Influence of excessive water on wastewater treatment performance

An analysis using key performance indicators

Master's thesis in the Master's programme Innovative and Sustainable Chemical Engineering

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Department of Civil and Environmental Engineering
Division of Water Environment Technology
CHALMERS UNIVERSITY OF TECHNOLOGY
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Cover: A picture of the active sludge basins at the waste water treatment plant of Sjölunda.

Department of Civil and Environmental Engineering, Gothenburg, Sweden 2015

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ABSTRACT

High amounts of inflow to a wastewater treatment plant influence the performance of the wastewater treatment plant. The magnitude of the inflow also affects the chemical and physical composition of the sewage water. Great amounts of excessive water will reduce the performance of the wastewater treatment plant and the treatment process might need to be adjusted in order to not exceed the discharge limits.

The aim of the master thesis has been to describe and compare how the performance of different Swedish wastewater treatment plants is influenced by the total inflow. To make comparisons and evaluations, the key performance indicators below have been calculated for seven different waste water treatment plants:

- Flow per capita: Litre /person and day
- Extent of dilution: $\frac{\text{Litre inflow/person and day}}{\text{Litre charged water /person and day}}$
- Surface loading: m^3 inflow/m^2 of biological treatment and day
- Volumetric loading: m^3 inflow/m^3 of biological treatment and day

The master thesis has been carried out in corporation with Gryaab. Inflow data have been collected for 2010-2013 from the following wastewater treatment plants; Gryaab, Bromma, Henriksdal, Käppala, Syvab, Sjölunda and Gässlösa

As a result, Gryaab showed to be the wastewater treatment plant with the highest values regarding all key performance indicators. Gryaab, Gässlösa and Käppala had the largest variation in flow during the years included in the study. As a consequence of the large variations in flow, Gryaab bypassed the highest percentage of incoming water.

The study confirms the problem associated with Gryaab; the water reaching the treatment plant consists of large amounts of excessive water. Due to the restricted land use and how costly an expansion would be, the amount of water reaching Gryaab must be reduced.

Key words: wastewater treatment plant, excessive water, discharge limits, key performance indicators, inflow data

Tillskottsvattens inverkan på avloppsrening
En analys genomförd med hjälp av nyckeltal

Examensarbete i masterprogrammet innovativ och hållbar kemiteknik
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SAMMANFATTNING

Höga flöden in till en avloppsverk påverkar avloppsverkets prestanda. Mängden vatten är också avgörande för den kemiska och fysiska kompositionen av avloppsvattnet. Stora mängder tillskottsvatten påverkar reningen negativt och justeringar av reningsprocessen kanske måste göras för att inte överskrida utsläppskraven.

Syftet med examensarbetet har varit att beskriva och jämföra hur prestandan hos olika reningnsverk i Sverige påverkas av det totala inflödet. För att göra jämförelser och utvärderingar, har följande nyckeltal beräknats för sju olika reningsverk:

- Flöde per person: Liter/person och dag
- Utspädningsgrad: $\frac{\text{Liter inflöde/person och dag}}{\text{Liter debiterat vatten /person och dag}}$
- Ytbelastning: m^3 inflöde/m^2 av biologisk rening och dag
- Volymetrisk belastning: m^3 inflöde/m^3 av biologisk rening och dag

Examensarbetet har utförts i samarbete med Gryaab. Inflöde har samlats in för 2010-2013 från följande reningsverk: Gryaab, Bromma, Henriksdal, Käppala, Syvan, Sjölunda och Gässlösa.

Resultaten visade att Gryaab var det reningsverk med högst värden gällande alla nyckeltal. Gryaab, Gässlösa och Käppala hade störst variation i inflöde under de år som var inkluderade i studien. Som en konsekvens av de stora variationerna i inflöde, breddade Gryaab högst procent av inkommande vatten.

Studien bekräftar problemen associerade med Gryaab; vatten som når reningsverket innehåller stora mängder tillskottsvatten. Eftersom markytan är begränsad och en expansion skulle bli extremt kostsam, måste mängden vatten som når Gryaab minskas.

Nyckelord: avloppsverk, tillskottsvatten, utsläppskrav, nycketal, inflöde

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Camilla Molander

Gothenburg, Sweden

April, 2015

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1 Introduction

1.1 Background

The water reaching a wastewater treatment plant (WWTP) consists of different components. Except sewage water, extraneous water derived from different sources reach the WWTP. The extraneous water includes storm water derived from precipitation and infiltration/inflow (I/I) derived from both indirect and direct sources. This extraneous amount of water influences the performance of the WWTP. When the magnitude of the inflow increases, the WWTP has to work at a higher load in order to manage the discharge limits. If the capacity of the WWTP is exceeded, a part of the water must bypass the regular treatment process.

The amount of inflow also affects the chemical and physical composition of the wastewater. To evaluate the amount and influence of extraneous water, the extent of dilution is a common key performance indicator. The extent of dilution do not consider the duration of the flow and additional key performance indicators are required to clearer describe the influence of the extraneous water.

1.2 Aim

The aim of the project is to describe and compare how the performance of different Swedish WWTPs is influenced by the total inflow. The inflow should also be characterized in order to make a comparison between the WWTPs.

1.3 Research questions

The aim of the project is going to be fulfilled by answering the following research questions:

- What is the definition of high flow?
- How is the performance of the wastewater treatment influenced by high flows?
- More specifically:

  - How is the treatment process affected? Is specific treatment required?

  - How is the volume and area demand of the basins affected?

- How is the discharges influenced by the flow?
- How should the flow be characterized in order to compare the wastewater treatment plants?

1.4 Method

The research questions are going to be answered by calculating comparable key performance indicators.

The key performance indicators are the following:

- Flow per capita: Litre /person and day
- Extent of dilution: $\frac{\text{Litre inflow/person and day}}{\text{Litre charged water /person and day}}$
- Surface loading: m^3 inflow/m^2 of biological treatment and day
- Volumetric loading: m^3 inflow/m^3 of biological treatment and day

The extent of dilution is chosen as a comparable key performance indicator since it is generally used today. The other key performance indicators are chosen in order to investigate the loading on the WWTPs. By these key performance indicators, the variation in inflow and the capacity of the WWTPs can be evaluated.

The values of mean, median, 90 and 99 percentile are going to be calculated for each key performance indicator. To compare these values, duration curves, accumulated flows and bar charts are going to be used.

1.5 Limitations

The project will be restricted to the following WWTPs in Sweden: Gryaab (Rya), Bromma, Henriksdal, Sjölunda, Käppala, and Syvab (Himmelfjärdsverket) and Gässlösa. In order to investigate various inflows, data from the rainy years of 2011 and 2012 are going to be compared. In the view of precipitation, 2011 can be considered as a rich year and 2012 as even richer. For comparison, inflow data from 2010-2013, will be shown for a selection of the WWTPs. This comparison is going to be made in order to ensure that the years included in the study are rich in the view of precipitation. If a year in the study is considered as a dry year, the variations in the inflow will be too small.

The evaluation and comparison are going to be focused on the biological treatment.

2 Theory

2.1 The components of the water flow

The total amount of water reaching a WWTP consist of different components. It is important to describe these components, in order to understand how the magnitude of the inflow varies. The components are wastewater arriving from households and industries, infiltration inflow (I/I) and storm water. Both infiltration inflow and storm water are extraneous water derived from different sources. Storm water derives from precipitation while I/I derive from both indirect and direct sources.

Infiltration is related to the level of the groundwater table and the condition of the sewer pipes. A high groundwater table results in infiltration through defect pipes, joints and manhole walls. The amount of infiltrated water depends on the rate and distribution of the perception, the length and the condition of the collection system, and the permeability of the surface. On impervious surfaces, such as buildings and pavements, the permeability is reduced and the surface runoff will increase compared to more pervious and natural surfaces. Defect sewer pipes may not only cause infiltration but also exfiltration. On the contrary infiltration, exfiltration occurs when the groundwater table is low. This causes leakage of untreated water out of the pipes into the soil.

Inflow enters the collection system by drain connections, roof leaders, foundation and basement drains, or manhole covers. Water derived from foundation and basement drains, and drains from springs and swampy areas are so called steady inflow. The steady inflow is hard to quantify and is measured together with infiltration. Direct inflow is storm water runoff directly connected to the sanitary collection system by roof leaders, yard and areaway drains and manhole covers. A third type of inflow is delayed inflow which can take several days to reach the WWTP. Possible sources are sump pumps from cellars drainage or surface water entering through manholes in pounded areas.

To collect the water, two types of collection systems are used; separated collection systems including sanitary collection systems and storm collection systems and combined collection systems. Type of collection system is one of many factors affecting the total inflow to a WWTP. During wet periods, large fractions of storm water will be present in the combined collection systems. The total inflow to the WWTP will increase in comparison with inflow transported with separated collection systems (Metcalf & Eddy, 2004)

2.2 Problems associated with high flows

The magnitude and duration of the inflow will have impact on the performance of the WWTP as well as the collection system. The problems associated with high flows, such as discharged volumes, overflows and dilution of pollutants, will be discussed below.

2.2.1 Discharged water and risk of overflows

When the flow increases the operating and maintenance costs increase and the capacity of the WWTP might be exceeded. If this happens, the WWTP is no longer able to treat all of the water. A part of the water must bypass total treatment and be discharged into receiving waters. If the capacity of the pipes is exceeded, the risk of contamination of the water supply will increase due to exfiltration (Metcalf & Eddy, 2004)

The quality of the collection system deteriorates as a function of age, traffic load and overburden, poor design and lack of maintenance. Since the sewers are underground, defects and capacity limitations will not be discovered until a major failure occurs. The combination of deteriorating pipes and high flows will affect the entire sewerage system negatively and increase the risk of overflows to basements and streets (Lai, 2008).

The components of the flow have different influence on a WWTP regarding duration. The inflow reacts much faster on precipitation compared to infiltration which can increase the total inflow to the WWTP for several weeks after heavy precipitations. In an average WWTP, 35 % of the water is infiltration inflow, 35 % storm water and 30 % sanitary sewage. Accordingly, 70 % of the total inflow is non-or less polluted water that will leave the treatment plant more polluted than originally. To control the pollution, combined sewer overflow (CSO) tanks can be installed. It is a sufficient way to handle high flows if the tanks are emptied within a short time. If the flow exceeds the capacity of the WWTP, the emptying time will be considerably longer and the consequence is increased discharged pollutant load. Investigations have showed that CSO tanks are frequently underestimated which will impair the pollution control (Weiß,G., Brombach, H. and Haller,B., 2002).

2.2.2 Impacts of high flow regarding pollutants

The extraneous water treated in the WWTP will not only cause increased operating costs and increase the frequency of overflows. It will also have impacts regarding the load and concentration of pollutants. When the inflow increases, both the physical and chemical properties of the wastewater change.

The properties of the wastewater have impacts on the process performance and the quality of the effluent. The biological treatment including nitrification and denitrification will be affected but also the quality of the sludge and the ability to adsorb particles. If the ability of flocculation and adsorption is reduced, the concentration of suspended solids in the effluent might increase.

A study was carried out at the Rya WWTP in Gothenburg, Sweden. Figure 1a-f shows the concentration and mass flow of chemical oxygen demand (COD), total phosphorus (P(tot)), suspended solids (SS) and ammonium (NH_4^+) into the WWTP as a function of the flow (Q_{PS} = primary settled water). By looking at the figure, it can be concluded that the concentrations of these compound decrease with the flow while the mass flow to some extent increases. Both the concentration and mass flow of nitrate/nitrite (NO_3^-/NO_2^-), see Figure 1e-f, increased with the flow (Wilén, B-M.,Lumley, D., Mattsson,A and Mino,T., 2006).

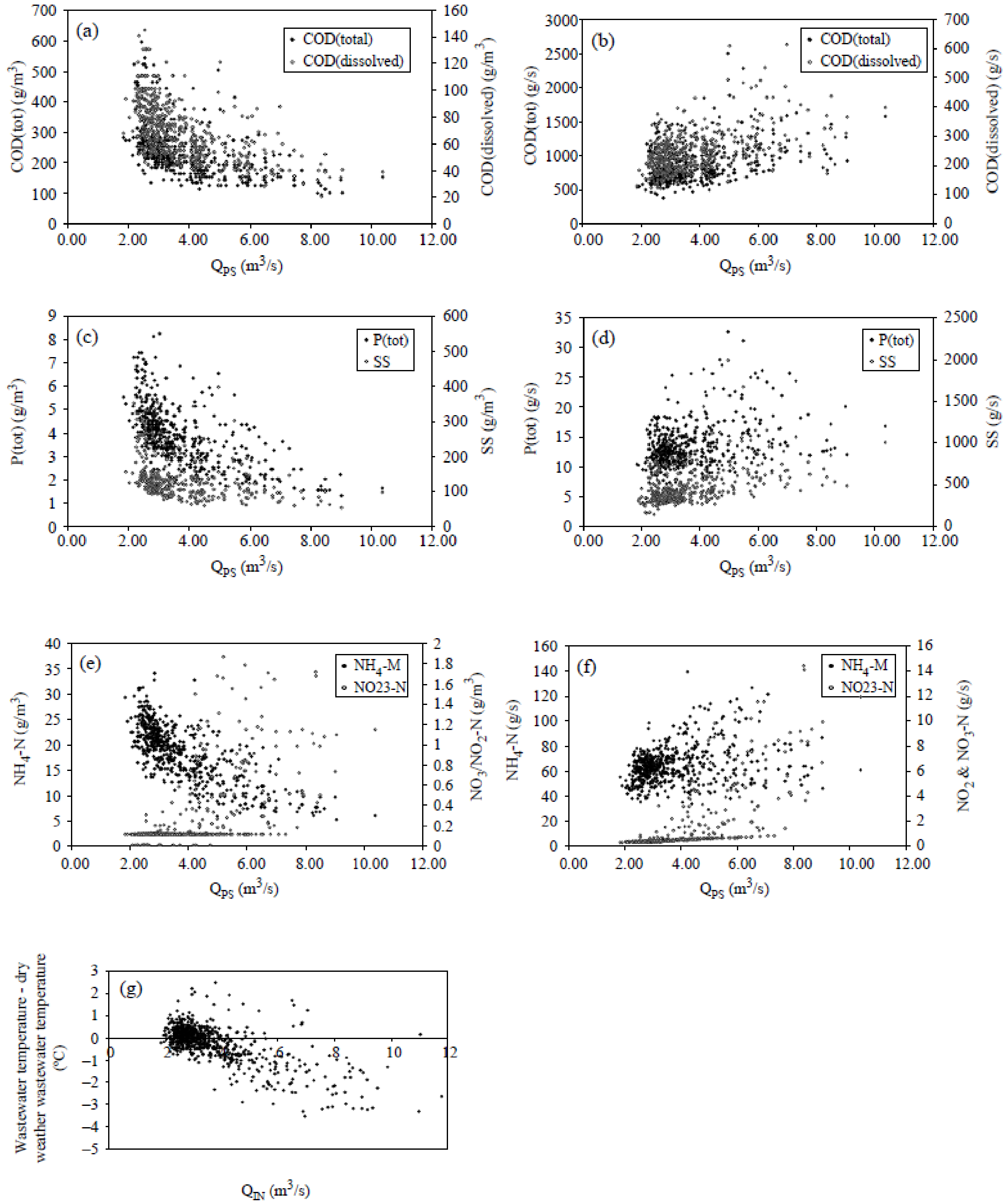


Figure 1a-g. Changes in process parameters as a function of the flow (a) concentration of COD; (b) mass flow of COD; (c) concentration of P(tot) and SS; (d) mass flow of P(tot) and SS; (e) concentration of NH_4-N and NO_3-N; (f) mass flow of NH_4-N and NO_3-N; (g) temperature difference between dry and wet weather conditions (Wilén, B-M.,Lumley, D., Mattsson,A and Mino,T., 2006).

The magnitude of the inflow has impact on both the amount of oxygen in the wastewater and the temperature of the water. As the inflow to the WWTP increases, the oxidation reduction potential of the incoming wastewater increases. The properties of the wastewater will change due to the fact that the biological processes are more aerobic compared to lower flows.

Figure 1g shows how the temperature drops with the flow. As well as it takes time (several hours) for the water to reach the same temperature as the incoming water, it also takes time to increase the temperature after a temperature drop.

Figure 2a-f shows the concentration and mass flow of COD, total phosphorus, SS and total dissolved phosphorus and phosphate (PO_4^{3-}) in the effluent as a function of the flow. The concentration of COD and total phosphorus in the effluent (Figure 2a,c) were quite independent of the flow. Also the concentration of nitrate/nitrite showed this behavior. By looking at Figure 2e, it can be seen that the concentration of dissolved phosphorus and phosphate in the effluent decrease with the flow. The same trend could also be seen by looking at the concentration of ammonium. Figure 2b,d,f show that the mass flow for all of the compounds increase with the flow (Wilén, B-M.,Lumley, D., Mattsson,A and Mino,T., 2006).

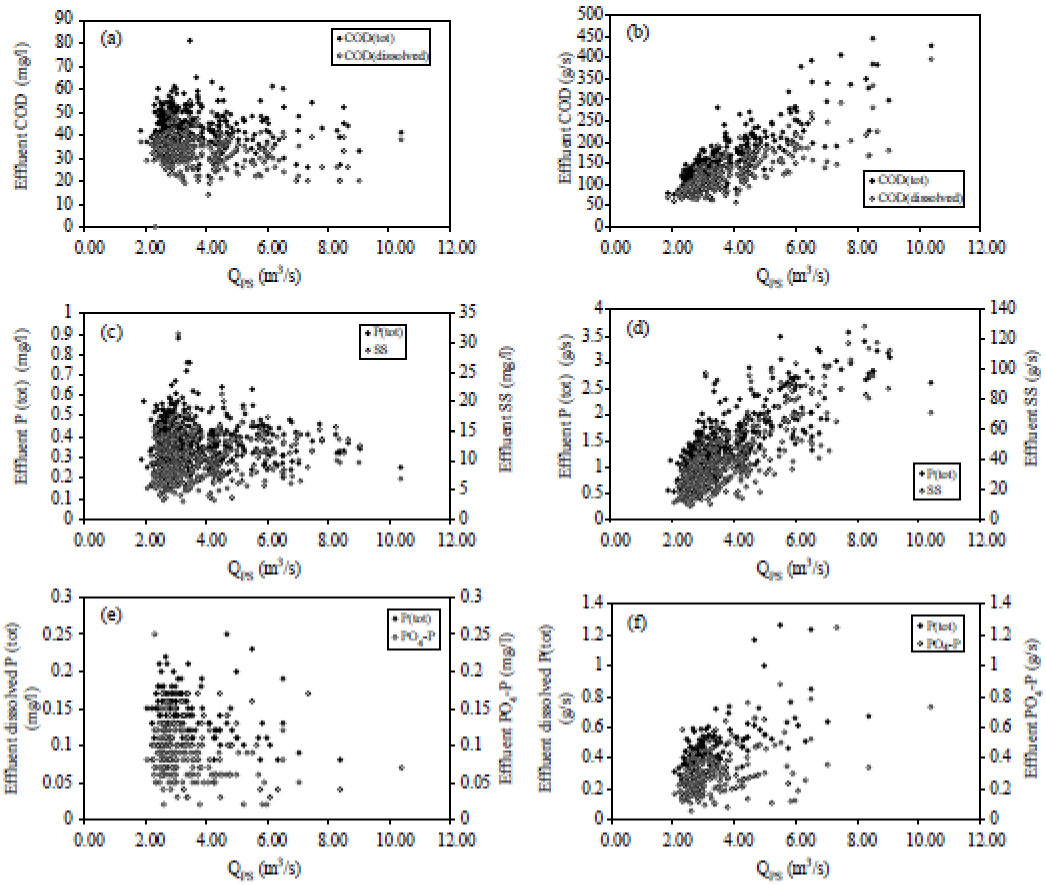


Figure 2. Change in effluent quality as a function of flow. (a) concentration of COD; (b) mass flow of COD; (c) concentration of P(tot) and SS; (d) mass flow of P(tot) and SS (e) concentration of P(tot) and phosphate (dissolved); (f) mass flow of P(tot) and phosphate(dissolved) (Wilén, B-M.,Lumley, D., Mattsson,A and Mino,T., 2006).

Another case study was carried out in the city of Dresden, Germany. The objective of the case study was to investigate the impact of infiltration rate regarding the load of COD, biological oxygen demand (BOD) and NH_4^+. The investigation also includes impacts of temperature regarding the NH_4^+ load. The infiltration rates were simultaneous varied by 0 %, 40 % and 80 % of the sanitary flow during dry weather conditions and the result is showed in Figure 3.

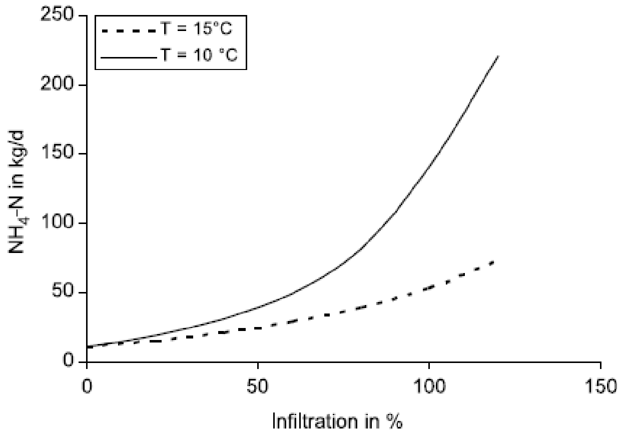


Figure 3. The load of NH_4^+ in the WWTP effluent as a function of infiltration rate and temperature (Schulz,N., Baur,R. and Krebs,P., 2005).

The load of NH_4^+ in the effluent increases as the infiltration rate increases and a higher temperature yields a lower load of NH_4^+. Also the load of chemical oxygen demand (COD) and biochemical oxygen demand (BOD) increases when the infiltration rate is increased. However, the concentration of COD and BOD will decrease due to the extra amount of water. When the infiltration rate is increased, the capacity of the WWTP is reduced and the concentration of ammonium in the effluent will increase. The impacts of increased infiltration rate regarding pollutant load and concentration are summarized in table 1 (Schulz,N., Baur,R. and Krebs,P., 2005).

Table 1. Impacts of increased infiltration rate regarding pollutant load and concentration (Schulz,N., Baur,R. and Krebs,P., 2005).

Impacts of increased infiltration rate		
Pollutant	Load	Concentration
WWTP COD	+	-
River BOD	+	-
WWTP NH_4^+	++	+
River NH_4^+	++	+

2.3 What methods are available to characterize the inflow?

To characterize the flow and quantify the components, different methods are applicable. The two methods presented below can be used for combined collection systems.

2.3.1 The triangle method

In the “triangle method”, illustrated in Figure 4, the curve represents the daily mean inflow sorted in ascending order. The sanitary sewage can be considered as constant and yields the black area in the figure. This value is calculated by multiply the number of people connected to the WWTP with the volume of charged water. The total area under the curve minus the black area is the annual volume of storm water runoff plus I/I. This area can be divided into two separate areas representing storm water and I/I. As an assumption, I/I are maximized after heavy precipitations and minimized when the sewer is filled with storm water. The explanation to this assumption is exfiltration. A straight line is drawn to the curve and the slope of this line depends on the number of days with surface runoff measured by the WWTP. By calculating the percentage of these days, the coordinates of intersection with the curve can be determined. The area above this line is storm water and area below is I/I.

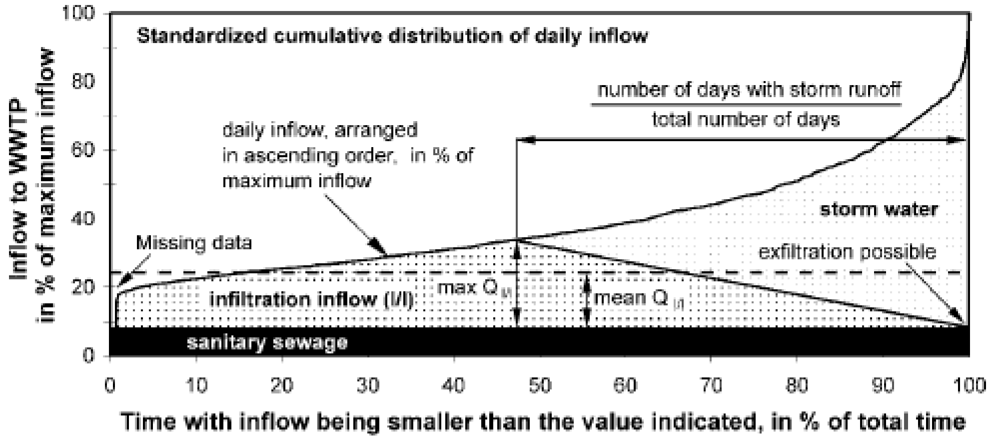


Figure 4. Characterization of the inflow using the triangle method. The graph shows the components sanitary sewage, storm water and I/I (Weiß,G., Brombach, H. and Haller,B., 2002).

The shape of the curve can directly be used to evaluate the amount of I/I. A high plateau at the beginning of the curve, see Figure 5, means larger amounts of I/I and less amounts of storm water (Weiß,G., Brombach, H. and Haller,B., 2002).

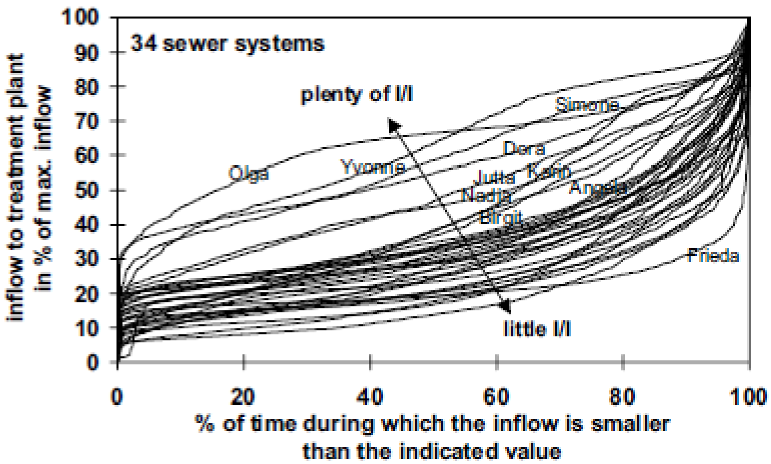


Figure 5. The distribution curves can directly be used to evaluate the amounts of I/I (Weiß,G., Brombach, H. and Haller,B., 2002).

2.3.2 The moving-minimum method

Another method to characterize the flow is the moving-minium method, illustrated in Figure 6.

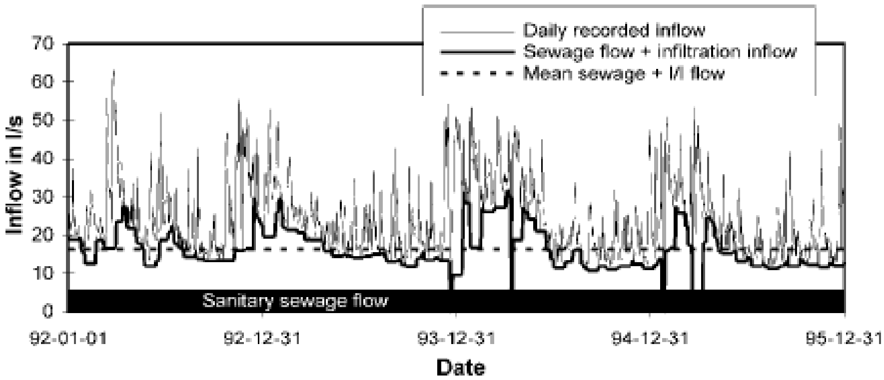


Figure 6. An example of the moving-minimum method (Weiß,G., Brombach, H. and Haller,B., 2002).

The sum of sanitary sewage plus I/I flow at any day is set equal to the dry weather flow by looking at the minimum daily inflow during the past 21 days. By this method, and in contrast to the triangle method, seasonal variation is taken into account (Weiß,G., Brombach, H. and Haller,B., 2002).

2.4 How are the discharges regulated and what regulations are expected in the future?

Sweden is a member of the European Union (EU) and must follow their water laws. These laws are incorporated into the Swedish legislation by the Environmental Code and in the Swedish EPA's Regulation. The regulations have been developed and enlarged during the years and in 2000, the Water Framework Directive was adopted. The directives involve among other things regulations about the discharges from wastewater treatment. Limit values for nitrogen, phosphorus and oxygen-consuming substances in the wastewater outflows are regulated by these directions (Naturvårdsverket, 2009).

In order to protect the marine environment, the Europe Union has started a programme named the Baltic Sea Action Plan (BSAP). The programme involves commitments for each country in order to reduce the amount of discharged nitrogen and phosphorous into the Baltic Sea. The commitments were established 2007 and Sweden was dedicated to reduce the nitrogen and phosphorous discharge with 20780 tons respectively 290 tons. These limits were revised 2013, meaning stricter phosphorus discharges (530 tons/year) while the discharge limit of nitrogen was reduced (9240 tons/year). The combination of growing population and stricter discharge limits of phosphorus is a challenge for the WWTP (HELCOM, 2013).

2.5 Description of the WWTPs

The wastewater treatment process consists of three fundamental treatments: mechanical, biological and chemical. These treatments can be carried out by different methods and the WWTPs described below all have their own configuration depending on amount of flow, available area and discharge limits. A general treatment process will be explained and afterwards will a description of the WWTP be presented, pointing out the similarities and differences between the WWTPs.

Detailed information about the WWTPs regarding dimensioned values, the biological treatment processes and discharge limits can be found in section 2.5.7. Process charts of the WWTPs can be found in the appendix (7.1).

The mechanical treatment includes bar screens, sand traps and primary sedimentation tanks. The bar screens catch pieces of waste called "screenings" which later are combusted in order to produce electricity and heat. In the sand trap heavier particles such as sand and gravel sink to the bottom and lighter particles follow the water flow.

The water is then treated in the primary sedimentation tanks where heavy particles sink to the bottom of the settlers. Fat is lighter than water and will float to the surface. Both the sludge on the bottom of the settlers and the fat at the surface can be scraped away.

In the chemical treatment the dissolved phosphorus is treated. By adding iron sulphate, the phosphorus precipitates with the iron salt for later removal together with the activated sludge in the secondary sedimentation tanks. The iron sulphate is either added before the primary settler (pre-precipitation) or just before or in the beginning of the aeration tank (simultaneous precipitation).

In the biological treatment, nitrogen is removed in two steps. The first one is the nitrification where ammonium nitrogen is transformed to nitrate. The second one is the denitrification where the nitrate is transformed to nitrogen gas and released to the air. These two steps can be carried out in activated sludge tanks divided into aerated and non-aerated zones but also in trickling filters, fluidized beds or by post-denitrification.

After the biological treatment, the water proceeds to the secondary sedimentation tanks where bacteria and clumped phosphorus from previous treatment sink to the bottom as sludge. To make the most of the bacteria and the potential of purification, most of the sludge is returned to the activated sludge tanks. Due to the fact that bacteria grow and proliferate, a portion of the sludge is pumped away to sludge treatment.

The last step in the treatment before the water is released into the river is the passage through the disc filters. Very small particles are removed from the water, containing for example phosphorus (Gryaab, 2009).

2.5.1 Gryaab

Storm water and wastewater derived from households and industries from the 7 municipalities in the Gothenburg area, ends up in Gryaab's tunnel system. The biological treatment at Gryaab consists of activated sludge tanks, trickling filters and post-denitrification.

The trickling filters treat a part of the effluent from the secondary sedimentation tanks. These trickling filters consist of a plastic material constructed in order to maximize the growth area of bacteria forming a biofilm. In order to make the most of the potential source of carbon in the wastewater, the pre-settled wastewater is mixed with the effluent from the trickling filters and return sludge for denitrification in the activated sludge tank. In order to reduce the load on the activated sludge process, a part of the effluent from the trickling filters is transported to post-denitrification basins (moving bed biofilm reactor=MBBR). These basins contain small pieces of plastic moving in the water. Bacteria grow on this plastic media, called suspended carriers, and transform the ammonium nitrate to nitrogen gas. An external and organic source of carbon, methanol, is added and used as fuel for the bacteria (Gryaab, 2009).

There are many reasons to Gryaab's choices of process steps and treatment methods. Gryaab has a limited area and in combination with high flows and stricter discharge limits, every installation needs to be carefully considered. When the post-denitrification process and the disc filters were installed, the most crucial reason was the lack of space. Both process steps are reliable, well-proven and got a potential for greater capacity in the future in order to meet the population growth and even stricter discharge limits (Gryaab, 2011).

As mentioned earlier, high flows increase the risk of exceeding the capacity of the WWTP. The capacity of the biological treatment at Rya is 7 m^3/s and when this limit is exceeded, specific actions must be taken. Instead of performing mechanical treatment, some of the primary settlers are configured in order to perform chemical treatment. By adding specific chemicals, phosphorus can be removed with the same effectiveness as in the regular process. This chemical treatment is called direct precipitation which means that an addition amount of 3 m^3/s can be treated (Gryaab, 2010).

2.5.2 Bromma and Henriksdal

The WWTPs at Henriksdal and Bromma are located in Stockholm. The WWTPs are similar to each other but Bromma is much smaller and a shutdown is planned in the near future (Stockholm vatten, 2011a). Bromma WWTP consists of two facilities, Åkeshov and Nockeby. The mechanical and chemical treatment is carried out at Åkeshov. The water proceeds to Nockeby for biological treatment. The biological treatment takes place in the activated sludge tanks where both nitrification and denitrifrication occurs. Most of the sludge is returned from the secondary sedimentation settlers to the active sludge tanks in the same way as in Gryaab's process. At last, the water runs through filters with sand in order to remove the smallest particles (Stockholm vatten, 2011b).

2.5.3 Syvab

The WWTP at Syvab is called Himmelfjärdsverket and is located in Södertälje. The biological treatment consists of activated sludge tanks and fluidized beds.

Nitrification takes place in the activated sludge tanks and denitrificaiton in the fluidized beds where bacteria grow on grains of sand. The capacity of the biological treatment at Syvab depends on the temperature of the water. A higher temperature during the summer increases the capacity while a lower temperature during the rest of the year decreases the capacity, see Table 2 below.

Syvab has two sedimentation steps after the activated sludge tanks. Before the secondary sedimentation tanks, there is an intermediate sedimentation step. In this step, the sludge on the bottom of the tanks is returned to the activated sludge tanks. The sludge that did not have time to sink to the bottom in the intermediate sedimentation step is taken care of in the secondary sedimentation step. This sludge is called tertiary sludge and is scraped away. As a last step in the process, filtration is carried out. The filtration takes place in the disc filters where 50 % of the suspended particles are removed. The rest of the suspended particles are removed in the sand filters (Syvab, 2009).

2.5.4 Käppala

The process at Käppala WWTP in Stockholm is similar to the processes at Bromma and Henriksdal. The nitrification and denitrification takes place in the activated sludge tanks. Unlike the other WWTP, iron sulphate is added in the end of the treatment to remove the remaining phosphorus that is not removed by the micro organisms in the biological treatment. The last step is filtration through sand filters where small particles are removed (Käppala Association, 2010).

2.5.5 Sjölunda

The incoming wastewater to Sjölunda WWTP in Malmö is pumped with two different capacity modes depending on the amount of the incoming water flow. During dry weather, the water is pumped with tree pumps. During precipitation and when higher flows are present, the water is directly pressed to the inlet of the WWTP by the pump stations. Combined sewage overflows occur when the capacity of the WWTP is exceeded. To handle this, water is pumped to a facility near the WWTP.

The treatment process at Sjölunda is almost identical to the process at Gryaab. The mechanical, chemical and biological treatment methods are the same except from the last step in process. As last step, a flotation process is used. Small particles from the nitrogen removal process formed as flocs are removed by adding small bubbles of air. The flocs will float to the surface and can be scraped away (VA Syd, 2013).

2.5.6 Gässlösa

Gässlösa is the largest WWTP in Borås. The biological treatment consists of activated sludge tanks. After the biological treatment the organic material sink to the bottom of intermediate sedimentation settlers. The sludge from the these settlers is either sent back to the activated sludge tanks in order to add more bacteria, or sent to the digesters.

The chemical treatment is carried out in basins where chemicals are added. By adding chemicals, flocs of phosphorus are created. These flocs become greater and greater and continue to the last step of the wastewater treatment, the final sedimentation. The final sedimentation consist of lamellas and in this step, the flocs sink to the bottom of the sedimentation and become sludge (Borås energi och miljö, 2014).

2.5.7 Detailed information about the WWTPs

The tables below include information about the WWTPs regarding dimensioned values (Table 2), the biological treatment processes (Table 3) and discharge limits (

Table 4).

Table 2. Dimensioned values of the WWTPs regarding populations connected, capacity and amount of sewage water.

Dimensioned values				
Value		Populations connected	Capacity of biological treatment (l/p/d)	Sewage water (l/p/d)
WWTP	Year			
Gryaab Gryaab	2011 2012	666441 693309	908 872	196 200
Bromma Bromma	2011 2012	316 200 320 500	820 809	182 198
Henriksdal Henriksdal	2011 2012	767 700 782 600	619 607	182 198
Syvab Syvab	2011 2012	290 412 294 419	494 (< 13^{o}C) 660 (> 13^{o}C) 487 (< 13^{o}C) 651 (> 13^{o}C)	242 241
Käppala Käppala	2011 2012	452 909 454 909	950 950	195 194
Sjölunda Sjölunda	2011 2012	291 200 303 240	1484 1425	254 245
Gässlösa Gässlösa	2011 2012	82 600 86 436	1569 1499	236 207

Table 3. A summary of the WWTPs biological treatment regarding included process areas and volumes.

Biological treatment					
WWTP	Included process steps	Area (m^2)	Area, secondary sedimentation tanks included (m^2)	Volume (m^3)	Volume, secondary sedimentation tanks included (m^3)
Gryaab	Activated sludge tanks, trickling filters, post-denitrification	8810	29910	78 500	150 700
Bromma	Activated sludge tanks	5000	10 600	24 000	50 000
Henrikdsdal	Activated sludge tanks	18 900	29 900	204 000	262 000
Syvab	Activated sludge tanks, fluidized beds	4762	17 002	22 600	68 200
Käppala	Activated sludge tanks	17 551	30 051	122 003	187 123
Sjölunda	Activated sludge tanks, trickling filters, post-denitrification	8550	14 620	34 770	57 140
Gässlösa	Activated sludge tanks	2280	3480	12 280	17 080

Table 4. Discharge limits (mg/liter) of pollutions.

Discharge limits			
Value *(mg/liter)*	BOD_7	P-tot	N-tot
Gryaab	10 (limit value per calendar year)	0,4[a] (limit value per calendar year)	10 (target value per calendar year)
Bromma	8 (mean value per quarter)	0,3 (mean value per quarter)	10[b] (mean value per calendar year)
Henrikdsdal	8 (mean value per quarter)	0,3 (mean value per quarter)	10[b] (mean value per calendar year)
Syvab	8 (target value per quarter)	0,5 (target value per calendar year)	10 (target value per calendar year)
Käppala	8 (limit value per quarter)	0,3 (limit value per calendar year)	10[b] (target value per calendar year)
Sjölunda	12 (target value per month)	0,3 (target value per month)	10 (target value per calendar year)
Gässlösa	10 (mean value per quarter)	0,3 (mean value per month)	10 (mean value per calendar year)

[a] 0,3 mg/liter as a target value per calendar year and as a mean value during the 3-month periods March-May and June-August.[b] 3 mg/liter NH_4 as mean value during July-October

3 Method

The project has been carried out in three steps and these will be explained below.

3.1 Literature review

As a first step, a literature review was done to study earlier experience regarding the subject. The research was focused on some specific areas:

- Included components in the water flow
- Problems associated with high flows
- Available methods to characterize the inflow
- Description of included WWTPs

After the literature review was done and summarized into a theory part, a couple of research questions were formulated.

3.2 Data collection

Based on the research questions, four key performance indicators were determined. To calculate these key performance indicators, a large amount of data was collected. Before the main collection of data could begin, limitations for the study were decided. Since investigation of various inflows was of importance, daily inflows from 2010-2013 were compared. The two years with the heaviest precipitation were chosen in order to restrict the data collection.

Data included in the collection was:

- Daily inflow
- Populations connected
- Capacity of the biological treatment
- Area and volume of the biological treatment
- Volume of sewage water

The data and process descriptions for each WWTP were obtained by e-mail conversations and from the home pages of the WWTPs.

Two methods to characterize the flow were chosen. To apply the triangle method, data regarding the weather were required. Number of days with precipitation was extracted from a database of the Swedish Meteorological and Hydrological Institute (SMHI).

3.3 Compiling of data and calculations

The large amount of data was compiled in Excel and the values of the key performance indicators were calculated. To compare the results, the calculated values were summarized in tables and graphs.

With the information from the SMHI and the known data mentioned above, the triangle -and moving minimum method were applied. Graphs showing both methods were created and calculations were performed in order to calculate the percentage of the different water components. To calculate the percentage for the triangle method, the trapezoidal rule was used.

4 Results and discussion

The results of the key performance indicators, relationship between capacity and amount of biological treated water and the methods to characterize the flow will be presented below. This section also contains a following discussion.

4.1 Key performance indicators

The results of the key performance indicators will be presented in the following order:

- Flow per capita: Liter/person and day
- Extent of dilution: $\frac{\text{Litre inflow}}{\text{Litre charged water}}$
- Surface loading: m^3 inflow per day/m^2 of biological treatment
- Volumetric loading: m^3 inflow per day/m^3 of biological treatment

Results of mean, median, 90 percentile, 99 percentile will be presented together in tables while the ratio of $\frac{\text{90 percentile}}{\text{median value}}$ and $\frac{\text{99 percentile}}{\text{median value}}$ will be presented in a separate table.

4.1.1 Flow per capita

In Table 5 and Figure 7 the results of flow per capita are summarized. The table includes results with data derived from 2011 and 2012 but also 2010 and 2013 for Gryaab and Bromma. A comparison of Gryaab and Bromma with data from 2010-2013 was made in order to ensure that no year, considered as dry year, was included in the study.

Table 5. Results of flow per capita.

Flow per capita					
Value (l/p/d)		Mean	Median	90 percentile	99 percentile
WWTP	Year				
Gryaab	2010	513	425	845	1296
Gryaab	2011	575	478	977	1549
Gryaab	2012	554	475	878	1364
Gryaab	2013	468	397	688	1148
Bromma	2010	399	358	541	875
Bromma	2011	388	355	509	791
Bromma	2012	443	410	570	933
Bromma	2013	405	382	503	754
Henriksdal	2011	324	296	427	688
Henriksdal	2012	361	330	477	791
Syvab	2011	417	404	499	669
Syvab	2012	411	397	483	635
Käppala	2011	312	277	433	760
Käppala	2012	361	330	499	799
Sjölunda	2011	398	354	532	921
Sjölunda	2012	322	299	427	579
Gässlösa	2011	533	466	776	1212
Gässlösa	2012	493	430	719	1092

The values derived from 2010 and 2013 for Gryaab in Table 5 were lower compared to the values derived from 2011 and 2012. For Bromma, the values derived from 2012 were the highest, but 2011 was the year with the lowest mean and median value. The values of the 90 and 99 percentile derived from 2011 were on the other hand higher compared to the values from 2010.

These results confirm that 2012 were richer than 2010 and 2013 in the view of precipitation. 2011 was the year with the richest precipitation in the west part of Sweden while 2012 was the year with the richest precipitation in the east part of Sweden. In order to investigate various inflows, the results will be focused on values derived from 2011 and 2012.

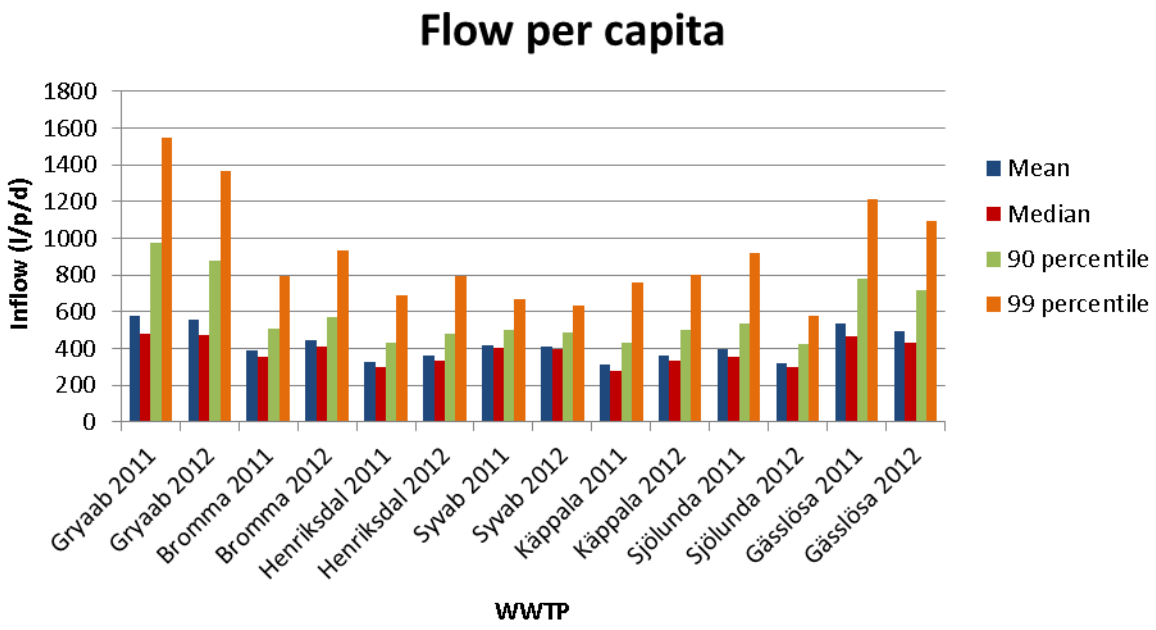


Figure 7. Results of flow per capita illustrated by a bar chart.

The bar chart illustrated in Figure 7 shows that Gryaab had the greatest mean, median, 90 percentile and 99 percentile, for both 2011 and 2012. Also the values of Gässlösa were greater than the other WWTPs. Compared to each other the rest of the WWTPs had quite similar values. By comparing the flow per capita during 2011 and 2012 for each WWTP it can be seen that Gryaab, Gässlösa and Sjölunda had greater values during 2011 while Bromma, Henriskdal and Käppala had the greatest values during 2012. Syvab had also greater values during 2011 but the difference between 2011 and 2012 was relatively small. The conclusion is that the precipitation was richer in the west and south part of Sweden during 2011 compared to 2012 and richer in the east part of Sweden during 2012 compared to 2011.

Conclusions can be made by looking at the difference between the mean and the median. Inflow with high peaks will increase the mean while the median is related to the number of high peaks. If the number of high peaks is low, the median will be less affected than the mean. Both Gryaab and Gässlösa are examples of this phenomenon. These two WWTPs had inflows with extremely high peaks which also explain the high values of the 99 percentile for these two WWTPs.

Figure 8 and 9 show the duration curves for 2011 respectively 2012.

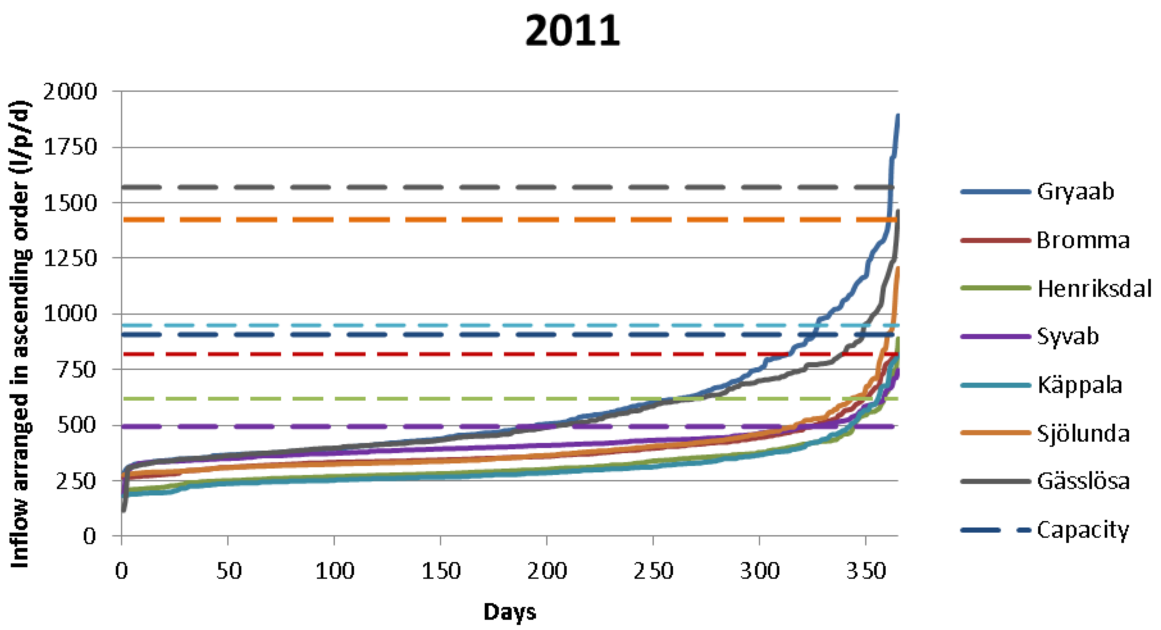


Figure 8. Duration curves representing the inflow for each WWTP arranged in ascending order (2011). The dashed lines represent the capacity of biological treatment for each WWTP.

In Figure 8, the line representing Gryaab is far more above the capacity than the other WWTPs. On an average, 5.5 % of the inflow to Gryaab exceeded the capacity. In comparison, Syvab exceeded the capacity with 2.6 % and Henriksdal with 0.6 %. The rest of the WWTPs did not exceed the capacity during 2011.

Two clusters can be identified in Figure 8. The upper one consists of WWTPs from the west part of Sweden (Gryaab and Gässlösa). The lower one consists of WWTPs from both the east and the south part of Sweden (Bromma, Henriksdal, Syvab, Käppala and Sjölunda). The lower duration curves are more flat compared to the duration curves in the upper cluster. The slope of the duration curve describes the flow pattern of the inflow to the WWTPs. If the curve is flat, as in the lower cluster, the flow pattern can be described as short and fast. In the upper cluster, on the other hand, the flow pattern can be considered as long and slow. As a consequence, the WWTPs in the west part of Sweden bypassed more water during 2011 than the WWTPs located in the east and south part of Sweden. Gryaab is the WWTP that bypasses most water but are also the only WWTP with permission to bypass as much as 3-4 times the amount of sewage water.

Another explanation to the duration curve of Sjölunda could be the possibility to even out the inflow in specific storages. Sjölunda is the WWTP that is most remarkable regarding capacity versus the magnitude of the inflow. The capacity of Sjölunda is almost 40 % larger than the capacity of Gryaab but during 2011, the mean of flow per capita was about 45 % less than the value of Gryaab.

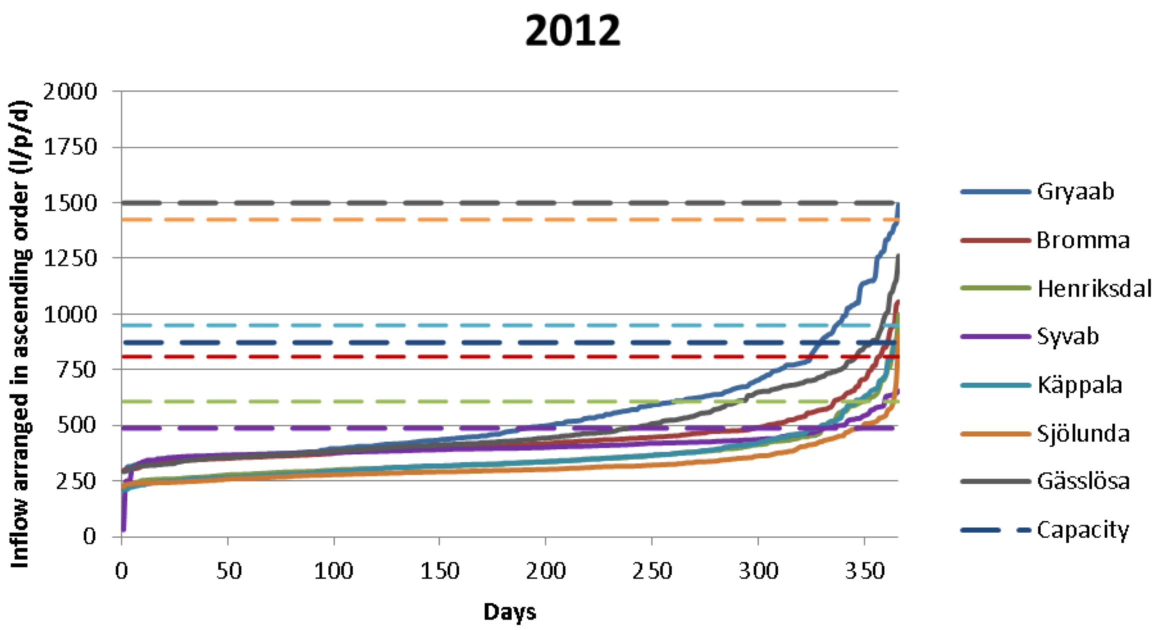


Figure 9. Duration curves representing the inflow for each WWTP arranged in ascending order (2012). The dashed lines represent the capacity of biological treatment for each WWTP.

Also in Figure 9, Gryaab is far more above the capacity compared to the other WWTPs. On an average, 4.4 % of the inflow to Gryaab exceeded the capacity, 1.4 % of the inflow to Syvab and 1.5 % of Henriksdal's inflow exceeded the capacity respectively. Compared to 2011, where Bromma did not exceed the capacity, the inflow exceeded the capacity with 0.6 % during 2012. The rest of the WWTPs did not exceed the capacity during 2012.

From these two graphs, the following differences can be seen: the amount of inflow to Gryaab and Syvab that exceeded the capacity decreased during 2012 while the inflow to Henriksdal and Bromma that exceeded the capacity increased during 2012.

By looking at the slopes of the duration curves, the same two clusters can be identified as for 2011. The two clusters are however harder to identify by looking at the results from 2012 compared to 2011. Gryaab and Gässlösa are still in the upper cluster but Bromma, for example, had a couple of days with heavy precipitation and this led to a much steeper slope at the end of the duration curve.

4.1.2 Extent of dilution

In Table 6 and Figure 10 the results of extent of dilution are summarized.

Table 6. Results of the extent of dilution.

Extent of dilution					
Value $\left(\frac{Litre\ inflow}{Litre\ sewage\ water}\right)$		Mean	Median	90 percentile	99 percentile
WWTP	Year				
Gryaab	2011	2.8	2.3	4.8	7.6
Gryaab	2012	2.8	2.4	4.3	6.7
Bromma	2011	2.1	2.0	2.8	4.3
Bromma	2012	2.2	2.1	2.9	4.5
Henriksdal	2011	1.8	1.6	1.2	3.8
Henriksdal	2012	1.8	1.7	2.3	3.8
Syvab	2011	1.7	1.7	2.1	2.8
Syvab	2012	1.7	1.7	2.0	2.6
Käppala	2011	1.6	1.4	2.2	3.9
Käppala	2012	1.9	1.7	2.5	4.1
Sjölunda	2011	1.6	1.4	2.1	3.6
Sjölunda	2012	1.3	1.2	1.7	2.3
Gässlösa	2011	2.3	2.0	3.3	5.2
Gässlösa	2012	2.4	2.1	3.5	5.3

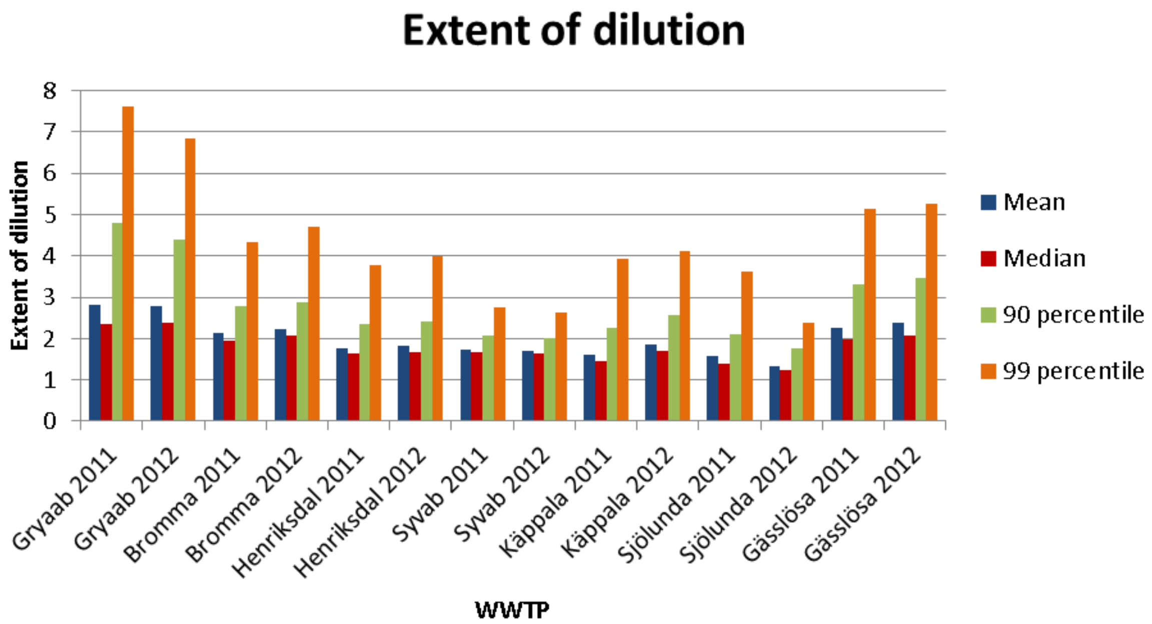


Figure 10. Results of extent of dilution illustrated by a bar chart.

As a consequence of the great amount of flow per capita, Gryaab and Gässlösa also had the greatest extent of dilution during both 2011 and 2012 (Figure 10). The mean was about 2.8 for Gryaab and 2.4 for Gässlösa (about 1.5-2 for the other WWTPs) but the most interesting is the value of the 90 and 99 percentile. These values were much greater compared to the values of the other WWTPs. This means that the inflow to Gryaab was remarkable high during some days during 2011 and 2012. Also Bromma stands out a bit regarding the 90 and 99 percentile.

4.1.3 Surface loading

The results for the surface loading below, as well as the volumetric loading, are based on calculations where the secondary sedimentation tanks have been both excluded and included. In Table 7 and Figure 11 the results of surface loading (secondary sedimentation tanks excluded) are summarized.

Table 7. Results of surface loading.

Surface loading						
Value $\left(\frac{m^3 \text{ inflow per day}}{m^2 \text{ of biological treatment}}\right)$		Mean	Median	90 percentile	99 percentile
WWTP	Year				
Gryaab	2011	43.5	36.1	73.9	117.4
Gryaab	2012	43.5	37.3	68.1	105.8
Bromma	2011	24.5	22.5	32.3	50.0
Bromma	2012	28.4	26.3	36.4	57.4
Henriksdal	2011	13.1	12.0	17.4	27.9
Henriksdal	2012	14.9	13.6	19.2	31.5
Syvab	2011	25.4	24.6	30.4	40.8
Syvab	2012	25.4	24.6	29.6	39.2
Käppala	2011	8.1	7.2	11.2	19.7
Käppala	2012	9.4	8.6	12.8	20.6
Sjölunda	2011	13.6	12.0	18.1	31.4
Sjölunda	2012	11.4	10.6	15.1	20.3
Gässlösa	2011	19.3	16.9	28.1	43.9
Gässlösa	2012	18.7	16.3	27.3	41.4

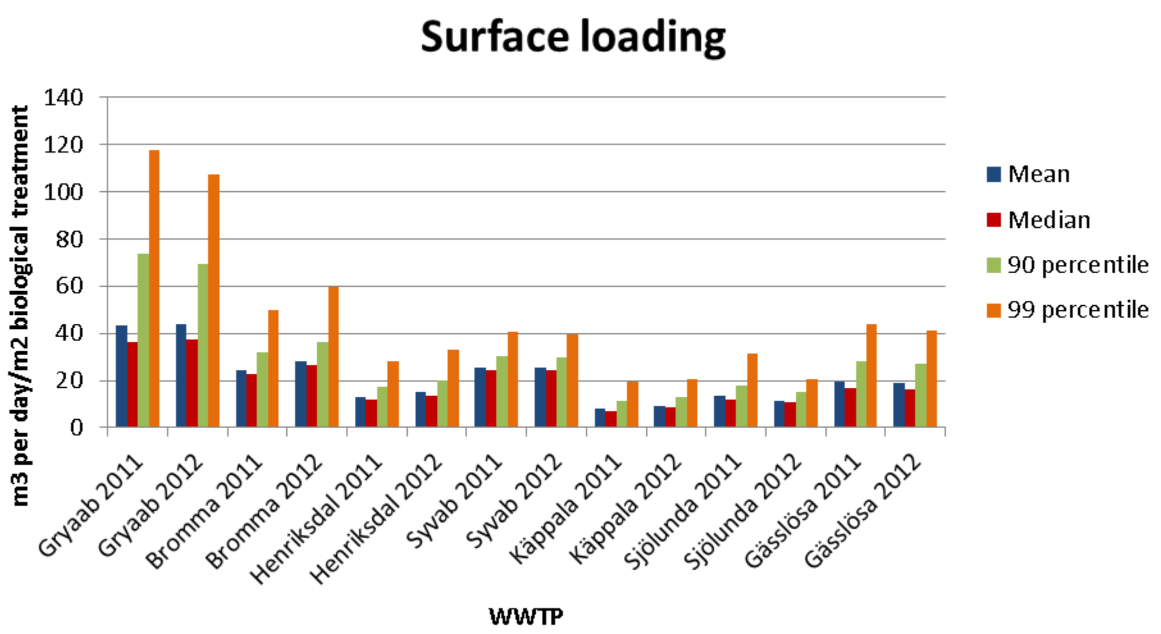


Figure 11. Results of surface loading illustrated by a bar chart.

From the results of the surface loading showed in Figure 11, it can be seen that Gryaab had the greatest surface loading during both 2011 and 2012. The biological treatment process of Gryaab has a relatively small area (8800 m^2) compared to the WWTPs with the largest area. The small area and the fact that the flow per capita was much greater than the other WWTPs consequently generated a great surface loading.

The two WWTPs with the largest area, Henriksdal (18 900 m^2) and Käppala (17 600 m^2), have almost four times the area of Bromma (5000 m^2) and Syvab (4800 m^2), and two times the area of Gryaab and Sjölunda (8600 m^2). Therefore, the surface loading of Henriksdal and Käppala are small and great for Bromma and Syvab.

In Table 8 and Figure 12 the results of surface loading (secondary sedimentation tanks included) are summarized.

Table 8. Results of surface loading (secondary sedimentation tanks included).

Surface loading secondary sedimentation tanks included					
Value $\left(\frac{m^3\ inflow\ per\ day}{m^2\ of\ biological\ treatment}\right)$		Mean	Median	90 percentile	99 percentile
WWTP	Year				
Gryaab	2011	12.8	10.6	21.8	34.5
Gryaab	2012	12.8	11.0	20.3	31.6
Bromma	2011	11.6	10.6	15.2	23.6
Bromma	2012	13.4	12.4	17.2	28.2
Henriksdal	2011	8.3	7.6	11.0	17.7
Henriksdal	2012	9.4	8.6	12.4	20.7
Syvab	2011	7.1	6.9	8.5	11.4
Syvab	2012	7.1	6.9	8.4	11.0
Käppala	2011	4.7	4.2	6.5	11.5
Käppala	2012	5.5	5.0	7.5	12.1
Sjölunda	2011	7.9	7.0	10.6	18.4
Sjölunda	2012	6.7	6.2	8.9	12.0
Gässlösa	2011	12.6	11.1	18.4	28.8
Gässlösa	2012	12.2	10.7	17.9	27.1

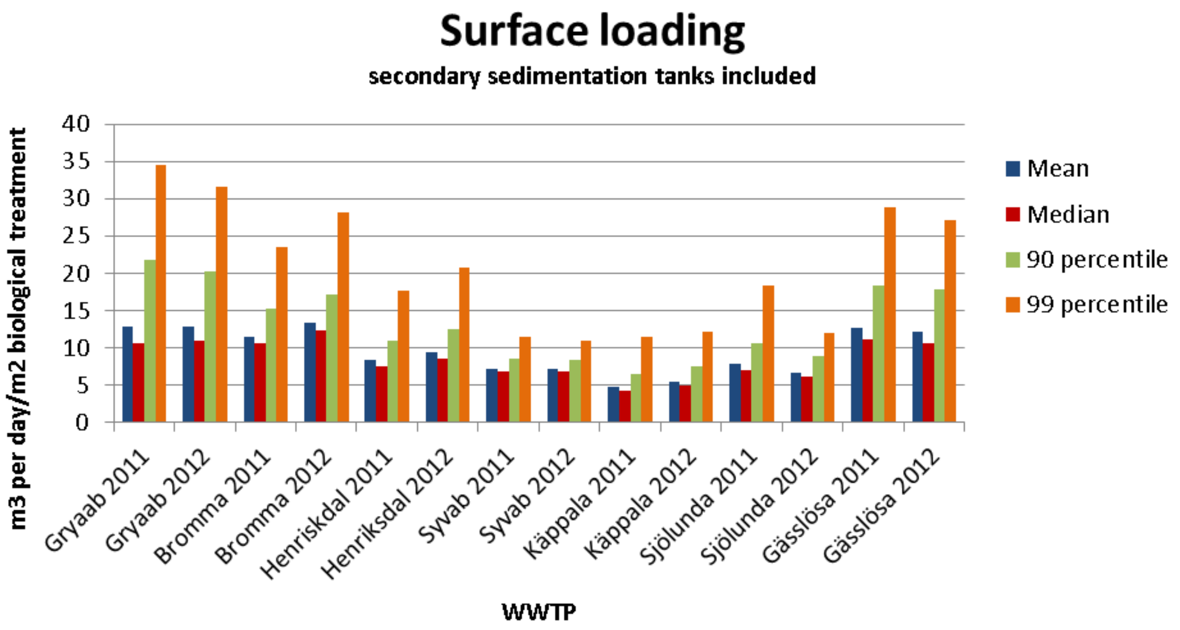


Figure 12. Results of surface loading (secondary sedimentation tanks included) illustrated by a bar chart.

When taking the secondary sedimentation tanks into account (Figure 12), the results of the surface loading were evening out compared to the other WWTPs. This is due to the fact that Gryaab has the greatest area (21 100 m^2) of the secondary sedimentations tanks. Both Bromma and Gässlösa have small sedimentation tanks (5600 m^2 respectively 1200 m^2) which mean that the surface loading will be large. By comparing Figure 11 and Figure 12, it can be seen that in case where the sedimentation tanks were included, the means and median were in the same range (11.6-13.4 m^3 per day/m^2 biological treatment respectively 10.6-12.4 m^3 per day/m^2 biological treatment) for Gryaab, Bromma and Gässlösa. These values were relatively much greater than the means and medians of the other WWTPs.

4.1.4 Volumetric loading

In Table 9 and Figure 13 the results of volumetric loading (secondary sedimentation tanks excluded) are summarized.

Table 9. Results of volumetric loading.

Volumetric loading					
Value $\left(\frac{m^3\ inflow\ per\ day}{m^3\ of\ biological\ treatment}\right)$		Mean	Median	90 percentile	99 percentile
WWTP	Year				
Gryaab	2011	4.9	4.1	8.3	13.2
Gryaab	2012	4.9	4.2	7.6	12.0
Bromma	2011	5.1	4.7	6.7	10.4
Bromma	2012	5.9	5.5	7.6	12.5
Henriksdal	2011	1.2	1.1	1.6	2.6
Henriksdal	2012	1.4	1.3	1.8	3.0
Syvab	2011	5.4	5.2	6.4	8.6
Syvab	2012	5.3	5.2	6.2	8.3
Käppala	2011	1.2	1.0	1.6	2.8
Käppala	2012	1.3	1.2	1.8	3.0
Sjölunda	2011	3.3	3.0	4.5	7.7
Sjölunda	2012	2.8	2.6	3.7	5.1
Gässlösa	2011	3.6	3.1	5.2	8.2
Gässlösa	2012	3.5	3.0	5.1	7.7

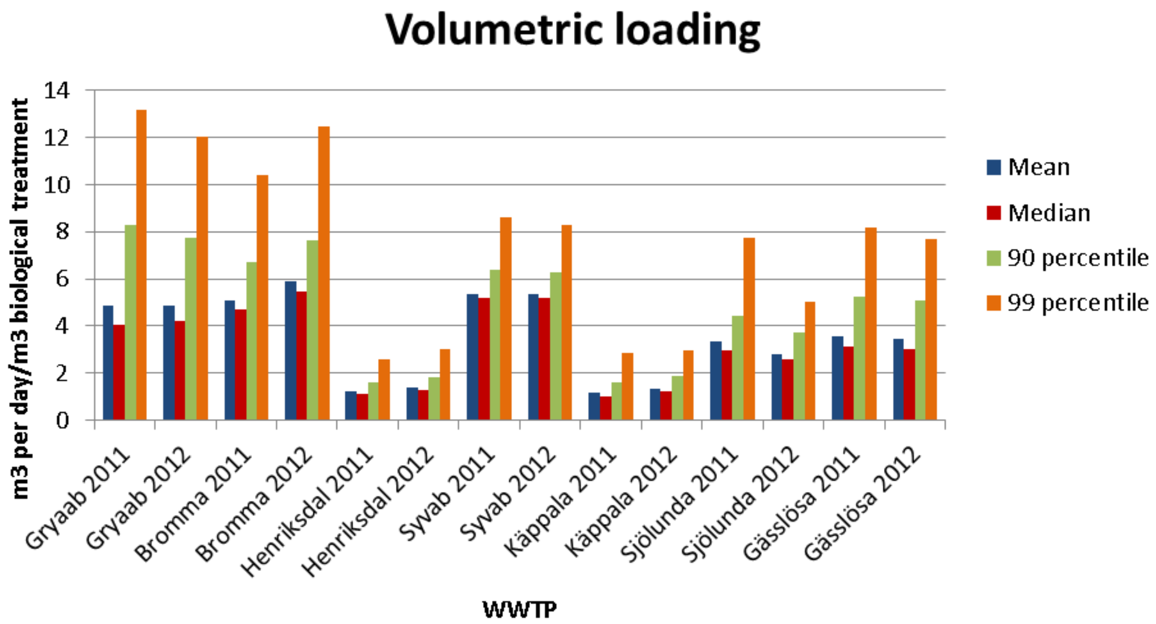


Figure 13. Results of volumetric loading illustrated by a bar chart.

In Figure 13 the result differs from the results of other key performance indicators. The volumetric loading of Gryaab's WWTP was great but the mean and median of the volumetric loading were greater for both Bromma and Syvab. This is a consequence of the fact that Bromma and Syvab are the smallest WWTPs regarding the volume of the biological treatment process (24 000 m^3 respectively 22 600 m^3). Gryaab is the WWTP with third largest biological treatment process (78 500 m^3) while Henriksdal definitively is the largest one (204 000 m^3). The second largest is Käppala (122 000 m^3) and as can be seen in Figure 13, the two WWTPs with the largest volumes of the biological treatment process were also the ones with the smallest volumetric loading.

Sjölunda is the WWTP with the same biological process steps as at Gryaab. What these two WWTPs also have in common, is the area of the biological treatment process. The area is almost the same but what differs, except from the flow per capita, is the volume. The volume of Sjölunda's biological treatment is about half of Gryaab's volume.

In Table 10 and Figure 14 the results of volumetric loading (secondary sedimentation tanks included) are summarized.

Table 10. Results of volumetric loading (secondary sedimentation tanks included).

Volumetric loading secondary sedimentation tanks included					
Value $\left(\frac{m^3\ inflow\ per\ day}{m^3\ of\ biological\ treatment}\right)$		Mean	Median	90 percentile	99 percentile
WWTP	Year				
Gryaab	2011	2.5	2.1	4.3	6.9
Gryaab	2012	2.5	2.2	4.0	6.3
Bromma	2011	2.4	2.2	3.2	5.0
Bromma	2012	2.8	2.6	3.7	6.0
Henriksdal	2011	0.9	0.9	1.3	2.0
Henriksdal	2012	1.1	1.0	1.4	2.4
Syvab	2011	1.8	1.7	2.1	2.8
Syvab	2012	1.8	1.7	2.1	2.7
Käppala	2011	0.8	0.7	1.0	1.8
Käppala	2012	0.9	0.8	1.2	1.9
Sjölunda	2011	2.0	1.8	2.7	4.7
Sjölunda	2012	1.7	1.6	2.3	3.1
Gässlösa	2011	2.6	2.3	3.8	5.9
Gässlösa	2012	2.5	2.2	3.6	5.5

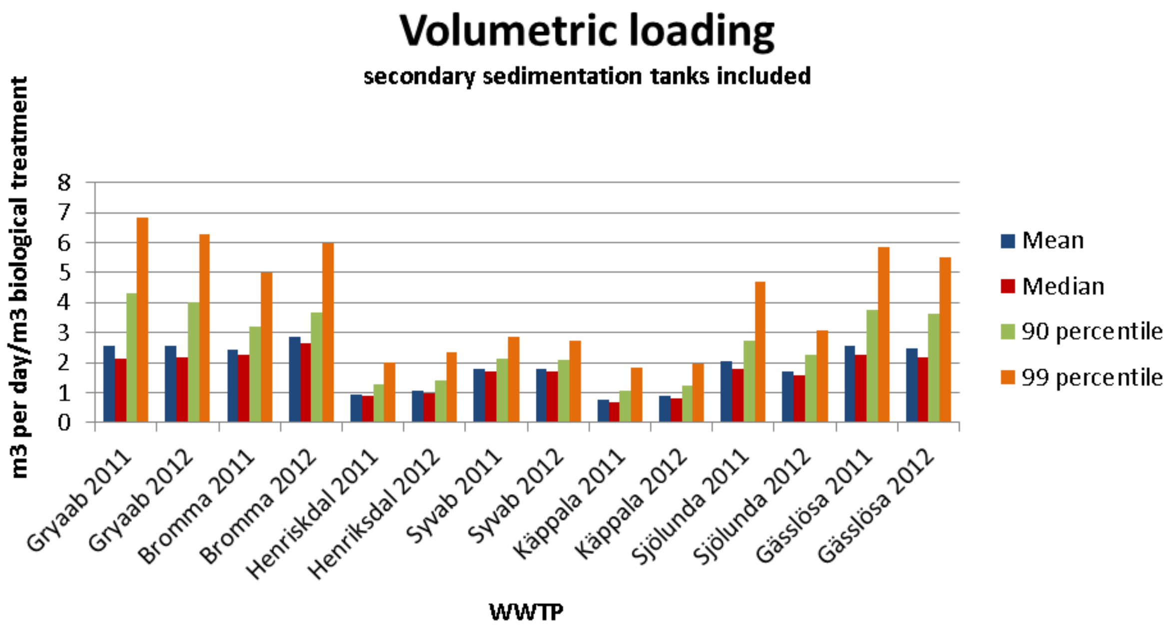


Figure 14. Results of volumetric loading (secondary sedimentation tanks included) illustrated by a bar chart.

By looking at Figure 13 and Figure 14, it can be seen that the difference between these two figures are quite small. These results are in contrary to the results of the surface loading and the conclusion is that the sedimentation tanks had greater impact on the surface loading than the volumetric loading. The reason is that the differences in area are greater than the differences in volume of the secondary sedimentation tanks.

Table 11 shows the relationship between the volume of the biological treatment and populations connected for each WWTP.

Table 11. Relationship between volume of the biological treatment (secondary sedimentation tanks included) and populations connected.

WWTP	Volume of biological treatment/person (dm^3/p)
Gryaab	217
Bromma	156
Henrikdsdal	334
Syvab	231
Käppala	411
Sjölunda	188
Gässlösa	198

The WWTP of Käppala has the greatest volume per connected person followed by the WWTP of Henriksdal. The fact that Bromma has the smallest volume of biological treatment per connected person, together with the results of surface and volumetric loading, all support the planned shutdown of the WWTP. The capacity of Bromma is too small and therefore will the wastewater in future be led to the WWTP of Henriksdal.

4.1.5 Calculated ratio

In Table 12 and Figure 15 the results of calculated ratio are summarized.

Table 12. Results of the calculated ratio.

Calculated ratio			
Value		90 percentile / median	99 percentile / median
WWTP	Year		
Gryaab	2011	2.0	3.3
Gryaab	2012	1.8	2.8
Bromma	2011	1.4	2.2
Bromma	2012	1.4	2.2
Henriksdal	2011	1.4	2.3
Henriksdal	2012	1.4	2.3
Syvab	2011	1.2	1.7
Syvab	2012	1.2	1.6
Käppala	2011	1.6	2.7
Käppala	2012	1.5	2.4
Sjölunda	2011	1.5	2.6
Sjölunda	2012	1.4	1.9
Gässlösa	2011	1.7	2.6
Gässlösa	2012	1.7	2.5

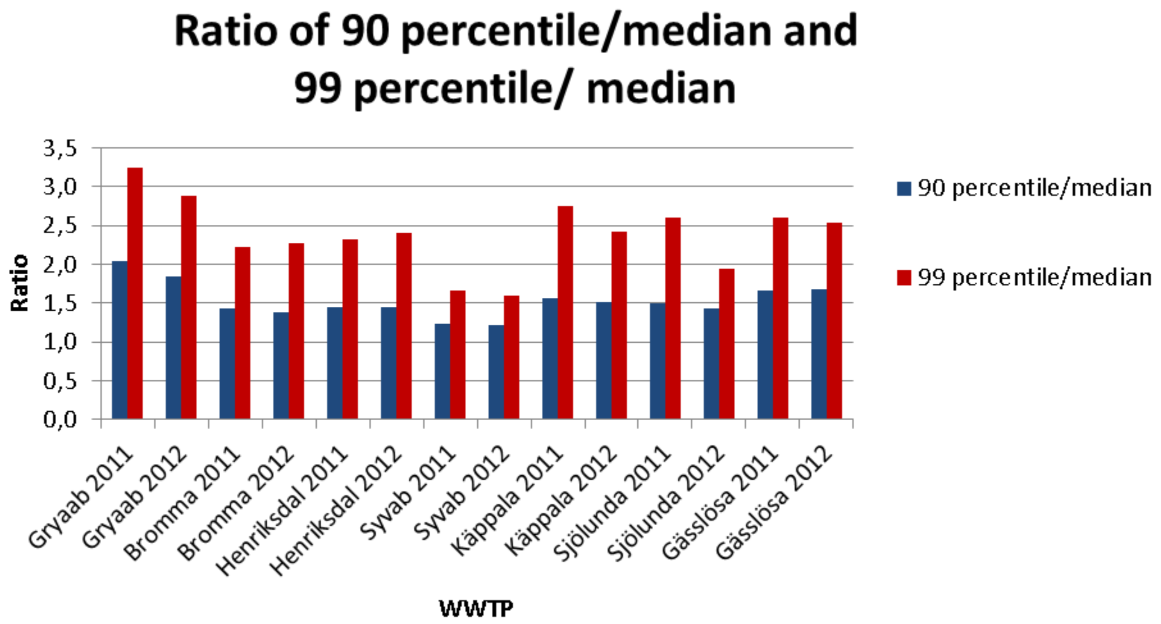


Figure 15. Results of the calculated ratio illustrated by a bar chart.

In Figure 15, the calculated ratio of all the key performance indicators is showed. The ratio describes how large the differences are between the median and the percentiles. A large ratio means that the difference between the 90 respectively the 99 percentile and the median are large and that the amounts of inflow to the WWTP vary a lot.

Gryaab and Gässlösa had the highest ratio even in this case but also the value for Käppala was quite high. The ratio of Sjölunda was high 2011 compared to the ratio during 2012. The fact that Gryaab and Sjölunda had the highest ratio during 2011 confirms the conclusion that the precipitation was richer in the west and southern Sweden during 2011. If the precipitation is richer during some periods, the variety of the inflow is greater.

The small ratios of Bromma, Henriksdal and Syvab indicate that the variations in inflow are much smaller than for the rest of the WWTPs.

4.2 Relationship between capacity and amount of biologically treated water

Figure 16 and Figure 17 show the relationship between the capacity of the WWTP and the amount of biologically treated water during 2011 respectively 2012.

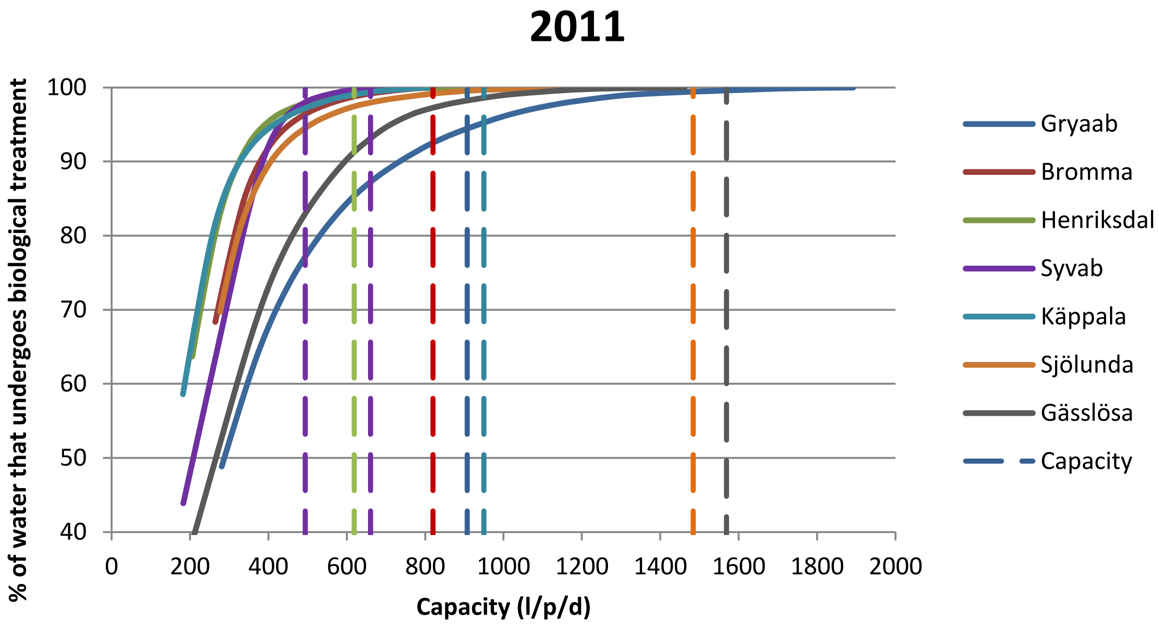


Figure 16. Graph showing the relationship between the capacity of the WWTPs and the amount of biologically treated water 2011.

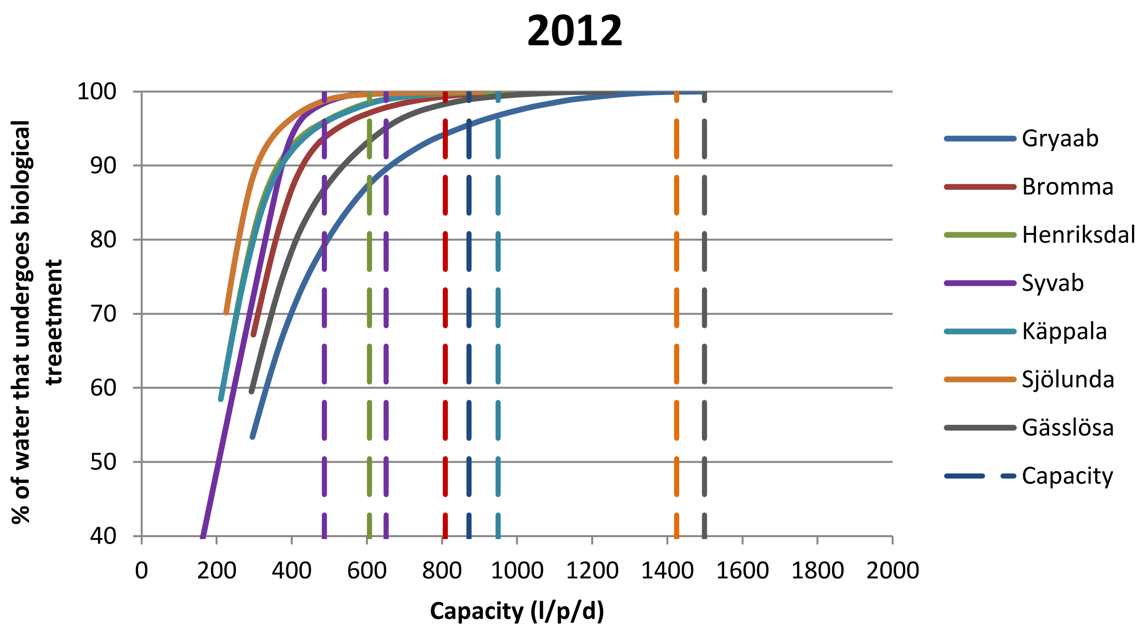


Figure 17. Graph showing the relationship between the capacity of the WWTPs and the amount of biologically treated water 2012.

Both figures can be used to determine how much capacity is required in order to biologically treat a specific amount of inflow. For example, 2011 Gryaab would require the same capacity as Sjölunda's (1500 l/p/d) to treat all of the inflow biologically. To turn the thing around, if the rest of the WWTPs would have the same capacity as Gryaab (900 l/p/d), all their inflow could be treated biologically.

4.3 Methods to characterize the flow

The results of the two methods to characterize the flow are shown below. A summary and comparison of the two the methods can be found in Table 14 in the end of this section.

4.3.1 The triangle method

By using the information included in Table 13, the triangle method was applied for each WWTP.

Table 13. Information required to applying the triangle method for each WWTP.

Information required to apply the triangle method							
Value		Location	Days with storm runoff		Maximum inflow (l/p/d)	Sewage water	
WWTP	Year		Number of days[1]	%		Mean (l/p/d)	% of maximum inflow
Gryaab	2011	Gothenburg	181	49.5	1892	204	10.8
Gryaab	2012	Gothenburg	201	54.9	1492	199	13.4
Bromma	2011	Stockholm	158	43.3	846	182	21.5
Bromma	2012	Stockholm	199	54.3	1055	198	18.8
Henriksdal	2011	Stockholm	158	43.3	889	182	20.5
Henriksdal	2012	Stockholm	199	54.3	998	198	19.8
Syvab	2011	Stockholm	158	43.3	747	242	32.4
Syvab	2012	Stockholm	199	54.3	655	241	36.8
Käppala	2011	Stockholm	158	43.3	819	193	23.5
Käppala	2012	Stockholm	199	54.3	885	194	21.9
Sjölunda	2011	Malmö	176	40.8	1205	254	21.1
Sjölunda	2012	Malmö	187	51.1	908	244	26.9
Gässlösa	2011	Borås	182	49.9	3237	236	7.3
Gässlösa	2012	Borås	208	56.8	1262	207	16.4

[1] (SMHI, 2011 and 2012).

The result of the triangle method is shown in the pie charts below. The distribution of the water components is based on calculations from the original graphs that can be found in the appendix (7.2).

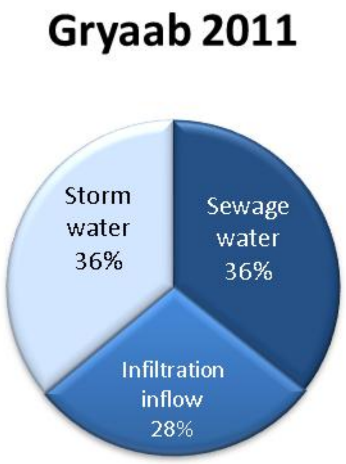


Figure 18. Pie chart showing the distribution of water components for Gryaab 2011.

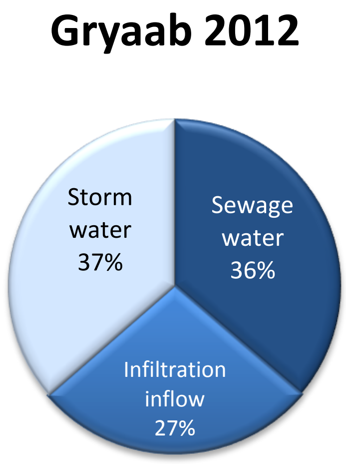


Figure 19. Pie chart showing the distribution of water components for Gryaab 2012.

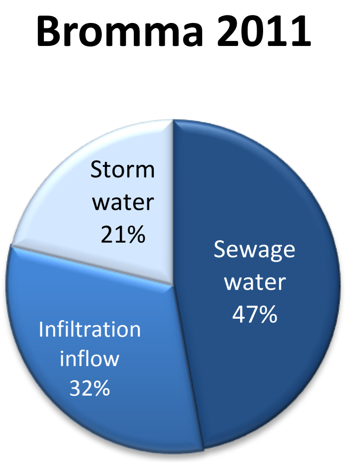


Figure 20. Pie chart showing the distribution of water components for Bromma 2011.

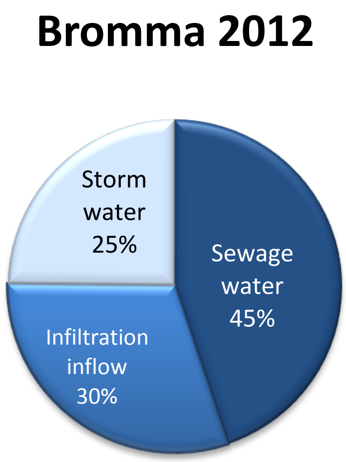


Figure 21. Pie chart showing the distribution of water components for Bromma 2012.

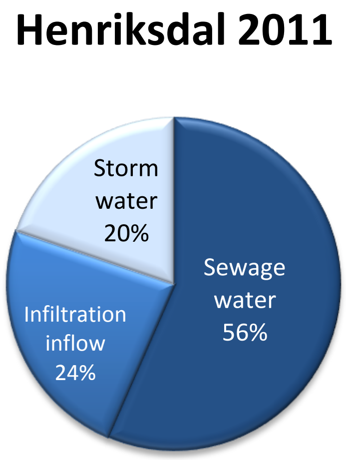


Figure 22. Pie chart showing the distribution of water components for Henriksdal 2011.

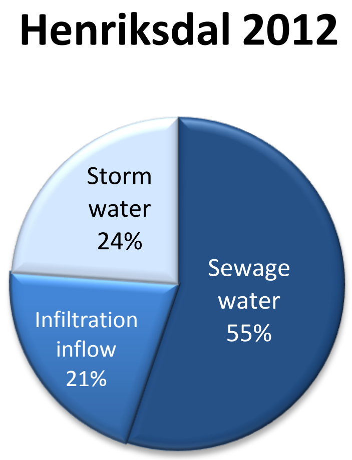


Figure 23. Pie chart showing the distribution of water components for Henriksdal 2012.

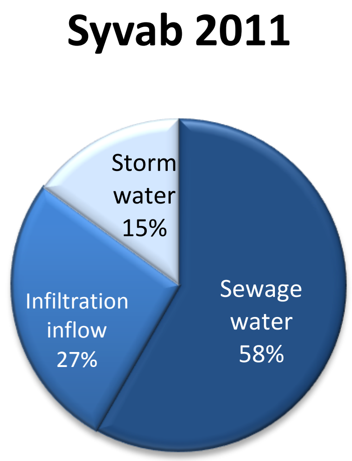


Figure 24. Pie chart showing the distribution of water components for Syvab 2011.

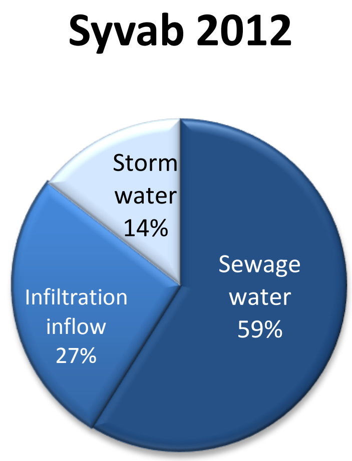


Figure 25. Pie chart showing the distribution of water components for Syvab 2012.

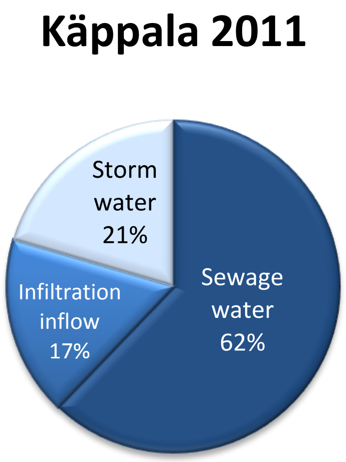


Figure 26. Pie chart showing the distribution of water components for Käppala 2011.

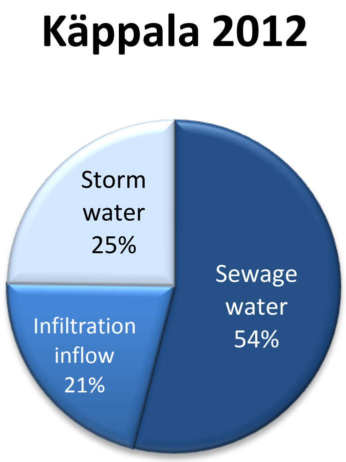


Figure 20. Pie chart showing the distribution of water components for Käppala 2012.

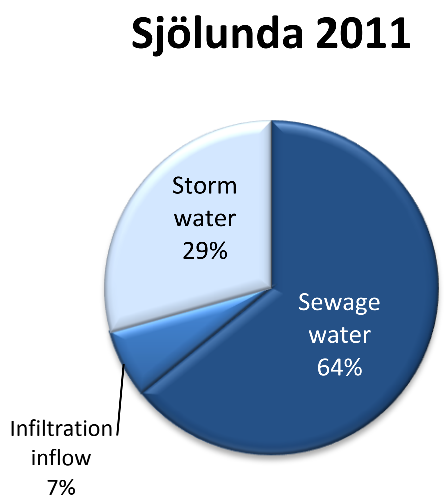


Figure 28. Pie chart showing the distribution of water components for Sjölunda 2011.

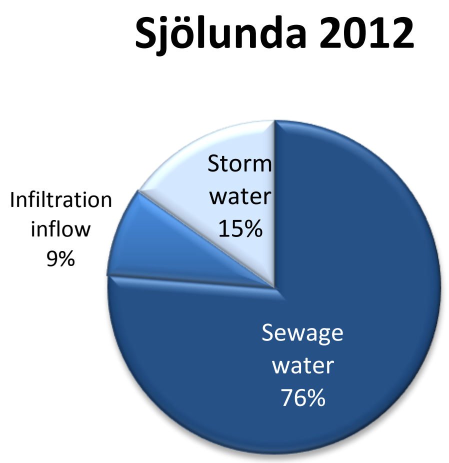
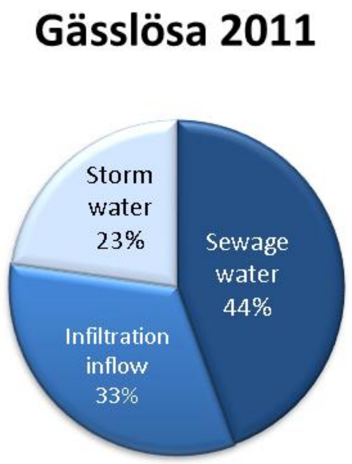


Figure 29. Pie chart showing the distribution of water components for Sjölunda 2012.



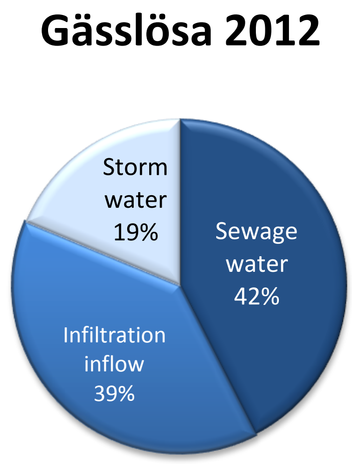
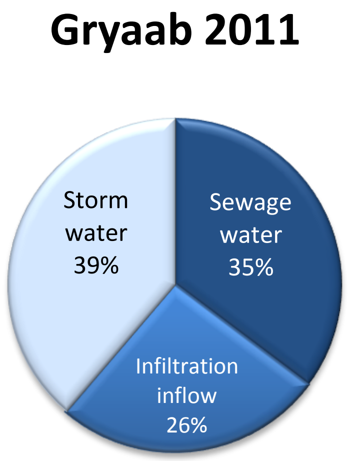


Figure 30. Pie chart showing the distribution of water components for Gässlösa 2011.

Figure 31. Pie chart showing the distribution of water components for Gässlösa 2012.

4.3.2 The moving minimum method



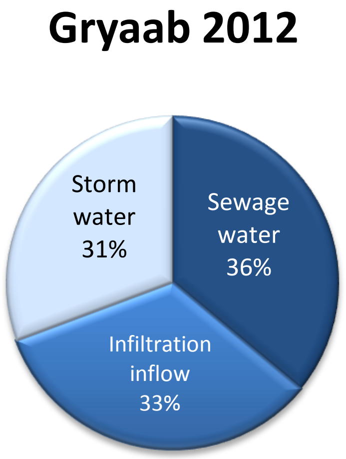
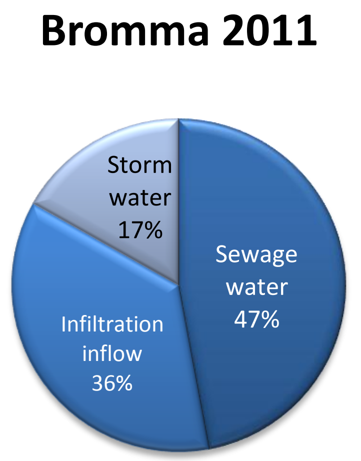


Figure 32. Pie chart showing the distribution of water components for Gryaab 2011.

Figure 33. Pie chart showing the distribution of water components for Gryaab 2012.



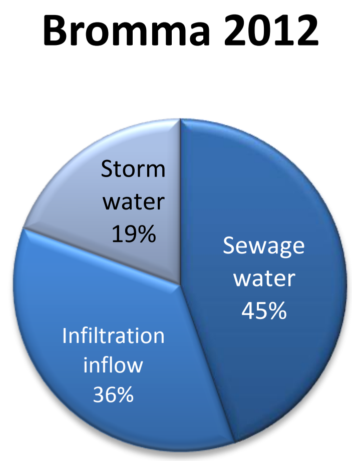
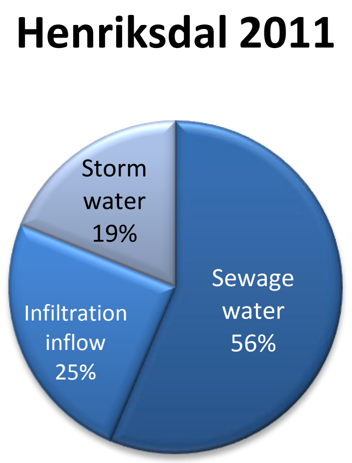


Figure 34. Pie chart showing the distribution of water components for Bromma 2011.

Figure 35. Pie chart showing the distribution of water components for Bromma 2012.



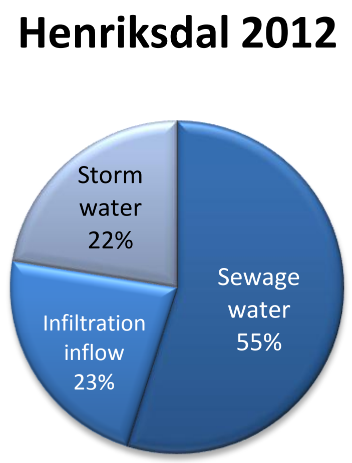
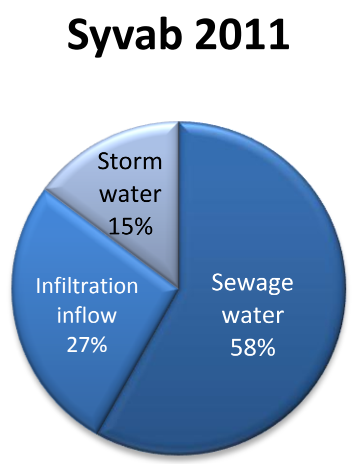


Figure 36. Pie chart showing the distribution of water components for Henriksdal 2011.

Figure 37. Pie chart showing the distribution of water components for Henriksdal 2012.



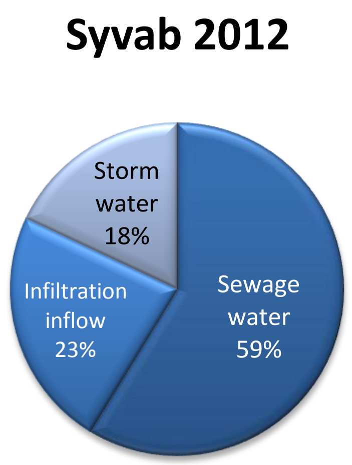


Figure 38. Pie chart showing the distribution of water components for Syvab 2011.

Figure 39. Pie chart showing the distribution of water components for Syvab 2012.

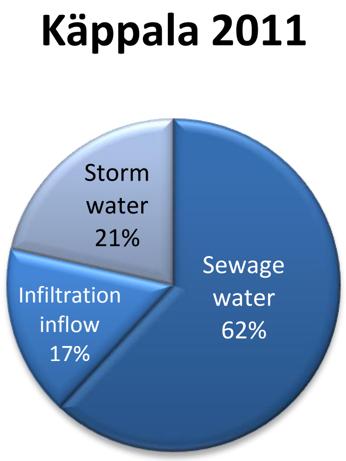


Figure 40. Pie chart showing the distribution of water components for Käppala 2011.

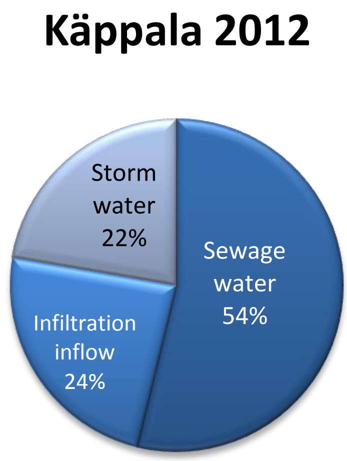


Figure 41. Pie chart showing the distribution of water components for Käppala 2012.

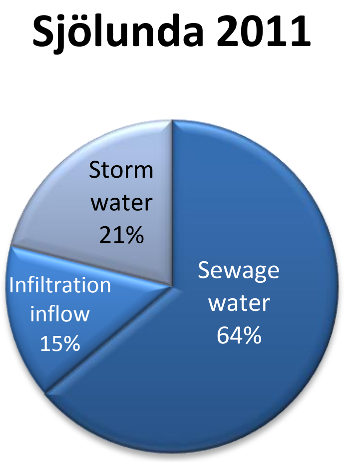


Figure 42. Pie chart showing the distribution of water components for Sjölunda 2011.

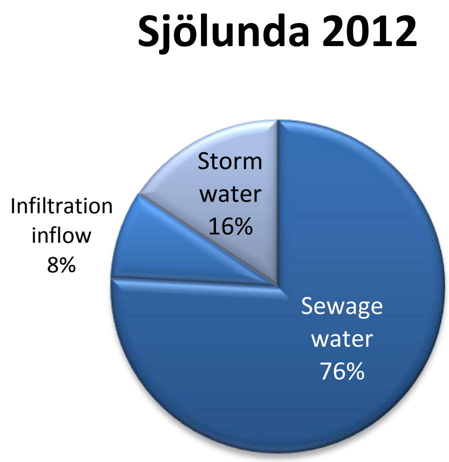


Figure 43. Pie chart showing the distribution of water components for Sjölunda 2012.

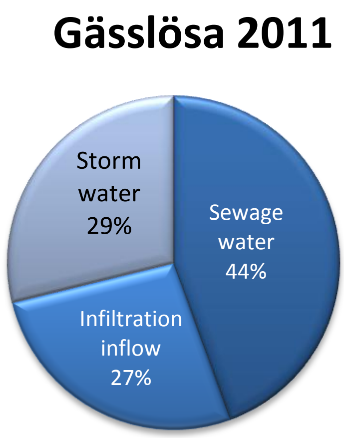


Figure 44. Pie chart showing the distribution of water components for Gässlösa 2011.

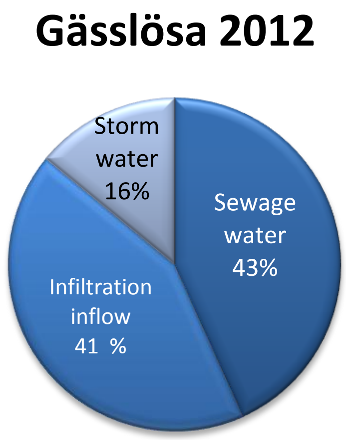


Figure 45. Pie chart showing the distribution of water components for Gässlösa 2012.

Table 14. A summary of the triangle -and moving minimum method.

Distribution of the water components							
Value (%)		Sewage water		Infiltration inflow		Storm water	
WWTP	Year	Triangle	Moving minimum	Triangle	Moving minimum	Triangle	Moving minimum
Gryaab	2011	36	36	28	36	36	39
Gryaab	2012	36	36	27	33	36	31
Bromma	2011	47	47	32	36	21	17
Bromma	2012	45	45	30	36	25	19
Henriksdal	2011	56	56	24	25	20	19
Henriksdal	2012	55	55	21	23	24	22
Syvab	2011	58	58	27	27	15	15
Syvab	2012	59	59	27	23	14	18
Käppala	2011	62	62	17	17	20	20
Käppala	2012	54	54	21	24	25	22
Sjölunda	2011	64	64	7	15	29	21
Sjölunda	2012	76	72	9	8	15	16
Gässlösa	2011	44	44	33	27	23	29
Gässlösa	2012	42	43	39	14	19	43

From these two methods it can be concluded that Gryaab is the WWTP with the lowest percentage of sewage water (36 %) and the highest percentage of storm water (about 35 %). Sjölunda is the WWTP with the highest percentage of sewage water (about 70 %) and a really low percentage of infiltration inflow (about 10 %). In comparison to Sjölunda's small amount of infiltration inflow, Bromma has a high percentage (about 33 %). The WWTP with the lowest percentage of storm water is Syvab (15 %).

When comparing the two methods, the moving minimum method tends to yield a greater amount of infiltration inflow than the triangle method. The different results between the methods can be explained by the assumptions and calculations applied for each method. The triangle method assumes that infiltration inflow are maximized after heavy precipitations and minimized when the sewer is filled with storm water. The moving minimum method on the other hand, takes seasonal variations into account by looking at the daily inflow for the past 21 days and set this equal to the dry weather flow. Due to this fact, the moving minimum might be a more reliable method. However, these two methods are both simplifications and do not give an adequate description of the reality. The assumption about exfiltration is rough and the rate of exfiltration is hard to estimate since the groundwater table constantly changes. The suggestion is to find more sufficient methods to characterize the flow.

5 Conclusions

- To define a flow as high or low is it important to look at the flow from different angles. The magnitude of the flow is the primary value but evaluations within a time perspective are required in order to estimate variations. In this study, the variations have been estimated by calculating the ratio of the median and the 90 respectively 99 percentile. Large variations mean that there are major deviations from the median flow. These deviations can be seen as high peaks and defined as high flows. Since the variations are individual for each WWTP, a flow considered as high for one WWTP is not necessary considered as high for another WWTP.

- Gryaab, Gässlösa and Käppala had the largest variations in flow during 2011 and 2012. As a consequence of the high flows, the capacity of Gryaab was exceeded and specific treatment was required. Even if Gryaab had the possibility to treat an extra amount of water using direct precipitation, the capacity was still exceeded for some days. As a result, Gryaab bypassed the greatest amount of water (percentage of total flow) of all WWTPs during 2011 and 2012.

- Due to the large variations, Gryaab was one of the WWTP with the greatest surface and volumetric loading. To decrease these loadings, and since an expansion in area and volume is both costly and restricted by land use, the amount of flow reaching the WWTP needs to be reduced.

- Calculations regarding discharges were not included in the study. According to the theory, both the concentration and mass flow will be affected by the magnitude of the flow. As the flow of the WWTP increases, the concentration of pollutants in the effluent will decrease or remain the same depending on pollutant. An increased flow leads however to changed properties of the water and reduces the ability of the WWTP to treat the water properly. As a consequence, the mass flow of pollutants out from the WWTP increases with increased flow. The discharge limits for each WWTP are stated in concentration (mg/l), but the commitments from the Baltic Sea Action Plan regarding phosphorus and nitrogen discharges are stated in tones/year. The combination of high flows and these commitments is a challenge for the WWTPs.

- The methods applied in order to characterize the flow were the triangle method and the moving minimum method. The results confirmed the problem regarding the flow to Gryaab; 35 % of the water is sewage water while 40 % is storm water. However, these two methods are based on uncertain assumptions and other methods are required to better describe the reality.

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7 Appendix

7.1 Process charts of the WWTPs

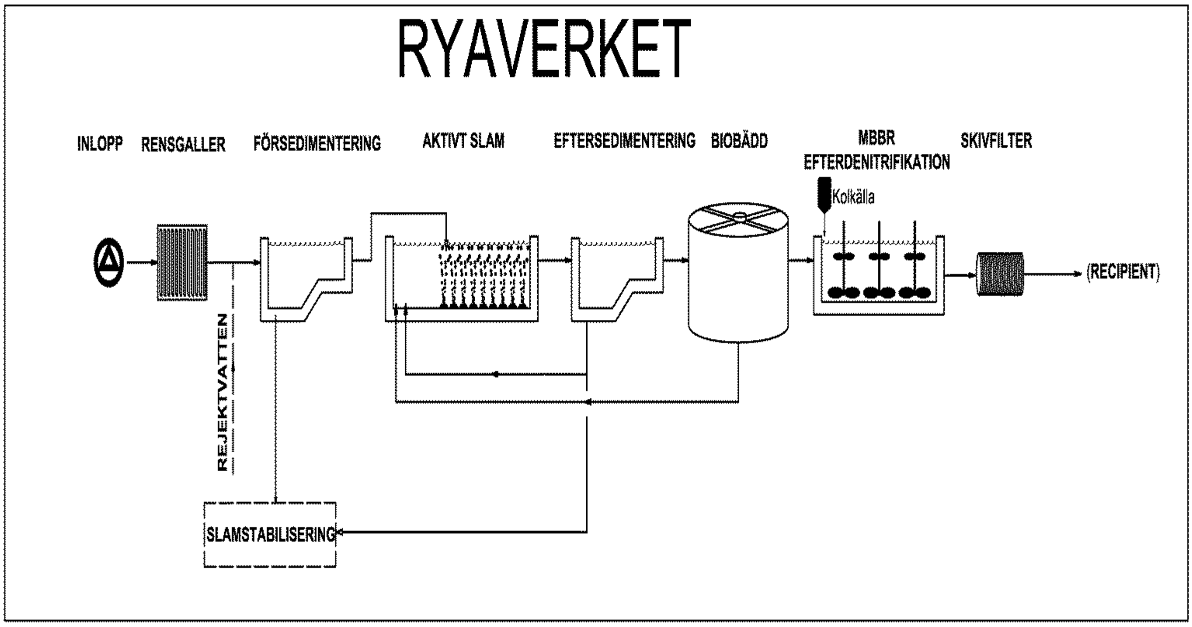

Figure 46. Process chart of Gryaab (Ryaverket) (Hagman, et al., 2013).

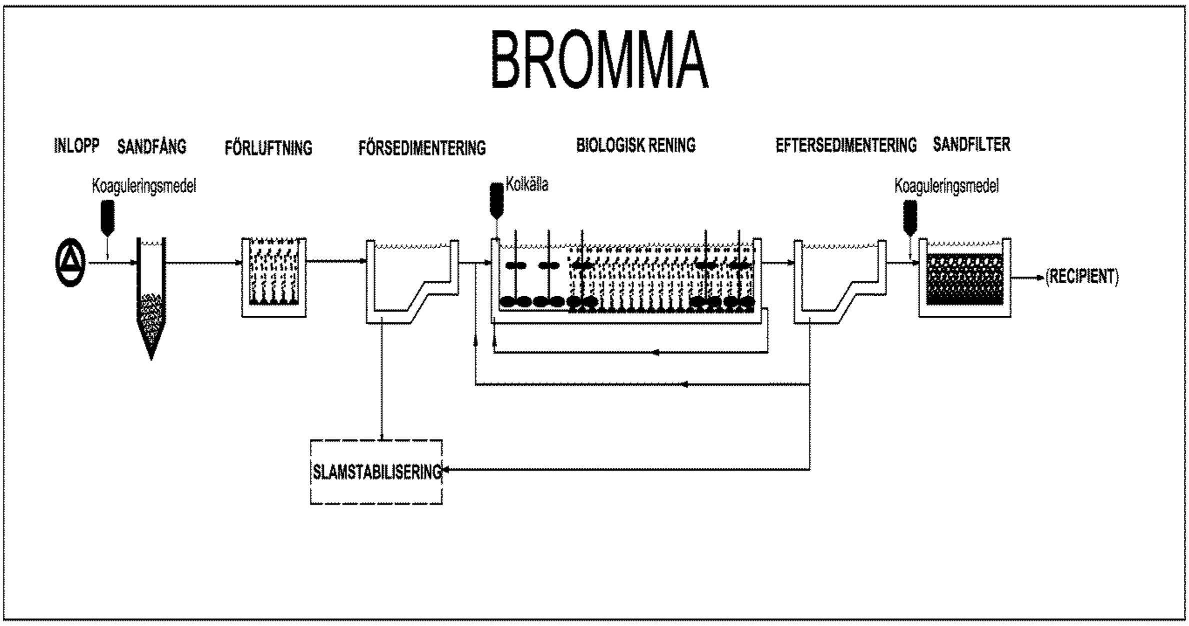

Figure 47. Process chart of Bromma (Hagman, et al., 2013).

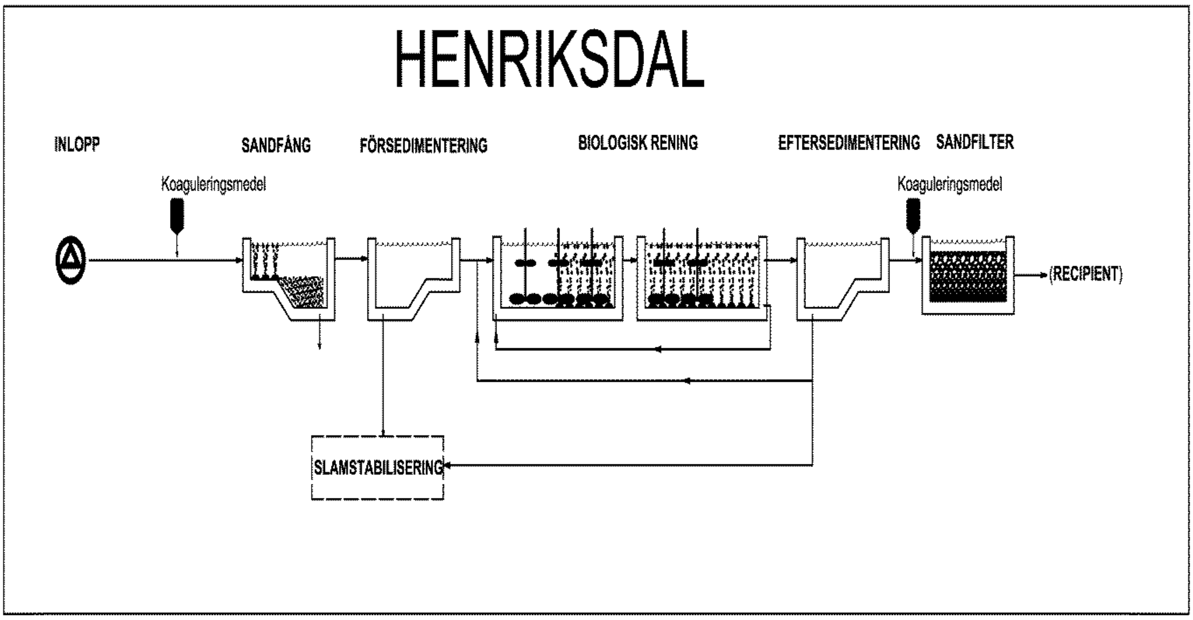

Figure 48. Process chart of Henriksdal (Hagman, et al., 2013).

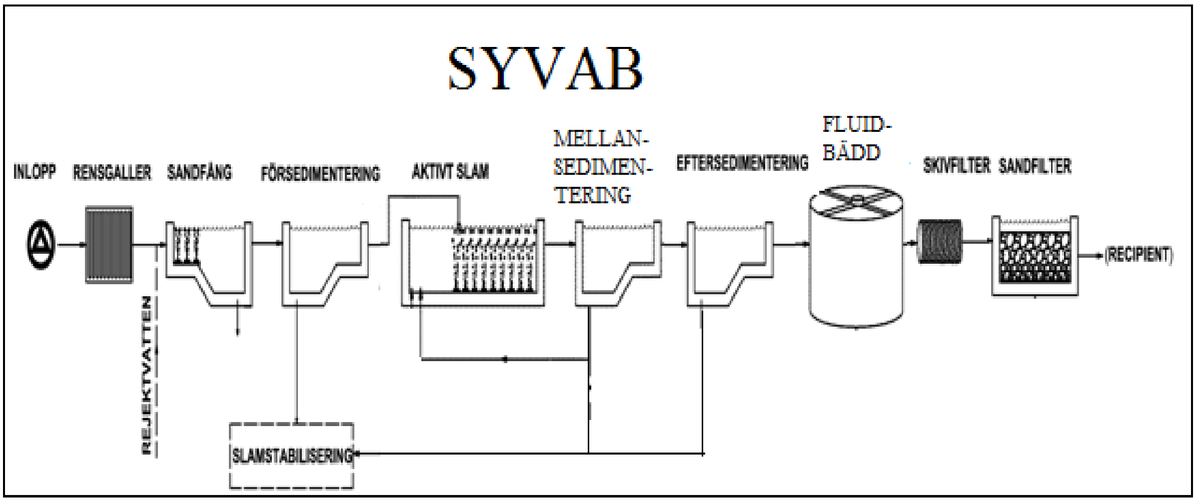

Figure 49. Process chart of Syvab (Hagman, et al., 2013).

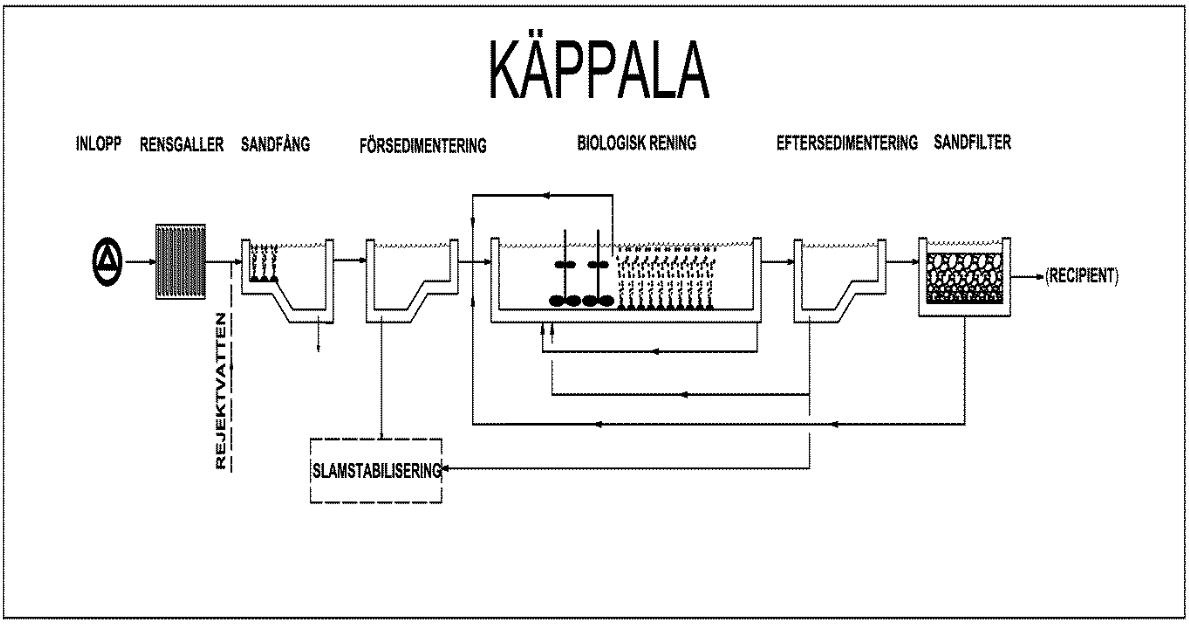

Figure 50. Process chart of Käppala (Hagman, et al., 2013).

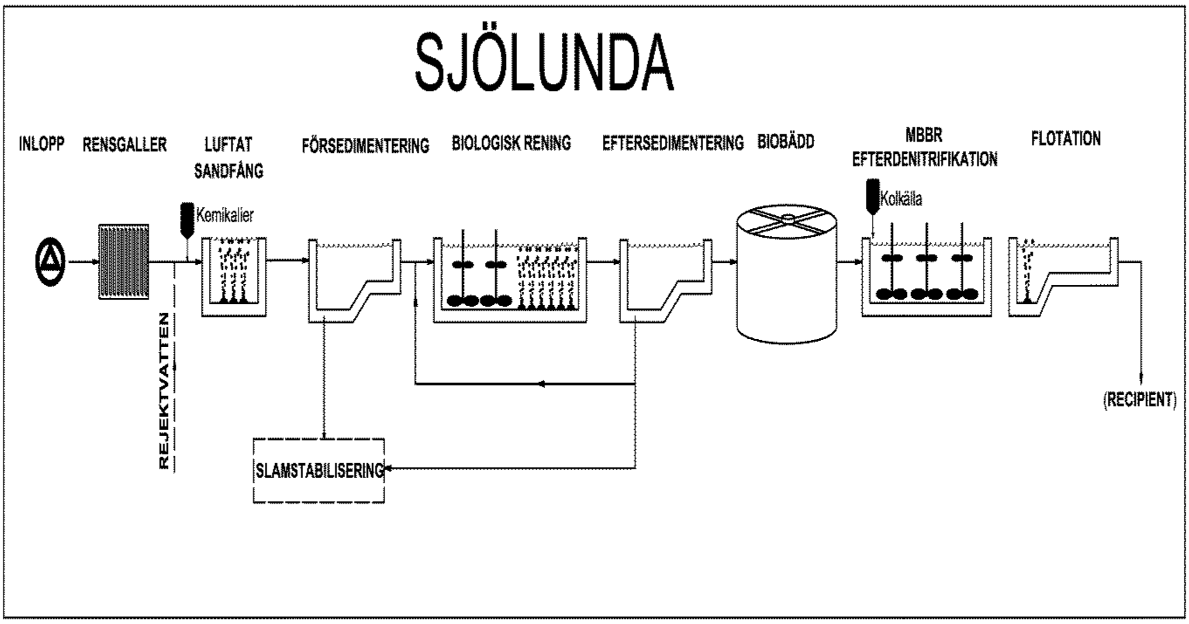

Figure 51. Process chart of Sjölunda (Hagman, et al., 2013).

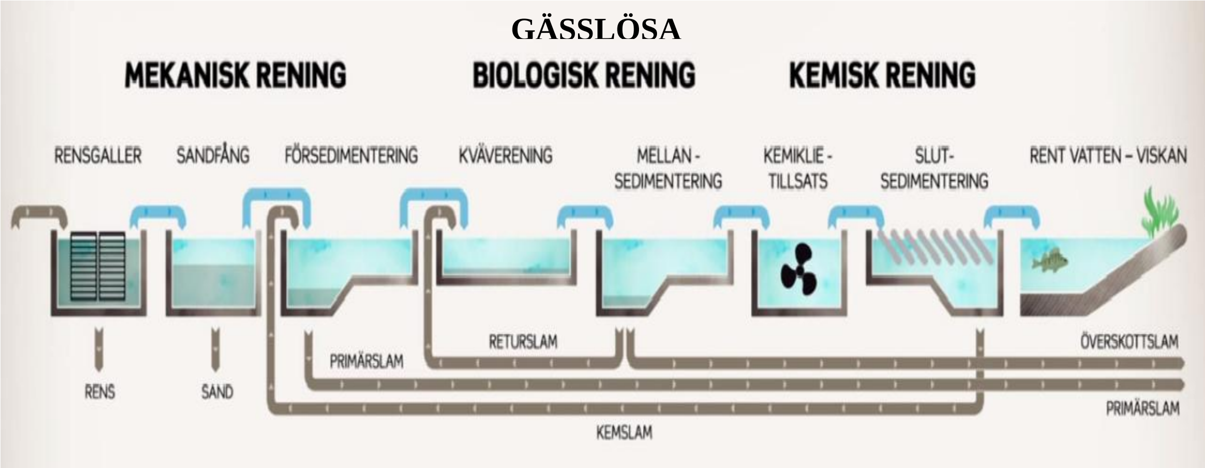

Figure 52. Process chart of Gässlösa.

7.2 The triangle method

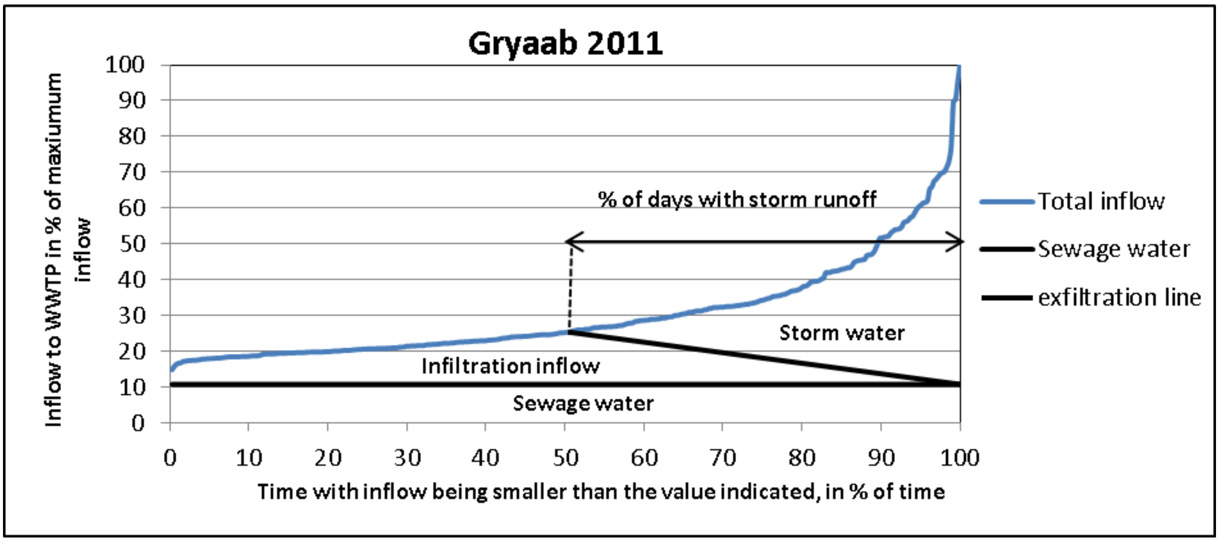

Figure 53. Graph showing the triangle method for Gryaab 2011.

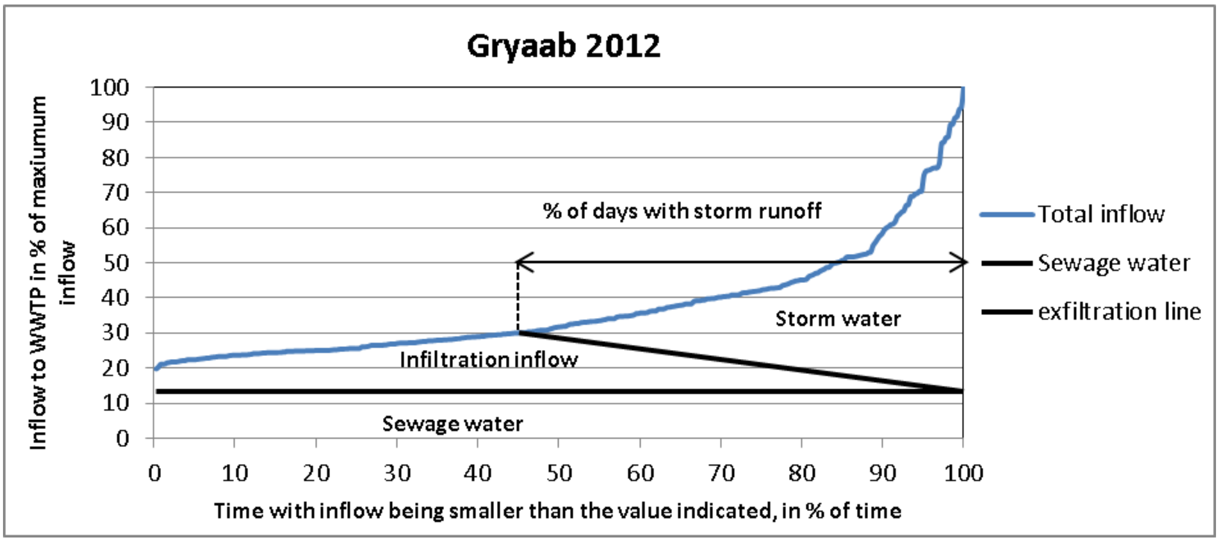

Figure 54. Graph showing the triangle method for Gryaab 2012.

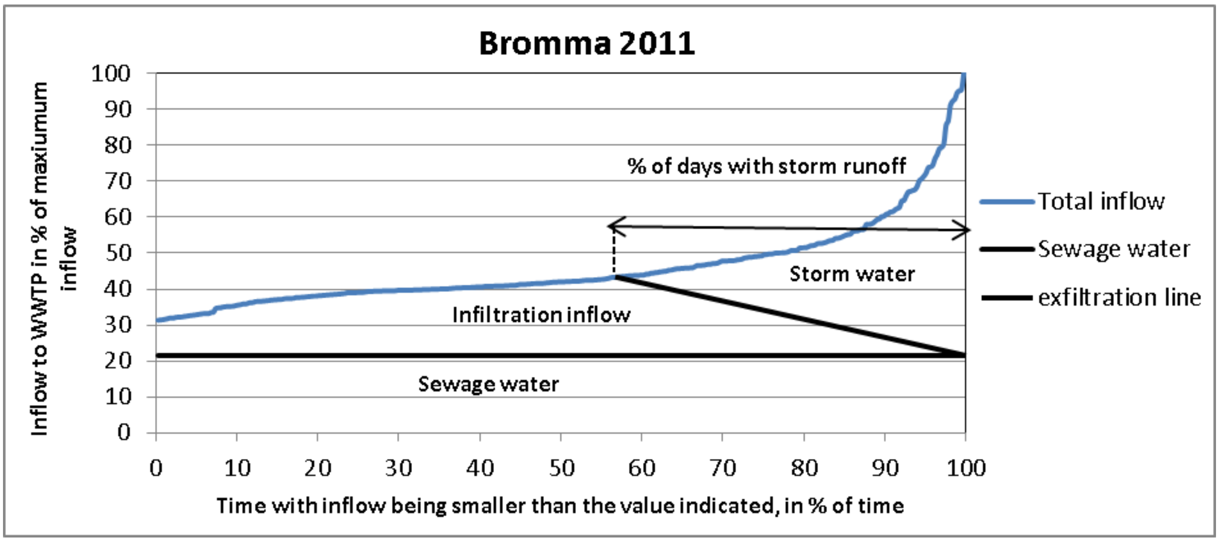

Figure 55. Graph showing the triangle method for Bromma 2011.

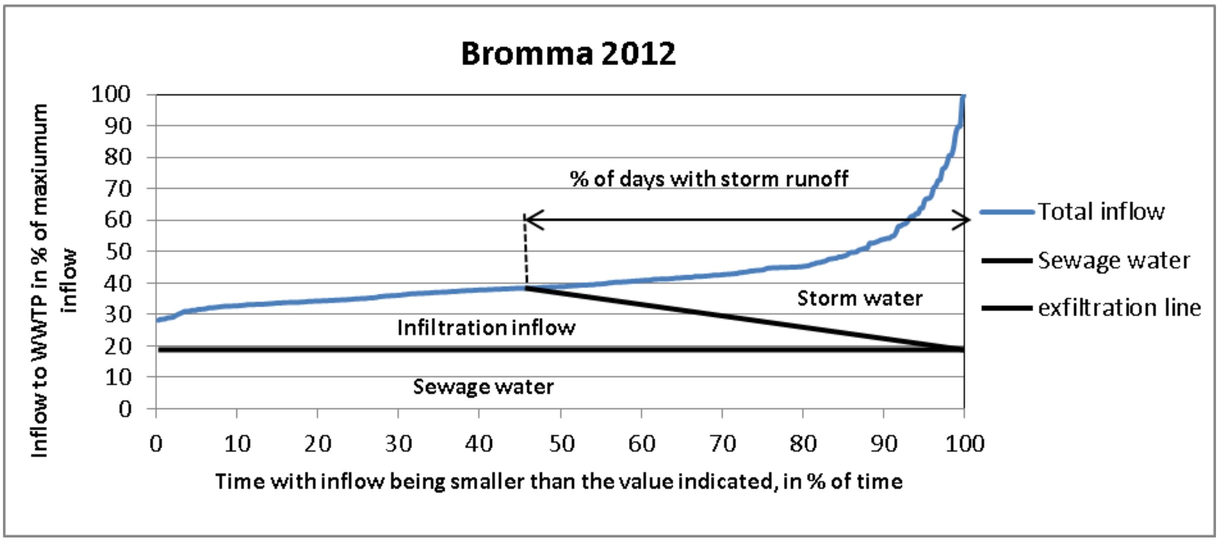

Figure 56. Graph showing the triangle method for Bromma 2012.

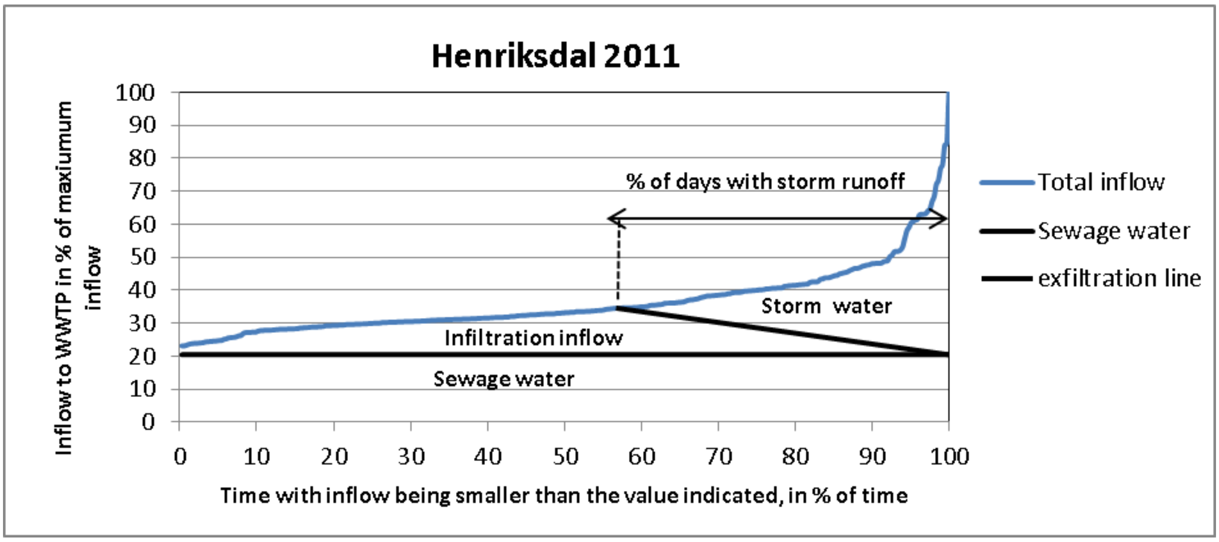

Figure 57. Graph showing the triangle method for Henriksdal 2011.

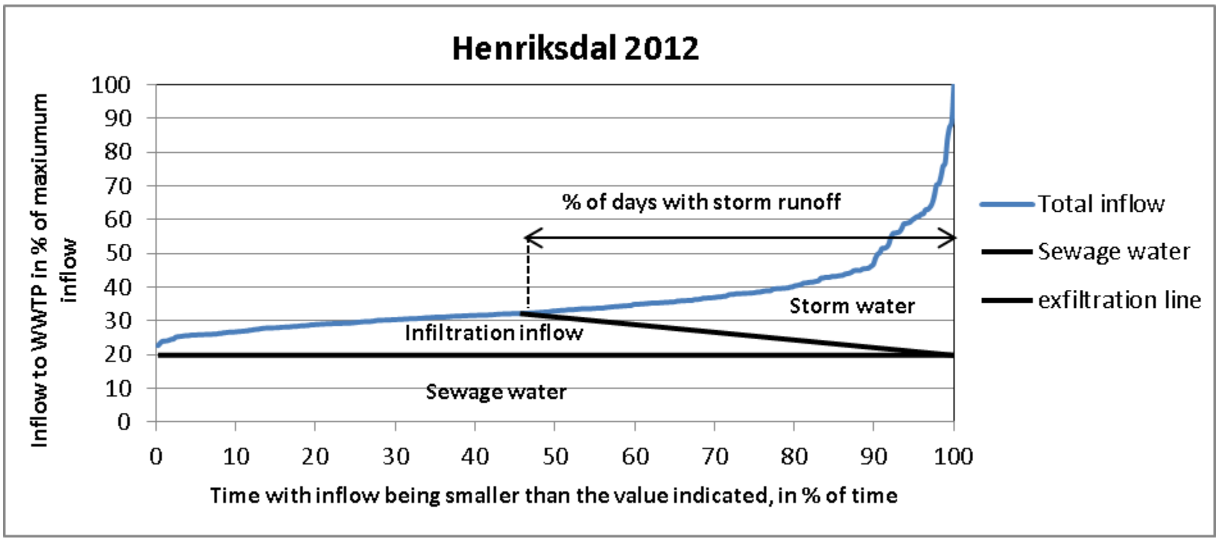

Figure 58. Graph showing the triangle method for Henriksdal 2012.

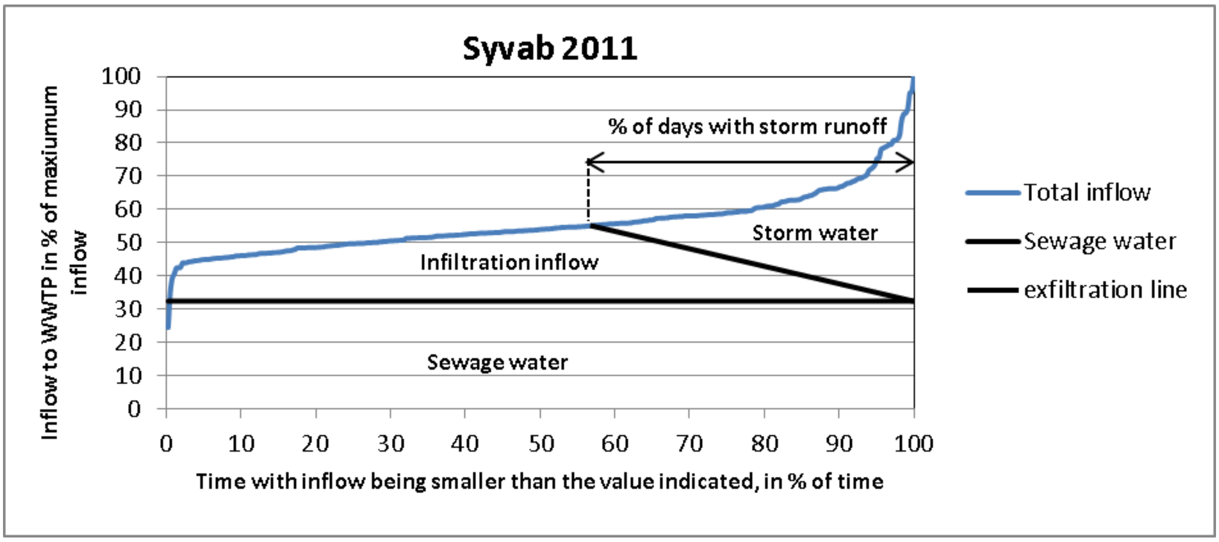

Figure 59. Graph showing the triangle method for Syvab 2011.

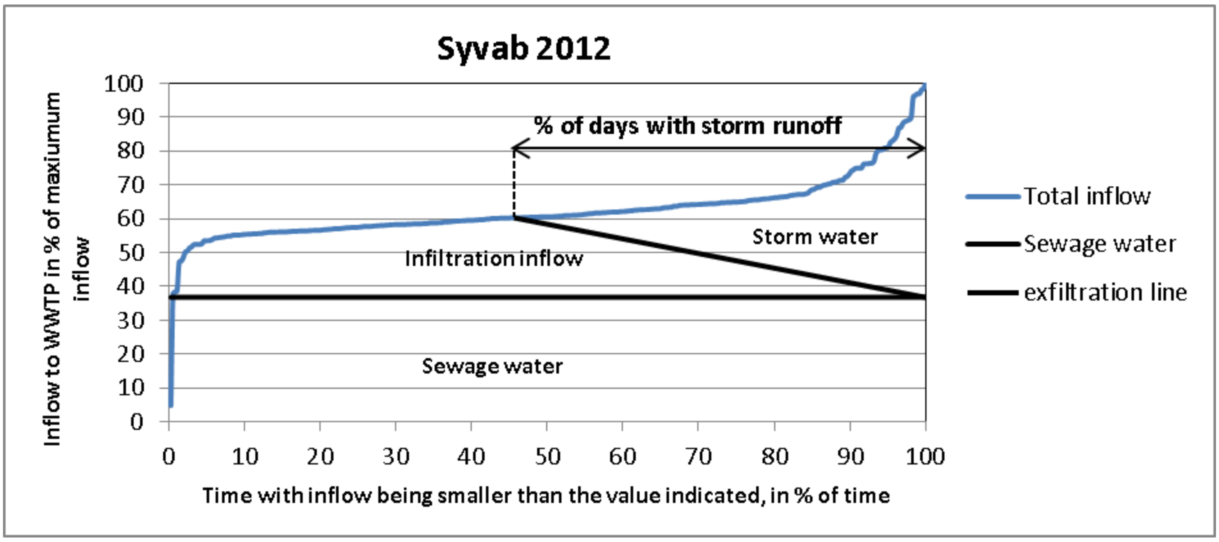

Figure 60. Graph showing the triangle method for Syvab 2012.

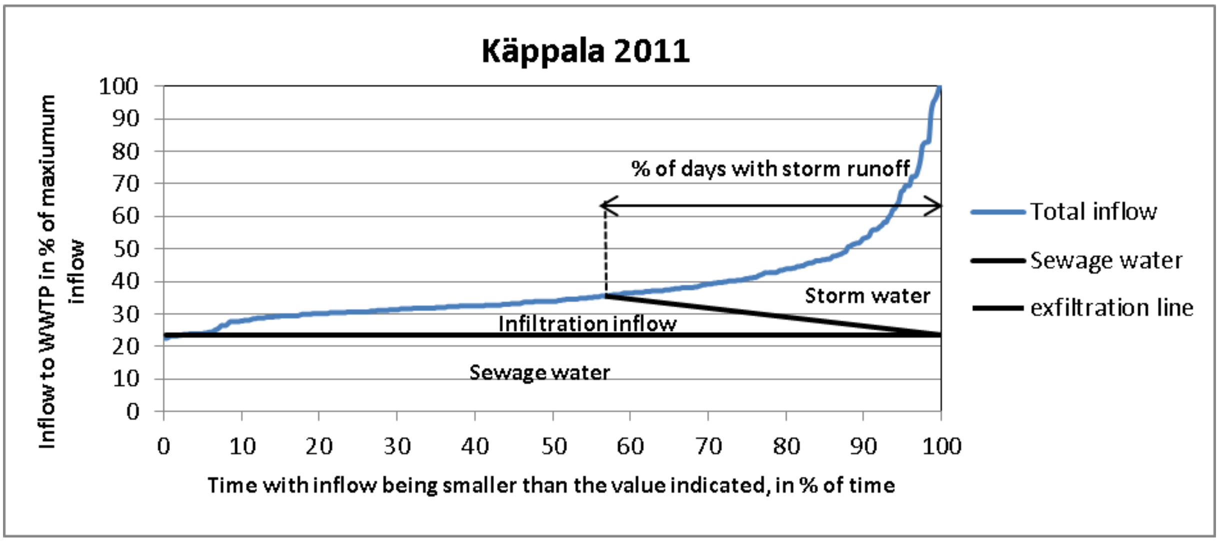

Figure 61. Graph showing the triangle method for Käppala 2011.

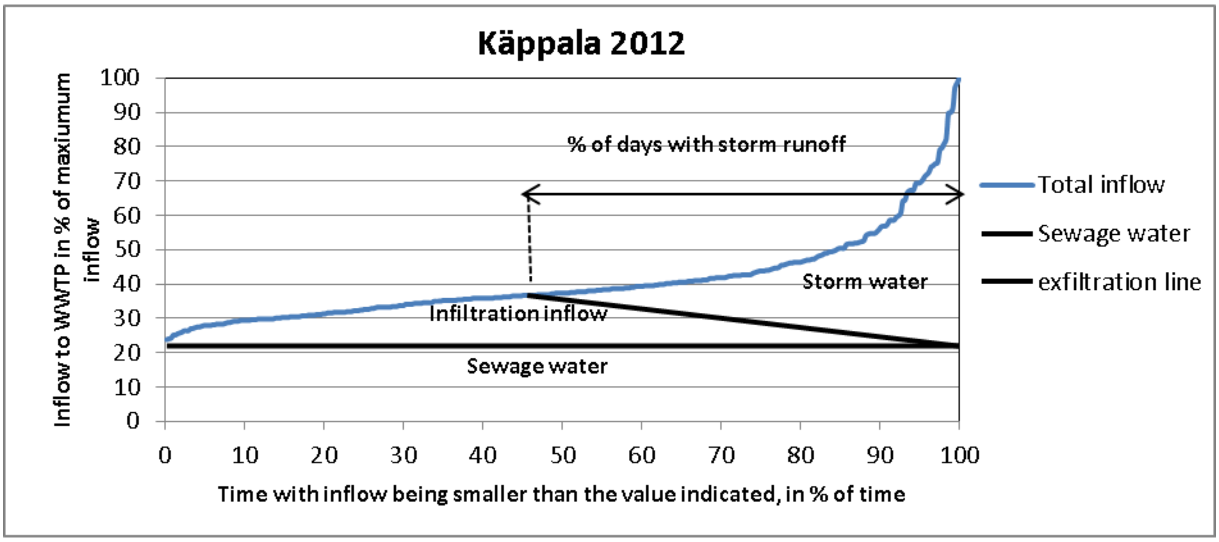

Figure 62. Graph showing the triangle method for Käppala 2012.

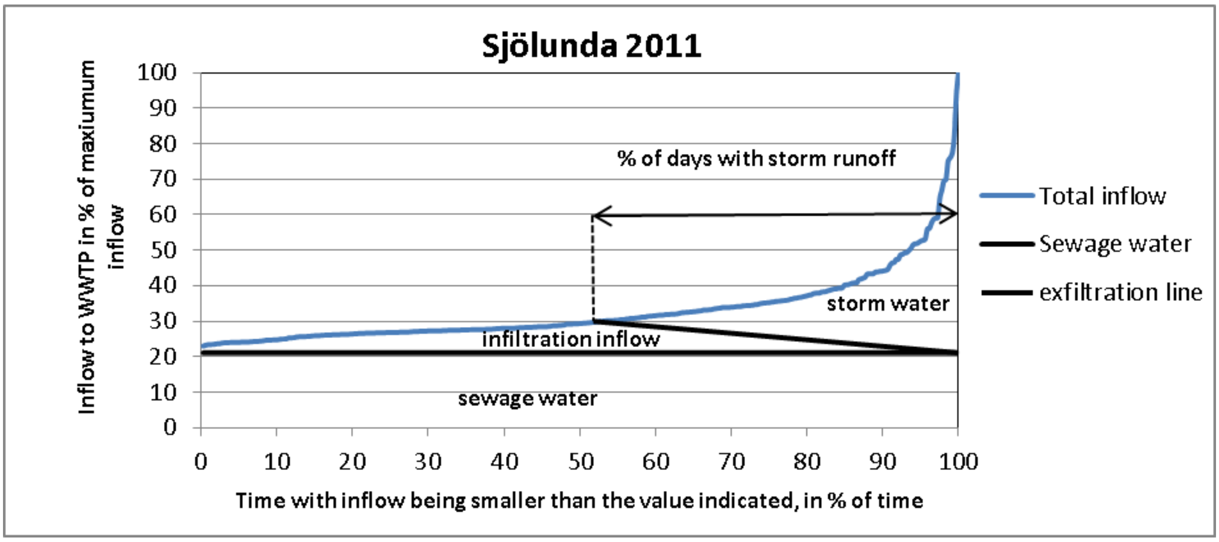

Figure 63. Graph showing the triangle method for Sjölunda 2011.

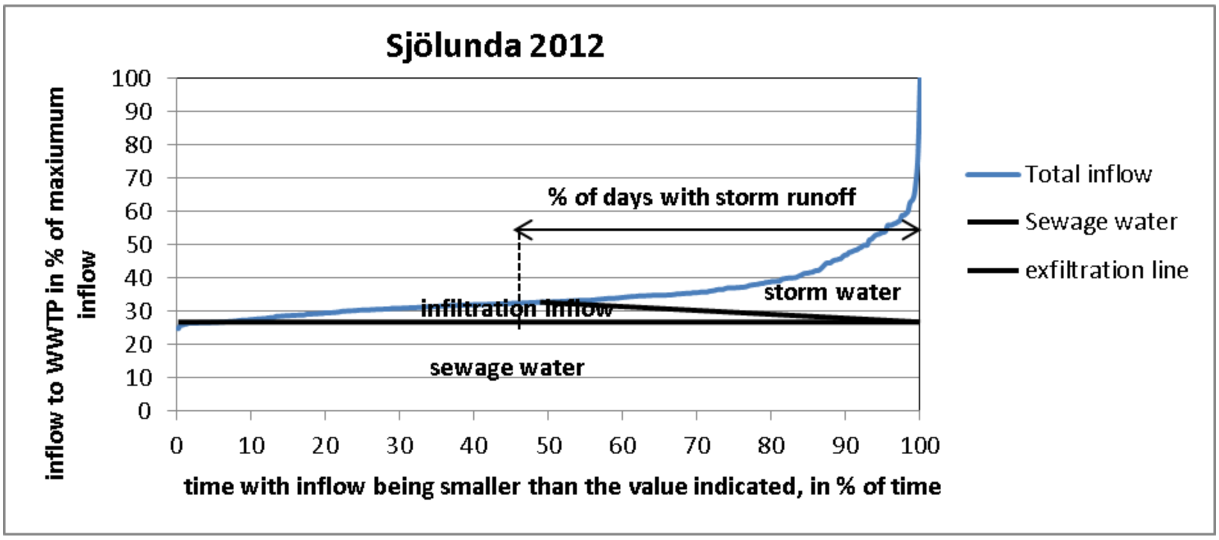

Figure 64. Graph showing the triangle method for Sjölunda 2012.

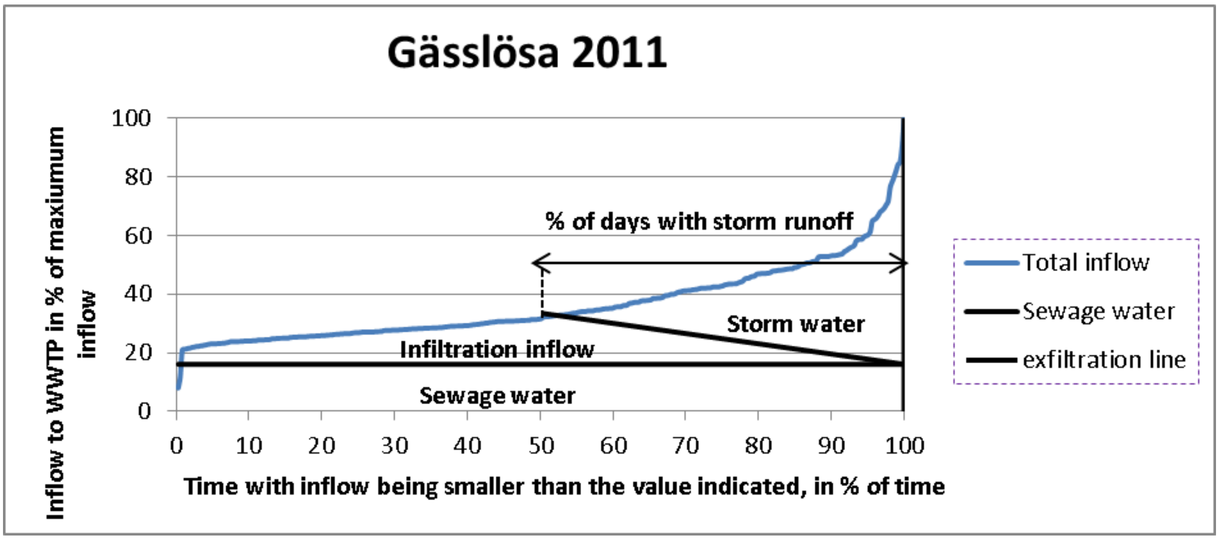

Figure 65. Graph showing the triangle method for Gässlösa 2011.

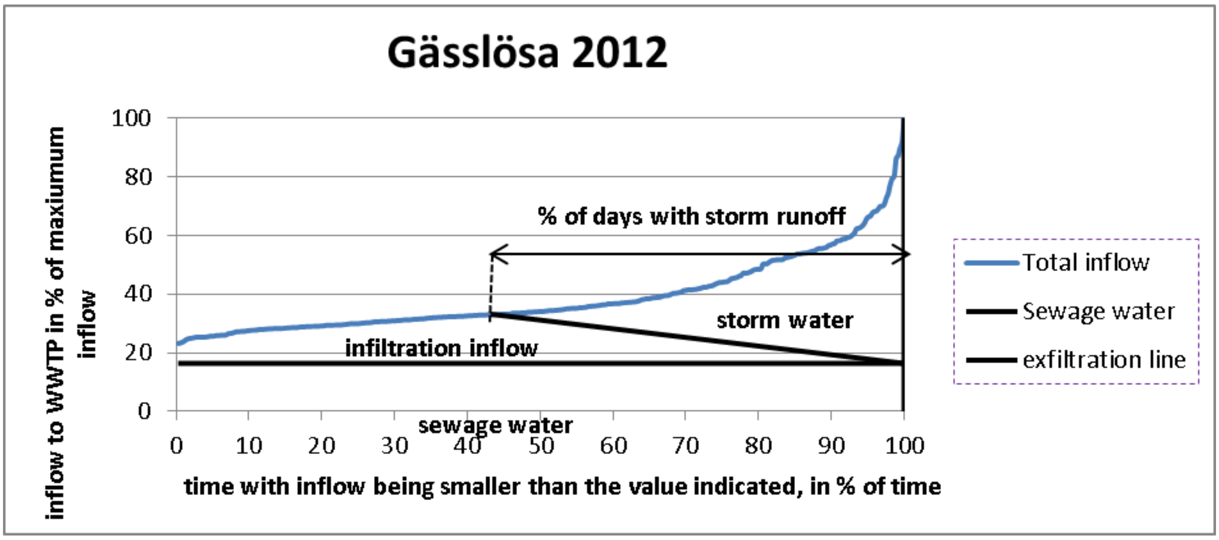

Figure 66. Graph showing the triangle method for Gässlösa 2012.

7.3 The moving minimum method

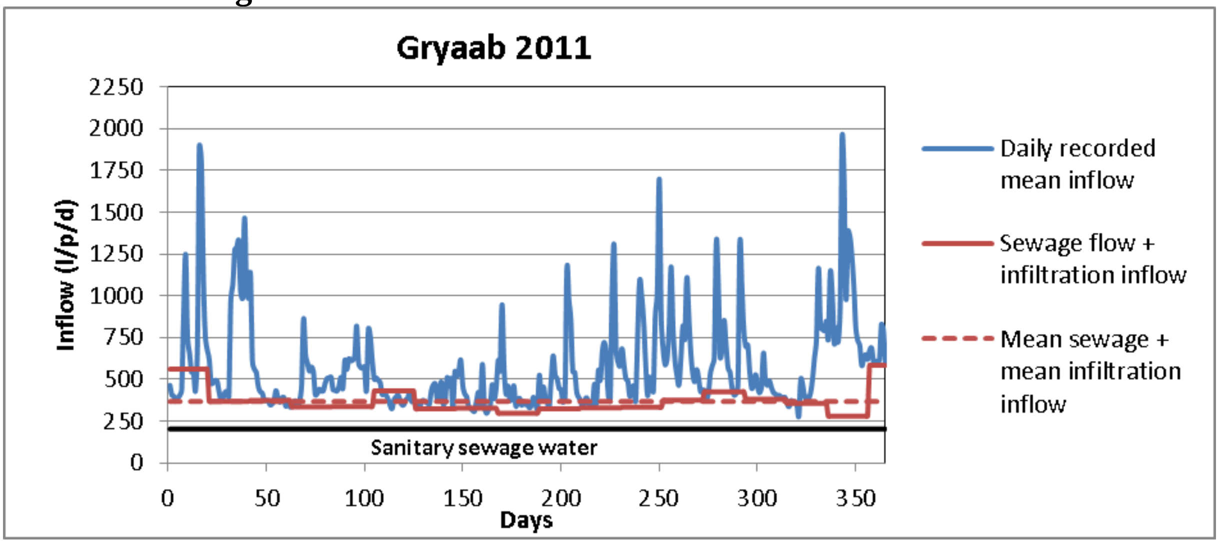

Figure 67. Graph showing the moving minimum method for Gryaab 2011.

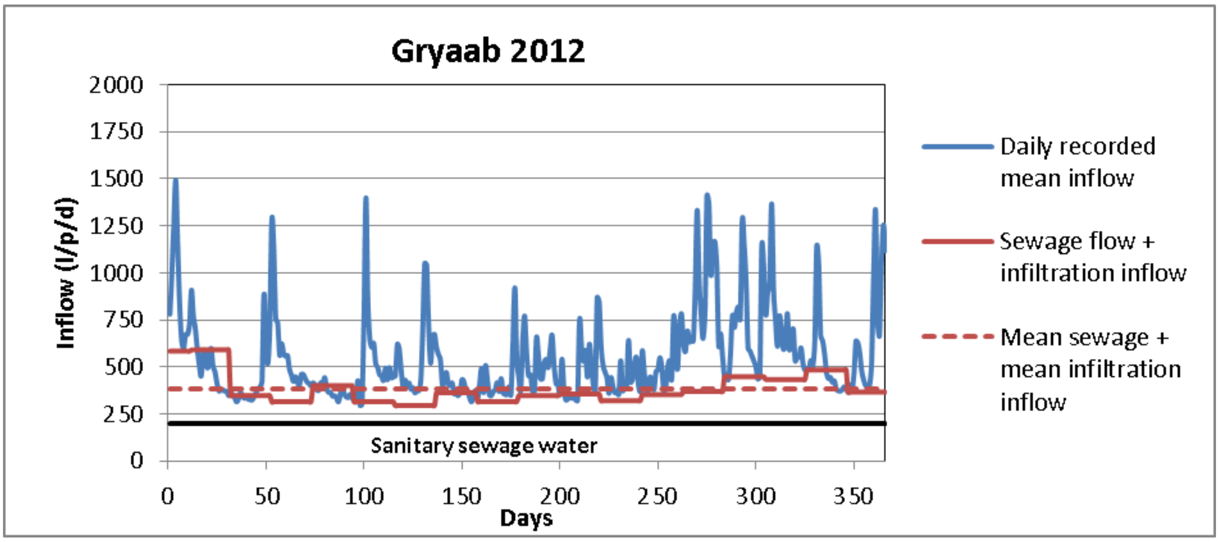

Figure 68. Graph showing the moving minimum method for Gryaab 2012.

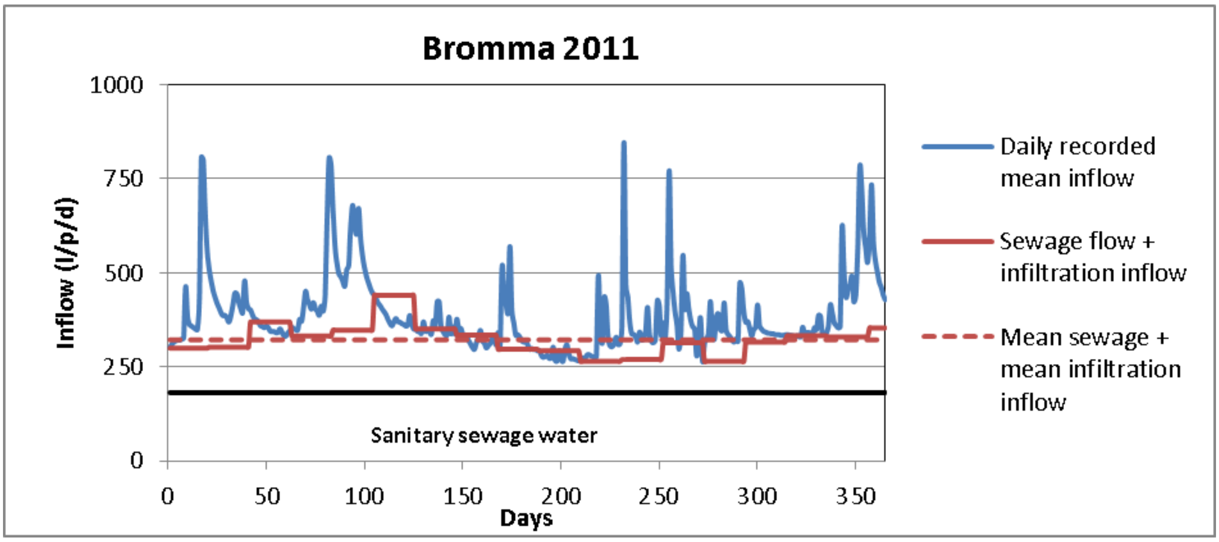

Figure 69. Graph showing the moving minimum method for Bromma 2011.

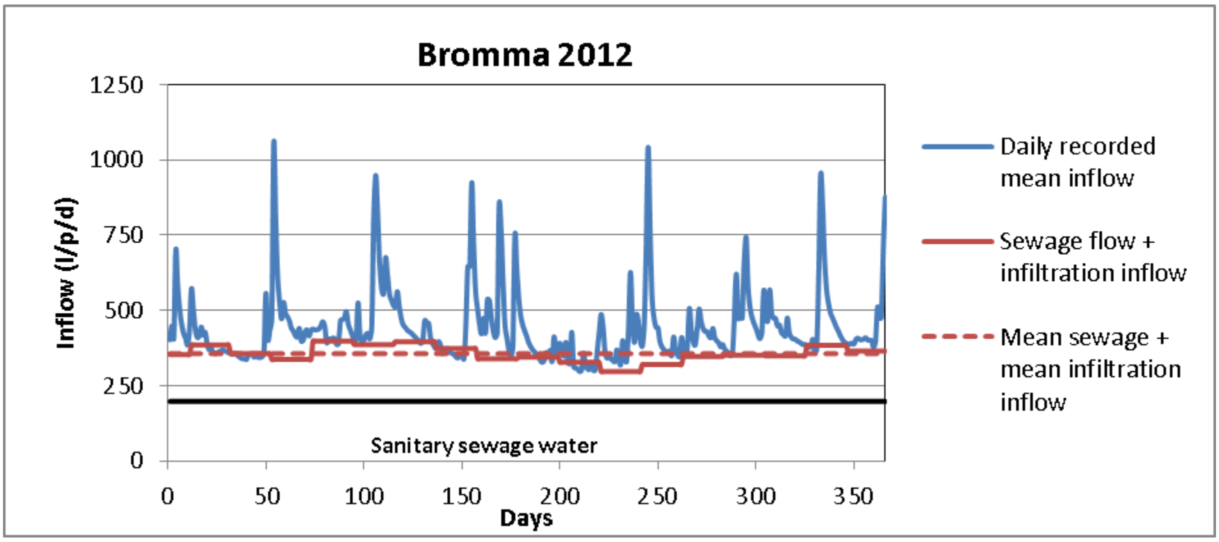

Figure 70. Graph showing the moving minimum method for Bromma 2012.

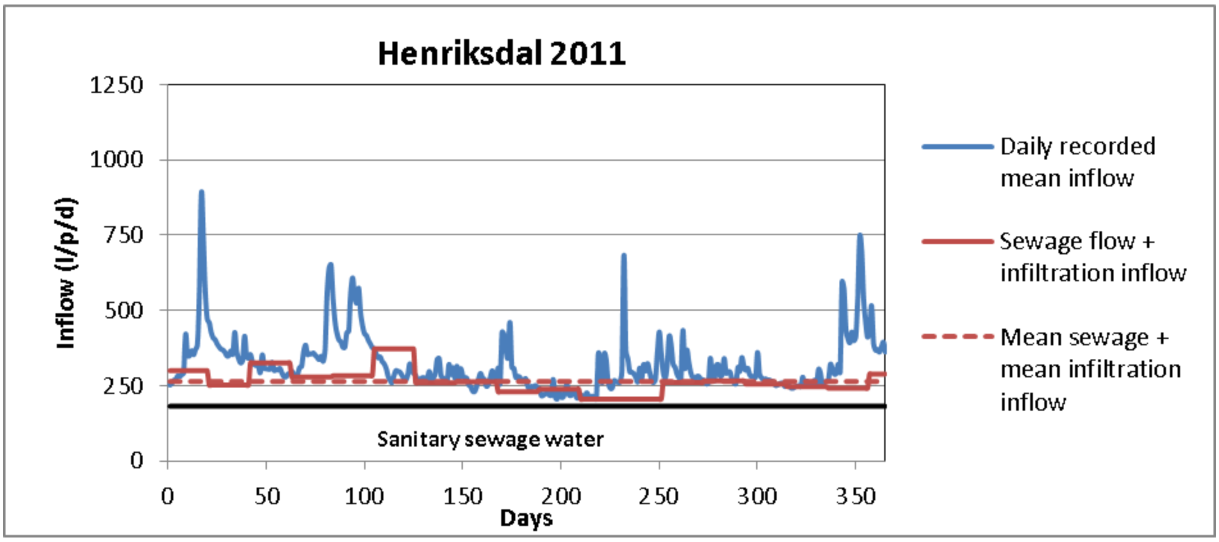

Figure 71. Graph showing the moving minimum method for Henriksdal 2011.

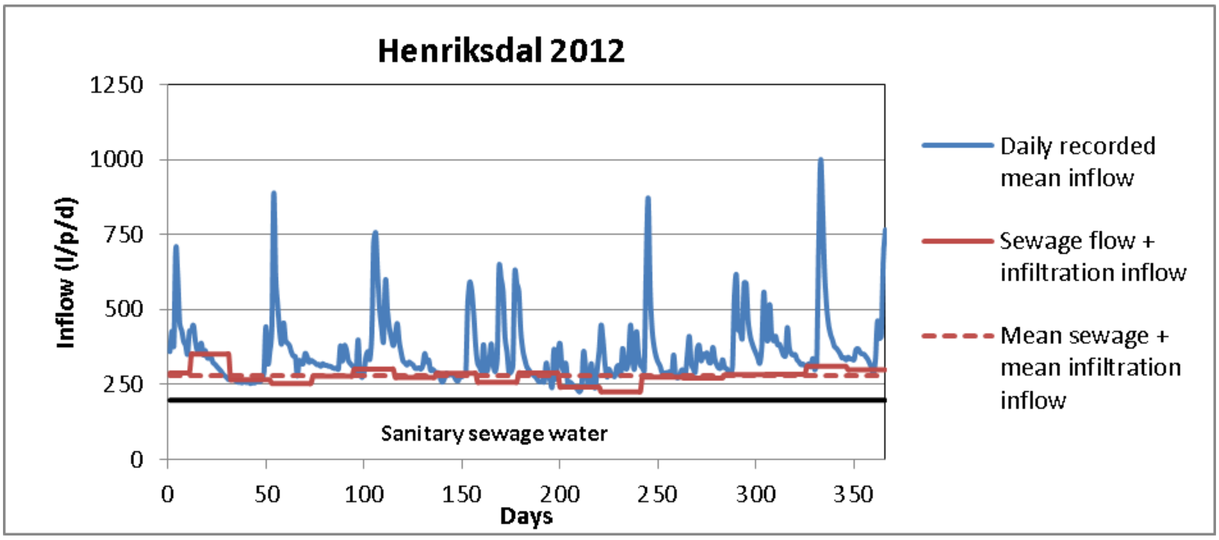

Figure 72. Graph showing the moving minimum method for Henriksdal 2012.

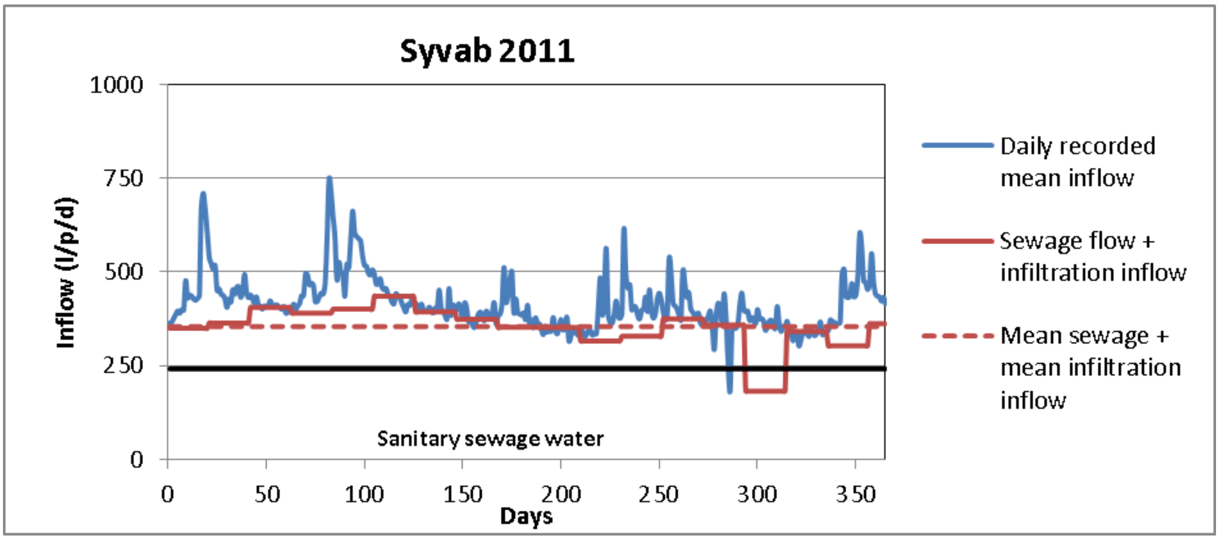

Figure 73. Graph showing the moving minimum method for Syvab 2011.

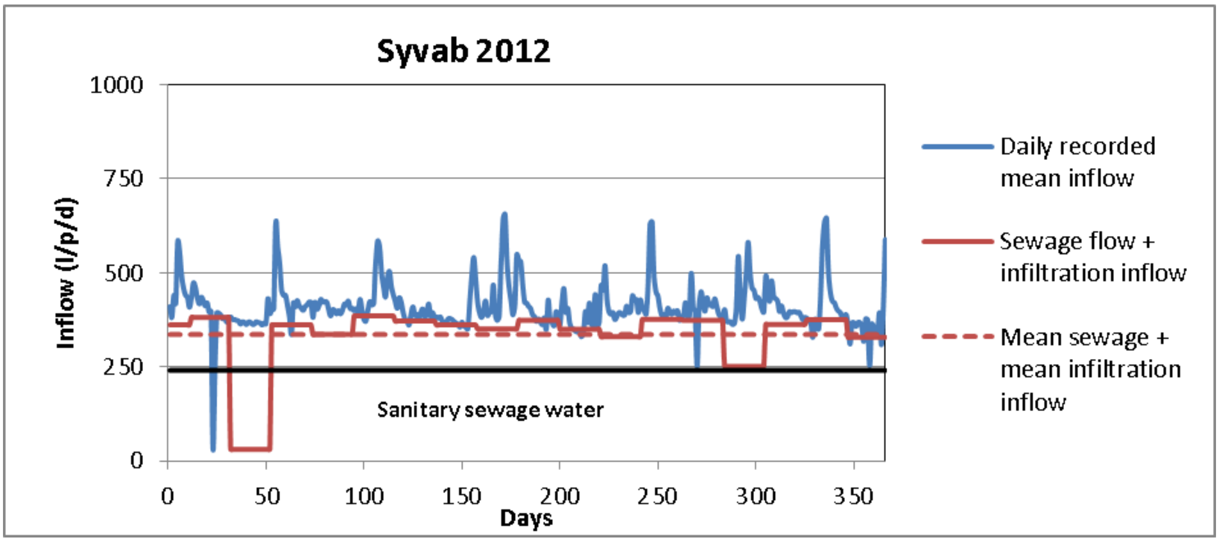

Figure 74. Graph showing the moving minimum method for Syvab 2012.

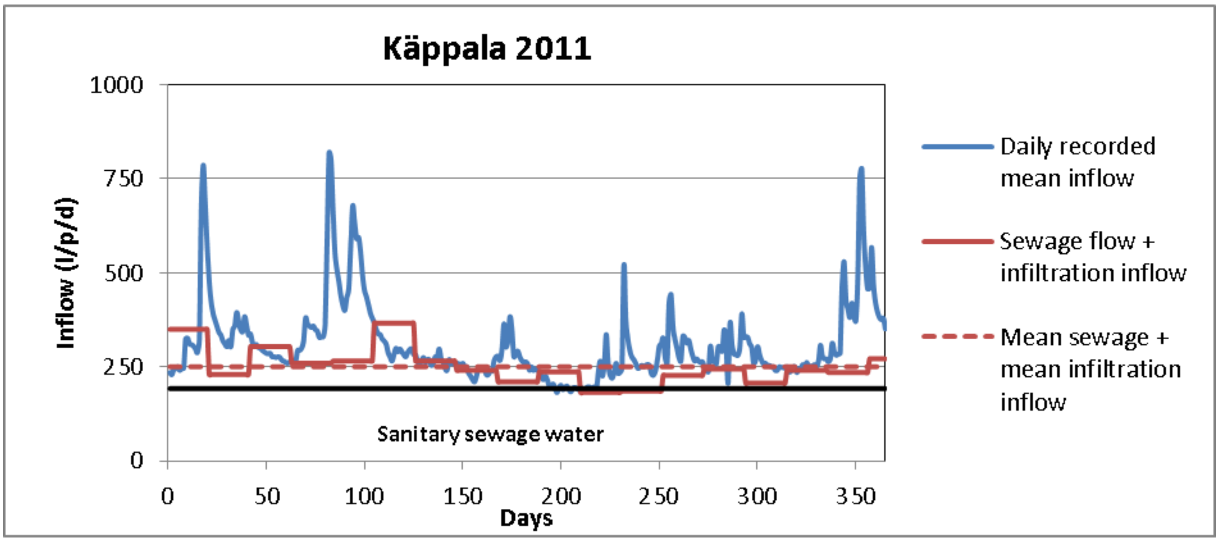

Figure 75. Graph showing the moving minimum method for Käppala 2011.

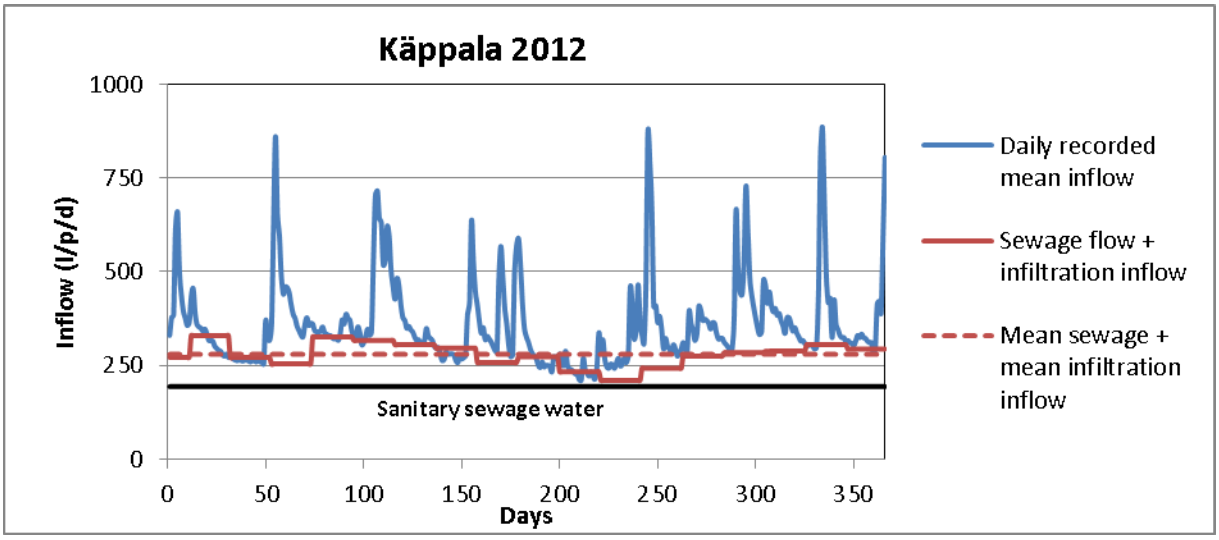

Figure 76. Graph showing the moving minimum method for Käppala 2012.

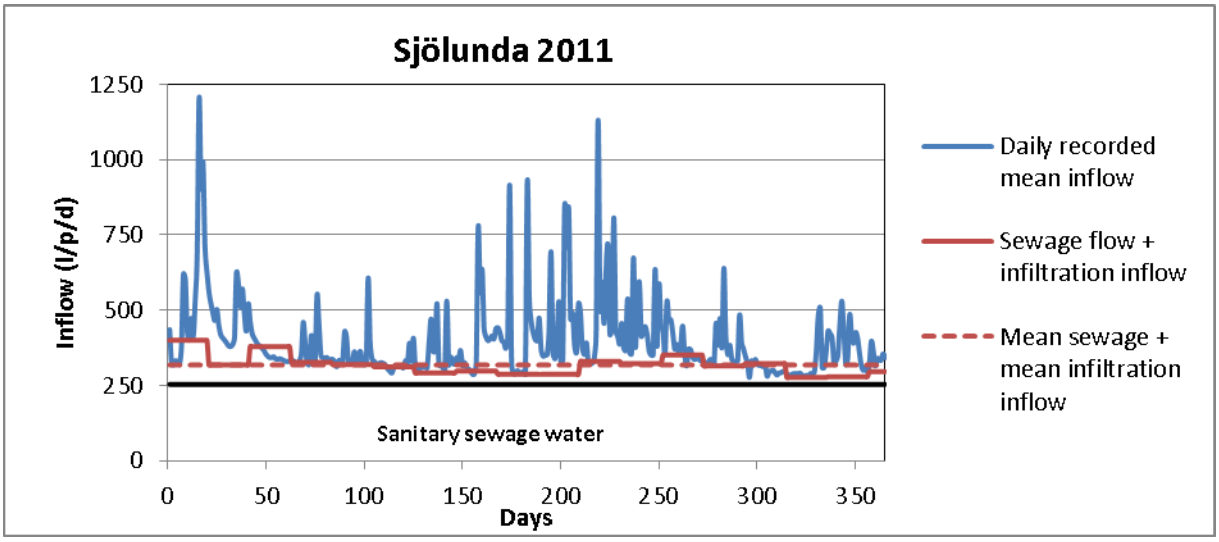

Figure 77. Graph showing the moving minimum method for Sjölunda 2011.

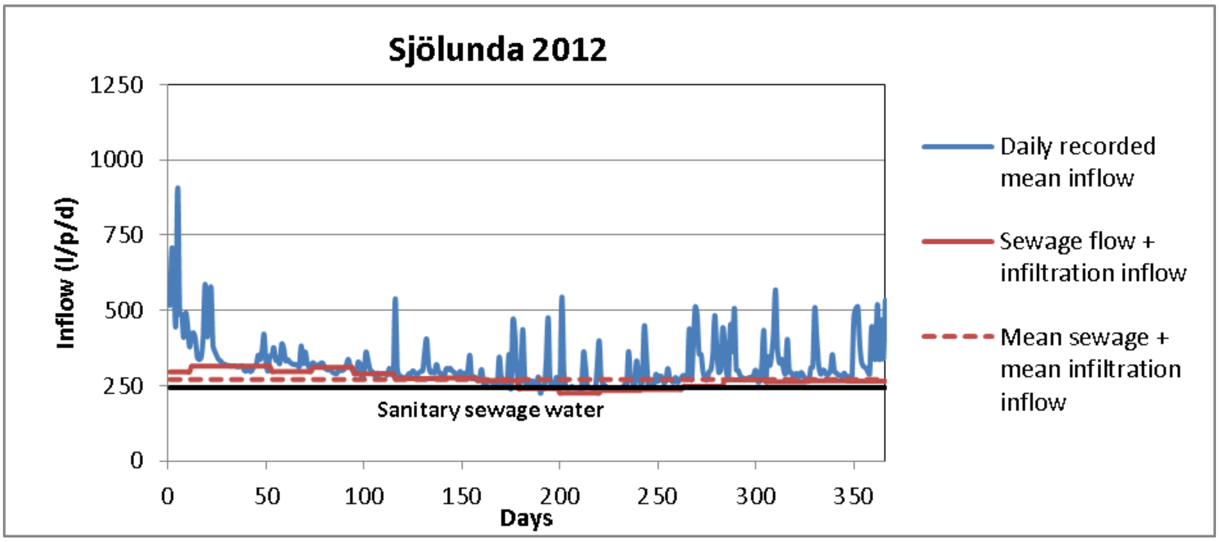

Figure 78. Graph showing the moving minimum method for Sjölunda 2012.

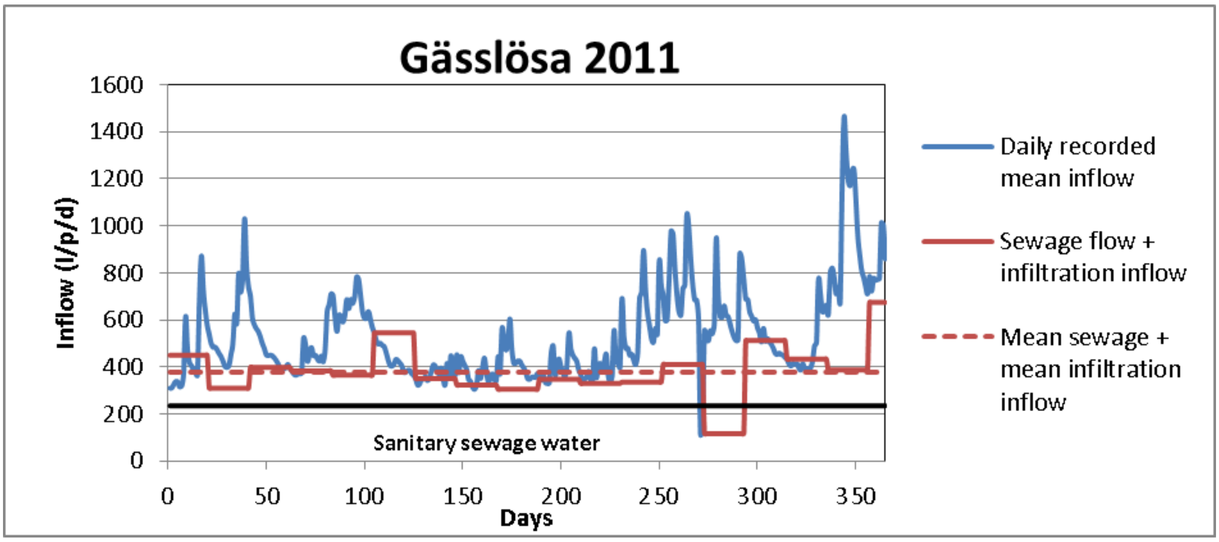

Figure 79. Graph showing the moving minimum method for Gässlösa 2011.

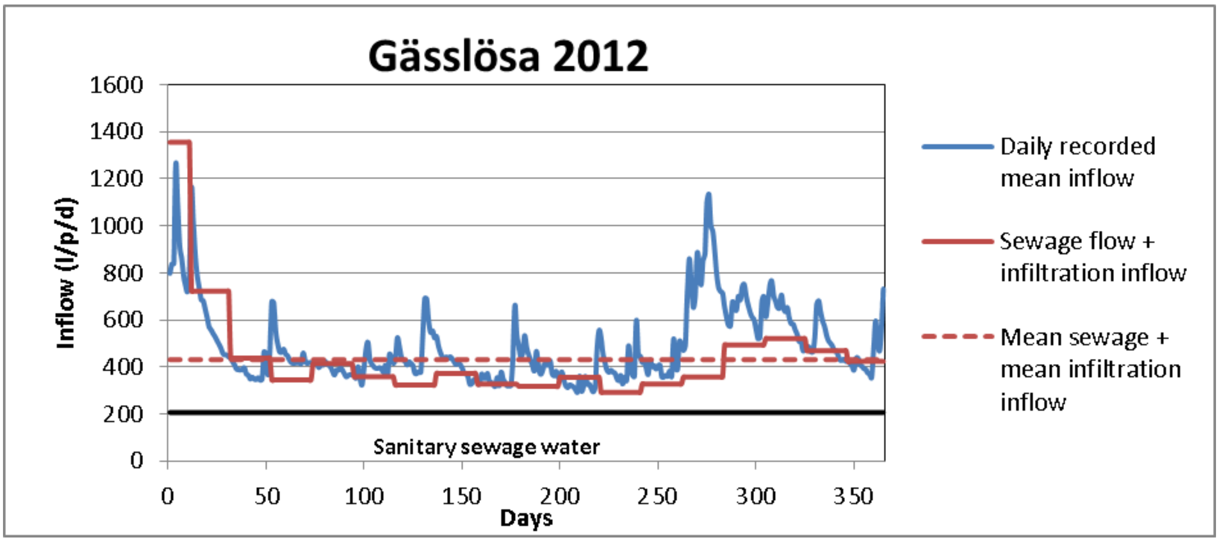

Figure 80. Graph showing the moving minimum method for Gässlösa 2012.