Identifying factors influencing Infiltration and Inflow-water (I/I-water) in wastewater systems using multivariate data analysis

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Summary

The share of infiltration and inflow water (I/I-water) in the wastewater network is influenced by several factors. The purpose of this study is to propose a method to investigate the relationship between different variables and the proportion of I/I-water in the wastewater network. The method tested is a multivariate modelling technique with which the following variables were examined; a) estimated water leakage from drinking water pipes, b) total volume of delivered drinking water, c) average age of the sewer pipes, d) renewed amounts of sewer pipes, e) system solution (share of combined system) and f) precipitation. The multivariate modelling analysis reveals different patterns in influencing factors. When using the proposed model it is possible to rank the variables included in the model and the optimal level of I/I-water should be determined after identifying the factors influencing the I/I-water. When aiming to remove I/I-water the most cost-efficient measures should be considered. These measures may vary according to context.

Sammendrag

Bruk av multivariat analyse som verktøy for å identifisere ulike påvirkningsfaktorer til fremmedvann i avløpssystemet. Fremmedvannsnivået i avløpsnettet påvirkes av flere ulike faktorer. Hensikten med denne studien har vært å undersøke hvorvidt bruk av multivariat analyse kan være en egnet metode for å finne sammenhenger mellom fremmedvann og ulike variable. De undersøkte variablene er a) drikkevannslekkasjer, b) andel levert drikkevann, c) gjennomsnittsalder på avløpsnettet, d) andel fornyet avløpsnett, e) andel fellessystem og f) nedbør. Ved hjelp av multivariat analysen har det blitt funnet ulike mønstre når det gjelder påvirkningsfaktorer til fremmedvann. Ved hjelp av den etablerte modellen er det mulig å rangere variablene som har vært inkludert i analysen. Det optimale fremmedvannsnivået bør settes etter at ulike påvirkningsfaktorer til fremmedvann er blitt identifisert. De mest kostnadseffektive tiltakene bør vurderes når fremmedvann skal fjernes. Disse tiltakene vil variere fra sted til sted.

Introduction

Leakages from drinking water pipes in Norway are high compared to other European countries. The average percentage of leakage for all Norwegian waterworks was estimated to be about 30% in 2017 (Statistisk Sentrabyrå (SSB), 2018a). In Norway, 50% of leakages from drinking water are traditionally presumed to end up as I/I-water (Ødegaard et al., 2012). This may be a consequence of the fact that drinking water pipes and wastewater pipes mostly are situated in the same trench. In Norway, a typical pipe trench is constructed as shown in figure 1. A high amount of drinking water leakages may potentially influence the level of I/I-water.

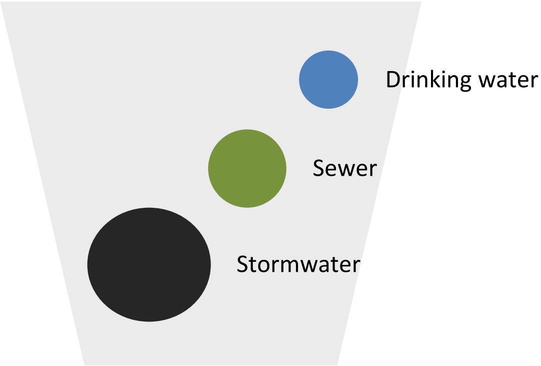


Figure 1. A typical Norwegian pipe trench

If it is indeed the case that drinking water contributes about 50% of I/I-water, this may be an important reason why the share of I/I-water in some areas in Norway is high.

How the groundwater level may influence the amounts of I/I-water is discussed in a study by Franz (2007), who argues that groundwater level is the main contributor to I/I-water. By using Multidimensional Scaling (MDS), Franz investigated which attributes influence the amounts of I/I-water the most. Franz concluded that the groundwater level is essential when characterising two wastewater districts by different attributes in Germany (Franz, 2007). The relationship between I/I-water and groundwater level was also investigated by Karpf and Krebs (2011). They found that both groundwater level and the year of installation of the sewer pipes were of importance regarding amounts of I/I-water (Karpf & Krebs, 2011). Even if the groundwater level is regarded as one of the most important influencing factors on the share of I/I-water, this variable is not included in this study. This is due to the fact that this study is based on Norwegian data and groundwater level is rarely measured in Norwegian wastewater districts.

The data used in this study are extracted from public sources of information, such as reports from the municipalities to the government. The variable *share of combined system* has only been reported from the municipalities to the Norwegian authorities since 2013. Even so, the analysis performed in this study includes this variable.

In 2012 the County Governor of "Oslo and Akershus" sent a request to all municipalities in Oslo and Akershus to mobilize against I/I-water. The County Governor had reason to believe that the level of I/I-water was too high and claimed the maximum acceptable level should be 30%. The level of I/I-water in the municipalities varied between 41% and 74% in 2010 (Fylkesmannen i Oslo og Akershus, 2011). The municipalities in this specific county vary a lot as far as topography and other local conditions are concerned. It is, therefore, reasonable to question if an equal level in all municipalities regarding I/I-water is achievable at a reasonable cost.

Wastewater is frequently divided into various fractions depending on its origin. The total share of I/I-water in the wastewater depends on the individual contribution of each of the components listed below:

- Sewage from households, industry, and institutions
- Drinking water leaking from drinking water pipes
- Groundwater, which is influenced by precipitation and seasons, but still is a relatively constant contribution.
  This contribution to the I/I-water is a consequence of leaky pipes and manholes
- Infiltrated rainwater. Rainwater also enters the sewer pipes through leaky pipes and

manholes. The share of infiltrated water depends on precipitation which infiltrates into the ground before it enters the sewer system. Groundwater may be a part of this contribution.
- Inflow water as a consequence of faulty connections. Sources may be house drainage, road drainage, unsealed manholes where water enters from the surface or streams connected to the sewer system.

The individual contribution may, for instance, be investigated using a calibrated hydraulic model. This was done in 2013 in a study from Oslo, Norway which correlated the following parameters to the share of I/I-water, I: share of combined system, II: average age of sewer pipes, III share of sealed surfaces, IV: number of crossings between sewer pipes and rivers, V: culverted rivers. The study concludes that the share of I/I-water is highly variable and difficult to predict (Torres, 2013). In 2014 another study was conducted in the Oslo area. In this study, different sources of I/I-water were calculated. The total share of I/I-water was calculated to be about 47%, of which leakages from drinking water pipes contributed with 15%, infiltrated rainwater contributed 75% and groundwater contribution was about 10% (Gammelsæter, 2014).

The contribution of different components to the I/I-water may also be investigated using a multivariate modelling technique. The goal of this study is to examine if such a multivariate modelling technique is a suitable method to identify the variables contributing to I/I-water in different locations. The variables included in this study are:

- estimated water leakages from drinking water pipes
- total volume of delivered drinking water
- average age of the sewer pipes
- rate of renewal of sewer pipes
- system solution (share of combined system)
- annual precipitation

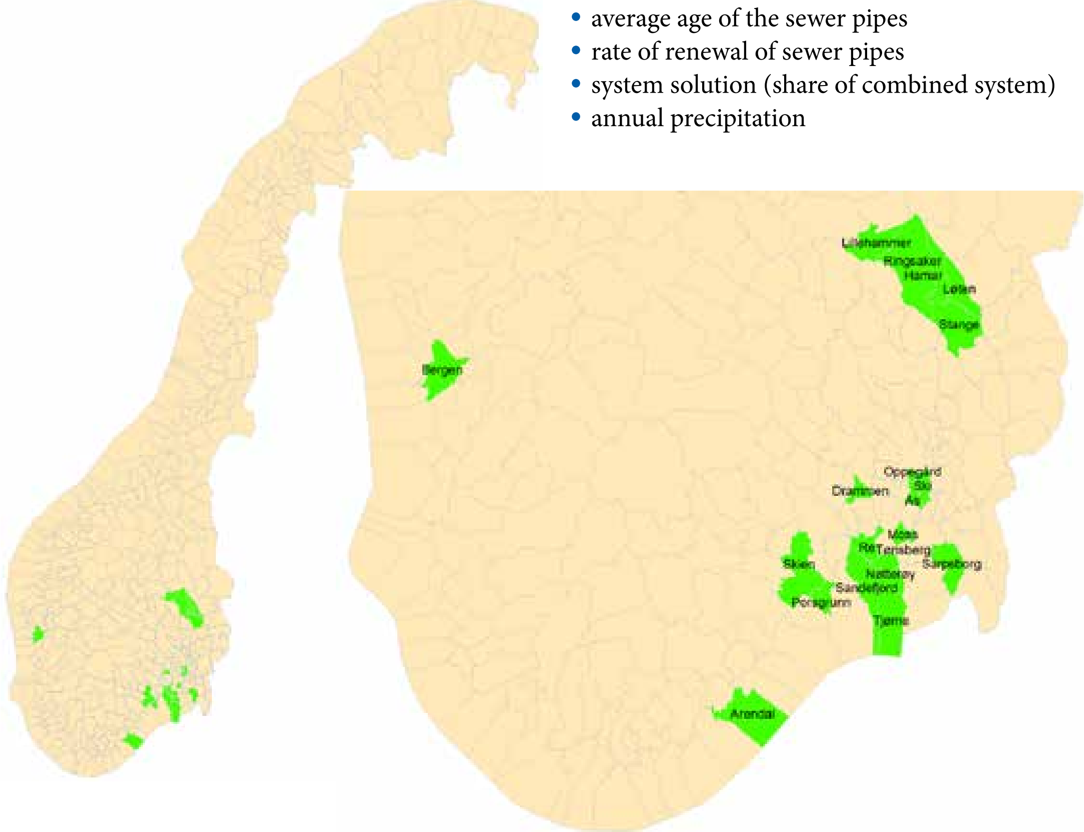


Figure 2. Map of the municipalities connected to the investigated WWTPs (Geodata AS, 2018).

Material and methods

Study area

Lindholm and Bjerkholt (2011) investigated the I/I-water situation for 14 of the largest wastewater treatment plants (WWTPs) in Norway. Of these, 11 WWTPs are further examined in this study. Due to lack of data it was not possible to investigate the remaining three WWTPs. The municipalities that have ownership in the WWTPs are shown in figure 2. The plants are also listed in table 1.

Some of the municipalities have been restructured in the period of the study. In total, about 770,000 persons are connected to the 11 WWTPs investigated in this study (Statistisk Sentrabyrå (Stastistics Norway), 2018) {Statistisk Sentrabyrå (SSB), 2018 #50}.

In addition, the potential contribution from drinking water leakages on the total amount of I/I-water has been examined for Asker municipality.

Data collection and quality

Norwegian municipalities/entities are required by law to make annual reports to the national government on several parameters related to municipal wastewater management/emissions (Lovdata, 2018; Statistisk Sentrabyrå (SSB), 2018b). Some of the reported parameters are collected by KOSTRA (a Norwegian municipality to the Government reporting program) (KOSTRA, 2019). The information on Total-Phosphorus (Tot-P) used in this study was given by the Norwegian Environment Agency (Finnesand, 2017). In addition, data on estimated water leakages, total amounts of drinking water delivered average age of the sewer pipes, total length of renewed sewer pipes as a percentage of the complete system, and the share of combined systems has been collected from the KOSTRA website (KOSTRA, 2019). The municipalities report to the Norwegian Environment Agency and KOSTRA every year, without any further quality control. It is therefore assumed that the quality of the data may vary. Some figures may also be missing for certain years, and are difficult to complement. Precipitation data have been extracted from MET, the Norwegian Meteorological Institute's database eKlima (Meteorologisk institutt (MET)). MET runs a network of weather stations all over Norway and all results are published online.

As mentioned above, the datasets may be incomplete due to incorrect or missing registrations and it has been necessary to do some simplifications and assumptions during this study. This comes as a consequence of one or both of the following facts:

- Some WWTPs included in the investigation may not be connected to the entire

Table 1. Wastewater treatment plants (WWTPs) and rain gauges investigated in the study.

Wastewater treatment plant	Connected municipalities	Rain gauge identity number	Rain gauge name
Kambo (Ka)	Moss	17251	Moss brannstasjon
Alvim (Al)	Sarpsborg	3190	Sarpsborg
Solumstrand (So)	Drammen	26900	Berskog
Sandefjord (Sf)	Sandefjord	27600	Sandefjord
Knardalstrand (Kr)	Porsgrunn, Skien	27600	Sandefjord
Saulekilen (Sau)	Arendal	36200	Torungen fyr
Knappen (Kn)	Bergen	50540	Florida
Lillehammer (L)	Lillehammer	12680	Sætherengen
Tønsberg (Tøn)	Tønsberg, Nøtterøy, Tjøme, Re, Stokke	27270	Kilen
HIAS (Hi)	Hamar, Løten, Ringsaker, Stange	12320	Stavsberg
Nordre Follo (NoF)	Ski, Ås, Oppegård	17850	Ås

wastewater system in a municipal wastewater district.
- Some WWTPs receive effluent from more than one municipality.

In these cases, the average values of the investigated variables have been calculated.

Precipitation may vary significantly over short distances. One must therefore anticipate some uncertainty if relying on data from a single location to represent the precipitation of an entire district. Despite this fact, for the purpose of this study, one station per district was chosen to simplify the analysis.

The potential drinking water contribution to I/I-water has been investigated in five points in Asker municipality. The discharges in the wastewater network have been measured for several years in these points and are considered reliable. In four of the points, the amounts of I/I-water have been calculated based on the number of person equivalents (pe) connected to the point. The investigated period for these four points was the summer of 2018, which was really dry in Asker. In the fifth point the measured discharges in the wastewater pipes have been compared to delivered amounts of drinking water.

In table 2 the selected measuring points in the wastewater network is shown.

Methods

Determination of I/I-water

The share of I/I-water may be calculated using the dilution method (Lindholm & Bjerkholt, 2011). Concentrations on Tot-P into WWTP are considered a measure on how big the share of I/I-water into the same plant is. The amount of I/I-water is calculated according to formula (1) (Jenssen Sola et al., 2018).

$$\text{Amount of I/I-water [\%]} = (1 - (ci)/(P_{pd}/Q_{ap})) \times 100 \qquad (1)$$

Where:

I/I = I/I-water in the plant [%]

P_{pd} = produced phosphorus (TOT-P) per person and day [mg/pe day]

ci = concentration of Tot-P into the plant [mg/l]

Q_{ap} = amount of wastewater produced per person per day [*l*/pe day]

In Norway, a phosphorus production of 1.8 g Tot-P per person per day is commonly used (Lindholm & Bjerkholt, 2011; Ødegaard et al., 2012). In formula (1) both commuting and industry is considered negligible. The amount of wastewater produced per person per day is set to be 140 liters (Jenssen Sola et al., 2018).

When calculating I/I-water in Asker, the water balance method was used according to formula (2) (Jenssen Sola et al., 2018).

$$\text{Amount of I/I-water [\%]} = (Q_{tot} - pe \times Q_{ap})/\,Q_{tot}) \times 100 \qquad (2)$$

Where:

I/I = I/I-water in the wastewater system [%]

Q_{tot} = total amount of water being transported to the measuring point [*l*/day]

pe = the number of persons situated within the catchment area

Q_{ap} = the amount of wastewater each person produces per day [*l*/pe day]

Table 2. Selected measuring points in Asker.

Manhole number	Number of connected pe	Method
10286	7530	Discharge and dry weather flow
160376	6140	Discharge and dry weather flow
4666	4666	Discharge and dry weather flow
2600	14003	Discharge and dry weather flow
10268	3200	Discharge and delivered amounts of drinking water

Linear regression

Linear regression was used to investigate the relationship between different variables. One by one the variables were correlated against Tot-P, one location at the time. A 95% confidence interval was used in the regression calculations.

Multivariate data analysis

When investigating several variables (X) simultaneously, and to conduct more explorative analysis, multivariate data analysis is applied. Multivariate analysis is useful to single out which variables are the most important, and what relationships there are between the variables. The Unscrambler 10.5 (Camo Software AS, 2014) was used to perform the calculations in this study.

Principal Component Analysis (PCA) is a method to find hidden data structures and correlations between variables (Esbensen & Swarbrick, 2018). Hidden trends in datasets, which otherwise could be difficult to discover may be revealed (Esbensen & Swarbrick, 2018). When correlations exist between variables in the dataset, PCA performs a dimensional reduction of uncorrelated latent variables that describe the principal directions in the data (Principal Components (PCs)) Several PCs are extracted which all together explains the relationships found in a multivariate dataset (Esbensen & Swarbrick, 2018).

The **Score plot** shows how the samples are related to each other. The **Influence plot** is used when interpreting the PCA and may be used to identify if the dataset is under the influence of possible outliers. If many points are situated in the first quadrant this may indicate that these samples are outliers. **The Correlation Loading plot** shows which variables are significant and how the variables correlate (Camo Software AS, 2014; Esbensen & Swarbrick, 2018). The 2-D plot contains two ellipses that indicate how much variance is taken into account by the model. The outer ellipse is the unit circle and indicates 100% explained variance. The inner ellipse indicates 50% of explained variance. Variables with less than 50% explained variance are candidates to be left out of the analysis.

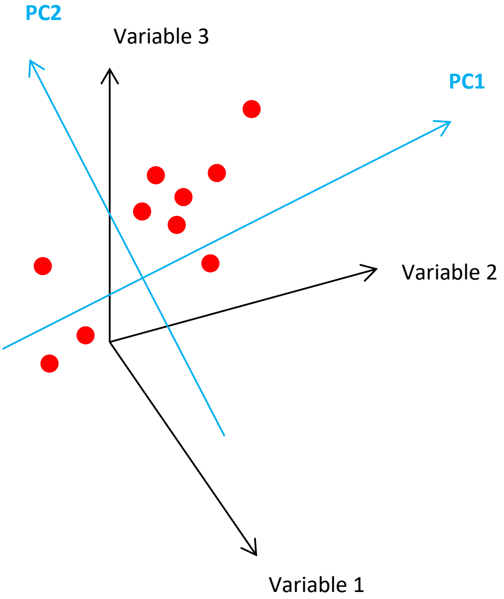


Figure 3. The extracting process of Principal Components from variables (Camo Software AS, 2014).

The extracting process of Principal Components is shown in figure 3. The first PC (PC1) accounts for the direction of highest variation in the data. The second PC (PC2) accounts for the next highest variation normal to PC1 direction and so on. This results in a new coordinate system with the PCs as bases.

The validation process is important when performing statistical analyses. A validation will show how general a model is. Cross-validation is used to screen the modelability of the data. In cases with few samples, cross-validation is used. When many data samples exist, a test set validation is better to use. In our case, we have used cross-validation with samples randomly sorted into blocks. In cross-validation a block of samples is left out and tested against the remaining samples. This procedure is repeated until every block of samples has been left out once (Esbensen & Swarbrick, 2018).

Results

Contribution from drinking water leakages

The summer of 2018 was very dry in Asker. The average precipitation in Asker municipality during June/July/August was 46/22/53 mm respectively (Rosim AS), whereas the average values for the current reference period (1961-1990) are 72/90/106 mm for the same months (YR, 2018). Because of the minor amounts of precipitation, there are reasons to believe that the main sources of I/I-water this summer were leakages from drinking water pipes, inflow from rivers/culverted rivers and possibly groundwater. Since the investigated period was very dry, it is also likely that the groundwater level was low. Even so, it may not be excluded that the measuring points may be influenced by groundwater.

The calculated level of I/I-water is shown along with gauged rainfall for the station "Mellomnes", in figure 4. The level of I/I-water has been calculated using the water balance method.

There is no registered rainfall between 17.06.18 and 09.07.18, and throughout this period the I/I-level decreased for all four points. Even though the I/I-level varies, the level is at a minimum between July 5th and July 8th for all points. In catchment area 10286 there are no obvious intersections between sewer pipes and open/closed streams. For catchment 160376 and 4666 some pipes run along streams and may be

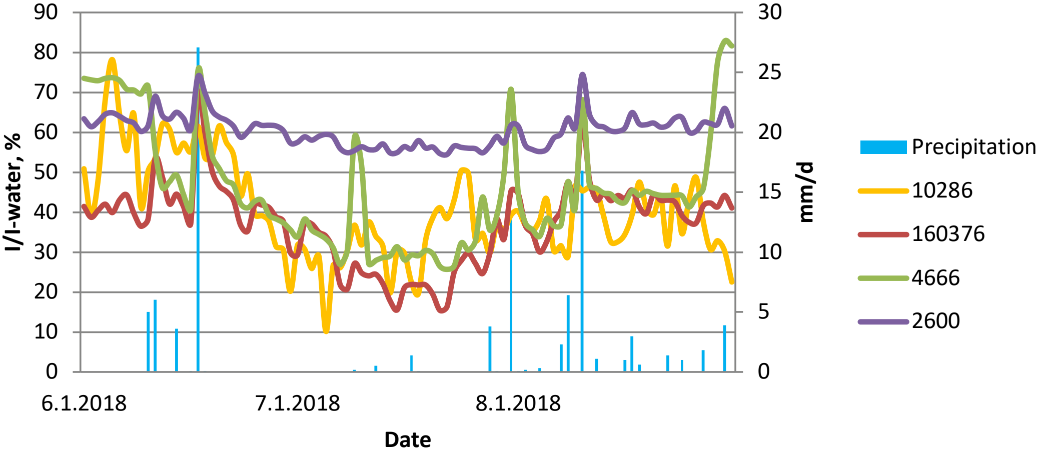


Figure 4. Calculated amounts of I/I-water in four locations/catchment areas, together with gauged rainfall measured at Mellomnes in June, July and August 2018.

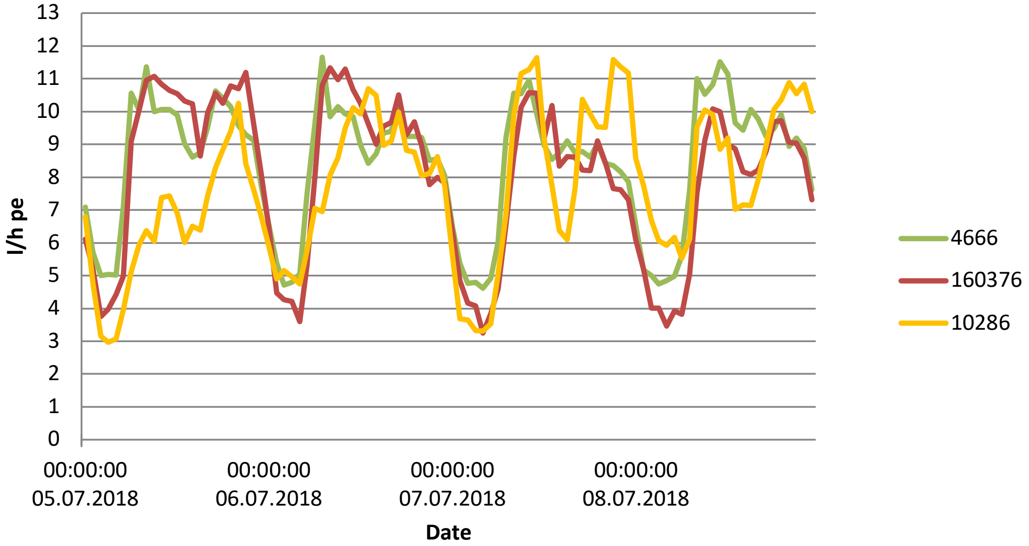


Figure 5. Measured discharge for three catchments between 05.07.-09.07.2018.

Table 3: Extracted and calculated information regarding flow measuring points in Asker municipality on the 05.07.2018-08.07.2018.

Manhole number	Number of connected pe	DWF (*l*/h pe), Minimum	DWF (*l*/d pe), Baseflow
10286	7530	3.0	72
160376	6140	3.6	86
4666	1538	4.6	110

influenced by this. In catchment area 2600 the sewer pipes are most likely to be influenced by a river. Due to the measured discharge in point 10286 there is reason to believe that leakages from drinking water pipes contribute to about 10% to 15 % of the total amount of I/I-water.

Figure 5 shows five days from July 5th to 9th when there was no precipitation for about three weeks. Measuring point 2600 is not included in figure 5.

The lowest registered level of discharge is at night-time, from 2 a.m. to 4 a.m. At this point, the dry weather flow (DWF) for 4666 is 4.4 *l*/pe hour, for 160376 it is 3.6 *l*/pe hour and for 10286 the lowest registered level of discharge is 2.3 *l*/pe hour. Table 3 sums up information regarding the three investigated measuring points.

By analysing data from the summer of 2018, we see that leakages from drinking water pipes may contribute to a minimum of 72*l*/d pe of the total discharge in the wastewater network.

On March 18th 2018, there was reported a leakage from a drinking water pipe in Asker. The measured amount of drinking water through one of the flow meters was abnormally high. In the same area a flow meter registered an increase in the measured discharge in a wastewater pipe, despite no registered precipitation during this period. The measured wastewater discharge and measured drinking water consumption is shown in figure 6, together with registered precipitation in station "Mellomnes".

The registered peak in discharge between the 18.03.2018 and the 02.04.2018 (figure 6) is not caused by precipitation, but must come as a consequence of the registered leakages from the drinking water pipe. Just before the pipe was damaged the discharge was about 400 m^3/d and

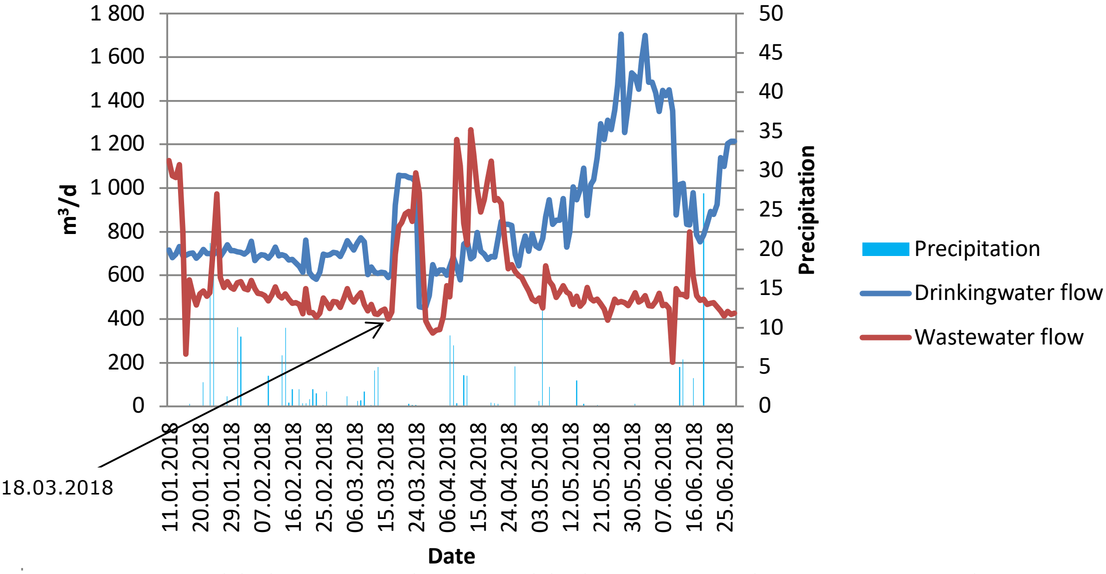


Figure 6. Measured discharge compared to measured drinking water use and precipitation measured at Mellomnes.

Table 4: Changes in measured water flows due to a broken drinking water pipe

Situation	Drinking water flow, m³/d	Wastewater discharge, m³/d
All pipes functioning as normal. Dry weather (not summer). 16.03.2018	590	400
Broken drinking water pipe. Dry weather (not summer). 19.03.2018	1050	820
"Lost" drinking water	460	
Increase in discharge		420

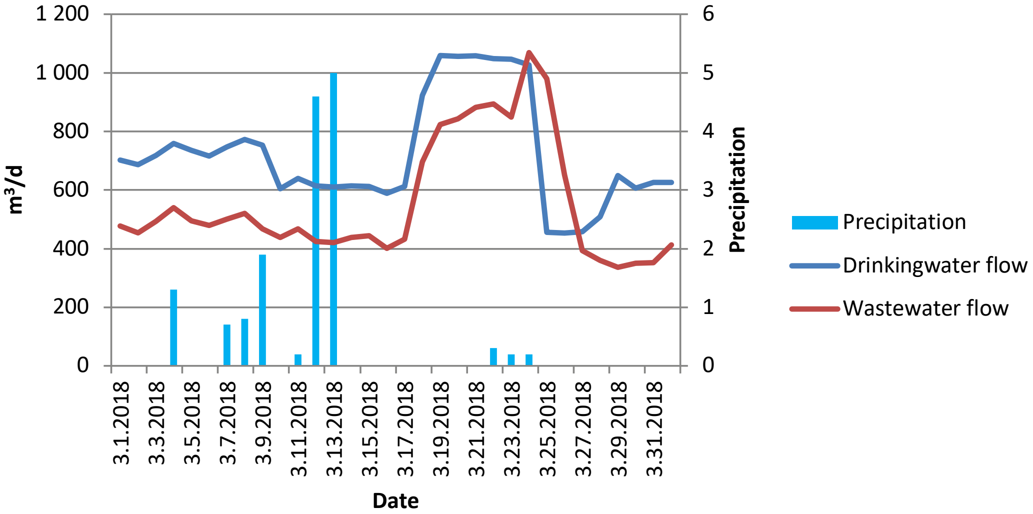


Figure 7. Measured drinking water flow and wastewater flow during a drinking water pipe break.

the water use about 600 m³/d. Both measured water flows peaks about 1100 m³/d.

A close up on the dates from 01.03.2018 to 01.04.2018 is shown in figure 7.

Extracted information from figure 6 and 7 is listed in table 4.

Investigations show that leakages from drinking water pipes contribute to a base flow of I/I-water at approximately 72 *l*/d pe, or a minimum of 10-15% of the total amounts of I/I-water. In the case of a sudden break on a drinking water pipe, as much as 91% of the leakages may be found in the waste water pipes. Drinking water may potentially be a considerable factor in some areas when investigating different sources of I/I-water.

Linear regression

In figure 8 the development of the Tot-P concentration in the investigated WWTP is shown for all locations. Applying the dilution method, Tot-P may be used as a measure of the size of the share of I/I-water. Figure 8 shows that HIAS, Kambo, and Lillehammer have the highest Tot-P values, and therefore also the lowest proportion of I/I-water. Meanwhile, Sandefjord and Knardalstrand appear have the greatest challenges regarding I/I-water.

Results from the regression analysis on Tot-P, on all variables for each location, are shown in table 5. A p-value < 0.05, together with a relatively high r^2 value indicates that a variable may be significant, using a 95% confidence interval. These values are highlighted in green in table 5.

For most of the investigated variables, there is no correlation between any of the variables and the amount of Tot-P. It is difficult to point out one variable that may explain the challenges of I/I-water. When comparing table 5 and figure 8 it is reasonable to assume that the good results

Table 5: Results from a regression analysis performed on each variable for each location in relation to Tot-P. Green colour indicates which variables that may be significant.

WWTP	Water leakages		Water delivered		Precipitation		Average age on sewer pipes		Renewed sewer pipes, average of last 3 year	
	r^2	p-value	r^2	p-value	r^2	p-value	r^2	p-value	r^2	p-value
Kambo (Ka)	0.13	0.34	0.03	0.65	0.11	0.36	0.15	0.29	0.01	0.80
Alvim (Al)	0.39	0.07	0.06	0.54	0.01	0.77	0.03	0.68	0.08	0.45
Solumstrand (So)	0.00	0.89	0.14	0.32	0.06	0.51	0.00	0.91	0.08	0.47
Sandefjord (Sf)	0.09	0.43	0.05	0.54	0.42	0.06	0.04	0.59	0.11	0.34
Knardalstrand (Kr)	0.01	0.84	0.002	0.90	0.25	0.17	0.29	0.13	0.20	0.23
Saulekilen (Sau)	0.08	0.47	0.06	0.54	0.12	0.36	0.08	0.46	0.33	0.10
Knappen (Kn)	0.34	0.10	0.28	0.14	0.04	0.63	0.00	0.96	0.28	0.14
Lillehammer (Li)	0.46	0.04	0.14	0.32	0.57	0.02	0.13	0.34	0.00	0.87
Tønsberg (Tøn)	0.44	0.05	0.53	0.03	0.06	0.53	0.22	0.20	0.08	0.46
HIAS (HI)	0.00	0.89	0.00	0.88	0.70	0.01	0.20	0.23	0.22	0.21
Nordre Follo (NoF)	0.00	0.99	0.18	0.26	0.51	0.03	0.42	0.06	0.15	0.31

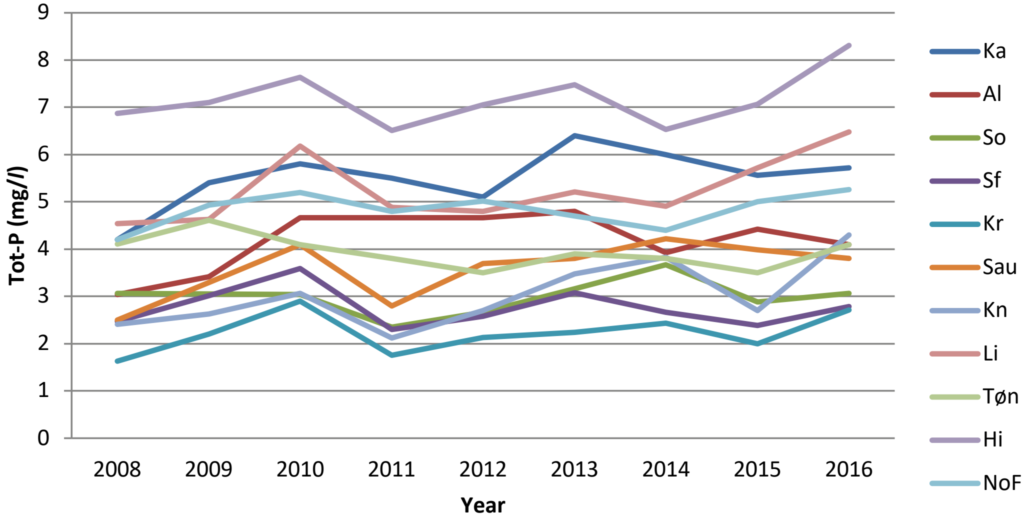


Figure 8. Development of Tot-P in the influent for different WWTP.

for HIAS and Lillehammer come as a consequence of low annual precipitation. Kambo´s low levels of I/I-water are more difficult to explain. Sandefjord and Knardalstrand both have bad results when it comes to the level of I/I-water, which cannot be explained from the results of the regression analysis.

Multivariate data analysis

As a supplement to the regression analysis, a multivariate principal component analysis was performed. The goal is to get a clearer picture of which variables influence the level of I/I-water the most in different locations. The analyses have been performed both with and without the variable "system solution" (share of combined systems).

The samples presented in the figures in this chapter are represented with an abbreviation of the name (also shown in table 5) along with the year of the sample. For instance, *Kn15* represent the value of Knappen in 2015.

PCA without the variable *system solution* (*share of combined system*)

The influence plot from this PCA is shown in figure 9.

The x-axis in the figure indicates how far from the centre of the model the samples are. The y-axis signifies how far from the principal component the samples are. Possible outliers are placed in the upper right corner of the plot (Camo Software AS, 2014).

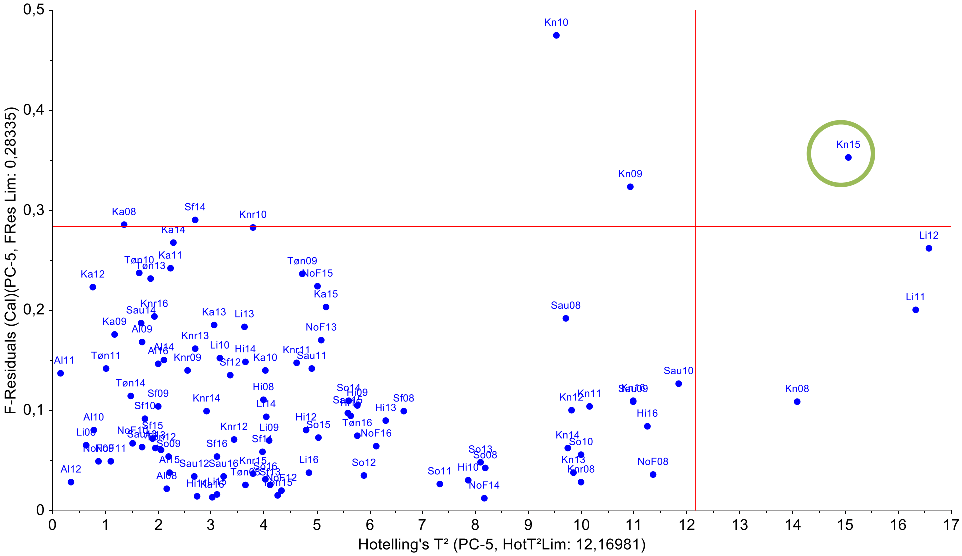


Figure 9. Influence plot of the PCA including all samples and without "system solution".

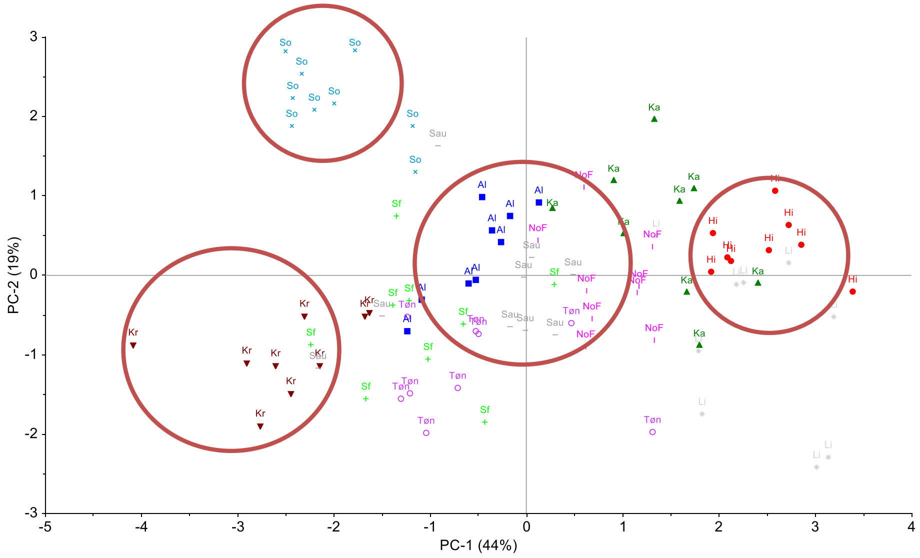


Figure 10. Scores plot of the PCA including the variable "system" and without the sample "Knappen".

The influence plot shows that KN15, which is marked out by a green circle in figure 9, may be an outlier candidate. Because of this a second model was established. The second model does not include Knappen, but includes the variable «system solution» (share of combined system).

PCA without Knappen (Kn) and including *system solution (share of combined system)*

The scores plot for this model is shown in figure 10.

PC1 and PC2 together explain about 63% (44%+19%) of the observations. The samples used in this analysis show that Solumstrand (So) and Knardalstrand (Kr) are in one end of the plot, along PC1, and HIAS/Kambo (Hi/Ka) and partly Lillehammer (Li) are in the other end of the plot. Groups on each side of the center may have opposing characteristics. PC1 is the most important PC for the spreading of the group. Other locations clustering in a group, such as Nordre Follo (NoF), Saulekilen (Sau) and Alvim (Al), have properties similar to one another.

The correlation between the loadings is shown in figure 11.

The correlation loadings plot shows that all of the investigated loadings are negatively correlated to the loading Tot-P. Variables with more than 50% variance explained are treated as significant which is the case for all of the investigated variables except for the variable *renewed*.

A high average pipe age, high amounts of delivered drinking water/leakages from the drinking water pipes, high precipitation and a high share of combined system will all lead to low values of Tot-P. All this follows an intuitive understanding of how a wastewater system is functioning.

The Scores plot and the Correlation plot may be interpreted together by placing the plots on top of each other as shown in figure 12.

It is likely that the high percentage of combined system together with a high amount of leakages from the drinking water system is the cause of Solumstrands low values on Tot-P, which is not the case for Sandefjord, Knardalstrand or Tønsberg. In these three locations the high amount of annual precipitation is most likely a key driver of the high levels of I/I-water.

The results from the PCA including the variable “share of combined system” are summarized in figure 13 and shows how the variables may be rated for each location when the locations are compared to each other.

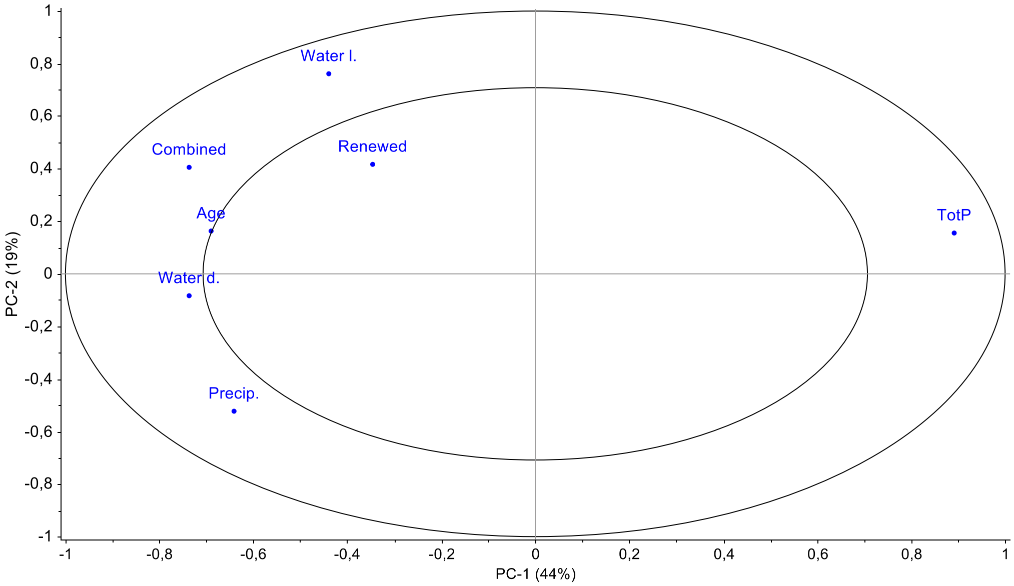


Figure 11. Correlation loadings plot for PCA including the variable “system” and without the sample “Knappen”.

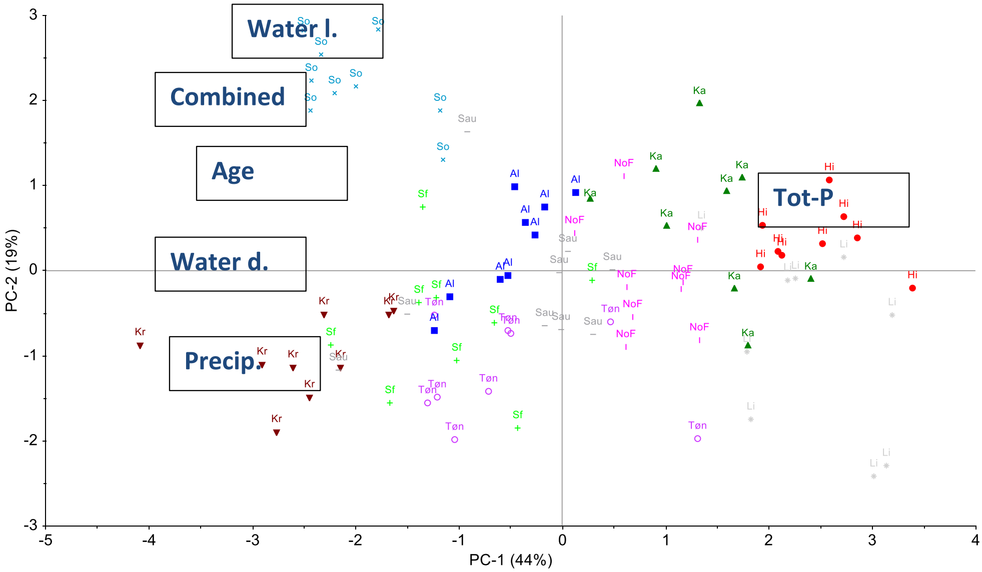
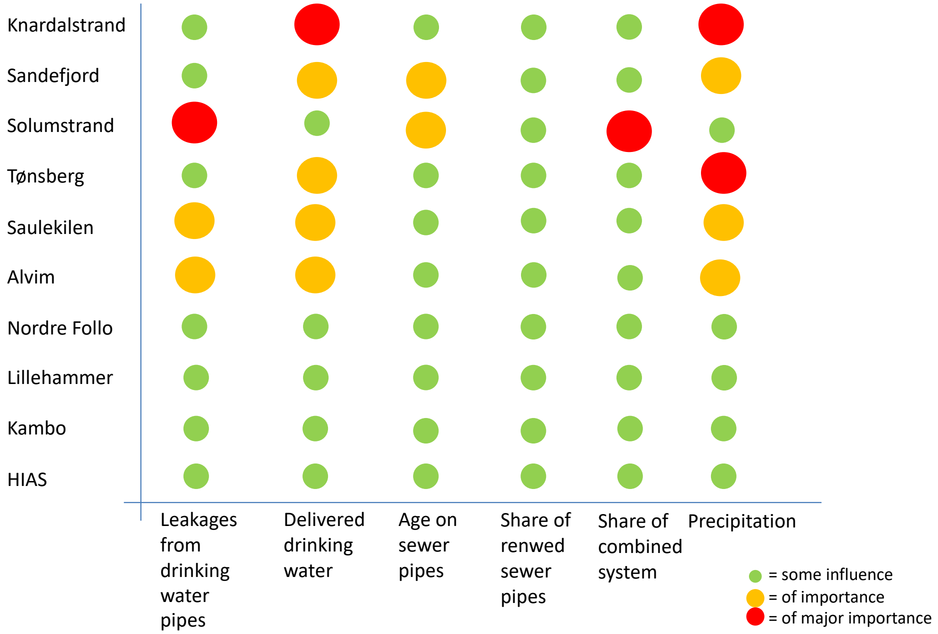


Figure 12. Interpretation of the correlation plot and the scores plot in relation to each other.



	Leakages from drinking water pipes	Delivered drinking water	Age on sewer pipes	Share of renwed sewer pipes	Share of combined system	Precipitation
Knardalstrand	🟢	🔴	🟢	🟢	🟢	🔴
Sandefjord	🟢	🟡	🟡	🟢	🟢	🟡
Solumstrand	🔴	🟢	🟡	🟢	🔴	🟢
Tønsberg	🟢	🟡	🟢	🟢	🟢	🔴
Saulekilen	🟡	🟡	🟢	🟢	🟢	🟡
Alvim	🟡	🟡	🟢	🟢	🟢	🟡
Nordre Follo	🟢	🟢	🟢	🟢	🟢	🟢
Lillehammer	🟢	🟢	🟢	🟢	🟢	🟢
Kambo	🟢	🟢	🟢	🟢	🟢	🟢
HIAS	🟢	🟢	🟢	🟢	🟢	🟢

🟢 = some influence
🟡 = of importance
🔴 = of major importance

Figure 13. The results from the PCA. Each variable has been rated according to importance for each location.

Discussion and conclusions

An even more complete model including for instance groundwater levels could give more reliable results. It is essential when performing analysis to control the most important parameters. Which parameters are the most important is difficult to predict, but a multivariate data analysis might give insight into which variables are significant. However, this study shows that there are probably several influencing variables on I/I-water.

The County Governor of Oslo and Akershus encourages the municipalities in his jurisdiction to work towards an I/I-level on 30%. This may be achievable for some municipalities, especially areas with low amounts of annual precipitation. For other municipalities, this goal may be hard to reach, partly because of local factors such as precipitation patterns.

When drinking water pipes and wastewater pipes are placed in the same trench, leakages from drinking water pipes may potentially be an important source of I/I-water.

For most of the locations included in the study, all the investigated variables contribute to the complete picture of how the sewer network is affected by I/I-water. A statistical tool, like multivariate analysis, can be applied to investigate the relationships between different variables. Such a tool will help our understanding of potential hidden patterns in the datasets.

In the examples presented in this study, different municipalities have been compared to each other. By comparing different locations within the same municipality, it seems suitable to use a multivariate analysis as one of several tools when aiming to identify the most socio-economically beneficial approach to reduce I/I-water within each area. By including other variables in addition to the ones used here, for instance the share of impermeable surfaces, groundwater level and crossings between sewer pipes and rivers, a multivariate analysis may be a very useful tool to gain further insights into the driving factors of I/I-water.

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