Norges miljø- og
biovitenskapelige
universitet

**Master's Thesis 2021    30 ECTS**
Faculty of Science and Technology

# Peak Demand Factors for Residential Water Demand in a Norwegian Municipality

Mahamud Hussein Dahir
Water and Environmental Engineering

# Preface

The master’s degree project is carried out in the spring semester of 2021 as the final part of the master’s program in water and environmental engineering at the faculty of Science and Technology at the Norwegian University of Life Sciences. The work has been done with the help of the municipality of Hvaler in Norway. The aim of this thesis to to analyse the different factors used in the design of water supply systems.

# Acknowledgement

First, I would like to thank my wife, Nasra, our sons and the family at large for their patience, support and understanding throughout my graduate studies.

I would like to send my indebted gratitude to my main supervisor, Ulf Rydningen from the Norwegian University of Life Sciences with whom without his help and advice, this thesis work would have been extremely challenging.

I also take this opportunity to thank my co-supervisors Vegard Nilsen and Oddvar Lindholm, both from NMBU, for their great support and valuable guidance. Your constructive feedback will always be remembered.

A special thank you to Engineer Per- Kåre Berg Rubach from the Municipality of Hvaler and Kjartan Slang, the product manager at MAIK for providing the data used in this thesis and their advice.

Mahamud Hussein Dahir

Drammen, June 2021

# Abstract

A well-designed and dimensioned pipeline system for water transport networks is required in order to deliver the required demand for drinking. A good estimation of the quantity of water to be consumed by the users in a certain area is therefore needed. Generally, water usage in private households vary according to the period. Peak factors are used to determine the size, design and dimensioning of water and wastewater supply pipes. Since there is a variation in consumption, the calculation is multiplied by a factor for the hourly and daily variation. Norwegian water (norsk: Norsk Vann) uses standardised values in recommending which factor to use. However, the origin of these factors could not be traced to Norwegian literature. Swedish publication P83 developed by the Swedish water (Svenskt Vatten) is mostly referred to. This has given rise to the need for a study based on recent water consumption in a typical household in Norway.

Smart water readers were used in this data collection procedure. This paper analyses the demand of a municipality's household consumption and has a population of less than 5000 people. Hourly and diurnal measurements was analysed for a period of 239 days of 2019. Based on the results shown, we can conclude that even though a more detailed study is needed, there is some correspondence in range between the Norwegian peak demand factors and those suggested by the Swedish publication.

Both diurnal and hourly demand factors were calculated using consumption from a Norwegian municipality. Result range for both agrees with the range used by the above-named publications. The extent of this analysis is limited with the small population of the municipality. However, the results show that the hourly demand factor reduces as the population increases.

Keywords:
Peak Demand Factor, diurnal variation, hourly peak demand, water distribution, smart water meters, consumption patterns

# Sammendrag

Det kreves et godt utformet og dimensjonert rørledningssystem for vanntransportnett for å levere den nødvendige mengde vann. Det er derfor nødvendig å estimere mengden vann som forbrukerne bruker i et bestemt område. Generelt, varierer vannforbruk i husholdninger. Variasjons-faktorer brukes til å bestemme størrelse, utforming og dimensjonering av vann- og avløpssystem. Siden det er en variasjon i forbruket, multipliseres beregningen med en maks døgnfaktor og maks timefaktor. Norsk Vann rapporter bruker standardiserte verdier for å anbefale hvilke faktorer som skal brukes. Vi kunne ikke finne hvor opprinnelig disse faktorer beregnes fra i norsk litteratur. Svensk publikasjon P83 er derfor mest referert til. Dette har gitt behovet for en studie basert på nylig vannforbruk i en typisk husholdning i Norge.

Smarte vannmålere ble brukt i denne masteroppgave. Det analyseres husholdningsforbruk i en norsk kommune som har under 5000 innbyggere. Time og døgnforbruk ble analysert for en periode på 239 dager i 2019. Basert på resultatene som er vist, kan vi konkludere med det finnes noe samsvar mellom de norske maks variasjonsfaktorene og de som anbefales av den svenske publikasjonen.

Nøkkelord:
Variasjonsfaktor, maks timefaktor, vannfordeling, vannmålere og forbruksmønstre.

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## Abbreviation

| | |
|---|---|
| fmin: | Minimum daily Peak factor |
| fmax: | Maximum daily Peak factor |
| kmin: | Minimum hourly Peak factor |
| kmax: | Maximum hourly Peak factor |
| l/p.d: | Litres per person per day. |
| NMBU: | Norwegian University of Life Sciences |
| SSB: | Statistics Norway – Norwegian bureau of Statistics |

## Glossary

| | |
|---|---|
| Average daily demand: | The total consumption for the review period divided by the number of days in the review period. |
| Consumption: | The amount of water that is recorded by the water meters in households or institutions. |
| Maximum daily demand: | The highest consumption recorded for the period on review. |
| Maximum diurnal factor: | (Also referred to as 'fmax') Consumption in the day of the year with the largest consumption over the average daily demand. |
| Minimum diurnal factor: | (Also referred to as 'fmin') Consumption in that of the day of the year with the least consumption over the average daily demand |
| Maximum hourly demand: | The consumption in the hour that the demand was highest. |
| Minimum hourly factor: | (Also referred to as 'kmin') The ratio between the lowest hourly demand and the average hourly consumption in a day. |
| Peak hourly factor: | (Also referred to as 'kmax') The ratio between the highest hourly demand per day and the average hourly consumption in a day. |
| Variations: | Difference in usage as recorded. |
| VA/Miljø-blad: | A foundation that produces guiding norms and technical solutions within the water industry. |

# 1 Introduction

Water is a vital substance for all living things. The sources that water is drawn from in Norway include lakes, groundwater, seawater, rivers and streams. The water flow and consumption for different uses determines the type, design and dimensions of the transport network including pipes for both water and wastewater. Water consumption is categorised in the following main categories:

- Water consumption in permanent households (average family in a single house).
- Consumption in households that are not used permanently. These are cottages, holiday homes and other small uses in similar categories.
- Water consumption in primary industries such as agricultural irrigation, fishing and forestry use.
- Water consumption in industries.
- Water consumption in other non-industrial commercial areas. This includes consumption in public buildings such as schools, nursing homes, swimming pools and kindergartens.
- Consumption for, among other things, cleaning and flushing of water pipes and pump stations, road cleaning, demand for firefighting, irrigation of parks and other public use.
- Leakage or non-billed water.

Consumption in private households accounted for the largest share in 2010, while leakages was the second most consumption(Myrstad et al., 2015).

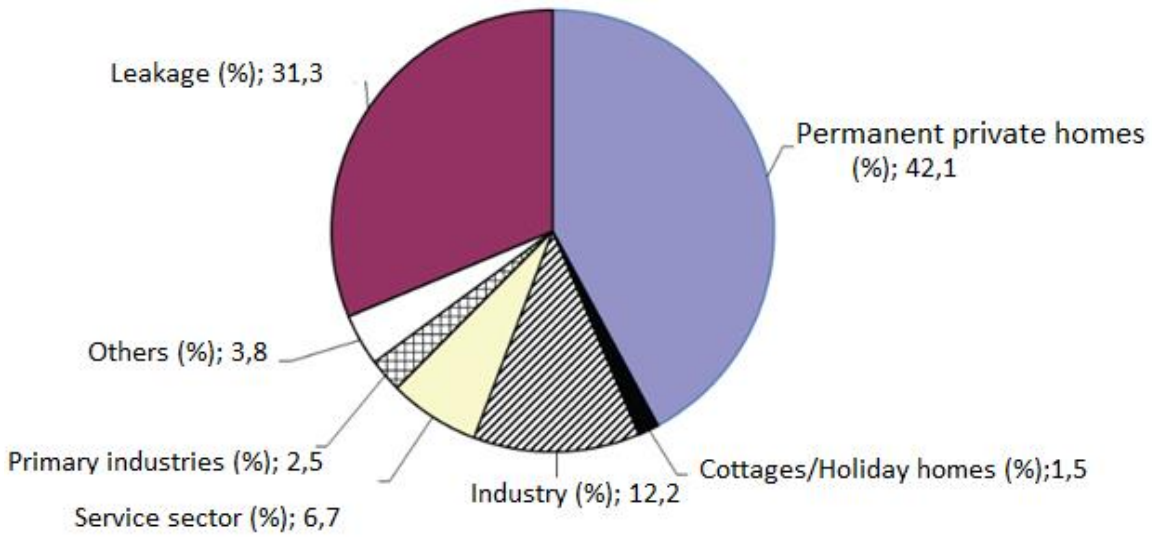


Figure 1: Water consumption: Source: Norsk Vannrapport 122 - 2015

Figure 1 shows how water consumption has been categorised in Norway. Generally, residential water is the most used category of water consumed(Guercio et al., 2001).

In Norway, like many other countries, water consumption is high in agricultural farms, but there are many other uses in private homes, schools, kindergartens, industry, power supply, outdoor life and other areas of use. There is abundance of water sources in Norway with groundwater and lakes being examples. However, Norwegians use more water than their neighbours Sweden and Denmark. The average water consumption per person per day in Norway is around 180 litres against 157 litres in Sweden and 100 litres in Denmark (SCB, 2015; Statistics, 2019; Statistisk sentralbyrå, n.d.).

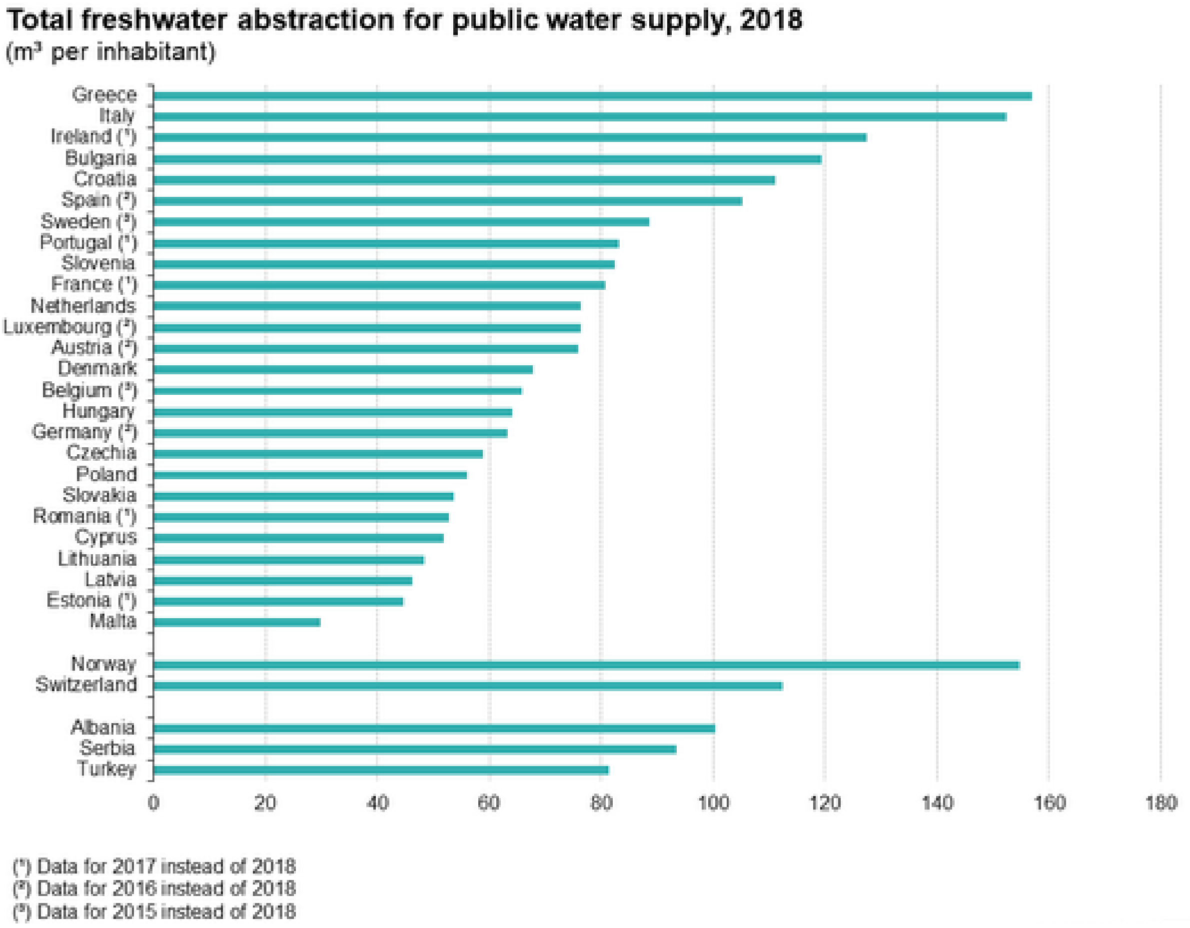


Figure 2: Total freshwater abstraction ($m^3$ per inhabitant 2018) Source: Eurostat

Norwegians use twice as much water as the Danes. Since producing water costs money and resources from the environment, it is important to understand the concept of water use and how it impacts the environment. Raw water from sources such as lakes and ponds is purified through different treatment mechanisms, then transported to households and other consumption points. Wastewater produced is then treated using complex energy intensive methods before being discharged into water bodies such as lakes or rivers. Both these processes require energy, water transport systems and chemicals.

The UN's sustainability goal number 6 is to ensure sustainable access to and management of sufficient clean water and good sanitation for all (Water and Sanitation – United Nations Sustainable Development, n.d.). Water resources must therefore be protected against undesirable events and utilized in a way that secures them for future generations. The regulations of ensuring the supply and quality of drinking water are found in the regulations on water supply, also called the drinking water regulations.

The consumption of water resources by an ever-increasing world population puts a strain on the already decreasing water level that is safe for use. Groundwater wells that are mostly used in many countries is not sustainable/reliable since this source of water is already being depleted due to excessive pumping and climate change. Other sources are also in danger of depletion due to farming, encroachment to catchment areas, urbanizations and need for more houses. The consumption and distribution of water is also strongly influenced by several factors such as geology, topography, consumption patterns among people, climate change and political decisions (Franczyk & Chang, 2009; van Zyl et al., 2007).

Design systems of water and wastewater supply are based on maximum water demand for a certain zone. Generally, water usage in private households vary according to the period. These variations can have peaks depending on different factors such as number of people in the house, the consumption pattern of people in the house as well as the time of the day the water is used. To find out which value is to the used for the peak hourly and daily variations in different municipalities, water consumption data has been studied. The peak demand factors from a municipality and the standardized figures used in the calculations is to be investigated and compared.
Most of the water infrastructure and transport systems is underground. It is therefore of utmost importance to design correct systems in order to avoid rehabilitation costs and loss of both resources and manpower in the future.

## 1.1. Goals

The main goals of this thesis are to gather insight and knowledge about the background for the municipalities that have been chosen water requires top values. Municipal technical norms and the standardized values used in the calculations are to be studied and used to find which peak factors water engineers in Norway use today in determining the water demand for an area.  To achieve the goal, the following issues were examined:

- What exactly is the basis for today's recommendations for diurnal and hourly peak factors in Norway.
- Are these recommendations based on data from Norwegian water users?
- Should these recommendations be updated with newer consumption measurements?
- Should these peak factors be differentiated to a greater extent between different types

of buildings, or should they be differentiated in other ways?

- Is it enough to use the consumption at household level with an hourly resolution or should the zone measurements also be used to determine good local variation factors?

## 1.2. Data analysis

Raw consumption data for this analysis is produced by the municipality of Hvaler in South East Norway. The municipality uses an analytics company called MAIK and the available data to be used includes both hourly consumption per household as well as the total daily consumption recorded by every water meter per day. Data received shall be complied in an Excel format. This is because Excel is a user-friendly and easily available statistical program. The data will thereafter be formatted to an acceptable format for the necessary calculations and analysis. Literature review is to be done using available reports and reviews from Norway, Sweden, Denmark and others.

## 1.3. Motivation

As far as the knowledge of the writer of this thesis is concerned, no such analysis of these variations and the factors affecting them have been carried out in Norway before on this scale. Engineers use standard values for these peak demands obtained from Swedish literature and thus the need for this analysis to be based on household consumption.

# 2 Background

Water is required for drinking, bathing, cooking, gardening, washing, leisure activities etc. in the houses. Domestic water demand depends on many aspects including social status (van Zyl et al., 2007), the habits and customs of the users (Trifunovic, 2006) and the climatic conditions (Franczyk & Chang, 2009; van Zyl et al., 2007). This variation indicates high water demand in certain areas, thus the significance in this knowledge during designing of supply pipes and infrastructure in order to avoid potential constrains on the capacity and the supply. It is therefore important to know how the demand varies during planning and managing distribution systems of residential water(Guercio et al., 2001).
It has been shown from results of a small-scall survey that water consumption in a number of houses display hourly and daily patterns(Butler, 1991). Some consumption activities such as bathing have their peaks at around 08:00. The average home recorded the first bathing at around 06:00 while little or no bathing activity occurs in the afternoon. Variations in the pattern of usage for the other appliances were classified into morning peaks which were between 06:00 and 10:00 and evening peaks between 19:00 to 23:00.

## 2.1. Consumer categories

The data used in this study is divided according to the different categories of consumers. The main consumer categories for the municipalities are residential and non-residential clients. The residential clients are however classified into private homes and holiday homes/cottages. Private homes may include single family or multiple family households.
Non-residential users include commercial buildings, offices, parks etc. The focus of this study will exclude data from non-residential subscribers. Different institutions and the consumption level to be used is presented in Table 2 below.
Water can also be categorized for use in fire extinguishing. The consumption type is stipulated by the plan and building act to an indicative amount of 20 l/s for small housing units and 50 l/s for other building types. The same recommendation is also provided in VA-Miljøblad nr. 82

## 2.2. Residential water consumption

Water usage at residential level comprises of usage at different points. Indoor water consumption can be recorded from the toilet, the kitchen tap, the shower, the washing machine, leaks and other usage.
To meet this demand, raw water from the source such as rivers or underground water is transported to a drinking water treatment plant. Here, the raw water is treated and pumped in bulk to a storage facility such as reservoirs and water towers where the municipality/water vendor distributes it through pipes to different zones and finally to the end-user pipes.

In the Norwegian water sector, different recommendations on the demand per person are given by different authorities and researchers ranging between 150 – 190 litres per person per day(Miljø Blad Nr.100, 2018; Statistisk sentralbyrå, n.d.). However, this amount is much higher where stand-alone houses have gardens and swimming pools which use more water both during watering of the gardens and filling the swimming pools(Lindholm et al., 2012). An average of 200 litres per person per day is therefore recommended when calculating for the residential demand in areas where there is no measurements that indicate otherwise(Ødegaard, 2009).

Table 1: Municipal water supply (SSB)

| | 2017 | 2018 | 2019 |
|---|---|---|---|
| Percentage of population connected to communal water supply | 84.9 | 84.8 | 84.4 |
| Percentage of water lost through leakages | 30.3 | 29.7 | 30.7 |
| Estimated amount of water per user per day [l/p.d] | 179 | 182 | 178 |

Table 1 shows references on the average consumption calculated by Statistics Norway (SSB) as reported by the different municipalities in Norway. Water consumption varies according to the type of usage. Table 2 is shows the hydraulic load of different types of institutions and areas of demand.

Table 2: Hydraulic load for institutions and business areas (Norsk Vann 2009)

| Type | Hydraulic load |
|---|---|
| Residential households | 200 l/p * d where no other information is given |
| Primary, secondary and upper secondary schools | 40 l/student * day |
| Offices | 80 l/employee * day |
| Hospital | 625 l/ bed * day |
| Nursing homes | 450 l / bed * day |
| Cabins, high standard (shower, WC, dishwasher) | 150 L/ guest * day |
| Cabins with running water, without WC | 75 l/ guest * day |
| Restaurants and coffee shops | 100 l/ sitting |
| Public swimming pools | 100 l / guest |

Socio-demographic factors also affect the water consumption patterns of a household. Households with more members are by default expected to consume more water and therefore the size and number of occupants of the household and their age groups is important in determining water distribution(Gregory & Di Leo, 2003).

## 2.3. Variations in water demand

Water distribution systems have the objectives to deliver water to every consumer at desired levels. Consumers water usage depends on the pressure, quantity and quality at any period from the municipal distribution systems. The maximum water flow for a certain zone is therefore used in the calculation of water distribution systems such as pipes. However, consumption varies from time to time and a maximum consumption for a single hour or day might be different for corresponding hour or day in a different period.

#### 2.3.1. Seasonal variation

Water demand varies from season to season for any community. The rate of consumption by individual homes reaches a maximum during the summer seasons due to usage of water for sprinkling purposes, gardening, lawn watering, swimming pool and other leisure activities(Griffin & Chang, 1991). The summer season is also the time where most families tend to deep clean their homes and the roofs thus spending more water.

#### 2.3.2. Diurnal variation and peak factor (f)

Daily variations are mostly due to the habits of people. A household where most of the people are out of the house during the day due to work, school or other reasons, would record a lower consumption during these days. The water demand is generally more during the weekends compared to weekdays. Laundry, family visits and other domestic usages are some of the factors that increase the rate of consumption during the weekends.

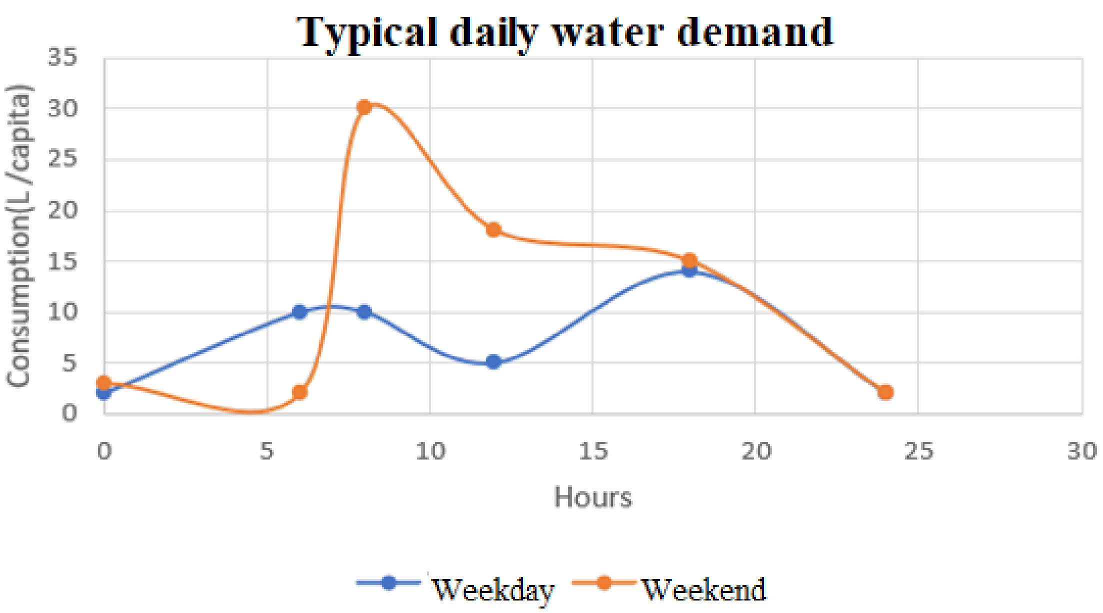


Figure 3: Hourly distribution for weekday and weekend (Buchberger & Wells, 1996)

The two types of variation factors that is used under daily water demand is calculated based in the consumption for the whole year.

Maximum daily demand factor($f_{max}$) is in the range of 1.3 for bigger waterwork systems with many users to 1.6 for smaller systems while the minimum daily demand factors range between 0.6 to 0.8 for small and large water systems respectively(Åsmund & Thorolfsson, 2001; Lindholm et al., 2012). The values for $f_{max}$ reduce with increase in the size of the supply system((Grov & Åsmund, 1970) as cited in (Åsmund & Thorolfsson, 2001).

### 2.3.3. Hourly variation and peak factor (k)

Water demand in a household also varies widely during the day. Generally, consumption of water and production of wastewater is higher when the users are at home. These periods are often early mornings before people go to work/school and then peaks reduce. A similar peak is seen in the early evenings after work/school.

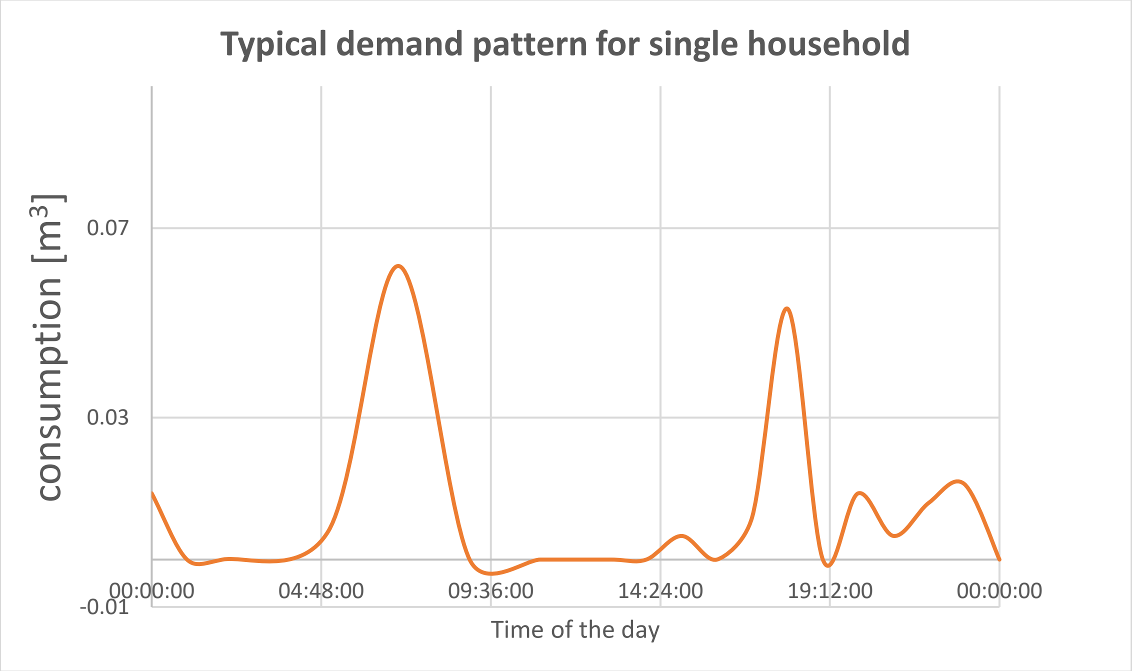


Figure 4: Consumption pattern for a random water meter in Hvaler

Other peaks could also happen just before bedtime where people take long showers. It is also common that people work in shifts and therefore the consumption pattern might differ sometimes. A typical demand pattern for a house in Hvaler is shown in Figure 4.

$k_{max}$ is the maximum hourly demand factor which is derived by dividing the hour with the highest consumption during a certain day by the average consumption of the day while $k_{min}$ is the minimum hourly factor derived by dividing the hour with the least consumption during the day by the average consumption of the day(Lindholm et al., 2012). For wastewater demand factors, the same definitions are used for wastewater produced (Lindholm, 2015).

$k_{max}$ ranges between 2-3 for small water supply systems and around 1.5 for larger ones while

$k_{min}$ values ranges from 0.3 and  to 0.7 respectively(Åsmund & Thorolfsson, 2001).

## 2.4. Determining actual water consumption

Understanding peak demands is necessity in determining the sufficient water distribution and the piping structure used to supply an area. The actual water consumption and wastewater produced should therefore be measured in every household in order to plan better for both the distribution and the treatment method of the effluent to the treatment plants. Determining the accurate water supply of a big town is difficult since any forecast for future consumptions depends on the development and rate of growth of the town and any future economic developments of an area. It is the responsibility of the municipality to then design a suitable water supply system for a certain zone with an anticipated change (mostly positive change) for the said community.

Zonal demand should be included in determining the actual water usage of an area in addition to the direct demand by homes, businesses, and industries. Municipalities use water for activities such as flashing of pipes, in pumping stations, cleaning of roads during the spring and other activities where water is used but not billed to the inhabitants of the area. The use of fire hydrants for fire extinguishing also affects the total amount of water used. Fire hydrants are usually fitted close to each area in order to provide enough pressure and supply during a fire breakout. The pressure of hydrants is normally maintained for about 4 hours. Sufficient water for the fire hydrant is a requirement in the Planning and Building Act Different recommendations are made for different house structures. A pre-accepted guidance to the building technical regulation (norwegian : Veiledning til Byggteknisk forskrift) gives the quantity of water required for a fire hydrant at 20 l/s for a single family house and 50 l/s for all other types of buildings and those close to the high density areas (Thelin & Wighus, 2016).

Leakages is defined as the difference between the delivered and debited/billed consumption. Leaks can occur in the transporting pipes or at homes. The amount of water lost varies widely in every municipality but a study from Hvaler Municipality in East Norway showed that this might be as high as 40 % (Norli, 2020). It is assumed for the purposes of this thesis that leaks occurring after the water meter reading should be included as consumption.

## 2.5. Products used in measuring water consumption

The water supply systems face higher challenges in both resources and expanded human consumption combined with an ever-changing climatic condition due to global warming. A good understanding of factors affecting residential water consumption is thereby required for any future development of these systems and conservation processes. Higher living standards and urbanization are among the factors leading to an increase in water demand. To be able to reduce and curtail the unnecessary water usage, technology development has been increasingly used by many service providers(Franczyk & Chang, 2009).

The municipalities charge the households for the consumption of water and sewage production. The calculation for the amount of water used and the sewage produced is determined pursuant to Act no. 17 of 1974 on municipal fees. The municipalities are not allowed to charge an amount that exceeds the necessary costs incurred by the municipality relating to the operating, maintenance and other costs. The user of a permanent structure is responsible for these costs based on an annual measured quantity. By using these solutions, the municipalities reduce the Non-Revenue water thus ensuring a steady water supply.
Water metering has evolved in the past due to the need for consumption and smart analysis of water resources.  Restrictions on water consumption due to unpredictable climatic conditions, the need for reporting to authorities on usage pattens and management, need to reduce wastage, leakages and costs are some of the reasons why technology is being used in monitoring water networks.


Figure 5: Smart Water flowIQ 2100 (Kamstrup)

Smart digital water products such as water meters and automatic meter readers are being used more and more in Norway. According to the Pollution Control Regulations (Lovdata, 2004), the municipality may require that any usage be measured using an approved type of water meter. However, this is so far not a requirement, but many municipalities are turning to using this type of measurement instead of the normal charging through which an average determination consumption based is calculated for the house. With smart meters, the user gets to control his/her own usage, which in turn means having control over own expenses.

Water meters are also used in order to reduce costs and increase optimal drift. It also helps in planning infrastructure and new development areas as the average can be taken from a previous known area with approximately the same number of people, geography and usage patterns.

Smart water meters collect data from the users through both handheld or fixed devices or long-distance networks, then the data is sent to the analysing company where tit is stored, analysed and sent to the billing department of the municipality.

There are many different types of water meters in the Norwegian market. Figure 5 is an example of such digital water meter widely used in Norway.

For water distributors, the advantages of using smart water meters include:

- Detailing the amount of water distributed to every consumer.
- Determine water pressure and distribution in specific zones.
- Reduction in unplanned usage and leakages in the distribution network.
- Discover water scarcity in the zones.

The Norwegian Food Safety Authority (Norwegian:  Mattilsynet) is responsible for publishing the records of the total yearly water supplied and consumed, the number of permanent residents in every household and the percentage of water used in household consumption. This report is collected once a year as reported by the owners of the water work plants. However, this data might be insufficient and a thorough and detailed report should be prepared. By using digital meters, the service providers get a better overview in reporting the correct amounts consumed.

## 2.6. Calculation of water demand

The design and dimensions of pipes in water/wastewater transport systems are determined based on the highest flow that occurs. The flow rate for any fluid flowing through the pipe is also dependent on the velocity of the fluid and the area of the pipe which the fluid is moving through. Assuming there are minimal leaks in the pipes, the amount of water from the main pipelines to the meters in the houses can be conserved, with no accumulation or depletion. Considering the law of fluid dynamics in the conservation of mass, the flow rate is dependent on the velocity of the water and the area of the pipe. The following can be used in designing the amount of water and the pipes needed for a zone (1).

$$Q = \nu * A \tag{1}$$

where:

$Q = \text{flow rate at any given time} \left(\frac{m^3}{s}\right)$

$\nu = \text{velocity of the fluid (m/s)}$

$A = \text{area of the pipes } (m^2)$

The per-capita demand including domestic, industrial and commercial use can be represented mathematically by:

$$q = \frac{\text{Total yearly water requirement of the city}}{365 \text{ days } * \text{ population of the city}} \text{ [l]} \tag{2}$$

The dimensioned water demand for a certain area can be calculated by the following formula:

$$q_{demand} = \frac{q_{person} * f_{max} * k_{max} * P_e}{24\frac{hrs}{day} * 3600\frac{s}{hr}} \text{ [ l/s ]} \tag{3}$$

where:

$q_{person}$ is the average daily consumer per person

$f_{max}$ is the maximum duinal variation factor

$k_{max}$ is the maximum hourly variation factor

$P_e$ is an approximation of the number of people the water will be supplied to ( $> 200$ pe)

From the formula above, we see how these variation factors are important in determining the water demand of a certain location. However, this demand does not remain uniform and varies throughout the year.
Finally, the demand is also affected by other factors that are not determined by the household consumption. These factors are represented as shown in (4).

$$Q_{max} = q_{demand} + Q_{leakage} + Q_{fire\ demand} + q_{industry} \quad (4)$$

From this mathematical formula, it is just as important to know how much the demand is as it is to know how much water is lost through leakages and unbilled water consumption.
Water losses ($Q_{leakage}$) vary for different municipalities. These losses can include but not limited to:

- Unbilled consumption
- Leakages in the distribution pipes
- Incorrect billing
- Lack of metered systems.

A report on the percentage of leaked water in Hvaler municipality in East Norway found that this could amount to be as high as 40 % of the water distributed in 2019 (Norli, 2020). However, the real percentage might be much higher since the results of this report was produced from the analysis of consumption of a short period of time. Most of the leakage in private homes and commercial properties occur in the toilet. However, it is difficult to estimate the specific percentage for a whole municipality or a given zone and thus an estimation of the assumed leakage is given in most cases.
Water losses are therefore not included in this study since the focus is the consumption at household level/user-end systems.

Water supply systems must also fulfil the demands for use during fire extinguishing and services provided by the fire department. Fire hydrants use large amounts of water at high slow rates and thus must be determined in the designing of water transport systems. The dimensions of the pipes and the pressure of water pumps are therefore expected to account for a combination of these different demands.

## 2.7. Literature review from other countries

In examining the hourly and diurnal patterns for typical households, it was found that the volume of water used peaked when the occupants of the households were at home and subsequently lowered during absent hours and sleeping times due to the frequency of usage, the duration each time and appliance is in use among other factors(Blokker et al., 2010). From other research reviews, these peak demands are noted in the early mornings and late evenings (Gato-Trinidad & Gan, 2014).

In the Swedish literature, the maximum daily factor has been found to be between 1.4 and 2.05 for a population of 5000 users.

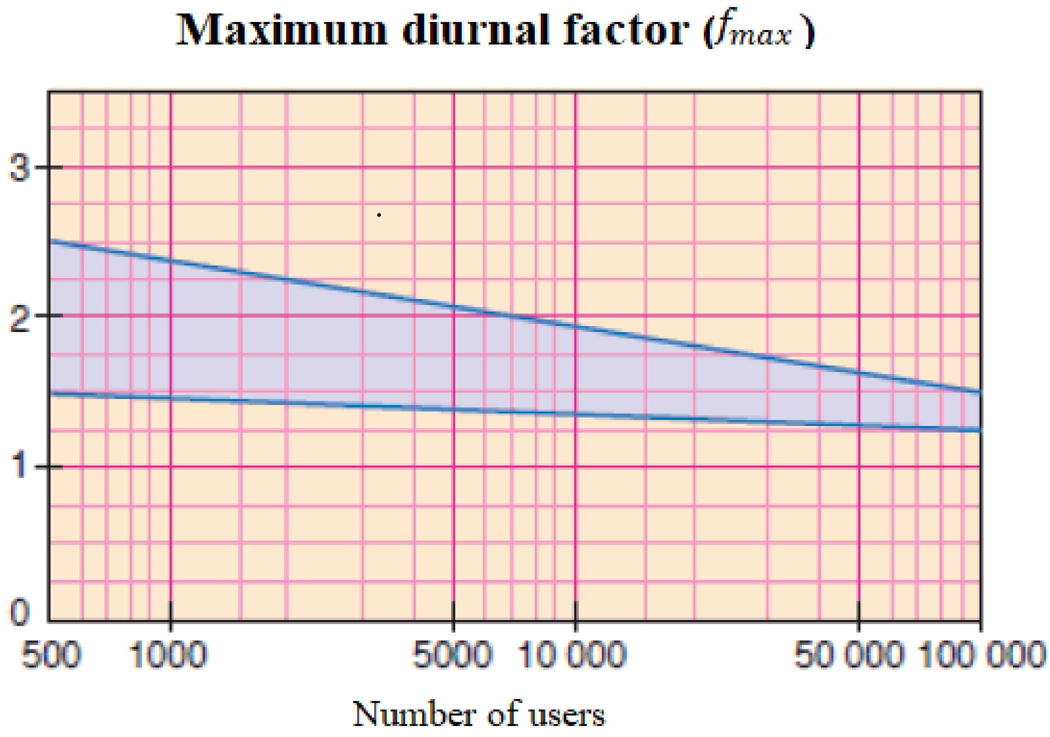


Figure 6: Peak diurnal factor (Svensk Vatten P83 in Norsk Vann-Rapport 193-2012)

The Swedish water publication P83 gives the Figure 6 as an illustration for maximum diurnal factor(Svensk Vatten p83, 2001, as cited by (Lindholm et al., 2012). based on the same definitions in the Norwegian water publication. The minimum daily demand factor lies between 0.6 to 0.8 for small and very big waterwork systems respectively while fmax lies between 1.3 to 1.6 for bigger and smaller systems respectively. However, some later publications have recommended that these numbers should be substituted by recently done analysis as some numbers might be different from this recommendation (Genomg, 2019; Ullén & Abdu, 2014).

A similar illustration is also shown in Figure 7 showing the peak hour demand factor. In Norway, these two illustrations are used widely (Genomg, 2019) in determining the demand variation factors against the population where the residential water is to be supplied to.

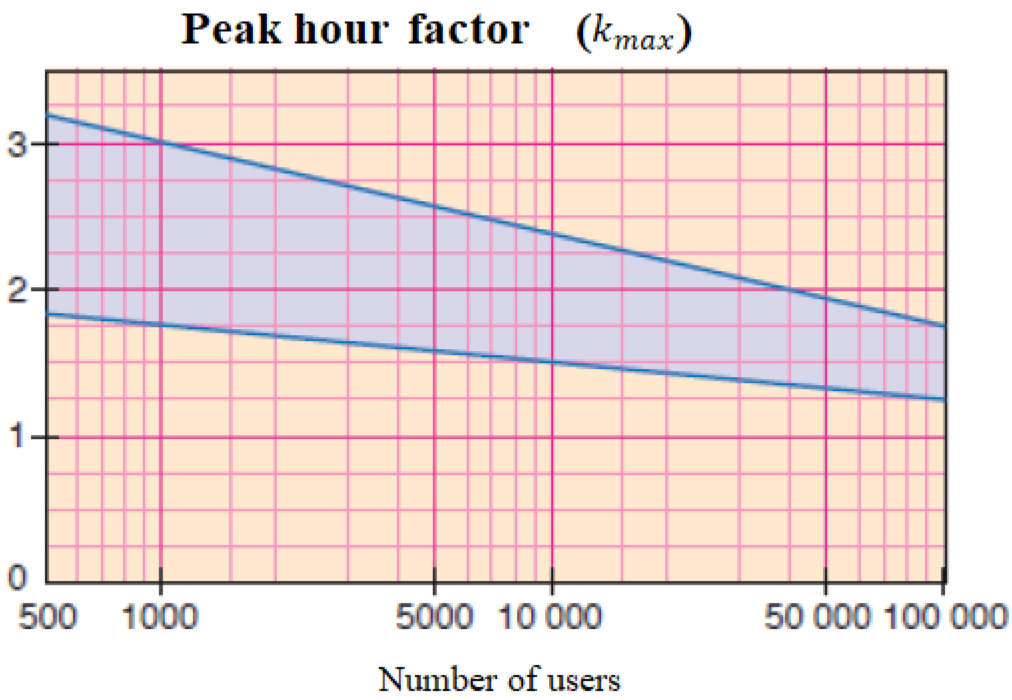


Figure 7: Peak hourly factor (Svensk Vatten P83 in Norsk Vann-Rapport 193-2012)

A study from Italy (Balacco et al., 2017) documents that variation factors for water consumption are calculated based on the number of people in the consumption area. In Egypt, variation factors are calculated according to litres of wastewater consumed (Imam & Elnakar, 2014).

Several other studies have been undertaken to understand the different peak demand factors. Gato et al. (Gato-Trinidad & Gan, 2014) carried out an analysis on seven suburbs in Melbourne, Australia based on a 5-min interval which shows to give more accurate results. Balacco et.al investigated the demand of 128 towns in Southern Italy, concluding that the number of users can be used as a function when determining the peak factors (Balacco et al., 2017).

The peaking factor (k) is also expressed as a dimensionless factor as a ratio of the maximum flow ($Q_{max}$) of water received in a household during a certain period of the day against the daily average flow ($Q_{average}$).

$$k = \frac{Q_{max}}{Q_{average}} \qquad (5)$$

The literature review also shows that this factor is interpreted as a probabilistic function. The maximum flow is studied, and the peak factor are derived from an estimation of the instantaneous maximum rate of flow(Scheepers, 2012).
A simple calculation describing the peak factor during a given hour is given as the ratio between the demand for that particular hour and the average demand for an observed period (Trifunovic, 2006). It has also been found that the peak factor is dependent on the number of consumers. Peak factor levels decrease with the increase of consumers(Trifunovic, 2006).

Other research papers approach the determining water demand using two methods:

1. Modelling of water usage at a whole system.
2. End-user water consumption at an individual level/meter

The latter is proposed as a Poisson Rectangular Pulse (PRP) model usually a stochastic process determined from instantaneous residential water demands. This model uses three other characteristics of elementary use, namely; intensity, duration and frequency(Buchberger & Wells, 1996; Guercio et al., 2001). Data loggers/sensors in four single-family households in the city of Milford, Ohio, transmitted water demand at an interval of 1 s, giving a 0.5 L/min and retrieved weekly and converted into rectangular pulse. Leaks were not included in this model(Buchberger & Wells, 1996).
(Gato-Trinidad & Gan, 2014) has also analysed the correlation between the maximum peaking factors with the population using different formulas. Gato concludes that the peaking factor decreases with increase in population.

# 3 Method

In this section, the method and analysis type will be discussed. The determination of the maximum water demand is an integral part in the design of water supply systems. Since water usage is not constant during the day, the peak hourly demand is to be determined. The water consumption data used in this paper is from the household level. The main objective of collecting this data is to determine the water consumption as collected on an hourly basis. The data for registered water demand patterns for a zone will be used to calculate the variation values based on the durations monitored.

## 3.1. Study area

The area of study is called Hvaler, a municipality in the county of Viken in Eastern Norway with a population of 4694 and an expected increase to 5493 in 2030(Kommunefakta Hvaler - SSB, n.d.). The household occupancy is 2.08 inhabitants per household according to the above report. This municipality is known for its many Islands and is connected by a network of pipelines that transport water from one island to another. The drinking water for the municipality is supplied by Fredrikstad Water (FREVAR KF) from the neighbouring Fredrikstad municipality. The raw water is received from Isnesfjord and Vestvannet lake which is tributary to Glomma river. The estimated average consumption per connected user per day is 205 l/pe per day in 2019 (Statistisk sentralbyrå, n.d.). 54 % of the water intended for Hvaler was used in private households in 2019 while 26 % was used in cabins and holiday homes.

Hvaler is also one of the country’s leading municipalities in terms of the coverage of remote read/ digital smart meters with almost 100 % coverage in smart meters connectivity(Hvaler - Ny Vannmåler - Smart Vann, n.d.). This project has been used since 2017 and the consumption is monitored using alarms (Hvaler - Ny Vannmåler - Smart Vann, n.d.). The solution also makes it possible for the municipality to alert the consumers of any unrealistic consumption or unplanned incidents in the water system. By using this system, the individual client gets the basic understanding of the total consumption which in turn helps reduce invoicing conflicts.

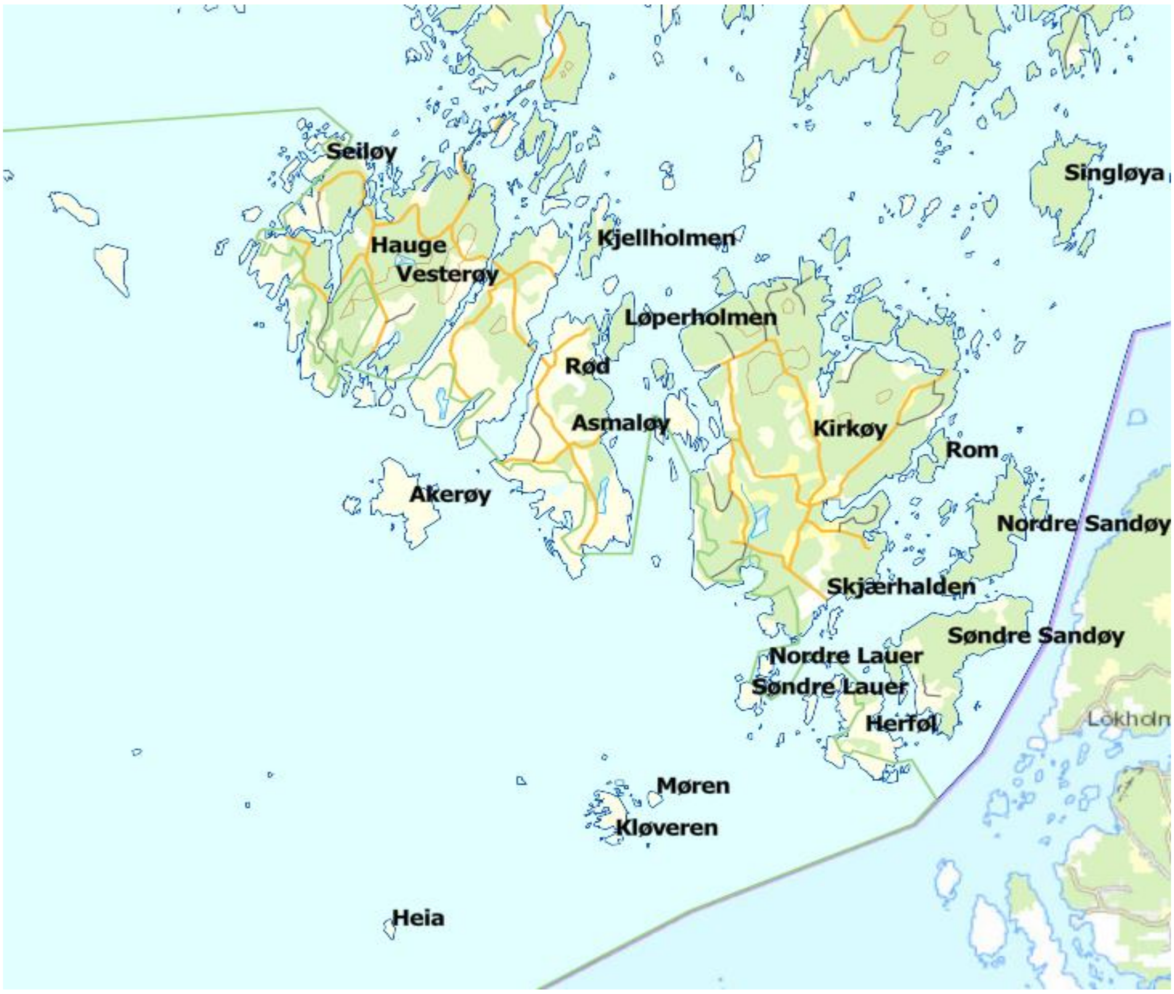


Figure 8: The municipality of Hvaler with its archipelago of Islands (Geonorge SePlan)

With the pipeline network of this municipality, it is important to design water and wastewater supply systems based on the different factors discussed in this thesis work.

## 3.2. Data from the smart meters

In Hvaler, the use of smart water meters for both residential and holiday homes is nearly at 100 percent coverage. These meters are installed and networked directly to the municipalities' remote reading systems. With this network, the municipality is able to identify leaks using alarms while at the same time find abnormalities in the distribution network by recording usage per zone.

From the municipality of Hvaler, the data used is from over 5000 different smart meters connected to the municipality's central system. However, since this analysis is only based on household consumption, a maximum of 1858 of these meters were used in this analysis. The water meter type used in this municipality is Multical 21 produced by Kamstrup as shown in Figure 5, which sends crypted communication to the municipal systems thus making it hard for unauthorised readings. It is the users' responsibility to install the smart meters and thus other types of meters can also be found. However, these meters relay the same type of information to the central control systems.

The data received and used for this thesis project is real water consumption data from the household units in the above municipality. The consumption is captured every hour by the smart meters. These readings are however uploaded to the department's servers once every 24 hours. Thereafter, the engineers and data analysts of the municipality or their representatives can process this information.

## 3.3. Period of the year

The water demand data analysed in this section is an hourly-based consumption data collected once every hour over a period of 239 days, between the 8$^{th}$ of May 2019 and 01$^{st}$ of January 2020. There were two different datasets used in this thesis. One includes households' consumption on an hourly basis for 24 hours daily.

The other one is the total diurnal consumption for each meter read. The consumption is in cubic meters for both datasets.

## 3.4. Data validation

Data validation was done to clean up some unnecessary consumption. Fine tuning and checks were done in order to use only those meters reading that were within demand pattern of the user. An example is in the scenario where there is an extremely high usage/value for a short period (an hour or two) while the rest of the hours in the week are within the same range, such reading would be regarded as unacceptable and thus the reading was not used. Figure 9 shows the simple process used in the validation process.

To ensure that the data was of the correct type, the worksheet was converted in a format with

the right data type such as integers, float and string formats applied.
Data validation and verification of the results produced is also another important aspect of the calculations in this thesis report. All calculations done will be validated by comparing the results to previously done reports.

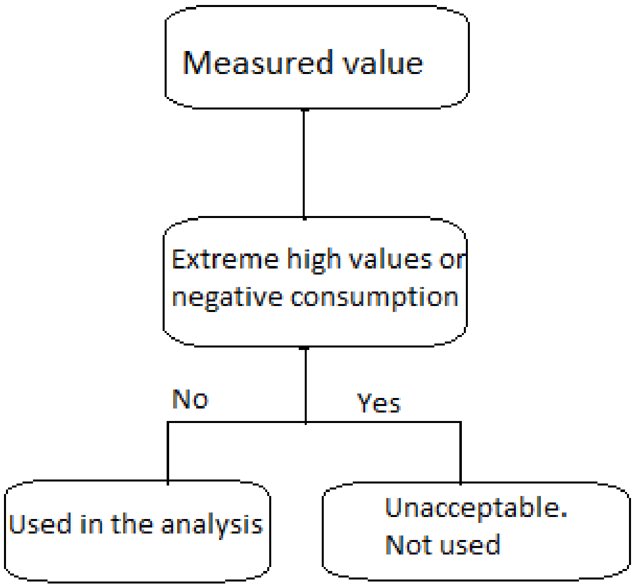


Figure 9: Data validation process

## 3.5. Data processing and analysis

The data received from the municipality included unique meter numbers for every household, the date of consumption, unique identity numbers and the demand values for every water meter. Microsoft Excel was used to construct, analyse and report the findings of this project. The overall size of the data received was too large for Microsoft Excel and thereby other programs such as Notepad was used to convert the size of the file received. The limitations arising from the user-friendly and readily available spreadsheet program Microsoft Excel included the complexity and the size of the data to be analysed. Computation was to be carried out using data for the whole year but was limited by Microsoft Excel worksheet ability of only a maximum number of rows. However, data of water consumption for short durations were carried out. 239 days was therefore computed instead of 365 days. Data was also sorted using the filtering process in order to remove any duplicate meter readings.

Another software program used is the Feature Manipulation Engine (FME) provided by safe software. FME is a data integration software that combines information by reading data from multiple sources and types, transform the data to the users' desired format, processing and then creates an output in a format that suits the user.

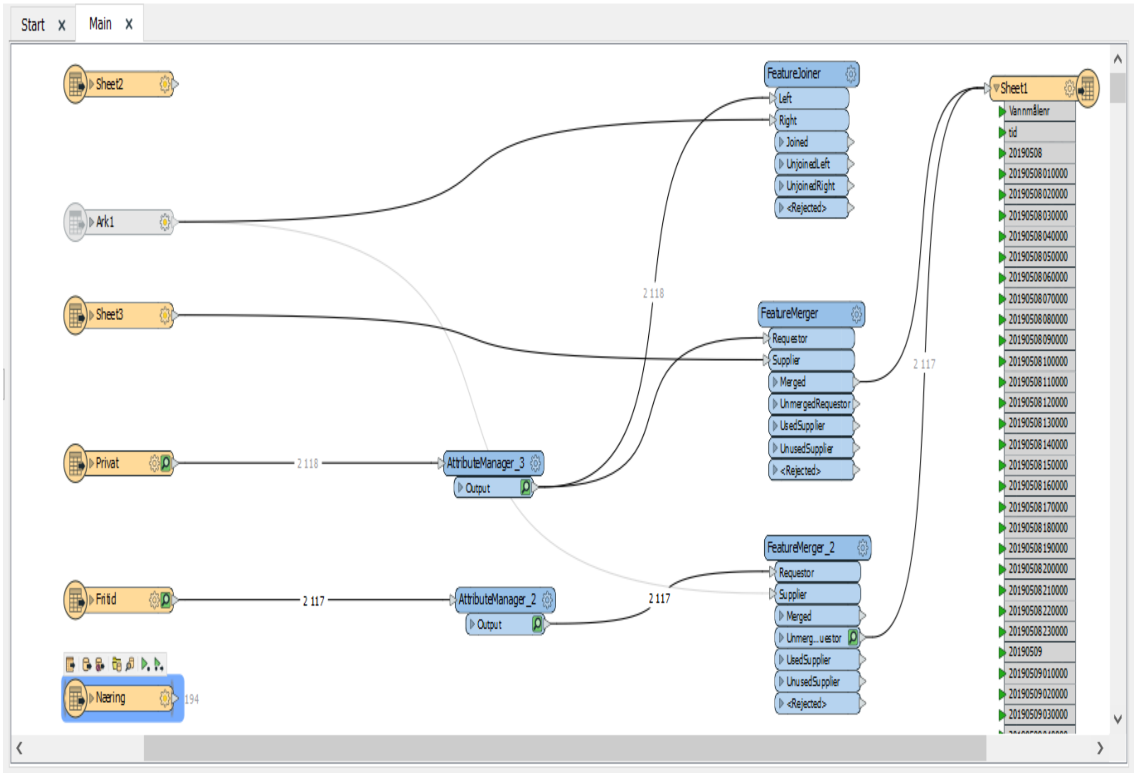


Figure 10: Merger feature using FME

FME was used to merge the different lists of building types from the different Excel worksheets. An attribute was created to convert a list to the same data format as the main file. Then a merger feature was used to join these two lists together to the corresponding correct consumption data. A writer link is then used to produce the different formatted workbook and saved as an Excel worksheet. A screenshot from that procedure is shown in Figure 10.
The version used was FME workbench 2021.0.2

## 3.6. Calculation method

In this section, the calculation type will be discussed. There were several calculations done to find the maximum daily factor and peak hour demand. Every water meter represents a household and as noted in section 3.1, every household has an average of 2.08 people. The water demand data profile provided by the municipality of Hvaler were used. Spreadsheets using Excel were created calculating the peak factors against the mean consumption.

### 3.6.1. Diurnal factor

To find the maximum daily factor. The consumption of each day was compiled. The consumption was checked to see if there were any negative values or extremely high values that is not consistent with the daily patterns of consumption for that household. Extreme values could arise from a failure by the system due to a power outage, freezing of the meter functions or even leakages. Since it is not easy to ascertain the exact cause and the appropriate consumption therein, these values were set aside and not used in the calculation. A schematic is shown in section 3.4 above.

The acceptable values are the used for the rest of the calculation using the following steps:

1. The sum of the total consumption for the whole period from the 08th of May 2019 to 01st of January 2020 was calculated. The total days in the period was thus 239 days.
2. The mean average consumption was determined by dividing the total consumption over the total days in the period.

$$Q_{\text{d mean}} = \frac{Q_{\text{total period}}}{239} \qquad [\frac{m^3}{\text{day}}] \tag{6}$$

3. The day with the maximum ($Q_{\text{d max}}$) and the day with the least usage ($Q_{\text{d min}}$)were then obtained.
4. The peak diurnal factor ($f_{max}$)was then calculated using the formula (7) below.

$$f_{max} = \frac{Q_{\text{d max}}}{Q_{\text{d mean}}} \tag{7}$$

While $f_{min}$ was calculated using (8) below.

$$f_{min} = \frac{Q_{d\,min}}{Q_{d\,mean}} \tag{8}$$

5. For comparison reason, the diurnal demand factors for different number of water meters were complied. These were:
   a. 100 water meters
   b. 200 water meters
   c. 500 water meters
   d. 1000 water meters
   e. 1858 water meter (all the available water meters used in this work)

Every water meter represents a household and should therefore be multiplied by the number per inhabitants per household, in this case 2.08 for Hvaler, to get the population represented by these water meters.

### 3.6.2. Hourly demand factor

To find the hour demand factors, water demand data at 1-hour intervals over the period of 239 days has been analysed for 1858 household water meters. The following steps were followed:

1. The total demand per hour for all the households were then calculated by adding consumption for every hour.
2. Thereafter, the total consumption per day was calculated separately for all the 239 days.
3. The mean average consumption per hour was then found by dividing the total consumption per hour by the total consumption for the 24 hours of the day.

$$Q_{hour\ average} = \frac{Q_{total\ day}}{24\ hours} \qquad [\frac{m^3}{hour}] \tag{9}$$

4. The hour with the highest consumption for the day was then determined and was used to calculate the maximum hourly demand factor (10) while the hour with the lowest consumption for the day was used in calculating the minimum hourly demand factor (11).

(10)

$$k_{max} = \frac{Q_{hour\ max}}{\mathrm{Q}_{\mathrm{hour\ meab}}}$$

$$k_{min} = \frac{\mathrm{Q}_{\mathrm{hour}\ min}}{\mathrm{Q}_{\mathrm{hour\ mean}}} \tag{11}$$

5. The maximum hourly factor for each hour was then calculated by dividing the maximum in step 4 above by the average consumption as found in step 3 above. The corresponding calculation was done for the minimum demand factor.
6. Two different calculations were carried out in order to find which hourly demand factors should be recommended. One calculation was to find the absolute maximum/minimum of the result found in step 5 above while the other calculation was to use the average of all the results found in step 5.

Calculations were done in accordance with the definitions of peak hour demand factor (See section 0) and given by Norwegian Water (Lindholm et al., 2012). Peak hourly factors vary between 1.6 to 2.6 for a population of 3900 people from the reading in Figure 7.

# 4 Results and discussion

In this section, the results from the analysis will be produced and discussed. Results for both the peak diurnal demand and minimum daily demand will be analysed and compared to results from the literature review.

## 4.1. Values for diurnal variations.

After fine turning the data during validation, the data was compiled and the processes in section 0 were performed. Total consumption for different water meters were calculated.

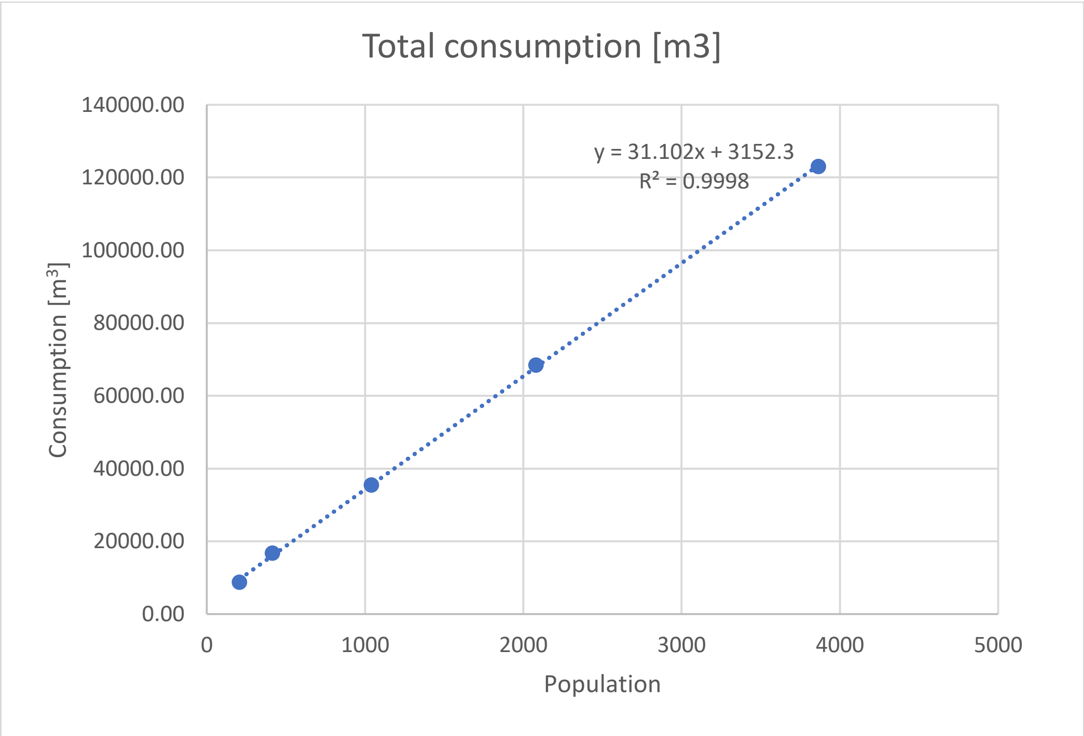


Figure 11 Total consumption for household in the study period

The total consumption for the different water meters were calculated. Total consumption for the 239 days with 1859 units was at 123058 cubic meters. Consumption was also recorded for the other quantity of water meters as mentioned in section 3.6 above.

To find the population of the people, the number of meters is to be multiplied by the average inhabitants in Hvaler in 2019.
This would mean for example 100 water meters represents 100 * 2.08 people = 208.

*Table 3: Comparison of results found for different number of water meters*

| **Water meters** | **100** | **200** | **500** | **1000** | **1859** |
|---|---|---|---|---|---|
| Population | 208 | 416 | 1040 | 2080 | 3866 |
| Total consumption [$m^3$] for 239 days | 8715.80 | 16760.33 | 35482.37 | 68432.47 | 123058.33 |

The following results were found for the diurnal demand factors for the different population sizes.

*Table 4:* $f_{min}$ *and* $f_{max}$

| **Diurnal factor** | **Population** | | | | |
|---|---|---|---|---|---|
| | **208** | **416** | **1040** | **2080** | **3866** |
| $f_{min}$ | 0.70 | 0.68 | 0.69 | 0.71 | 0.72 |
| $f_{max}$ | 6.31 | 4.57 | 3.04 | 2.19 | 1.84 |

The diurnal demand factors found for the number of occurrences (239 days) are shown in Table 4.
We see the general characteristics showing that there is an increase in the minimum diurnal demand factor with increase in population. Compared to the results of previous studies which suggest that the minimum diurnal factors lie between 0.6 to 0.8 for small and bigger supply systems respectively, this results shown in the table above is in agreement(Lindholm et al., 2012).

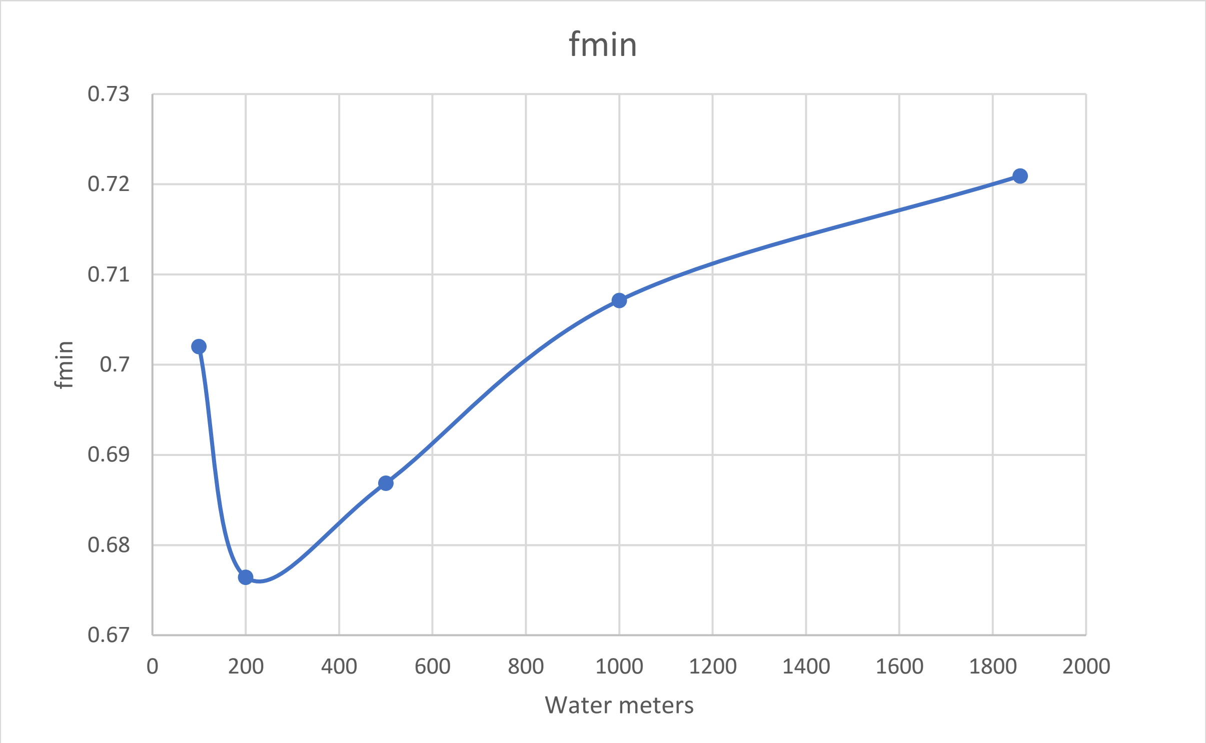


Figure 12 Minimum daily demand factor

The minimum diurnal factor, fmin, for the household in the study is shown in Figure 12 showing a range of water meters and the corresponding minimum diurnal demand factor. The range for fmin obtained by the analysis is between 0.67 to 0.72. Comparing this to the values in the literature review of section 3.6 from the Swedish Water, the result of this analysis is withing the range.

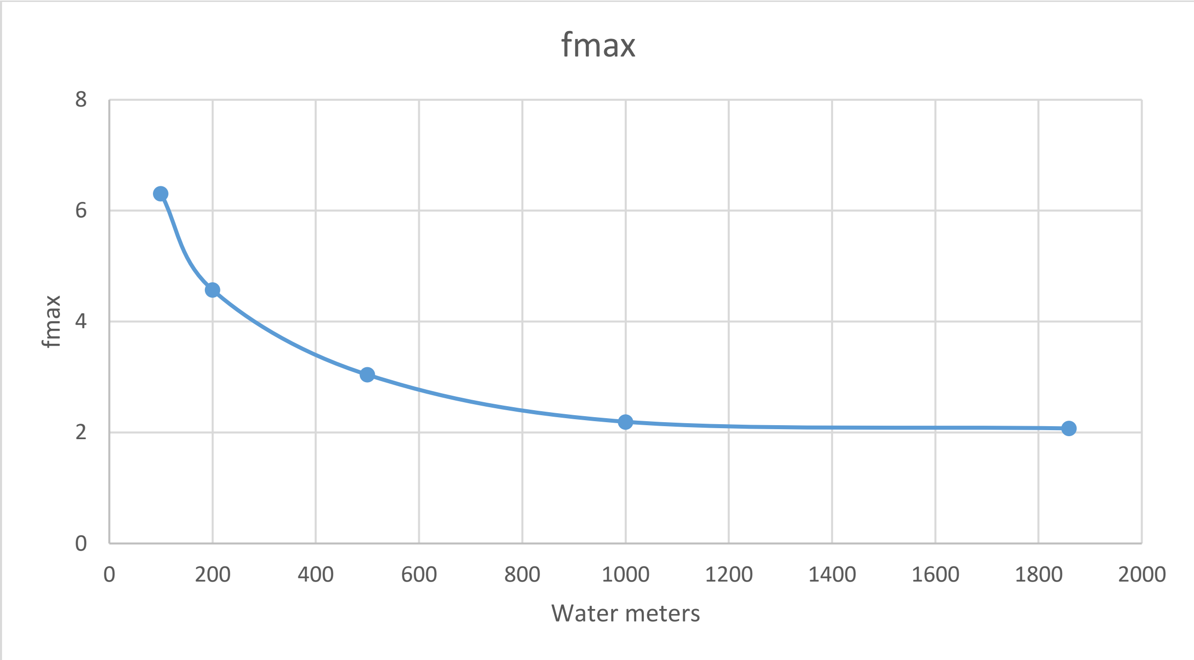


Figure 13 Peak daily demand factor

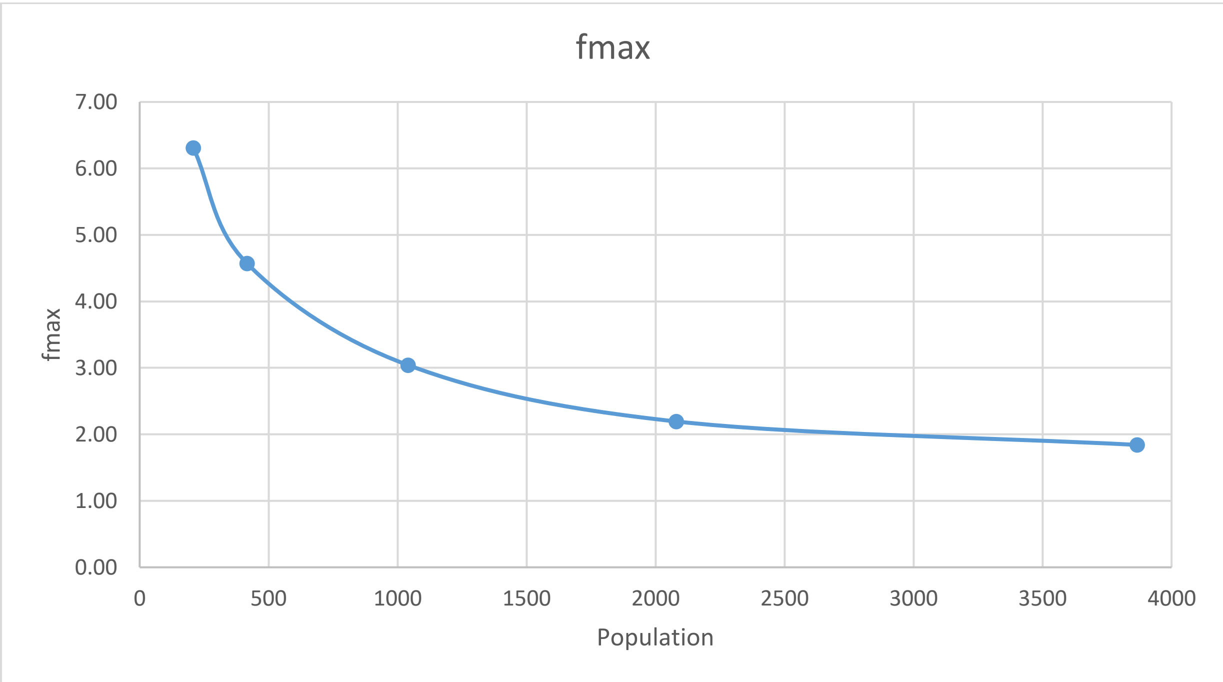


Figure 14 Correlation between peak diurnal demand factor and population

The peak daily demand for household was also obtained for different water meters in Hvaler. This is presented in Figure 13 and the fmax against the population is shown in Figure 14 above.

From the values above, we see that fmax decreases with an increase in population. This finding is in agreement with past reviews such as (Åsmund & Thorolfsson, 2001). It was not clear in this analysis whether this decrease is true in all population range.

In the literature review, fmax varies and is given as a range between 1.3 to 1.6 for big and smaller systems respectively. The results in this research is compatible with the results found in the Swedish literature (Swedish water)(Genomg, 2019; Ullén & Abdu, 2014).(Genomg, 2019). However, the scope of their study was done using larger cities. The scope of this work was based on a small supply system of less than 4000 people. Lower population seem to have a larger fmax.

A comparison between the population and the two diurnal factors and the results obtained was also carried out and the result is shown in Figure 15. The results show the maximum diurnal demand factor decreasing with the increase in population.

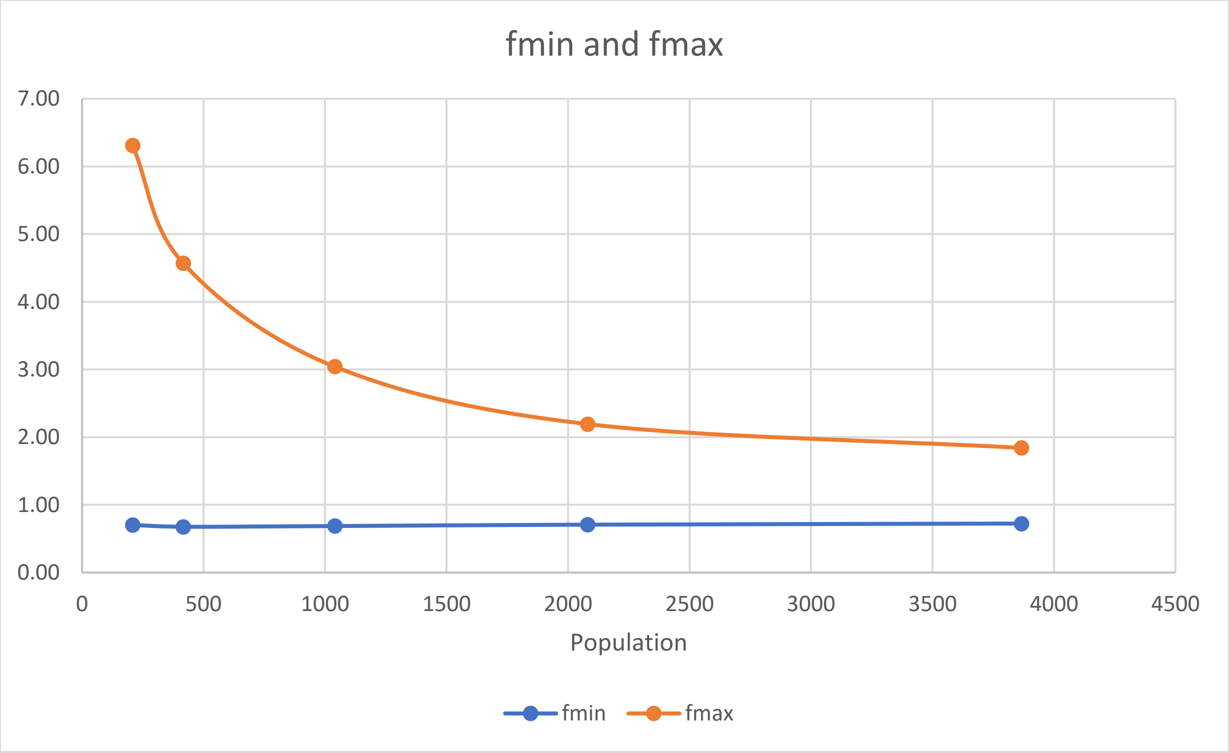


Figure 15 Max and minimum diurnal factors

Consumption was also compared between 2 different households for the entire period on review. This was to investigate if there was a large difference in the consumption of houses in the same municipality.

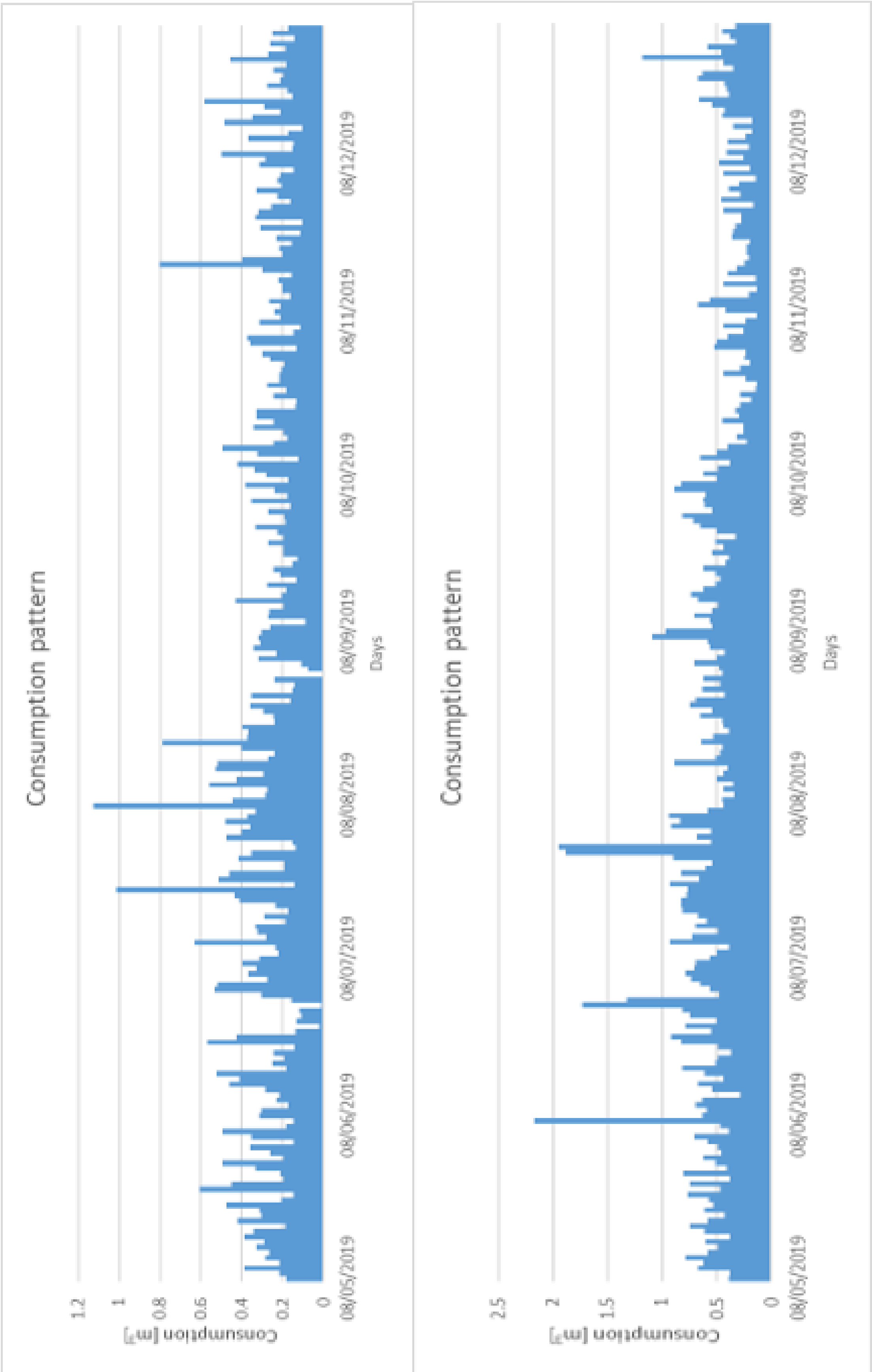


Figure 16 Comparison of daily demands for 2 houses

Figure 16 shows the amount of water spent by 2 randomly chosen households for the period under study. Some few spikes in the consumption are seen and a closer look of some of these days show that they either fall on a Friday, the weekend or on a day where people are free from work. One of these spikes happens on the 07th of June which is a Friday while the other happens on a Saturday. Reasons for the increased consumption could be that since it was in the summer holiday months, there could have been filling up the swimming pool if there was one in the said household. Other guesses could be thorough cleaning of the houses, watering the garden among many other guesses. The last one is on the 26th of December, a day the whole family gathers after Christmas. As discussed earlier in section 2.3, it is expected that there will be this type of increase in the use of water in this season and days.

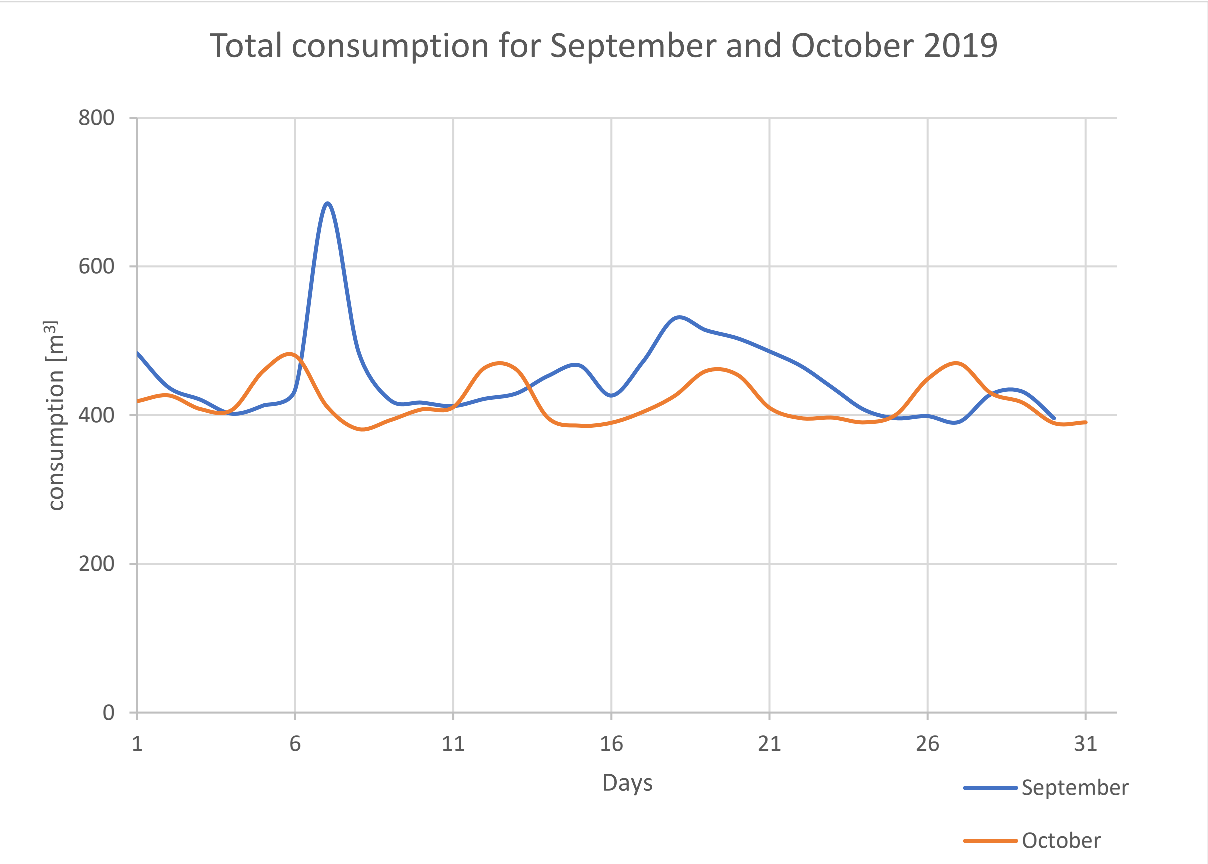


Figure 17: Daily demand pattern for September and October 2019

Total demand for all the households in the two months of September and October was also analysed and the result is represented in the pattern as shown in Figure 17. The consumption generally ranged between 400 and 500 cubic meters [$m^3$] daily for both months. However, a few differences are noticeably seen in the month of September. From the data and for the number of households being studies, the total demand for the month of September was about

4 percent than in October. Possible explanations could be that people still spend time outdoors in September, for example cleaning cars in preparation for the winter season, since it is autumn while October is generally colder.

## 4.2. Values for hourly variations

### 4.2.1. Peak hourly demand factor $k_{max}$

Two calculations were carried out to find the peak hourly demand factor as mentioned in section 3.6.2. The absolute $k_{max}$ is the largest possible value in the results found for the hourly demand variation factors for every hour given while the average $k_{max}$ is the mean maximum of this demand factor.

*Table 5: $k_{max}$values*

| | Population | | | | |
|---|---|---|---|---|---|
| | **208** | **416** | **1040** | **2080** | **3866** |
| Absolute $k_{max}$ | 3.61 | 2.65 | 2.24 | 5.11 | 3.43 |
| Average $k_{max}$ | 2.25 | 1.92 | 1.73 | 1.69 | 1.68 |

It is not clear from the literature review which $k_{max}$ is used or which one is the correct one to use. However, from Table 5 the absolute $k_{max}$ gives larger values than what is mentioned in the literature review.

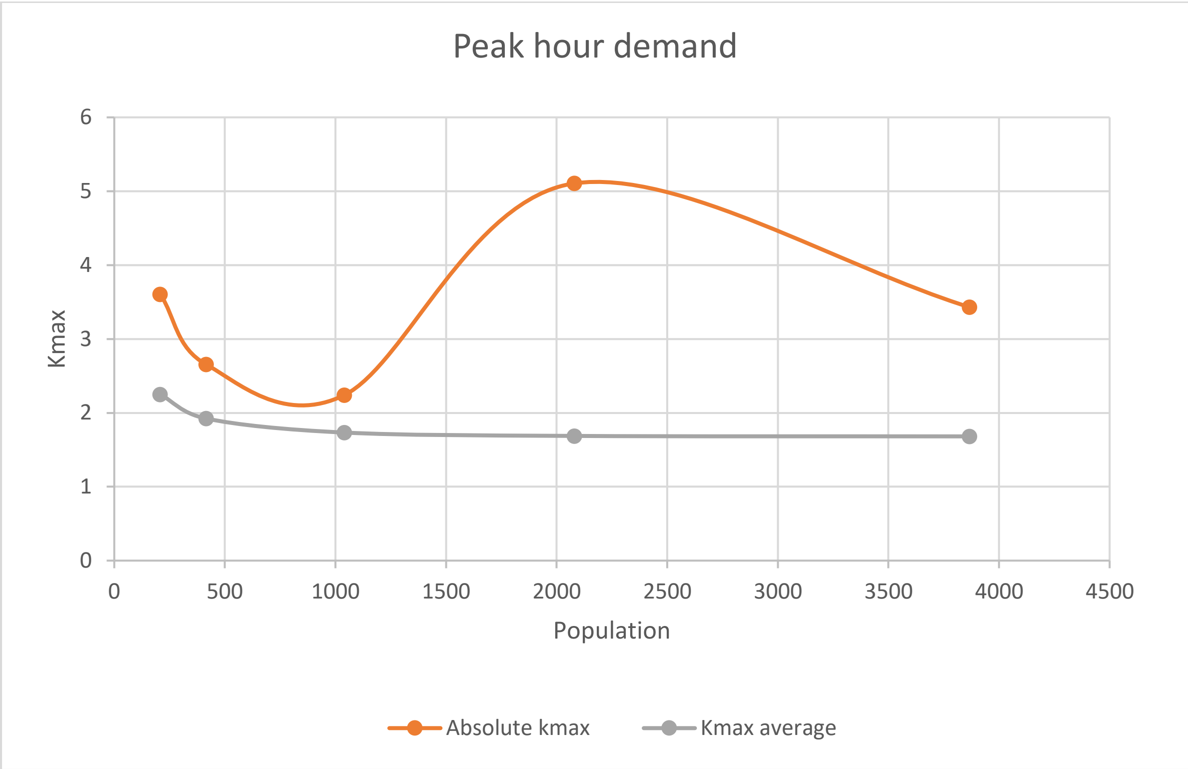


Figure 18 Comparison between absolute and average kmax

There is also not consistency in the values of the absolute kmax since these values fall then increase without any logical explanation. As shown in Figure 18, the absolute kmax does not decrease with increase in population as has been found in previous studies. We can therefore conclude that the correct method of use of kmax is by using the average kmax.

On the other hand, the average kmax decreases with increase in population. This trend is similar to both the graph produced by Swedish Water and recommendations in the literature review in section 2.7. The correlation between the peak demand factor and the population is given in Figure 19 below. Since this is a system supplying a small number of users, kmax does not reduce much.

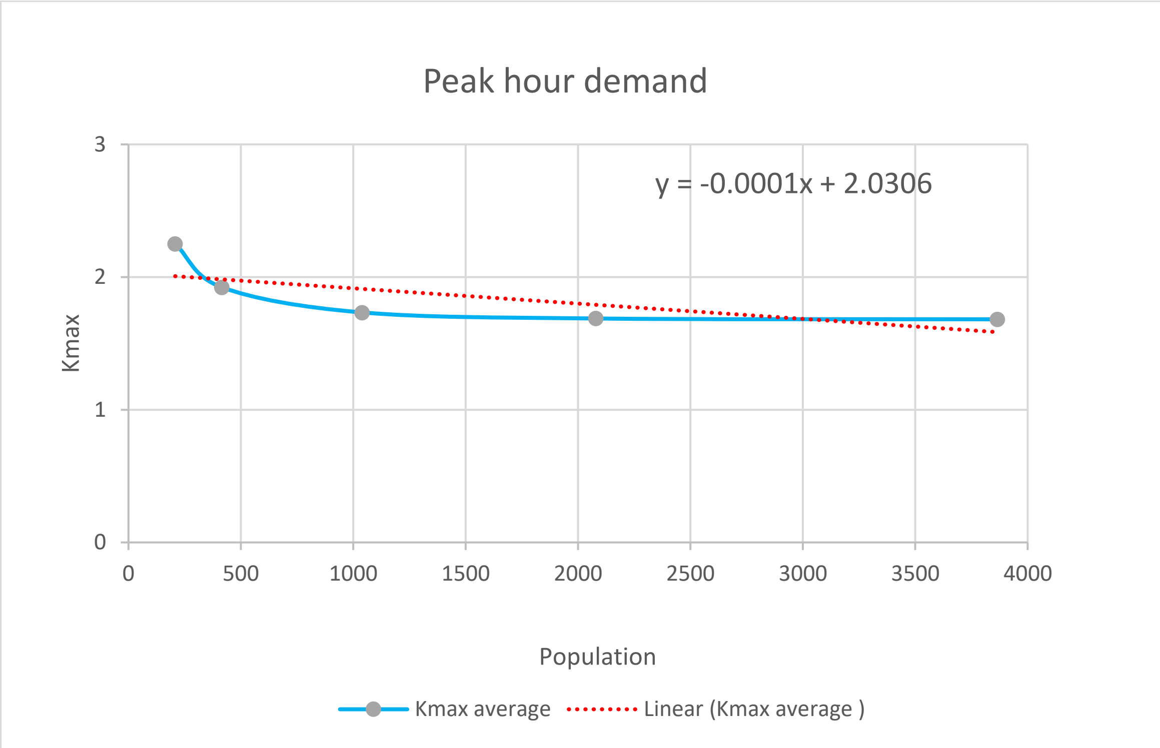


Figure 19 Correlation between peak demand factor and population

### 4.2.2. Minimum hourly demand factor $k_{min}$

On calculating the minimum daily factors, there was need to compare which kmin values was to be recommended for use. Three calculations were therefore carried out to compare which values correspond with results in other literature namely:

- Absolute least kmin
- Absolute largest kmin
- Average kmin

| Population | 208 | 416 | 1040 | 2080 | 3866 |
|---|---|---|---|---|---|
| Absolute least kmin | 0.03 | 0.05 | 0.08 | 0.10 | 0.10 |
| Absolute largest kmin | 0.39 | 0.67 | 0.70 | 0.54 | 0.53 |
| kmin average | 0.11 | 0.16 | 0.17 | 0.18 | 0.19 |

The absolute kmin based on the least kmin values was calculated for the different population quotas. The absolute largest kmin is based on the largest possible value of kmin results from (11) in section 3.6.2.

From the table above, by using both the absolute least kmin and absolute largest kmin, much of the data will not be reflected. Therefore, the average values seem to be the correct method.

Much of the literature do not mention much about which value to use.

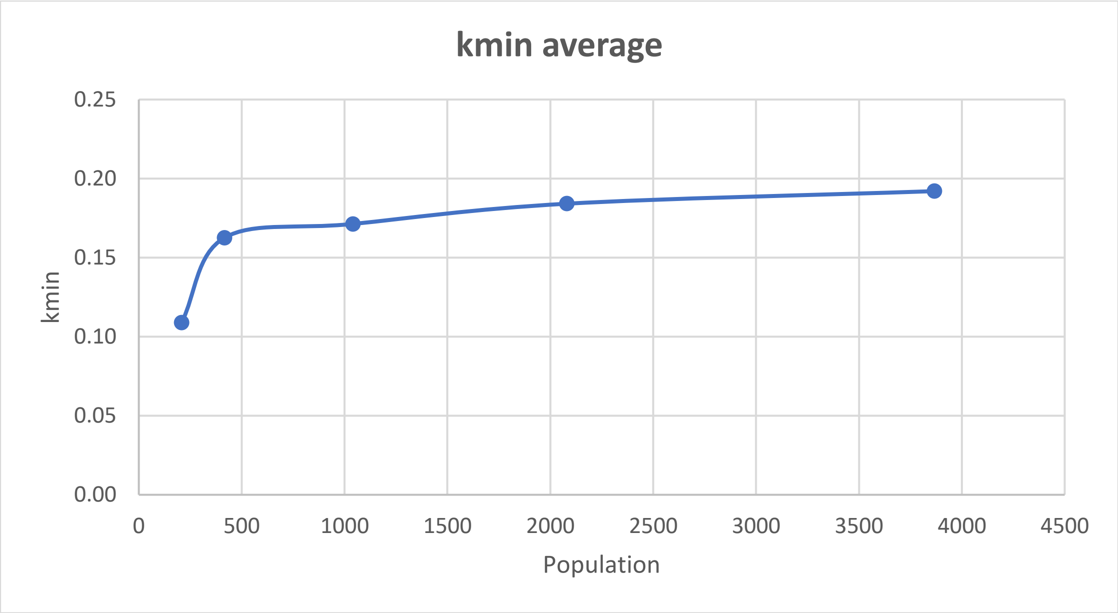


Figure 20 kmin average in relation to population

## 4.3. Correlation between population and maximum peaking factors

The correlation between population and maximum peaking factor was also compared to a review even though the methods were calculated differently.

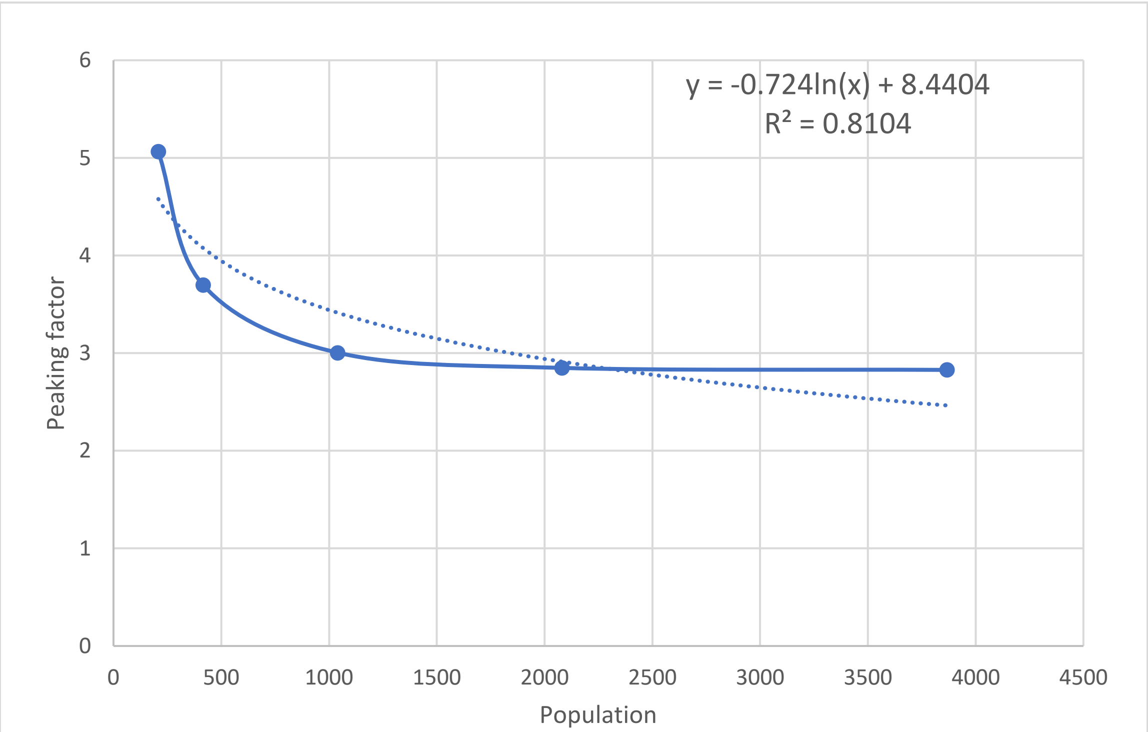


Figure 21 Correlation between population and maximum peaking factor

As mentioned in the literature review, the peaking factor has been compared to the population of the municipality. Peaking factor is the product of the peak diurnal demand factor and the peak hourly demand factor. The results obtained showed that the peaking factors decreased with an increase in the population. The resulting curve is shown in Figure 21 above. Similar conclusion was arrived in results produced by Gato (Gato-Trinidad & Gan, 2014) even though the analysis in this thesis research is for smaller number of users.

## 4.4. Limitations and impact on results

The analysis in this thesis work has shown interesting information on understanding the different demand factors. However, more data is required in order to counter any impact due to deviations, rounding off and the shorter periods analysed. The following limitations might arise from the data included in this thesis:

- Limited amount of registered consumption data from other municipalities.
- Water leakage at the household level might be included in the some of these data. It is therefore not easily defined on if the demand is based on real consumption, or a certain level of leakage has occurred within the household itself.
- Short period of survey. In this analysis, 239 days were considered. A better understanding could have been found if the review period was a whole year. However, at this stage, there is no indication that the results would be different.

## 4.5. Calculations for wastewater variations

Calculations for the demand found in this thesis is used mostly for drinking water and its consumption. However, it is a broadly accepted principle that water produced equals wastewater discharged and that what goes in as a demand/consumption is produced as waste for an average household(Lindholm, 2015). Water produced is equal to wastewater discharged. For the purpose of this thesis work, the variation factors can also be applied when designing a wastewater distribution system.

# 5 Conclusion and recommendation

## 5.1. Conclusion

The consumption data of permanent households of a typical small Norwegian municipality has been investigated in order to derive values for the maximum and minimum peak demand factors based on the drinking water. Variations are recorded for different types of the day and different days of the week.

The results of the analysis presented in this study compares with the results from other studies. However, this comparison is only within the range and not the exact comparison.

It was also found that the peak factors had a correlation to the number of households analysed. An increase in the number of households would reduce both the maximum diurnal factor and peak hourly demand. The review of literature also shows this increment and decrease of the magnitude of peaking factors in relation to the population increase/decrease.

The literature review suggestions of multiplying a demand by a peak factor is the most common way of estimating peak demands. The results found in this thesis agree with this calculation.

The range in peaking factors found by the results using data from Norwegian water users agree with the general characteristics of the peaking factors found in both the Norwegian water and Swedish water publications. However, the results in this research was exclusively based on a small supply system. The extent of this agreement in peaking range is therefore not established for larger supply systems.

## 5.2. Suggestions for Further Research

In this study, only household indoor demand was considered. However, supply systems are designed for more than just residential water demand. It would be beneficial to consider outdoor water demand as well as other demands such as industrial water, unbilled water and distribution-based losses.

Water demand depends on many other factors including pressure, different types of buildings and age of users among other factors. The results of the peak demand factors could drastically change if these factors are considered.

More data is needed especially for larger cities. Comparison with previous studies would yield better understanding on the peak demand factors.

Most municipalities in Norway are now installing smart water meters but few are collecting data on an hourly basis or less. More efforts should be taken to analyse data from consumption in shorter intervals such as 5-min intervals.

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**Norges miljø- og biovitenskapelige universitet**
Noregs miljø- og biovitskapelege universitet
Norwegian University of Life Sciences

Postboks 5003
NO-1432 Ås
Norway