CHALMERS

Evaluation of T-bladsmetoden

An assessment of a proposed evaluation method for excess water

Master of Science Thesis in the Master's Programme Infrastructure and Environmental Engineering

ABDIKHANI SHURIYE

Department of Civil and Environmental Engineering
Division of Water Environment Technology

CHALMERS UNIVERSITY OF TECHNOLOGY
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ABSTRACT

Wastewater management has always been a major part of society and is still very relevant in today's society since a well-functioning sewage system is central to human and environmental health and wellbeing. As time passes by and society evolves there will always be new problems which come with change. One of these issues which have become more prominent in present times is excess water. Excess water is hard to describe but refers to any water found in the sanitary sewer systems which does not technically belong there. It enters the system through many different pathways and causes elevated flows in the systems which lead to difficulties. It is therefore hard to describe the excess water characteristics, such as volume, source and flows, in an area and also locate all the point of entries such as cracks misconnections.

T-bladsmetoden is a proposed method which is intended to make it easier to determine the nature of excess water flow in pipelines for specific areas and make a comparison to the flow led to treatment plants. T-bladsmetoden uses flow measurements from an area in the sewage network and compares it with the flow to the treatment plant. Out of these measurements key performance indicators can be created which can later be used to compare different areas.

This thesis is aimed at evaluating T-bladsmetoden, by implementing it on some areas in the Gothenburg region, as well as comparing it to other similar methods.

Results show that the method does give a good overview of the excess water situation in selected study sites and furthermore appears to be a useful tool when it comes to these matters. It is not however a tool which is to be used by itself and therefore be used either as a compliment to other methods or as start for further investigations.

Key words: T-bladsmetoden, Excess water, key performance indicators, wastewater management, sewage system, infiltration, inflow

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Preface

This thesis has been mostly carried out from August 2013 to December 2013 at the Department of Water Environmental Technology which is part of the Civil and Environmental Engineering Department of Chalmers as well as at Kretslopp och Vatten under the supervision of Annika Malm. It concluded the final part of the Infrastructure and Environmental Engineering programme.

I would like to thank Annika Malm and Håkan Strandner at Kretslopp och Vatten for their valuable input and feedback throughout the work in making this thesis possible and express gratitude towards the other employees at Kretslopp och Vatten who assisted with useful knowledge as well as data necessary for the project.

Göteborg, December 2013

Abdikhani Shuriye

1 Introduction

Wastewater management has always been a major part of society and is still very relevant in today's society since a well-functioning sewage system has continuously been central to human and environmental health and wellbeing. As time passes by and society evolves there will always be new problems which come with change. One of these issues which have become more prominent in present times is excess water.

1.1 Aim

The aim of this study is to evaluate the proposed new method, which is called T-bladsmetoden, by studying the method itself as well as applying it to certain study sites in order to determine the feasibility of the method. In addition to this the study will also show other methods which are in use and possibly compare them to the new method.

1.2 Method

This thesis will be consisting of a literature review which comprises background information about the subject as well as a description of the new method. The literature study will also include similar methods which are practiced in the field today. T-bladsmetoden is then applied on several case study sites which are specifically chosen and the results are then analysed and discussed in the following chapters.

1.3 Delimitations

The studied sites are all in the Gothenburg region and connected to the main sewage network of the city out of practicality and they were chosen after consultation with supervisors at Kretslopp och Vatten.

1.4 Background

Excess water will in this thesis refer to any water found in the sanitary sewer systems which does not technically belong there. Ideally the separated sewer systems transport only foul water from houses and industries as well as agriculture connected to the sewage system, but this is not always the case since groundwater and stormwater enter the system frequently. This water may have entered the sewer pipes through many different pathways, but consists mainly of groundwater and surface water, and can be described in the terms of inflow and infiltration, (Bäckman et al, 1997). These terms inflow and infiltration or I/I are the definitions used in most of the literature discussing these matters.

The term inflow refers to water that enters the sewer systems through connections in the system, which means that sources of surface- and stormwater are directly or indirectly connected to the sewer system. Such sources could be drains and downspouts from houses or other pipes such as stormwater sewers that are erroneously connected to the sewer pipe system. Other surfaces that also could be incorrectly connected are roofs, streets and courtyards, as well as manholes which are not sealed tight enough. It is considered that almost every sewer system will have at least some infiltration of inflow (EPA, 1985). The outcome of this is that water from these areas is discharged straight into the sewer system and contributes with large flows.

Infiltration on the other hand refers to water that enters the sewer systems through leakage in cracks and failures in the sewer system. These cracks and leakages allow groundwater to enter the sewer systems, particularly where the pressure is not adequate i.e. where the groundwater table is higher than the pipe levels, see figure 1 for some of the pathways.

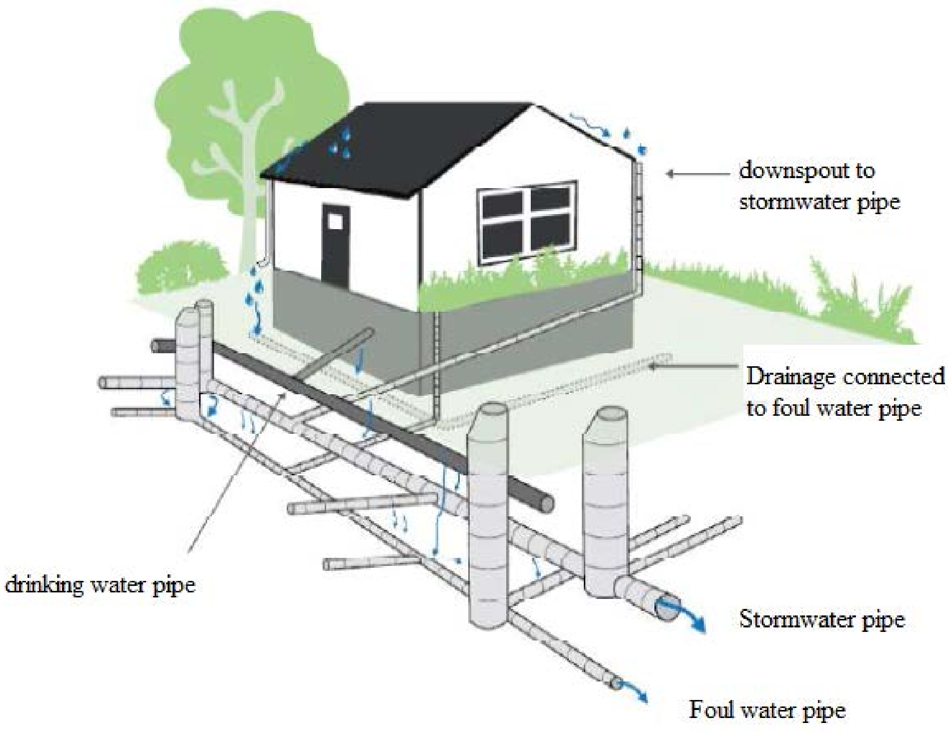


Figure 1: Some pathways of excess water into foul water pipes (Svenskt Vatten concept P101)

The fact that excess water can enter the sewage systems in many different ways and forms through many different sources is apparent. This makes it difficult to monitor both the amount of excess water in the systems as well as their sources, as can be seen in figure 1 . The difficulty lies in the fact that the sewage system is mostly hidden underground and also covers several kilometres of pipelines which vary in age and material. The behaviour of the excess water itself is also subject to many different factors. Some of these factors include rainfall, moisture conditions, depth to groundwater, depth to bedrock, land slope, number and size of sewer system defects, type of storm drainage system, and soil characteristics (Vallabhaneni et al, 2007). In addition to this the pipes are exposed to different types of loads from the ground level and earth pressures. Another point which also must be taken into consideration is the many different types of pipes, with varying materials and structures which have been part of the network for different amounts of time.

A detailed measurement to track where excess water is initially originating from in a catchment area is very difficult. A study showed that 1l/s excess water on average was originally water which came from a surface area of 4,7 ha and over time through infiltration and inflow came to be in the sewage system (Brombach et al 2002).

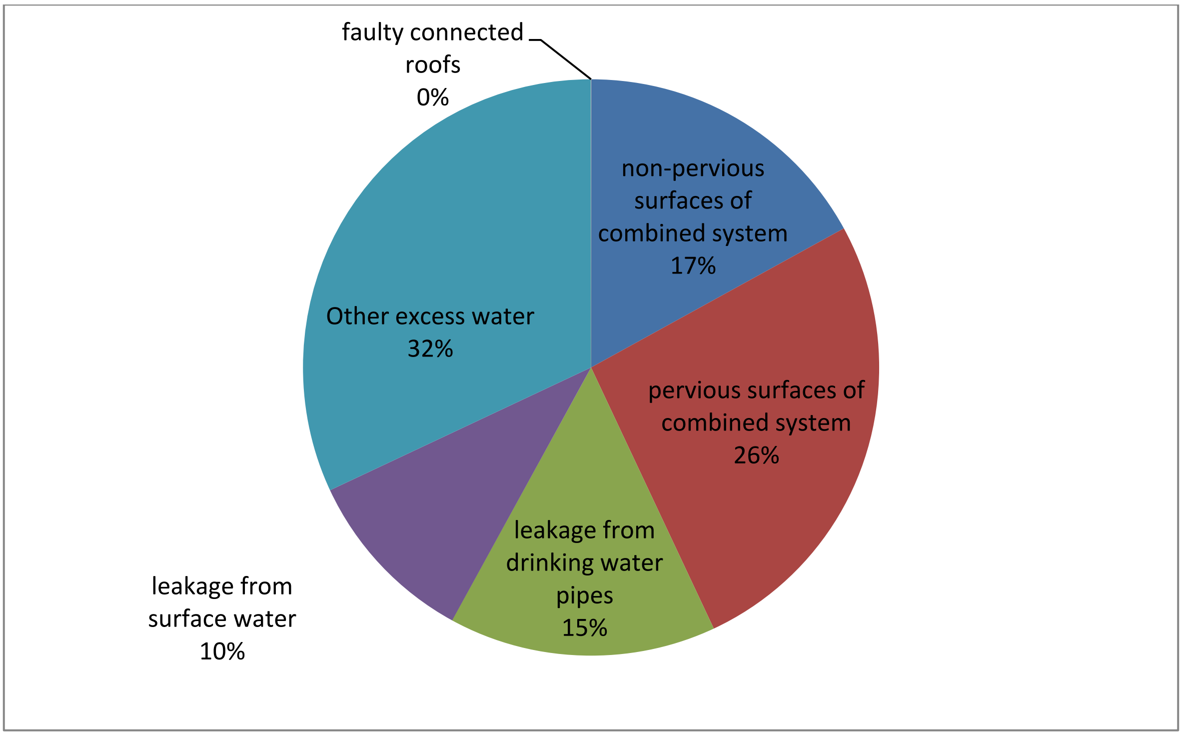


Figure 2: Flow distribution of excess water sources in Gothenburg (Jansson, 2010)

1.5 Gothenburg sewer system

Gothenburg's sewage system consists of 2500 km sewage pipe network in total, including around 66 000 manholes, and over 200 pumping stations. The sewage water is led to Gothenburg's wastewater treatment plant Ryaverket which has over 700 000 people connected to the system (Göteborg Stad, 2010)

The central and eastern areas of Gothenburg consist of a combined system where permeable and impermeable surfaces are connected to the sewer system. Combined systems consist of one main pipe which leads both sewage water as well as stormwater. Since the 50s however the sewer systems where constructed in the form of duplicate and separate systems, meaning that the sewage water and the stormwater where separated in different pipes (Göteborg stad, 2012). Changes from a combined system to separate system are not always without flaw and it is not uncommon that remnant direct drainage connections cause inflow and infiltration of excess water in the wastewater system during storms (EPA, 2004). The sewage system also contains sewage overflows, which are outlets that lead overflow water straight into recipient during heavy rain events, in order to limit the flows into Ryaverket at very high flows.

Kretslopp och Vatten always works towards improving the sewage network through maintenance as well as implementing future plans. One of the goals in the action plan that was prepared for Gothenburg in 2011 was to decrease the amount of excess water to Ryaverket to less than 50 %of the total from Gothenburg. Another one of the goals linked to excess water was that the amount of surfaces connected to the combined system was to be decreased by 15 hectares per year. Both points are part of guidelines for a long term sustainable sewage system aimed at being fulfilled for year 2030 (Norlander, 2010)

The amount of excess water into Ryaverket can be calculated with the following formula (Jansson, 2012)

$Q_{Excess} = Q_{Rya,tot} - Q_{Rya,recyc} - Q_{tunnel} - Q_{n,c} - Q_{Bsf} - Q_{Gbg,own}$

Where

Q_{Excess} = excess water to Ryaverket

$Q_{Rya,tot}$ = Measured flow to Ryaverket

$Q_{Rya,recyc}$ = Recirculated flow at Ryaverket

Q_{tunnel} =Leakage into tunnel system

$Q_{n,c}$ = Measured flows from neighbouring municipalities

Q_{Bsf} = Base sanitary flow, calculated on water consumption patterns

$Q_{Gbg,own}$ = Water used for the purpose of flushing sewage system and used within the wastewater treatment plants.

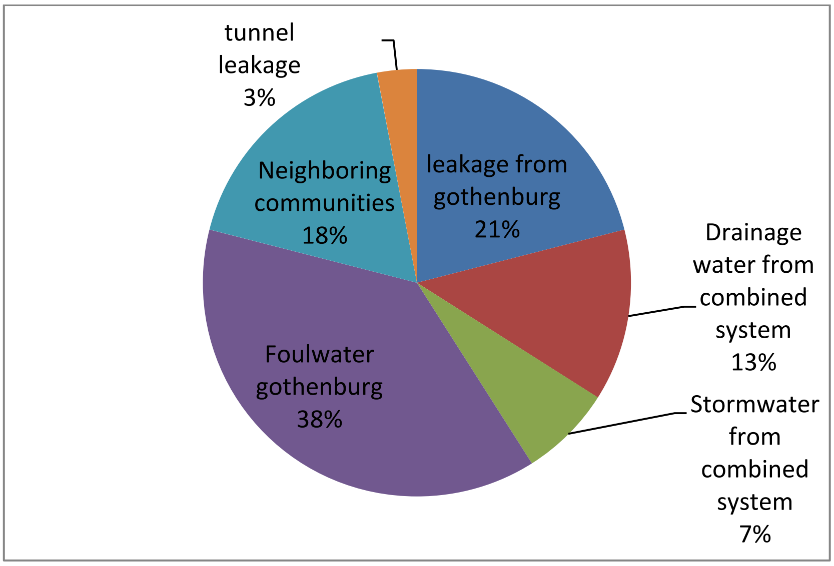


Figure 3:Flow distribution to Ryaverket from Gothenburg and neighbouring municipalities (Jansson 2010)

1.6 Problems and impacts on the sewage network

As previously mentioned there is constantly a presence of excess water in the sewage system due to many different types of pathways and sources. The excess water then causes many impacts and complications in the sewage network.

1.6.1 Wastewater treatment plants

Wastewater treatment plants are dimensioned to handle a certain flow of water; this flow is based on dry weather flow (Q-dim). The dry weather flow, also called base sanitary flow, is based on consumption patterns of the households in the population and industries connected to the sewer system and are also generally constant over a 24 hour period. It is therefore usually not subject to major changes from day to day, although it may vary over the months. In this report dry weather flow will be synonymous to sewage water since there are many terminologies for the same entity.

In order to incorporate the excess water into the calculations the dry weather flow is multiplied with a factor to produce a maximum flow which the treatment plant should be able to manage (Bäckman et al, 1997). The amount of excess water nonetheless is often more than what the treatment plant and sewer systems can handle.

This can result in water flows reaching the treatment plants being diluted, meaning that treatment processes are not optimal in the different facilities of the treatment plant. This is particularly true when there is heavy rainfall or snow melting where the excess water flow causes the systems to be overflown and dilutes the sewage water flows. There is undoubtedly a direct link between the flow variation into the sewage plant and the amount of water which can be treated. Large flows into Ryaverket mean that some treatment processes will not be able to be used since they are not dimensioned for those amounts of flows. A German study showed that up to around 70 % of the water which is treated in an average treatment plant is originally non polluted, meaning that it is not sewage water but in fact excess water (Brombach et al 2002). This is confirmed by studies made on Ryaverket, Gothenburg's sewage treatment plant, which show that during the highest flows only one third of the water coming in consists of sewage water and the rest is excess water (Mattsson, 2010).

1.6.2 Sewage pipes and surrounding environment

Excess water in the sewage pipe network can also have troublesome effects on the environment. During heavy rainfall events excess water is led to sewage overflows since the wastewater treatment plant cannot handle the flows, meaning that unprocessed water is led directly to recipients, causing an environmental impact. Another consequence of high flows is that the pressure in the system becomes too high which can result in surcharging and flooding of basements and other low-lying areas. On the other hand during infiltration into the sewage system, groundwater leaks in through cracks and holes in the pipes resulting in lowering of the groundwater table. Another effect of infiltration is that unwanted pollutants can enter the sewage network, such as organisms, bacteria, soils and metals (Falvey, 1999).

1.6.3 Costs

All of the above mentioned impacts due to excess water have a costly effect, both on the environment and the community itself. Wastewater treatment plants may be redesigned to incorporate the excessive volumes. Furthermore excess water also has a costly effect due to the fact that treating more water costs more in many forms (Mattsson, 2010). This could be costs from increasing the capacity of the wastewater treatment plants and also costs from pumping larger volumes.

After heavy storm events there is a risk for surcharging and flooding's which, after causing damages to houses and roads, will need maintenance and possibly reconstruction. Many components in the sewage network such as pipes and pumps are also worn out faster due to increased flows and will therefore need maintenance more often. The cost on the environment on the other hand comes from untreated water entering local recipients as well as ground water levels being altered due to infiltration.

2 Theory and methodology

This chapter aims to study and present some of the existing survey techniques and detection methods concerning excess water as well as presenting and describing T-bladsmetoden.

2.1 Monitoring excess water

In order to determine the amount of excess water in an area or a whole sewage system the system has to be evaluated. Common for most evaluation methods (Dublin, 2005, Carvalho et al 2007, USEPA 1985, Lundblad et al, 2012) is to divide the sewage system into sub-catchments or subsystems. Naturally this is reasonable since evaluating a whole system in one go is an immense project and the division alleviates considerably. It is however important to investigate all of the subsystems to describe the system as a whole. An overview of the system is then made by studying the sewage network (pipes, pumps) and existing data (usually flow and rainfall data) as well as the calculated dry weather flow based on population, industries and agriculture. Since excess water is directly connected to rainfall it is essential to study rainfall patterns and how resulting rainfall affects the sewage system. One way is to monitor both the flows in the sewage system as well as the amount of rain falling in an area over an extended timeframe. Then by accessing the dry weather flow from the connected households and/or industries connected to the area, and comparing to the flows in the sewage network as well as rainfall an evaluation can be made about the excess water. This evaluation requires large amounts of data and perhaps additional installment of several flow meters and rainfall monitors in order to collect the data. (Burton et al, 2003). Moreover the groundwater table must be monitored because of the infiltration component (FCM, 2003). The next step in the system evaluation is then to determine the sources of the excess water, and this can be done through source detection methods.

2.2 Domestic Examination Methods

According to an extensive survey made by Svenskt Vatten (The Swedish Water & Wastewater Association, SWWA) (Lundblad et al, 2012) there are 5 different procedures that an examination method should contain in order to determine the sources of excess water for a certain area. Namely to:

- Identify the non-pervious surfaces that are directly connected to the wastewater system.
- Clarify unknown cross connections between stormwater pipes and wastewater pipes, both in the public and private pipes, and the location of those.
- Clarify if there is leakage between leaky storm drains and leaking sewage pipes, both in the public and private lines and the location of those.
- Identify wastewater manhole located in low points and at risk of significant water supplements exist.

- To control the whereabouts of excess water from known sewage overflows into the sewage network.

There are several ways of investigating what specific sources that are cause for excess water in the network. Coloured water can for example be used to search for faulty connections. Other methods to determine where exactly excess water is entering the system are flow meters, tv inspections as well as even purposely damming some networks in order to better search for faults (Lundblad et al 2012). A survey was carried out where several professionals where asked questions regarding how they generally treated the excess water in their systems. When asked what methods they had used to detect excess water in the system for different causes the answers were as follows:

Coloured water was commonly used to detect faulty connections in the system, followed by searching with the help of smoke. Leakages where inspected primarily with TV inspections as well as visual inspections. Not many of the questioned, when asked about leakages between stormwater and foul pipes, had investigated this matter. Those who did however had inspected by using water (in this case using water means tracking the flow of specific water in the pipes). Excess water from known CSOs and emergency (overflows) are mostly inspected visually (Lundblad et al, 2012).

2.3 Source detection methods

Most of the monitoring methods which are used out in the field today are source detection methods meaning that they are carried out to detect a specific source in a certain point of the sewage network. These methods are common for many countries and some of them are applied by Swedish engineers in the survey made by Svenskt Vatten.

2.3.1 Flow measurements

Flow meters are a good tool and often used in practice to monitor and measure amount of excess water in the system through flow trends. In order to identify areas with abundant excess water by using flow meters however it is important to conduct measurements in small limited areas (Jansson, 2010). The flow meters are used to measure during dry weather periods and usually during night-time.

2.3.2 Visual inspections

This type of inspection is carried out during a dry day where the groundwater level is relatively high in the inspected area. It is performed by manually entering the sewage systems, following the flow and evaluating accordingly. With visual inspections the inspector is able to get a good overview and is able to delimitate areas with lot of excess water fairly easily. This method is a simple and fast method to get a good estimate of an area since the person inspecting can detect errors in the area directly. The results from the inspection are however directly related to the experience of the inspector and there is a probability of errors during inspection.

2.3.3 Dilution gauging

This method is primarily used in coastal areas and is performed by measuring the amount of chloride concentrations in the groundwater and in the pipes, as opposed to ammonium concentrations of the previous method. The concentrations in the groundwater and the sewage pipe are then compared to determine the salinity infiltration. The drawbacks with this method are that it needs to be analysed by a specialist and is also mostly useful in coastal areas (Dublin, 2005).

2.3.4 TV inspection

A TV inspection is made by placing a camera on a small vehicle which is then driven through the pipe network by remote. This camera then feeds back a visual of the pipe network that can be inspected on a screen. TV inspection is similar to visual inspection in the sense that it is based on ocular inspection, the difference being that TV inspection can be made in smaller pipes. On the downside however is that this method is both costly as well as time consuming which makes it difficult to use by itself, it is however a good compliment when used with other methods.

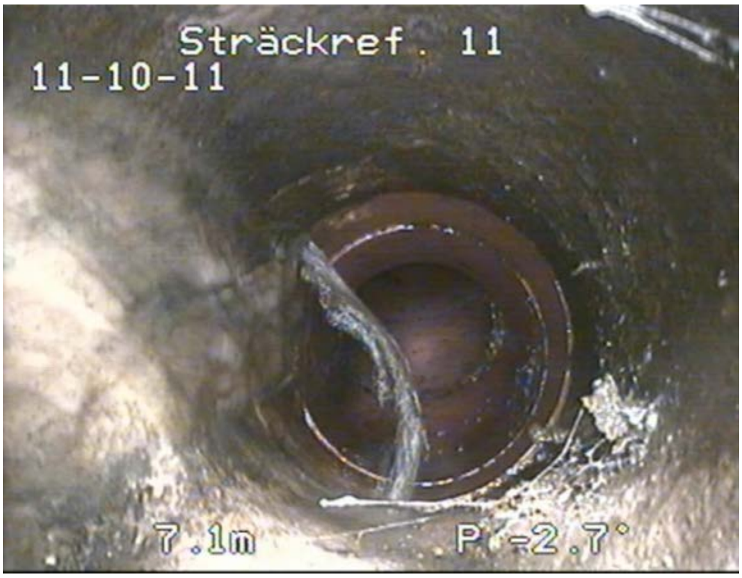


Figure 4: TV inspection showing a leak (Lunblad 2012)

2.3.5 Ammonium testing

Ammonium testing is a method procured by Norrköping Vatten (Lundblad, 2012) where a sample of the water in a pipe is taken and tested for traces of ammonium. The ammonium content can then be directly linked to amount of excess water. The premise being that diluted water contains less quantity of ammonium compared with foul water. The positive side of this method is that it is fairly simple to perform and gives a good overview of where in the system excess water can be expected. On the other hand it does not show what kind of excess water and cannot pinpoint which pipes that are affected.

2.3.6 Isolation

This method is as it sounds an isolation of a whole catchment area in order to test it for inflowing or infiltrating water sources. It is performed by closing of a section and then monitoring all the flows in the area. This method is very effective but on the other hand time-consuming as well as costly since the isolation requires water to be diverted into other pipes during the testing (DEP, 2003).

2.3.7 Monitoring flow and rainfall

Since excess water is directly connected to rainfall it is essential to study rainfall patterns and how resulting rainfall affects the sewage system. One way is to monitor both the flows in the sewage system as well as the amount of rain falling in an area over an extended timeframe. Then by accessing the dry weather flow from the connected households and/or industries connected to the area, and comparing to the flows in the sewage network as well as rainfall an evaluation can be made about the excess water. This method requires large amounts of data and perhaps installing several flow meters and rainfall monitors in order to collect the data. (Burton et al, 2003)

2.3.8 Mike Urban RDII

Advancements in technology have been made in every field and wastewater engineering is no different. Today there are plenty of software which are actively used out in the fields and which make it easier to overview and analyse the sewage network. One of these software which was used in this project was Mike Urban RDII.

Mike Urban RDII is a software that uses data from a certain area (rainfall, characteristics of the landscape, and other factors) to calculate the amount of this water which comes from infiltration and inflow i.e. excess water.

The RDII model is a conceptual mathematical model, which means hydrological processes within the urban catchment area in the system are described by several boxes. These boxes simulate the real conditions by transforming them into parameters such as volumes and discharge/time. It divides the inflow of water coming into the system into different components, FRC and SRC. The FRC (Fast Response Component) denotes the initial response of water after a rainfall and is not dependent on previous hydrological conditions. This component of water flows relatively quickly into the sewer system after impact. The SRC (Slow Response Component) is as the name implies the water which responds to rainfall by flowing into the sewer system over a longer period of time. This component is dependent on previous hydrological conditions meaning that if for example the soil was previously saturated, the volume of this component will be increased by the following rain, other factors that also are taken into consideration are air temperature and evapotranspiration (Gustafsson et al 1999), see figure 5.

Data needed for an RDII model to be created are: initial conditions, meteorological data, a description of the area and also several RDII parameters. This includes rainfall data over a period of time, the amount of pervious to impervious areas present in the studied area amongst others.

In order to correctly match the measured water flow in the area to the RDII model the parameters must be fine-tuned and calibrated for a longer period, usually 1 to 3 years, this in turn produces the volumes of FRC and SRC which can be used to create key performance indicators, see Appendix III.

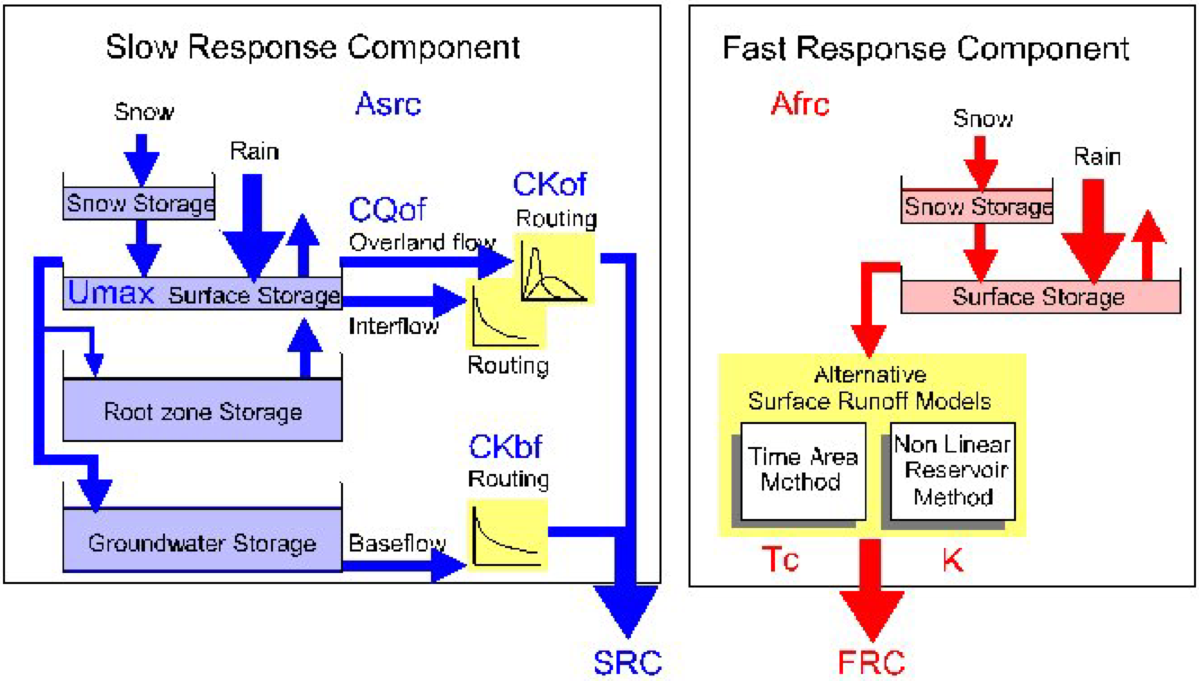


Figure 5: The slow and fast components of the excess water displayed here as conceptual models (Gustafsson et al 1999).

2.4 T-bladsmetoden

Most current investigations on excess water are based on locating where in the network the excess water is entering and specifically where in the network the fault is occurring with so called source detection methods. Unfortunately these types of investigations are just too specific and usually carried out after the realisation that an area is prone to excess water. The flow monitor methods used to overview the excess water levels in an area, before implementing source detection methods, are extensive and also time consuming. The main projected difference with T-bladsmetoden compared to the other existing methods is that it is focused on being a simple tool in which a quick overview of the excess water situation of a subsystem can be made. The point is later to start investigating the area even further with source detection methods based on the results from the T-blad.

2.4.1 How to create T-blad

For this project the flow values for the catchment areas were obtained from pump station readings. Since all the studied sites had their sewage network connected to pumping stations it was ideal to calculate the flow in these areas by how much water is pumped through the station. From these flow values a daily mean flow in litres per second is calculated. Besides the flow for the catchment area it is also necessary to know the total amount water in the Gothenburg system tunnels. Both the pump flows as well as the tunnel flows were acquired through assistance from consultants at Kretslopp och Vatten.

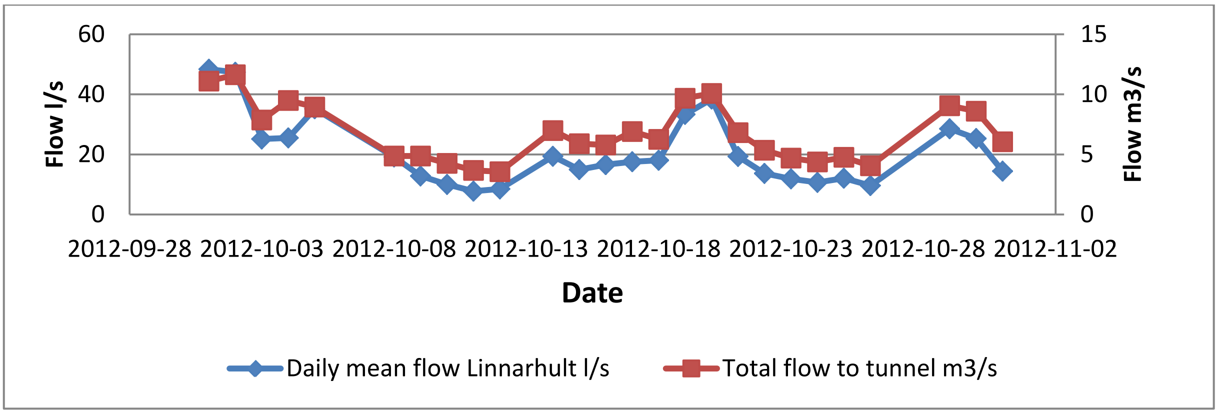


Figure 6: Correlation between the flow of a catchment area and the total flow into the tunnel system leading to Ryaverket.

2.4.2 Errors

One main issue with the pump flows was that the readings were not always correct. The reason behind it being that the signal to the pumps is lost at times; considering this is an electronic network and the readings are incorrectly measured every so often. Fortunately when this happens, the system marks these values so that they are distinguishable from actual 0 readings. These marks are indicated in the pump readings as “G” so as to be distinguishable although the system does not differentiate the origin of the fault. The duration of these errors do however often continue throughout a couple of hours or days which then shows as fluctuations when graphed.

598	2012-10-05 03:30		6		5	11	24.9
599	2012-10-05 03:40		7		1	8	18.10909
600	2012-10-05 03:50		0		6	6	13.58182
601	2012-10-05 04:00		6		6	12	27.16364
602	2012-10-05 04:10		6		0	6	13.58182
603	2012-10-05 04:20	G	0	G	16	16	36.21818
604	2012-10-05 04:30	G	0	G	17	17	38.48182
605	2012-10-05 04:40	G	0	G	17	17	38.48182
606	2012-10-05 04:50	G	0	G	17	17	38.48182
607	2012-10-05 05:00	G	0	G	17	17	38.48182
608	2012-10-05 05:10	G	0	G	17	17	38.48182
609	2012-10-05 05:20	G	0	G	17	17	38.48182

Figure 7: Values of pump flows where signal is lost are displayed with a ”G” value.

The solution is to remove these values, usually the whole day, from the calculations. How this affects the final results is of course a matter which can be discussed but in the graphs it is clear how these readings affect the final outcome when plotting the flows. They are presented as anomalous spikes and dips in the readings which also then transfer onto the T-blad if they are not removed. Below are two graphs; the topmost graph includes errors from the pump readings and the second one has been improved by removing these spikes which results in a much smoother and plausible graph.

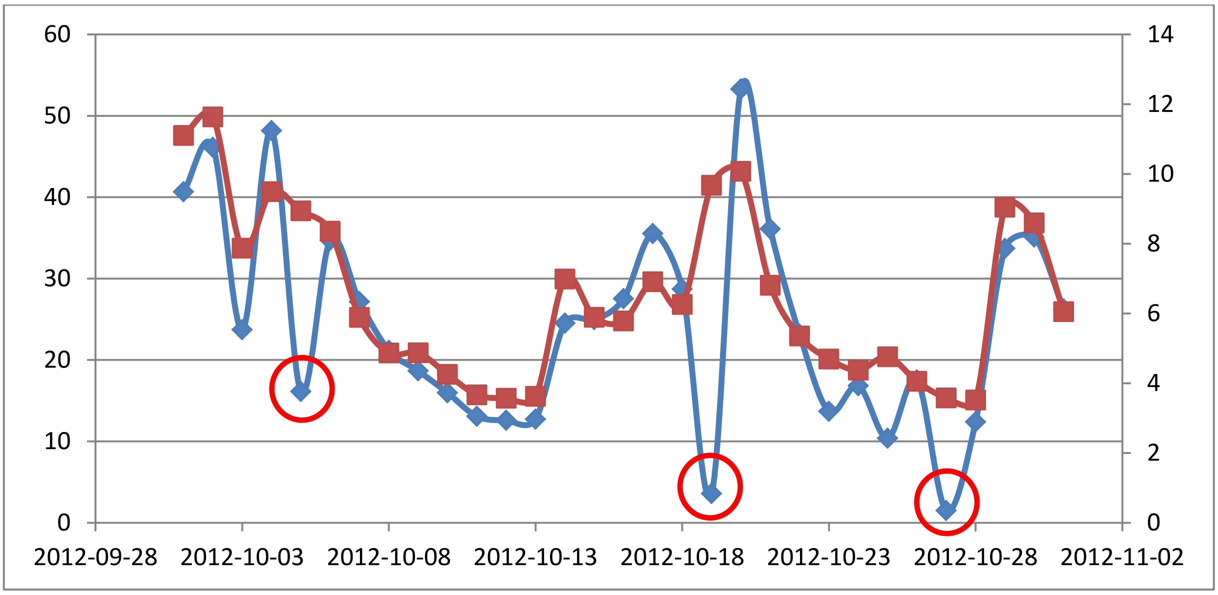


Figure 8: daily mean flow chart in relation to total flow. Spikes which are caused by errors are highlighted with red circles

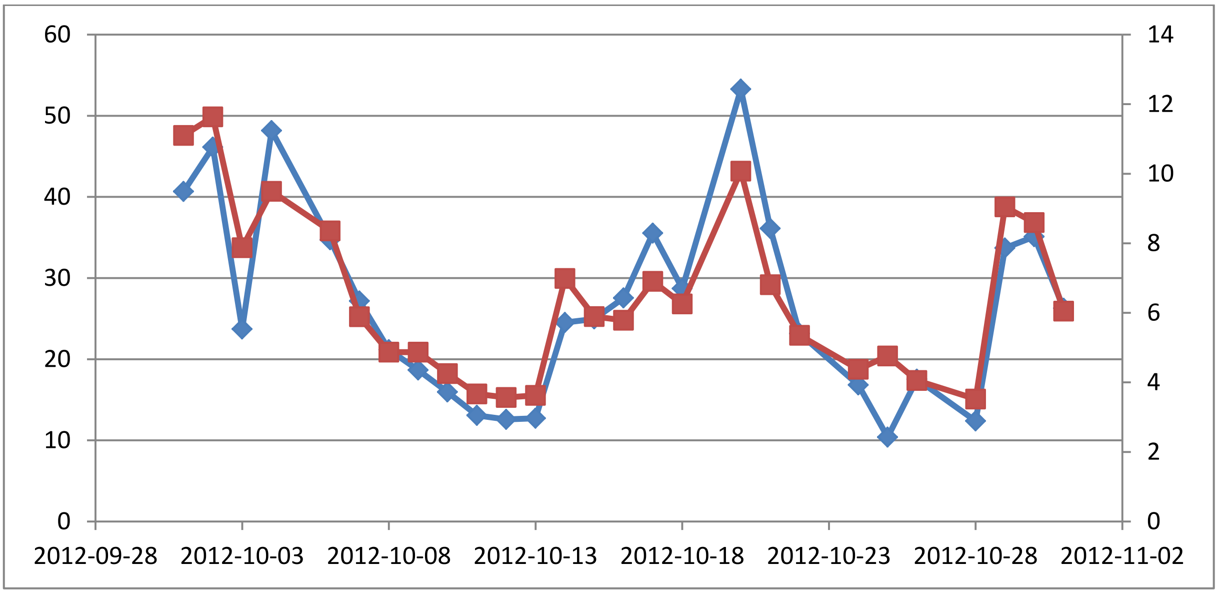


Figure 9: Same two flows as in previous figure but this time with the errors removed which results in a much better correlation between the two flows

2.4.3 Regression analysis

With the daily mean flow and the total flow of water into the tunnels a chart can be produced which shows the ratio of daily mean flow to total flow of water. From this chart a trend line can be plotted by doing a regression analysis which shows the amount of water from that particular area into the main tunnel system.

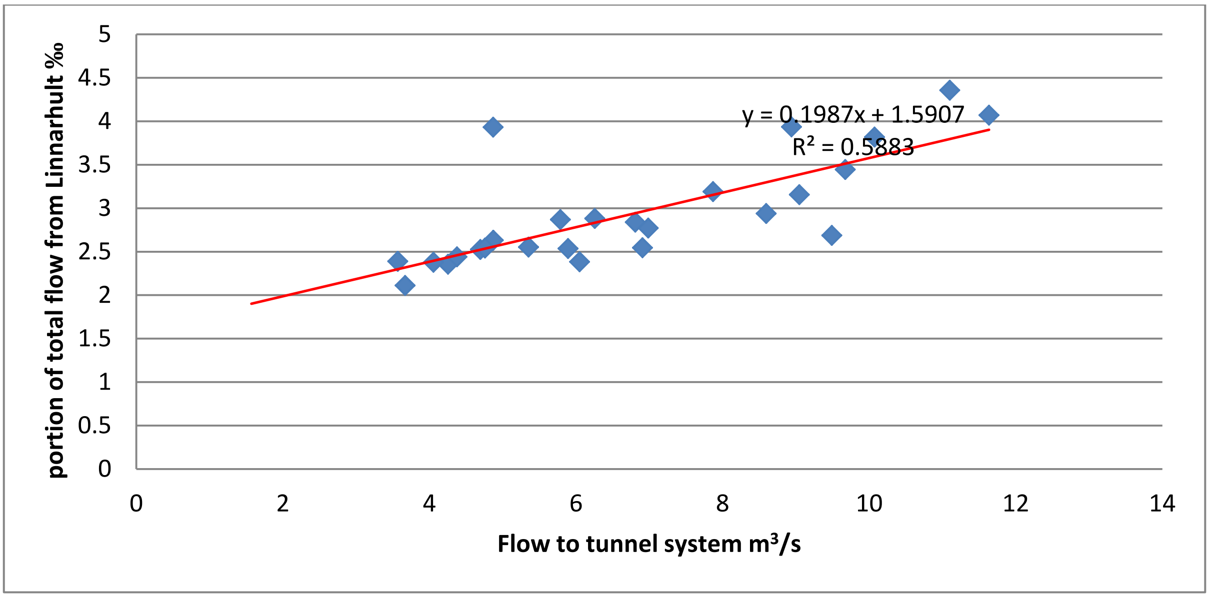


Figure 10: The total flow into the tunnel system plotted against the share of a catchment area. Each blue point indicates daily values and the red line is a trend line which shows the linear correlation.

If the trend line is increasing it indicates that the excess water in this area increases faster than the rest of the tunnel system. Equally can be deduced that if the trend line is declining that it points to that the excess water in this location is decreasing slower than for the rest of the tunnel system. A more comprehensive walk-through of how to produce a T-blad is presented in the Appendix II.

2.4.4 Key performance indicators

From this trend line we are able to produce key performance indicators. Key performance indicators (nyckeltal for Swedish readers) are values which are used to evaluate a certain process in comparison to set figures which can indicate extreme conditions; these are referred to as critical key performance indicators.

The purpose of the key performance indicators is to quickly and easily show how much a catchment area is affected by excess water at different flows. This is made by comparing obtained values to critical key performance indicators which indicate excessive excess water. These figures can then be used as decision basis when a sewage system is being evaluated. The table shown below gives an example of how key performance indicators can be presented to give a quick overview.

Table 1.The table shows key performance indicators for a particular area in the yellow field. In the next column is a list of critical key performance indicators for the different fields which are considered as excessive excess water

Excess water at high flow	l/s, km	1.44	2.5
Excess water at low flow	l/s, km	0.29	0.6
Excess water at high flow	l/s, ha	0.13	0.2
Excess water at low flow	l/s, ha	0.03	0.05

Two key performance indicators are needed in order to deduce the character of the excess water and these are centred on the flow. One of the key performance indicators is produced for low flows and the other for high flows. This is in order to evaluate the behaviour of the system at the two extremes, on one hand at low flows where infiltration is possible into the sewage network and at high flows where there are risks for basement flooding. The low flow was subsequently chosen to be at 3 m3/s and the high flow at 8 m3/s into the tunnel (Jansson, 2012).

The limits for critical key performance indicators are necessary in order to set limits for how much excess water is “too much” for future analysis and measures. The critical key performance indicators were therefore chosen based on measurements of the separate sewage pipes in the Gothenburg region. The average excess water values for both low flows (3 m3/s and high flows (8 m3/s) were then observed and from them critical key performance indicators could be established (Jansson, 2012)

3 Results

This chapter presents the results from the application of T-bladsmetoden on selected study sites, as well as some information the study sites themselves.

3.1 Case Study Sites

For this study to be performed it was necessary to find study sites for which T-bladsmetoden could be applied and tested. Based on the expertise of supervisors at Kretslopp och Vatten and following discussions, a set of particular sites where chosen to be studied. The criterion for which these sites where chosen was based on previous knowledge of certain pumping stations which indicated that the areas had experience of problems with excess water. After the pumping stations were chosen it was necessary to examine the areas in order to determine catchment area and sewage network. This was acquired through the software Solen X, which essentially is a map system over the city of Gothenburg available as a GIS tool (Geographic Information System) at Kretslopp och Vatten. Several of the data needed to produce a T-blad for each site were derived from this map, including pipe length as well as location of pumping stations. It was also used as a template for the Mouse DHII model later in the study. Geographically the study sites were spread across Gothenburg, with two of the sites located in the south-western part of Gothenburg, one in the western and the last one in the north-eastern part. The study sites were named after their corresponding main pumping station and the location of each pumping station for the study sites is displayed in the figure below.

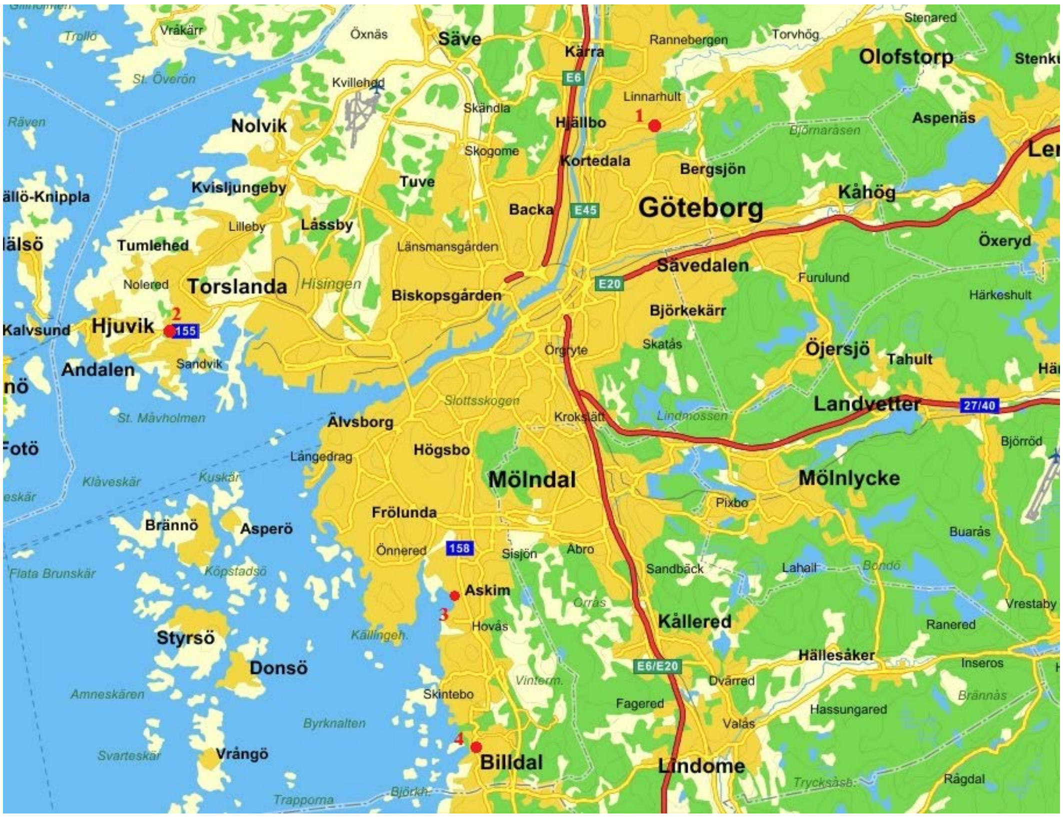
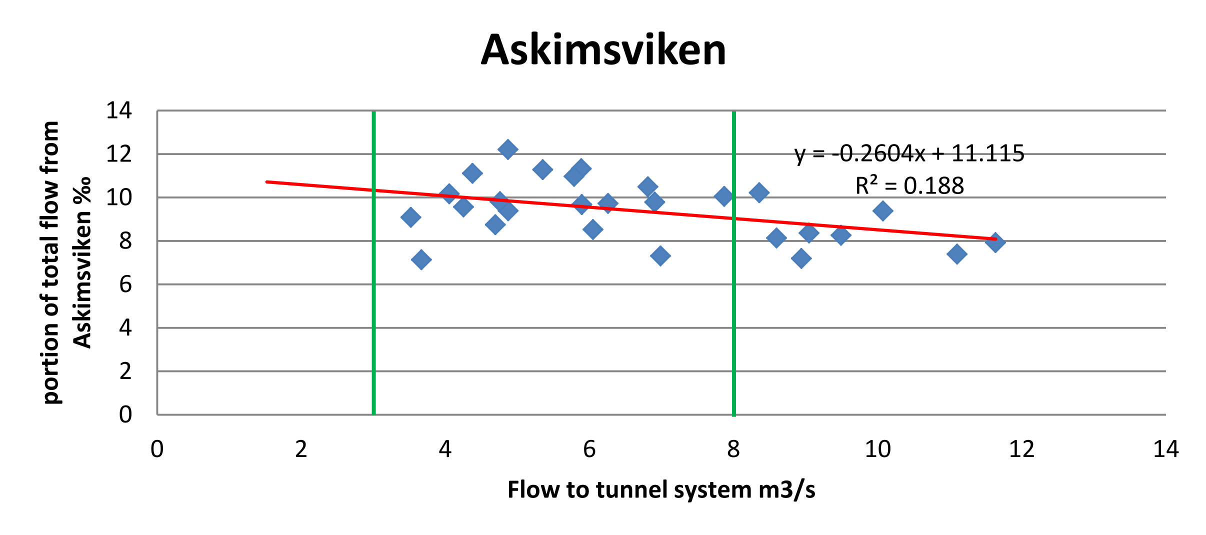
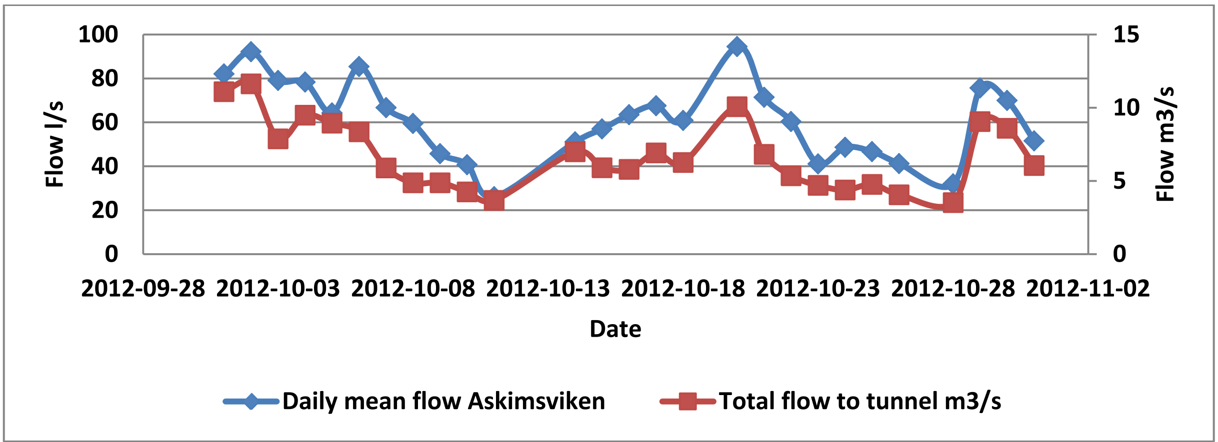


Figure 11 Locations of the 4 pumping stations, 1: Linnarhult, 2: Hällsviksvägen, 3: Askimsviken, 4: Billdal (eniro.se, 2013)

3.1.1 Askimsviken

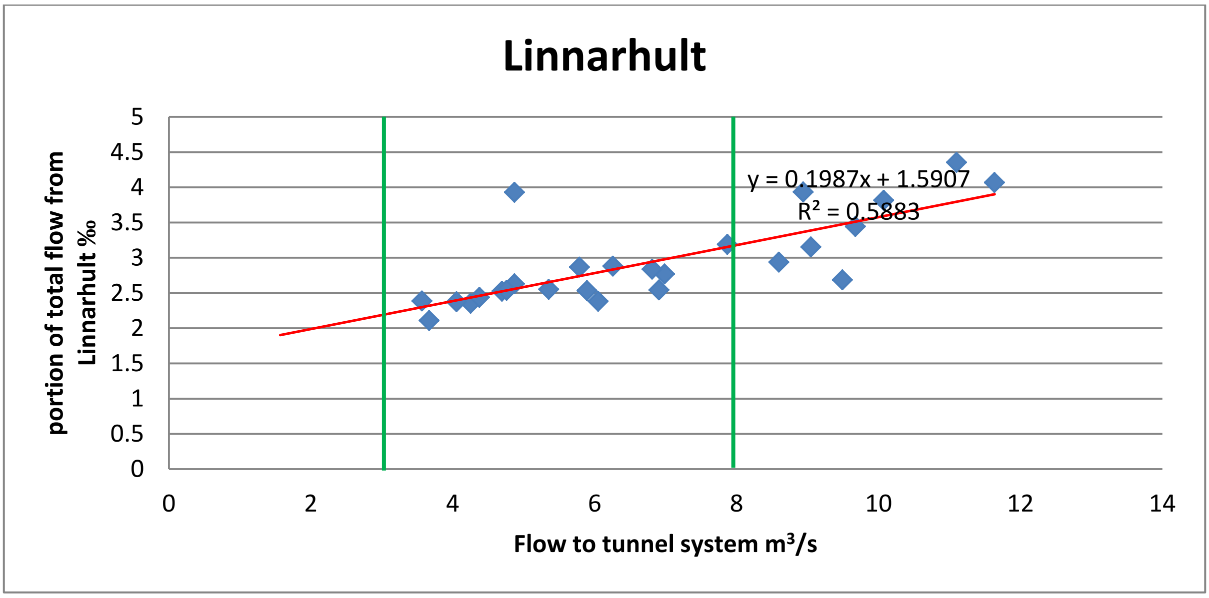


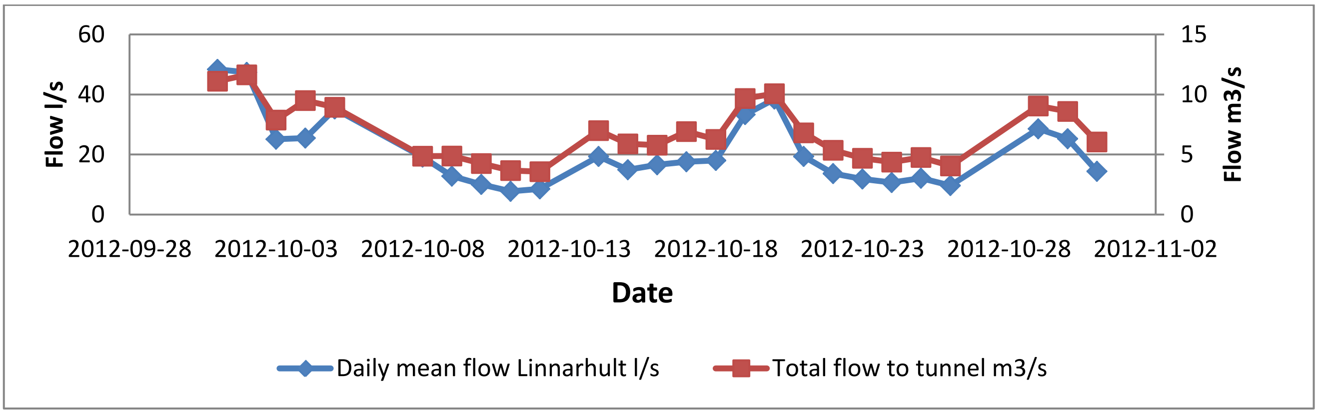


T-blad Askimsviken	Unit		
Sewer pipe length	m	35683	
Catchment area	ha	397.3	
Sanitary sewage flow	l/s	20.73	
Portion at high flow	‰	9.03	
Portion at low flow	‰	10.33	
Duration	Days	27	
Flow at high flow	l/s	72.25	
Flow at low flow	l/s	31.00	"critical limits":
Excess water at high flow	l/s, km	1.44	2.5
Excess water at low flow	l/s, km	0.29	0.6

Excess water at high flow	l/s, ha	0.13	0.2
Excess water at low flow	l/s, ha	0.03	0.05
Excess water at high flow	l/s / l/s spill	3.49	
Excess water at low flow	l/s / l/s spill	1.50	
Difference high/low (portions of flow)		0.87	

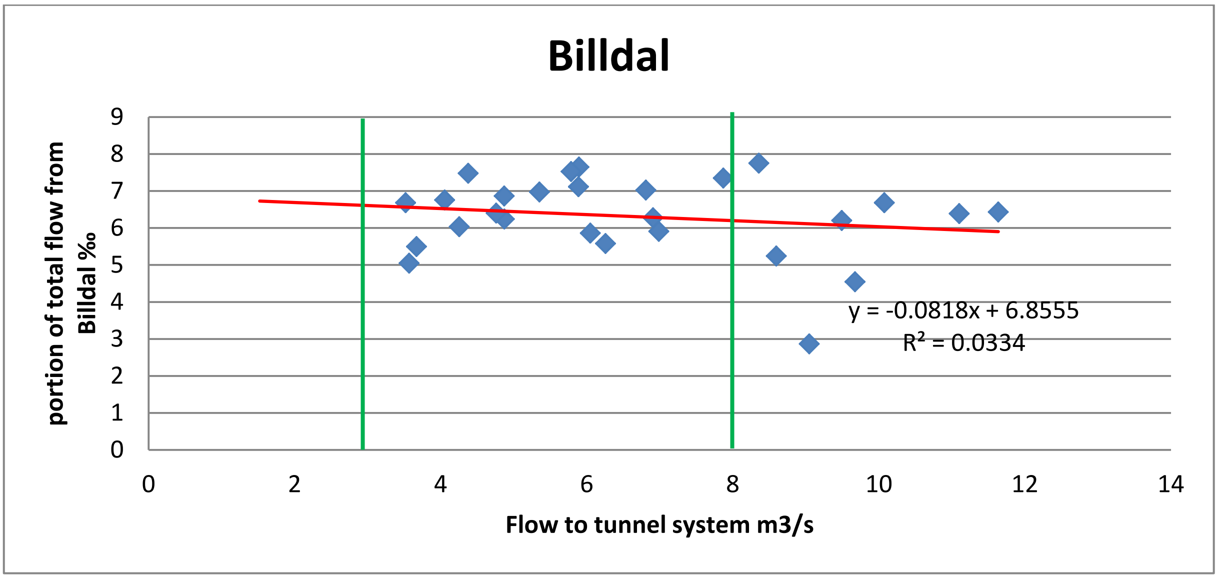
3.1.2 Linnarhult

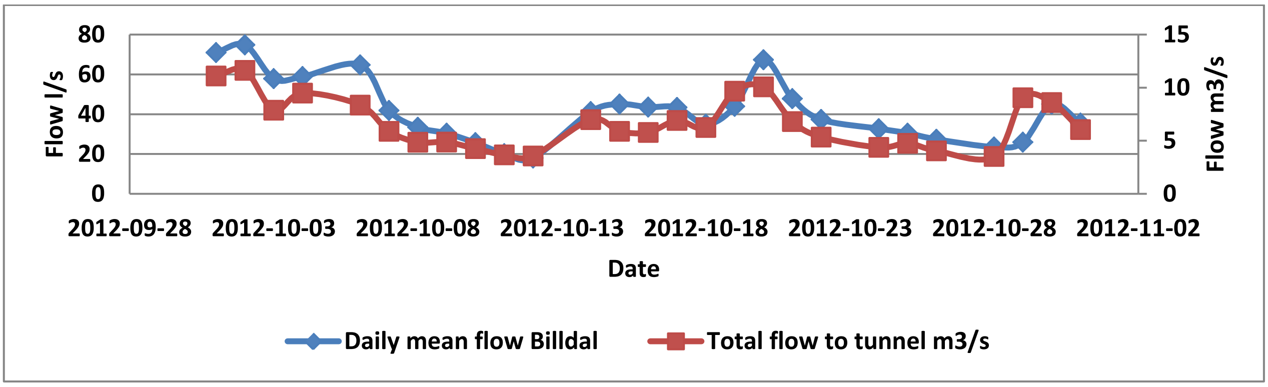




T-blad Linnarhult	Unit		
Sewer pipe length	m	15019	
Catchment area	ha	185.5	
Sanitary sewage flow	l/s	4.58	
Portion at high flow	‰	3.18	
Portion at low flow	‰	2.19	
Duration	Days	26	
Flow at high flow	l/s	25.44	
Flow at low flow	l/s	6.56	"Critical limits":
Excess water at high flow	l/s, km	1.39	2.5
Excess water at low flow	l/s, km	0.13	0.6
Excess water at high flow	l/s, ha	0.11	0.2
Excess water at low flow	l/s, ha	0.01	0.05
Excess water at high flow	l/s / l/s spill	5.56	
Excess water at low flow	l/s / l/s spill	1.43	
Difference high/low (portions of flow)		1.45	

3.1.3 Billdal

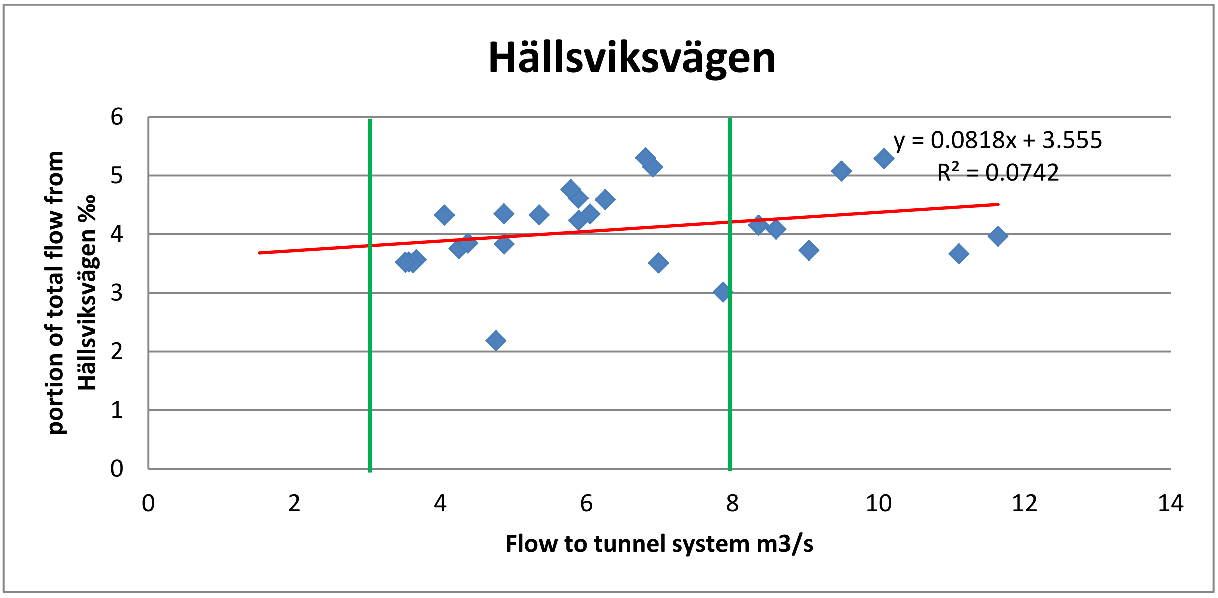


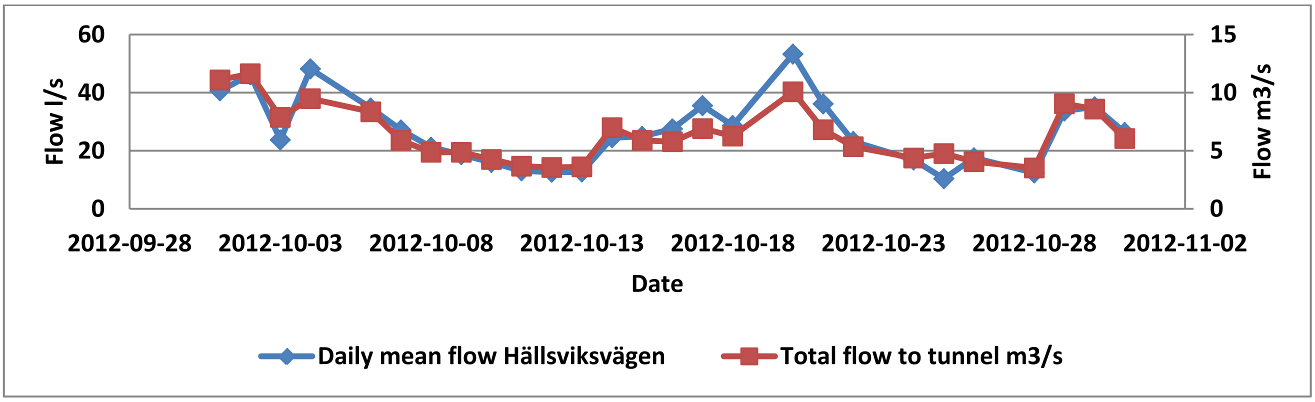


T-blad Billdal	Unit		
Sewer pipe length	m	26671	
Catchment area	ha	358.62	
Sanitary sewage flow	l/s	12.00	
Portion at high flow	‰	8.33	
Portion at low flow	‰	7.74	
Duration	Days	27	
Flow at high flow	l/s	66.63	
Flow at low flow	l/s	23.23	"Critical limits":
Excess water at high flow	l/s, km	2.05	2.5
Excess water at low flow	l/s, km	0.42	0.6
Excess water at high flow	l/s,	0.15	0.2

	ha		
Excess water at low flow	l/s, ha	0.03	0.05
Excess water at high flow	l/s / l/s spill	5.55	
Excess water at low flow	l/s / l/s spill	1.94	
Difference high/low (portions of flow)		1.08	

3.1.4 Hällsviksvägen





T-blad Hällsviksvägen	Unit		
Sewer pipe length	m	23084	
Catchment area	ha	302.8	
Sanitary sewage flow	l/s	14.11	
Portion at high flow	‰	4.21	
Portion at low flow	‰	3.80	
Duration	Days	26	
Flow at high flow	l/s	33.68	
Flow at low flow	l/s	11.40	"Critical limits":
Excess water at high flow	l/s, km	0.85	2.5
Excess water at low flow	l/s, km	-0.12	0.6
Excess water at high flow	l/s, ha	0.06	0.2
Excess water at low flow	l/s, ha	-0.01	0.05
Excess water at high flow	l/s / l/s spill	2.39	
Excess water at low flow	l/s / l/s spill	0.81	
Difference high/low (portions of flow)		1.11	

4 Analysis

An analysis of each of the presented T-blad for each study site is presented in this chapter.

4.1 Askimsviken

The regression analysis for Askimsviken shows that the trend line is declining as the flow in the tunnel increases. This indicates that the rate of change for the excess water is slower for higher flows than for low flows. The gradient of the trend line is nonetheless gradual which means that the difference between high and low flows is not that great. Looking at the key performance indicators for the different flows and scenarios shows that this area is not a problem area when it comes to excess water since all the figures are not near the critical values and relatively low. The catchment area for this subsystem as well as the sewer pipe length is the longest in comparison to the others. This could have an impact on the results considering the magnitude of the catchment area. Notable is also that the flow chart in comparison to the flows in the main tunnel are a bit skewed, which could indicate some faults in the pump capacity readings.

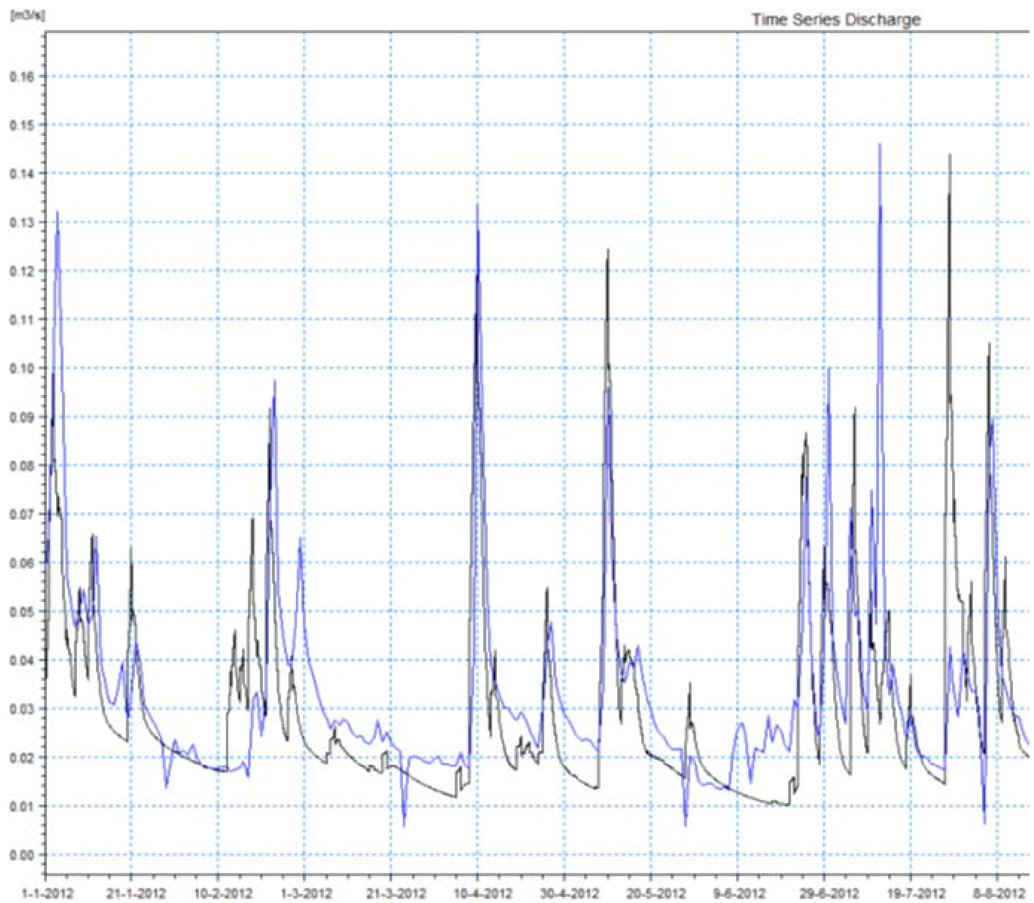
4.2 Linnarhult

The regression analysis for Linnarhult shows a trend line which increases with a steep gradient as the flow increases in the system. This points to that there is a greater change at higher flows in comparison to low flows and also indicates that as the flow increases, so does the share of contribution of flow from Linnarhult into the main tunnel. This area was however the smallest area both in catchment size as well as pipe length and sanitary sewage flow indicative of a smaller area with not so many households. When it comes to the key performance indicators they are not near the critical values both for high and low flows.

4.3 Billdal

Billdal is the only area where the key performance indicators show that excess water could be a concern for the area. Although none of the values actually surpass the critical limits they are all relatively high, especially in comparison to the other sites. The gradient of the trend line is declining but slightly.

Since Billdal was the most afflicted area of the selected site an additional RDII model was performed to further study the excess water. After the simulation a Time/discharge chart was plotted and this showed that the model calibrated flow gave a very good correlation to the actual measured flow. This can be seen in the figure below, where the calibrated flow is plotted in blue and the real flow in black, the full series is available in the Appendix III.



Following the simulation of the RDII model it is possible to derive information about the area which is presented as a summary. This information is summarized in the pie chart which is presented below. The chart shows that the most water in the system belong to the slow response component and also that the spill water is relatively small in comparison. The division also complies with the previous assumption that sewage water only corresponds to around 1/3 of the water in sewage networks where excess water is prevalent.

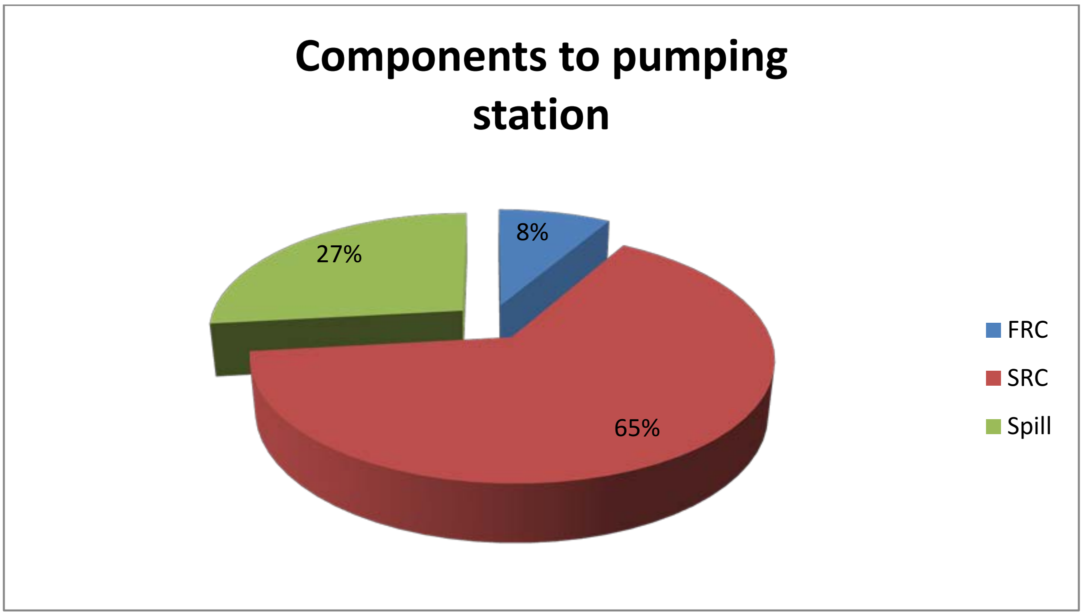


Figure 12 :Chart showing the different components of water in the Billdal area, spill indicates sewage water and FRC and SRC are fast response component and slow response component respectively. These two components make up excess water.

4.4 Hällsviksvägen

As for Hällsviksvägen the trend line shows an increase of share from Hällsviksvägen as the flow in the main tunnel increases. The key performance indicators for Hällsviksvägen are not surpassing the critical limits for any scenarios. What is however most notable for this subsystem is that the lower flow scenarios show negative values for the key performance indicators. The answer to this conundrum can be found in the calculations of the T-blad. The negative values are simply a result of the fact that the calculated flow during the "low flow" period, of 2 m3/s into the main tunnel system, is smaller than the sanitary sewage (dry weather) flow. This seems to point to that during this "low flow" there is only sanitary sewage flow present in this subsystem.

4.5 Comparison of the different sites

	Unit	askim	linnarhult	billdal	Hällsviksv.
Sewer pipe length	m	35683	15019	26671	23084
Catchment area	ha	397.3	185.5	358.62	302.8
Sanitary sewage flow	l/s	20.73	4.58	12.00	14.11
Portion at high flow	‰	9.03	2.47	8.33	4.21
Portion at low flow	‰	10.33	1.92	7.74	3.80
Duration	Days	27	26	27	26
Flow at high flow	l/s	72.25	19.75	66.63	33.68
Flow at low flow	l/s	31.00	5.76	23.23	11.40
Excess water at high flow	l/s, km	1.44	1.01	2.05	0.85
Excess water at low flow	l/s, km	0.29	0.08	0.42	-0.12
Excess water at high flow	l/s, ha	0.13	0.08	0.15	0.06
Excess water at low flow	l/s, ha	0.03	0.01	0.03	-0.01
Excess water at high flow	l/s / l/s spill	3.49	4.31	5.55	2.39
Excess water at low flow	l/s / l/s spill	1.50	1.26	1.94	0.81
Difference high/low (portions of flow)		0.87	1.29	1.08	1.11

When comparing all the sites at the same time it is possible to see the potential of this method. The key performance indicators can be compared side to side and with a fairly simple overview an assessment can be made. In this case it is possible to see which site is the most afflicted and therefore makes it possible to evaluate the different sites and then rank them in order of importance. Also the different subsystem catchment areas, pipe lengths and sanitary sewage flow are presented and can be compared promptly.

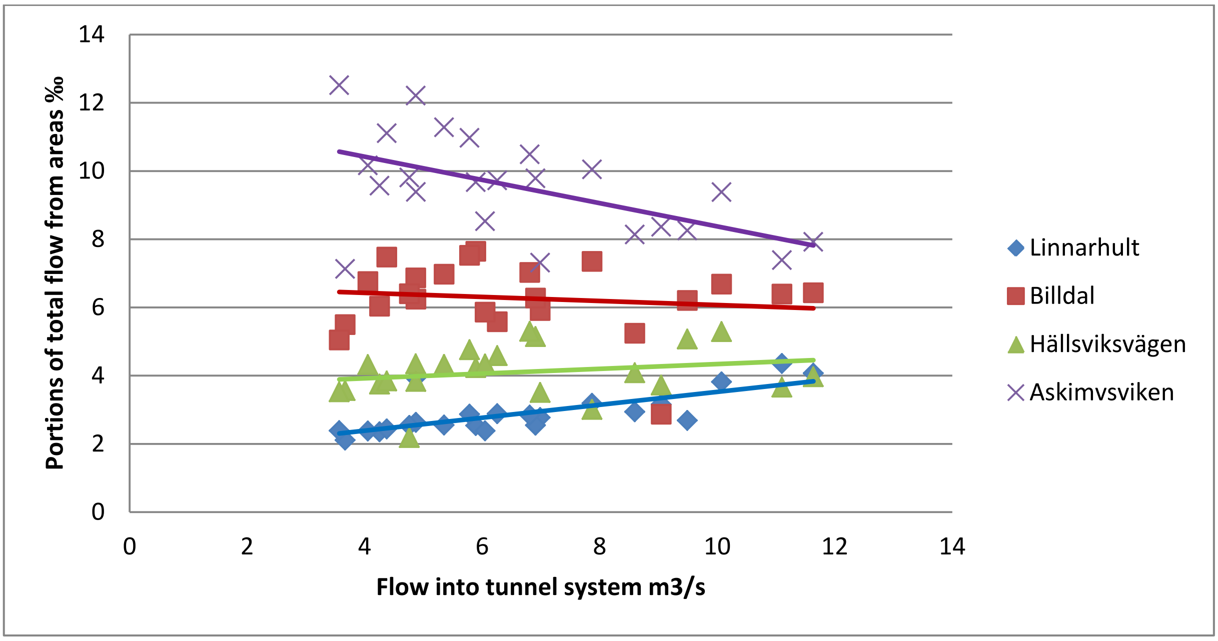
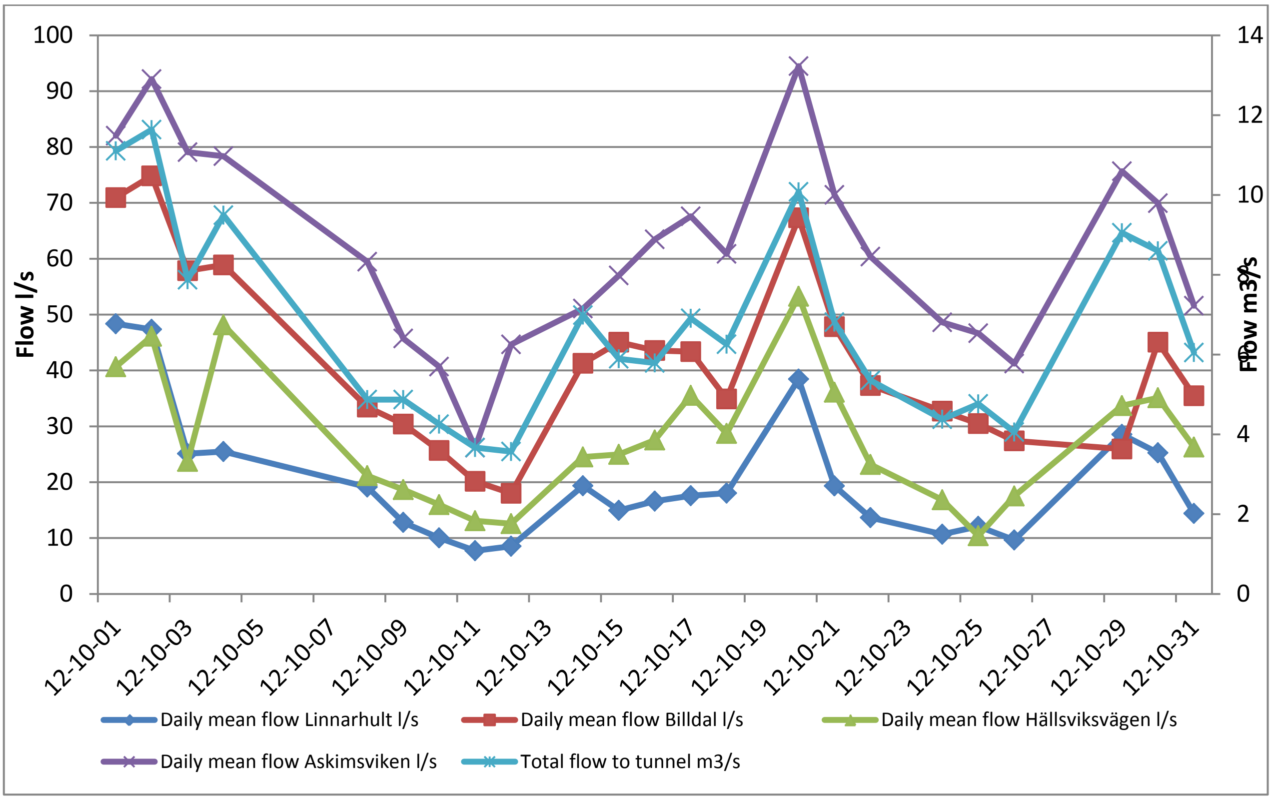


Figure 13:All the trend lines from the regression analyses compiled in one chart

Similarly the regression analysis and flowcharts can also be compiled for all the sites for a comparison. This does not take a lot of effort to produce after the T-blad are made and also shows plenty of valuable information in the same diagram. In this diagram, the shares of the total flows into the main tunnel shows that the larger subsystems have more declining trendlines and the smaller systems have inclining trendlines.



Figur 14: Flow charts fom all the subsystems compiled in one chart

Likewise a composition of the flow charts can be made, gathering all of the flows in one diagram. This diagram is useful when it comes to spotting errors in the flow charts. A flow chart with little error will correlate strongly with the flow into the tunnel system. As is seen here most of the subsystems seem to follow the main flow smoothly. Also distinguishable is that Hällsviksvägen deviates from the main total flow at around 05 -October, and this is shown through a spike. This can indicate that there was some sort of error made during the flow calculations for this area.

5 Discussion

This chapter wishes to discuss the findings from the analysis and the results and possible arising thoughts.

5.1 Key performance indicators

Key performance indicators are meant to be figures which are easy to compare and quickly give a scope of the excess water situation in an area, and that was also one of the objectives for this thesis. To answer that question we can look at the results from the T-blad. It is apparent that the key performance indicators are easy to identify when they are presented in T-bladsmetoden. Also when they are displayed next to the critical key performance indicators the reader gets a good scope of the amount of excess water, as it is possible to instantly compare the two values and draw conclusions.

The critical performance indicators play a very important role in "T-bladsmetoden". They define how much excess water is deemed a problem or the limits for when there is reason to be concerned. If these figures are over- or underestimated in any way it will be reflected in the results of the T-bladsmetod. Therefore it is important to specify the correct critical key performance indicators and they should also be based on the area which is being studied.

5.2 Errors

The pump flows from the pumping stations contained some errors due to technical difficulties. Fortunately the errors were also marked which made it easy to pinpoint the faulty readings. They were however relatively frequent and on average 3 to 4 days had to be removed per month. Although this had not very much influence in the final results it should at least be considered. Also the excel file contains very large amount of values which makes human error a possibility when plotting these values and calculating in front of computer. If an error is made it easily follows through to the rest of the calculations and may be hard to locate at a later stage. This was one of the issues when one of the sites contained wrong pump capacity readings which translated into the T blad showing strange results. After much backtracking the problem was located and could be managed. Yet from the analysis when all the flows where compiled in figure 14 a previously unknown error was found, when the Hällsviksvägen flow showed a deviance from the main flow. This was not the case in the flow diagram for Hällsviksvägen where it did not look so erroneous.

The same site, Hällsviksvägen produced negative values for some of the key performance indicators. Negative values could mean two scenarios, one being that there is no excess water in that circumstance and the other could be that the water flow could flow in the other direction meaning that water is flowing out from the system somehow. This scenario is not likely considering that for water to flow out from the system the pressure in the pipes must be higher than the surroundings and this occurs when there is a lot of excess water. The negative values were however reached at the low flow of 2 m3/s which indicates that the first hypothesis is more valid. The question which then arises is what is the flow at this point? Since the T-blad shows that it is close to11 l/s and the dry weather flow is more than 14 l/s. This is a point for discussion if further research arises.

5.3 Comparison to other methods

T-bladsmetoden is not a source detection method so it is not reasonable to compare it with the source detection methods which were presented in this thesis. It is however a method which can be used in the initial evualtion part of an investigation to give an overview of the excess water situation in an area. This was also the aim of the method in the first place and it does seem to give a good overview when it comes to excess water. The results are easily manageable and if necessary the key performance indicators can be compared straightaway. It could be compared to the computer software programme Mouse RDII which was similar to T-bladsmetoden in the sense that a whole catchment area with its subsequent sewage network could be studied in both cases. Worth mentioning was that the two methods complemented each other well in the case study where both were used and this could be a future application area.

5.4 Consistency

Another point which can be discussed is consistency. Although it was not covered in this thesis it could be important to see whether the results will repeat for different measuring times. A suggestion is to extend the time period to one year and examine the results. Results from this work suggest that the time period should not give much trouble. Which leads to another point which can be discussed is the fact that October month was studied in this thesis. This decision can be justified since October is statistically one of the rainiest months in Gothenburg (SCB, 2013) and therefore ideal for calculating excess water. The question however is how the results would look for a less rainy month; since the values are dependent on the flow it would not be reasonable to evaluate the flow at 8 m3/s as is done with October. Perhaps a lower limit would be chosen since the flows would also be lower. The difference between the amounts from each site, i.e. the linear regression would still likely yield similar trend lines.

5.5 Applications

T-bladsmetoden could potentially have many different application areas as was seen in the analysis of this thesis.

A scenario where this method would be particularly potent is when comparing and ranking different areas with respect to excess water if the question arises for future planning. It gives an indication to which areas are most problematic when it comes to excess water and based on this it is possible to decide how much further investigation is needed. However T-bladsmetoden does not give any detail to how the situation in the pipes actually is, just whether there is “much” or “little” excess water there is as to say. Therefore it is crucial that it is not used as a standalone method and is better combined with other methods.

Asides from excess water and sewage system, perhaps a modification of this method can be used to evaluate drinking water systems and highlight which in areas there are much leakages and losses in the drinking water pipeline.

6 Conclusions

This master thesis has focused on evaluating T-bladsmetoden as a potential method to be used as foundation for evaluation of excess water. Results indicate that the method does give a good overview of the excess water situation of a selected study site and furthermore appears to be a useful tool when it comes to these matters. It is not however a tool which is to be used by itself and therefore be used either as a compliment to other methods or as foundation for further investigations

Key performance indicators are very important to this method and give a good indication, and also a quick overview, but in order for them to be functional the critical performance indicators must be suitable. Since they are used as guidelines they must be specific for the area so perhaps a national mean value is not appropriate and instead they have to be calculated for the conditions present in the sewage system and also the surrounding environment.

The consistency of this method is dependent on the errors and in actual fact there is possibility throughout the production of T-bladsmetoden for an area that errors might appear in the calculations. It is therefore necessary to either check for mistakes during calculations or redesign the method so that fewer errors are made.

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Appendix I

Linnarhult

Datum	Daily mean flow Linnarhult l/s	Total flow to tunnel m3/s	Daily mean flow/total flow to tunnel
2012-10-01	48.34659091	11.10125	4.355058296
2012-10-02	47.34289553	11.6354	4.068867037
2012-10-03	25.1120434	7.87168	3.190175845
2012-10-04	25.49086651	9.49155	2.685637911
2012-10-05	35.18068182	8.94095	3.934781183
2012-10-06	16.12840909	8.35819	1.929653321
2012-10-07	31.101822	5.88676	5.283351453
2012-10-08	19.14033063	4.86991	3.930325331
2012-10-09	12.81155303	4.87151	2.629893612
2012-10-10	10.01344697	4.25372	2.354044688
2012-10-11	7.740110406	3.66831	2.109993541
2012-10-12	8.520075758	3.56847	2.387599099
2012-10-13	1.304734848	3.62599	0.359828584
2012-10-14	19.35827607	6.98735	2.770474654
2012-10-15	14.93423332	5.89311	2.5341854
2012-10-16	16.6	5.78689	2.868552884
2012-10-17	17.57462121	6.90785	2.544152119
2012-10-18	18.03049242	6.25727	2.881526996
2012-10-19	33.31678706	9.67479	3.443670308
2012-10-20	38.44794897	10.07456	3.816340264
2012-10-21	19.33522727	6.8106	2.838990291
2012-10-22	13.66041667	5.3526	2.552108633
2012-10-23	11.85265152	4.69476	2.52465547
2012-10-24	10.67367424	4.37626	2.438994539
2012-10-25	12.08844697	4.75992	2.539632382
2012-10-26	9.636174242	4.05467	2.376561901
2012-10-27	1.509090909	3.57927	0.421619746
2012-10-28	0	3.52121	0
2012-10-29	28.53809755	9.04858	3.153875807
2012-10-30	25.26155303	8.59703	2.938404662
2012-10-31	14.41496212	6.05021	2.382555667

	Pump capacity l/s	**A**	**l/s/A**
P1	49	22	2.227273
P2	48.3	21	2.3
P1+2	62	43	1.44186

Billdal

Datum	Daily mean flow Billdal l/s	Total flow to tunnel m3/s	Daily mean flow/total flow to tunnel
2012-10-01	70.94591975	11.10125	6.390804616
2012-10-02	74.82969939	11.6354	6.431209876
2012-10-03	57.86869468	7.87168	7.351504974
2012-10-04	58.88737175	9.49155	6.204189173
2012-10-05	146.5334642	8.94095	16.38902624
2012-10-06	64.80441636	8.35819	7.753403113
2012-10-07	41.88807751	5.88676	7.115642137
2012-10-08	33.44147704	4.86991	6.866959972
2012-10-09	30.40410954	4.87151	6.241208484
2012-10-10	25.6735669	4.25372	6.035556385
2012-10-11	20.16389994	3.66831	5.496781881
2012-10-12	18.01319216	3.56847	5.047875464
2012-10-13	35.66116979	3.62599	9.83487814
2012-10-14	41.28953147	6.98735	5.909183235
2012-10-15	45.06645839	5.89311	7.647313285
2012-10-16	43.56197743	5.78689	7.527700964
2012-10-17	43.36313841	6.90785	6.277371166
2012-10-18	34.90740758	6.25727	5.578696073
2012-10-19	43.96878584	9.67479	4.544675992
2012-10-20	67.34752036	10.07456	6.684909351
2012-10-21	47.84208882	6.8106	7.024651105
2012-10-22	37.31883796	5.3526	6.972095422
2012-10-23	48.72266162	4.69476	10.37809422
2012-10-24	32.72829422	4.37626	7.478599129
2012-10-25	30.48222487	4.75992	6.403936383
2012-10-26	27.40224901	4.05467	6.758194627
2012-10-27	5.489377268	3.57927	1.533658335
2012-10-28	23.54010536	3.52121	6.685231885
2012-10-29	25.94240538	9.04858	2.867013982
2012-10-30	45.06544391	8.59703	5.241978208
2012-10-31	35.46740319	6.05021	5.862177212

	Pump capacity l/s	**A**	**l/s/A**
P1	89	71.3	1.248247
P2	82	49	1.673469
P1+2	92	43	2.139535

Hällsviksvägen

Datum	Daily mean flow Hällsviksvägen l/s	Total flow to tunnel m3/s	Daily mean flow/total flow to tunnel
2012-10-01	40.66514588	11.10125	3.663114143
2012-10-02	46.13187315	11.6354	3.964786182
2012-10-03	23.71110619	7.87168	3.012204027
2012-10-04	48.16767519	9.49155	5.074795496
2012-10-05	16.12175591	8.94095	1.803136794
2012-10-06	34.70144342	8.35819	4.151789253
2012-10-07	27.15999437	5.88676	4.613742426
2012-10-08	21.17234129	4.86991	4.34758369
2012-10-09	18.65752699	4.87151	3.829926859
2012-10-10	15.96607693	4.25372	3.753438622
2012-10-11	13.0740405	3.66831	3.564050066
2012-10-12	12.58005912	3.56847	3.525336942
2012-10-13	12.72376279	3.62599	3.509045197
2012-10-14	24.52243318	6.98735	3.509546993
2012-10-15	24.95953186	5.89311	4.235375185
2012-10-16	27.53422268	5.78689	4.758034572
2012-10-17	35.53672102	6.90785	5.14439674
2012-10-18	28.70780269	6.25727	4.587911771
2012-10-19	3.577622715	9.67479	0.369788152
2012-10-20	53.28113092	10.07456	5.288680689
2012-10-21	36.09956041	6.8106	5.300496346
2012-10-22	23.15724828	5.3526	4.326355095
2012-10-23	13.68777494	4.69476	2.91554306
2012-10-24	16.8312928	4.37626	3.84604498
2012-10-25	10.39157192	4.75992	2.183140036
2012-10-26	17.53484204	4.05467	4.324603985
2012-10-27	1.502900923	3.57927	0.419890347
2012-10-28	12.39444187	3.52121	3.519938281
2012-10-29	33.6955177	9.04858	3.723845918
2012-10-30	35.10860383	8.59703	4.083806132
2012-10-31	26.27681554	6.05021	4.343124542

	Pump capacity l/s	A	l/s/A
P1	91.3	21.7	4.207373
P2	101.1	22.9	4.414847
P1+2	192.4	44.6	4.313901

Askimsviken

Datum	Daily mean flow Askimsviken l/s	Total flow to tunnel m3/s	Dygnsmedelvärde/tunnelflöde
2012-10-01	82.02879985	11.10125	7.389149857
2012-10-02	92.17262705	11.6354	7.921741156
2012-10-03	79.08427552	7.87168	10.04668324
2012-10-04	78.36458879	9.49155	8.256247799
2012-10-05	64.31602827	8.94095	7.193422206
2012-10-06	85.42649312	8.35819	10.22069289
2012-10-07	66.66513757	5.88676	11.32458901
2012-10-08	59.45655001	4.86991	12.2089628
2012-10-09	45.72686652	4.87151	9.386589891
2012-10-10	40.69352355	4.25372	9.566573153
2012-10-11	26.15663496	3.66831	7.130431987
2012-10-12	44.65830619	3.56847	12.51469291
2012-10-13	12.65722373	3.62599	3.490694605
2012-10-14	51.07700062	6.98735	7.309924452
2012-10-15	56.99931102	5.89311	9.672195329
2012-10-16	63.48059802	5.78689	10.96972606
2012-10-17	67.60036023	6.90785	9.786020286
2012-10-18	60.85620792	6.25727	9.725680356
2012-10-19	98.04190099	9.67479	10.13374977
2012-10-20	94.49016558	10.07456	9.379086093
2012-10-21	71.43747093	6.8106	10.48915968
2012-10-22	60.39333806	5.3526	11.28299108
2012-10-23	41.07189764	4.69476	8.748455223
2012-10-24	48.61616446	4.37626	11.10906675
2012-10-25	46.67547153	4.75992	9.805936135
2012-10-26	41.21836504	4.05467	10.16565221
2012-10-27	2.050543478	3.57927	0.572894327
2012-10-28	31.99091938	3.52121	9.085206331
2012-10-29	75.65770152	9.04858	8.361278955
2012-10-30	69.9509853	8.59703	8.136645481
2012-10-31	51.58249836	6.05021	8.525736852

	Pump capacity l/s	**A**	**l/s/A**
P1	78.1	46	1.697826
P2	80.6	48	1.679167
P3	45.5	24	1.895833
P1+P2	135.2	94	1.438298

P1 + P2 + P3	180.7	118	1.531356

Appendix II

How to produce T.blad

Walkthrough

Current (in ampere) from pump stations was given in 10 minute intervals

	A	C	E	F
1	Time	P1	P2	Total current
2	2012-10-01 00:10	21	9	30
3	2012-10-01 00:20	20	12	32
4	2012-10-01 00:30	22	0	22
5	2012-10-01 00:40	6	11	17
6	2012-10-01 00:50	5	12	17
7	2012-10-01 01:00	15	1	16
8	2012-10-01 01:10	9	8	17
9	2012-10-01 01:20	10	7	17
10	2012-10-01 01:30	0	21	21

At the event of errors the faulty values are indicated in the readings with a “G” reading. These values are eventually removed since they give false information.

604	2012-10-05 04:30	G	0	G	17
605	2012-10-05 04:40	G	0	G	17
606	2012-10-05 04:50	G	0	G	17
607	2012-10-05 05:00	G	0	G	17
608	2012-10-05 05:10	G	0	G	17
609	2012-10-05 05:20	G	0	G	17
610	2012-10-05 05:30	G	0	G	17
611	2012-10-05 05:40	G	0	G	17
612	2012-10-05 05:50	G	0	G	17
613	2012-10-05 06:00	G	0	G	17
614	2012-10-05 06:10	G	0	G	17
615	2012-10-05 06:20	G	0	G	17
616	2012-10-05 06:30	G	0	G	17
617	2012-10-05 06:40	G	0	G	17
618	2012-10-05 06:50	G	0	G	17
619	2012-10-05 07:00	G	0	G	17
620	2012-10-05 07:10	G	0	G	17
621	2012-10-05 07:20	G	0	G	17
622	2012-10-05 07:30	G	0	G	17
623	2012-10-05 07:40	G	0	G	17
624	2012-10-05 07:50	G	0	G	17
625	2012-10-05 08:00	G	0	G	17
626	2012-10-05 08:10	G	0	G	17
627	2012-10-05 08:20	G	0	G	17
628	2012-10-05 08:30	G	0	G	17
629	2012-10-05 08:40	G	0	G	17
630	2012-10-05 08:50	G	0	G	17
631	2012-10-05 09:00	G	0	G	17
632	2012-10-05 09:10	G	0	G	17
633	2012-10-05 09:20	G	0	G	17
634	2012-10-05 09:30	G	0	G	17
635	2012-10-05 09:40	G	0	G	17

The flow was then calculated from the current and the measured pump capacities

f_x =IF(F2>23;F2*S6;F2*T3)

F	G	H
Total currei	FLow l/s	
30	43.25581	

P	Q	R	S	T
	Pumpkap	A	l/s/A	mean
P1	49	22	2.227273	
				2.263636
P2	48.3	21	2.3	
P1+2	62	43	1.44186	

The flow is calculated through a function which choses the correct current, depending on the current it is possible to see whether only one pump was used or if they were both pumping.

When the flows are calculated then the Total Daily flow in l/s can be calculated as seen below. The flows for one day are added up.

f_x =SUM(G2:G144)

D	E	F	G	H	I	J
ng 432P2.A	Linnarhult K. motorström P2 #A#	Totalström	Flöde l/s		Datum	Total daily flow
	9	30	43.25581		2012-10-01	=SUM(G2:G144)
	12	32	46.13953		2012-10-02	6817.376956
	0	22	49.8		2012-10-03	3616.134249
	11	17	38.48182		2012-10-04	3670.684778
	12	17	38.48182		2012-10-05	5066.018182

And can then be summarized into a Daily mean flow in l/s by dividing the total flow by the amount of entries. In this case 144 - 2 = 142 entries for the first day.

f_x =J2/142

	J	K
	Total daily flow	Daily mean flow
0-01	6961.909091	=J2/142
0-02	6817.376956	47.34289553
0-03	3616.134249	25.1120434
0-04	3670.684778	25.49086651
0-05	5066.018182	35.18068182

Now when we have the Daily mean flows we can compile the whole month and also based on the readings from the pumps determine which days contained errors. They are then marked in red and not taken into the further calculations.

Datum	Total daily flow	Daily mean flow
2012-10-01	6961.909091	48.34659091
2012-10-02	6817.376956	47.34289553
2012-10-03	3616.134249	25.1120434
2012-10-04	3670.684778	25.49086651
2012-10-05	5066.018182	35.18068182
2012-10-06	2322.490909	16.12840909
2012-10-07	4478.662368	31.101822
2012-10-08	2756.207611	19.14033063
2012-10-09	1844.863636	12.81155303
2012-10-10	1441.936364	10.01344697
2012-10-11	1114.575899	7.740110406
2012-10-12	1226.890909	8.520075758
2012-10-13	187.8818182	1.304734848

After this is done the daily mean flow/ total flow into tunnel is calculated in order to create the regression analysis by plotting it against the total flow to tunnel. Note that the daily mean flow/ total flow into the tunnel is in per mille ‰ because of the units of the input values.

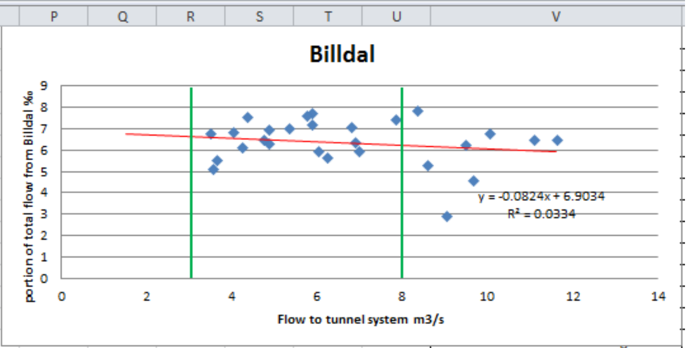
fx =K2/M2

	K	L	M	N	O
	Daily mean flow		Total flow to tunnel m3/s	Daily mean flow/ flow into tunnel	
44	71.44204506		11.10125	=K2/M2	
71	75.352984		11.6354	6.476183371	
33	58.27337086		7.87168	7.4029141	

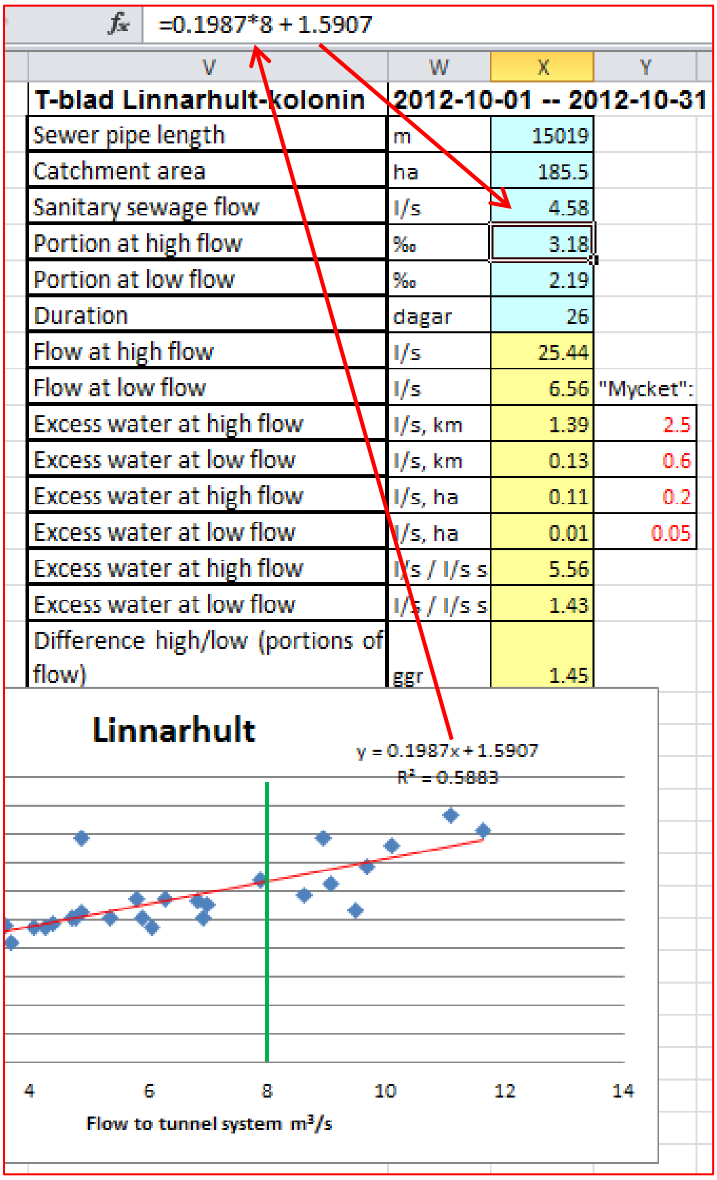
Each entry shows as one point on the regression analysis. A trend line is created to show the correlation of the points.

129 fx =K2/M2

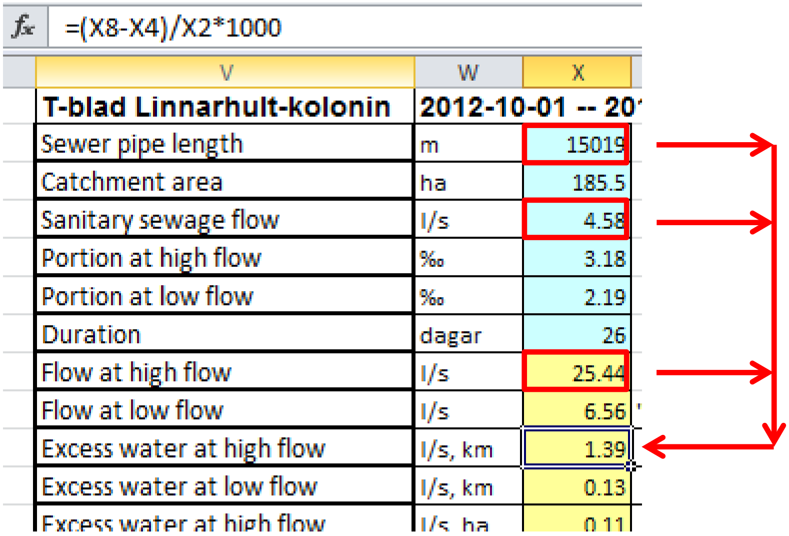
M	N
Total flow to tunnel m3/s	Daily mean flow/ flow into tunnel
11.10125	6.435495558
11.6354	6.476183371
7.87168	7.4029141
9.49155	6.247575112
8.94095	16.50363482
8.35819	7.807622715
5.88676	7.165401872
4.86991	6.914980672
4.87151	6.284853298
4.25372	6.077763073
3.66831	5.535220915
3.56847	5.083175293
3.62599	9.903653512
6.98735	5.950506194



The equation for this trend line is significant and is used in the T –Blad as can be seen below. The portion at low flow is calculated in the same manner and then the the real flows for the area at high and low flows can be calculated, they are denoted “Flow at low flow” and “Flow at high flow”.


=0.1987*8 + 1.5907

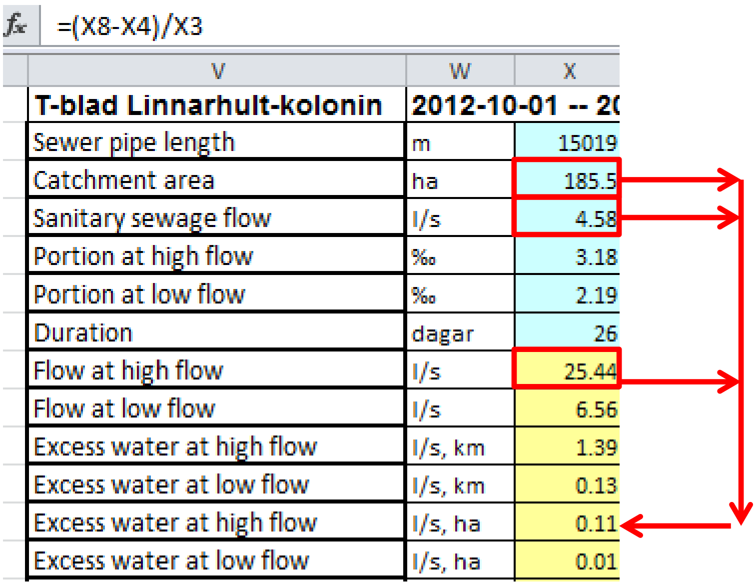
V	W	X	Y
T-blad Linnarhult-kolonin	2012-10-01 -- 2012-10-31		
Sewer pipe length	m	15019	
Catchment area	ha	185.5	
Sanitary sewage flow	l/s	4.58	
Portion at high flow	‰	3.18	
Portion at low flow	‰	2.19	
Duration	dagar	26	
Flow at high flow	l/s	25.44	
Flow at low flow	l/s	6.56	"Mycket":
Excess water at high flow	l/s, km	1.39	2.5
Excess water at low flow	l/s, km	0.13	0.6
Excess water at high flow	l/s, ha	0.11	0.2
Excess water at low flow	l/s, ha	0.01	0.05
Excess water at high flow	l/s / l/s s	5.56	
Excess water at low flow	l/s / l/s s	1.43	
Difference high/low (portions of flow)	ggr	1.45	



=(X8-X4)/X2*1000

V	W	X
T-blad Linnarhult-kolonin	2012-10-01 -- 20	
Sewer pipe length	m	15019
Catchment area	ha	185.5
Sanitary sewage flow	l/s	4.58
Portion at high flow	‰	3.18
Portion at low flow	‰	2.19
Duration	dagar	26
Flow at high flow	l/s	25.44
Flow at low flow	l/s	6.56
Excess water at high flow	l/s, km	1.39
Excess water at low flow	l/s, km	0.13
Excess water at high flow	l/s, ha	0.11

The excess water at flows **l/s, km** ((Flow – sanitary sewage flow)/sewer pipe length) is derived from the excel sheet, multiplied by a thousand to convert into kilometres. Same procedure is made for the low flow value.



=(X8-X4)/X3

V	W	X
T-blad Linnarhult-kolonin	2012-10-01 -- 20	
Sewer pipe length	m	15019
Catchment area	ha	185.5
Sanitary sewage flow	l/s	4.58
Portion at high flow	‰	3.18
Portion at low flow	‰	2.19
Duration	dagar	26
Flow at high flow	l/s	25.44
Flow at low flow	l/s	6.56
Excess water at high flow	l/s, km	1.39
Excess water at low flow	l/s, km	0.13
Excess water at high flow	l/s, ha	0.11
Excess water at low flow	l/s, ha	0.01

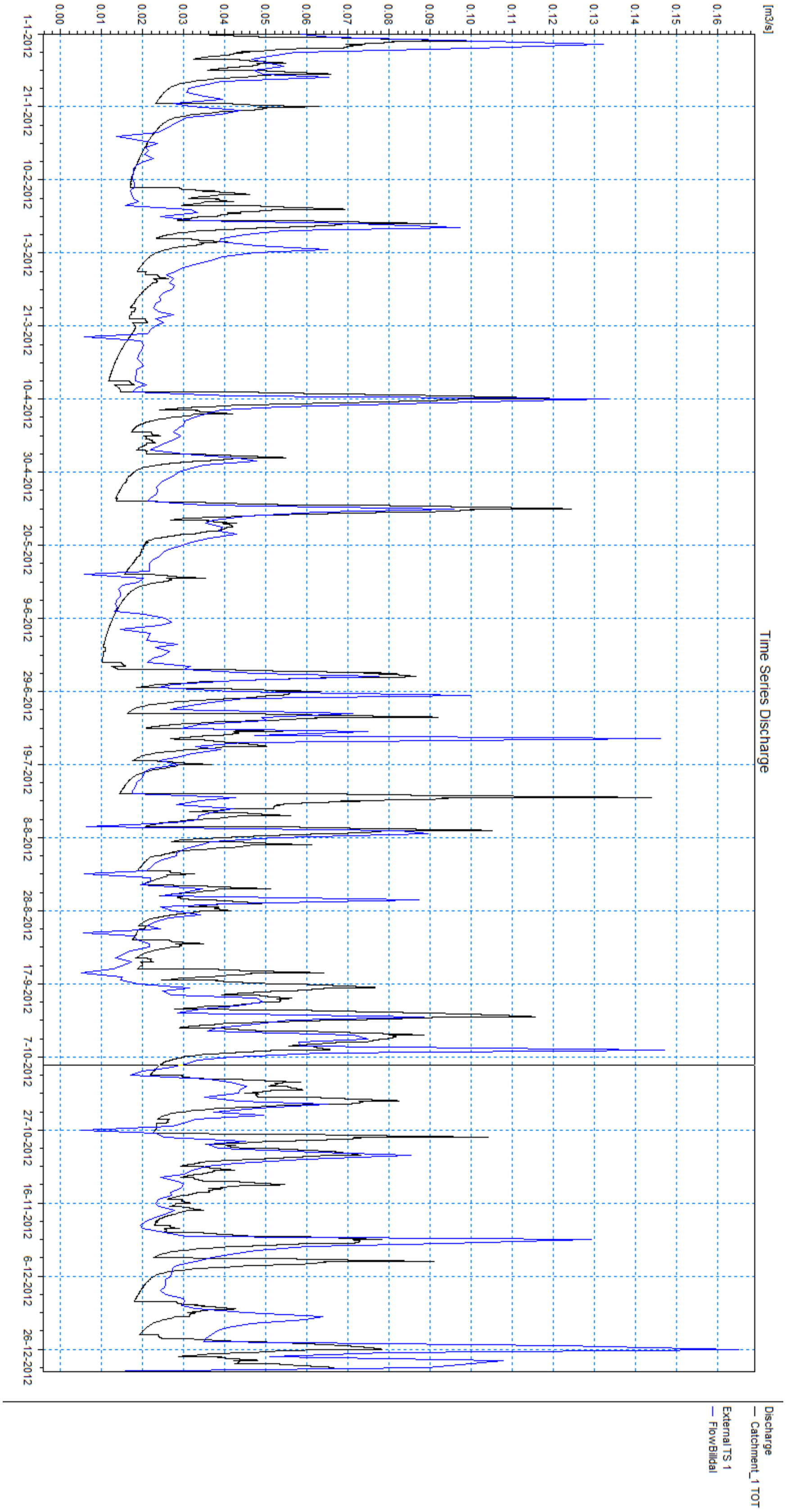
Similarly the Excess water at flows in **l/s, ha** is calculated through the spreadsheet by ((Flow – sanitary flow)/catchment area).

=(X8-X4)/X3

V	W	X
T-blad Linnarhult-kolonin	**2012-10-01 -- 2(**	
Sewer pipe length	m	15019
Catchment area	ha	185.5
Sanitary sewage flow	l/s	4.58
Portion at high flow	‰	3.18
Portion at low flow	‰	2.19
Duration	dagar	26
Flow at high flow	l/s	25.44
Flow at low flow	l/s	6.56
Excess water at high flow	l/s, km	1.39
Excess water at low flow	l/s, km	0.13
Excess water at high flow	l/s, ha	0.11
Excess water at low flow	l/s, ha	0.01

Appendix III

RDII time series discharge



RDII parameters