# Quantifying Excessive Water Inflow in Urban Sewer Systems: A Case Study in a mid-sized Norwegian municipality

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## Sammendrag

*Kvantifisering av fremmedvann i urbane avløpssystemer: En casestudie i en mellomstor norsk kommune.* Måling av infiltrasjon og tilstrømning i avløpssystemer er essensielt for å oppnå effektiv transport og behandling av avløpsvann. Arbeidet presentert i denne artikkelen hadde som mål å vurdere infiltrasjon og tilstrømning i et ikke-overvåket avløpssystem i en mellomstor norsk by. For dette formålet ble det satt opp en målekampanje, og høyoppløselige data ble samlet inn over en lengre periode. Resultatene viste at nedbørstilstrømning var den viktigste kilden til fremmedvann, med en MNF-verdi som økte med omtrent 4,3 ganger i våtværsperioder sammenlignet med den i tørrvær. Videre identifiserte analysen av MNF-verdier en grunnvannsinfiltrasjonsrate på omtrent 0,7 l/s. Studien fremhever fordelene ved strømningsmåling for å identifisere problemer som feilaktig tilkoblede overvannsrør og grunnvannsinfiltrasjon i systemet. Likevel er studiens viktigste bidrag de høyoppløselige dataene som ble samlet inn over 16 måneder, som spenner fra strømningsverdier og temperatur til nedbør, og som nå er fritt tilgjengelige for fremtidig forskning.

## Summary

Measuring infiltration and inflow (I/I) into sewer systems is essential for ensuring efficient wastewater transport and treatment. This research aimed to assess I/I in an under-studied sewer system in a mid-sized Norwegian city. For this purpose, a measurement campaign was set up, and high-resolution data were collected over an extended period. The results showed that precipitation inflow was the main source of extraneous water, with the MNF value increasing by about 4.3 times during the wet period compared to the dry period. Moreover, analysis of MNF values identified a groundwater infiltration rate of approximately 0.7 l/s. The study highlights the benefits of flow measurement in identifying issues like improperly connected stormwater pipes and groundwater intrusion into the system. Nevertheless, the study's key contribution is the high temporal resolution data collected over 16 months, ranging from flow values and temperature to precipitation, which is now freely accessible for future research.

## Introduction

Water and residues originating from homes, businesses, and industries are referred to as wastewater. Rainwater or groundwater that has seeped into the sewer system is not included in that definition per se. In this regard, the direct entry of surface water into a sewer system is known as inflow. While, infiltration primarily stems from groundwater intrusion (Karpf & Krebs, 2013) due to pipe or manhole damage. In the current text, I/I will be used from now on as an abbreviation for infiltration and inflow (Weiß et al., 2002). The volume of I/I can be an order of magnitude greater than the average sewage flow (Brian & Bertrand-Krajewski, 2010; Li et al., 2019), which can lead to major issues including sewer overflows which damaging sewer facilities (Vallabhaneni et al., 2008) and pollute the environment and put human health in risk (Rehan et al., 2014). Additionally, it may result in overload of wastewater treatment facilities (Yuan et al., 2019). This is a growing concern for this sector because of the numerous issues it can cause, including destruction of the biological balance of treatment systems, environmental issues arising from untreated wastewater, and operation costs due to extra energy requirements for pumping, addition of chemicals and extra labor costs (Bentes et al., 2022; Hey et al., 2016). It is therefore of utmost importance to know the undesirable I/I flows for the management of wastewater systems. This issue becomes more important considering the restrictions imposed by the new wastewater directive in the EU commission (2024).

Many guidelines for controlling I/I have been published by different countries (to see the list please refer to Hey et al., 2016) and several studies have been conducted on the estimation and calculation of I/I. For instance, a case study of the Brussels system reveals a significant seasonal fluctuation in the inflow and infiltration (de Ville et al. 2017). It ranged from 15% (in summer) to 45% (in winter) of dry weather flow. Large quantities of extraneous water were found in a review of I/I in Finland, Denmark, Sweden, and Norway (Sola et al. 2018). For instance, based on a survey conducted on 14 Norwegian cities, the average I/I value in 2016 was 67% (Hey et al., 2016) while in some municipalities like Tromsø and Kristiansund, estimated I/I value goes up to almost 80% (Jørgensen & Rostad, 2022). In another investigation, a Trondheim analysis revealed that 46% of the sewage discharged to the WWTP during dry weather was extraneous water (Beheshti & Sægrov, 2018). Additionally, the Municipality of Asker in Norway receives around 63% of its water from I/I, and in 2017 the municipality paid NOK34 million for this extra water (Sola et al., 2020). In a recent study by Skagsoset (2023), it was estimated that 76% of the total transported volume over a 40-day evaluation period in Horten Municipality was attributed to I/I. This was mainly due to significant snowmelt and rainfall, with sub-optimal manhole design and the placement of pipes in ditches likely amplifying the issue. All these findings indicate a considerable excess flow volume in the Norwegian sewage network, prompting municipalities to seek solutions for detecting and reducing this unwanted water. This effort is particularly crucial as the Norwegian Water Association has set a sustainability goal to reduce I/I in sewer systems by 30% by the year 2030 (Norsk Vann Rapport 255, 2020).

To the best of the authors' knowledge, this study is one of the few in Norway to continuously monitor sewer flow in a well-defined and limited area with a temporal resolution of 5 minutes over a period of 16 months to detect and calculate I/I. The more common case is a more data-scarce environment (Skagsoset, 2023). The primary aim of this research was to monitor the flow within the sewer system to detect I/I and accurately determine their proportions over an extended period, while also attempting to identify their sources. Additionally, given the lack of freely available comprehensive sewer flow measurement data series in Norway in this field, this study aimed to publish the collected database for future research use (Mohan Doss et al., 2024).

## Materials and Methods

This study focuses mostly on fieldwork and is broken down into different phases, including gathering site data, calibrating flowmeters, visiting the site and installing devices, and collecting and analyzing data. More details are presented in the following sections.

### Equipment used

In the current study, two NivuFlow Mobile 750 devices were utilized to measure the flow into and out of the study area. The flow velocity measurement method is based on the ultrasound reflection principle, and data transmission is automatic. For more information about the device and its characteristics please visit here. It should be noted that the equipment was calibrated before installation at the site in order to avoid measuring inaccurate data. The calibration exercises were performed at the Hydraulic Laboratory of NTNU by the first author.

### Theory of I/I measurement

The EPA and the Massachusetts Department of Environmental Protection separate the overall effluent flow into four unique components (MassDEP, 2017):

1. Domestic use, institutional flows, and wastewater from business and industrial activities all correlate to sanitary flow.
2. The water in the soil that permeates the network through the joints is known as groundwater infiltration.
3. Direct rainfall, which includes, among other things, rainwater and melted snow that enter the networks directly through manhole covers and improper connections.
4. Water that enters the network through infiltration into the soil during a rainstorm is known as rain-induced infiltration water.

The term ”dry weather flow” refers to the wastewater flow rate that is exclusively caused by sanitary flow and groundwater infiltration (items 1 & 2) (USEPA, 1990). In other words, it only includes water that flows via pipes during the absence of precipitation events. Given that water consumption is almost nonexistent or sanitary flow is nearly zero between the hours of 0 and 6 am (especially in small towns), the total flow measured during this time roughly corresponds to the flow of groundwater infiltration (during dry spells). To address items 3 and 4, it is crucial to have access to precipitation records, which are necessary to determine the onset and cessation times of rainfall events. This information is essential for estimating both direct rainwater and rain-induced infiltration. In general, flows that swiftly enter the network at the start of a rainfall event and immediately cease after the rain ends are referred to as direct rainwater. Nevertheless, this study did not differentiate between direct rainwater and rain-induced infiltration. Here, if there was a rain/snow event on a day, that day was considered a wet-day, and the corresponding flow in the system was treated as wet-flow.

Methods for detecting, localizing, and quantifying I/I can be categorized into two types: quantitative methods, which assess the magnitude, volume, and discharge of I/I, and qualitative methods, which detect the locations of I/I sources (Beheshti et al., 2015). Generally, physical methods such as visual and odor inspection, dye testing or smoke testing, closed-circuit television (CCTV) inspection, and temperature sensing are used for qualitative analysis (Ye et al., 2023). For quantitative analysis of I/I, Weiß et al. (2002) proposed the ‘triangle’ method and the ‘moving-minimum’ method. The former assumes that domestic sewage flow remains constant over a certain period, thus only providing the average I/I without showing the variation of the infiltration process over time. While the later assumes that the sum of sanitary sewage plus I/I on any given day equals the minimum daily flow over the preceding 21 days, though this method lacks a physical basis. Another method in this category is the minimum night flow (MNF) method, which has been applied in various studies to quantify I/I (e.g. Bogusławski et al., 2022; Flores, 2015). The foundation of this method is the presumption that (groundwater) infiltration flow is constant. The least amount of infiltration happens between 3:00 and 5:00 in the morning during a dry spell (Pangle et al., 2022). According to De Bénédittis & Bertrand-Krajewski (2005), sufficient observation time


*Figure 1. Installation of flowmeters inside the upstream and downstream manholes of the studied area*

can reduce the uncertainty of the MNF estimation to about 10%. In this study, the MNF method, one of the most common methods especially for estimating groundwater infiltration into the system (Zhang et al., 2018), was used due to its simplicity. This makes it practical for many municipalities in Norway to use without requiring advanced technical expertise.

## Case study

The investigation was based on the high-resolution recorded data from part of the sewer system in the city center of a mid-sized municipality in Norway. Here, the flow was expected to consist of purely wastewater as it is part of a completely separated system. The flowmeters were installed separately in the upstream and downstream manholes of the studied area with assistance of municipal technicians (Figure 1). The initial months were dedicated to estimating a balance between the temporal resolution of measurement and data transmission, and the energy consumption of flowmeters, along with the associated need for battery charging and maintenance.

All pipes in the studied area are made of plastic, mostly PVC. Information on the pipe diameters and lengths is presented in Table 1.

The schematic of the study area, including the locations of the flow meters, is depicted in Figure 2. It is worth highlighting that one can assume that the difference between the MNF at the outlet and the MNF at the inlet is equal to the infiltration into the system. Over the measurement period, the sensors were regularly checked for their functionality in situ, and the data was constantly monitored online, as described by Bertrand-Krajewski et al. (2021). When necessary, the sensors were maintained to ensure data quality, including plausibility, synchronicity, calibration, and maintenance.

*Table 1. Information on the pipe diameters and lengths in the studied area*

| Diameter (mm) | Length (m) |
|---|---|
| 110 | 132 |
| 160 | 168 |
| 200 | 307 |
| 225 | 35 |
| | $\Sigma = 642$ |

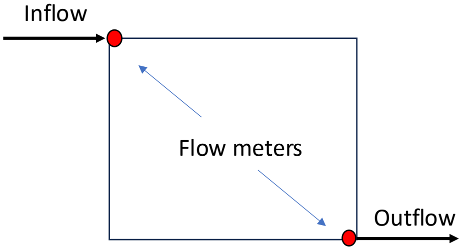


*Figure 2. The schematic of the study area and the locations of the flow meters.*

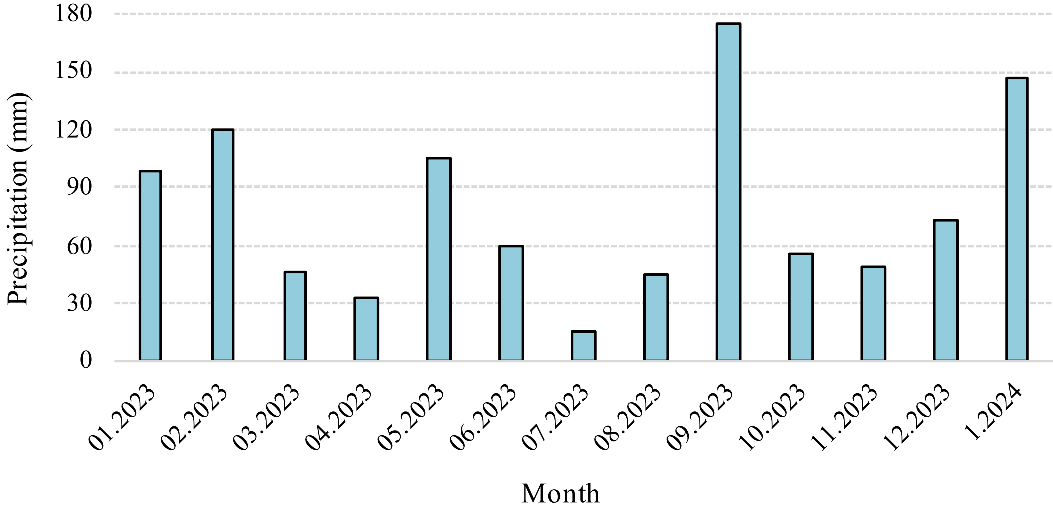


*Figure 3. Local monthly precipitation data during the study period*

Regarding the precipitation, highly resolute daily precipitation data (1-10 minutes) were downloaded from Norsk KlimaServiceSenter. The precipitation data is measured, quality controlled, and pre-processed by the station operators (NVE). The performance and exposure category is defined as C2. Monthly precipitation data during the study period is illustrated in Figure 3.

## Results and discussion

The analysis of recorded data during the study period is depicted in Figure 4. Under dry weather flow conditions, the examination of MNF values indicates an estimated (groundwater) infiltration rate of approximately 0.7 liter per second (l/s) into the studied system. Comparing the MNF at the inlet of the study area between dry and wet seasons, assuming consistent nighttime water consumption, suggests an additional inflow of around 0.25 (l/s) from the upper zone during wet conditions.

However, significant discrepancies are observed when examining flow values at the inlet and outlet of the study region during wet periods, indicating a substantial inflow within the study area. Specifically, during the wet period, the MNF value is approximately 4.3 times higher and the maximum average flow rate at the outlet is 3.3 times higher compared to the dry period. It is noteworthy that confidence intervals during the wet period are larger than those during the dry period due to increased flow fluctuations resulting from variable precipitation patterns. Also, for detecting outliers in this study, a Z-test was applied using a window containing 5 timesteps (2 timesteps before and 2 timesteps after the data under study). In the case of missing data, the average of the surrounding timesteps was used as a replacement.

As these findings demonstrate a strong direct correlation between precipitation and flow within the system, which was not expected in a separated system, they were discussed with the local municipality. This discussion revealed the presence of stormwater pipe branches spanning over 80 meters in total length. These branches, ranging in diameter from 110 to 200 mm, were found to be directly connected to the sewer network. While the municipality claimed they were previously aware of these improper connections, the findings of this research underscore the effectiveness of flow measurement investigations in identifying various issues such as illegal rainwater connections and wrongly connected stormwater pipes to the sewer network.

Nevertheless, to assess the pipe capacity and determine whether the maximum flow within

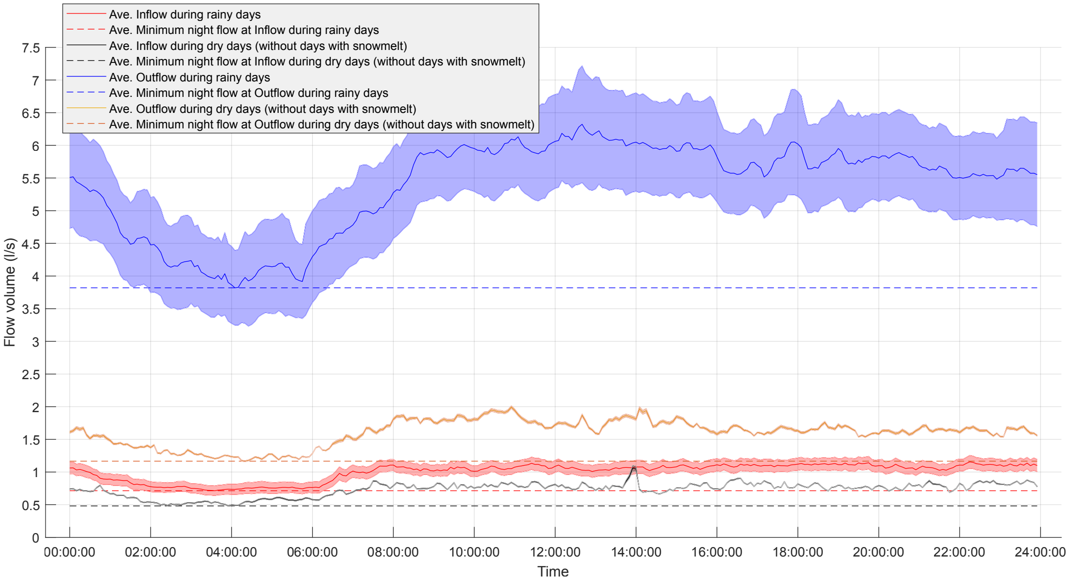


*Figure 4. The average flow values into/out of study area during wet and dry weather conditions throughout the study period*

the system would result in a combined sewer overflow (CSO) event, the capacity of the pipe at the outlet of the study area was calculated. This was done utilizing the Colebrook-White chart methodology. The PVC pipe under consideration has a diameter of 200 mm and a slope of 54%. Based on these parameters, the calculated capacity of the pipe is approximately 42.5 (l/s). This capacity far exceeds the maximum average flow observed in the pipe during the study period, which was approximately 6.25 (l/s). Therefore, it can be concluded that there is no risk of a CSO occurring due to capacity limitations in this pipe.

As another contribution of this work, the recorded data from the entire campaign period is now freely available online Mohan Doss et al. (2024). The reported parameters include Battery Voltage (V), Instantaneous Flow (l/s), Cumulative Flow ($m^3$), Water Temperature (°C), Velocity (m/s), and Water Level (m). Additionally, high temporal resolution precipitation data (1-minute intervals) is provided. All of this information is presented in Excel format. Since sewer networks are part of critical infrastructure, datasets used for analyses are often restricted, making it difficult for practitioners and researchers to evaluate their models. Publishing such an extensive dataset allows for the development of more precise I/I detection and evaluation algorithms, as well as detailed modeling and simulations.

## Conclusion

The research aimed to evaluate the extent of extraneous water inflow into the part of the sewer system in the city center of a mid-sized municipality in Norway. Utilizing the MNF method, infiltration estimates were derived, while inflow assessment relied on the analysis of recorded flow data during varying weather conditions over a span of more than a year, from January 2023 to end of January 2024. The findings indicate that inflow emerged as the primary source of extraneous water. Particularly during the wet period, the MNF value increased approximately 4.3 times, with the maximum average flow rate at the outlet experiencing a 3.3-fold surge compared to the dry period. Conversely, groundwater infiltration was estimated at around 0.7 (l/s). Apart from some on-site challenges, which are typically part of the standard procedure for setting up any measurement campaign, the compatibility of campaign findings with system data was an issue here. While the recorded data showed an obvious correlation with rainfall events, the system data did not support this, as it presented the system under study as being fully separated. Nevertheless, the local knowledge of the operators about the system, which was not fully reflected in the system data, resolved this discrepancy and led to the correct conclusion. Accordingly, this research underscores the efficacy of flow measurement studies in identifying various issues, including improper stormwater connections and illicit rainwater connections to the sewage system.

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