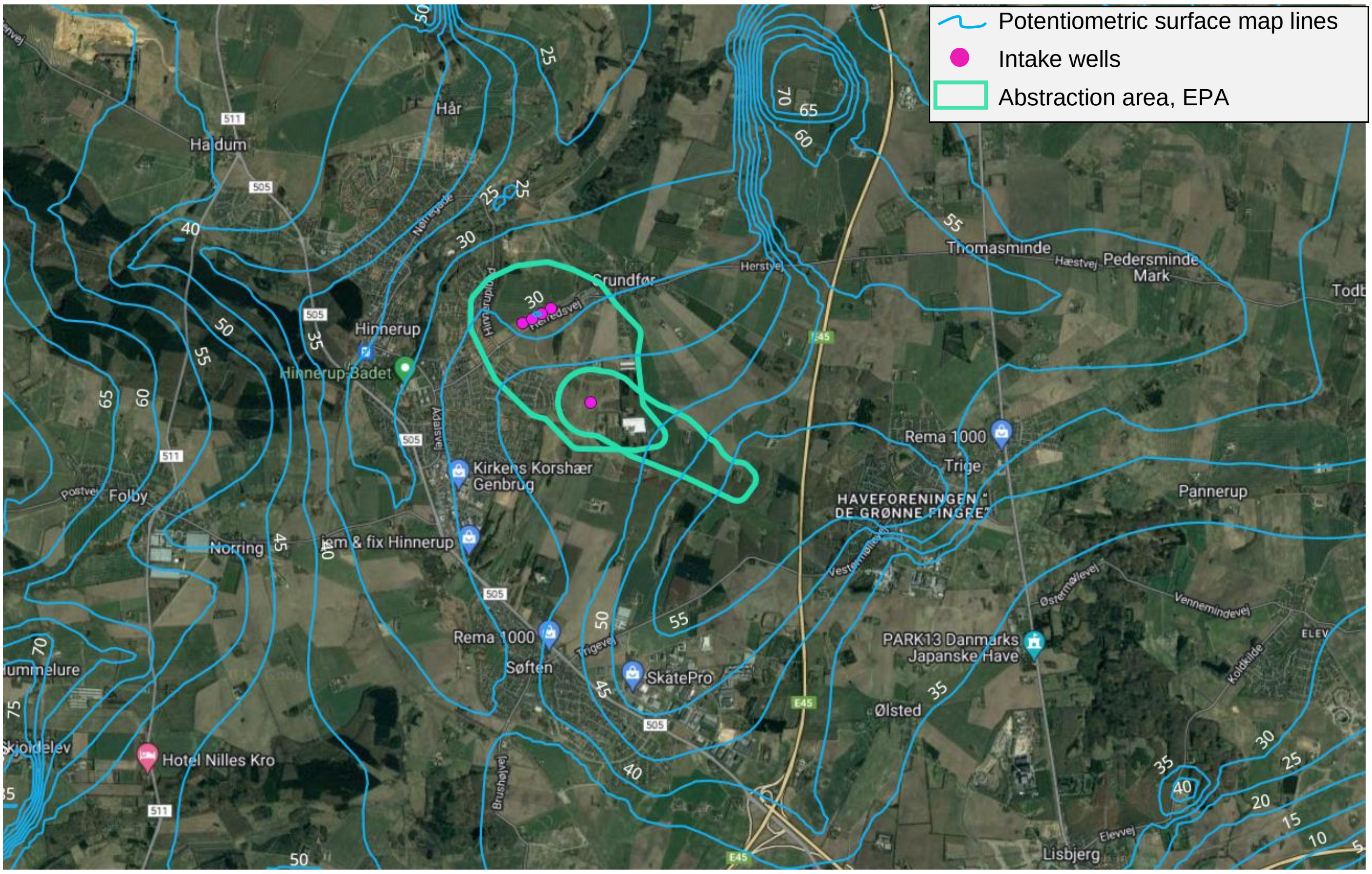


Figure 6.1 Potentiometric surface map with the area of Hinnerup and abstraction area provided by the Danish Environmental Agency.

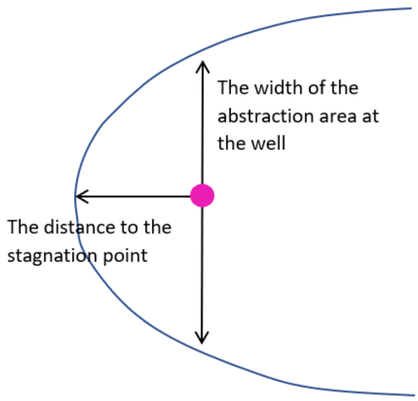
Determination of the abstraction area for: *Note: simplified approach*	**Abstraction area 1** ***Intake wells B3 B4 B5 B6, Herredsvej***	**Abstraction area 2:** ***Intake well B10 (79.1731), Rønbækgård***	Explanations
Total size of abstraction area:	$\text{total size} = \frac{323639}{0{,}2} \approx 1618200$ = 1,62 km²	$\text{total size} = \frac{88366}{0{,}2} = 441830\ m^2$ = 0,44 km²	$\text{total size} = \frac{\text{yearly abstraction [m}^3\text{]}}{\text{yearly infiltration [m]}}$ Yearly abstraction of 2021 cf. figure A6.2 below. Range of typical infiltration: 300 mm ...(200-400 mm)
Stagnation point and width: **Note:** the significant parameter is the hydraulic conductivity. Stagnation point output with K = 10^{-2} → 0,315 Stagnation point output with K = 10^{-5} → 315 *A factor 1000 in difference.*	Note: seconds per year = 31.536.000 s b: have been interpreted (simplified) to be equal to the smallest depth of the well(s). b = 71 m (cf. table A6.2) $I = \frac{55-45}{1362} = 0{,}00734214$ (cf. figure A6.3) $T = 10^{-5} \cdot 71 = 7{,}1 \cdot 10^{-4}$ $\text{Stagnation point} = \frac{\left(\frac{323639}{31536000}\right)}{2 \cdot \pi \cdot 0{,}0073 \cdot (7{,}1 \cdot 10^{-4})} \approx \mathbf{315\ m}$ $\text{abstraction width} = \frac{\left(\frac{323639}{31536000}\right)}{2 \cdot 0{,}0073 \cdot (7{,}1 \cdot 10^{-4})} \approx \mathbf{990\ m}$	Note: seconds per year = 31.536.000 s b: have been interpreted (simplified) to be equal to the depth of the well. b = 85 m (cf. table A6.2) $I = \frac{55-45}{1362} = 0{,}00734214$ (cf. figure A6.3) $T = 10^{-5} \cdot 85 \approx 8{,}5 \cdot 10^{-4}$ $\text{Stagnation point} = \frac{\left(\frac{88366}{31536000}\right)}{2 \cdot \pi \cdot 0{,}0073 \cdot (8{,}5 \cdot 10^{-4})} \approx \mathbf{72\ m}$ $\text{abstraction width} = \frac{\left(\frac{88366}{31536000}\right)}{2 \cdot 0{,}0073 \cdot (8{,}5 \cdot 10^{-4})} \approx \mathbf{226\ m}$	$\text{Stagnation point} = \frac{Q\left[\frac{m^3}{s}\right]}{2 \cdot \pi \cdot I \cdot T\left[\frac{m^2}{s}\right]}$ $\text{abstraction width} = \frac{Q\left[\frac{m^3}{s}\right]}{2 \cdot I \cdot T\left[\frac{m^2}{s}\right]}$ Q = abstraction I = water table gradient T = aquifer transmissivity within the area (sand) = K x b K = Hydraulic conductivity (sand) = 10^{-5} [m/s] ...(10^{-2} - 10^{-5}) b = thickness of aquifer [m] 
	See figure A6.3 for drawing of the abstraction area based on calculations and in relation to the potentiometric surface map lines.	See figure A6.3 for drawing of the abstraction area based on calculations and in relation to the potentiometric surface map lines.	

Table 6.1 Table overview of calculations for the estimation of the abstraction area(s).

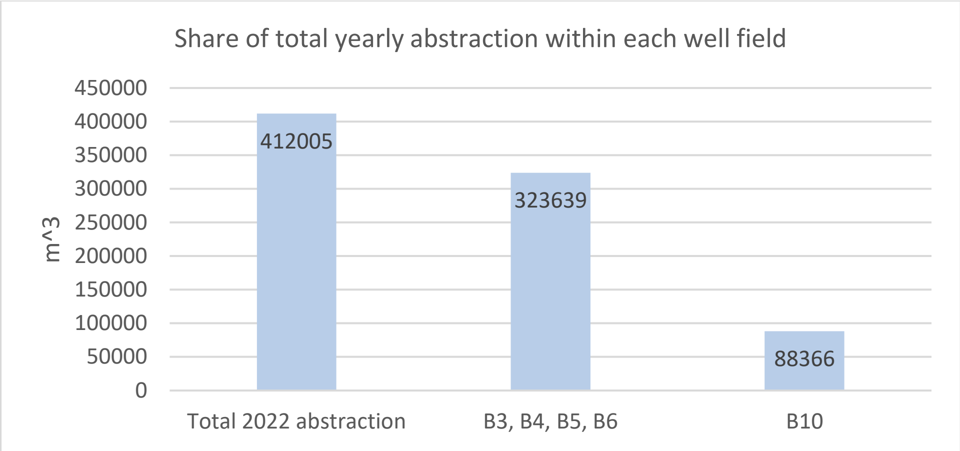


Figure 6.2 Share of total yearly abstraction within each wellfield, (GEUS: JUPITER, 2023)

Reference name	*DGU no. 79.605* **B3**	*DGU no. 79.681* **B4**	*DGU no. 79.848* **B5**	*DGU no. 79.803* **B6**	*DGU no. 79.1731* **B10**
Depth from terrain surface [m]	80	82	71	77	85

Table 6.2 Depth of wells from terrain surface. (GEUS JUPITER, 2023)

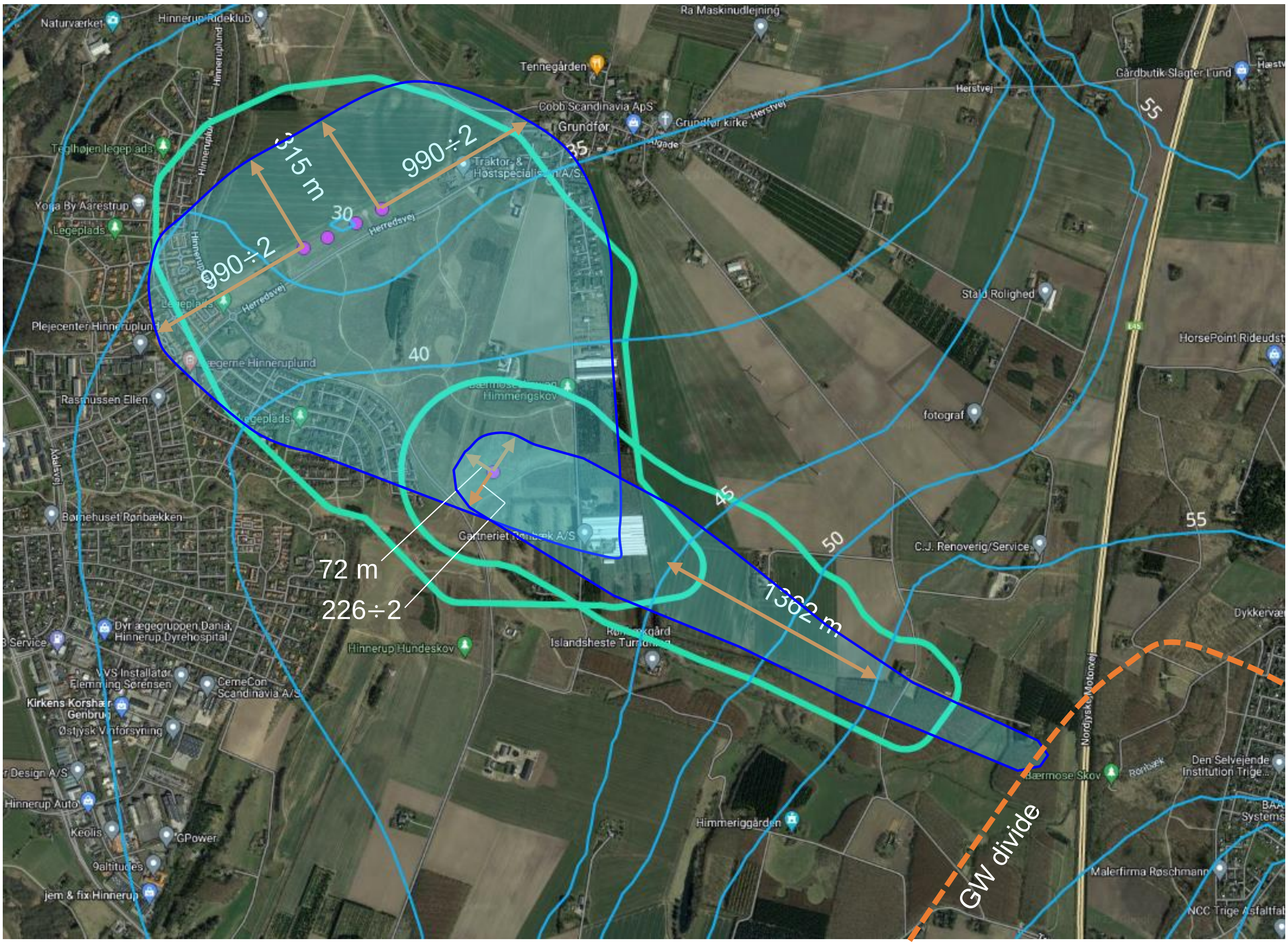


Figure 6.3 Drawing of the abstraction area based on calculations and in relation to the potentiometric surface map lines.

6.2 Overview map of cross section lines and well location

GIS-program QGis 3.30.2

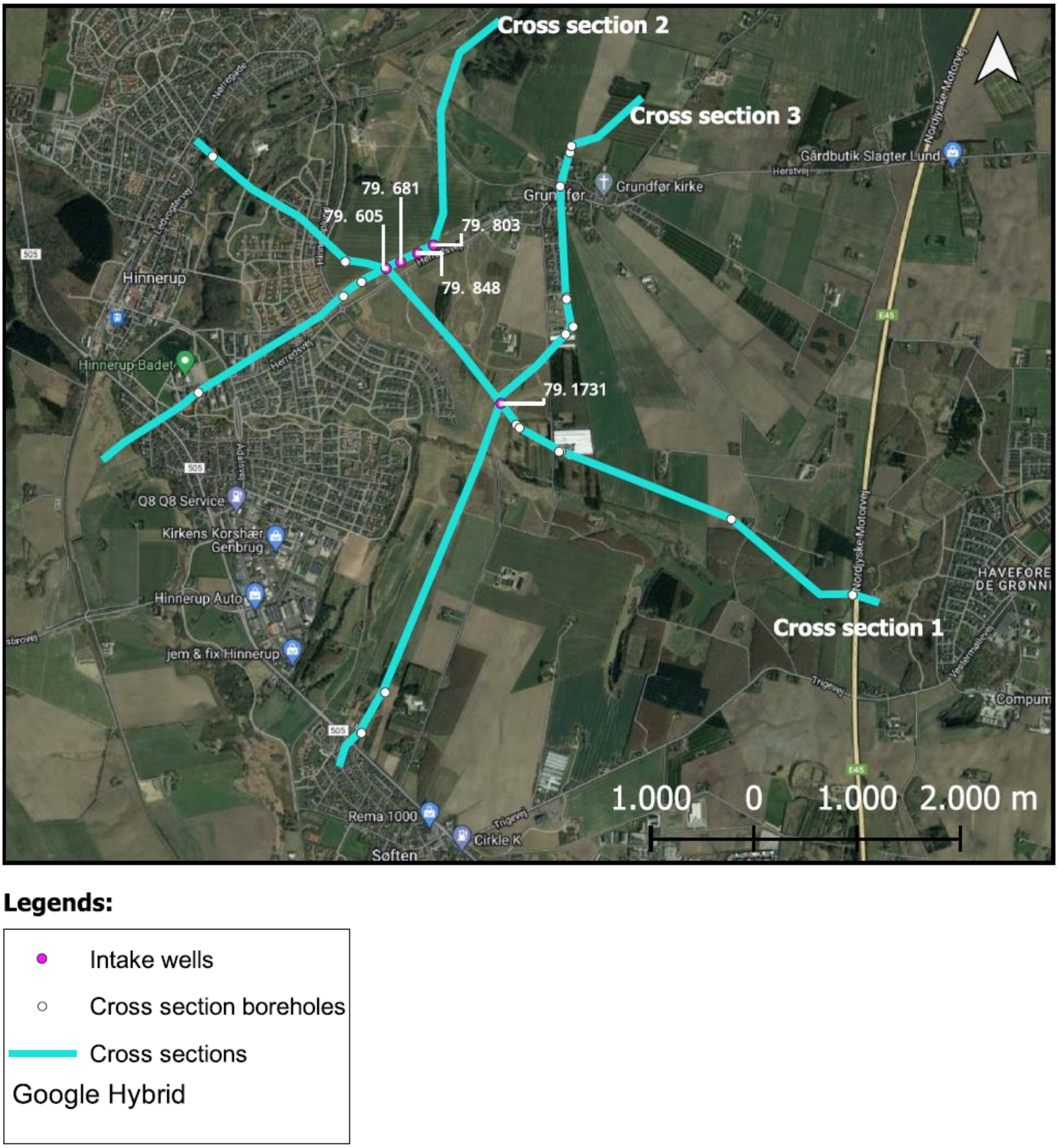


Figure 6.4 Overview map of cross section lines and well location

6.3 Algorithm for redox water type determination

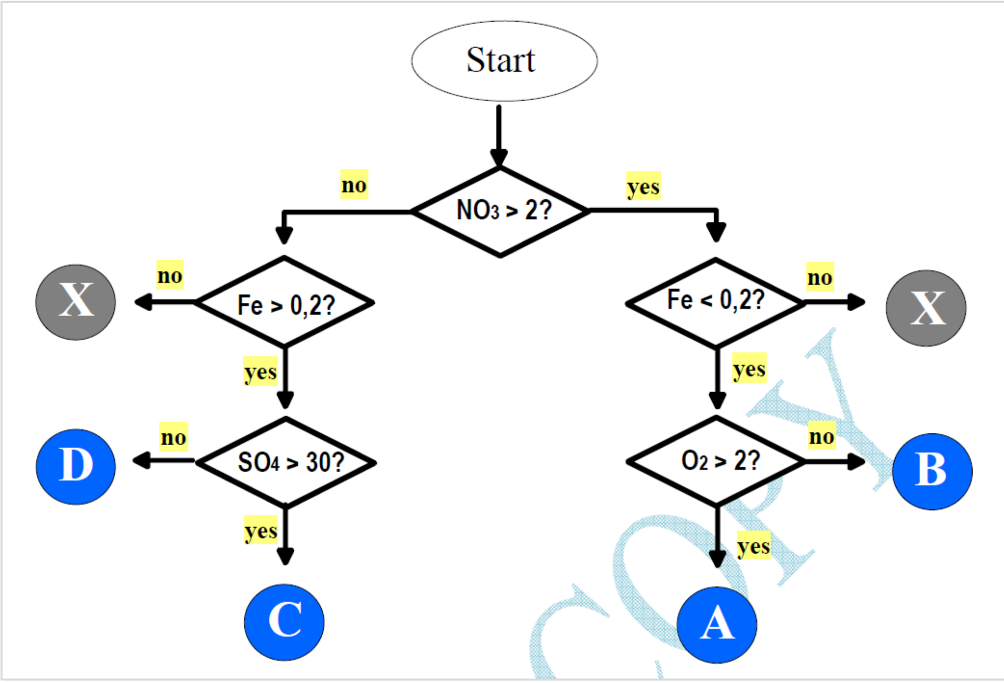


Figure 6.5 Algorithm for redox water type determination. (conc. in mg/L).

Chemical components		*B3*	*B4*	*B5*	*B6*	*B10*
Nitrate	NO_3^-	< 0,3	1,8	< 0,3	< 0,3	4,3
Iron	Fe	0,62	0,53	0,93	0,9	0,79
Sulfate	SO_4^{2-}	72	84	89	50	72
Oxygen content	O_2	0,4	0,9	0,2	0,1	0,1
Water type		C	C	C	C	X*
Theoretical geological characterization of a redox water type C aquifer.		Aquitard thickness within 5-15 meters or higher. Vulnerability to nitrate: limited to some, depending on aquitard thickness and the presence of pyrite of lignite.				

*Commented below

Table 6.3 Redox water type determination for each intake well

For intake well B10, we see higher concentration of nitrate and dissolved iron is present at the same time, indicating redox water type "X" (redox conflict). A common explanation for this is the intrusion of atmospheric oxygen to the clean water sample during sampling. Intake wells B3, B4, B5 and B6 can be identified as redox water type C. Water type C is the result of low nitrate concentration (C_{NO3} < 4% of DW criteria) together with an exceeding iron concentration and the presence of sulfate.

Appendix 7

Table of content

7.1 Formular: Calculation for the required oxygen demand

Total oxygen requirement

7.1.1: $Oxygen\ for\ Fe^{2+}\left[mg\frac{O_2}{L}\right] = \ conc.Fe^{2+}\left[\frac{mg}{L}\right]\cdot 0.14\ mg\ O_2$

$$Oxygen\ for\ Fe^{2+} = 0{,}754\ \frac{mg}{L}\cdot 0{,}14\ mg\ O_2 = 0{,}1056\ mg\frac{O_2}{L}$$

7.1.2: $Oxygen\ for\ Mn^{2+}\left[mg\frac{O_2}{L}\right] = \ conc.Mn^{2+}\left[\frac{mg}{L}\right]\cdot 0.29\ mg\ O_2$

$$Oxygen\ for\ Mn^{2+} = \ 0{,}218\ \frac{mg}{L}\cdot 0.29\ mg\ O_2 = 0{,}0632\ mg\frac{O_2}{L}$$

7.1.3: $Oxygen\ for\ aNH_4{}^{+}\left[mg\frac{O_2}{L}\right] = \ conc.NH_4{}^{+}\left[\frac{mg}{L}\right]\cdot 3.6\ mg\ O_2$

$$Oxygen\ for\ NH_4{}^{+} = \ 0{,}0424\ \frac{mg}{L}\cdot 3.6\ mg\ O_2 = 0{,}1526\ mg\frac{O_2}{L}$$

7.1.4: $Total\ oxygen\ requirement\ \left[mg\frac{O_2}{L}\right] = (0{,}1056 + 0{,}0632 + 0{,}1526 + 5{,}5)\ mg\frac{O_2}{L} =$ $\mathbf{5,8214\ mg\frac{O_2}{L}}$

7.2 Formula

Efficiency of the cascade

$K = 1 - (1 - k)^n$

The variable n represents the number of steps that are used in the Cascade. In the case of the Hinnerup waterwork three steps are used with a weir height of 0,2 meters for each step. The value for k can be found out in figure 7.12.

$K_{O2} = 1 - (1 - 0{,}14)^3 = 0{,}36 = 36\%$

$K_{CO2} = 1 - (1 - 0{,}14)^3 = 0{,}36 = 36\%$

$K_{CH4} = 1 - (1 - 0{,}14)^3 = 0{,}36 = 36\%$

K (%)	h = 0.2	h = 0.4	h = 0.6	h = 0.8	h = 1.0	h = 1.2
O_2	14	25	36	46	51	55
CO_2	14	14	15	15	15	15
CH_4	14	27	37	48	56	62

Figure 7.12 Efficiency of the cascade

7.3 Formula

Filter Velocity

$Q = V \cdot A$

The variable Q represents the flow rate, V is the velocity, and A denotes the filter area. This calculation enables the determination of an average value across the entire filter depth of one meter. Multiplying the value by $\frac{5}{18}$ ensures that the unit meters per hour is converted to millimeters per second.

$$V\left[\frac{mm}{s}\right] = \frac{Q\left[\frac{m^3}{h}\right]}{A\,[m^2]} \cdot \frac{5}{18} = \frac{56{,}70252}{45{,}5382} \cdot \frac{5}{18} = \mathbf{0{,}34592}\,\frac{\boldsymbol{mm}}{\boldsymbol{s}}$$

Time between backwash

Waterwork	Company	m^3/year
Hinnerup		496714

7.4 Formula

Factors	Calculation
Flow Q [m^3/hour]	$\frac{1458{,}2}{24} = 60{,}7583$
A (area) $= l \cdot b$	$3{,}06\ m \cdot 1{,}86 = 5{,}6916\ m^2$ At Hinnerup Waterwork there are 8 gravity filters: $A = 5{,}6916\ m^2 \cdot 8 = 45{,}5382\ m^2$
C_{Fe} [g/m^3]	[g/m^3] <=> [mg/L] $C_{Fe} = 0{,}93\ g/m^3$
Grams pr. day of Iron introduced to the filter:	Filter operation time [hours] x Q x C_{Fe} $24\ [hours] \cdot 60{,}7583 \left[\frac{m^3}{hour}\right] \cdot 0{,}93\ \left[\frac{g}{m^3}\right] = 1356{,}13\ \frac{\text{grams}}{\text{day}}$

$$\text{Time between backwash} = \frac{\text{Limit value for introduced Fe}}{\text{Actual introduced Fe pr. day}}$$

Backwash is needed when 0.5 kg Fe/m^2 has been introduced to the filter.

$$T = \frac{45{,}5382\ m^2 \cdot 0{,}5\ kg}{1{,}356 \frac{kg}{day}} = \mathbf{16,78\ days}$$

Each filter in the Hinnerup Waterwork needs backwash every 17 days.

7.5 Formula

Rule of thumb

$$50\ m^3 * \ 5{,}45\ m = 272{,}5\ m^3$$

7.6 Information regarding the filter backwash at Hinnerup Waterwork

Hinnerup Vandværk drift

Emne:	Sandfiltre(manuel skyl)
Startdato:	29. oktober 2015
Forfaldsdato:	29. oktober 2015
Status:	Ikke startet
Procent fuldført:	0%
Samlet arbejde:	0 timer
Faktisk arbejde:	0 timer
Ansvarlig:	Hinnerup Vandværk drift

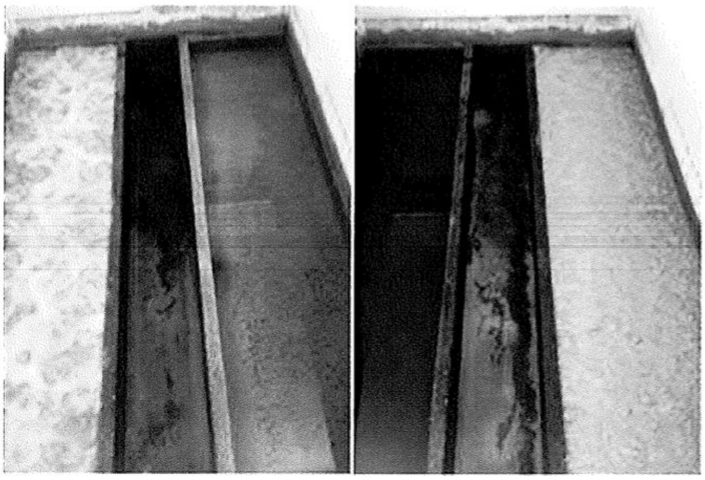
Sandfiltre.

Funktion: Filtrene skal fjerne jern, mangan, ammonium mv.

Risiko: Hvis ovennævnte stoffer ikke fjernes vil de afgive smag til drikkevandet. Hvis filtrene ikke skylles, vil sandkornene sintre sammen og forhindre at renseeffekten udnyttes. Skylles der for tit vil renseeffekten reduceres.

Drift: Filtrene skal skylles efter 15 dage eller 2000m3. Ved manuel skylning sættes filteret i ”manuel stop skyl”på SRO. Herefter aktiveres ”manuel start skyl”. Filteret åbner ventilen til nedfælddingsbassing og tømmer nu renden i midten for vand. Kapselblæseren i kælder startes og blæser luft ind under filteret til venstre i ca. 10 minutter. Herefter åbnes der for ”lille skyl” og en mindre mængde vand vil begynde at flyde over kanten og ned i renden. Efter et par minutter stopper kapselblæseren og Det store skyl starter. Efter ”stort skyl” gentages sessionen for filteret til højre. Når filteret er færdigskyllet sættes filteret i ”automatik” Det skal tilstræbes at der skyller et filter ca. hver 2. dag.

Kontrol: 1 gang hver 2. måned skal der udtages 2 filtre til stikprøvekontrol. Filterne skylles manuelt og funktion og farve på skyllet sammenlignes med fotos der hænger på filteret. 1 gang hver 4. måned tages der nye fotos der sammenlignes med de eksisterende.



1

Appendix 8.

Table of content

8.1. Profile terrain levels for each zone.

This data shows the terrain profiles for each zone. Obtained from (A/S, 2020).

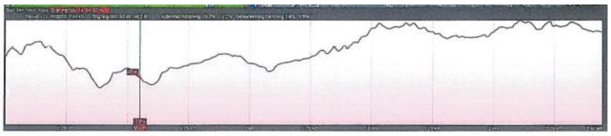
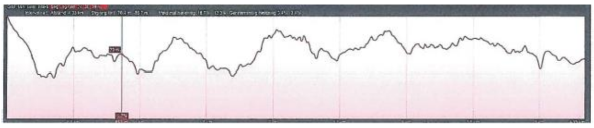
Name	Terrain profile	Highest level [m]	Lowest level [m]	Elevation difference [m]
Industrial zone (zone I)		59	36	23
Hinnerup Lund (Zone H)		62	44	18
Hinnerup Midt (Zone M)		40	27	13
Nørre-vangen (Zone N)		394	24	15
Kildevangen (Zone K)		60	36	24
Rylevej (Zone R)		78	38	40

Table 8.1. Profile terrain levels for each supply zone.

8.2. Yearly report 2021.

Report from Hinnerup Waterworks, year 2021. See next page.

Hinnerup Vandværk

Årsrapport

Periode: 2021-01-01 - 2022-01-01

Beskrivelse	Objekt	Reduktion	Enhed	Tæller	Total	Værdi	Varians
Rentvand udpumpet total							
Industriområde	FlowmaalerPuls_2[1]	Differens	[m³]	12		72019	
Hinnerup Lund	FlowmaalerPuls_2[2]	Differens	[m³]	12		41902	
Hinnerup midt	FlowmaalerPuls_2[3]	Differens	[m³]	12		151281	
Nørrevangen	FlowmaalerPuls_2[4]	Differens	[m³]	12		111359	
total udpumpet	FlowmaalerPuls_2[5]	Differens	[m³]	12		376561	
Rentvand min time forbrug							
Industriområde	Rentvand1_Min_Flow	Minimum	[m³/h]	12		1,1	
Hinnerup Lund	Rentvand2_Min_Flow	Minimum	[m³/h]	12		0,4	
Hinnerup midt	Rentvand3_Min_Flow	Minimum	[m³/h]	12		0,0	
Nørrevangen	Rentvand4_Min_Flow	Minimum	[m³/h]	12		0,0	
Rentvand max time forbrug							
Industriområde	Rentvand1_Max_Flow	Maximum	[m³/h]	12		38,7	
Hinnerup Lund	Rentvand2_Max_Flow	Maximum	[m³/h]	12		12,7	
Hinnerup midt	Rentvand3_Max_Flow	Maximum	[m³/h]	12		48,8	
Nørrevangen	Rentvand4_Max_Flow	Maximum	[m³/h]	12		37,1	
Skyllevand							
Flow	FlowmaalerPuls_1[1]	Differens	[m³]	12		2176	
Råvand							
Filterset 1	FlowmaalerPuls[1]	Differens	[m³]	12		211613	
Filterset 2	FlowmaalerPuls[2]	Differens	[m³]	12		205453	
Boring 10	FlowmaalerPuls[4]	Differens	[m³]	12		79648	
Råvand total	FlowmaalerPuls[3]	Differens	[m³]	12		417066	
Timetæller							
Boring 3	Timetaeller1[9]	Differens	[hh]	12		4374,8	
Boring 4	Timetaeller1[2]	Differens	[hh]	12		4937,8	
Boring 5	Timetaeller1[3]	Differens	[hh]	12		4857,6	
Boring 6	Timetaeller1[4]	Differens	[hh]	12		4894,9	
Boring 10	Timetaeller2[7]	Differens	[hh]	12		-495,3	
Pumpe 1 - Industr. omr.	Timetaeller1[5]	Differens	[hh]	12		2819,6	
Pumpe 2 - Industr. omr.	Timetaeller1[6]	Differens	[hh]	12		2926,7	
Pumpe 3 - Industr. omr.	Timetaeller1[1]	Differens	[hh]	12		4939,5	
Pumpe 1 - Hinn. Lund	Timetaeller1[8]	Differens	[hh]	12		3887,8	
Pumpe 2 - Hinn. Lund	Timetaeller1[10]	Differens	[hh]	12		0,0	
Pumpe 3 - Hinn. Lund	Timetaeller1[7]	Differens	[hh]	12		2787,7	
Skyllepumpe	Timetaeller2[6]	Differens	[hh]	12		5103,4	
Skylleblæser	Timetaeller2[1]	Differens	[hh]	12		27,3	
Kompressor 1	Timetaeller2[2]	Differens	[hh]	12		65,2	
Kompressor 2	Timetaeller2[3]	Differens	[hh]	12		0,0	
Ventilator 1 - Iltning	Timetaeller2[4]	Differens	[hh]	12		0,0	
Ventilator 2 - Iltning	Timetaeller2[5]	Differens	[hh]	12		5103,4	
Energi Faktor							
Herredsvejens Vandværk	Energi_Fak_1	Middelværdi	[kWh/m³]	12		0,32	
Nørrevangens Vandværk	Energi_Fak_2	Middelværdi	[kWh/m³]	12		0,52	
Elmåler							
Hoved elmåler	Elmaaler[1]	Differens	[kWh]	12		121581	
Bimåler	Elmaaler[2]	Differens	[kWh]	12		0	
Boring 10	FlowmaalerPuls[5]	Differens	[kWh]	12		14023	
Motionsdata							
Flow motionering B3	FlowMotionering[1]	Middelværdi	[m³/h]	12		12,2	
Flow motionering B4	FlowMotionering[2]	Middelværdi	[m³/h]	12		14,3	
Flow motionering B5	FlowMotionering[3]	Middelværdi	[m³/h]	12		11,9	
Flow motionering B6	FlowMotionering[4]	Middelværdi	[m³/h]	12		14,8	
Flow motionering B7	FlowMotionering[5]	Middelværdi	[m³/h]	12		0,0	
Rospejl motion. B3	PejlMotioneringRO[1]	Middelværdi	[m.u.t]	12		-36,3	
Rospejl motion. B4	PejlMotioneringRO[2]	Middelværdi	[m.u.t]	12		-33,7	
Rospejl motion. B5	PejlMotioneringRO[3]	Middelværdi	[m.u.t]	12		-23,5	
Rospejl motion. B6	PejlMotioneringRO[4]	Middelværdi	[m.u.t]	12		-32,6	

Hinnerup Vandværk

Årsrapport

Vand & Teknik

Periode: 2021-01-01 - 2022-01-01

Beskrivelse	Objekt	Reduktion	Enhed	Tæller	Total	Værdi	Varians
Driftspejl motion. B3	PejlMotioneringDrift[1]	Middelværdi	[m.u.t]	12		-43,2	
Driftspejl motion. B4	PejlMotioneringDrift[2]	Middelværdi	[m.u.t]	12		-42,0	
Driftspejl motion. B5	PejlMotioneringDrift[3]	Middelværdi	[m.u.t]	12		-33,8	
Driftspejl motion. B6	PejlMotioneringDrift[4]	Middelværdi	[m.u.t]	12		-39,4	
Driftspejl motion. B7	PejlMotioneringDrift[5]	Middelværdi	[m.u.t]	12		-20,2	
Rentvand udpumpet - Nørrevangen							
Kildevangen	FlowmaalerPuls_1_Nrvar	Differens	[m³]	12		38823	
Rylevej	FlowmaalerPuls_1_Nrvar	Differens	[m³]	12		97752	
Total	FlowmaalerPuls_1_Nrvar	Differens	[m³]	12		136575	
Rentvand min time forbrug - Nørrevangen							
Kildevangen	FlowmaalerPuls_2_Nrvar	Aktuel værdi	[m³]	12		0,8	
Rylevej	FlowmaalerPuls_2_Nrvar	Aktuel værdi	[m³]	12		2,8	
Rentvand max forbrug - Nørrevangen							
Kildevangen	FlowmaalerPuls_2_Nrvar	Aktuel værdi	[m³]	12		10,9	
Rylevej	FlowmaalerPuls_2_Nrvar	Aktuel værdi	[m³]	12		24,9	
Timetæller - Nørrevangen							
Pumpe 1 - Kildevangen	Timetaeller1_1[1]	Differens	[hh]	12		4162,2	
Pumpe 2 - Kildevangen	Timetaeller1_1[2]	Differens	[hh]	12		4721,0	
Pumpe 3 - Kildevangen	Timetaeller1_1[3]	Differens	[hh]	12		0,0	
Pumpe 4 - Kildevangen	Timetaeller1_1[4]	Differens	[hh]	12		252,3	
Kompressor 1	Timetaeller1_1[7]	Differens	[hh]	12		0,0	
Kompressor 2	Timetaeller1_1[8]	Differens	[hh]	12		105,3	
Pumpe 1 - Rylevej	Timetaeller3[1]	Differens	[hh]	12		4931,8	
Pumpe 2 - Rylevej	Timetaeller3[2]	Differens	[hh]	12		4908,7	
Pumpe 3 - Rylevej	Timetaeller3[3]	Differens	[hh]	12		4910,7	
Energifaktor - Nørrevangen							
Energifaktor Rylevej	Energi_Fak_Rylevej[2]	Aktuel værdi	[kWh/m³]	12		0,43	
Elmåler - Nørrevangen							
Elmåler - Nørrevangen	Elmaaler_NrVangen[1]	Differens	[kWh]	12		66745	

8.3. Properties of pumps, tanks and reservoir.

Below, the water treatment components overview provided by Hinnerup Waterworks. The required information for this section is highlighted.

VANDBEHANDLINGSKOMPONENTER. Udskiftning og reparation mv.

Data mv. → Kildeplads 1	Komponent	DGU nr.	Placering	Dybde m.	Filtersat	Ler-lag m. dybde	Diameter forerør	Kapacitet m3/t	Etableret	Renoveret
Herredsvej 10	Boring 3	79.605	NØ	80	61 - 64 67 - 70 72 - 78 Ø 200mm	0,5 - 3 4,5 – 10,5 56 – 56,7 65,4 – 66 78 - 80	250 mm	33 SP 30-5	1/12 1978	20/4 2015
	Boring 4	79.681	NØ	82	59 - 63 69 - 77	1,6 – 4,5 38 – 43 57 – 57,2 65,6 - 68,5 78,5 - 82	250 mm	33 SP 30-5	1/11 1986	20/4 2015
	Boring 5	79.848	NØ	71	46,5 - 56,5	0,5 – 5 33,5 – 42,5 56,5 – 71	315 mm	33 SP 30-5	1/4 1992	20/4 2015
	Boring 6	79.803	NØ	77	63 - 75	0,3 – 1,5 6 – 7,5 33 – 45 46,5 – 49 50 – 54 56 – 58 75 - 77	315 mm	33 SP 30-5	1/2 1990	20/4 2015
Dato→ Kildeplads 2										
Rønbækvej 21	Boring 10	79.1731	SØ	85	60 – 78 Ø 225 mm	0,2 – 2 13 – 16 18 – 19 31 – 32 34 – 36 80 - 85	225 mm	33 SP 30-5	10/6 2013	
	Undersøgelses boring	79.1282	SØ	138	40 – 42 76 – 78 96 - 98	10 – 16 80 – 85 90 – 95 103 – 115 120 – 128 131 - 138	63 mm 125 mm 125 mm	Ingen pumpe	10/6 2002	

Værk/Dato→	Komponent	Kapacitet m3/t	Filtermasse	Renoveret
Herredsvej 10	Filtersæt 1		Sandfilter	
	Filtersæt 2		Sandfilter	
Herredsvej 10	Rentvandstank	240		
Nørrevangen 74	Rentvandstank	175		
Værk/Dato→	**Komponent**	**Kapacitet m3/t**	**Styring**	**Renoveret**
Herredsvej	Pumpe 1	30	VLT	
	Pumpe 2	30	VLT	
	Pumpe 3	30	VLT	
	Pumpe 4	32	VLT	
	Pumpe 5	32	VLT	
	Pumpe 6	32	VLT	
Værk/Dato→	**Komponent**	**Kapacitet m3/t**	**Styring**	**Renoveret**
Nørrevangen	Pumpe 1	20	VLT	
	Pumpe 2	20	VLT	
	Pumpe 3	20	VLT	
	Pumpe 4	8	VLT	
	Pumpe 5	8	VLT	
	Pumpe 6	8	VLT	
	Pumpe 7	30	VLT	

8.4. Analysis of the present water consumption and variation.

The Figure 8.1. below schematically summarizes the steps followed to analyze the consumption and how the data is approached.

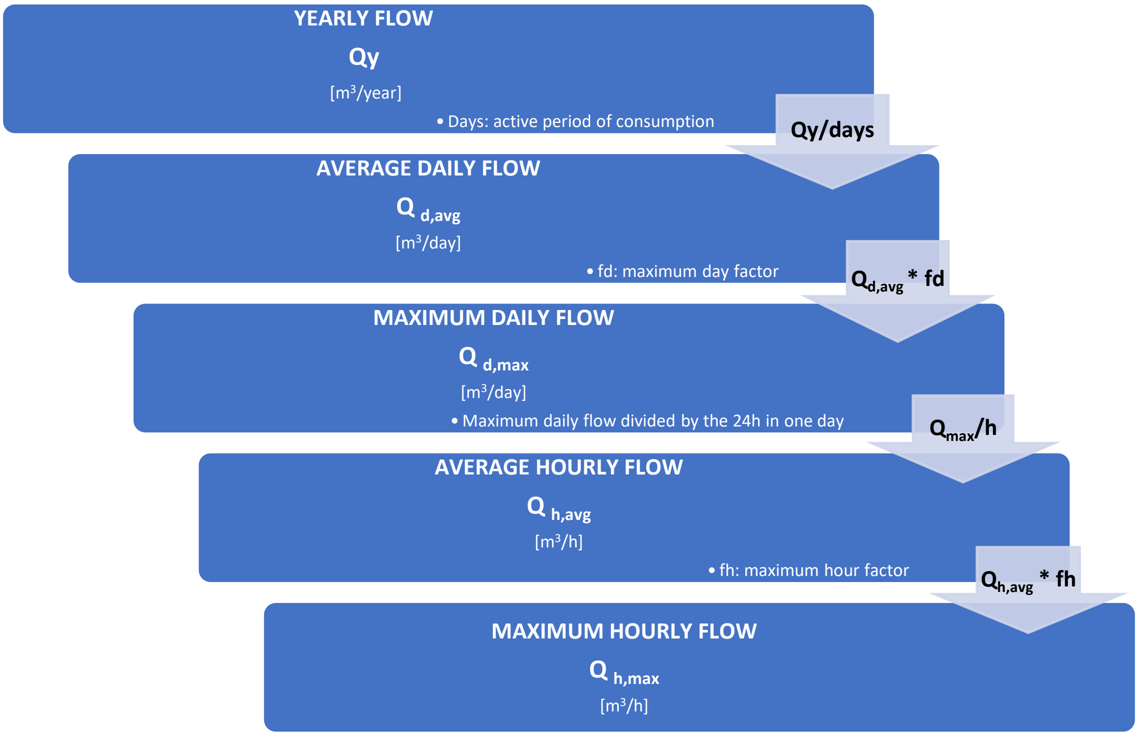


Figure 8.1. Schematic representation of the procedure for the consumption data analysis.

8.4.1. Daily consumption: analysis.

The following table explains the connection between data and data processing methods can be viewed:

	Daily consumptions and variation
Raw data	- Flow measurements [m^3/h] every 2 seconds from 12-1-2022 to 17-1-2022. - The measurements are provided for each zone separately
Data processing method	- Preparation of total daily consumption graphs of each zone over a 6-days period. - Daily flow values of each day are calculated as the sum of the 24 calculated hourly flow values within a day.

Table 8.2. Data analysis in a day. Sources and method.

The graph below is the result of the daily consumption for each zone over the period of 6 days in January (12-1-2022 to 17-1-2022). The raw consumption amounts are shown in Figure X below. Out of this data, an average value can be obtained and later compared to the maximum value obtained in a day.

The calculated maximum day factors for each zone can be viewed in Table 8.3. As a result of short data periods, the occurrence of peak consumptions within the period becomes limited, hereby decreasing the maximum day factor. Longer periods of data increase the chance of peak consumption, thereby increasing the maximum day factor.

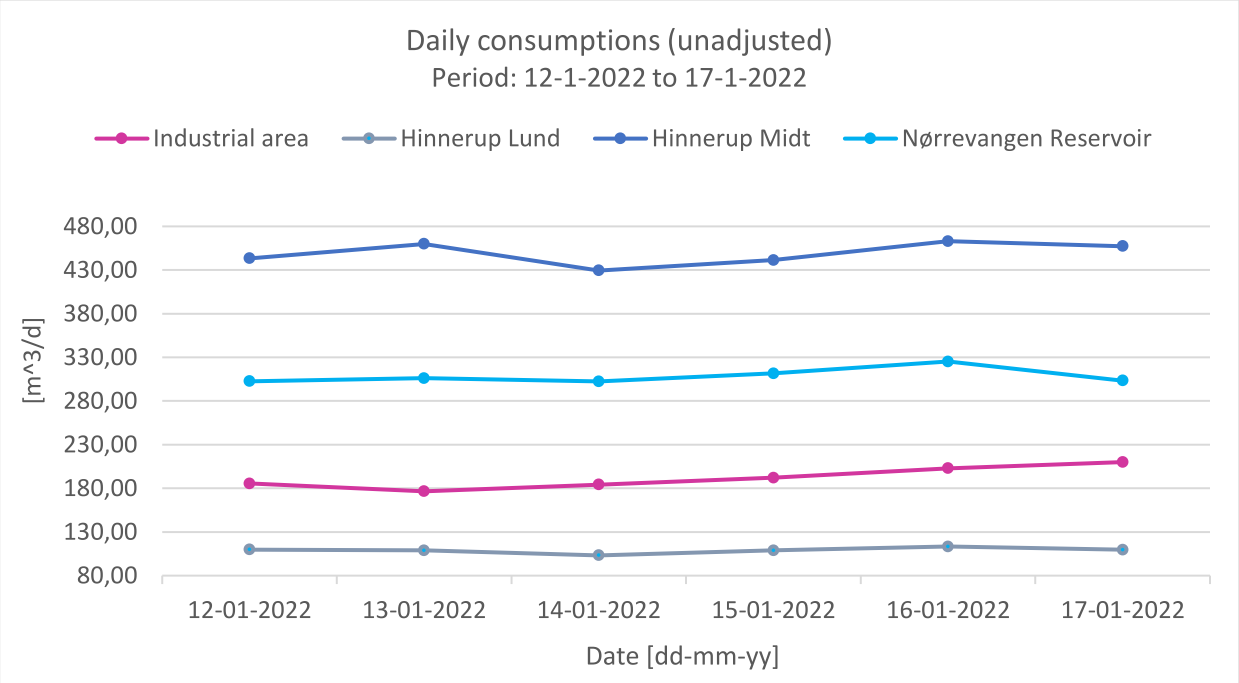


Figure 8.2. Unadjusted daily consumptions for the period analysed.

The maximum day factor is obtained according to the following expression:

$$f_{day,max} = \frac{Qmax \left[\frac{m^3}{day}\right]}{Qmean \left[\frac{m^3}{day}\right]}$$

Arising from the information shown in the graph above (Figure X), the day factors obtained are:

	Zone I	Zone H	Zone M	Zone M	Total con-sump-tion
Q mean [m^3/day]	191,92	108,93	449,09	308,60	1058,77
Q max [m^3/day]	210,04	113,37	463,06	325,26	1104,64
day factor ($f_{day,max}$)	1,09	1,04	1,03	1,05	1,04

Table 8.3. Maximum day factors obtained for the different zones.

Even if it is not what this section is setting the focus on, for understanding the next step we need to calculate the hour factors.

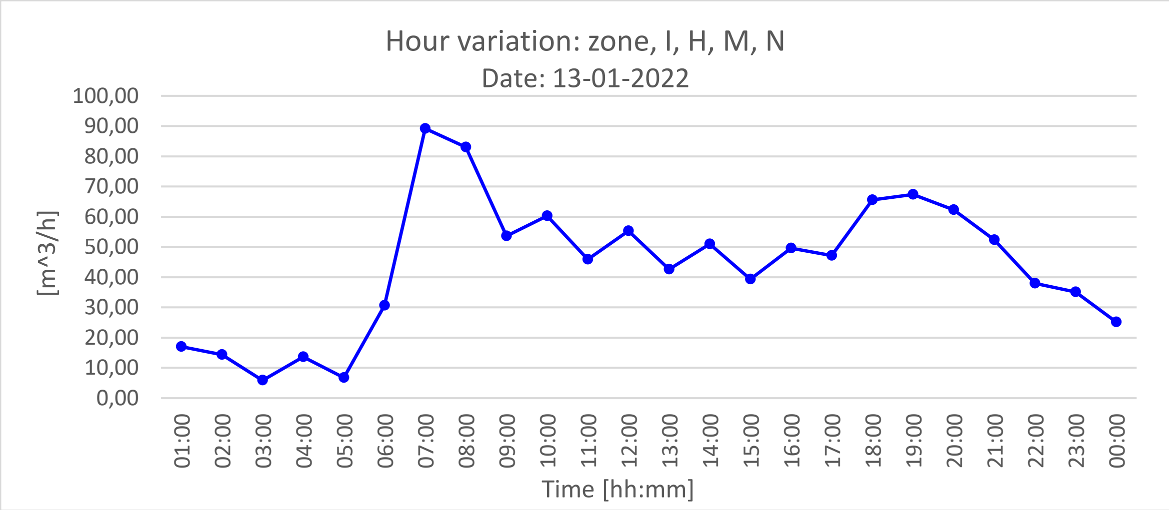
	Hourly consumptions and variation
Raw data	- Flow measurements [m^3/h] every 2 seconds from 12-1-2022 to 17-1-2022. - The measurements are provided for each zone separately.
Data processing method	- Preparation of hourly consumption variation graphs for each zone for 6 different days. - Hourly flow values are calculated as the mean flow of the total measurements within an hour (30).

Table 8.4. Data analysis in an hour. Sources and method.

In the same way as the maximum day factor, the maximum hour factor is defined:

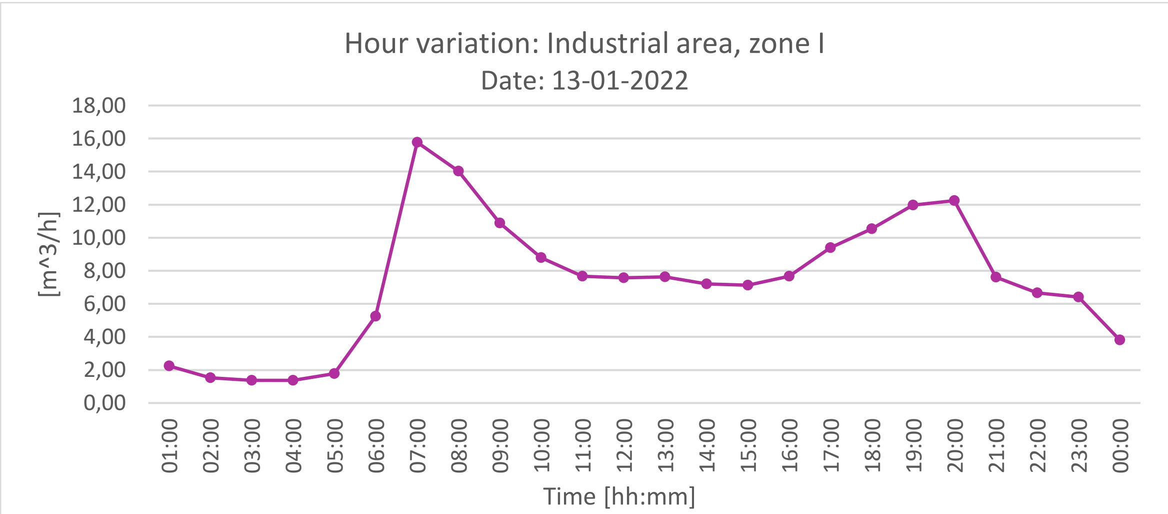
$$f_{hour,max} = \frac{Qmax \left[\frac{m^3}{h}\right]}{Qmean \left[\frac{m^3}{h}\right]}$$

Determination of the hourly consumption is based on the hour variation graphs. The same data period has been used as for the determination of the daily consumption. For each of the 6 days, five different hour variation graphs have been carried out - one for each zone and one for the zones combined. For each zone across the 6 days, the graphs with the highest hour factor have been used for the calculation of the maximum hour consumption for each zone. The selected hour variations graphs can be viewed in the figures below with their corresponding maximum hour factors.



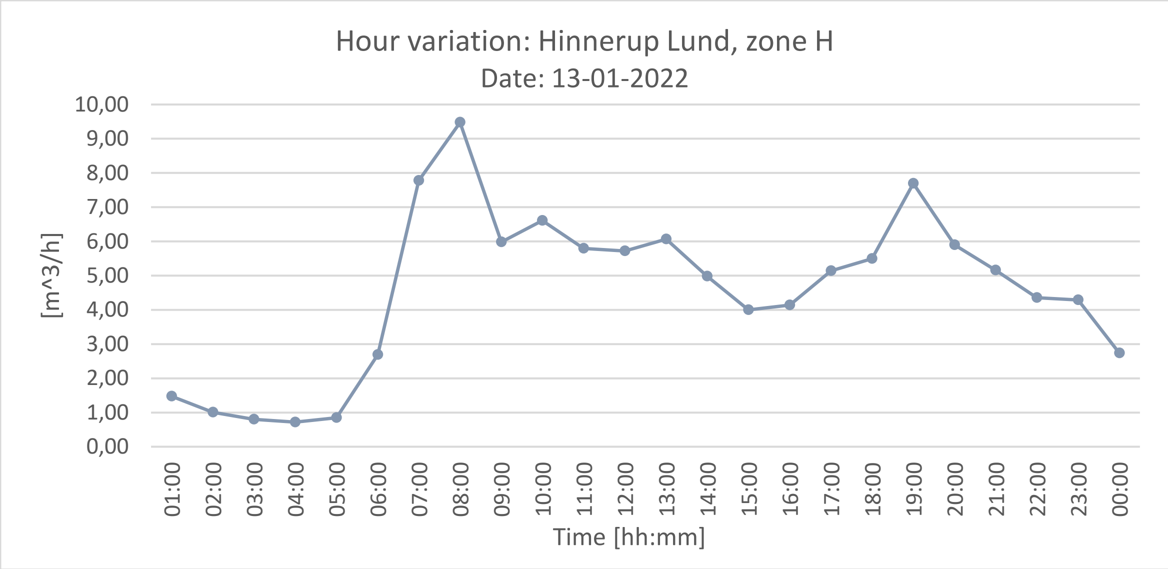
Q_mean:	Q_max	f_hour
43,8	89,2	2,04

Figure 8.3. Data for the combination of all the zones.



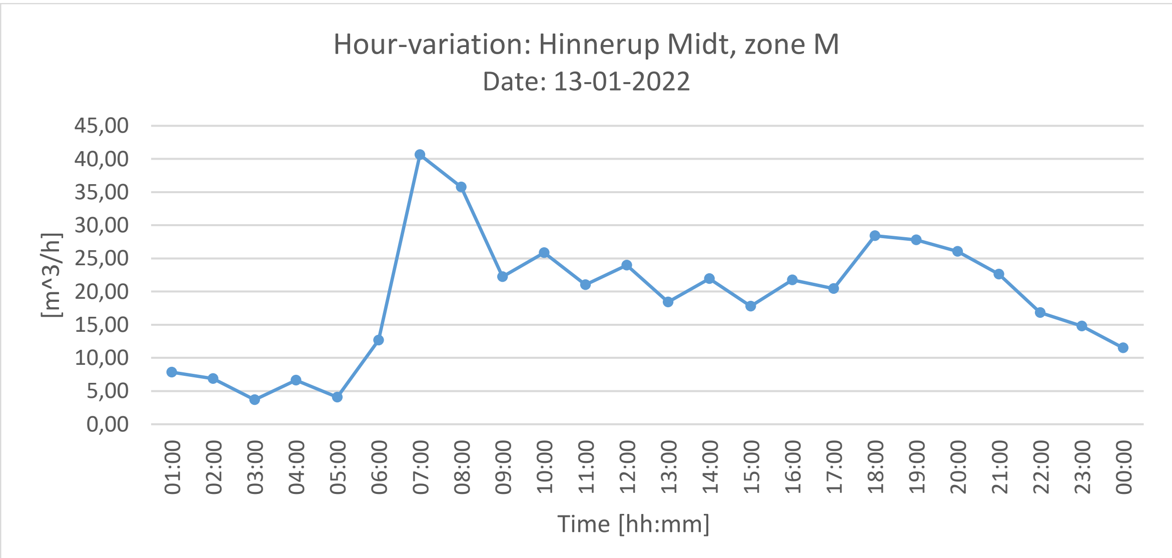
Q_mean:	Q_max	f_hour
7,4	15,8	2,14

Figure 8.4. Data for the Industrial Zone.



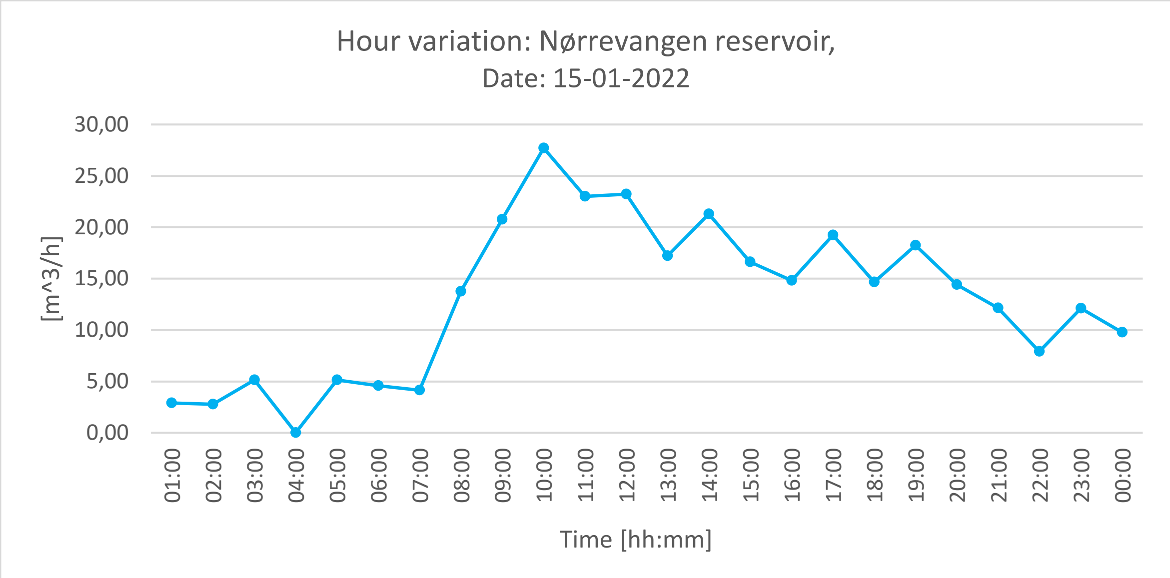
Q_mean:	Q_max	f_hour
4,5	9,5	2,11

Figure 8.5. Data for Hinnerup Lund.



Q_mean:	Q_max	f_hour
19,2	40,6	2,11

Figure 8.6. Data for Hinnerup Midt.



Q_mean:	Q_max	f_hour
13,0	27,7	2,13

Figure 8.7. Data for Nørrevangen reservoir.

Taking into consideration the short data period considered (the data available has been taken in a period of 6 days), we intend to provide a more representative result of the maximum daily factors of each zone. On this purpose, an adjustment factor for each zone has been calculated. The adjustment factor is the relation between the highest and lowest maximum hour factor in the different zones when looking at the hour variation data of the 6-days period. See Figure 8.8. below.

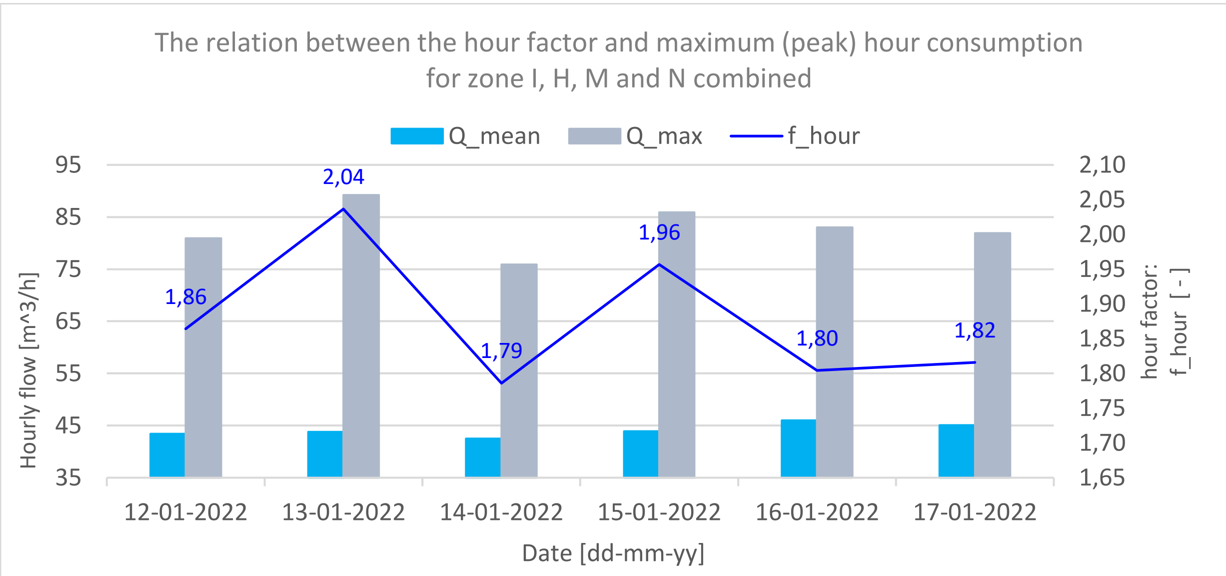


Figure 8.8. Relation between the f hour and the maximum consumption in the combination of all the zones throughout the studied days.

Deriving from the data shown in Figure 8.8., considering the consumption data from the combination of the 4 zones supplied by Herredsvej, the obtained adjustment factor is:

$$f_{adj,total} = \frac{Max\ f\ hour}{Min\ f\ hour} = \frac{2,04}{1,79} = 1,14$$

For further analysis, the same procedure has been carried out for each zone separately. The last step is to obtain the "Maximum day factor, adjusted".

$$f_{day\ max,adjusted} = f_{day} * f_{adj}$$

Thus, the following results have been obtained:

	Industrial area	Hinnerup Lund	Hinnerup Midt	Nørrevangen
				Reservoir
Maximum day factor, unadjusted	1,09	1,04	1,03	1,05
Maximum hour factor	2,14	2,11	2,11	2,13
Minimum hour factor	1,79	1,78	1,61	1,80
Calculated adjustment factor	1,19	1,18	1,31	1,18
Maximum day factor, ***adjusted***	**1,31**	**1,23**	**1,35**	**1,25**

Table 8.5. Factor adjustment for the different zones.

8.4.2. Hourly consumption: analysis.

The maximum hour factors and the way to obtain them have already been explained in Appendix 8.4.1.

The noted yearly consumption of each zone is taken from the Waterwork's yearly report anno 2021-22, which can be found in Appendix 8.2. Mean consumption values are equal to the yearly consumption divided by the period. Maximum day consumption is equal to the mean consumption multiplied by the maximum day factor.

The data above is only examining the zones supplied by Herredsvej Waterwork. For the zones Kildevangen and Rylevej, since there is not available data about the consumption, f-factors for are taken from comparable zones with regards to yearly consumption and their active period. Similarities are explained below.

For Kildevangen, the yearly consumption value is similar to the yearly flow of Hinnerup Lund. Hence, their day and hour maximum factors are the most suitable ones. See Table 8.6. below for the values.

	Q year [m^3/y]	Period [days]	f_day	f_hour
Zone H	41.902	365	1,23	2,11
Zone K	38.823	365	1,23	2,11

Table 8.6. Comparison between Kildevangen and Hinneruplund for determining the maximum day and hour factors.

For Rylevej, even if the flow quantity is closer to the Industrial zone, the active period considered is different (250 days). Thus, the day factor could be slightly different from the one obtained if a period of 365 days was considered. However, in Hinnerup Midt the active period is of 365 days. This is the reason why their day and hour factors have been considered.

	Q year [m^3/y]	Period [days]	f_day	f_hour
Zone M	151.281	365	1,35	2,11
Zone I	72.019	250	1,31	2,14
Zone R	97.752	365	1,35	2,11

Table 8.7. Comparison for determining the maximum day and hour factors of Rylevej.

	Q_{year} [m³/y] Yearly report	Period [days]	Q_{mean} [m³/d]	f_{day}	$Q_{max\ day}$ [m³/d]	f_{hour}	$Q_{max\ hour}$ [m³/h]	
							Calculated	Yearly report
Herredsvej Waterwork								
Industrial area	72.019	250	288,1	1,31	376,6	2,14	33,5	38,7
Hinnerup Lund	41.902	365	114,8	1,23	141,5	2,11	12,4	12,7
Hinnerup Midt	151.281	365	414,5	1,35	559,7	2,11	49,3	48,8
Nørrevangen reservoir	111.359	365	305,1	1,25	380,3	2,13	33,8	37,1
Total	376.561	-	1.122,4	-	1.458,2	-	129,0	137,3
Nørrevangen reservoir								
Kildevangen	38.823	365	106,4	1,23	131,1	2,11	11,5	10,9
Rylevej	97.752	365	267,8	1,35	361,7	2,11	31,9	24,9
Total	136.575	-	374,2	-	492,8	-	43,4	35,8

Table 8.8. Result presentation for the whole studied area.

8.5. Network area description.

Industrial area, Zone I	It is mostly organized as a dead-end network, except for one small grid. Therefore, it is a combination of dead-end and gridiron network. This allows for control in specific sections and increases supply security. If a pipe from the gridiron was damaged, the supply would still be guaranteed. Three valves can be identified in three different ends of the network.
Hinnerup Lund, Zone H	The display is a dead-end network, in which water always flows in the same direction. Consequently, it's sensitive to pipe bursts. However, it is constructed for a low demand, with just 5 ends within the network, so this would not mean a very severe problem.
Hinnerup Midt, Zone M	It is the biggest supply area, combining both dead-end and gridiron network. However, there is not a single valve. This zone is connected to Nørrevangen by a supply pipe. As mentioned before, the grid offer redundancy, so if one section is affected by a disruption, there are alternative pathways for water. However, the implementation of additional grids ought to be considered to create a more secure system.
Rylevej, Zone R	Exclusively dead-end network system. Given the size of the area, once again, the installation of a grid system would serve as a prudent measure to enhance the level of reliability.
Kildevangen, Zone K	Exclusively dead-end network system, coherent with the size.

Table 8.9 Detailed network area description

8.6 The use of MIKE+ EPANET

In the hydraulic model, the name *node* and *junction* are used for points of connection between pipes. In these points, pressure level and flow demand can be investigated and applied. In the pipes, the user can view flow, velocity and friction loss (head loss). In addition, the roughness of each pipe can be specified. Lastly, pumps with specified pump-curve can be added in the model to secure pressurized supply.

In this report, two simulations have been prepared:

1) Steady state simulation: Provides results about the pressure level [mWc] for each node in the network, as well as flow demand, velocity and frictions loss within each pipe.

2) Extended period water quality - *water age*: Provides results about the residence time (water age) of the water within the network based on specified hourly variations in the flow demand.

In general, the hydraulic model has been simplified to are more manageable extent, which has included splitting of the whole network model into separate zone-models, and additionally removal of smaller supply pipes leading into residential roads. The influence of the following simplifications of the model is described in subsection 8.2.2.

8.7 Consumer pressure in network

Consumer pressure has been investigated for each zone separately. For each zone, consumer pressure during maximum hour demand has been modeled for 2 scenarios:

Scenario 1) Flow evenly distributed within the zone. Most critical discharge point (critical node) is identified
The flow has been evenly distributed within each zone by applying a flow demand to every dead-end-node. The flow demand to each dead-and-node is equal to the total max. hour demand of the zone divided by the number of dead-end-nodes within the zone.
Scenario 2) 50% of maximum hour demand distributed to the most critical discharge point.
The same method has been used as above. Here the identified critical discharge point (critical dead-end-node) have been given a flow equal to 50% of the total max hour demand of the zone, with the remaining 50% flow being evenly divided between the rest of the dead-end-nodes.

Table 8.10 Scenarios explanation

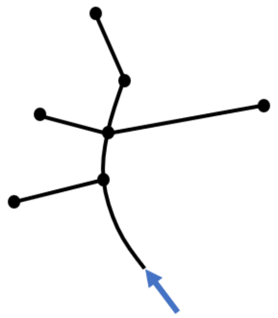
Example:	
➢ 7 nodes in total ➢ 4/7 being dead-end-nodes Max hour demand of zone: 5 L/s 	**Scenario 1** Flow demand to each dead-end-node is: 5 L/s ÷ 4 = <u>1,25 L/s</u> **Scenario 2** 50% of total flow demand is applied to the identified most critical discharge point (critical node): 2,5 L/s Remaining flow goes to the rest of the dead-end-nodes. 2,5 L/s ÷ 3 <u>= 0,83 L/s</u>

Table 8.11 Example of node flow demand determination

In the following sections, the model parameters that have been used for the preparation of the results presented in the main report (section 8.0) as well as in this Appendix, will be described. A sensibility assessment of the model parameters can be viewed in subsection 8.7.2 of this Appendix.

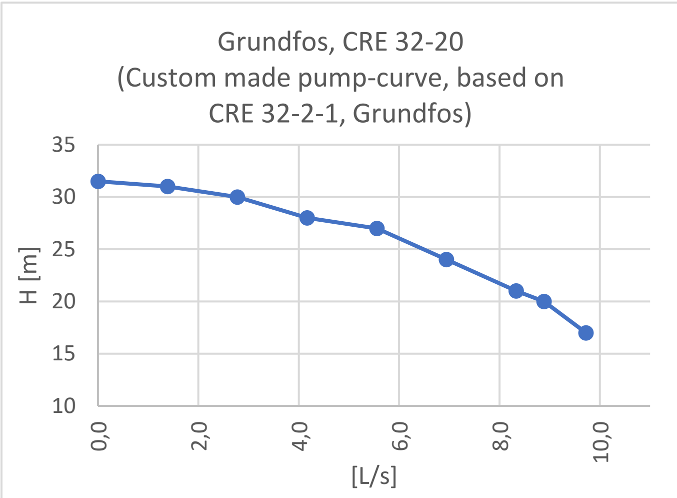
8.7.1 Overview of the model parameters

Maximum hour flow demand for each zone has been used as demand parameters, as higher flow gives more friction loss within the network. In addition, the total flow demand being divided between the dead-end-nodes, results in more water flowing within the network. In the case of scenario 2, this analysis should be considered as a robustness analysis of the network, in the case of fire within the area of the node with 50% of the total demand.

Overview of model parameters for each zone:

Zone: Hinnerup Lund (H)		
Simulation setup MIKE+		
Model type	Steady state simulation	
Duration	1 hour	
Flow demand parameters		
Max hour demand	12,7	[m³/h]
Max hour in L/s	3,53	[L/s]
Total end-nodes	6	nodes
Scenario 1 Demand per node	0,21	[L/s]
Scenario 2 Demand critical node	1,76	[L/s]
Flow remaining nodes	0,35	[L/s]
Other model parameters		
*Roughness**	0,60	[mm]

Pump specifications:



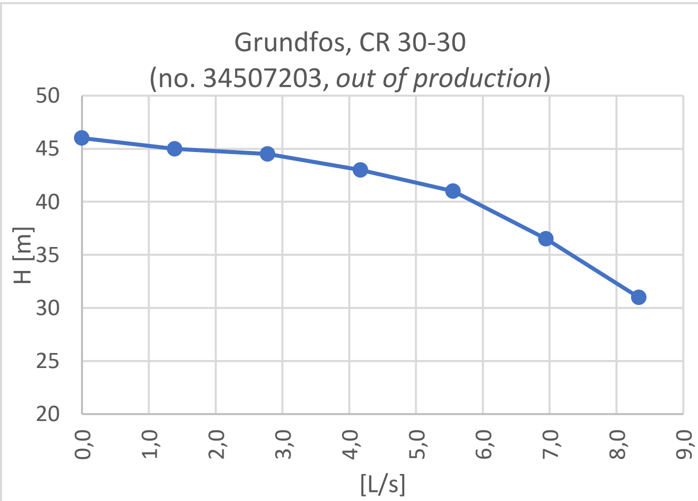
Pump Efficiency: 100%

A roughness of 0,6 mm has been used which is equivalent to the roughness of old PVC or PE distribution pipes. The influence of increased roughness is described in subsection 8.7.2

Table 8.12 Model parameters, Hinnerup Lund, consumer pressure within network

Zone: Industrial area (I)		
Simulation setup MIKE+		
Model type	Steady state simulation	
Duration	1 hour	
Flow demand parameters		
Max hour demand	38,7	[m³/h]
Max hour in L/s	10,8	[L/s]
Total end-nodes	9	nodes
Scenario 1 Demand per node	1,19	[L/s]
Scenario 2 Demand critical node	5,38	[L/s]
Flow remaining nodes	0,67	[L/s]
Other model parameters		
Roughness	0,60	[mm]

Pump specifications:



Pump Efficiency: 100%

Table 8.13 Model parameters, Industrial area, consumer pressure within network

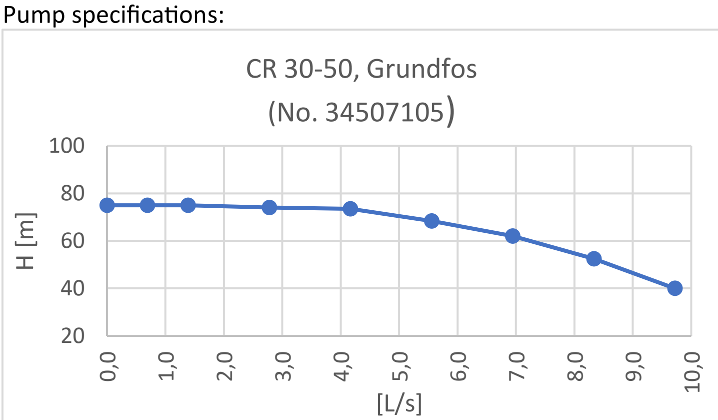
Zone: Hinnerup Midt (M)		
Simulation setup MIKE+		
Model type	Steady state simulation	
Duration	1 hour	
Flow demand parameters		
Max hour demand	48,8	[m³/h]
Max hour in L/s	13,6	[L/s]
Total end-nodes	29	nodes
Scenario 1 Demand per node	0,47	[L/s]
Scenario 2 Demand critical node	6,78	[L/s]
Flow remaining nodes	0,24	[L/s]
Other model parameters		
Roughness	0,60	[mm]

Pump specifications: None, supply by gravity

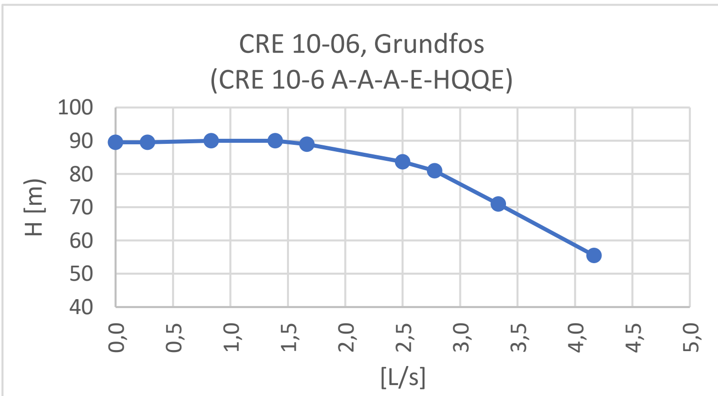
Table 8.14 Model parameters, Hinnerup Midt, consumer pressure within network

Zone: Kildevangen (K)		
Simulation setup MIKE+		
Model type	Steady state simulation	
Duration	1 hour	
Flow demand parameters		
Max hour demand	10,9	[m³/h]
Max hour in L/s	3,03	[L/s]
Total end-nodes	15	nodes
Scenario 1 Demand per node	0,20	[L/s]
Scenario 2 Demand critical node	1,51	[L/s]
Flow remaining nodes	0,11	[L/s]
Other model parameters		
Roughness	0,60	[mm]

Pump specifications:



Pump Efficiency: 100%

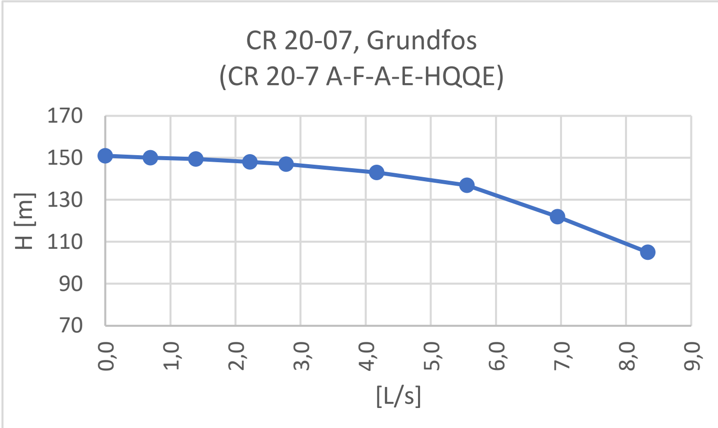


Pump Efficiency: 100%

Table 8.15 Model parameters, Kildevangen, consumer pressure within network

Zone: Rylevej (R)		
Simulation setup MIKE+		
Model type	Steady state simulation	
Duration	1 hour	
Flow demand parameters		
Max hour demand	24,9	[m^3/h]
Max hour in L/s	6,92	[L/s]
Total end-nodes	28	nodes
Scenario 1 Demand per node	0,25	[L/s]
Scenario 2 Demand critical node	3,46	[L/s]
Flow remaining nodes	0,13	[L/s]
Other model parameters		
Roughness	0,60	[mm]

Pump specifications:



Pump Efficiency: 100%

Table 8.16 Model parameters, Rylevej, consumer pressure within network

8.7.2 Sensibility assessment of model parameters

Sensibility assessment: *Roughness*

Higher roughness results in higher friction loss and is therefore an ideal parameter to adjust. In figure 8.9 and 8.10 below, is can be viewed that friction loss is exponentially increasing in relation to increasing flow. This means that the roughness parameter is even more significant with increasing flow. In addition, the figures illustrate that the difference in friction loss between a 160 mm pipe and a 63 mm pipe with a flow of 3 L/s and a roughness of 0,6 mm is a factor 140.

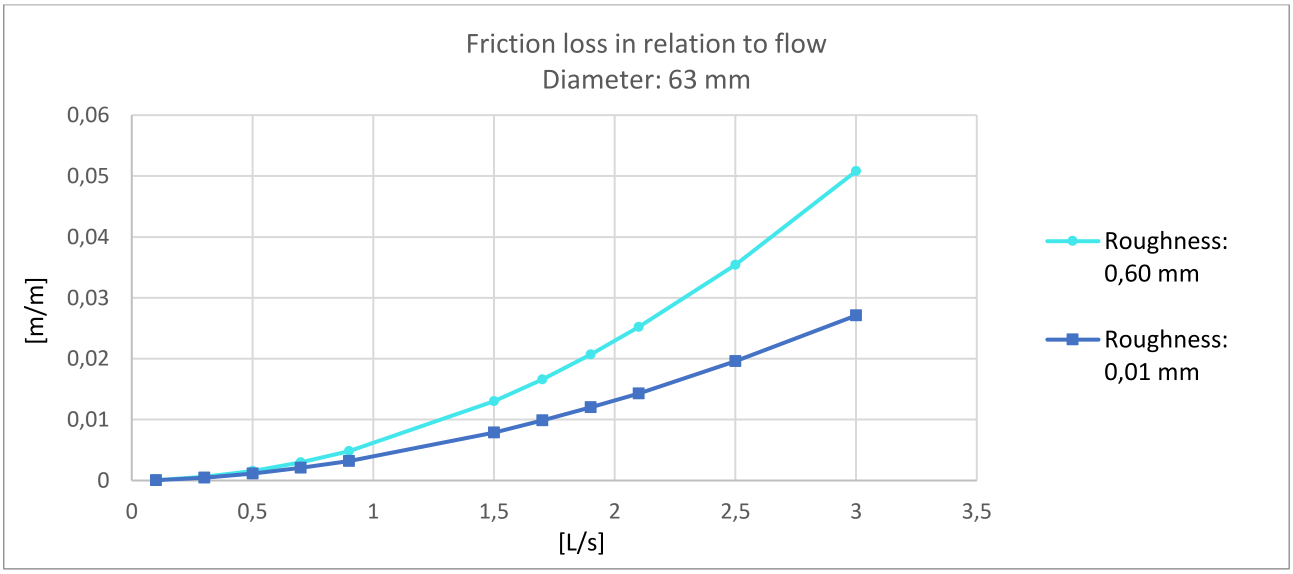


Figure 8.9 Friction loss in relation to flow at different roughness, diameter of 63 mm.

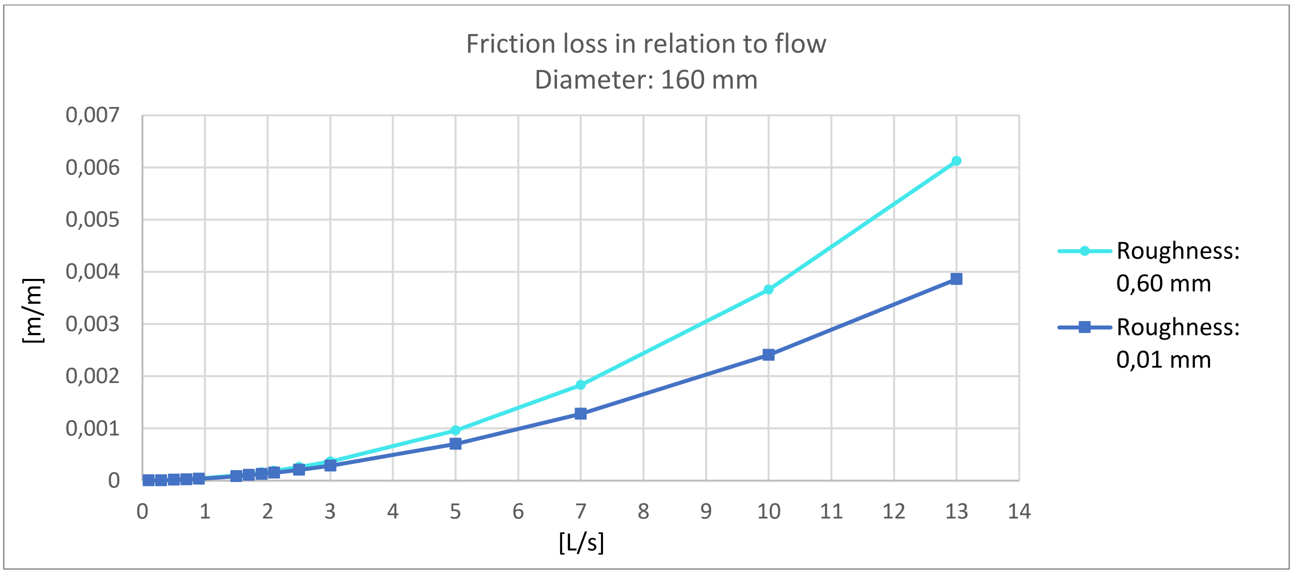


Figure 8.10 Friction loss in relation to flow at different roughness, diameter of 160 mm.

Sensibility assessment: *simplification of network model*

As mentioned in section 8.1 of this Appendix, the model has been simplified which include splitting of the whole network model into separate zone-models, and additionally removal of smaller supply pipes leading into residential roads.

Is it not clear to say what influence the splitting of the network has in relation to uncertainties in the modelling. Overall, the network can be considered zonally divided, but with the placement of shut-off-valves that enables the connection between different zones and section of the network in case of pipe repair work or other incidences.

With regards to the removal of smaller supply pipes leading into residential roads, this could be considered as a significant factor with regards to pressure and friction loss. With smaller pipes, more friction loss will occur, hereby decreasing the pressure of the water even further before the end destination. As viewed on figure 8.9, the friction loss is significantly larger with smaller pipes. However, the flow that would be supplied to the smaller residential-road-pipes, should be considered very low and there not having a significant influence on the friction loss.

8.7.3 Map overview of pressure at different points in relation to the elevation for each zone.

Node pressure in relation to elevation are shown for scenario 1 for each zone. For the case of Rylevej, an additional map overview is shown for scenario 2 due to critical pressure levels.

A simulation error control of the critical discharge point of Rylevej, scenario 2, has been made. This can be viewed below on the map overview: *Rylevej, zone R, node pressure in relation to elevation, Scenario 2*. Below the map overview, the Simulation error control to be viewed below.

Hinnerup Lund, zone H
Node pressure in relation to elevation, **Scenario 1**

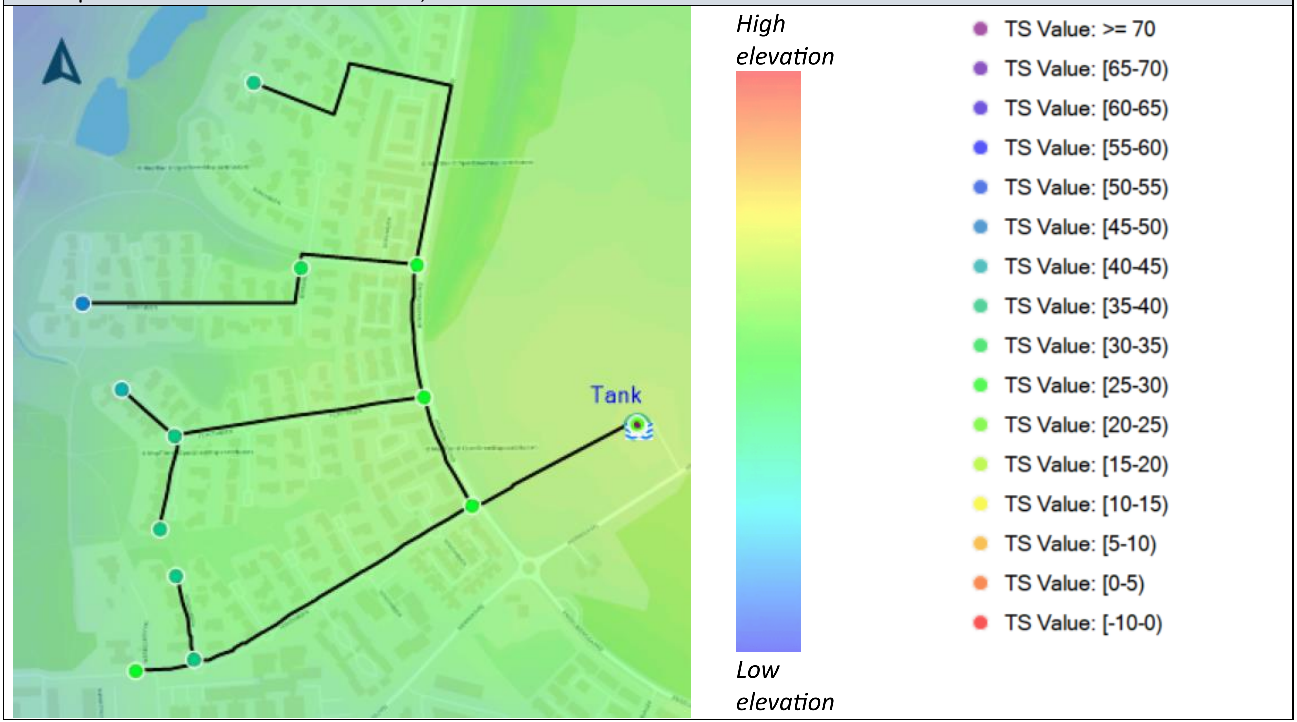


Figure 8.11 Hinnerup Lund, zone H, node pressure in relation to elevation, Scenario 1

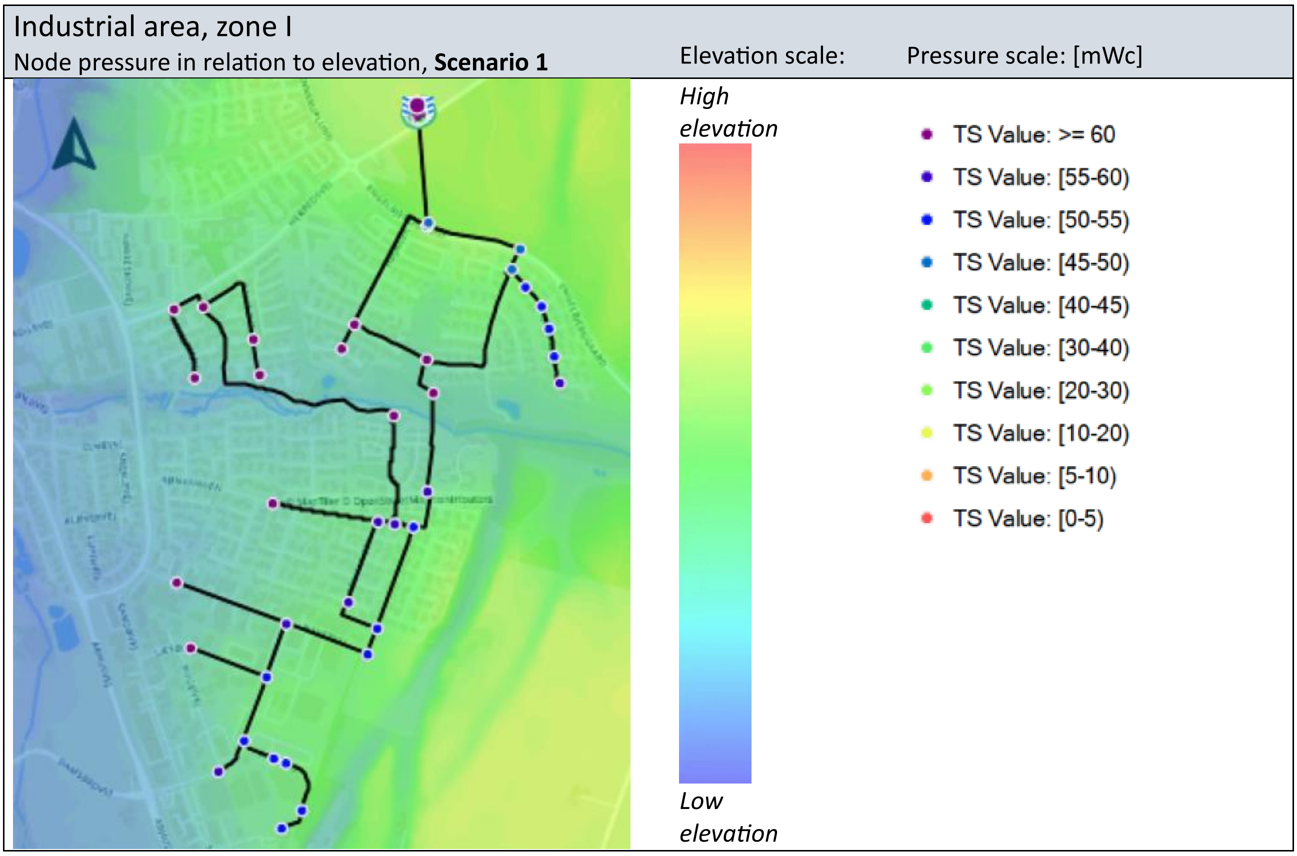


Figure 8.12 Industrial area, zone I, node pressure in relation to elevation, Scenario 1

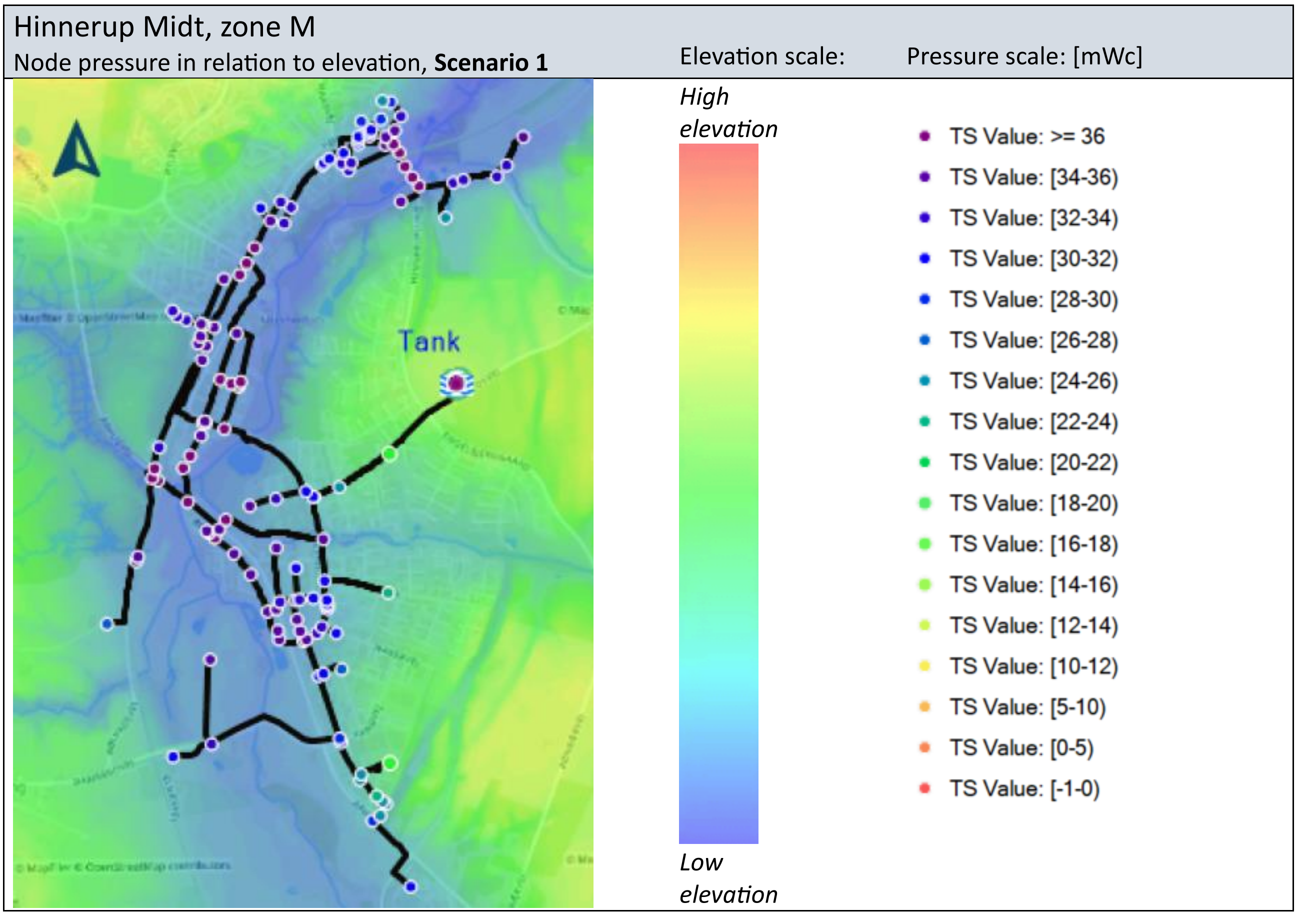


Figure 8.13 Hinnerup Midt, zone M, node pressure in relation to elevation, Scenario 1

Kildevangen, zone K
Node pressure in relation to elevation, **Scenario 1**

Elevation scale: Pressure scale: [mWc]

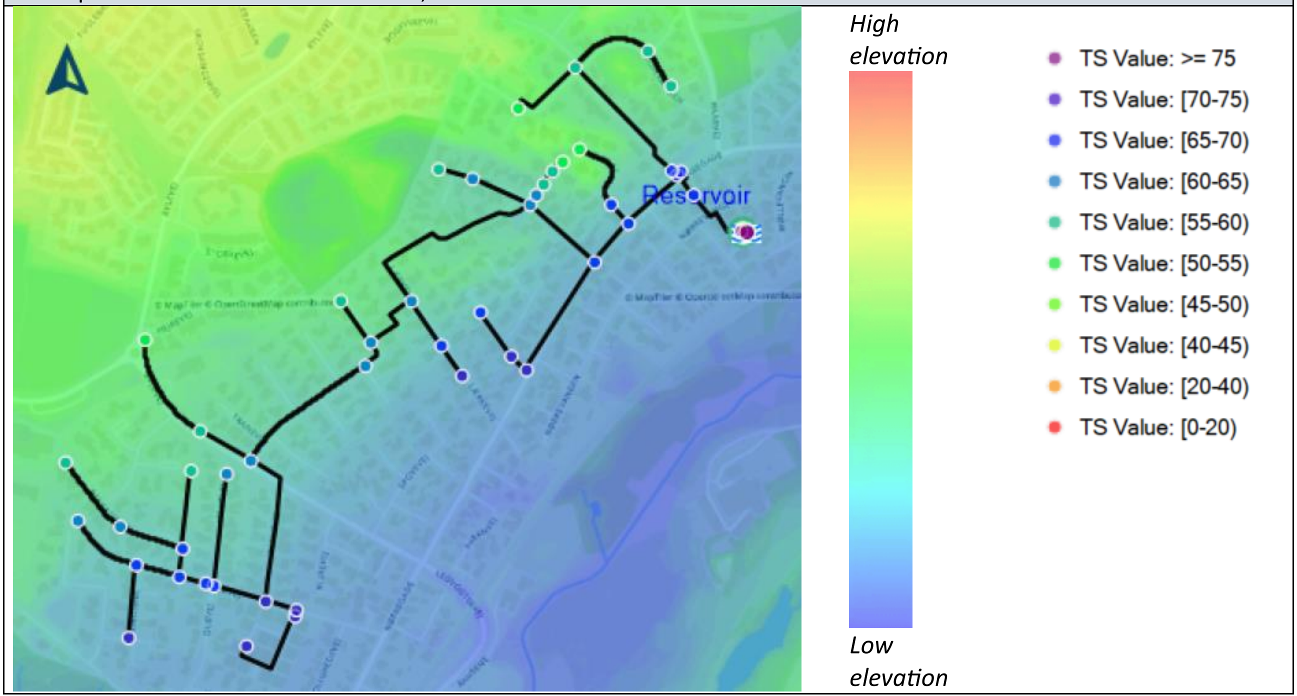


Figure 8.14 Kildevangen, zone K, node pressure in relation to elevation, Scenario 1

Rylevej, zone R
Node pressure in relation to elevation, **Scenario 1**

Elevation scale: Pressure scale: [mWc]

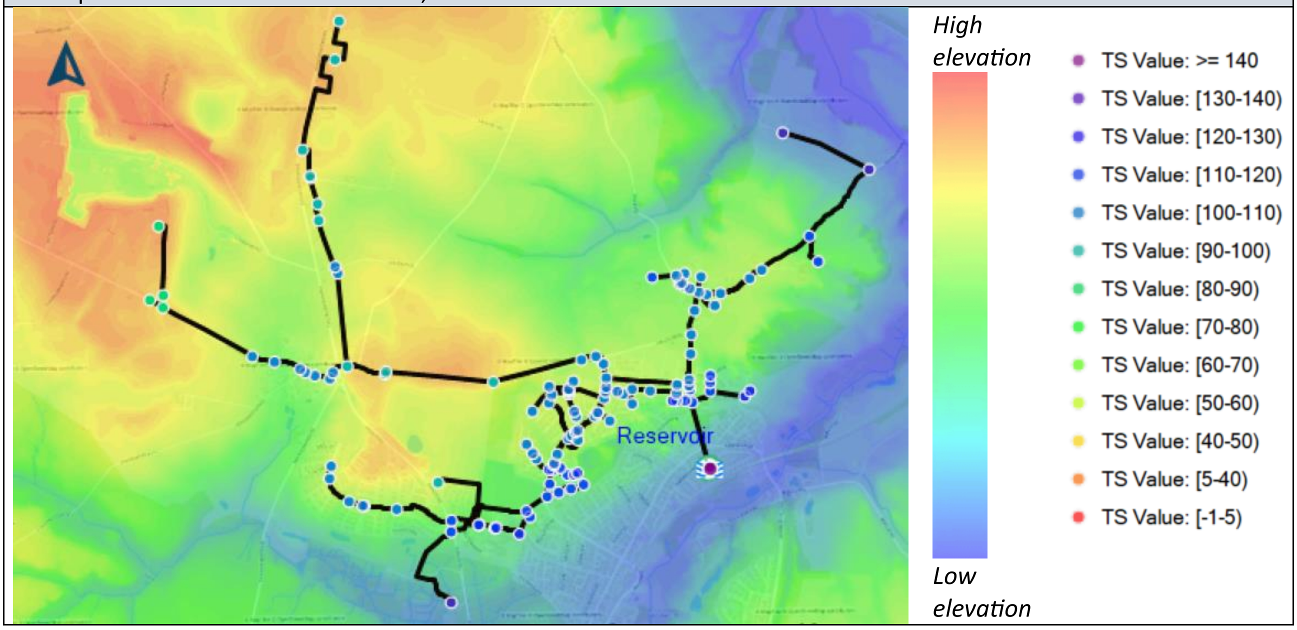
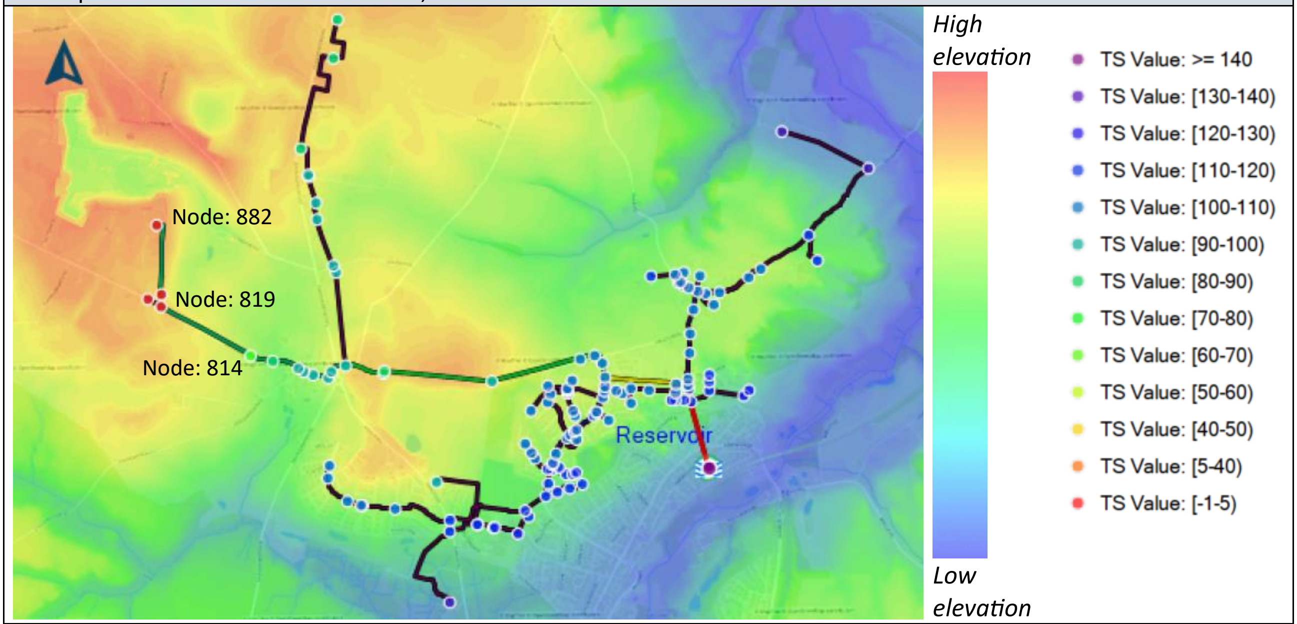


Figure 8.15 Rylevej, zone R, node pressure in relation to elevation, Scenario 1

Rylevej, zone R
Node pressure in relation to elevation, **Scenario 2**

Elevation scale: | Pressure scale: [mWc]



Colored pipes indicate flow-level.
Red = max hour demand flow. **Green** = 50% of max hour demand.
Junction 882 was identified as the most critical discharge point in figure A8.1.

Figure 8.16 Rylevej, zone R, node pressure in relation to elevation, Scenario 2

Simulation error control:
Simulation OK

Node: 814 Elevation 64,0 m Pressure 65,9 mWc	Friction loss per m: 0,0974 m	Pressure drop due to friction: 542,4 x 0,0974 m = 52,83 m
Node: 819 Elevation 77,0 m Pressure 0,0 mWc		Pressure drop due to rise in elevation: 77 - 64 = 13 m
Connecting pipe: Pipe length 542,4 m Diameter 50 mm		Total pressure drop = 65,83 m
		Remaining pressure: = 0,07 mWc Simulation OK

Table 8.17 Simulation control

8.7.4 Profile plot for each zone visualizing the change in pressure

Profile plot for each zone visualizing the change in pressure, when the water is moving from the main supply pipe to the identified critical discharge point of the zone.

Blue dash line: pressure. Grey line: pipe and node bottom.

Hinnerup Lund: Profile plot, scenario 1.

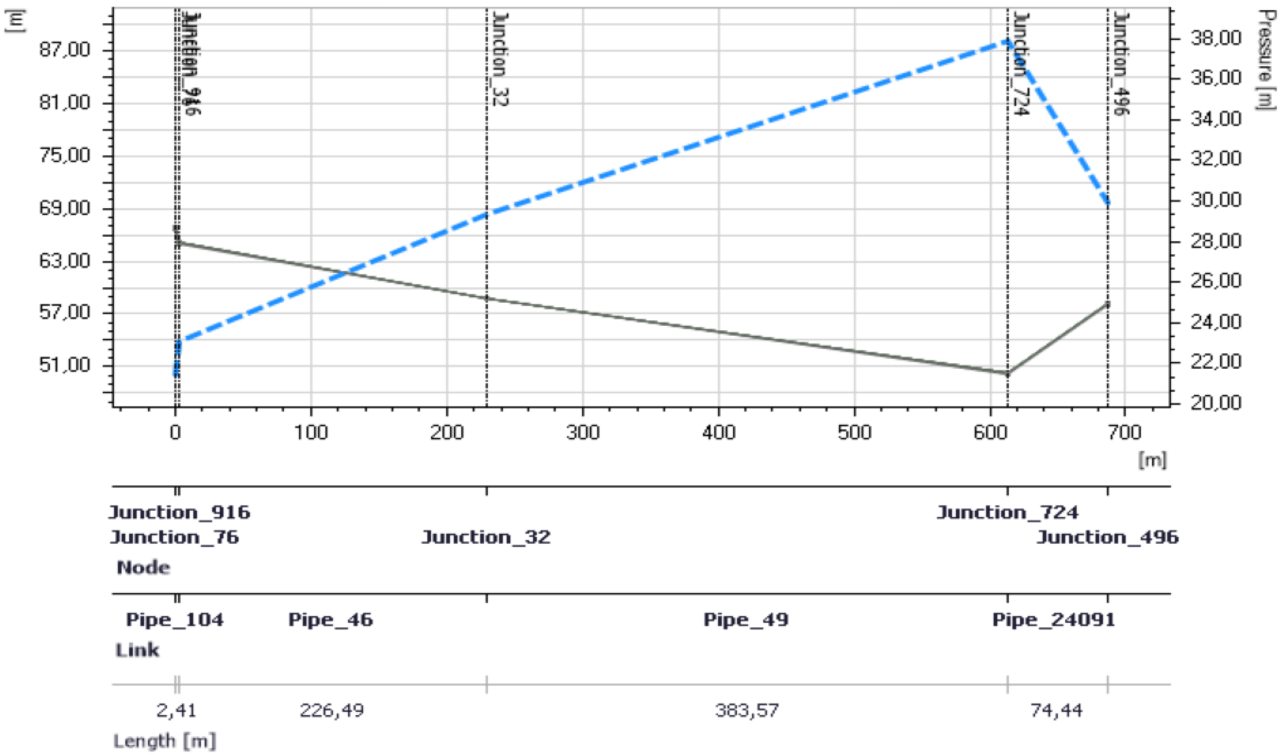


Figure 8.17 Profile plot of change in pressure. Water moving from main supply pipe to identified critical discharge point within the zone.

Industrial area: Profile plot, scenario 1.

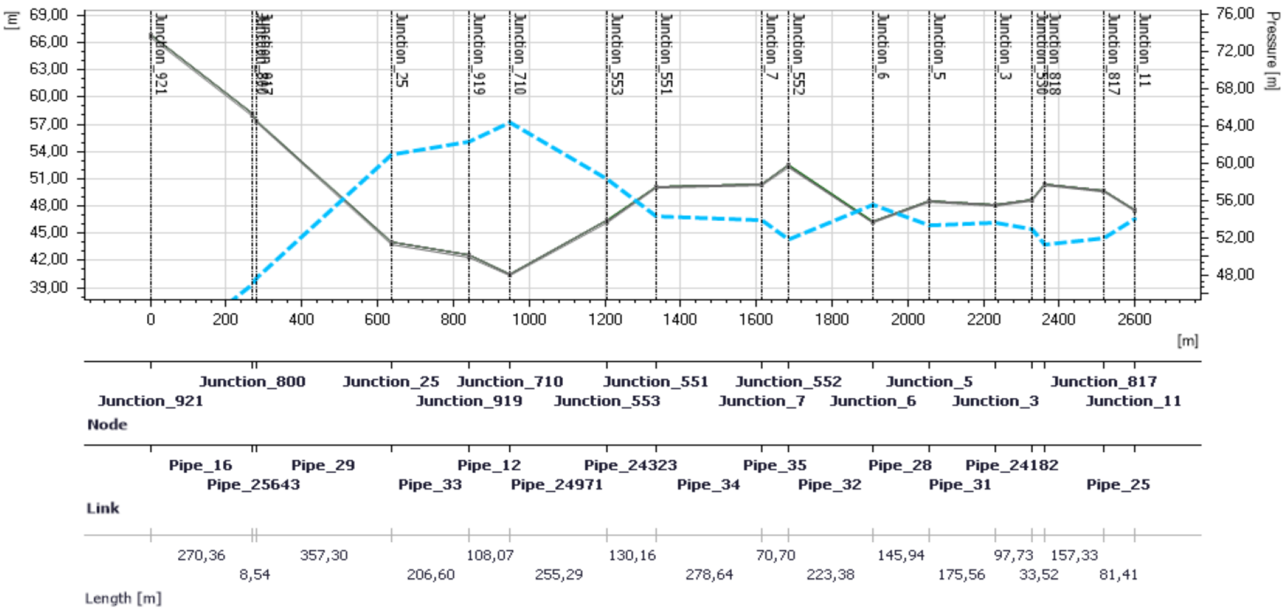


Figure 8.18 Profile plot of change in pressure. Water moving from main supply pipe to identified critical discharge point within the zone.

Hinnerup Midt: Profile plot, scenario 1.

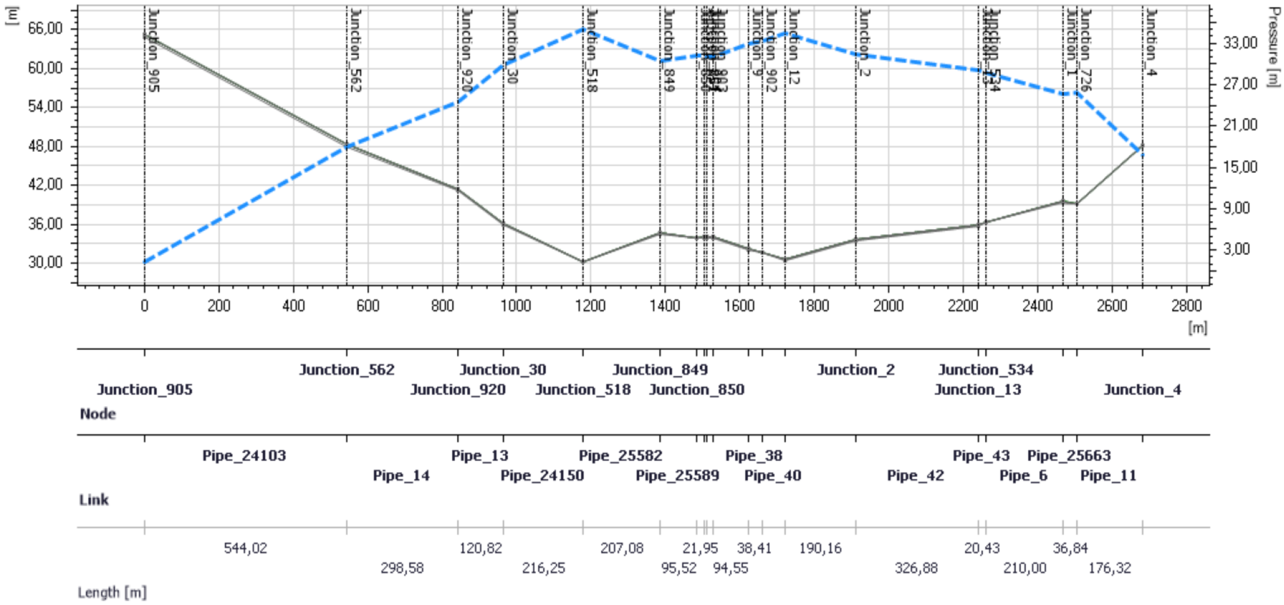


Figure 8.19 Profile plot of change in pressure. Water moving from main supply pipe to identified critical discharge point within the zone.

Kildevangen: Profile plot, scenario 1.

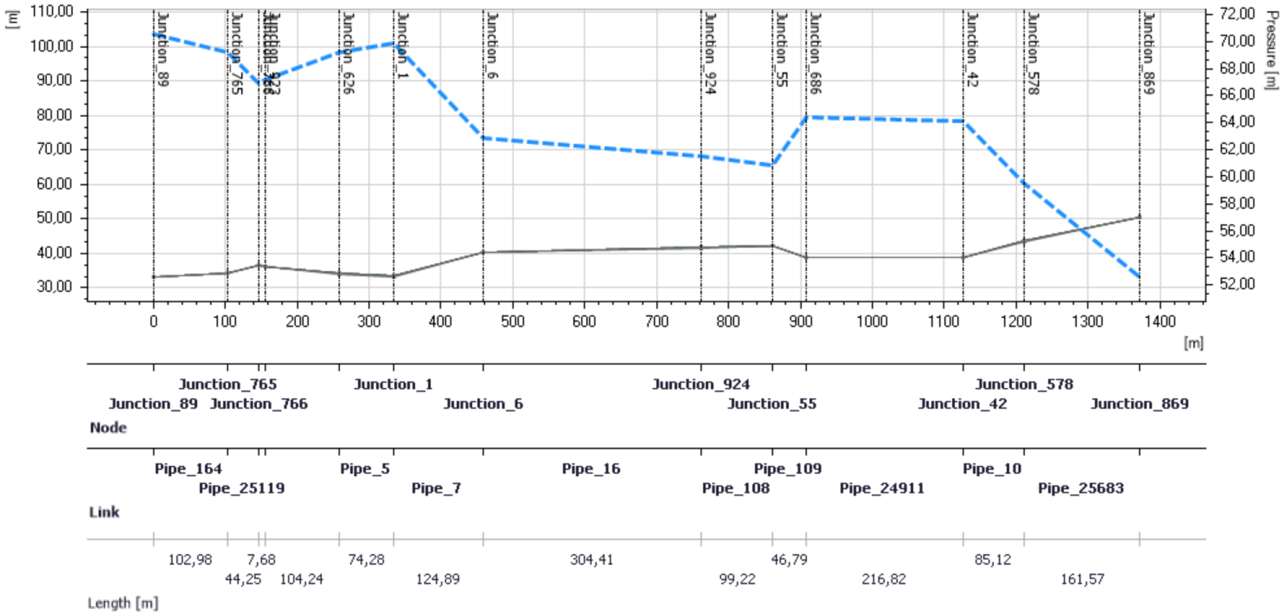


Figure 8.20 Profile plot of change in pressure. Water moving from main supply pipe to identified critical discharge point within the zone

Rylevej: Profile plot, scenario 1.

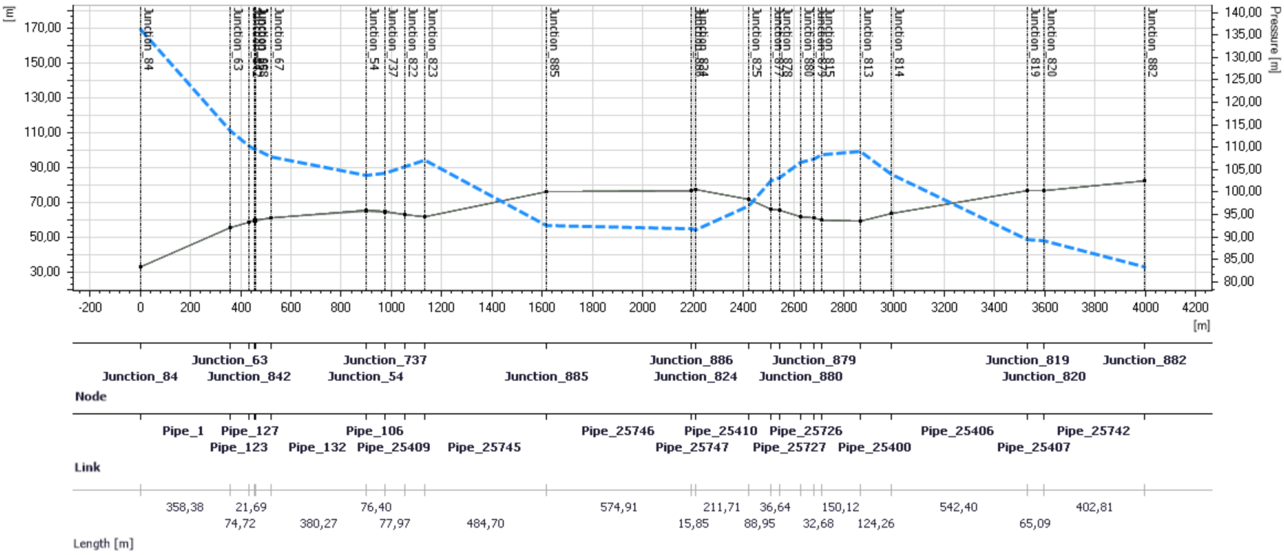


Figure 8.21 Profile plot of change in pressure. Water moving from main supply pipe to identified critical discharge point within the zone

Rylevej: Profile plot, scenario 2.

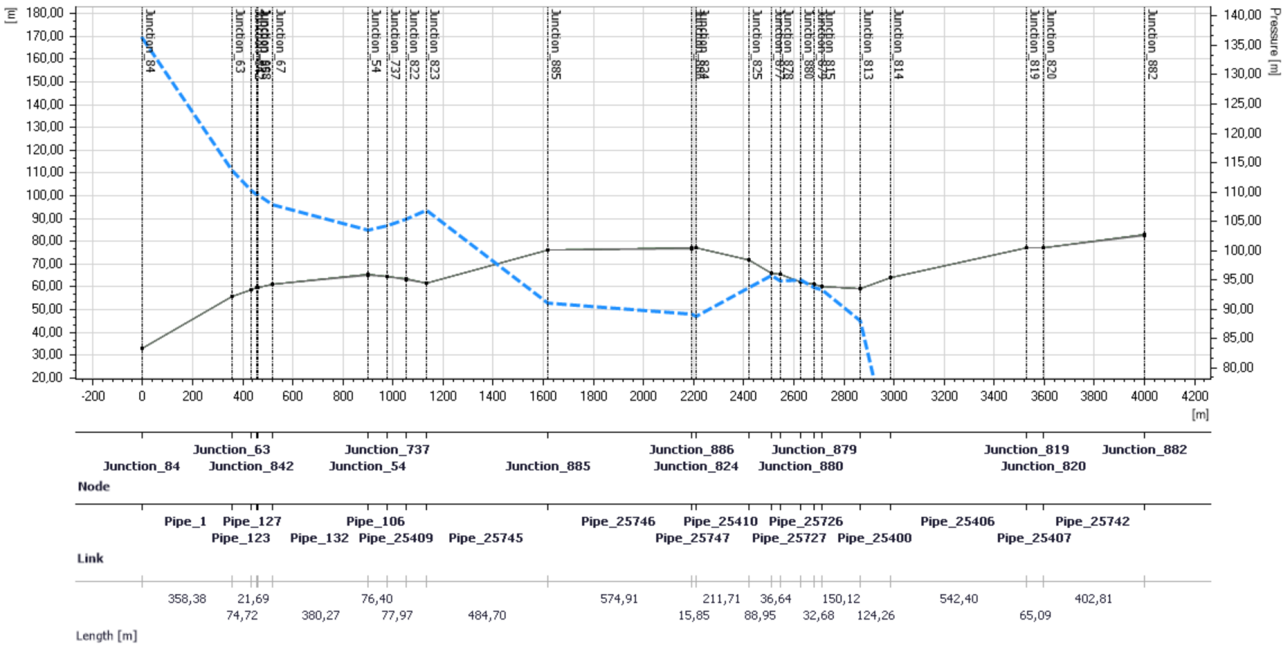


Figure 8.22 Profile plot of change in pressure. Water moving from main supply pipe to identified critical discharge point within the zone

8.7.5 Overview of velocity and pump operation within each zone.

Overview of velocity and pump operation shown for scenario 1 for each zone.

	Max hour demand [L/s]	Pump Flow [L/s]
Hinnerup Lund	**3,53**	
Grundfos CRE 32-20		1,76
Grundfos CRE 32-20		1,76
Industrial area	**10,75**	
Grundfos CR 30-30		3,58
Grundfos CR 30-30		3,58
Grundfos CR 30-30		3,58
Hinnerup Midt	**13,56**	
Gravity		none
Kildevangen	**3,03**	
Grundfos CRE 10-06		1,52
Grundfos CRE 10-06		1,52
Grundfos CR 30-50		0
Rylevej	**6,92**	
Grundfos CR 20-07		2,31
Grundfos CR 20-07		2,31
Grundfos CR 20-07		2,31

Table 8.18 Overview of velocity and pump operation shown for scenario 1 for each zone.

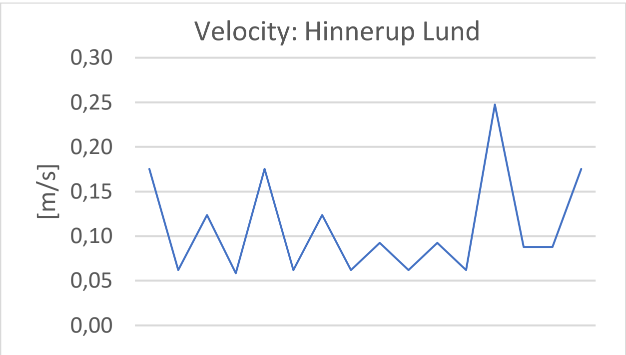


Figure 8.23 Variation in velocity within network, zone H

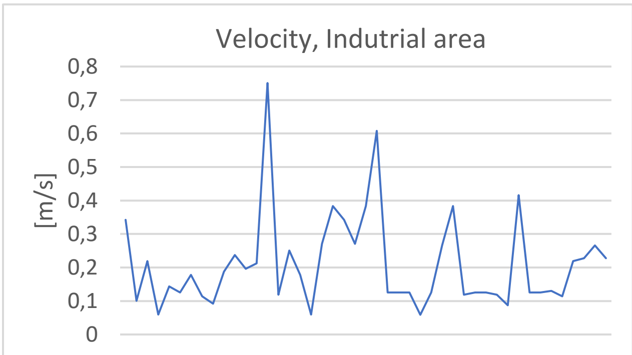


Figure 8.24 Variation in velocity within network, zone I

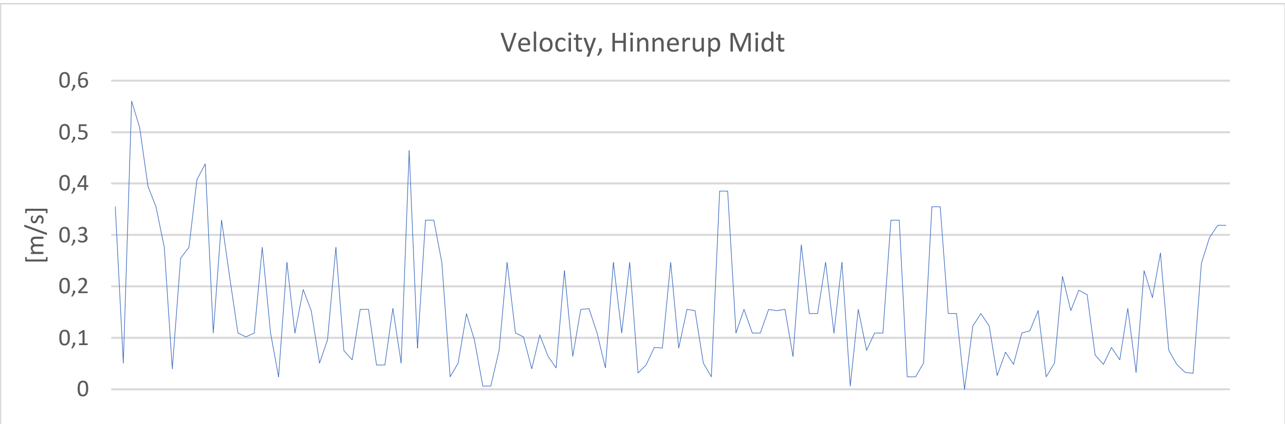


Figure 8.25 Variation in velocity within network, zone M

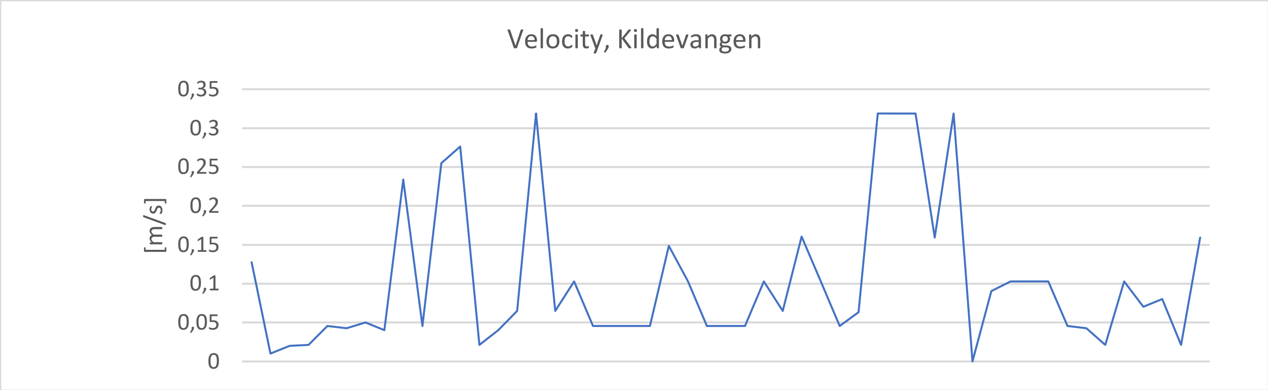


Figure 8.26 Variation in velocity within network, zone K

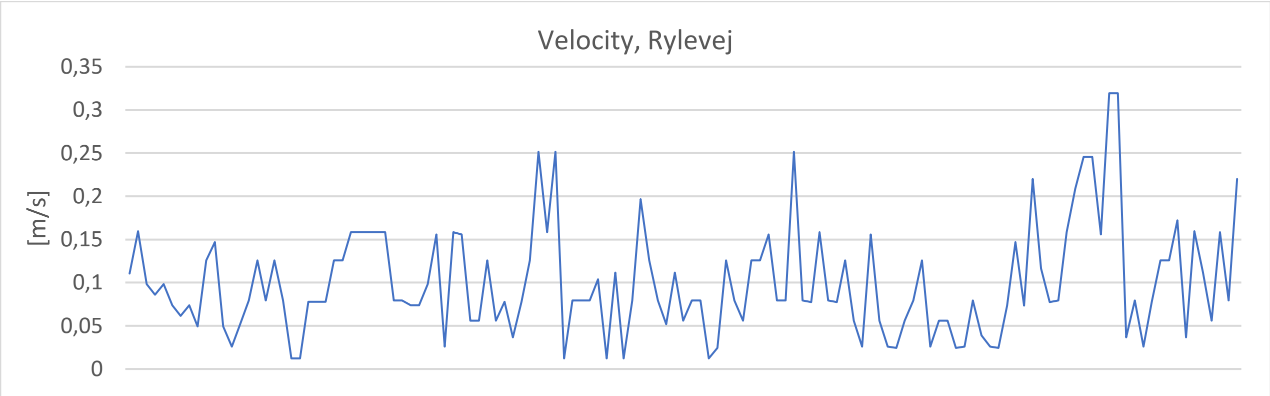


Figure 8.27 Variation in velocity within network, zone R

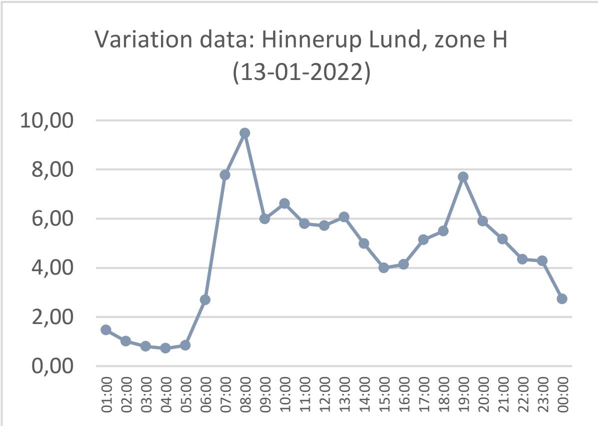
8.8 Max residence time of the water

Demand parameters is based on variation data within the month of January where consumption is lowest compared to the rest of the year. The lower the consumption, the lower the flow in the system and the lower the velocity. The risk of high water age in the system is most critical at low velocity. Therefore, the results of the following model simulations for each zone can be used to estimate the highest water age that may occur within the supply system throughout the whole year.

8.8.1 Overview of the model parameters

Zone: Hinnerup Lund (H)		
Simulation setup MIKE+		
Model type	Extended period water quality, water age	
Duration	3 days of 24 hours	
Consumption parameters		
Average hour	4,50	[m³/h]
Max hour	9,50	[m³/h]
Max hour factor	2,11	[-]
Total end-nodes	6	nodes
Demand per node	0,21	[L/s]
Demand pattern	*see demand pattern curve below*	
Other model parameters		
Roughness	0,60	[mm]

Variation data: [m^3/h]



Q average:	Q max	f hour
4,5	9,5	2,11

Calculated values based on variation data

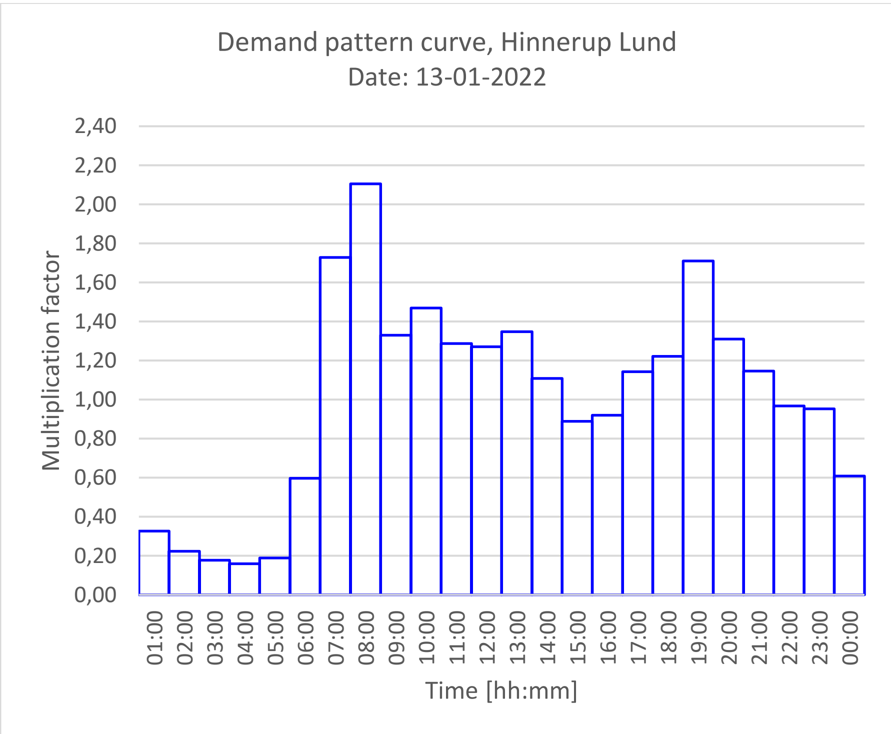


Figure 8.28 Model parameters, Hinnerup Lund, max residence time

Multiplication factor per hour:

[hh:mm]	[m³/h]	factor
01:00	1,47	0,33
02:00	1,01	0,22
03:00	0,80	0,18
04:00	0,72	0,16
05:00	0,85	0,19
06:00	2,69	0,60
07:00	7,77	1,73
08:00	9,47	2,11
09:00	5,98	1,33
10:00	6,61	1,47
11:00	5,79	1,29
12:00	5,72	1,27
13:00	6,06	1,35
14:00	4,98	1,11
15:00	4,00	0,89
16:00	4,14	0,92
17:00	5,14	1,14
18:00	5,50	1,22
19:00	7,69	1,71
20:00	5,90	1,31
21:00	5,16	1,15
22:00	4,35	0,97
23:00	4,29	0,95
00:00	2,73	0,61

Zone: Industrial area (I)

Simulation setup MIKE+

Model type	Extended period water quality, water age
Duration	3 days of 24 hours

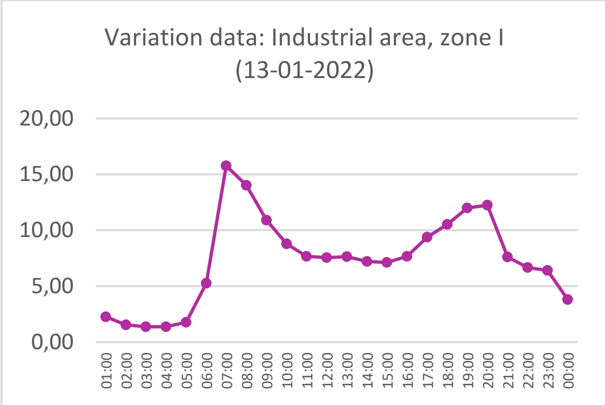
Consumption parameters

Average hour	7,40	[m³/h]
Max hour	15,8	[m³/h]
Max hour factor	2,14	[-]
Total end-nodes	9	nodes
Demand per node	0,23	[L/s]
Demand pattern	*see demand pattern curve below*	

Other model parameters

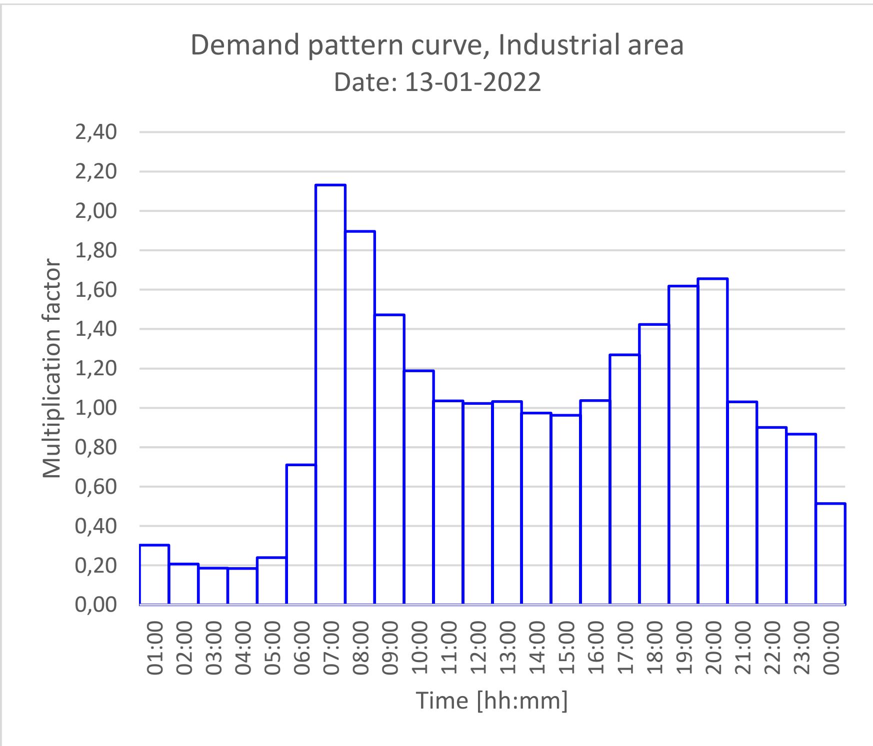
Roughness	0,60	[mm]

Variation data: [m^3/h]



Q average:	Q max	f hour
7,4	15,8	2,14

Calculated values based on variation data



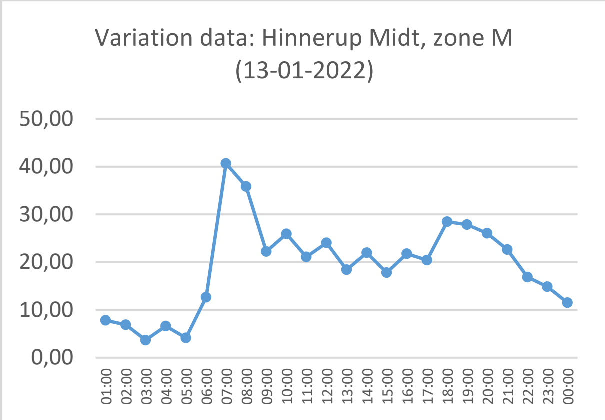
Multiplication factor per hour:

[hh:mm]	[m³/h]	factor
01:00	2,24	0,30
02:00	1,53	0,21
03:00	1,37	0,19
04:00	1,37	0,19
05:00	1,77	0,24
06:00	5,25	0,71
07:00	15,77	2,13
08:00	14,03	1,90
09:00	10,89	1,47
10:00	8,79	1,19
11:00	7,67	1,04
12:00	7,57	1,02
13:00	7,64	1,03
14:00	7,21	0,97
15:00	7,13	0,96
16:00	7,67	1,04
17:00	9,39	1,27
18:00	10,54	1,42
19:00	11,98	1,62
20:00	12,25	1,66
21:00	7,62	1,03
22:00	6,66	0,90
23:00	6,41	0,87
00:00	3,81	0,51

Figure 8.29 Model parameters, Industrial area, max residence time

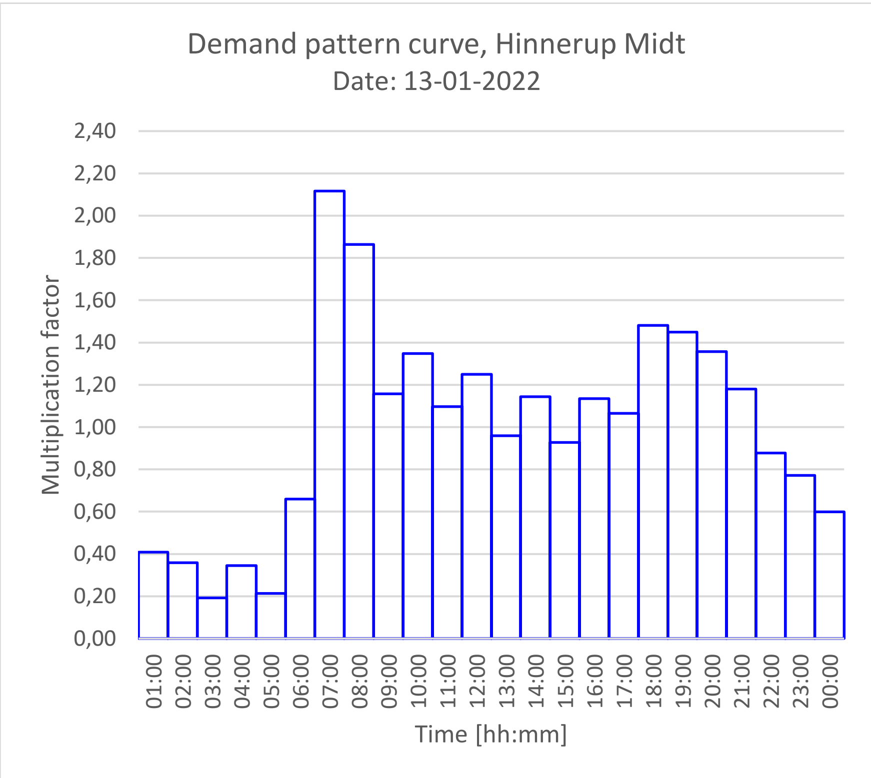
Zone: Hinnerup Midt (M)		
Simulation setup MIKE+		
Model type	Extended period water quality, water age	
Duration	3 days of 24 hours	
Consumption parameters		
Average hour	19,2	[m^3/h]
Max hour	40,6	[m^3/h]
Max hour factor	2,12	[-]
Total end-nodes	28	nodes
Demand per node	0,19	[L/s]
Demand pattern	*see demand pattern curve below*	
Other model parameters		
Roughness	0,60	[mm]

Variation data: [m^3/h]



Q average	Q max	f hour
19,2	40,6	2,11

Calculated values based on variation data



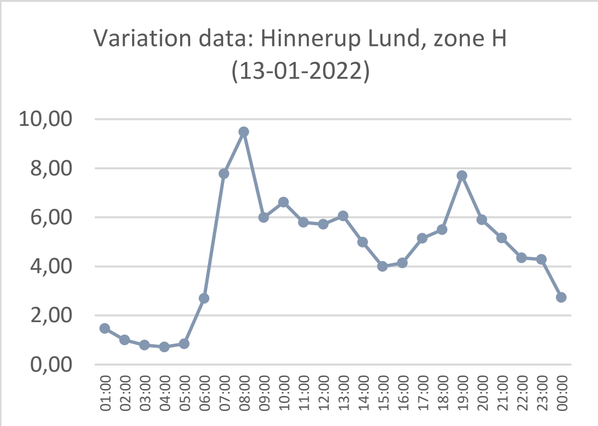
Multiplication factor per hour:

[hh:mm]	[m^3/h]	factor
01:00	7,84	0,41
02:00	6,88	0,36
03:00	3,69	0,19
04:00	6,62	0,34
05:00	4,10	0,21
06:00	12,66	0,66
07:00	40,64	2,12
08:00	35,79	1,86
09:00	22,23	1,16
10:00	25,88	1,35
11:00	21,05	1,10
12:00	24,01	1,25
13:00	18,42	0,96
14:00	21,97	1,14
15:00	17,80	0,93
16:00	21,77	1,13
17:00	20,43	1,06
18:00	28,43	1,48
19:00	27,82	1,45
20:00	26,04	1,36
21:00	22,64	1,18
22:00	16,84	0,88
23:00	14,82	0,77
00:00	11,51	0,60

Figure 8.30 Model parameters, Hinnerup Midt, max residence time

Zone: Kildevangen (K)		
Simulation setup MIKE+		
Model type	Extended period water quality, water age	
Duration	3 days of 24 hours	
Consumption parameters		
Average hour	4,50	[m^3/h]
Max hour	9,50	[m^3/h]
Max hour factor	2,11	[-]
Total end-nodes	15	nodes
Demand per node	0,083	[L/s]
Demand pattern	*see demand pattern curve below*	
Other model parameters		
Roughness	0,60	[mm]

Variation data: [m^3/h]

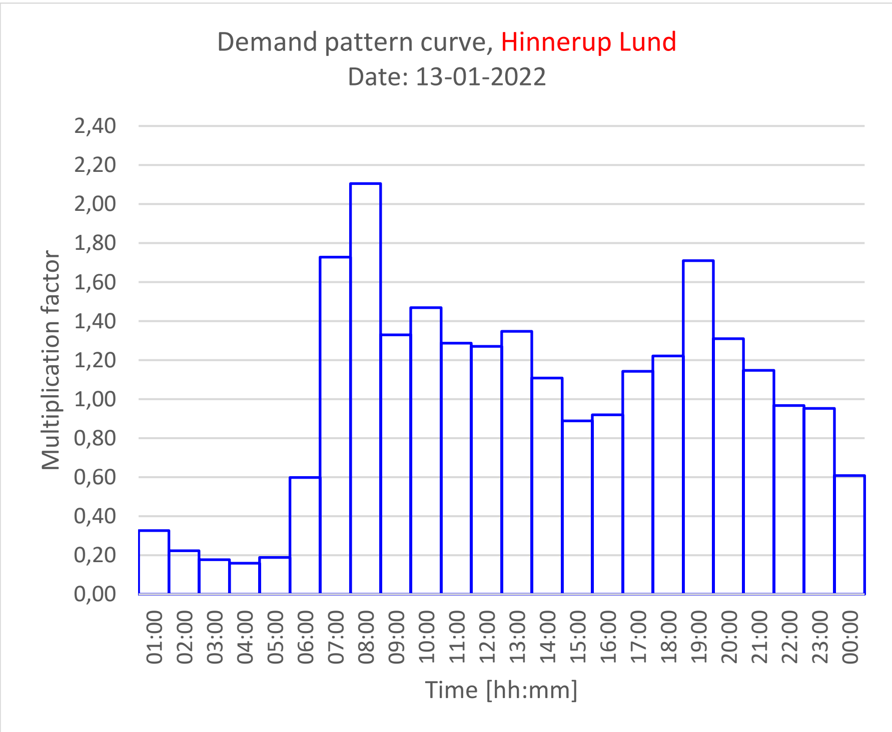


Q average:	Q max	f hour
4,5	9,5	2,11

Calculated values based on variation data

Note: The demand pattern curve of Hinnerup Lund is used here, as there is no available variation data for the zone of Kildevangen.

The two zones are comparable based on the reported yearly consumptions and max hour consumptions viewed in the Waterwork' yearly report of 2021.



Multiplication factor per hour:

[hh:mm]	[m^3/h]	factor
01:00	1,47	0,33
02:00	1,01	0,22
03:00	0,80	0,18
04:00	0,72	0,16
05:00	0,85	0,19
06:00	2,69	0,60
07:00	7,77	1,73
08:00	9,47	2,11
09:00	5,98	1,33
10:00	6,61	1,47
11:00	5,79	1,29
12:00	5,72	1,27
13:00	6,06	1,35
14:00	4,98	1,11
15:00	4,00	0,89
16:00	4,14	0,92
17:00	5,14	1,14
18:00	5,50	1,22
19:00	7,69	1,71
20:00	5,90	1,31
21:00	5,16	1,15
22:00	4,35	0,97
23:00	4,29	0,95
00:00	2,73	0,61

Figure 8.31 Model parameters, Kildevangen, max residence time

Zone: Rylevej (R)

Simulation setup MIKE+

Model type	Extended period water quality, water age	
Duration	3 days of 24 hours	

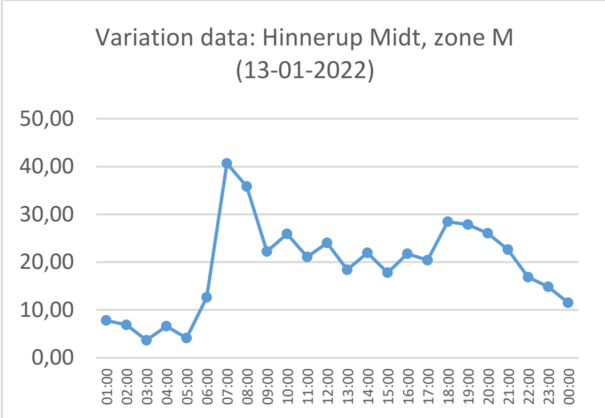
Consumption parameters

Average hour	9,80	[m³/h]
Max hour	-	[m³/h]
Max hour factor	2,12	[-]
Total end-nodes	28	nodes
Demand per node	0,097	[L/s]
Demand pattern	*see demand pattern curve below*	

Other model parameters

Roughness	0,60	[mm]

Variation data: [m^3/h]



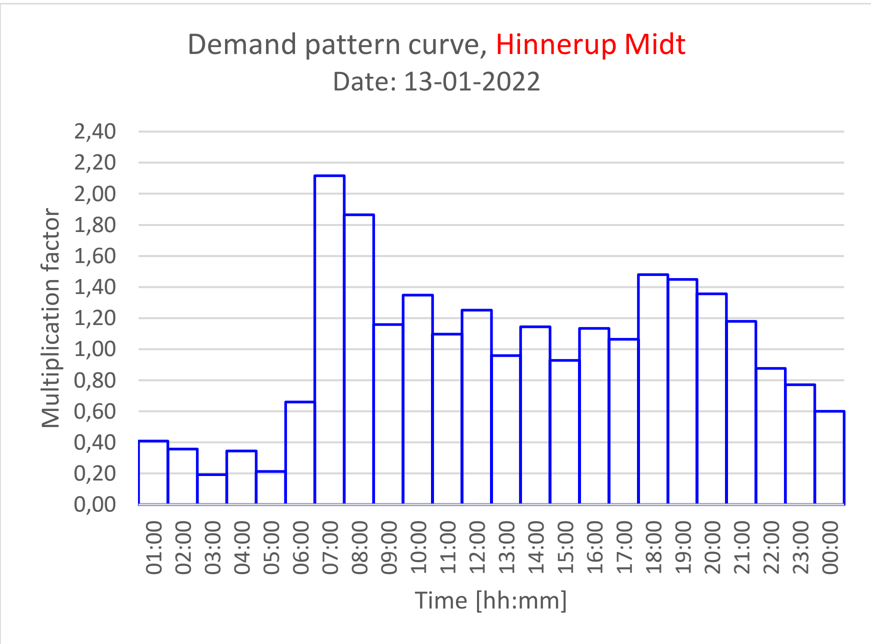
Q average	Q max	f hour
19,2	40,6	2,11

Calculated values based on variation data

Note: The demand pattern curve of Hinnerup Midt is used here, as there is no available variation data for the zone of Rylevej.

The relation between the reported max hour of Hinnerup Midt and Rylevej is a factor 1,96 in difference.
(48,8 ÷ 24,9 = 1,96)

The average hour is then calculated as the average consumption of Hinnerup Midt of 19,2 divided by the factor 1,96.
(19,2 ÷ 1,96 = 9,8)



Multiplication factor per hour:

[hh:mm]	[m³/h]	factor
01:00	7,84	0,41
02:00	6,88	0,36
03:00	3,69	0,19
04:00	6,62	0,34
05:00	4,10	0,21
06:00	12,66	0,66
07:00	40,64	2,12
08:00	35,79	1,86
09:00	22,23	1,16
10:00	25,88	1,35
11:00	21,05	1,10
12:00	24,01	1,25
13:00	18,42	0,96
14:00	21,97	1,14
15:00	17,80	0,93
16:00	21,77	1,13
17:00	20,43	1,06
18:00	28,43	1,48
19:00	27,82	1,45
20:00	26,04	1,36
21:00	22,64	1,18
22:00	16,84	0,88
23:00	14,82	0,77
00:00	11,51	0,60

Figure 8.32 Model parameters, Ryleevej, max residence time

8.8.2 Sensibility assessment of model parameters

Sensibility assessment regarding the simplification of the network as well as the chosen roughness for the simulations, can be viewed in subsection 8.7.2.

8.8.3 Map overview of max residence time

Map overview: Hinnerup Lund (zone H), max. residence time	Symbology:

Residence time [hh]: *Maximum residence time in hours*

- TS Value: >= 24
- TS Value: [20-24)
- TS Value: [15-20)
- TS Value: [14-15)
- TS Value: [13-14)
- TS Value: [12-13)
- TS Value: [11-12)
- TS Value: [10-11)
- TS Value: [9-10)
- TS Value: [8-9)
- TS Value: [7-8)
- TS Value: [6-7)
- TS Value: [5-6)
- TS Value: [4-5)
- TS Value: [3-4)
- TS Value: [2-3)
- TS Value: [1-2)
- TS Value: [0-1)

Figure 8.33 Map overview: Hinnerup Lund (zone H), max. residence time

Map overview: Industrial area (zone I), max. residence time	Symbology:
	Residence time [hh]: *Maximum residence time in hours* TS Value: >= 30 TS Value: [28-30) TS Value: [26-28) TS Value: [24-26) TS Value: [22-24) TS Value: [20-22) TS Value: [18-20) TS Value: [16-18) TS Value: [14-16) TS Value: [12-14) TS Value: [10-12) TS Value: [5-10) TS Value: [0-5)

Figure 8.34 Map overview: Industrial area (zone I), max. residence time

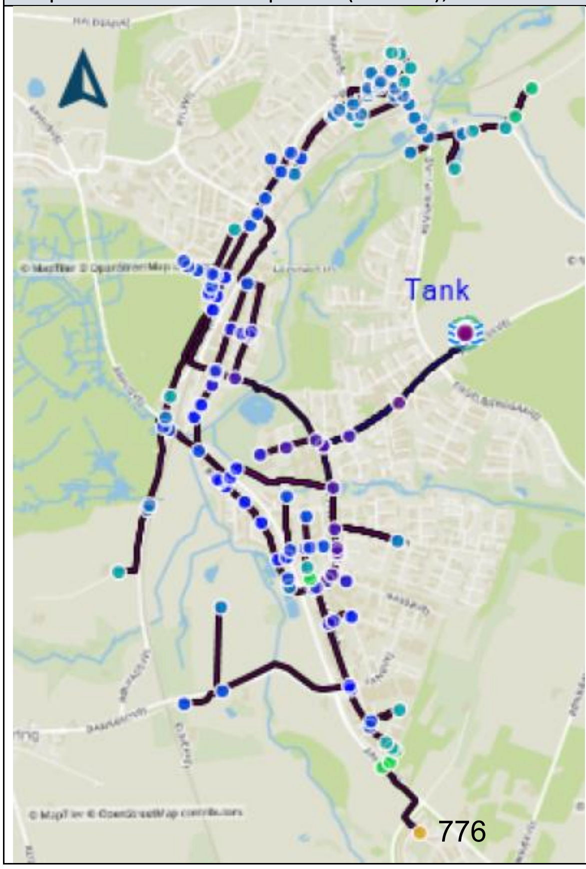
Map overview: Hinnerup Midt (zone M), max residence time	Symbology:
	Residence time [hh]: *Maximum residence time in hours* TS Value: [32-34) TS Value: [30-32) TS Value: [28-30) TS Value: [26-28) TS Value: [24-26) TS Value: [22-24) TS Value: [20-22) TS Value: [18-20) TS Value: [16-18) TS Value: [14-16) TS Value: [12-14) TS Value: [10-12) TS Value: [5-10) TS Value: [0-5)

Figure 8.35 Map overview: Hinnerup Midt (zone M), max residence time

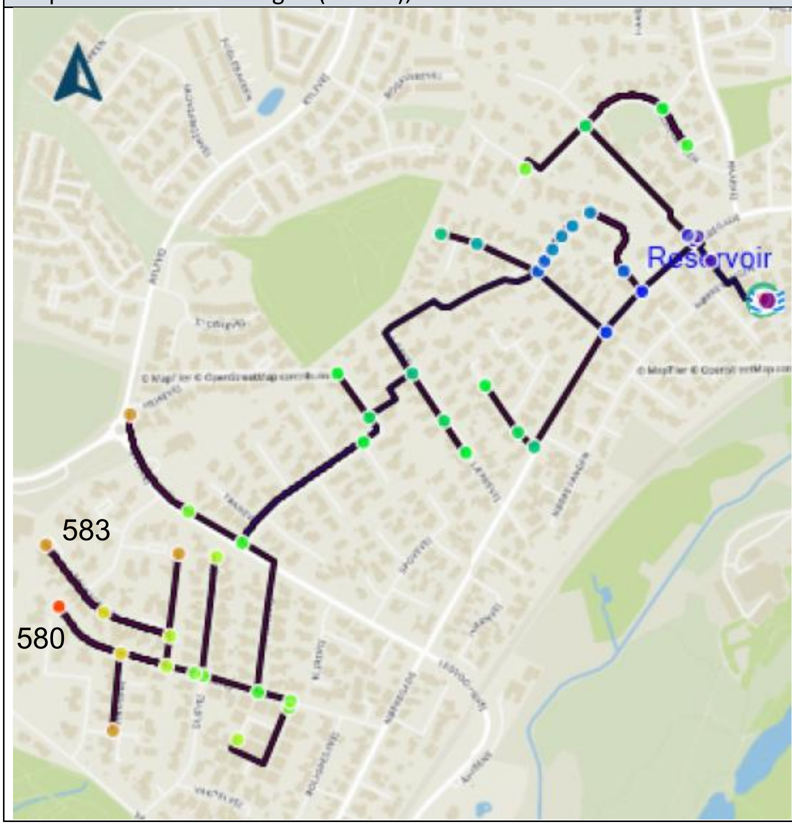
Map overview: Kildevangen (zone K), max residence time	Symbology:
	Residence time [hh]: *Maximum residence time in hours* TS Value: >= 24 TS Value: [20-24) TS Value: [15-20) TS Value: [14-15) TS Value: [13-14) TS Value: [12-13) TS Value: [11-12) TS Value: [10-11) TS Value: [9-10) TS Value: [8-9) TS Value: [7-8) TS Value: [6-7) TS Value: [5-6) TS Value: [4-5) TS Value: [3-4) TS Value: [2-3) TS Value: [1-2) TS Value: [0-1)

Figure 8.36 Map overview: Kildevangen (zone K), max residence time

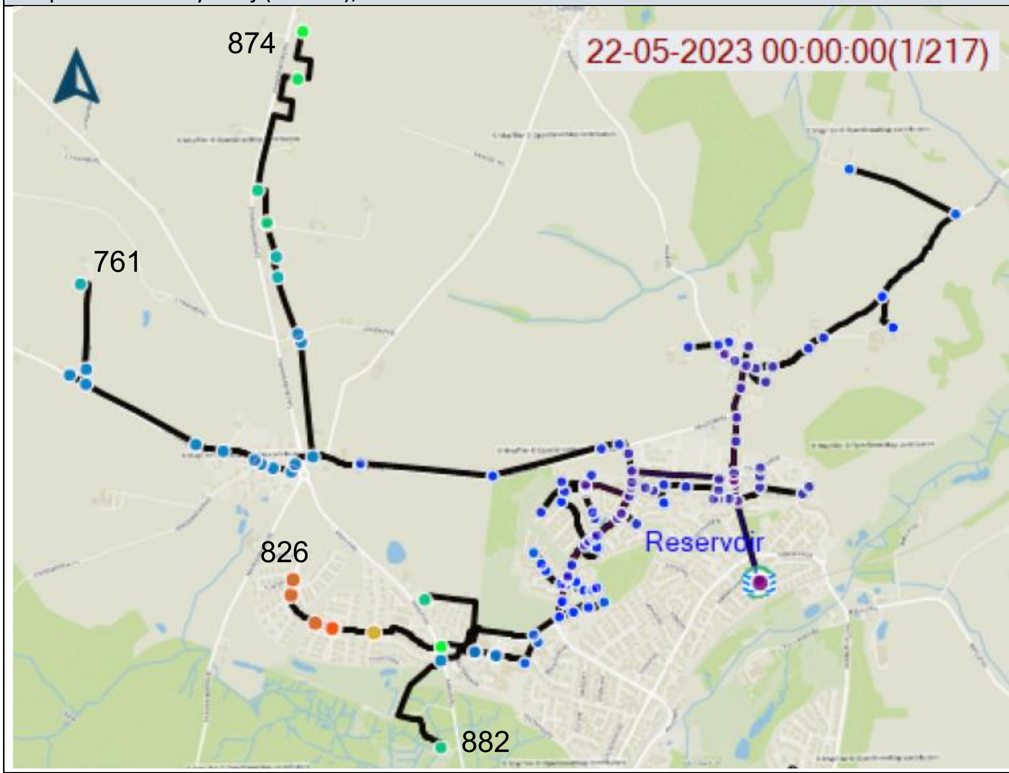
Map overview: Rylevej (zone R), max residence time	Symbology:
	Residence time [hh]: *Maximum residence time in hours* TS Value: >= 72 TS Value: [65-72) TS Value: [60-65) TS Value: [55-60) TS Value: [50-55) TS Value: [45-50) TS Value: [40-45) TS Value: [35-40) TS Value: [30-35) TS Value: [25-30) TS Value: [20-25) TS Value: [15-20) TS Value: [12-15) TS Value: [10-12) TS Value: [5-10) TS Value: [0-5)

Figure 8.37 Map overview: Rylevej (zone R), max residence time

8.8.4 Graphical view of max residence time

Graphical view of max residence time for nodes with highest residence time based on the overview map.

Hinnerup Lund: max residence time, graphical view

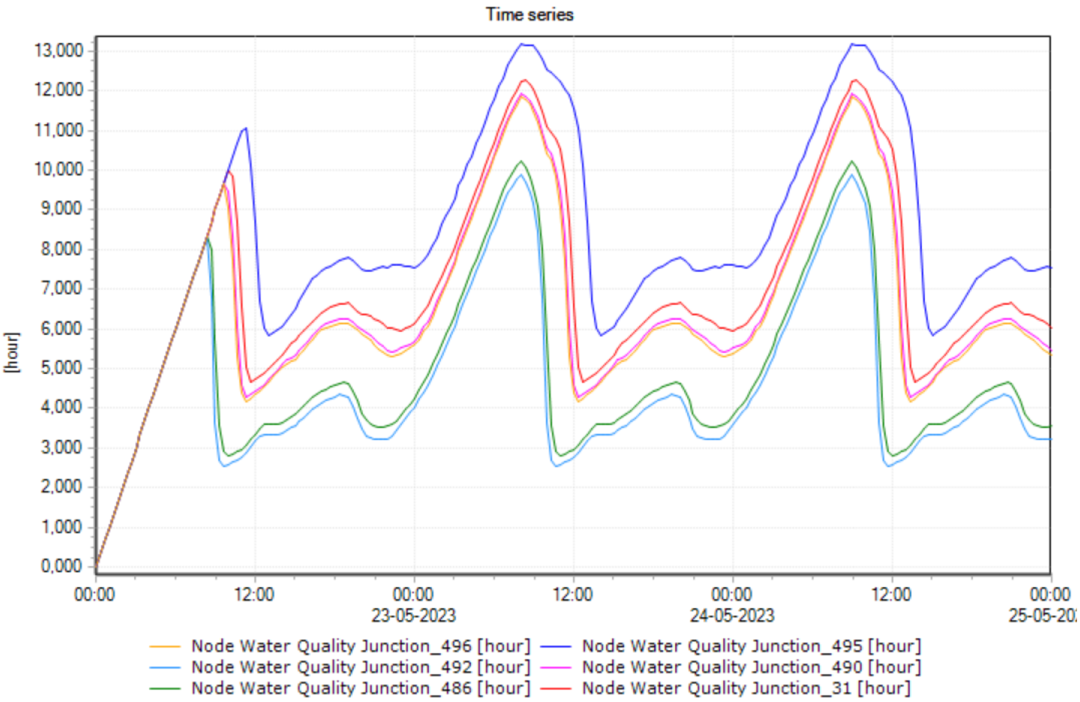


Figure 8.38 Hinnerup Lund: max residence time for nodes with highest residence time

Water age in end-nodes as a function of time. All 6 end-nodes are plotted. Average water age for junction 495 is approx. 6-13 hours.

Industrial area: max residence time, graphical view

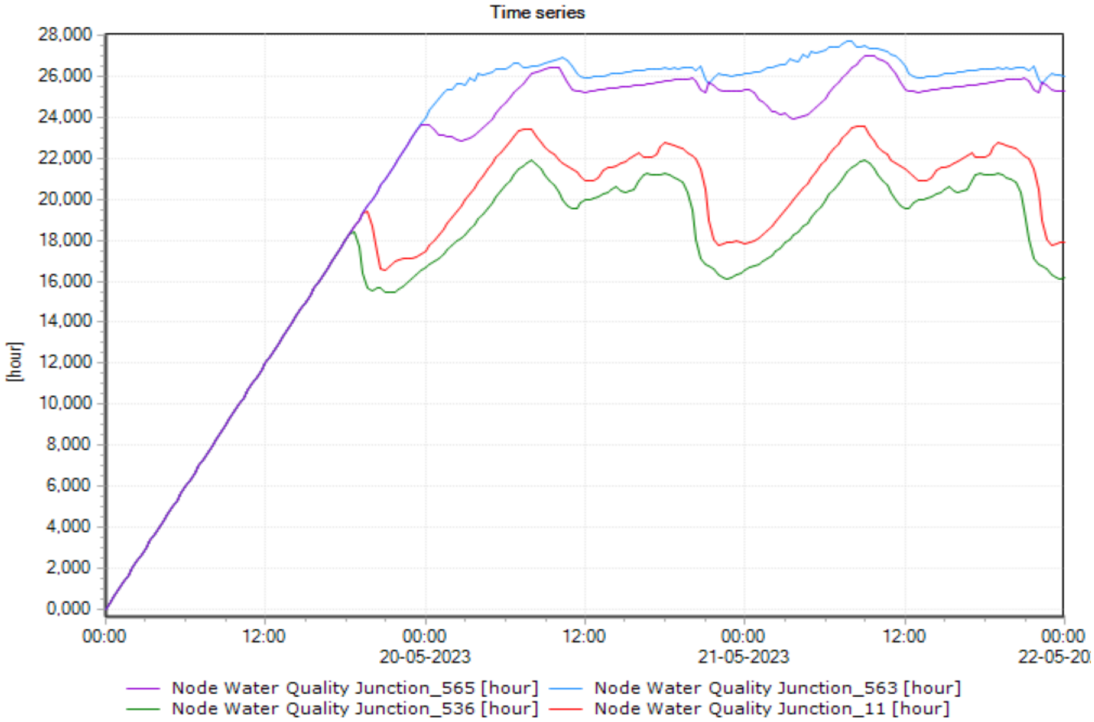


Figure 8.39 Industrial area: max residence time for nodes with highest residence time

Water age in end-nodes as a function of time. The 4 highest end-nodes are plotted. Average water age for junction 563 is approx. 26-28 hours.

Hinnerup Midt: max residence time, graphical view

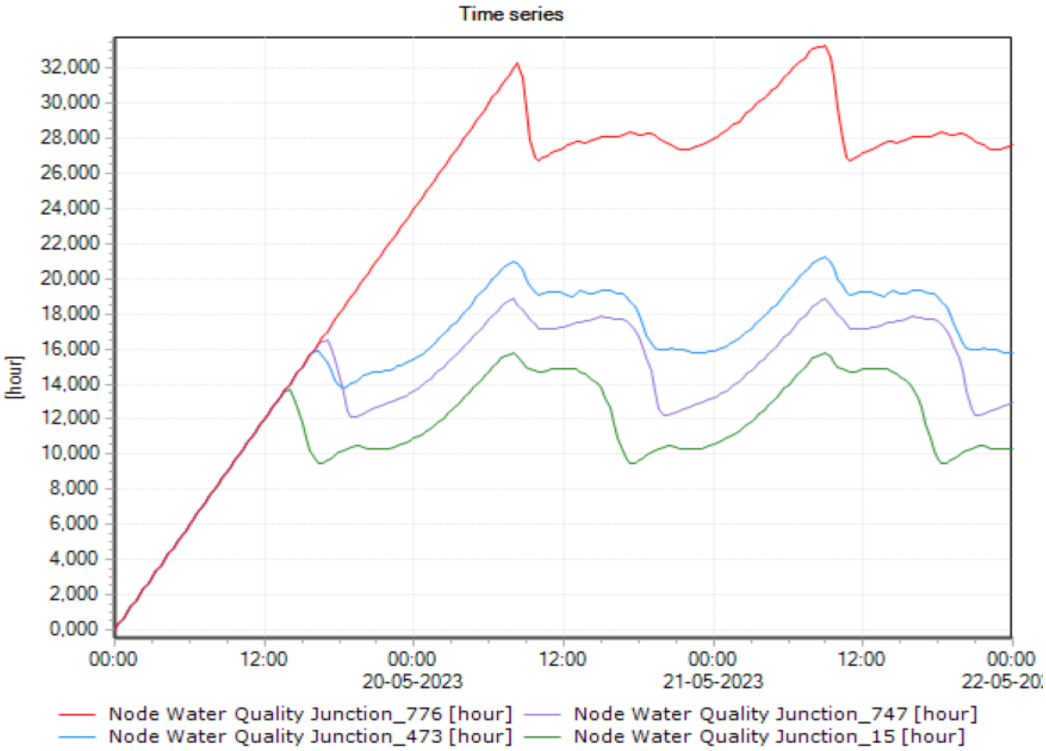


Figure 8.40 Hinnerup Midt: max residence time for nodes with highest residence time

Average water age for junction 776 is approx. 27-34 hours.

Kildevangen: max residence time, graphical view

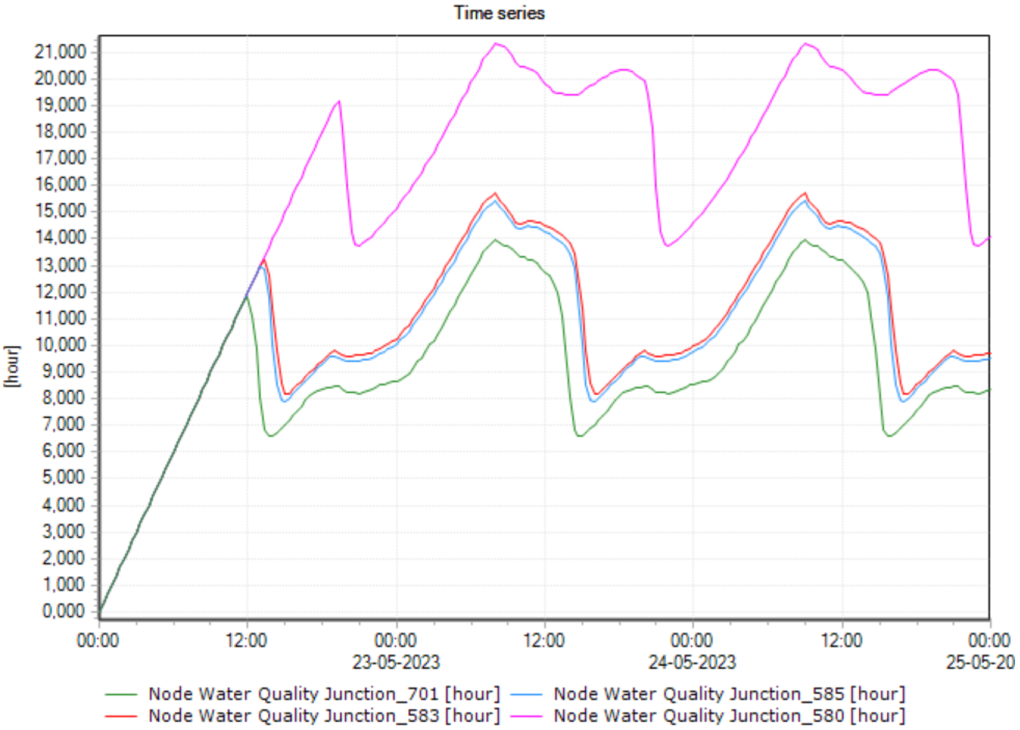


Figure 8.41 Kildevangen: max residence time for nodes with highest residence time

The high water age in junction 580 compared to its neighbor junction 583, is due to the small pipe diameter of 50 mm. Smaller diameter means higher velocity, hereby decreasing the transport time of the water.

Rylevej: max residence time, graphical view

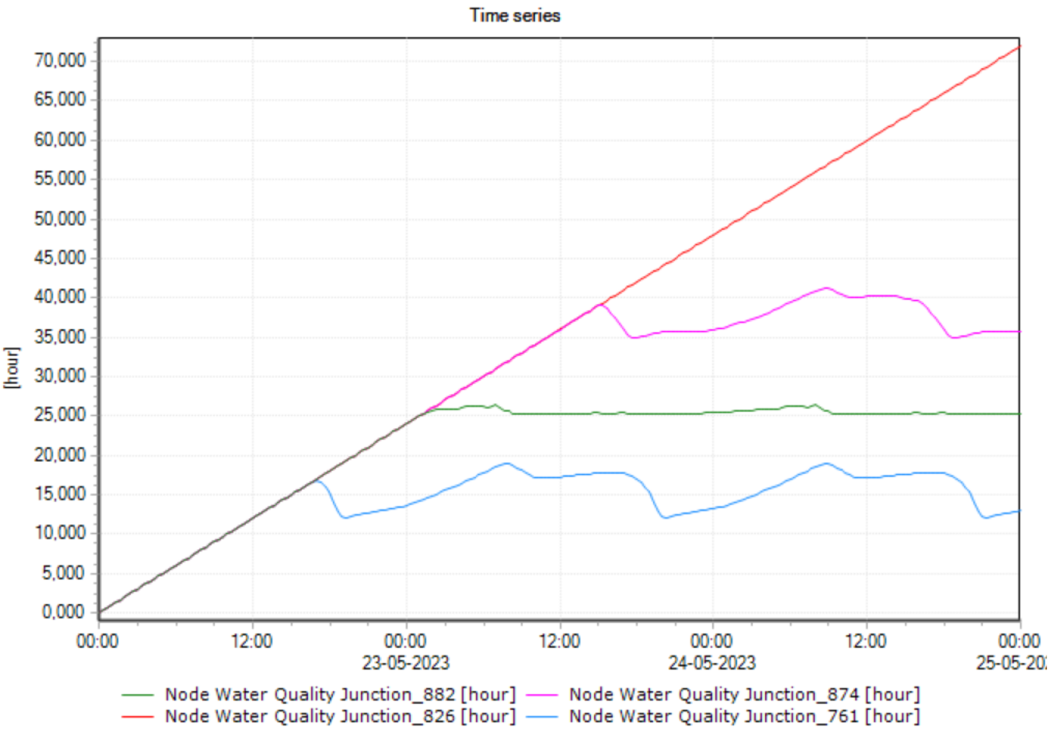


Figure 8.42 Rylevej: max residence time for nodes with highest residence time

High exceeding water age of +72 hours for junction 826 due to a pipe diameter of 160 mm. This results in a very low velocity because of the limited node demand of 0,097 L/s.

Appendix 9.0

Table of content

9.1. Assessment of the future water consumption.

Method for calculating the raw amount of water consumption in the new urban area. Starting from the final calculation, the following parameters are defined:

$$(1)\ Total\ distribution\ \left[\frac{m^3}{year}\right] = D + E$$

- D [m^3/year]: ideal water distribution quantity, without additional consumptions.
- E [m^3/year]: Extraordinary consumption, including firefighting demand and water waste. According to Danish Standards DS442, there should be a reserve of 8-10% of the ideal water consumption. Hence, we have chosen to be conservative by considering 10%.

$$(2)\ Fd = 0{,}10 * D$$

To quantify D:

- **N: total expected number of households**.
  The expected population growth is between 1000 to 1500 households in the following 10 to 15 years. To guarantee the supply, the worst scenario in terms of supply has been considered, so 1500 buildings have been considered for the estimation.
- **p: number of people per household.**
  In Favrskov municipality there are between 2,4 and 2,5 people per house (Danmarks Statistik, 2020), so the assumption made is of 2,5 people per house.
- **w: quantity of water consumed per person per day**.
  There are several sources providing information:
  - According to (Danmarks Statistik, 2020), the consumption is of 108 liters per person and per day.

- The consumption varies between 100 and 130 liters per person and per day (A/S, 2020).
- The consumption varies between 155 and 180 liters per person and per day (Dansk standard, 1988).
- The value for Aarhus in 2008 was 114 l/p/day (Møller, 2023).
- The average value in Denmark in 2008 was 116 l/p/day (Møller, 2023).

Considering all factors, a daily average of 120 liters per person per day has been taken into consideration, striking a balance between being neither excessively high nor excessively low.

- **d: active period of consumption**.
  Given that it is a residential zone, just households have been considered, with their respective consumption period of 365 days per year (A/S, 2020).

$$(3)\ D = N * p * w * d = 1500\ households * 2{,}5 \frac{people}{household} * 0{,}12 \frac{m^3}{person * day} * 365 \frac{days}{year} = 164250 \frac{m^3}{year}$$

Knowing D, the firefighting reserve can be found:

$$(2)\ Fd = 0{,}10 * 164250 = 16425 \frac{m^3}{year}$$

Coming back to (1):

$$Total\ distribution \left[\frac{m^3}{year}\right] = 164250 + 16425 = 180675 \frac{m^3}{year}$$

9.2. Evaluation of point of connection for new supply zones.

9.2.1. Hydraulic capacity.

The yearly value for Zone R has been obtained from Appendix 8.2. The one for Zone F is calculated in Appendix 9.1.

	Q_{year} [m³/y] Yearly report	Q_{year} [m³/y] Estimation	Q_{mean} [m³/d]	$Q_{max\ day}$ [m³/d]	f_{day}	$Q_{max\ hour}$ [m³/h]	f_{hour}
Zone M	151.281	-	414,5	559,7	1,35	49,3	2,11
Future urban area (F)	-	180.675	594	(2)	(1)	(4)	(3)

Table 9.1. Estimation of the values for the future urban zone, in relation to Hinnerup Midt.

For calculating Q_{day}, in both cases: $Q_{day} = \frac{Q_{yearly\ report}}{365 \frac{days}{year}}$

(1) $f_{d,F} = f_{d,M} = 1{,}35$

(2) $Q_{\max day,F} = Q_{day,F} * f_{d,M} = 495 \frac{m^3}{day} * 1{,}35 = 668{,}5 \frac{m^3}{day}$

(3) $f_{h,F} = f_{h,M} = 2{,}11$

(4) $Q_{\max hour,F} = \frac{Q_{\max day,F}}{24} * f_{h,M} = \frac{495 \frac{m^3}{day}}{24 \frac{h}{day}} * 2{,}11 = 58{,}8 \frac{m^3}{h}$

The maximum flow velocity in a pe pipe with 200 mm outside diameter is calculated below. Referring to, the inside diameter of this pipe is 188 mm (Wavin, s.f.).

According to the equation of continuity, the following expression can be used for calculating the flow velocity:

$$v\left[\frac{m}{s}\right] = \frac{Q\left[\frac{m^3}{s}\right]}{A\,[m^2]} = \frac{\frac{58{,}08\frac{m^3}{h}}{3600\frac{s}{h}}}{\pi * \frac{0{,}188^2\,m^2}{4}} = 0{,}59\frac{m}{s}$$

9.2.2. Geographical location.

Information about the distribution pumps is provided (Favrskov Vandforsyningsplan (2020-30), 2020), but not updated. Thanks to pictures taken in the visit to Hinnerup Waterworks, the capacity for every pump group is known (mentioned in section 8.1.2.). This sets the maximum amount of water possible to distribute.

When dimensioning pumps, the parameter to look at is the max hourly consumption. The data needed has already been calculated in table 8.8. (Appendix 8.4.) and Appendix 9.2.1. The table 9.2. below shows the aim of distribution of Nørrevangen reservoir.

	Q_{year} [m^3/y] Yearly report	Q_{year} [m^3/y] After implementation of Zone F	$Q_{max\ day}$ [m^3/d]	f_{day}	$Q_{max\ hour}$ [m^3/h]	f_{hour}
Kildevangen (K)	38.823	38.823	132,8	1,25	11,7	2,11
Rylevej (Ry+F)	97.752	(1)	(2)	(3)	(4)	(5)

Table 9.2. Estimation of the water consumption after implementing the new urban area.

(1) $Q_{\text{year},Ry+F} = Q_{year,F} + Q_{year,Ry} = 180.675 + 97.752 = 278.427\,\frac{\text{m}^3}{\text{day}}$

(2) $Q_{\max day,Ry+F} = Q_{maxday,F} + Q_{maxday,Ry} = 668{,}5 + 361{,}7 = 1030{,}2\,\frac{\text{m}^3}{\text{day}}$

(3) $f_{d,Ry+F} = f_{d,Ry} = f_{d,F} = 1{,}35$

(4) $Q_{\max hour,Ry+F} = Q_{maxhour,F} + Q_{maxhour,Ry} = 58{,}8 + 31{,}9 = 90{,}8\,\frac{\text{m}^3}{\text{day}}$

(5) $F_{h,Ry+F} = f_{h,Ry} = f_{h,F} = 2{,}11$

Furthermore, Nørrevangen reservoir is supplied by Herredsvej Waterworks. The impact of the implementation of the Zone F is studied in the Table 9.3. below.

	Q_{year} Yearly report [m^3/year]	Q_{year} After implementation of Zone F [m^3/year]	Q_{mean} [m^3/d]	$Q_{max\ day}$ [m^3/d]	f_{day}	$Q_{max\ hour}$ [m^3/h]	f_{hour}
Zone I (I)	72.019	72.019	288,1	376,6	1,31	33,5	2,14
Zone H (H)	41.902	41.902	114,8	141,5	1,23	12,4	2,11
Zone M (M+N+R2)	151.281	151.281	414,5	559,7	1,35	49,3	2,11
Nørrevangen Reservoir (R1)	111.359	(1)	(3)	(4)	(2)	(6)	(5)
Total distribution flow	376.561	557.236		2075,2		183,8	

Table 9.3. Estimation of water distribution from Herredsvej after implementing the new urban area.

(1) $R1, future[m^3] = R1, present + F = 111.359 + 180.675 = 292.034\ m^3$/year

(2) f_{day} has already been assessed for the current consumption in Table 8.8. (Appendix 8.4.2.)

$$f_{day,R1\ future} = f_{day,R1\ present} = 1{,}25$$

(3) $Q_{\text{mean},,R1} = \frac{292.034 \frac{\text{m}^3}{\text{year}}}{365 \frac{\text{days}}{\text{year}}} = 800{,}1 \frac{\text{m}^3}{\text{day}}$

(4) $Q_{\max day,R1} = Q_{mean,R1} * f_{d,R1} = 800{,}1 \frac{\text{m}^3}{\text{day}} * 1{,}25 = 997{,}4 \frac{\text{m}^3}{\text{day}}$

(5) f $_{hour}$ has already been assessed for the current consumption in Table 8.8. (Appendix 8.4.2.)

$$f_{hour,R1\ future} = f_{hour,R1\ present} = 2{,}13$$

(6) $Q_{\max hour,R1} = \frac{Q_{\max day,R1}}{24} * f_{h,R1} = \frac{997{,}4 \frac{m^3}{day}}{24 \frac{h}{day}} * 2{,}13 = 88{,}6 \frac{m^3}{h}$

The values for the last row (Total distribution flow) are the sum of the above quantities. Once that the values have been characterized, the maximum flow velocity for the pipe providing R1 can be determined. The inside diameter of this pipe is 190 mm (Wavin, s.f.).

$$v \left[\frac{m}{s}\right] = \frac{Q \left[\frac{m^3}{s}\right]}{A\ [m^2]} = \frac{\frac{88{,}6 \frac{m^3}{h}}{3600 \frac{s}{h}}}{\pi * \frac{0{,}190^2\ m^2}{4}} = 0{,}87 \frac{m}{s}$$

After reaching Nørrevangen Reservoir, the water must be pumped up to the consumption points. The following table compares the present situation in the distribution pumps with the one predicted for the future. Data regarding pump capacity can be consulted in section 8.1.2. The "Highest value of max hour supply" values for the future are value (4) from Table 9.2. above.

Zone	Pump group capacity [m³/h]	Highest value of max hour supply [m³/h]	Performanc e (%) (4)
Kildevangen	54,2	12	22,14
Rylevej - present	63	29	46,03
Rylevej - future with current installation	63	(3)	144,13
Rylevej - future with pump group combination	(1)	(3)	77,47
Rylevej - future with additional pump	(2)	(3)	97,63

Table 9.4. Different scenarios regarding the water distribution for the future.

(1) $Capacity = Capacity, R + Capacity, K = 54{,}2 + 63 = 117{,}2 \frac{m^3}{h}$

(2) $Capacity = Capacity, R + 30 \frac{m^3}{h} = 63 + 30 = 93 \frac{m^3}{h}$

(3) Value (4) from Table 9.2. above.

(4) $Performance = \frac{Highest\ value\ of\ \max hour\ supply}{Pump\ group\ capacity} * 100$

9.2.3. Water quality.

In this part the effectiveness of the treatment plant regarding the future planned abstraction will be proved. Specifically, the sand filtration.

To continue, the hourly flow is needed from the maximum daily flow estimated in the whole distribution quantity.

$$Flow\left[\frac{m^3}{h}\right] = \frac{2075{,}2\,\frac{m^3}{day}}{24\,\frac{h}{day}} = 86{,}46\,\frac{m^3}{h}$$

The same iron concentration as in the calculation for the present conditions has been considered, given that the water is to be obtained from the same wells as in the present and it is the latest data available. The pumps do not have a determined functioning time: they run or not depending on the water level on the tank. Consequently, the filter running time is 24h. Deriving from these conditions, the quantity of iron retained in the filter per day is the following.

$$24\,h * 86{,}46\,\frac{m^3}{h} * 0{,}93\,\frac{g}{m^3} = 1.929{,}94\,\frac{g\,Fe}{day} = 1{,}93\,\frac{kg\,Fe}{day}$$

The filters' dimensions were already obtained in Section 7. The maximum acceptable amount of time between backwash is:

$$time = \frac{45{,}533\,m^2 * 0{,}5\,kg}{1{,}93\,\frac{kg}{day}} = 11{,}79\,days.$$

9.2.4. Infrastructure compatibility.

9.2.4.a.

Information about the abstraction pumps is obtained from (Favrskov Vandforsyningsplan (2020-30), 2020), providing data for the capacity of the pump per hour.

$$Capacity\ per\ day = Capacity\ per\ hour * 24\,\frac{hours}{day}$$

	B3	B4	B5	B6	B10
Capacity per hour [m^3/h]	30	30	30	30	14
Capacity per day [m^3/day]	690	690	690	690	322

Table 9.5. Capacity for the abstraction pumps.

$$Total\ abstraction\ capacity = 690 * 4 + 322 = 3082\,\frac{m^3}{day}$$

For calculations related to abstraction, the value to count is the maximum daily consumption. This value has already been calculated in Table 9.3. in the Appendix 9.2.2.

9.2.4.b. Maximum flow velocity in the main supply pipes.

Columns regarding dimensions depend on the materials of the pipe and the established measures (Wavin, s.f.), see. The highest max hourly flow value is obtained from sections 8 and 9 in the main report.

Flow	Outside diameter [m]	Inside diameter (Di) [m]	Highest max hourly flow value [m^3/h]	Flow velocity [m/s] (3)
Ry	0,2	0,188	31,79	0,32
Ry + F	(1)	(1)	90,8	0,91
F	(2)	(2)	58,8	0,59

Table 9.6. Data regarding maximum velocity flow.

(1) The pipe is not supposed to change for the future supply, so the value would be the same as for the present.

$D_{outside}$ = 0,2 m
D_{inside} = 0,188 m

(2) In order to guarantee the best connection possible to the existing network, the diameter chosen is the same as the joint connection to the Rylevej.

(3) $D_{outside}$ = 0,16 m
(4) D_{inside} = 0,154 m

(5) Values are obtained according to the following expression:

$$Velocity\left[\frac{m}{s}\right]=\frac{Flow\left[\frac{m^3}{s}\right]}{Pipe\ section\ [m^2]}=\frac{Flow}{\pi*\frac{Di^2}{4}}$$

9.2.5. Regulatory compliance.

At this point, the only estimation regarding the flow is about the water distribution, and it has been calculated considering data records from similar zones. However, this quantity differs from the abstracted volume of water (See Appendix 1.1). For this reason, the relation over the last years on the abstracted vs. distributed volume are shown in the table below:

Year	Abstracted volume [m3]	Distributed volume [m3]	Relation = Abs. / Distr. [-]
2018	382517	364514	1,0494
2019	378022	356361	1,0608
2020	375719	343685	1,0932
2021	417066	376561	1,1076
		Average	**1,0777**

Table 9.7. Estimated relation between values for abstraction and distribution.

The aim of this comparison is to find a tendency in the relationship between both values over the years. The result obtained is favorable: all values exhibit a high degree of similarity. Hence, the average value will be used.

The estimated flow to be distributed is of 557.236 m^3.

$$Abstracted\ volume = Relation * Distributed\ volume = 1{,}0777 * 557.236 = \ 600.533{,}24\ m^3$$

9.3 Overview of the model parameters

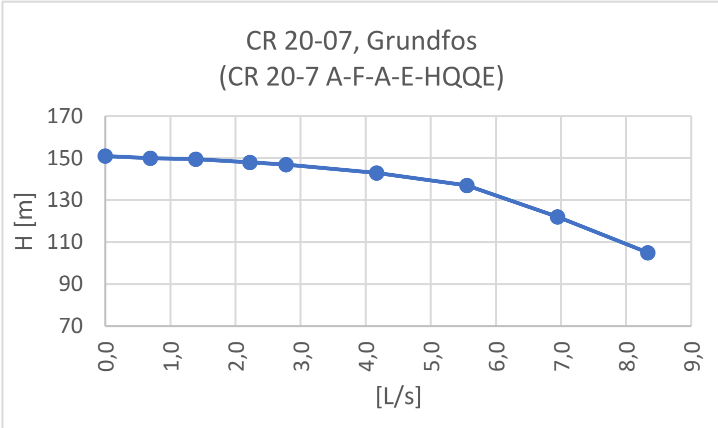
9.3.1 Consumer pressure at critical discharge points: model parameters

The model parameters of the future area (zone F) is applied only within the new constructed network which has been presented on figure 9.1.

The model parameters that have been used for the current existing network of Rylevej, is equal to the model parameters used for the investigation of consumer pressure (scenario 1) within the zone of Rylevej in subsection 8.4, in accordance with Appendix 8.7.1.

Zone: Future area (F)		
Scenario 1 simulation		
Simulation setup MIKE+		
Model type	Steady state simulation	
Duration	1 hour	
Flow demand parameters		
Max hour demand	58,8	[m^3/h]
Max hour in L/s	16,33	[L/s]
Total end-nodes	5	nodes
Demand per node	3,26	[L/s]
Other model parameters		
*Roughness**	0,01	[mm]

Pump specifications:
Zone F is supplied by pump group of zone R with location at Nørrevangen Reservoir.



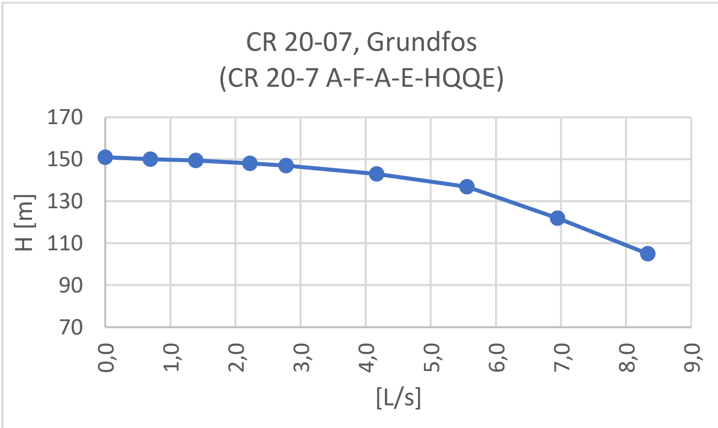
Pump Efficiency: 100%

*A roughness of 0,01 mm has been used which is equivalent to the roughness of new PVC or PE distribution pipes.

Table 9.8 Model parameters, Future area (zone F), consumer pressure within network

Zone: Rylevej (R)		
Scenario 1 simulation		
Simulation setup MIKE+		
Model type	Steady state simulation	
Duration	1 hour	
Flow demand parameters		
Max hour demand	24,9	[m^3/h]
Max hour in L/s	6,92	[L/s]
Total end-nodes	28	nodes
Scenario 1 Demand per node	0,25	[L/s]
Scenario 2 Demand critical node	3,46	[L/s]
Flow remaining nodes	0,13	[L/s]
Other model parameters		
*Roughness**	0,6	[mm]

Pump specifications:



Pump Efficiency: 100%

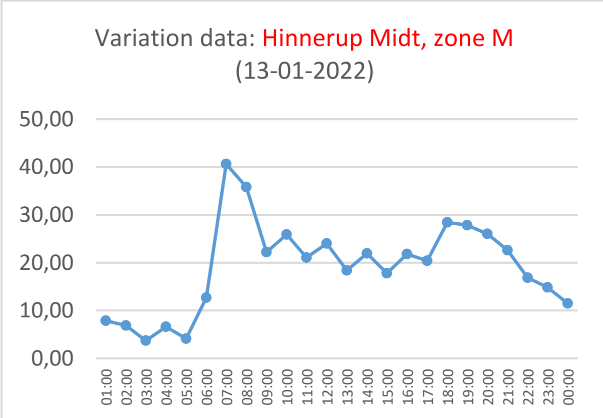
Table 9.9 Model parameters, Rylevej (zone R), consumer pressure within network

9.3.2 Max residence time of the water: model parameters

Note: The demand pattern curve of Hinnerup Midt is used here, as there is no variation data for the new area. The two zones can be considered comparable in terms of yearly consumptions. Regarding consumption parameters for the new area zone F, the average hour consumption of Hinnerup Midt has been used. This average hour consumption should be viewed as too small for the new area, due to the estimated max hour consumption of 58,8 m^3/h for the area. Using a significantly lower average hour consumption that what would actually be the case for the new area, is on the safe side in relation to max residence time of the water, as less flow will result in decreasing velociy and thus increasing of residence time.

Zone: Future area (F)		
Simulation setup MIKE+		
Model type	Extended period water quality, water age	
Duration	3 days of 24 hours	
Consumption parameters		
Average hour	19,2	[m^3/h]
Max hour	40,6	[m^3/h]
Max hour factor	2,11	[-]
Total end-nodes	5	nodes
Demand per node	1,06	[L/s]
Demand pattern	*see demand pattern curve below*	
Other model parameters		
Roughness*	0,01	[mm]

Variation data: [m^3/h]



Q average	Q max	f hour
19,2	40,6	2,11

Calculated values based on variation data

*A roughness of 0,01 mm has been used which is equivalent to the roughness of new PVC or PE distribution pipes.

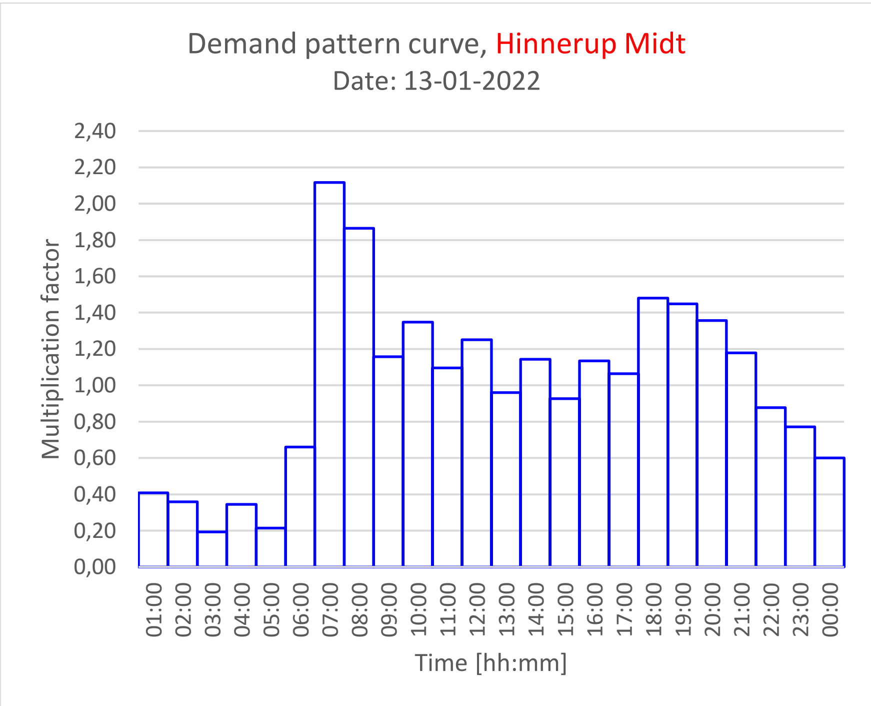


Figure 9.1 Model parameters, Future area (zone F), max residence time

Multiplication factor per hour:

[hh:mm]	[m^3/h]	factor
01:00	7,84	0,41
02:00	6,88	0,36
03:00	3,69	0,19
04:00	6,62	0,34
05:00	4,10	0,21
06:00	12,66	0,66
07:00	40,64	2,12
08:00	35,79	1,86
09:00	22,23	1,16
10:00	25,88	1,35
11:00	21,05	1,10
12:00	24,01	1,25
13:00	18,42	0,96
14:00	21,97	1,14
15:00	17,80	0,93
16:00	21,77	1,13
17:00	20,43	1,06
18:00	28,43	1,48
19:00	27,82	1,45
20:00	26,04	1,36
21:00	22,64	1,18
22:00	16,84	0,88
23:00	14,82	0,77
00:00	11,51	0,60

Zone: Rylevej (R)

Simulation setup MIKE+

Model type	Extended period water quality, water age	
Duration	3 days of 24 hours	

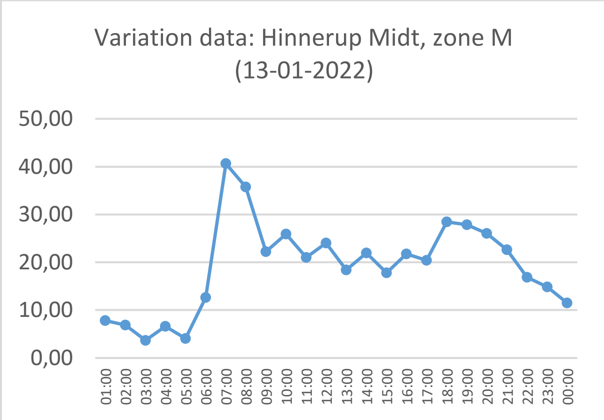
Consumption parameters

Average hour	9,80	[m³/h]
Max hour	-	[m³/h]
Max hour factor	2,12	[-]
Total end-nodes	28	nodes
Demand per node	0,097	[L/s]
Demand pattern	*see demand pattern curve below*	

Other model parameters

Roughness	0,6	[mm]

Variation data: [m^3/h]



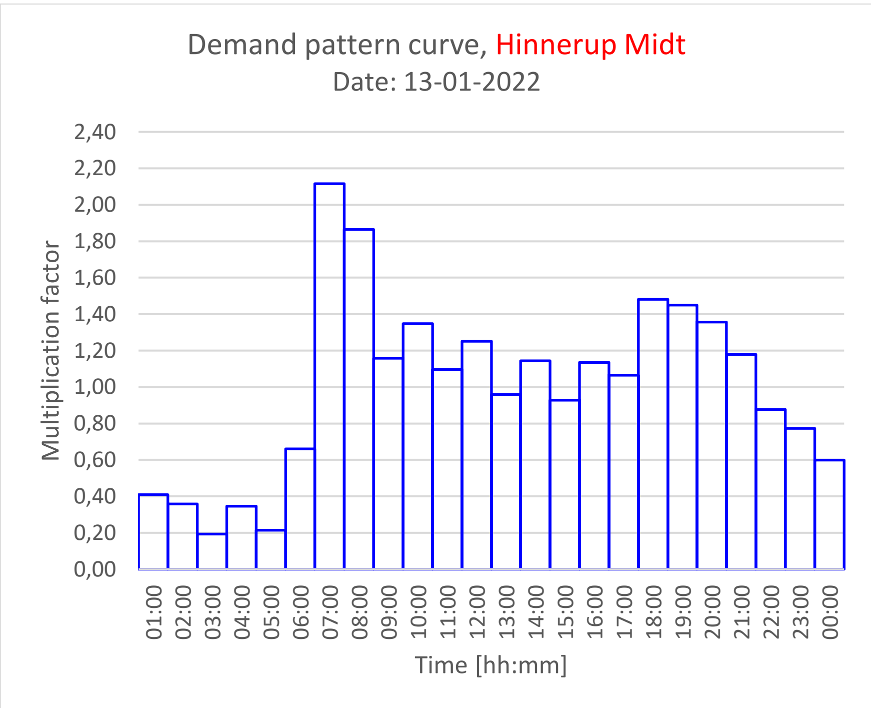
Q average	Q max	f hour
19,2	40,6	2,11

Calculated values based on variation data

Note: The demand pattern curve of Hinnerup Midt is used here, as there is no available variation data for the zone of Rylevej.

The relation between the reported max hour of Hinnerup Midt and Rylevej is a factor 1,96 in difference.
(48,8 ÷ 24,9 = 1,96)

The average hour is then calculated as the average consumption of Hinnerup Midt of 19,2 divided by the factor 1,96.
(19,2 ÷ 1,96 = 9,8)



Multiplication factor per hour:

[hh:mm]	[m³/h]	factor
01:00	7,84	0,41
02:00	6,88	0,36
03:00	3,69	0,19
04:00	6,62	0,34
05:00	4,10	0,21
06:00	12,66	0,66
07:00	40,64	2,12
08:00	35,79	1,86
09:00	22,23	1,16
10:00	25,88	1,35
11:00	21,05	1,10
12:00	24,01	1,25
13:00	18,42	0,96
14:00	21,97	1,14
15:00	17,80	0,93
16:00	21,77	1,13
17:00	20,43	1,06
18:00	28,43	1,48
19:00	27,82	1,45
20:00	26,04	1,36
21:00	22,64	1,18
22:00	16,84	0,88
23:00	14,82	0,77
00:00	11,51	0,60

Figure 9.2 Model parameters, Rylevej (zone R), max residence time

Appendix 10.0

Table of content

10.1. Abstraction pumps operation over a 24 hour period.

(B10) time	B10 Flow	B6 Flow	B5 Flow	B4 Flow	B3 Flow
0:15:00	0,0	0	0,0	0,0	0,0
0:30:00	0,0	0	0,0	0,0	0
1:00:00	0,0	0	0,0	0,0	0
1:44:05	26,5	20,8	17,7	20,2	14,3
1:44:07	26,5	20,8	17,7	20,2	14,3
1:44:09	26,5	20,8	17,7	20,2	14,3
1:44:11	26,5	20,8	17,7	20,2	14,3
1:59:51	26,5	20,8	17,7	20,2	14,3
1:59:53	0,0	0	0,0	0,0	0
1:59:55	0,0	0	0,0	0,0	0
1:59:57	0,0	0	0,0	0,0	0
1:59:59	0,0	0	0,0	0,0	0
2:00:00	0,0	0	0,0	0,0	0
2:36:49	0,0	0	0,0	0,0	0
2:36:51	26,8	20,8	17,7	20,2	14,3
2:36:53	26,8	20,8	17,7	20,2	14,3
2:36:55	26,8	20,8	17,7	20,2	14,3
2:36:57	26,8	20,8	17,7	20,2	14,3
2:49:36	26,8	20,8	17,7	20,2	14,3
2:49:38	0,0	0	0,0	0,0	0
2:49:40	0,0	0	0,0	0,0	0
2:49:42	0,0	0	0,0	0,0	0
2:49:44	0,0	0	0,0	0,0	0
3:00:00	0,0	0	0,0	0,0	0
3:41:15	26,8	20,8	17,7	20,2	14,3
3:41:17	26,8	20,8	17,7	20,2	14,3
3:41:19	26,8	20,8	17,7	20,2	14,3
3:41:21	26,8	20,8	17,7	20,2	14,3
3:53:23	26,8	20,8	17,7	20,2	14,3
3:53:25	0,0	0	0,0	0,0	0
3:53:27	0,0	0	0,0	0,0	0

3:53:29	0,0	0	0,0	0,0	0
4:00:00	0,0	0	0,0	0,0	0
4:31:46	26,8	20,8	17,7	20,2	14,3
4:31:48	26,8	20,8	17,7	20,2	14,3
4:31:50	26,8	20,8	17,7	20,2	14,3
4:31:52	26,8	20,8	17,7	20,2	14,3
4:44:34	26,8	20,8	17,7	20,2	14,3
4:44:36	0,0	0	0,0	0,0	0
4:44:38	0,0	0	0,0	0,0	0
4:44:40	0,0	0	0,0	0,0	0
5:00:00	0,0	0	0,0	0,0	0
5:13:51	0,0	0	0,0	0,0	0
5:13:53	26,8	20,8	17,7	20,2	14,3
5:13:55	26,8	20,8	17,7	20,2	14,3
5:13:57	26,8	20,8	17,7	20,2	14,3
5:13:59	26,8	20,8	17,7	20,2	14,3
5:40:11	26,8	20,8	17,7	20,2	14,3
5:40:13	0,0	0	0,0	0,0	0
5:40:15	0,0	0	0,0	0,0	0
5:40:17	0,0	0	0,0	0,0	0
5:56:40	0,0	0	0,0	0,0	0
5:56:42	26,8	20,8	17,7	20,2	14,3
5:56:44	26,8	20,8	17,7	20,2	14,3
5:56:46	26,8	20,8	17,7	20,2	14,3
5:56:48	26,8	20,8	17,7	20,2	14,3
6:00:00	26,8	20,8	17,7	20,2	14,3
6:51:20	30,6	27,2	23,1	26,4	18,7
7:00:00	30,6	27,2	23,1	26,4	18,7
8:00:00	30,6	27,2	23,1	26,4	18,7
8:39:08	26,8	20,8	17,7	20,2	14,3
8:39:10	26,8	20,8	17,7	20,2	14,3
9:00:00	26,8	20,8	17,7	20,2	14,3
9:22:48	26,8	20,8	17,7	20,2	14,3
9:22:50	0,0	0	0,0	0,0	0
9:22:52	0,0	0	0,0	0,0	0
9:22:54	0,0	0	0,0	0,0	0
9:22:56	0,0	0	0,0	0,0	0
9:32:09	26,8	20,8	17,7	20,2	14,3
9:32:11	26,8	20,8	17,7	20,2	14,3
9:32:13	26,8	20,8	17,7	20,2	14,3
9:32:15	26,8	20,8	17,7	20,2	14,3
10:00:00	26,8	20,8	17,7	20,2	14,3
10:37:49	26,8	20,8	17,7	20,2	14,3
10:37:51	0,0	0	0,0	0,0	0
10:37:53	0,0	0	0,0	0,0	0
10:37:55	0,0	0	0,0	0,0	0

10:37:57	0,0	0	0,0	0,0	0
10:47:45	26,7	20,8	17,7	20,2	14,3
10:47:47	26,7	20,8	17,7	20,2	14,3
10:47:49	26,7	20,8	17,7	20,2	14,3
10:47:51	26,7	20,8	17,7	20,2	14,3
11:00:00	26,7	20,8	17,7	20,2	14,3
11:51:56	26,7	20,8	17,7	20,2	14,3
11:51:58	0,0	0	0,0	0,0	0
11:52:00	0,0	0	0,0	0,0	0
11:52:02	0,0	0	0,0	0,0	0
11:52:04	0,0	0	0,0	0,0	0
12:00:00	0,0	0	0,0	0,0	0
12:07:36	26,3	20,8	17,7	20,2	14,3
12:07:38	26,3	20,8	17,7	20,2	14,3
12:07:40	26,3	20,8	17,7	20,2	14,3
12:07:42	26,3	20,8	17,7	20,2	14,3
12:45:29	26,3	20,8	17,7	20,2	14,3
12:45:31	0,0	0	0,0	0,0	0
12:45:33	0,0	0	0,0	0,0	0
12:45:35	0,0	0	0,0	0,0	0
12:45:37	0,0	0	0,0	0,0	0
12:55:23	26,8	20,8	17,7	20,2	14,3
12:55:25	26,8	20,8	17,7	20,2	14,3
12:55:27	26,8	20,8	17,7	20,2	14,3
12:55:29	26,8	20,8	17,7	20,2	14,3
13:00:00	26,8	20,8	17,7	20,2	14,3
13:28:46	26,8	20,8	17,7	20,2	14,3
13:28:48	0,0	0	0,0	0,0	0
13:28:50	0,0	0	0,0	0,0	0
13:28:52	0,0	0	0,0	0,0	0
13:41:36	26,8	20,8	17,7	20,2	14,3
13:41:38	26,8	20,8	17,7	20,2	14,3
13:41:40	26,8	20,8	17,7	20,2	14,3
13:41:42	26,8	20,8	17,7	20,2	14,3
13:41:44	26,8	20,8	17,7	20,2	14,3
14:00:00	26,8	20,8	17,7	20,2	14,3
14:16:23	26,8	20,8	17,7	20,2	14,3
14:16:25	0,0	0	0,0	0,0	0
14:16:27	0,0	0	0,0	0,0	0
14:16:29	0,0	0	0,0	0,0	0
14:16:31	0,0	0	0,0	0,0	0
14:26:39	0,0	0	0,0	0,0	0
14:26:41	26,8	20,8	17,7	20,2	14,3
14:26:43	26,8	20,8	17,7	20,2	14,3
14:26:45	26,8	20,8	17,7	20,2	14,3
14:26:47	26,8	20,8	17,7	20,2	14,3

14:55:23	26,8	20,8	17,7	20,2	14,3
14:55:25	0,0	0	0,0	0,0	0
14:55:27	0,0	0	0,0	0,0	0
14:55:29	0,0	0	0,0	0,0	0
14:55:31	0,0	0	0,0	0,0	0
15:00:00	0,0	0	0,0	0,0	0
15:09:22	0,0	0	0,0	0,0	0
15:09:24	26,8	20,8	17,7	20,2	14,3
15:09:26	26,8	20,8	17,7	20,2	14,3
15:09:28	26,8	20,8	17,7	20,2	14,3
15:09:30	26,8	20,8	17,7	20,2	14,3
15:40:18	26,8	20,8	17,7	20,2	14,3
15:40:21	0,0	0	0,0	0,0	0
15:40:23	0,0	0	0,0	0,0	0
15:40:25	0,0	0	0,0	0,0	0
15:52:18	26,8	20,8	17,7	20,2	14,3
15:52:20	26,8	20,8	17,7	20,2	14,3
15:52:22	26,8	20,8	17,7	20,2	14,3
15:52:24	26,8	20,8	17,7	20,2	14,3
16:00:00	26,8	20,8	17,7	20,2	14,3
17:00:00	26,8	20,8	17,7	20,2	14,3
18:00:00	26,8	20,8	17,7	20,2	14,3
19:00:00	26,8	20,8	17,7	20,2	14,3
20:00:00	26,8	20,8	17,7	20,2	14,3
21:00:00	26,8	20,8	17,7	20,2	14,3
22:00:00	26,8	20,8	17,7	20,2	14,3
22:00:04	0,0	0	0,0	0,0	0
22:00:06	0,0	0	0,0	0,0	0
22:00:08	0,0	0	0,0	0,0	0
22:00:10	0,0	0	0,0	0,0	0
22:15:56	26,8	20,8	17,7	20,2	14,3
22:15:58	26,8	20,8	17,7	20,2	14,3
22:16:00	26,8	20,8	17,7	20,2	14,3
22:16:02	26,8	20,8	17,7	20,2	14,3
22:45:49	26,8	20,8	17,7	20,2	14,3
22:45:51	0,0	0	0,0	0,0	0
22:45:53	0,0	0	0,0	0,0	0
22:45:55	0,0	0	0,0	0,0	0
22:45:57	0,0	0	0,0	0,0	0
23:00:00	0,0	0	0,0	0,0	0
23:10:57	0,0	0	0,0	0,0	0
23:10:59	26,8	20,8	17,7	20,2	14,3
23:11:01	26,8	20,8	17,7	20,2	14,3
23:11:03	26,8	20,8	17,7	20,2	14,3
23:11:05	26,8	20,8	17,7	20,2	14,3
23:27:37	26,8	20,8	17,7	20,2	14,3

23:27:39	0,0	0	0,0	0,0	0
23:27:41	0,0	0	0,0	0,0	0
23:27:43	0,0	0	0,0	0,0	0
23:27:45	0,0	0	0,0	0,0	0

Table 10.1. Pump abstraction over the time in a 24-hour period.

10.2. Pump performance in a failure scenario.

The following table compares the present situation in the distribution pumps with the hypothetical ones in case of a pump group failure. Data regarding pump capacity can be consulted in section 8.1.2. The "Highest value of max hour supply" values for the future can be seen in Table 9.2. (Appendix 9.2.2.).

Zone	Pump group capacity [m^3/h]	Highest value of max hour supply [m^3/h]	Performance (%) (4)
Kildevangen	54,2	12	22,14
Rylevej	63	29	46,03
Kildevangen + Rylevej. Failure of Kildevangen	(1)	(3)	65,08
Kildevangen + Rylevej. Failure of Rylevej	(2)	(3)	75,65

Table 10.2. Pump capacity vs. maximum hourly consumptions in different failure scenarios.

(1) The capacity if the pump group supplying Kildevangen fails is the capacity of the pump group providing Rylevej, thus 63 m^3/h.
(2) The capacity if the pump group supplying Rylevej fails is the capacity of the pump group providing Kildevangen, thus 54,2 m^3/h.
(3) In both cases, the target supply is the sum of both zones' maximum hour consumption:

$$Max\ hour\ supply\ (combination) = 12 + 29 = 41\frac{m^3}{h}$$

(4) $Performance = \frac{Highest\ value\ of\ \max hour\ supply}{Pump\ group\ capacity} * 100$