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Evaluation of Sewer System Overflows

Uusimaa Region

Helsinki Metropolia University of Applied Sciences

Bachelor of Science

Environmental Engineering

Thesis

20 April 2015

Authors Title Number of Pages Date	Aleksi Mäkinen Evaluation of Sewer System Overflows: Uusimaa Region 52 pages + 10 appendices 20 April 2015
Degree	Bachelor of Engineering
Degree Programme	Environmental Engineering
Specialisation option	Waste-, Water- and Environmental Engineering
Instructors	Ari Kangas, Superintendent Juhatuomas Vuorisalo, Lecturer

As a term, *overflow* refers to a wastewater discharge from the sewer system before reaching the treatment facility. Normally all the wastewater reaches the treatment plant; however, due to various reasons, overflows occasionally occur, mostly due to capacity problems. Overflows are something that should be mitigated due to the adverse environmental and health effects they cause. It is suggested that the risk assessment and management procedures are properly conducted to yield efficient results in overflow reduction and minimisation of the impacts caused.

This thesis was made for the Centre for Economic Development, Transport and the Environment, in co-operation with the Ministry of Agriculture and Forestry. The aim was to provide an overall picture of sewer system overflows in the Uusimaa region, as well as the state of individual networks. Additionally, the overflow causes and effects of network's length and weather were to be evaluated. Data for the analyses were collected from plants that are subject to environmental permit and must deliver an annual report. In addition to annual reports, data was also acquired from the VAHTI-program as well as from e-mails. A total of 77 plants were subject to environmental permission and the time period the data was collected was set to be seven years, from 2007 to 2013.

From the 77 plants, 65 had a real sewer network, from where 35 had bypasses and/or overflows. Finally, this led to 21 plants with actual sewer overflows. Two plants were left out from the evaluation, one due to time-units and the other due to very minimal overflow, which led to 19 plants to be investigated. During the data collection, several deficiencies in reporting were found and thus the reporting should be improved in the future, to yield more detailed information. Results are displayed in percentages to partly neglect the size differences that the plants have. There were not many overflows because the yearly overflow average among the 19 plants was only 0.18%. No increasing trend in overflows was detected. Although, the time period of seven years is not sufficient enough to make solid conclusions. Naturally there were differences in performance between individual plants; which led to further questions: are water works doing their best in order to minimize and prevent overflows? Should more systematic procedures be adapted to minimise overflows, and should a method for risk identification and management be established?

Keywords	overflow, wet weather flow, urban runoff, sewer system, risk assessment and management, reporting

Tekijä Otsikko Sivumäärä Päivämäärä	Aleksi Mäkinen Viemäriverkoston Ylivuotojen Määritys Uudenmaan Alueella 52 sivua + 10 liitettä 20 Huhtikuuta 2015
Tutkinto	Insinööri (Ammattikorkeakoulu)
Koulutusohjelma	Ympäristötekniikka
Suuntautumisvaihtoehto	Jäte-, Vesi- ja Ympäristötekniikka
Ohjaajat	Ari Kangas, Ylitarkastaja Juhatuomas Vuorisalo, Lehtori

Ylivuodolla tarkoitetaan jätevesipäästöä verkostossa, ennen sen päätymistä jätevedenpuhdistamolle. Yleisesti kaikki jätevedet päätyvät puhdistettavaksi, mutta erinäisistä syistä johtuen ylivuotoja tapahtuu satunnaisesti. Yleisin syy ylivuotoihin ovat hulevesien aiheuttamat kapasiteettiongelmat. Ylivuotoja tulisi välttää niiden aiheuttamien ympäristö- ja terveyshaittojen vuoksi. Hyvä riskien määrittäminen ja hallinta tarjoaa mahdollisuuden tehokkaaseen ylivuotojen rajoittamiseen ja päästöjen kontrollointiin.

Tämä tutkimus toteutettiin Elinkeino-, liikenne- ja ympäristökeskukselle, yhteistyössä Maa- ja metsätalousministeriön kanssa. Työn tarkoituksena oli tuottaa yleinen kuva ylivuotojen nykyisestä tilasta Uudellamaalla sekä kartoittaa yksittäisten verkostojen tilannetta. Lisäksi ylivuotojen syitä, jätevesiverkoston pituutta ja sään vaikutusta arvioitiin. Dataa analyysejä varten kerättiin ympäristöluvallisten laitosten vuosiraporteista. Vuosiraporttien lisäksi dataa poimittiin VAHTI-ohjelmasta ja sähköpostiviesteistä. Kaiken kaikkiaan 77 puhdistamoa oli ympäristöluvallisia ja dataa kerättiin vuodesta 2007 vuoteen 2013.

Kaikista 77 puhdistamosta, 65:llä oli oikea jätevesiverkosto, joista 35:llä oli ohituksia ja/tai ylivuotoja. Tämä lopulta johti 21 laitokseen, jolla oli ylivuotoja. Kaksi laitosta jätettiin tarkastelun ulkopuolelle, yksi puuttuvien kuutiometriarvioiden vuoksi ja toinen hyvin pienen ylivuodon vuoksi, jolloin jäljelle jäi 19 laitosta. Datan keräyksen aikana raportoinnissa paljastui useita puutteita, jonka vuoksi jätevedenpuhdistamoiden raportointia tulisi tulevaisuudessa parantaa. Parempi raportointi tarjoaisi enemmän hyödyllistä tietoa viranomaisille, kuin myös laitoksille itselleen.

Tulokset ovat ilmoitettu prosentteina, sillä tämä osittain kumoaa puhdistamojen välillä olevia kokoeroja. Kaiken kaikkiaan voidaan todeta, ettei Uudellamaalla ole paljon ylivuotoja, koska näiden 19 puhdistamon ylivuotoprosentti oli vain 0,18 %. Mitään kasvavaa trendiä ylivuodoissa ei havaittu. Seitsemän vuotta ei kuitenkaan ole riittävän pitkä ajanjakso luotettavien päätelmien tekemiseksi. Yksittäisten verkkojen välillä oli luonnollisesti eroja; tämä sen sijaan johti uusiin kysymyksiin: tekevätkö laitokset riittävästi toimia ylivuotojen vähentämiseksi? Tulisiko ylivuotojen vähentämiseen soveltaa nykyistä systemaattisempia keinoja ja perustaa menettely riskien tunnistamiseen ja niiden hallinnan toimenpideohjelmiin?

Avainsanat	ylivuoto, hulevesi, viemäriverkko, jätevesiverkko, riskien määritys ja hallinta, raportointi

Acknowledgements

I would like to express my deepest appreciation to all people who have assisted and supported me to successfully conduct this study. Firstly, I would like to express my deepest gratitude to my instructor Ari Kangas for his endless advice, encouragement and the possibility to work with such a great professional of the field. Also special thanks to my supervisor Juhatuomas Vuorisalo for the valuable instructions and time devoted towards this study. Additionally, I would like to thank Veli-Matti Taavitsainen for the detailed teaching in statistics.

Furthermore I would like to thank the Centre for Economic Development, Transport and the Environment, and the Ministry of Agriculture and Forestry for this great opportunity and interesting topic.

I would like to express my greatest gratitude to my family: Nina, parents and siblings for the endless support I have received, not to forget my pets. Special thanks to my friends for balancing the time between studying and leisure time.

Helsinki, April 2015

Aleksi Mäkinen

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1 Introduction

Overflows have been present from the early day's sewer systems were built, and in all simplicity, the term refers to a wastewater discharge from the sewer system before reaching the treatment facility. Normally, all the wastewater reaches the treatment plant; however, due to various reasons, overflows occasionally occur, mostly due to capacity problems. Capacity problems are prone to occur during wet weather flows in the combined sewer system which carries both the sewage and runoff (Baker, 2004). Though, overflows in the separate sewer are not a rare phenomenon either. Common reasons for overflows are the already mentioned capacity problems, but additionally sewer fracture/blockage, pumping station factor, infiltration/inflow (I/I), system growth and system conditions do occur (NRMMC, 2005).

Overflows are something that should be mitigated due to the adverse environmental and health effects it causes. Especially the reduced levels of dissolved oxygen, physical damages, toxic substance releasing, bioaccumulation or bio-magnifications and elevated nutrient levels in receiving waters cause high concern (Frost 2009). Naturally also the terrestrial vegetation, wildlife and groundwater are affected. Although this thesis focuses more on environmental effects, one should remember that also health, economical, socio-cultural and technical consequences might occur (U.S. EPA, n.d.).

After introducing the general components of the sewer network, this study aims to provide information about the general steps in risk assessment and management. Short descriptions are given to vast majority of available sewer system management procedures, that are being conducted to minimise overflows and the negative impacts that tend to occur. As urban runoff is one of the general reasons for overflows, it alone is also capable of causing significant impacts to receiving waters. However, the impacts highly depend on the urban area and the conditions of the receiving waters. Due to the negative impacts of wet weather flows, also the general methods for runoff minimisation are explained. After all the theory, the analyses are explained: from where the data was collected and how it was sorted, proceeding with the actual analyses and results. Last but not least, the results will be discussed and conclusions will be drawn.

1.1 General, goal and scope

The study is made for the Centre for Economic Development, Transport and the Environment (ELY Centre) Uusimaa region (ELY-Keskus, 2015a); in co-operation with the Ministry of Agriculture and Forestry (MMM, 2015). There are a total of 15 ELY Centres in Finland and they are responsible for the regional implementation and development tasks of the central government. Generally ELY Centres gather information on the state of their regions' environment, business, and infrastructure and employment opportunities. Future trends are sought to be anticipated. ELY Centre's aim is to support regional decision making by ensuring that sufficient amount of facts are accessible (ELY-Keskus, 2015b).

As mentioned, there has been general debate about the current situation of overflows; what is the current state of overflows and reporting, have the overflows increased or has just the attention towards them increased? Initially the goal of the study was to estimate, by the amount, cause and destination, the quality and load of overflows, as well as determine the receiving water's sensitivity. However, due to undetailed reporting, no proper data was acquired for such analyses. Thus a new goal was made. The study was set to determine the current state of overflows in the Uusimaa region (Figure 1). The scope was to estimate the overall situation as well as the state of individual networks. Additionally, deficiencies in reporting, the overflow causes, and effects of network's length and weather were to be evaluated.

Figure 1: Map of the Uusimaa region (Kela, 2015)

2 Theoretical background

2.1 Sewer system's technical management

2.1.1 Gravity sewer system

Gravity sewer system is a network of pipes, laid deep in the ground. Gravity sewer system relies on the flow caused by gravity; thus, the pipes must be installed in a slight slope. The slope must be sufficient enough so that the water has enough speed to avoid sedimentation of the solids in the pipe (Ragsdale, n.d.). Often the topography is not such that the pipe could continue in a slope all the way to the plant; thus, pumping stations are needed. On top of that, also the costs of trenching very deep into the ground would be extremely high; hence, it is more convenient to install a pumping station to lift the water to a higher altitude. Gravity sewers can carry both wastewater and storm water, or have separate pipes for both (Buchanan, 2010).

Strandberg et al. (2010) claims that the wastewater in the pipe should have a minimum flow of 0.7 m/s to achieve the self-cleansing velocity. The slopes built are typically around 1%. The depth pipes are laid in is important especially when laid beneath roads; the pipes must withstand the pressure caused by traffic. Suggested minimum pipe internal diameter and depth installed is 150 mm and 0.9 to 1.2 meters respectively (UNEP 2002). Additionally the bedding of pipes must be carefully done, to provide support and protection. Other criteria are that the system must be designed to handle peak flows, which is determined by the size of the pipe, the type of the pipe and the downhill grade (Ragsdale n.d.). Service life should be long; typical design period ranges from 25 to 50 years. Another important factor is the appurtenances, which includes the manholes, vents, junction boxes and cleanouts (U.S. EPA 2002a).

Gravity sewers serve best in dense populated areas since it can carry large flows along with grid and other solids, does not require much mechanization and is cheap when it comes to maintenance. It possesses a low health risk (Strandberg et al. 2010). On the other hand, gravity sewers are expensive to construct and rather difficult to extend in populated areas (U.S. EPA 2002a). The pipe network is affected by inflows and infiltrations. Manholes possess a source of inflow, while infiltration is caused by broken pipes and leaking joints (Ragsdale n.d.). Both the inflow and infiltration increases the volume of wastewater to be treated, as well the size of pipes and pumping stations. Leakages from the system can be difficult to identify, which poses a risk of wastewater exfiltration and groundwater infiltration (U.S. EPA 2002a).

2.1.2 Pressure sewer system

Pressure sewage system is based on small pump stations that are located near households from which the wastewater is collected. It can typically be found in terrains that are not suitable for gravity flow, in areas that have high water tables or are subject to regular floods, or when it is impractical to build other types of sewer systems. It is basically a branched, small-diameter pipe system built underground – with only visible parts being the storage tank's lid and the control panel (U.S. EPA 2002b). There can be big variation in the size; a small system typically involves just a few households, while larger systems can have several hundred pump stations. Multiple households may be connected to a single pump station (Strandberg et al. 2010).

Working principle of the system is simple. The water from the household enters the property's drain, from which it enters the storage tank, the so called pumping unit. The pumping unit's storage volume is typically between 400-500 litres, which roughly correspond to a receiving capacity of 24 hours. To prevent clogging of the pump and the pipe system, a centrifugal or progressive cavity grinder pump (GP) is used. The pumping unit has two/three level switches (two in Scandinavia and three in the U.S.) installed. Other equipment typically installed are: shut-off valves, check valves, and a monitoring and control system (Strandberg et al. 2010). From the pumping unit the water enters the main sewer or a larger pump station for transportation to a wastewater treatment plant. Between the storage tank and the main sewer, a check valve is installed to avoid the wastewater flowing back into the pumping unit (Leonard 1991).

In addition to GP, there is also another pressure sewer system used, this is called the septic tank effluent pump system (STEP). The systems are pretty similar; however, the STEP system also has an interceptor tank, before the pumping unit, for removing the grease and solids. The separated sewage must be collected on regular basis and brought to a wastewater treatment plant. Another difference is that the STEP system does not require a grinder pump due to the grease and solid removal in the interceptor tank; thus, a less powerful pump may be used (Leonard 1991). U.S. EPA (2002b) claims that a typical STEP system is capable to remove approximately 50 percent of BOD, 75 percent of suspended solids, virtually all grid, and around 90 percent of grease.

Pressure systems main advantages are that it can be a cheaper option than gravity system, has smaller diameter pipes and can be placed closer to the ground, as low as 0.2 meters; this significantly reduces the material and trenching cost (UNEP 2002). In addition to that, the pipes can also be placed by horizontal direction drilling, i.e. there will be no disturbances to traffic (Buchanan 2010). Small pipe size also reduces the infiltration. Due to the under pressure transportation of sewage, the alignment and slope restrictions are looser; this also provides flexibility in siting of the wastewater treatment plant. Additionally, there are no manholes; only cleanouts and valve assemblies which can be placed further apart than manholes. Finally, also the hydraulic loadings are reduced (U.S. EPA 2002).

Pressure system also has its disadvantages. Since the system consists of many mechanical components, it will require more institutional involvement. Due to the amount of equipment, also the operation and maintenance cost is typically higher than gravity sewer's, if the gravity sewer system does not consist of many lift stations. Additionally, the life cycle of pressure system is shorter. As pump stations are located in private properties, there usually needs to be some public education (U.S. EPA 2002).

2.1.3 Separate sewer system

Separate sewer system has own pipes for wastewater and surface runoff. This type of network will cost more and require additional designing since two separate pipes must be installed. Even though the cost is higher, separate sewer system has other benefits to compensate (U.S. EPA 1999a). According to Baker (2004), most combined sewer systems designs cannot handle large rainfall events; thus, there will be combined sewer overflows (CSOs). He claims separate system to be the most efficient solution in prevention of CSOs; but at the same time the costliest. Separate sewers reduces flooding, reduces or even eliminates sanitary discharges to receiving waters, decreases the amount of pathogens and bacteria in receiving waters from domestic sewage and reduces impact to aquatic environment and species (U.S. EPA 1999a).

Even though separate sewer yields various benefits, it should be noted that, if wet weather flows are not mitigated, the impacts of separate sewers might not be so positive; especially in urban areas (U.S. EPA 1999a). Statistical analysis, conducted in 2003, where separate sewer and combined sewer with overflow storage capacity in Germany were compared claims that the separate system releases less load of BOD and especially of nutrients, while combined system was significantly better in terms of solids; especially heavy metals. The analysis consisted of 15 pollution parameters (Brombach et.al. 2006). Thus in general terms, it cannot be said which system is always serving the best (Welker 2008).

2.1.4 Combined sewer system

Combined sewer is a system that carries both the sanitary water and wet weather flows, and in some cases industrial wastewaters. Combined systems are known for its causes of sewer overflows when the capacity exceeds during wet weather flows. Capacity tends to fail because one cannot design the pipe to be too large (Baker 2004). Higher velocities due to wet weather flows may erode sediments in the pipes (Field and Struzeski 1972) and thus pollute the water significantly more; this phenomenon is called the first flush (U.S. EPA n.d.). Combined sewer can be a good option, at least then when storm water discharges are not mitigated in an urban area (U.S. EPA 1999a).

2.1.5 Manholes and cleanouts

Manholes are structures installed in gravity sewers to provide access for repairing, maintenance and cleaning of the sewer line. Typical cleaning equipment are 90-150 meters long, which naturally causes limiting factors for manhole spacing. Typically no manholes should be placed approximately over 120 meters apart in straight runs of pipe (Ragsdale n.d.), but this depends for example on pipe sizing (Water Agencies' Standards 2004). Manholes can also be found in places where there are changes in elevation, slope, direction, junctions or pipe size (WUTAP 2007). Manholes must be designed to withstand the pressure caused by traffic (Ragsdale n.d.).

Drop manholes are also commonly built, and the difference between the regular is that the drop manhole are used when there is elevation difference between the pipes or when the velocities get too high. High velocities, close to 3 m/s, along with the grit it carries may cause the pipe to erode. Cleanouts can be used to replace a manhole for cleaning purposes. These are mainly installed due to economic reasons because in comparison to manholes, cleanouts cost roughly one sixth of the price. These are often installed on the service line and the end of laterals (Ragsdale n.d.).

2.1.6 Lift stations

Lift stations are needed because there are limitations how deep one can install the pipe in. When this point is reached, the water must be pumped to a higher altitude to proceed with the gravitational flow (Buchanan 2010). These facilities that do the pumping are called the pumping/lift stations. There are two types of lift stations used; dry well and wet well (Ragsdale n.d.).

Dry well lift stations have two separate chambers, one for the wastewater collection and one to contain all the components such as: motors, pumps, electrical controls, auxiliary equipment and valves (WUTAP 2007). This separate dry chamber provides easy access for maintenance and repairs. Wet well lift stations on the other hand contain only one chamber where a pump can be used, above the well or in the wastewater (submersible pump). Wet well is naturally a cheaper option but it yields more problematic maintenance and possibly dangerous environment due to sewer gases. The pipe that carries the water to be lifted is called the force main, it discharges the water back to a gravity sewer (Ragsdale n.d.).

Common components found in pumping stations include: pumps (centrifugal pumps, pneumatic ejectors or screw pumps), hardware, bar racks, valves, electrical system, alarms, motor control centre, hours recorders and pump controls (WUTAP 2007). Lift stations are subject to mechanical and electrical failures due to many components involved (Delzingaro 2006). According to the WUTAP (2007) there are four typical problems occurring in lift stations and the list below yields also the general reasons for those:

- Power: power outages, burned out motor, or electrical circuit failure.
- Control system: pump control failure or telemetry system failure.
- Pumping system: pump failure.
- Structural: grit deposits, plugged check valve or force main.

Reliable source of power is needed for lift station to function properly, so during a power outage an emergency backup system is required (WUTAP 2007). A diesel engine is used as a typical emergency system, it can be installed during building or it can be a mountable version. Although, the diesel engine is not the only thing required in a backup system, also the following components must work for the system to function: generator, transfer switch, pump control and of course the pump itself. If any of the components fail, the pumping will cease. Pumping failure could lead to sewage overflow depending on flow; failure duration and surcharge capabilities of the gravity sewer that feeds the station (Delzingaro 2006).

2.2 Sewer system's risk assessment and management

2.2.1 Risk assessment

Risk assessment is a broad term and it is part of the whole risk management process. It is a process which provides understanding and evaluates the magnitude and probability of all risks associated with sewer systems (U.S. EPA 2001). Risk assessment aims to assess risks by organising and evaluating data, uncertainties, assumptions and information (EPA Victoria 2009). The assessment may be conducted to predict the probability of future overflows, or evaluate the probability that overflows are caused by past or current events, or activities (U.S. EPA 1998). Environmental risk assessment generally follows three steps: problem formulation, risk analysis and risk characterisation. However, before beginning the actual assessment, one must question the need for it. The risk assessment and management is presented as a flow chart in the Figure 2 (EPA Victoria 2009).

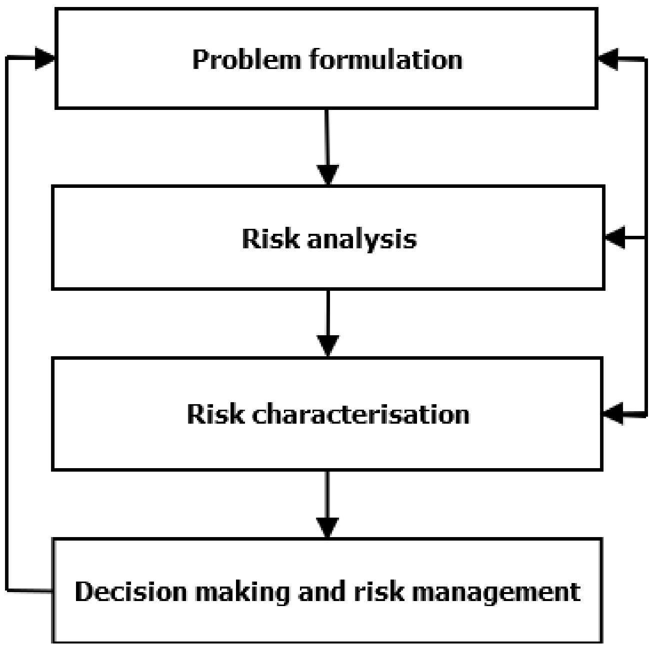


Figure 2: Risk assessment and management process (partly edited from EPA Victoria 2009)

The formulation phase assesses the focus and scope of the risks and how those can be managed (Hart et. al. 2005). It is advised that various experts from different fields take part in the formulation phase, such as: technical and scientific experts, risk managers, resource managers and other relevant stakeholders. General steps of the formulation phase includes: defining management goals, collation and integration of available data and information, defining all possible risks, creating conceptual models, identification of endpoints and a risk analysis plan (EPA Victoria 2009).

Management goals naturally are set goals to reach different objectives, such as: the mainline needs to be free from fractures. How to reach these goals are defined more precisely in the following management chapters. Collation and integration phase is where all the available data must be collected that is in connection with overflows. Defining of the potential risks requires clear definitions of all risks that cause overflows and all risks caused by overflows (EPA Victoria 2009). Conceptual models are diagrams that draw relationships between the hazards and effects, such as factors affecting the probability of risks occurring and impacts of overflows. Endpoints, on the other hand, are expressions of values to be protected and the means by how risks will be quantified (Hart et. al. 2005). Suter (1993) claims endpoints should be socially, politically and environmentally relevant, responsive to potential or known stressors, receptive to measurements, and substantive to management goals. Last but not least, risk analysis plan will summarize the formulation phase and yield the required details for the risk analysis (EPA Victoria 2009).

Risk analysis determines the probability and the size or magnitude of a risk (Hart et. al. 2005), with specific consequences occurring to beneficial uses and values during a certain timespan (Suter 1993). Various analysis tools are available that will differ on a case-by-case basis (EPA Victoria 2009). Generally three levels, so called tiers, of risk analysis exist: qualitative, semi-quantitative and quantitative risk analysis. Qualitative risk analysis describes the magnitude of possible consequences and the probability of occurrence in words (Hart et. al. 2005). However, one should be aware that since the qualitative risks are based on cultural, personal and professional experiences and values, meaning that the risks are represented as views and opinions, there may be many alternatives (Burgman 1999). Additionally, it should be noted that according to Regan et al. (2002) the whole risk assessment must deal with three uncertainties: variability, incertitude and language uncertainties.

Semi-quantitative level gives values to the qualitative scales to yield a more extended ranking scale. Quantitative risks analysis provides numerical values for the probability and consequences using data from variety of sources (Hart et. al. 2005). Quantitative risk assessment has various analysis methods available such as: environmental risk calculator (Hart et. al. 2005), decision or logic trees (Stewart and Melchers 1997; Hayes 2002), eco-toxicological and probabilistic methods (Solomon et. al. 2000; Calow and Forbes 2003), predictive models, deterministic models (Hart et. al. 2005), dynamic simulation models (Vose 2000) and Bayesian network (Clark 2005; Cain 2001; Wooldridge 2003).

Risk characterisation is phase where the information from problem formulation and risk analysis are evaluated and reported (Hart et. al. 2005). The goal is to provide the required information for decision making and risk management. The main points from this phase, which are needed to be reported, are: identification of the risks; for each identified risks the probability and impact; identification and evaluation of the interactions between the risks; prioritisation and comparison of the risks; reporting of the uncertainties, assumptions and limitations and strengths of the risk analyses; a discussion of all the information gained in the assessment that is relevant to risk management and decision making; a summary of the expert and stakeholder participation for the period of the risk assessment; and suggested assessment and monitoring program to assess risk assessment predictions and potential efficiency of management actions (EPA Victoria 2009).

2.2.2 Risk management general

The information used in risk management is all based on the results and insights of risk assessment. Risk management's goal is to define what actions should be done to minimise the risks to provide sustainable management. It includes priority setting, predicting, decision-making and merging different viewpoints (Beer and Ziolkowski 1995). These risk managements actions are combined with political, economic, social and environmental factors (Hart et. al. 2005). NRMMC (2005) states that minimising emissions of sewage, odour and/or noise is anticipated; however achieving zero emissions cost-effectively will be unlikely for existing systems. Since zero overflows are unlikely in long sewer networks, then so called "frequency limits" should be determined; what is acceptable level of overflows for the plant? Overflow management is an integral part of efficient sewage management (NRMMC 2005).

2.2.3 Risk management planning

Before going into action, a risk management plan should be made. The goal of the plan is to find the most efficient way to address the risks. There are multiple different schemes available and the selection of the best one might not be very simple. The plan should determine what parts are at most risk; why those parts are at risk; what methods to use for minimisation of the risks effectively; weather the methods are acceptable and cost-effective (Hart et. al. 2005).

Generally the management plan generation has four steps: identify actions to reduce risks, decision process, develop management action plan and implement the plan. When identifying the actions, different options will be carefully weighted. In decision making step, the options will be decided by taking into account the political, economic, social and environmental factors. The final plan will take into account the protection, active management, rehabilitation and low priority for any action (Hart et. al. 2005). One another approach is to make two different plans; one for short-term which focuses on management and maintenance and one for long-term that focuses on structural actions. The plant should also include a schedule, which takes into account financial and institutional considerations. When the plan has been implemented, it must be monitored and reviewed so that possible improvements or even revisions can be made (NRMMC 2005).

2.2.4 Management and maintenance activities

The following chapters will describe the common management activities in sewer systems, problems encountered and methods to correct them. The content will be list-like due to many methods available. According to NRMMC (2005), there are three levels of maintenance: preventive maintenance that uses scheduled maintenance to prevent risks, corrective maintenance where failed non-critical assets are repaired or replaced and emergency maintenance that corrects critical asset failures that have an effect on environment and human health.

2.2.4.1 Testing and inspection

Testing and inspection of sewer lines are crucial when installing new pipe lines, but also to check the existing network condition. Testing and can also detect and locate the source of inflow and infiltration (I/I), roots, grease, damage, corrosion (Ragsdale n.d.), and sand and other sediment blockages (WUTAP 2007). Typical tools available for testing are: dye testing which is used to determine drains connected to the system; pressure testing that is usually made for new pipes; smoke testing which is applicable to indicate illegal taps and broken lines (Ragsdale n.d.); and mandrel testing that is commonly done for new pipes to test if the pipe has proper flushing, and horizontal and vertical tolerance (NEIWPCC 2003). Common inspection methods, on the other hand, are: closed-circuit television (CCTV), cameras, visual inspection and lamping inspection. All of the inspection methods should be conducted during low flows. CCTV is claimed to be most frequently used, most cost-effective and most effective method for inspection (U.S. EPA 1999b).

Overflows are occasionally reported by public; however, in areas where it is unlikely that overflows will be reported, regular walk inspections may be conducted. Manholes and overflow structures are commonly visually checked (NRMMC 2005). As pumping stations possess a source for overflows (Delzingaro 2006), they must be regularly inspected. Techniques for pumping station testing and inspection include inspection of instrumentation and telemetry; checking penstocks and valves; electrical and mechanical inspection; and pump testing (NRMMC 2005).

2.2.4.2 Cleaning

Cleaning of sewer system is required on regular basis. The system should be free from sediments that will eventually cause blockages (NEIWPCC 2003). In pumping stations, the sediments and grit should be removed from wet wells, and the wet well control devices should be cleaned so that grease and fat accumulation do not cause pumping failures (NRMMC 2005). A list of technologies is presented with short descriptions:

- Rodding: long rod with a tool attached to the end. Used to cut roots and clear different blockages (Ragsdale n.d.). Various different rodding tools exist and each serves different purposes. Two types exist: hand and power rodders, power rodder being the more effective one (WUTAP 2007).
- Bucket machine: two winches drag a porcupine or a bucket through the pipe. Used for same purposes as rodding (Ragsdale n.d.).
- Cable machine: operates and does the same as bucket machines. The difference is that cable machine’s winch is usually truck-mounted (NEIWPCC 2003).
- Balling: a ball that scrubs the pipe while spinning as flow increases in the sewer. Used to remove settled materials, such as grease and inorganic materials.
- Flushing: flushing is done through a manhole. The large flushing flow will remove floatables, and some grit and sand (U.S. EPA 1999b).
- Jetting: a nozzle is propelled with water pressure, this directs water to the pipe walls, and removes grease and blockages (WUTAP 2007). In small diameter pipes, even the roots may be cut (U.S. EPA 1996b). Different nozzles serve different purposes (Ragsdale n.d.)
- Silt traps: collect settled materials from convenient locations. Regular emptying is a must.
- Grease traps and oil/sand interceptors: these are used to remove grease in facilities that deal with greases, such as automotive industry and restaurants (U.S. EPA 1999b).
- Scooter: a steel frame on small wheels that has a shield at one end. Shield pushes the debris and causes it to accumulate, and then the shield is dropped so that water masses can flush the debris down the line (Ragsdale n.d.).
- Kites, bags and poly pigs: similar to the ball, both in usage and purposes.
- Chemicals: various chemicals types available. Used to control corrosion, roots, grease, odours, rodents and insects (U.S. EPA 1999b).

From the methods available, also a table (Table 1) is created to present the efficiency of given methods for different problems. Values are given only to the methods that work well on the problem (U.S. EPA 1999b).

Table 1: Efficiency of the cleaning equipment (edited from U.S. EPA 1999b).

	Problem				
Solution	Emergency stoppage	Grease	Roots	Sand, grit, debris	Odours
Balling		2		2	3
Jetting	5	1		2	3
Flushing					4
Scooters		3		3	
Buckets				4	
Rodding	2-3	5	3-4		
Chemicals		4	3		3

Levels 1- 5 from most to least effective, respectively

2.2.4.3 Repairs and rehabilitation

Sewer lines and manholes need to be rehabilitated to avoid infiltration, inflow and leakage. Additionally pumping stations must be functioning well to avoid overflows. The pipes can be renewed either by trenchless technology, off-line replacement or by open excavation. Non-trenchless methods are generally avoided due to the cost and disturbances it causes, if the pipes are installed deep in the ground. However, sometimes a broken or collapsed sewer requires them (NRMMC 2005). One must also pay attention to that the pipe is properly bedded and backfilled (Ragsdale n.d.).

According to U.S. EPA (2009), sewer repairing means the actions that deal with localized deteriorations or efforts to restore the sewer back to operating condition. Rehabilitation aims to extend the operational life and to restore the pipe's functionality. Finally, replacement technologies will replace the existing pipe with a new one. Manhole and lift station renewal technologies aim to eliminate or reduce the infiltration/inflow and reduce future impacts of corrosion. Various different methods exist for each category (U.S. EPA 2009) and thus the most common ones are aimed to be listed. For more detailed listing about different management methods and information for sewer systems, one should see (Griggs 2003), (U.S. EPA 2009), (Read 2004), (Read and Vickridge 1997) and (Stein 2001, 2005), and for manholes (Hughes 2002) and (Muenchmeyer 2007).

General pipe repair methods include: cured-in-place pipelining (CIPP), robotic repair, and internal sleeves and joint repairs. In CIPP, pipes are lined with a flexible liner that will be held in place, and cured for the fabrics to harden and provide structural support. Although in repairing only a short section, a spot, must be lined (Ragsdale n.d.). Different curing methods for CIPP exist, some common ones being thermal (Insituform 2015) and ultraviolet cure (RELINEEUROPE 2015). Robotic repair can perform, wide variety of different tasks, such as cleaning, sealing and grouting. Internal sleeves and joint repairs are used to repair a joint or spot; however, different installing methods exist. Manholes are repaired by sealing holes; adding seals/pans; usage of patching and plugging compounds for minor leaks; sealing joints and chimney area; installing precast bench and invert inserts; and by replacing parts such as castings, covers, adjustment rings and manhole steps. Lift stations can typically be repaired by person entry into the area. Broken equipment need to be repaired and minor leakages should be sealed. Same materials can be used (U.S. EPA 2009).

CIPP is the most used technology in rehabilitation. Chemical grouting is also regularly found. In chemical grouting, the grout is sprayed to seal joints, to harden and provide support to the pipe (Ragsdale n.d.). Many different lining technologies are accessible which differ by material and installation. Same rehabilitation styles are also used in manholes, for example chemical grouting, and various different liners and coatings. Lift stations have generally three approaches that can be used separately or combined: coatings and linings, cast-in-place repairs, and/or grouting for leaks. Cast-in-place provides a new structural layer by for example using a formwork and poured concrete (U.S. EPA 2009). Appropriate technology selection depends on the goals that are wanted for the rehabilitation to yield. Selection should also consider accessibility, existing and future impacts of corrosion, and existing structural deterioration and infiltration (Muenchmeyer 2007).

Replacement can be split into two categories: on-line and off-line. On-line methods include sliplining and trenchless methods (U.S. EPA 2009). In sliplining a new smaller diameter pipe is directly installed in the old deteriorated pipe either by pushing or pulling. Often used trenchless method is pipe bursting. In pipe bursting the old pipe will be demolished so that as large or larger pipe can be installed at the same time by sliplining. Pipe bursting is more adapted method, mainly because it has the ability to up-size the piping and the fact that it does not fail in certain misalignment or grade problems (Ragsdale n.d.). Three bursting techniques exist: static, pneumatic and hydraulic; static being the simplest. Off-line replacement is done without disturbances to the existing pipe's grade and line, by installing a totally new pipe. Well known off-line techniques are microtunneling and horizontal direction drilling. Extremely deteriorated manholes or lift stations might be best to be totally replaced, by open excavations (U.S. EPA 2009).

2.2.4.4 Remote monitoring and automation

The use of remote monitoring and automation is an important part of overflow management. This study will focus on wireless sensor networks, as well as to real time control (RTC) for active management of sewer network on a general level. RTC can be thought to be a system that dynamically adjusts the operation of facilities in response to the measurements from the field to maintain and meet the operation objectives in all sorts of weather conditions (U.S. EPA 2006). Three elements are typical in RTC: sensors, actuators and strategies (Field et. al. 2000). Various telemetry solutions are available, however typically these, as well as the RTC algorithms are connected to a supervisory control and data acquisition (SCADA) system (U.S. EPA 2006). SCADA system likely consists of the following (Stoianov et. al. 2006):

- Outstations, that consists of remote telemetry and automation devices.
- Data-loggers and programmable logic controllers (PLCs) for actuator control.
- Data gatherers which acquire the data and manages it.
- Data server to yield data for users and other purposes.
- Workstations that provide the user interface.

Most sewer systems are operated passively, but if control is provided it tends to be local such as in lift stations. It is not yet common for a wastewater treatment plants to have SCADA, not to mention automated controlling (Vélez et. al. 2008). SCADA processes all incoming and outgoing data, and generates alarms if necessary (NRMMC 2005). The data is "communicated" to SCADA by different methods. The data can be transmitted by leased telephone circuits, wireless communication systems, cellular systems or by satellite communication devices (Schütze et al. 2002). RTC collects the information, compares it with desired values, determines the settings for desired states and implements the settings into actions for actuators. Actuators are the elements present in the sewer network, such as inflatable damns, gates, pumps and valves (U.S. EPA 2006).

Sensors used in RTC for data acquiring are rain gauges, flow gauges, water level gauges and quality gauges (Schütze et. al 2006). For material selection one must remember that sensors must deal with fairly harsh environment because the networks has a corrosive, or even explosive atmosphere; high humidity; periodic submergence; exposure to wastes, greases and oils; changing levels and flows; silting; confined space; and lack of nearby communication and power (U.S. EPA 2006).

Rain gauges measures precipitation and the data can be used to forecast rainfall and the effects of it. However the forecasting of precipitation is difficult due to various variables and objectives. Forecast is defined by duration; volume; horizon and intensity of the forecast; spatial and temporal distributions within the rainfall and probably even by the type of precipitation. For flow gauges various technologies exists, but most used are area/velocity flow meters and flumes, such as Palmer-Bowlus flume. Finally water level gauges are sensors that measure the water levels continuously or when the level reaches certain point; a point level measurement device. Once again, various technologies exist, but the commonly used are direct submerged pressure transmitters and ultrasonic level technologies (U.S. EPA 2006). Quality gauges simply measures the water quality, but requires rather high operation and maintenance skills (Schütze et. al 2006).

Wireless sensor network's advantages have provided interesting solutions for maximizing combined sewer system storage. A case example from Quebec; the Quebec's sewer system initially consisted of five controllable gates. The data implemented for gate control was acquired from 17 flow monitors and weather stations. Results from this 2.6 million dollar investment yielded a 70% reduction in overflows. The system has since been vastly expanded (Schütze et al. 2002; Pleau et. al. 2000). Even though the system is cheaper than the sewer separation, the benefits and cost should be carefully weighted in smaller combined sewer systems (Ruggaber 2006). Overall the operational goals than can be achieved with real time monitoring include: sending alarms if spills occur, reducing or eliminating overflows, managing/reducing energy consumption, avoiding sediment deposition, managing flows during planned and un-planned disturbances and finally by managing the flows arriving to the wastewater treatment plant (U.S. EPA 2006). The received data can also be projected to geographical information system (GIS) to help minimizing the effects of contamination (Stoianov et. al. 2006).

Network can also be controlled without PLCs and centralized control schemes, for example by the use of CSONet that relies on small nodes that gathers data and implements it into actions for so called smart vales to maximize water storing capacity at any time (Ruggaber & Talley 2005; Ruggaber et. al. 2006). Sewer Intelligence^{TM} system has also interesting solutions for monitoring (Quist et. al. 2008). Alarms in lifts stations can be generated by different means, such as with small electronic node box receiving signals from the sensor(s) and further transporting the information to a distant database server; but an advanced alternative is to have the elements connected to the SCADA. This will lessen the liability and risk to the utility and personnel; reduce equipment repair cost due to early detection of automated warnings/diagnosis of pump equipment and lift station problems; lessen frequent inspection and maintenance visits; provide data storing capacity for further usage or for strategic planning; and minimize ongoing and capital maintenance cost for SCADA and telemetry equipment (Pavlik 2003).

2.2.4.5 Sewerage upgrade

Overflows can also be encountered by upgrading sewers. In lift stations one can provide additional volume, install additional pumps, upgrade equipment, provide additional power supply or upgrade the alarm system along with other telemetry. Additionally the amplification of sewer systems along with other wet weather flow mitigation systems is desired (NRMMC 2005). The wet weather flow mitigation techniques will be gone through in more detail at the next chapter.

2.2.4.6 Wet weather flow mitigation and overflow prevention

This study is set provide general solutions for wet weather flow mitigation, mostly by structural means and by emphasizing green infrastructure solutions. Most technologies presented are also the best practises according to U.S. EPA (2012). As wet weather flows are significant factor in combined sewer overflows, these should be mitigated. Additionally proper runoff management may reduce flood damage and soil erosion; maintain groundwater recharge; reduce pollution; minimize the runoff and pollutants in it; and to protect environment, humans and wildlife (NJDEP 2004).

In grey infrastructure one of the most common technologies is off-line storage where the peak flows are stored in deep tunnels located adjacent to the sewer system, or in tanks or basins until it is safe to be transported. Overflows may also be prevented by sewer separation, in-line storage, or by expanding the network and/or the wastewater treatment plant (U.S. EPA 2014). Vastly used slow-release methods include dry/wet detention basins and ponds, different filtration structures to provide slow infiltration (WVDEP 2012); and curb and gutter removal which aims to yield non-direct runoff feed into manholes (U.S. EPA 2012). However various other design factors are also crucial, such as where to direct the runoff and locations of manholes. The previous are some of the so called non-structural means (NJDEP 2004).

Green infrastructure relies on natural, hydrologic process to reduce the rate and/or quantity of wet weather flows into the combined sewer. Although it comes along with other benefits regarding better air quality, reducing urban heat island effect, reducing energy usage, improve liveability and creates green jobs. Numerous methods are available that control the runoff by infiltration, evapotranspiration, and/or by capture and use. The most common solutions in urban areas are (U.S. EPA 2014):

- Disconnection: directs the runoff from impervious areas such as parking lots onto previous areas such as lawns, rather than straight into storm drains.
- Rain harvesting: the runoff from roofs is collected to a cistern tank for further usage, such as irrigation.
- Rain garden: a solution which has an engineered soil mixture that provides vegetative growth. The soil is capable to store and infiltrate the runoff, and thus retain a portion for plant uptake.
- Green roofs: roofs are covered with vegetation, which naturally has the availability for capture and store of some portion of the storm water.
- Infiltration trench: an option where an area is excavated and filled with gravel to collect the runoff and infiltrate it into the native soil.
- Street planters: these concrete box structures are built along sidewalks and parking areas. The box is filled with engineered soil that provides the capability for vegetative growth. Below the soil, a gravel bed is installed to provide additional storage and infiltration to native soil.
- Porous pavement: excavated areas where the cover is permeable concrete or asphalt mixture and below the cover a gravel layer is used to store and infiltrate the water.

2.2.4.7 Design

Multiple design factors have already been brought up. However design is a crucial part in overflow management; everything needs to be properly interacting to provide a safe sewer system. Design generally concerns: sewers, flows, manholes, cleanouts, lift stations and locations for all the previous. The following elements should be included in the design phase: overflow structures if required, in-system storage if required, back up for all different failures, bypass facilities for pumping stations, availability and response time of support service, and proper management and maintenance (NRMMC 2005).

2.3 Impacts of wastewater overflows

2.3.1 Wastewater overflow's quality and load

Wastewater overflows are something that should be avoided due to their negative impacts on environment and health (NJDEP 2004). According to Akpor and Muchie (2013), the characteristics that cause highest concern are: pH, dissolved oxygen (DO), chemical oxygen demand (COD), biological oxygen demand (BOD), total suspended solids (TSS), total dissolved solids (TDS), total nitrogen (N), total phosphorus (P), and heavy and trace metals: arsenic, cadmium, calcium, chromium, cobalt, copper, iron, lead, magnesium, manganese, mercury, molybdenum, nickel, potassium, selenium, sodium, vanadium and zinc. Despite the fact that those are some of the most important parameters, there are also various other characteristics that are being tested, such as microorganisms (Akpor and Muchie 2013).

The impacts of wastewater overflow depend on the volume, type, chemical and microbiological composition/concentration, and of course on the characteristics of the receiving waters. About the important characteristics, the pH is a good measure of acid and base properties (Akpor and Muchie 2013). Most aquatic biota are claimed to be sensitive to pH changes and additionally it is known to cause fish kills, and reduction and change of other species (Novotny and Olem 1994). To continue, DO on the other hand is required for respiration of the aerobic microorganisms and all forms of aerobic life. So if low levels of DO are detected it will effect on the survival of aquatic species; cause retardation in growth, hamper swimming ability, alterations in migration and feeding, and at its worst it will cause rapid death. Thirdly, both COD and BOD measure the oxygen demand of the microorganisms as they feed on organic solids (Akpor and Muchie 2013).

There are various ways to measure amount of solids, TSS and TDS being the most typical (Akpor and Muchie 2013). When the solid levels are elevated also the turbidity will increase, as well as the light penetration reduces, which means the growth of plants could be limited. The settled solids may contribute to sedimentation, which eventually could destroy habitat for aquatic species. The solids will yield a medium for accumulation, transport and storage of other pollutants. Nitrogen and phosphorus are claimed to be the principal nutrients in wastewater that cause eutrophication and algal blooms. Heavy metals, especially copper, lead and zinc, cause high concern in receiving waters for their capability to impact water supply and cause acute and/or chronic impacts on aquatic life. Finally pathogens are disease-producing organisms, such as viruses, bacteria, fungi, protozoa and helminths. A widely adapted method for harmful pathogen detection in wastewater is faecal coliform indicator (U.S. EPA 1999c).

To summarize, the adverse environmental impacts caused by overflows are reduced levels of dissolved oxygen, physical damages, toxic substance releasing, bioaccumulation or bio-magnifications and elevated nutrient levels in the receiving waters. Naturally also the terrestrial vegetation, wildlife and groundwater are affected. Although this study focuses more on environmental effects, one should remember that also health, economical, socio-cultural and technical consequences might occur, such as drinking water contamination; odours; aesthetic impairment; disturbances; fishing restrictions; beach closures; and adverse health effects (U.S. EPA n.d.). In the next chapter typical values for some of the previous characteristics are given for domestic wastewaters. Industrial wastewaters tend to yield higher values, especially the industries listed in the Council Directive 91/271/EEC – Article 13, which mainly concerns food industry (Frost 2009).

2.3.2 Urban wet weather flow's quality

As wet weather runoff sweep the land in an urban area, it collects the accumulated debris; tire and vehicular residue; pollution fallout; animal droppings; eroded soil; pesticides, polychlorinated biphenyls, fertilizers, and other chemical additives; decayed vegetation; heavy metals; and many other pollutants. Thus, highly depending on the urban area, even the runoff/discharge can yield impacts on environment (U.S. EPA n.d.). According to Horner et al. (1994) the pollutants fall into the following categories: solids, oxygen-demanding substances, nitrogen, phosphorus, pathogens, synthetic organics, metals and petroleum hydrocarbons.

The impacts on receiving waters can be thought to be short-term, long-term or physical. Short-term impacts increase temporarily the concentration of certain pollutants, while long-term impacts are caused by cumulative effects that occur during repeated storm water discharges. Finally physical impacts are the ones caused by erosion, scour, and deposition that are consequences from increased volume and frequency of runoff that alters aquatic environment (U.S. EPA 1995).

In a study conducted in Durham, NC revealed that biochemical oxygen demand (BOD) from surface wash storm waters was almost equal to that of secondary treated wastewater, and the chemical oxygen demand (COD) were to exceed the amount expected in the raw wastewater (Field and Struzeski 1972). High loadings of storm water have also been reported in other studies (Field and Turkeltaub 1981).

To compare the qualities between raw sewage and runoff, a table is formed (Table 2). Due to different pollution concentrations in different studies, in this report pollution parameters were taken from following sources, from different urban areas: U.S. EPA (1986); Pitt et al. (2003); Weibel (1969); Luo et al. (2012); Bastian (1997); Droste & Hartt (1975); Smullen et al. (1999); GSI (2015); Kamal et al. (2014); Delft University of Technology (2015); City of Sultan (2011); and Ahmed (2014), and from these average concentrations were calculated. For some median values were used, as those were thought to be more exact. To provide comparison, the minimum secondary treatment targets in the EU are also provided; in phosphorus and nitrogen the values depend on the number of inhabitants, while BOD reduction percent is affected by the water temperature because cold waters are not so effectively biologically treated, by also taking into account the adverse effects on environment (Frost 2009).

Table 2: Pollution parameters of urban runoff and domestic wastewater, and performance limits.

Constituent	Urban Runoff Average	Domestic Wastewater Average	Minimum Secondary Treatment Performance and Load Reduction
COD	99,0 mg/l	462,1 mg/l	125,0 mg/l – 75 %
TSS	184,2 mg/l	196,7 mg/l	35,0 mg/l – 90 %
Total P	0,6 mg/l	8,9 mg/l	1,0-2,0 mg/l – 80 %
Total N	2,5 mg/l	40,2 mg/l	10,0-15,0 mg/l – 70-80 %
BOD_5	11,5 mg/l	247,7 mg/l	25,0 mg/l – 70-90 %

2.3.3 Receiving water's sensitivity

According to the European Urban Waste Water Directive, the Council Directive 91/271/EEC of 21 May 1991, sensitive water areas are natural freshwater lakes and other freshwater bodies, estuaries, and coastal waters that are eutrophic or which might become eutrophic in near future if no protective actions are implemented. Additionally the term concerns surface freshwaters intended for abstraction of drinking water which does or could contain more than 50 mg/l concentration of nitrate (75/440/EEC) and areas where other Council Directives must be complied, such as the directives on bathing waters, fish waters, shellfish waters, and on the conservation of wild birds and natural habitats (EUR-Lex 2004; EUR-Lex 1999).

3 Methodology

3.1 Data collection

3.1.1 Annual reports

All of the wastewater treatment plants that are subject to environmental permission must deliver an annual report. Annual reports provide information for both the monitoring authorities and residents. The report typically consists of general information about the plant, monitoring data and overall performance limit's fulfilment. If performance limits are exceeded, the information should be reported without delay. A calculation of yearly average treatment results should be included, and weighted against the whole plant and its sewerage system, by taking in the account bypasses and overflows. If network overflows do happen, generally the amount of the discharge should be reported.

The bypasses, overflows and flows were collected from tables that can typically be found from the appendices of the annual report. More specific details could be found from the actual text, such as reasons for the bypasses and/or overflows, what was the flows like and how was the plant functioning overall. One of the objectives was to collect data from 77 plants that are or have been functioning in the Uusimaa region during the years 2007-2013. It was requested to transfer the overflow and bypass information of the reports into an electrical form (Excel); to provide easier access for ELY-Centre and to carry out this evaluation. A total of 469 annual reports were inspected in the process. There were few cases where a plant had failed to deliver the report.

3.1.2 Other sources

ELY-Centres receive information of the overflows in many different formats: VAHTI-program, e-mails, phone calls and from authorities. Although annual reports should include all of the overflows, there were instances when some of the overflows were only mentioned in the VAHTI-program. Other sources were investigated, not only because of the previous reason, but to yield better understanding of the situation and to find a reason for the overflow.

VAHTI (Valvonta- ja kuormitustietojärjestelmä) is a monitoring and loading information system. It is used to collect information of plant's operations, for example discharges into the water and emissions into the air, as well as wastes. The information stored in VAHTI is mostly used to handle permit applications and to monitor (Ympäristö 2013a). In addition to VAHTI, the data was also collected from received e-mails.

3.2 Data analysis

3.2.1 Sorting

The data from all the sources mentioned previously were exported into Excel. Each year had its own tab and under each year all the plants were listed. All the plants had their own tables created where the following information was listed: days/weeks/months when there were overflows and/or bypasses; flow at that time; amount of bypasses and/or overflows; was the bypasses happening before any treatment, after mechanical treatment or after pre-clarification; bypass percent; overflow percent; overall percent of all bypasses and overflows combined, and the amount of wastewater treated. In addition to that also the reasons, if mentioned, for overflows were collected along with the faults found in reporting.

As this report focuses only on the network overflows, the plants without any overflows were left out. Among the 77 plants investigated, 65 had a real sewer network, from where 35 had bypasses and/or overflows. Finally this led to 21 plants with actual sewer overflows. From the 21 plats, three did not report their overflows in cubic meters and were thus contacted to estimate their overflows in cubic meters. One of the plants that reported the overflows in time units was left out from the comparison since they were not able to convert the overflows into cubic meters, which is completely fine because the current demands only require the estimation of overflows in time units. The other plant was left out due to extremely small overflow percentage and the fact that a large portion of this three cubic meter overflow was most likely river water. A list of all the 77 plants can be seen in the Appendix 1.

3.2.2 Analyses

The data was analysed in various ways. Firstly, a plot which included all the 19 plant's bypasses and overflows (m^3/a) during the seven years was drawn. Secondly the same was done, but with percentages. Plants were also evaluated in size groups, as well as individually. It is not very detailed to plot everything in cubic meters to a same graph since there are enormous differences between the large and small plants, thus the results are only displayed in percent because that partly neglects the size difference between the plants. The cubic meters can be used to reveal the significance of the overflows.

The individual performance was also evaluated statistically. The statistical analysis was conducted with R programming language (R Project 2015). Firstly principal components were acquired, from where the data was further processed to provide a biplot of the performance. Principal Component Analysis (PCA) is a common procedure in multivariate data analysis. It is a dimension-reduction tool that aims to reduce a data set to a smaller set that still yields most of the information from the original set. This procedure basically transforms a number of possibly correlated variables into a smaller number of uncorrelated variables, into the so called principal components (Statgen 2007). The first principal component accounts as much as possible of the variability in the data and each component afterwards accounts for as much of the remaining variability as possible (Taavitsainen 2011). In the study, two principal component explained sufficient amount of variability both in percentage as well as according to Kaiser's criterion, i.e. Eigen values over one (Statsoft 2015). Finally, biplot is a presentation that tries to represent both the variables and observations of data in the same plot (SAS 2015).

To obtain more understanding about the overflows, also the number of days overflows occurred were analysed. Even though if the overflows in cubic meters or percent are not showing an increasing trend, the number of days could still yield valuable information. The overflow amounts do not necessarily mean fewer breakages because for example, a more enhanced repairing naturally causes fewer overflows. Three largest plants in the region: Viikinmäki, Somenoja and Hermanninsaari did not report all of their overflows in daily values and were thus left out from the comparison. Viikinmäki and Suomenoja represent the monthly overflows, whereas Hermanninsaari reports the daily/weekly values.

3.2.3 Amount of individual overflows

All the individual overflows were gathered. In this part the overflow amounts from Viikinmäki and Suomenoja were left out due to monthly values and Suursuo due to time units. However, Hermanninsaari's values were taken in the consideration because most of the daily values were available and that the weekly values could be estimated to daily values. Total of 21 size classes were made from self-determined bin limits and overflow amount distribution was carried out.

3.2.4 Overflow causes

As mentioned, the causes for overflows were also listed into the tables. The reasons were, if given, said in the report's text, VAHTI or e-mails. There are various reasons for overflows, but the most common found during data analysis was wet weather flows. Lijklema and Tyson (1993), claims that in many regions, even a rainfall of 0.254 cm can cause multiple overflows yearly. Other common reasons for overflows are: sewer fracture/blockage, pumping station factor, infiltration/inflow (I/I), system growth, system conditions and major industrial discharges (NRMMC 2005). In the beginning, categories like these were expected to be found, but due to indefinable explanations in the reports, the categories were needed to be decreased. In the end there were three categories for overflows: pipe fracture/blockage, automation/equipment failure and other. Other reasons were heavy rain, snow melting, storm, power failure and overflows that were mentioned separately in the report's text (or in VAHTI/e-mail), but no reason was granted. Reasons for overflows were given to a clear minority of the actual dates when there were overflows.

3.2.5 Weather

As wet weather flows are known to cause overflows the weather in the Uusimaa region was evaluated. Five plants were chosen from locations that would cover the region, these were: Porvoo, Hermansö; Raasepori, Skeppsholmen; Hyvinkää, Kalteva; Helsinki, Viikinmäki and Loviisa, Vårdö. Some of the annual reports had daily flow values plotted and some were done by hand. From the plots the flow spikes that went clearly above the plant's capacity were calculated and compared. The years were then placed into a descending order, with first year being the one with most flow spikes. After that the years were valued; the year with most flow spikes received the highest number (7) and the year with least flow spikes the lowest (1). Finally, all the valued years of the plants were summed and plotted. The plot was assumed to show similar trend with the overall flows at the Uusimaa region. Another plot was done according to the height and width of the flow spike, by also taking in the account the amounts when there were really high flow spikes. It, on the other hand, was thought to have more relations with overflow trend; because the more and longer the capacity is surpassed the more there might be overflows.

3.2.6 Network size

Network's size was evaluated to determine how it affects the overflows. Does it always mean that the longer the network, the more overflows? This investigation could also provide information about the condition of each plant's network. The network length estimations were acquired from VELVET (Vesihuoltolaitostietojärjestelmä). VELVET is a water supply and sewerage systems information network that gathers data from water supply and sewerage. The system has information about water supply and sewerage's materials and amounts, the number of customers, economical figures, acquired and delivered water amounts and water supply and sewerage system's forms of activity (Ympäristö 2013b).

4 Results

4.1 Deficiencies in reporting

The annual reports were found to have significant differences between the plants and consulting companies. There were even differences between the same plant's annual reports. If there were differences in same plant's reporting, mostly the reporting style was going in to a better direction, but unfortunately not always. The deficiencies are listed on the next page. The deficiencies occurred in multiple cases, if not mentioned otherwise. It should be noted that most of these are not actual failures, but something that affects the report's intelligibility and results into further investigation.

- Wrong calculations: often the bypass/overflow was divided by the amount of water treated, not the actual flow, and in few cases the time unit was divided by the flow which naturally does not yield anything.
- Missing information: the following were missing from time to time, but luckily not usually all at the same time: days overflows occurred, treated water amount, flow, bypasses and overflows.
- Inaccurate information: occasionally only one value (m^3/d) was given to overflows, even if there were multiple days. This made it impossible to know how much overflows there were in certain days and in some, the m^3/d was calculated wrong. Sometimes if there were bypasses, the report did not point out where the bypass occurred, meaning it was not known was the water mechanically treated, pre-clarified etc.
- Terminology: often overflows were referred as bypasses. In Finnish the difference between the terms doesn't seem to be different enough.
- Missing overflows: when browsing VAHTI, it revealed that not all the overflows were mentioned in the annual reports (only few cases).
- Wrong assumptions: in few occasions a plant assumed bypassed water as treated, i.e. if the water was only mechanically treated it was assumed to be fully treated. This yields notable error.
- Lack of information: sometimes it was impossible to know if there had been overflows because no mentions about it were given.
- Inconsistency: differences were found between the values in the appendix tables, compared to the same ones in the text. Some of the numbers were completely different; this led in to problems when determining which one of the values was right. At least in one report it was found out that this happened due to the fact that the values used in the previous year's reports text was forgotten to be changed.
- Legibility: in two reports where there were no yearly flows given, and to acquire the value the weekly flows were to be summed. However, due to the thick marker used, along with blurry scanning, the yearly flow acquired cannot be considered precise since few values were impossible to read. This was also the case in multiple other reports, but luckily the values were also mentioned elsewhere in the report.

4.2 Overflows by size groups

4.2.1 Overall situation

As described earlier, after cropping the data, 19 plants with overflows were acquired; Figure 3 below presents the overall situation with the plant's yearly overflow percentages, as well as the number of days overflows occurred. One must remember that the figure does not include the days from Viikinmäki, Suomenoja and Hermanninsaari since they did not report all of their overflows in days.

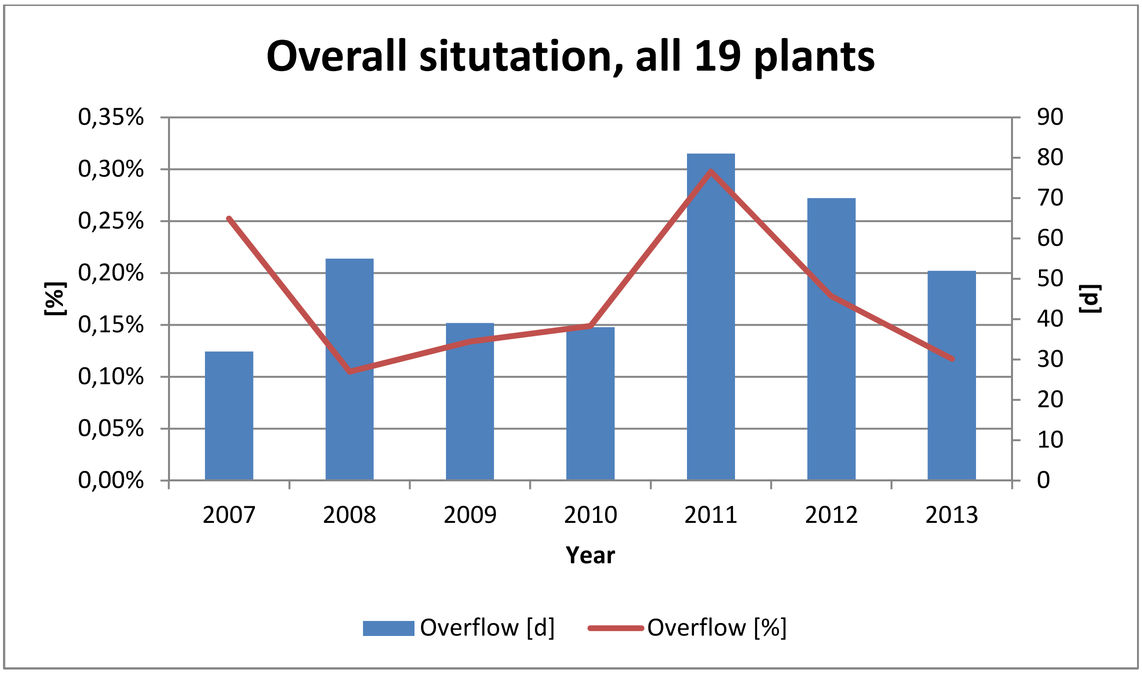


Figure 3: Overall situation of overflows.

4.2.2 Grouping

The plants were split into groups before individual evaluation. The grouping was done according to the flow values. Plants that were roughly in the similar flow range belong into same group. The groups could also be called the significance groups because larger flows usually mean the larger the overflows in cubic meters; when the size difference is remarkable. So even if a large plant is functioning really well in percentages, it still often has more overflows in cubic meters than a small plant with much higher overflows in percentages. From the 19 plants a total of 5 groups were formed; the grouping can be seen in Table 3.

Table 3: Grouping of plants by their flows.

Q 2007-2013 [m^3]	Group	Plant names in descending order
711779987	1	(1) HSY, HELSINKI, VIIKINMÄKI
248491363	1	(2) HSY, ESPOO, SUOMENOJA
31671485	2	(3) PORVOO, HERMANNINSAARI
25551012	2	(4) HYVINKÄÄ, KALTEVA
21643256	2	(5) LOHJA, PITKÄNIEMI
16365414	2	(6) NURMIJÄRVI, KLAUKKALA
13896246	2	(7) HANKO, SUURSUO
9480213	3	(8) RAASEPORI, SKEPPSHOLMEN
7084070	3	(9) MÄNTSÄLÄ, KIRKONKYLÄ
6880031	3	(10) LOHJA, PELTONIEMI
6325599	3	(11) KARKKILA, KESKUSPUHDISTAMO
6142727	3	(12) VIHTI, NUMMELA
1920258	4	(13) VIHTI, KIRKONKYLÄ
1479138	4	(14) SIUNTIO, PIKKALA
1106810	4	(15) INKOO, JODDBÖLE
1003942	4	(16) NUMMI-PUSULA, SAUKKOLA, Out of Business Since 2.7.2013
836230	4	(17) RINNEKOTI, ESPOO
751681	4	(18) UPINNIEMEN VARUSKUNTA, KIRKKONUMMI
97459	5	(19) HYVINKÄÄ, KAUKAS

Additionally plots from the groups were made (Figures 4, 5, 6, 7 and 8), to see if any groups yield an increase in overflows and how significant the overflow percentage is, along with the days. The grouping is used to split the overall situation into smaller, roughly equal sized, sets.

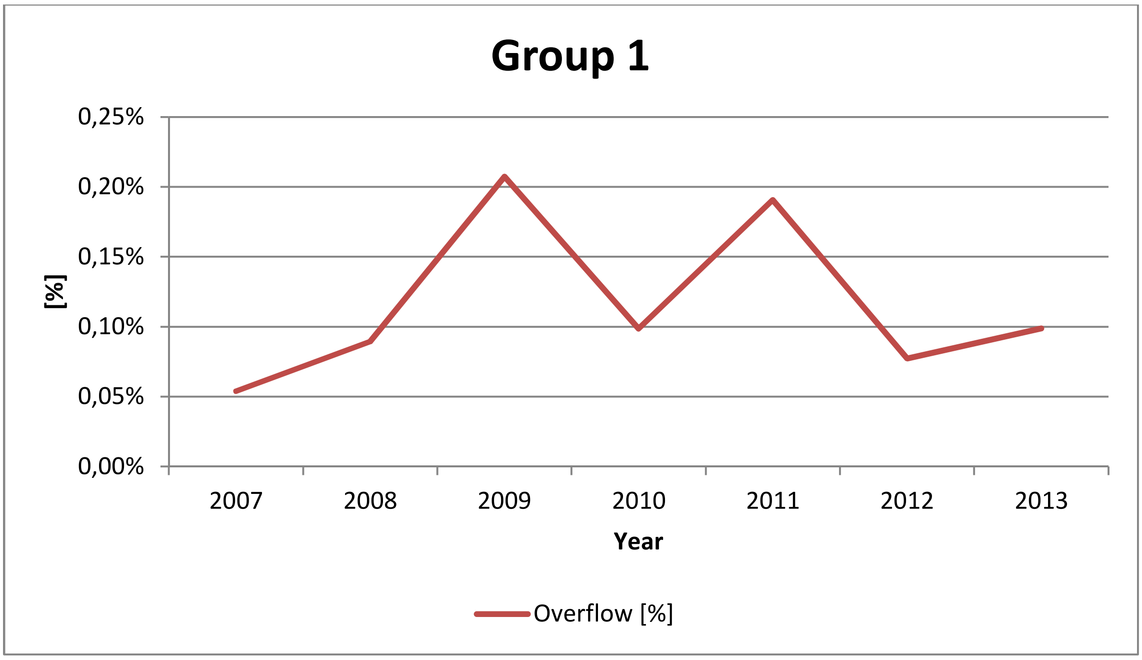


Figure 4: Group one.

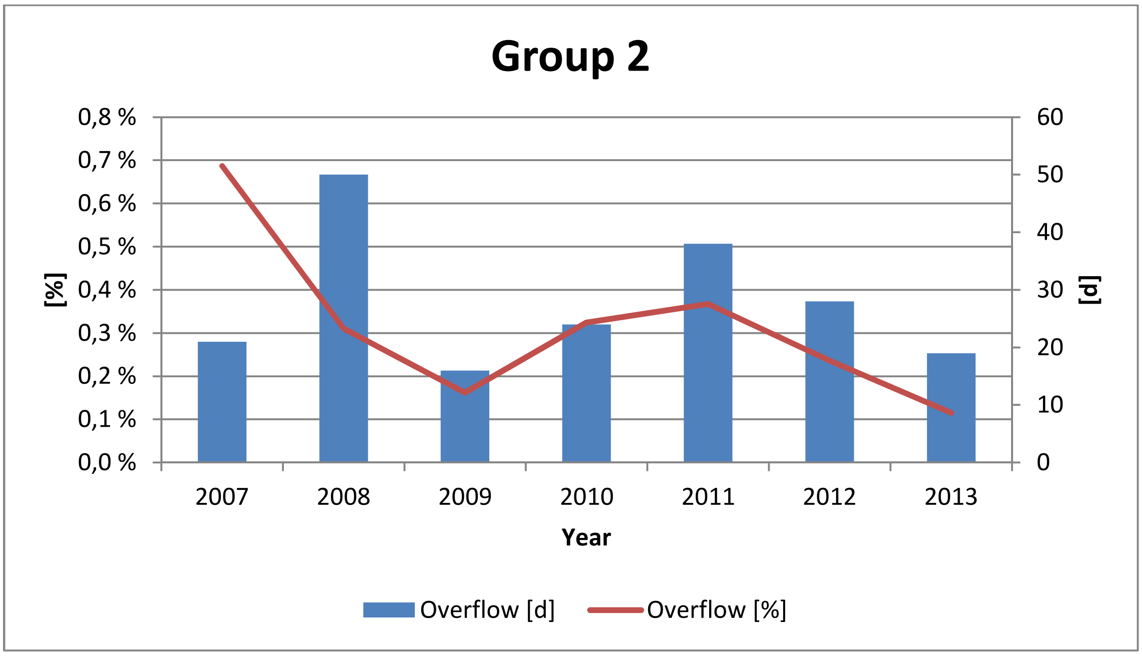


Figure 5: Group two.

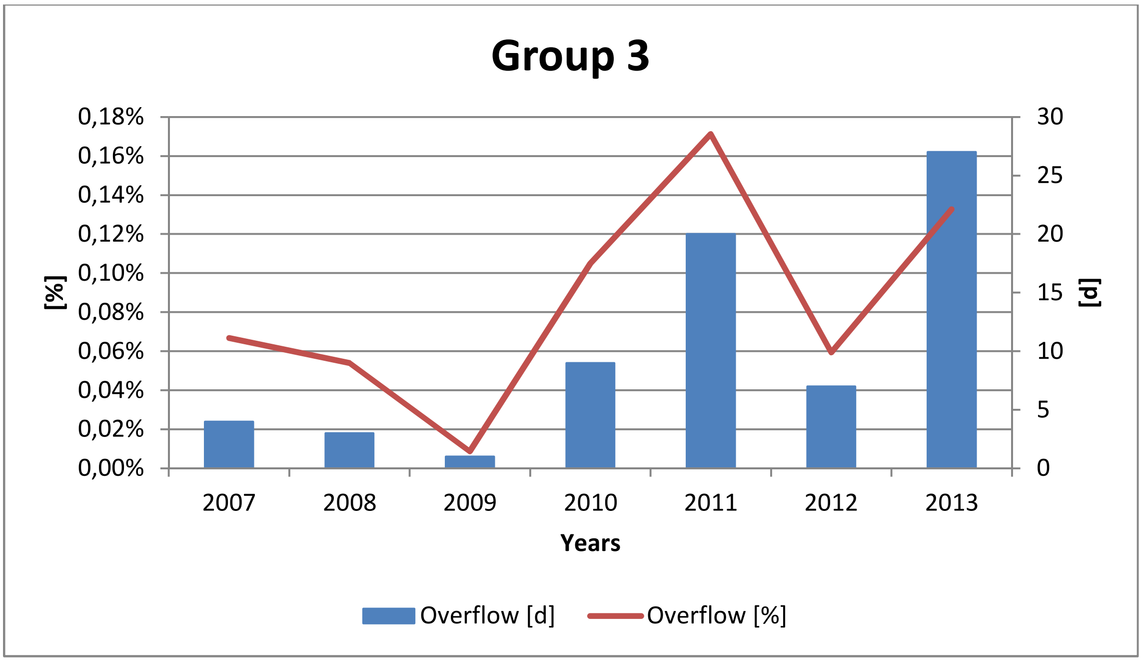


Figure 6: Group three.

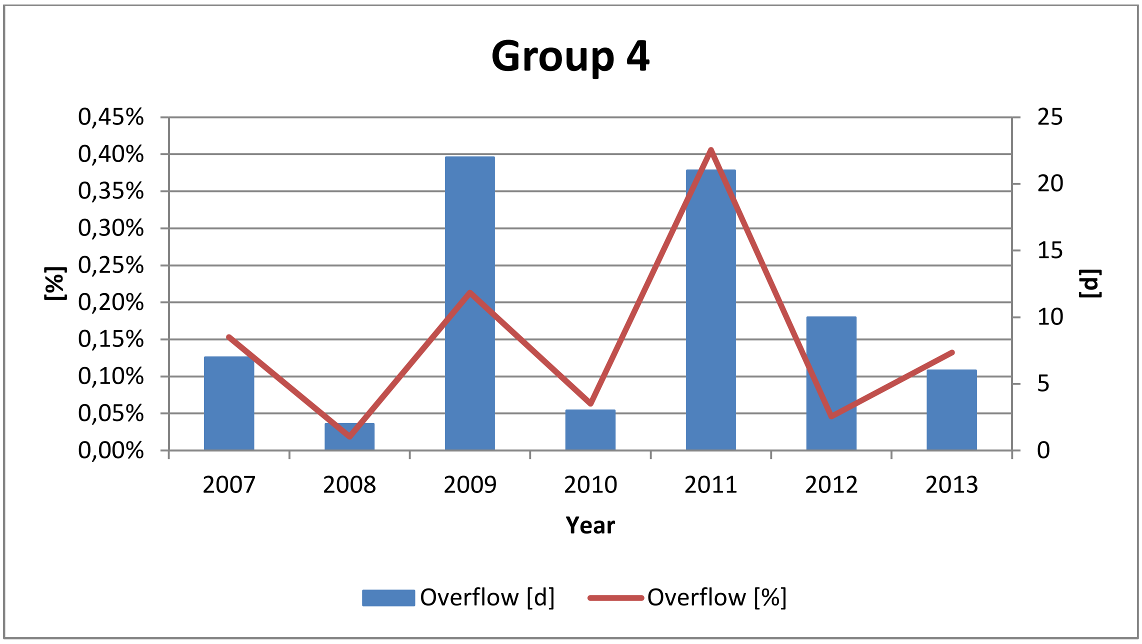


Figure 7: Group four.

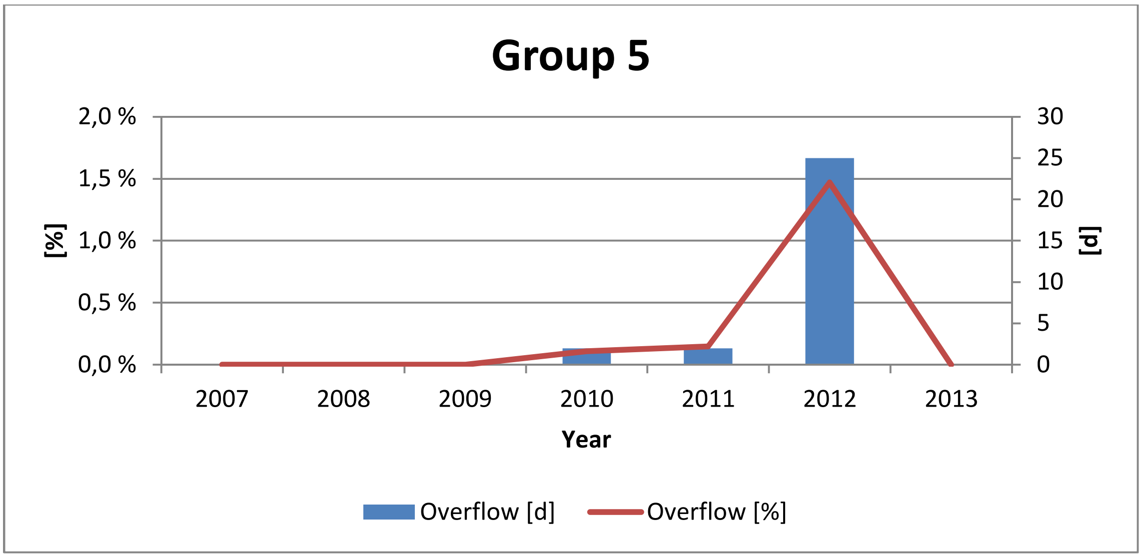


Figure 8: Group five.

4.3 Overflows of individual plants

After grouping, the plants were evaluated individually. The Figure 9 visualizes all the plants and their overflows in descending order; the figure also includes the number of days overflows occurred. The overflow average during the seven years was 0.18%; this was used to help determine how the plant functions in comparison to others. All the individual plots of the plants can be seen in Appendix 2.

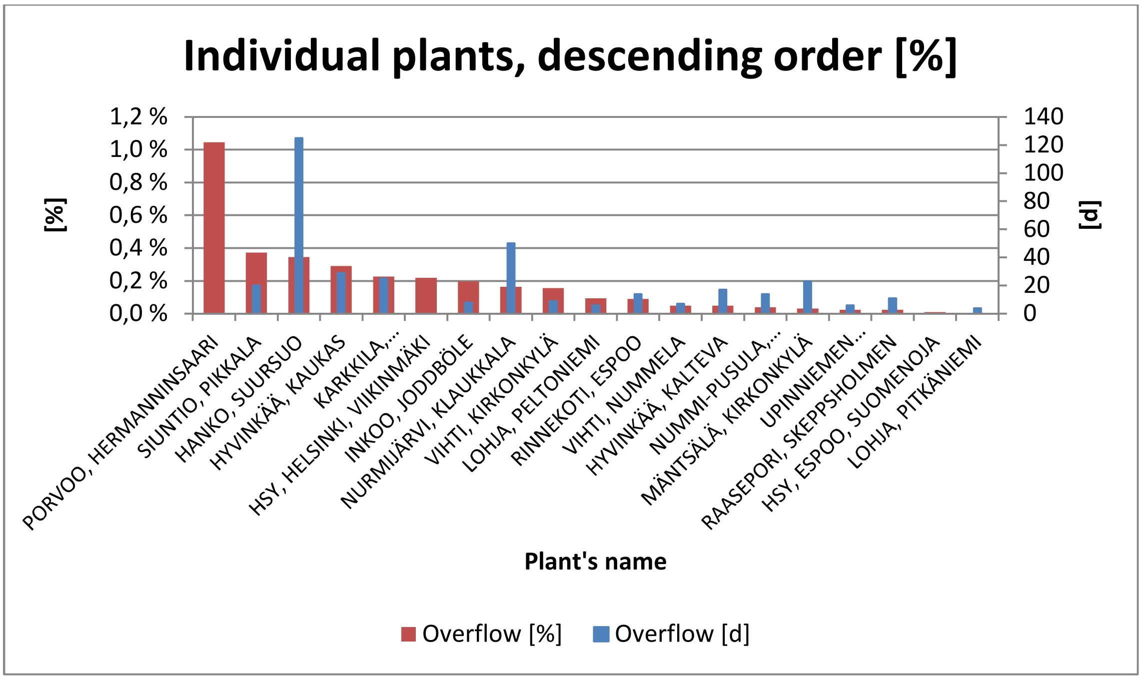


Figure 9: Individual plants performance in descending order.

Statistical approach was used to evaluate the individual performance of plants. The results can be seen from a ggbiplot in Figure 10. The values from 1 to 19 are the plants in same order as in table 3. In lay-man-terms, the values close to the x-axis presents plants that have overflows yearly, whereas the values far from the middle are plants that have had some significantly larger overflows in comparison to the average (0.18 %) at certain years. The length of the red arrow somewhat describes how much there have been overflows during the year, while the direction is determined by the variables; the closer a plant is to the year, it is likely that during that year the plant had its highest overflows.

However one must remember that all the previous is affected by the individual variables, thus everything cannot be visually determined. Outlier detection was used to point out six plants that have had highest overflows in a certain year. Outlier detection states the following plants: 3 (Porvoo, Hermanninsaari), 14 (Siuntio, Pikkala), 19 (Hyvinkää, Kaukas), 15 (Inkoo, Joddböle), 7 (Hanko, Suursuo), 17 (Rinnekoti, Espoo) and 13 (Vihti, Kirkonkylä).

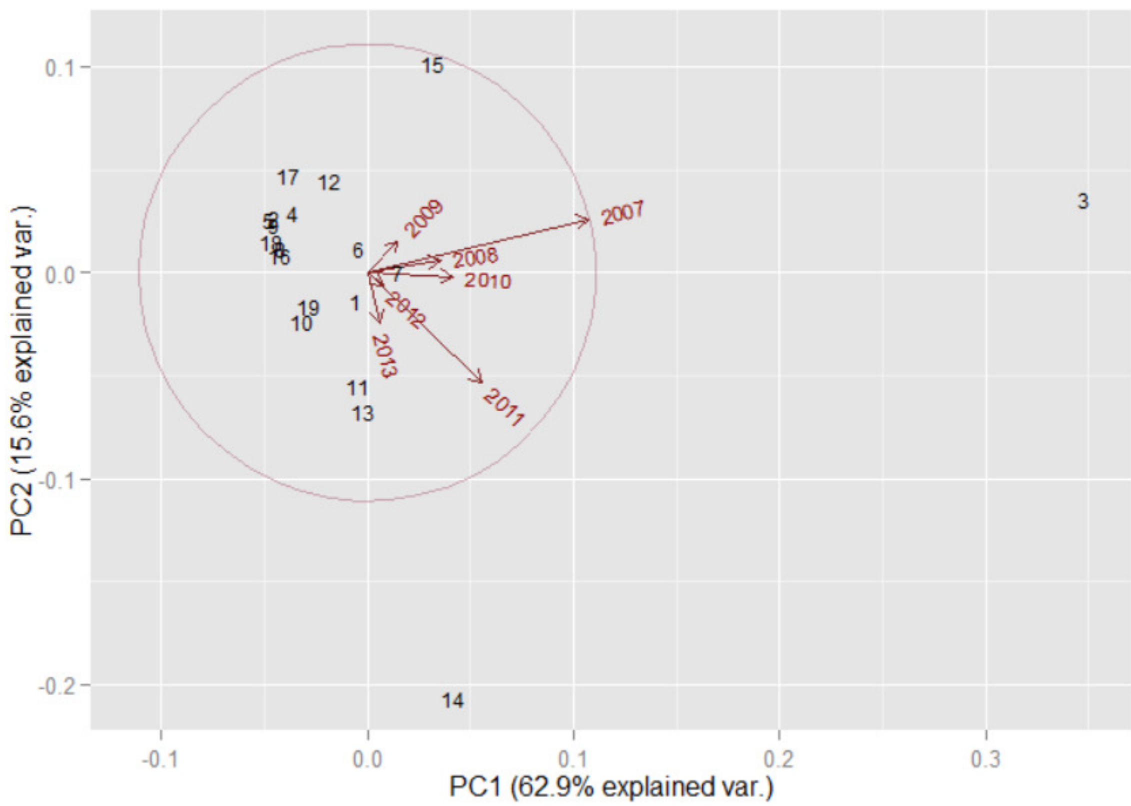


Figure 10: Ggbiplot of the individual plant’s performance.

4.4 Overflow amount distribution

The overflow amounts are presented with a distribution graph in Figure 11. It should be pointed out that the size classes, the bin limits, are not equal because the overflows are generally in the smaller end.

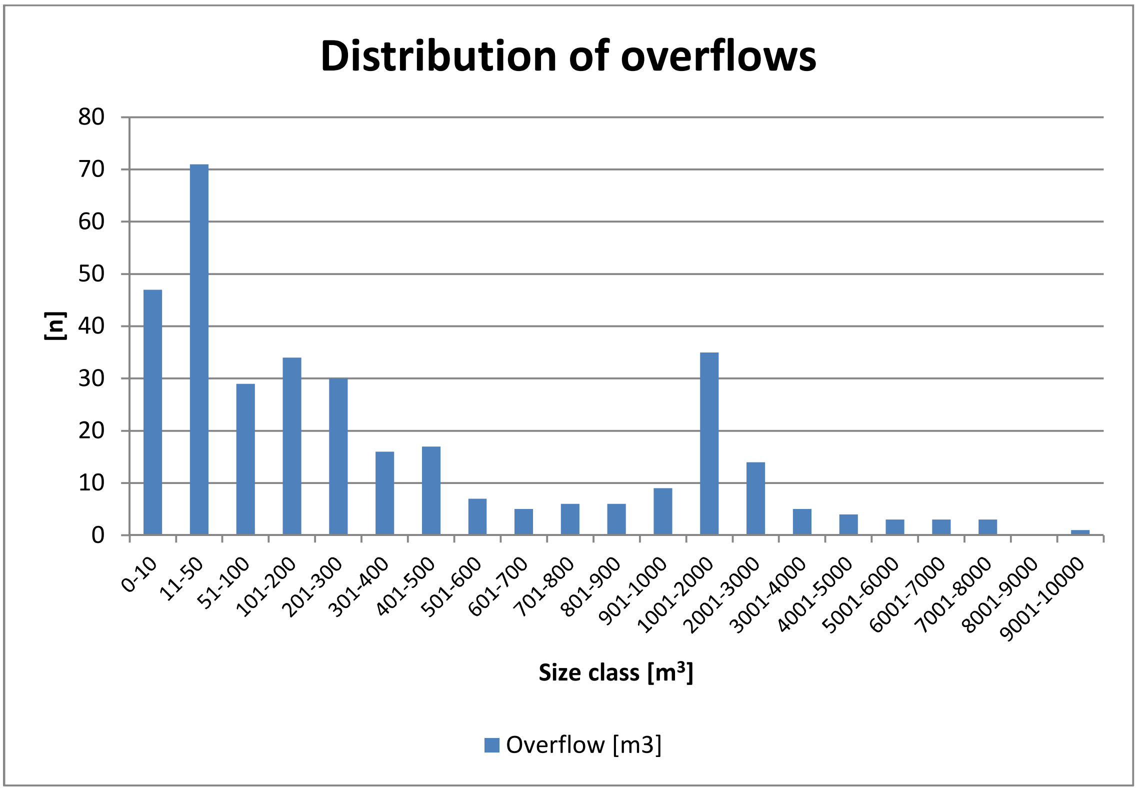


Figure 11: Distribution of overflows in cubic meters.

4.5 Overflow causes evaluation

The causes for overflows were found to be quite problematic to evaluate because for only a small proportion of the overflows a reason was given. No big changes were found in the any of the categories, as seen from Figure 12. As mentioned in methodology chapter, the other reasons category includes heavy rain, snow melting, storm, power failure and overflows that were mentioned separately in the report's text (or VAHTI/e-mail), but no reason was granted.

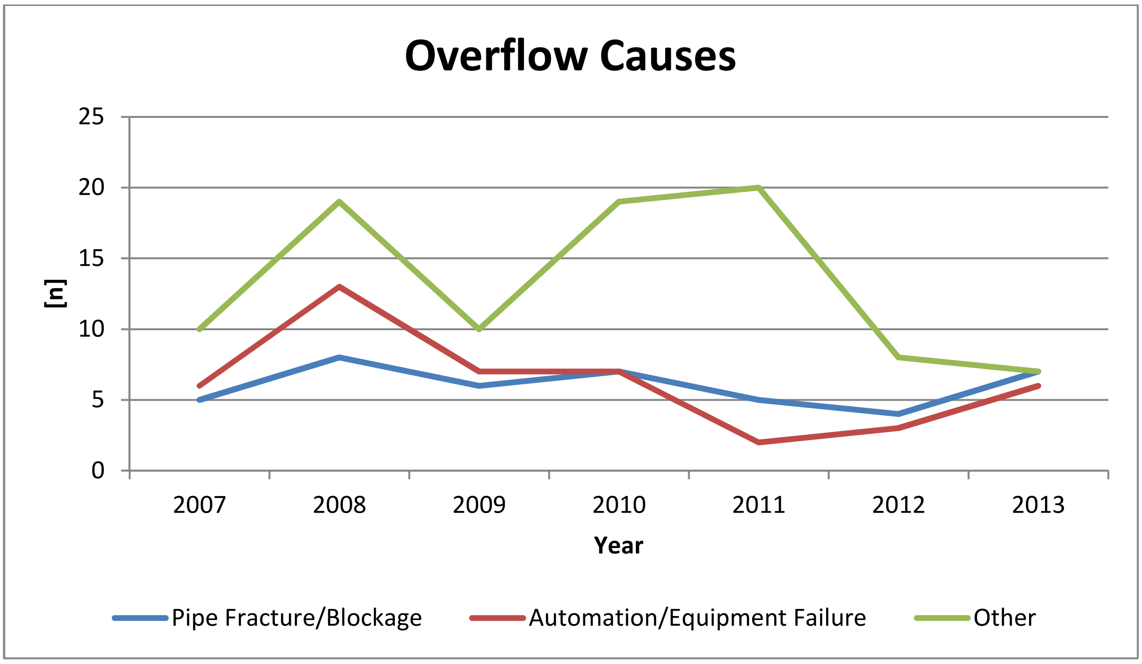


Figure 12: Overflow causes evaluation.

4.6 Effects of weather

The effects of weather were evaluated in two steps. Firstly, the amount of flow spikes was compared against the yearly flows. Both of the categories' years were weighted and placed into a descending order so that comparable results could be obtained. The results were assumed to be equal, and in this case they were; as seen from the Figure 13. In the step two the same method was used, but the flow spike's height, width and occurrence was compared against the overflow percentage. Once again here a similar trend was assumed to be seen, but there were a couple of differences found (Figure 14).

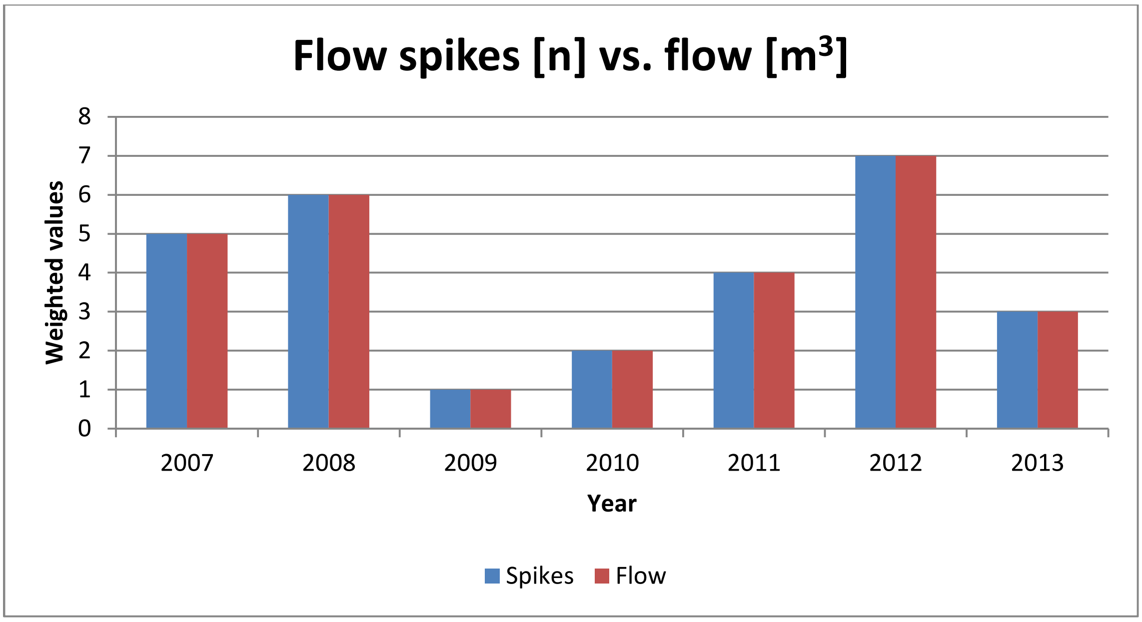


Figure 13: Amount of flow spikes versus flows.

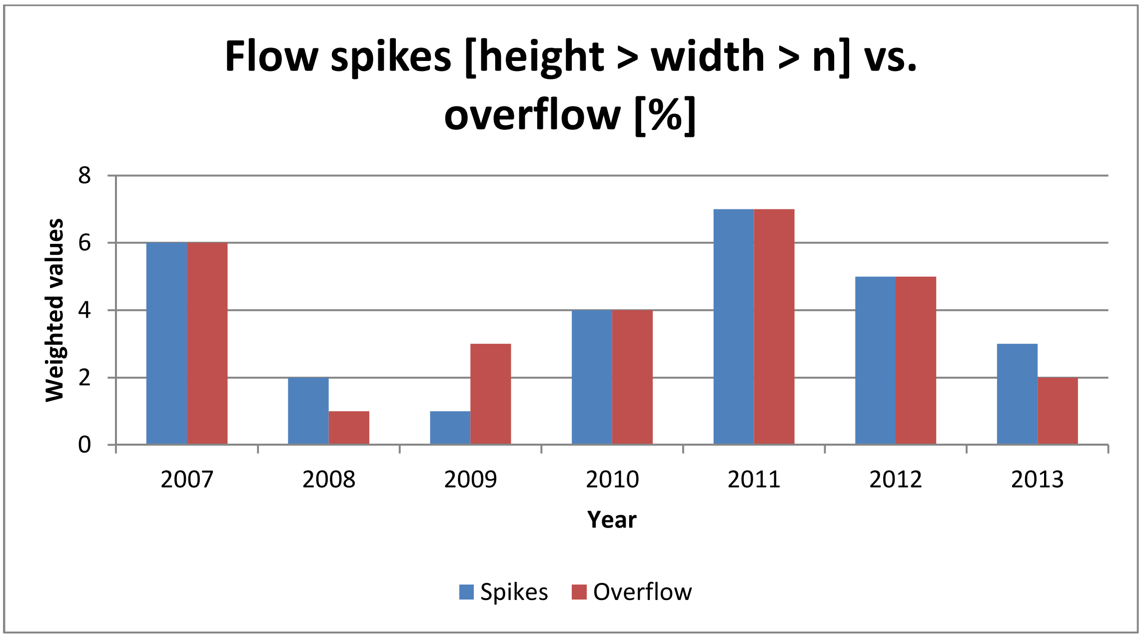


Figure 14: Overflow spike's height, width and amount versus overflow percentage.

4.7 Effects of the network's size

Size of the network was evaluated both in cubic meters as well as in percentages. These are illustrated in Figures 15 and 16 respectively. Figure 15 had to be scaled so that the high cubic meter values of the large plants do not flatten the line and make the other values unreadable.

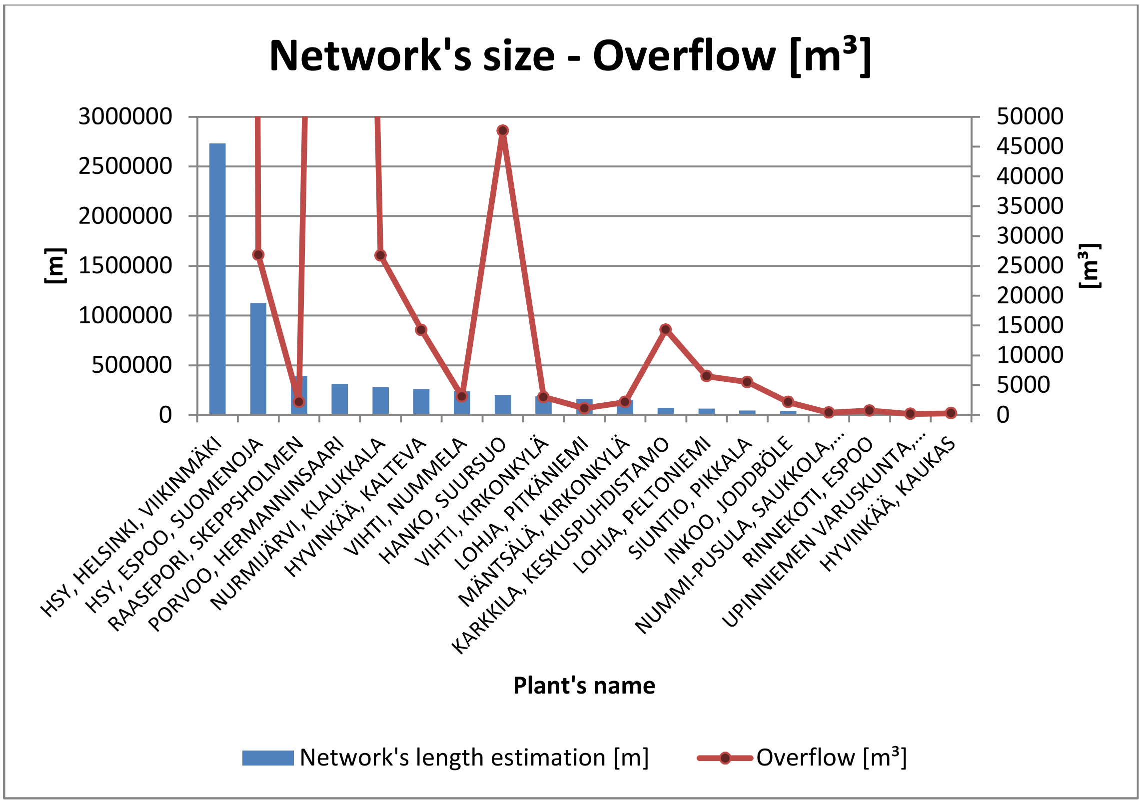


Figure 15: Network’s size and overflows in cubic meters.

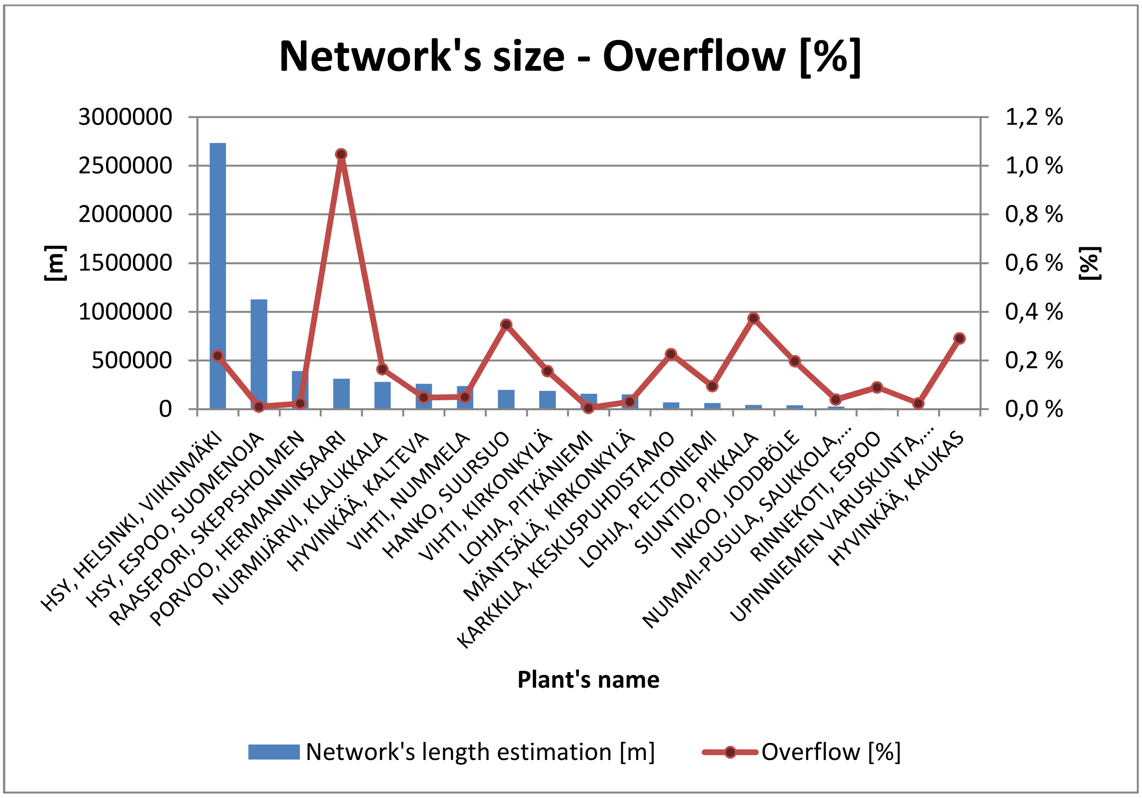


Figure 16: Network’s size and overflow percentages.

5 Discussion

The initial goal of the study was to estimate the cause, destination, and the quality and load of overflows, as well as determine the receiving water's sensitivity. However, it was realised quite early during the data harvesting that no sufficient details will be acquired because the reporting generally does not provide such information. Some of the reports did provide more specific details and some did not provide anything; additionally the style was completely different among many reports. Thus, it could be suggested that the plants should have a more uniform reporting style. There were significant differences found, especially in terminology, that could lead into misunderstanding, at least when reviewed by community. The reporting of the overflows should be more specific. The wrongly calculated values were first thought to be humane mistakes, but since those were often encountered it cannot be said for sure anymore. The wrong values can cause considerably different end results. Overall, in many cases it felt like the overflows and bypass information were not so thoroughly given.

Currently the bypasses and overflows are informed in a same sheet. The sheets works fine with the bypasses if properly filled because it defines where the bypasses happen, but it does not provide any specific information about the overflows, just the amount. Detailed reporting of the overflows would provide knowledge for the monitoring authorities as well as for the plant itself. More available data about the overflows would yield valuable information for the risk assessment and management, such as: are there frequently overflows at the same area and how to encounter them, the significance of the overflow area's terrestrial and aquatic environment and what typically causes the overflows. So, a separate report of the overflows would be advisable. Below a list of factors is presented that could be beneficial in the report form:

- Start and end day, and time
- Location of the spill (if possible: latitude and longitude)
- Volume, rate and dimension of the spill, and how was it estimated
- Volume of spill recovered
- Estimation of spill's load and quality (for example is there storm water mixed)
- At what part of the system the spill occurred (mainline, pump station etc.)
- What caused the spill and where did the failure occur
- Did the spill discharge to surface waters, storm drain and/or land; what was the volume and volume recovered in each

- Environmental values of receiving terrestrial and aquatic environment
- Any exposure pathways to public
- Final destination of the spill

It can be quite clearly said that there is not much overflows if the average is 0.18 % when only the plants are considered that have had overflows. Supported by the fact the overflows did not affect the treatment results. So if all 64 plants with sewer network were to be evaluated, the average would be really, really small. However, if there were no overflows it would be weird considering the size of the network and the fact that Uusimaa region wastewaters represents 25-30% of all Finland's load (Kangas 2014). Positive is that overflows in percentages did not follow an increasing trend, but when evaluating the days a minor proof for increase can be seen. Although, one must remember that the time period of seven years is not sufficient enough to make any solid conclusions.

Plants were also grouped by their flows; a total of five groups were formed. The grouping was made so that roughly the same size plants would belong into same group, to provide better comparability. This analysis was used to split the overall situation into smaller groups because the overall situation itself did not yield any trend. From the split it can be seen that group three has a slightly increasing trend, while group two has higher overflows every year in comparison to the average.

Individual evaluation shows differences between plants; some had only one to few overflows, whereas some had over-the-average overflows every year. Here important questions are faced: are water works doing their best in order to minimize and prevent overflows? Are there proper tools for the network management and for the locating of the problematic areas? If there were systematic risk assessment and evaluation method that provides an action programme, would that lead into to a more enhanced network management procedures and thus into reduction of overflows? This evaluation should be done for each network individually because they differ in equipment, size and age. Initially there were a thought, that should the networks be permitted and should the overflows be restricted. However, such restrictions and permits would not be allowed according to the current laws and even the Council Directive 86/278/EEC: if one consciously passes sewage to the environment it should be treated first. Authorities could restrict the overflows by for example assigning the plant to find and fix a problem that causes overflows to occur frequently in the same area.

From statistical perspective the outliers are not necessarily the plants that need to be focused on because some of those have only one year with high overflows, combined with a proper reason. Instead it could be more necessary to focus on the plants close to the x-axis and furthest to the right, the plants that have over the average overflows yearly.

Analyses show that the individual overflow amounts were mostly from the smaller half of the scale, majority of overflows being on the range from 11 to 50 m^3. For some this might be much and for some not. One must remember that it is the receiving area/water along with wastewater quality that determines the severity. If a lot of rainwater is mixed in the wastewater, the quality is clearly better although for some sensitive areas even few cubic meters can be serious.

Determination of overflow causes ended up being somewhat undetailed because for majority of the overflows no reason was given. However, usually it was the same plants that reported in more detailed way, which thus provided slightly more reliability to the analysis. From the plot, no clear trends can be determined for all the causes. It would have been interesting to determine the exact causes for overflows; to yield information what management procedures should be conducted.

Weather was analysed from the results of five different plants; chosen from locations to cover the area of Uusimaa region. Firstly, the flow spikes were calculated and the compared against the overall flows in Uusimaa. The results were identical. Secondly the flow spike's height and width were evaluated and compared against overflows to see if there is a connection. In the years 2007 and 2010-2012, the highest overflows were identical; however, in the last three remaining years they were not. To conclude, when evaluating the amount of flow spikes, i.e. how rainy the year was, it most likely will also predict how much there will be flows. The case with overflows is not so clear. It could be said wet weather flows do account for many overflows, but naturally it does not include other reasons for overflows and thus yields uncertainty. Although, since the wet weather flows accounts for majority of the overflows, more enhanced wet weather flow mitigation systems could be suggested.

When it comes to network size and overflows, it can be generally thought that the longer the network is, the more there is overflows. However, from the plots it can be seen that it is not the case in Uusimaa region, neither in cubic meters nor percentages.

When comparing the same sized networks against each other, it could identify the networks that need more management, repairs and/or rehabilitation. Another interesting point is that when comparing the initial order of plants, in terms of yearly flows, with the plant order in network size, it can be seen that the orders are not equal. This on the other hand might provide information about capacity problems, if the plant differs from the order and is having troubles with overflow mitigation. For example, Raasepori, Skeppsholmen, has third largest network but is having eight largest flows, whereas Porvoo, Hermanninsaari has fourth largest network and is having third largest flows.

As a final note, it can be seen from the Appendix 1 that Myrskylä, Kirkonkylä had an overflow of three cubic meters. The situation occurred in 2010 when abundant melting waters caused a river to flood. The river water ended up in the drains and caused this three cubic meter spill to occur from a stationary pumping station. This value was left out due to very highly water mixed sewage and the fact that the overflow of the plant would have only been 0.00063 % during the years 2007-2013.

6 Conclusions

Reporting of sewer system overflows is something that could be improved to yield better understanding and to provide possibilities for improvements. Same requirements for reporting and terminology should be set so that the plants would have uniform reporting style to mitigate possible misunderstandings. Overall the amount of overflows in Uusimaa region is fairly low and no increase can be detected; although the timespan of sever years is not sufficient for conclusions. Additionally, the amounts of individual spills were typically small. However, there were clear differences between plants and by having limits for allowable overflows, the differences might even.

The causes for overflows were mostly due to wet weather flows and thus more wet weather flow mitigation technologies should be considered to be adapted. Even though the wetness of the year determines how much there will be flows, it will not provide very precise information how many overflows there will be because the wet weather flows could be evenly distributed throughout the year and thus result into absence of high flow spikes. It was also pointed out that the length of the network does not mean that the longer the network is, the more overflows there are; even a much smaller network could have higher overflows than a clearly longer one.

References

Ahmed, S.S. (2014). *Evaluation of Different Wastewater Treatment Processes and Development of a Modified Attached Growth Bioreactor as a Decentralized Approach for Small Communities*. Available at: http://www.slideshare.net/shhhoaib/different-wastewater-treatment-processes-and-development. Last accessed 15 April 2015.

Akpor, O.B., Muchie, B. (2013). *Environmental and public health implications of wastewater quality*. African Journal of Biotechnology, 10(13).

Baker, R. (2004). *Management of Combined Sewer Overflows*. Available at: http://home.eng.iastate.edu/~tge/ce421-521/Baker.pdf. Last accessed 12 March 2015.

Bastian, R.K. 1997. Potential Impacts on Receiving Waters. Effects of Water Development and Management on Aquatic Ecosystems. Proceedings of an Engineering Foundation Conference. L.A. Roesner, ed. American Society of Civil Engineers. New York, NY.

Beer, T., Ziolkowski, F. (1995). Environmental Risk Assessment: An Australian Perspective, Report No. 102, Supervising Scientist, Barton, Canberra.

Brombach, H., Weiss, G., Fuchs, S. (2005). *A new database on urban runoff pollution: comparison of separate and combined sewer systems*. Wat. Sci. Tech., 51, (2). pp. 119-128.

Buchanan, J.R. (2010). *Cost of Decentralized Unit Processes.* pp. 45-55. Available at: http://ndwrcdp.werf.org/documents/DEC2R08/DEC2R08web.pdf. Last accessed 25 February 2015.

Burgman, MA (2005). *Environmental Risk and Decision Analysis: For Conservation and Natural Resource Management*. Cambridge University Press, London.

Cain, J. (2001). *Planning improvements in natural resources management*. Centre for Ecology & Hydrology: Wallingford, UK.

Calow, P., Forbes, V.E. (2003). *Does ecotoxicology inform ecological risk assessment?* Environ. Sci. Tech. 37: pp. 146-151.

City of Sultan (2011). *General Sewer Plan: Chapter 4 - Wastewater Characteristics*. Available at: http://ci.sultan.wa.us/wp-content/uploads/City_Hall/City_Departments/Community_Development/Long_Range_Planning/Draft_GSP_Chapters-Agency_Review_Version/Appendix_I-Chapter_4_of_the_WWTP_Engineering_Rep. Last accessed 15 April 2015.

Clark, J.S. (2005). *Why environmental scientists are becoming Bayesians*. Ecological Letters 8: pp. 2-14.

Delft University of Technology (2015). *Wastewater Treatment*. Available at: https://courses.edx.org/c4x/DelftX/CTB3365x/asset/Wastewater_Lecture_Note.pdf. Last accessed 15 April 2015.

Delzingaro M.J. (2006). *There's No Use Crying Over Spilled Sewage: Using Standby Lift Station Pumps to Prevent SSOs before They Happen*. pp. 1-3. Available at: http://www.environmental-expert.com/Files%5C5306%5Carticles%5C8984%5C168.pdf. Last accessed 14 March 2015.

Droste, R.L., Hartt, J.P. (1975). *Quality and variation of pollutant loads in urban storm water runoff.* Cdn J Civ Eng; 2: pp. 418-429.

ELY-Keskus (2015a). *Centre for Economic Development, Transport and the Environment*. Available at: http://www.ely-keskus.fi/en/web/ely-en/. Last accessed 5 April 2015.

ELY-Keskus (2015b). *Centre for Economic Development, Transport and the Environment.* Available at: http://www.ely-keskus.fi/en/web/ely-en/yleista. Last accessed 5 April 2015.

EPA Victoria (2009). *Guidelines for Risk Assessment of Wastewater Discharges to Waterways*. Publication 1287, July 2009.

EUR-Lex (1999). *61997J0293*. Available at: http://eur-lex.europa.eu/legal-content/FI/TXT/?uri=CELEX:61997CJ0293. Last accessed 15 April 2015.

EUR-Lex (2004). *52004DC0248*. Available at: http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:52004DC0248. Last accessed 15 April 2015.

Field, R., Struzeski E.J. (1972). *Management and Control of Combined-sewer Overflows*. Journal Water Pollution Control Federation, 44 (7). pp. 1393-1415.

Field, R., Turkeltaub R. (1981). *Urban Runoff Receiving Water Impacts: Program Overview*. Journal of the Environmental Engineering Division, EE1, February. pp. 83-100.

Field, R., Villeneuve, E., Stinson, M. K., Jolicoeur, N., Pleau, M., Lavallee, P. (2000). "Implementing real-time control schemes offers combined sewer overflow control for complex urban collection systems." Water Environment and Technology, 12(4), pp. 64-68.

Frost, R.C. (2009). *EU Practice in setting wastewater emission limit values*. Available at: http://www.wgw.org.ua/publications/ELV%20-%20EU%20practice.pdf. Last accessed 14 April 2015.

Grigg, N.S. 2003. *Water, Wastewater and Stormwater Infrastructure Management*. Lewis Publishers: CRC Press, Boca Raton FL, ISBN 1-56670-573-8.

GSI (2015). *One off housing wastewater*. Available at: http://www.gsi.ie/Programmes/Groundwater/Projects/One+off+housing+wastewater.htm. Last accessed 15 April 2015.

Hart, B., Burgman, M., Webb, A., Allison, G., Chapman, M., Duivenvoorden, L., Feehan, P., Grace, M., Lund, M., Pollino, C., Carey, J., McCrea A., 2005. *Ecological Risk Management Framework for the Irrigation Industry*. Report to the National Program for Sustainable Irrigation (NPSI) by Water Studies Centre: Monash University, Clayton, Australia.

Hayes, K.R. (2002). *Identifying hazards in complex ecological systems. Part 1: fault-tree analysis for biological invasions*. Biol. Invasions 4: pp. 235-249.

Hughes, J.B. (2002). Manhole Inspection and Rehabilitation, Pipelines 2002 - Beneath Our Feet: Challenges and Solutions. ASCE, Reston VA

Insituform (2015). *Installation Method*. Available at: http://www.insituform.com/Water-Rehabilitation/InsituMain/InstallationMethod.aspx. Last accessed 5 April 2015.

Kamal S., Azhari, N.N., Abdul-Talib S. (2014*), Bio-Precipitation of Zn (II) from Municipal Wastewater Spiked with Zinc*, Journal of Research & Developments in Chemistry, Vol. 2014.

Kangas, A. (2014). *Viemäriverkoston ylivuodot - Selvitys Uudenmaan ELY-Keskuksen alueella*. Presentation. Helsinki.

Kela (2015). Uusimaa. Available at: http://www.kela.fi/orh-uusimaa. Last accessed 24 March 2015.

Leonard B. (1991). *Alternative Wastewater Collection Systems.* Darby, PA, U.S.A: Diane Publishing Co. pp. 3-6.

Luo, H., Li, M., Xu, R., Fu, X., Huang, G., Huang, X. (2012). *Pollution characteristics of urban surface runoff in a street community*. Sustain. Environ. Res. 22 (9), pp. 61-68.

MMM (2015). Frontpage. Available at: http://www.mmm.fi/en/index/frontpage.html. Last accessed 5 April 2015.

Muenchmeyer, G. (2007). *Performance Specification Guideline for the Renovation of Manholes Structures*. NASSCO, Inc.: Owings Mills, MD.

NEIWPCC (2003). *Optimizing Operation, Maintenance, and Rehabilitation of Sanitary Sewer Collection Systems*. Available at: http://www.mass.gov/eea/docs/dep/water/laws/i-thru-z/omrguide.pdf. Last accessed 23 March 2015.

NJDEP (2004): New Jersey Stormwater Best Management Practices Manual: Appendix C – Sample Municipal Stormwater Management Plan. New Jersey. Available at: http://www.njstormwater.org/tier_A/pdf/NJ_SWBMP_C.pdf. Last accessed 11 April 2015.

Novotny, V., Olem, H. (1994). *Water Quality: Prevention, Identification and Management of Diffuse Pollution*. Van Nostrand Reinhold. New York, NY.

NRMMC (2005). *Guidelines for sewerage systems: sewerage system overflows*. Canberra, A.C.T: Natural Resource Management Ministerial Council.

Lijklema, L., Tyson J.M. (1993). *Urban Water Quality: Interactions between Sewers, Treatment Plants, and Receiving Waters*. Water Science and Technology. 27(5). pp. 29-33.

Pavlik, F. (2003). *Remote Monitoring of Sewage Pump Stations*. Available at: http://www.wwdmag.com/automation/remote-monitoring-sewage-pump-stations. Last accessed 10 April 2015.

Pitt, R. Maestre, A., Morquecho R. (2003). The National Stormwater Quality Database (NSQD, version 1.0). Water Environment Federation Technical Exposition and Conference, Los Angeles. October.

Pleau, M., Pelletier, G., Meunier, C., Bonin, R. (2000). *Real-time control for CSO management: Quebec urban community system start-up*, Proceedings of the 29th annual WEAO Technical Symposium and OPCEA Exhibition, Hamilton, Canada.

Quist, G.M., Drake, D., Davisson, C., Wasko, D. (2008). *Improved Collection System Operations and Spill Prevention using Remote Wireless Real-Time Monitoring*. Available at: http://www.mysmartcover.com/Documents/WEFTEC_Paper_2008.pdf. Last accessed 10 April 2015.

R Project (2015). *The R Project for Statistical Computing*. Available at: http://www.r-project.org/. Last accessed 26 March 2015.

Ragsdale F. (n.d.). *Wastewater System Operator's Manual*. Chapter 13. Available at: http://www.ragsdaleandassociates.com/js2524/index.php/tmats/wastewater-system-operator-s-manual. Last accessed 25 February 2015.

Read G.F., Vickridge, I. (1997). *Sewers: Repair and Renovation*. Elsevier Butterworth-Heinemann: Oxford, UK.

Read, G.F. (2004). *Sewers: Replacement and New Construction*. Elsevier Butterworth-Heinemann: Oxford, UK, ISBN 0-7506-5083-4

Regan, H.M., Colyvan, M., Burgman, M.A. (2002). *A taxonomy and treatment of uncertainty for ecology and conservation biology*. Ecological Applications 12: pp. 618-628.

RELINEEUROPE (2015). *UV curing systems*. Available at: http://relineeurope.com/en/equipment/uv_curing_systems/uv_curing_systems_index.php. Last accessed 5 April 2015.

Ruggaber, T.P., Talley, J.W. (2005). Detection and Control of Combined Sewer Overflow Events Using Embedded Sensor Network Technology. Proceedings of the World Environmental and Water Resources Congress, Anchorage, AK.

Ruggaber, T.P. (2006). Detection and Control of Combined Sewer Overflows Using a Distributed Wireless Embedded Network and the In Situ Treatment of Wastewater Using Enzymatic Processes and Hydrogen Peroxide. Notre Dame, Indiana: Master's Thesis. pp. 8-13.

Ruggaber, T.P., Talley, J.W., Montestruque, L.A. (2006). *Using embedded sensor networks to monitor, control, and reduce CSO events: A pilot study*. Environmental Engineering Science. Submitted.

SAS (2015). *Biplots*. Available at: http://support.sas.com/documentation/cdl/en/imlsug/62558/HTML/default/viewer.htm#ugmultpca_sect2.htm. Last accessed 26 March 2015.

Schütze, M., Campisano, A., Colas, H., Schilling, W., Van Rolleghem, P.A. (2002). *Real-time control of urban wastewater systems - where do we stand today?* Proceedings of the Ninth International Conference on Urban Drainage, Portland, pp. 1-17.

Smullen, J.T., Shallcross, A.L., Cave, K.A. (1999). Updating the US nationwide urban runoff quality data base. Water Sci. Technol., 39(12), 9-16.

Solomon, K., Giesy, J., Jones, P. (2000). *Probabilistic risk assessment of agrochemicals in the environment*. Crop Protection 19: pp. 649-655.

Statgen (2007). *Introduction to Principal Components and Factor Analysis*. Available at: ftp://statgen.ncsu.edu/pub/thorne/molevoclass/AtchleyOct19.pdf. Last accessed 26 March 2015.

Statsoft (2015). How to Reduce Number of Variables and Detect Relationships, Principal Components and Factor Analysis. Available at: http://www.statsoft.com/textbook/principal-components-factor-analysis. Last accessed 26 March 2015.

Stein, D. (2001). *Rehabilitation and Maintenance of Drains and Sewers*. Ernst & Sohn, Germany.

Stein, D. (2005). *Trenchless Technology for Installation of Cables and Pipelines*. Stein & Partner, Germany.

Stewart, M.G., Melchers, R. E. (1997). *Probabilistic Risk Assessment of Engineering Systems*. Chapman & Hall, London.

Stoianov, I., Nachman, L., Whittle, A., Madden, S., Kling, R. (2006). *Sensor networks for monitoring water supply and sewer systems: lessons from Boston*. Proceedings of the 8th Annual Water Distribution Systems Analysis Symposium, pp. 1–6.

Strandberg, T., Hedmark, P., Held, H., Ström A. (2010). *PSS Handbook*. Sundbyberg, Sweden: ITT Water & Wastewater AB. pp. 2-10.

Suter, G.W. (1993). *Ecological Risk Assessment*. Lewis Publishers: Chelsea MI.

Taavitsainen VM. (2011). *Introduction to multivariate data analysis*. Course material.

UNEP (2002). *International Source Book On Environmentally Sound Technologies for Wastewater and Stormwater Management.* Available at: http://www.unep.or.jp/Ietc/Publications/TechPublications/TechPub-15/main_index.asp. Last accessed 25 February 2015.

U.S. EPA (n.d.). *Combined Sewer Overflow (CSO)*. pp. 2-6. Available at: http://www.epa.gov/nrmrl/wswrd/wq/stormwater/cso.pdf. Last accessed 12 March 2015.

U.S. EPA (1983). *Results of the Nationwide Urban Runoff Program*. Water Planning Division, PB 84-185552, Washington, D.C.

U.S. EPA (1998). *Guidelines for Ecological Risk Assessment*. Report No. EPA/630/R95/002F, U.S. EPA, Washington, DC.

U.S. EPA (1999a). *Combined Sewer Overflow Management Fact Sheet: Sewer Separation*, *EPA 832-F-99-041*. Office of Water: Washington, DC. pp. 1-5.

U.S. EPA (1999b). Collection Systems O&M Fact Sheet: Sewer Cleaning and Inspection. Washington, D.C..

U.S. EPA (1999c). *Preliminary Data Summary of Urban Storm Water Best Management Practices*. U.S. Environmental Protection Agency. EPA-821-R-99-012.

U.S. EPA (2001). *National Research Needs Conference Proceedings: Risk-based Decision-making for Onsite Wastewater Treatment*. EPRI, Palo Alto, CA, US: Environmental Protection Agency and National Decentralised Water Resources Capacity Development Project: 1001446.

U.S. EPA (2002a). *Wastewater Technology Fact Sheet: Sewers, Conventional Gravity.* pp. 1-2. Available at: http://water.epa.gov/scitech/wastetech/upload/2002_10_15_mtb_congrasew.pdf. Last accessed 24 February 2015.

U.S. EPA (2002b). *Wastewater Technology Fact Sheet: Sewers, Pressure.* pp. 1-4. Available at: http://water.epa.gov/scitech/wastetech/upload/2002_10_15_mtb_presewer.pdf. Last accessed 24 February 2015.

U.S. EPA (2006) *Real Time Control of Urban Drainage Networks*. (Ed, EPA's Office of Research and Development): United State Environment Protection Agency, Washington, p. 96.

U.S. EPA (2009). *State of technology review report on rehabilitation of wastewater collection and water distribution systems*. Office of Research and Development: Cincinnati, OH, EPA/600/R-09/048.

U.S. EPA (2012). *Stormwater Management Best Practices*. Available at: http://www.epa.gov/greeningepa/stormwater/best_practices.htm. Last accessed 11 April 2015.

US EPA (2014). *Greening CSO Plans: Planning and Modelling Green Infrastructure for Combined Sewer Overflow (CSO) Control*. EPA-832-R-14-001. Washington, D.C.

Vélez, C., Lobbrecht, A., Price, R., Mynett, A. (2008) *Optimization of Urban Wastewater Systems using Model Based Design and Control*. In 11th International Conference on Urban Drainage Edinburgh, Scotland, UK.

Vose, D. (2000). Risk Analysis: A Quantitative Guide, John Wiley & Sons, Chichester.

Water Agencies' Standards (2004). *Design Guidelines for Water and Sewer Facilities*. pp. 1-2. Available at: http://www.sdwas.com/Documents/Vol1/Section6/6.2_SewerManholes&Cleanouts.pdf. Last accessed 14 March 2015.

Weibel, S.R. (1969). *Urban Drainage as a Factors in Eutrophication. In: Eutrophication: Causes, Consequences, Correctives*. National Academy of Science, Washington, D.C. pp. 383-403.

Welker, A. (2008). Emissions of pollutant loads from combined sewer systems and separate sewer systems – which sewer system is better?. Proc. of the 11th International Conference on Urban Drainage: Edinburgh, Scotland, UK. p. 8.

WUTAP (2007). *Wastewater Systems Operator Certification Study Manual*. Available at: http://www.nmrwa.org/sites/nmrwa.org/files/WastewaterOperatorStudyManual.pdf. Last accessed 14 March 2015.

Wooldridge, S. (2003). *Bayesian Belief Networks*. Centre for Complex System Science: CSIRO, Canberra.

WVDEP (2012). *Stormwater Management Structure Guidance Document*. Available at: http://www.dep.wv.gov/WWE/Programs/gw/Documents/14469_gw_Stormwater_Management_Structure_Guidance_Combined.pdf. Last accessed 11 April 2015.

Ympäristö (2013a). *Valvonta- ja kuormitustietojärjestelmä (VAHTI) - ohjeita tiedontuottajille*. Available at: http://www.ymparisto.fi/fi-FI/Kartat_ja_tilastot/Tietojarjestelmat/Valvonta_ja_kuormitustietojarjestelma_VA%2826252%29. Last accessed 22 March 2015.

Ympäristö (2013b). *Vesihuoltolaitostietojärjestelmä (VELVET) - ohjeita tiedontuottajille*. Available at: http://www.ymparisto.fi/fi-FI/Kartat_ja_tilastot/Tietojarjestelmat/Vesihuoltolaitostietojarjestelma_VELVET_%2826132%29. Last accessed 22 March 2015.

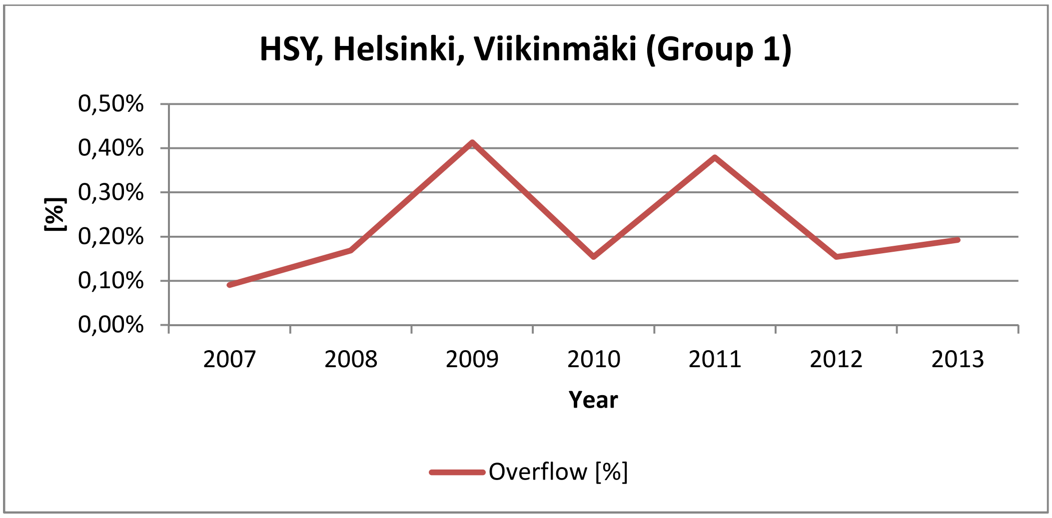
List of all the plants

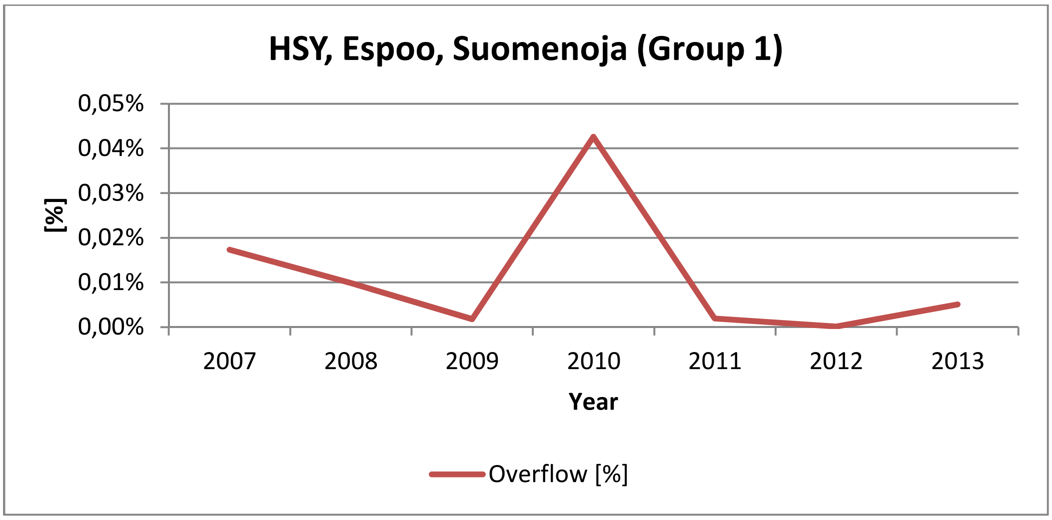
All results are displayed in m^3, and the values are from the years 2007-2013. The possible date after plant describes when the plant went out of business.

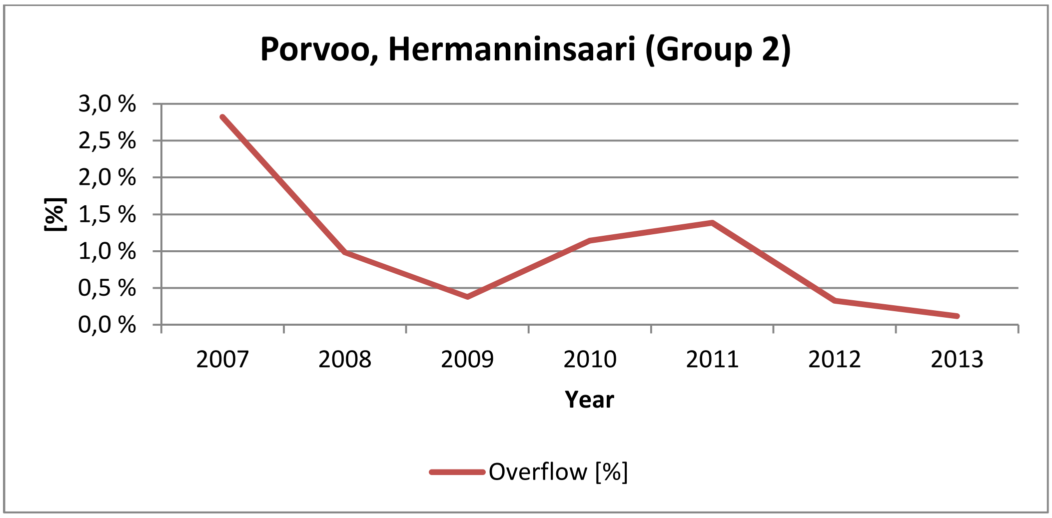
Plant's name	Flow	Overflow	Bypass
HSY, Viikinmäki	711779987	1556968	6246391
HSY, Suomenoja	248491363	26844	0
Porvoo, Hermansö	31671485	331344	596711
Hyvinkää, Kalteva	29446457	14268	829
Lohja, Pitkäniemi	21643256	1125	3972
Nurmijärvi, Klaukkala	16365414	26749	28223
Hanko, Suursuo	13896246	47658	58000
Raasepori, Karjaa-Pohja	10902706	NA	NA
Raasepori, Skeppsholmen	9480213	2172	6670
Loviisa, Vårdö	9133948	0	87906
Mäntsälä, Kirkonkylä	7084070	2178	31400
Lohja, Peltoniemi	6880031	6500	0
Karkkila, Keskuspuhdistamo	6326799	14312	12546
Vihti, Nummela	6142727	3069	0
Nurmijärvi, Kirkonkylä	4941745	0	46764
Vihti, Kirkonkylä	1920258	3000	0
Siuntio, Pikkala	1479138	5524	722
Inkoo, Joddböle	1106810	2174	0
Nummi-Pusula, Saukkola, 2.7.2013	1003942	397	0
Karjalohja, Kirkonkylä, 8.7.2013	857567	0	3052
Rinnekoti, Espoo	836230	750	0
Upinniemen varuskunta, Kirkkonummi	751681	180	1990
Lapinjärvi, Kirkonkylä	697406	0	2996
Hanko, Lappohja, 31.12.2012	492305	0	5860
Porvoo, Hinthaara	483739	0	11048
Myrskylä, Kirkonkylä	477713	3	7414
Raasepori, Mustio	466272	0	1134
Loviisa, Koskenkylä	384036	0	0
Loviisa, Liljendal	375124	0	0
Lapinjärvi, Porlammi	340684	0	988
Lohja, Sammatti, 3.6.2013	316903	0	0
Pukkila, Kirkonkylä, 24.4.2013	303059	0	14437
Loviisa, Pernaja	284041	0	0
Loviisa, Isnäs	207213	0	0
Porvoo, Epoo	190673	0	8
Meltolan sairaala, Raasepori	146024	0	551
Lapinjärvi, Sjökulta	103866	0	0
Hyvinkää, Kaukas	97459	283	0

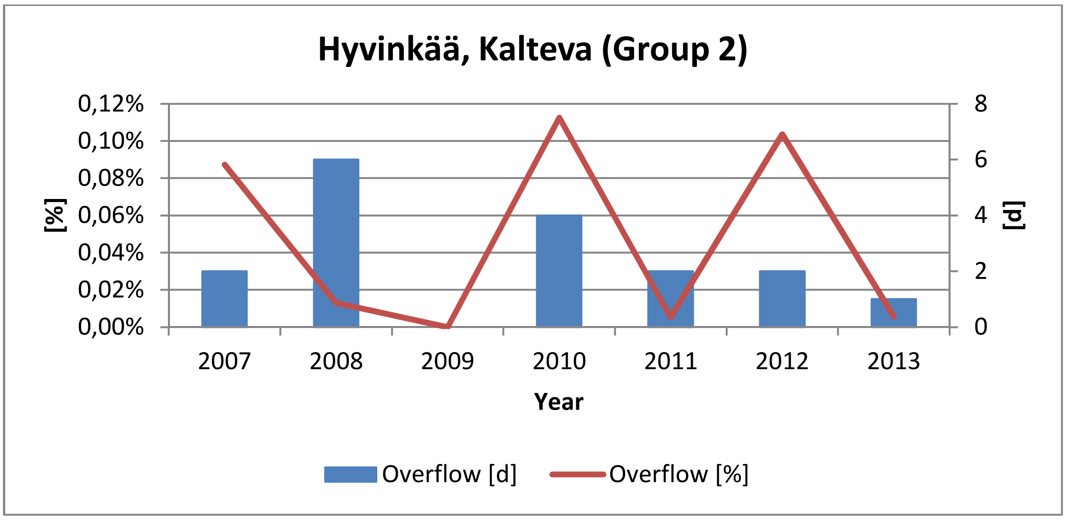
Plant's name	Flow	Overflow	Bypass
Ammatiopisto, Mäntsälä	81420	0	0
Porvoo, Kerkkoo, 13.1.2011	75712	0	0
Hyvinkää, Ridasjärvi, 16.11.2012	71933	0	0
Siikarannan kurssikeskus, Kirkkonummi	70173	0	0
Rönnäsgård, Loviisa	64728	0	0
Isosaari, Helsinki	64574	0	140
Aktiivikeskus, Kirkkonummi	60664	0	0
Hopeaniemen kuntoutumiskeskus, Vihti	51015	0	0
Aavarantaopisto, Kirkkonummi	49884	0	0
Solvallan urheiluopisto, Espoo, 30.8.2013	49417	0	0
Kaisankoti, Espoo	45383	0	0
Kisakeskuksen urheiluopisto, Raasepori	38817	0	0
Vakola, Vihti	37025	0	0
Betesda-säätiö, Kotivalli, Sipoo, 15.4.2013	35086	0	0
Volsin vanhainkoti, Kirkkonummi	30096	0	0
Raasepori, Bromarvin	28429	0	0
Ahtilan toipilassairaala Oy, Sipoo, 31.1.2013	28145	0	0
Kuusikoti, Espoo	27365	0	0
Lönnrot opisto, Lohja, 1.7.2013	27313	0	0
Oittaan ulkoilukeskus, Espoo	17459	0	0
Porvoo, Sannainen	16924	0	0
Tvärminnen eläintieteellinen asema, Hanko, 26.11.2011	16101	0	0
Outamo, Lohja	14776	0	0
K-Instituutti, Espoo	14675	0	0
Santalan Kristillinen kansanopisto, Hanko, 5.8.2011	14648	0	46
Liikkeenjohdon koulutuskeskus, Porvoo, 27.9.2010	9973	0	0
Kokoushotelli Elohovi, Nuorisokoti Nummela, Vihti	9481	0	0
Vivamon toimintakeskus, Lohja, 15.1.2010	9289	0	0
Västankvarn Gård, Inkoo	9062	0	3
Hilan leirikeskus, Kirkkonummi	8934	0	0
Calliolan koulutuskeskus, Raasepori	6820	0	0
Hill Side & Country Club Oy, Vihti	5387	0	0
Ekokylä, Raasepori, 15.11.2011	4202	0	0
Kullo Golf Oy, Porvoo, 28.9.2010	4019	0	0
Peuramaa Golf, Kirkkonummi	3797	0	0
Parkojan koulu, Pornainen, 17.8.2010	2689	0	0
Kurk Golf, Kirkkonummi	2605	0	0
Strömsö, Raasepori	1555	0	0
Russarö, Hanko	1375	0	0
Total	**1148619540**	**2045498**	**7169801**

Plots of individual plants








Hyvinkää, Kalteva (Group 2)
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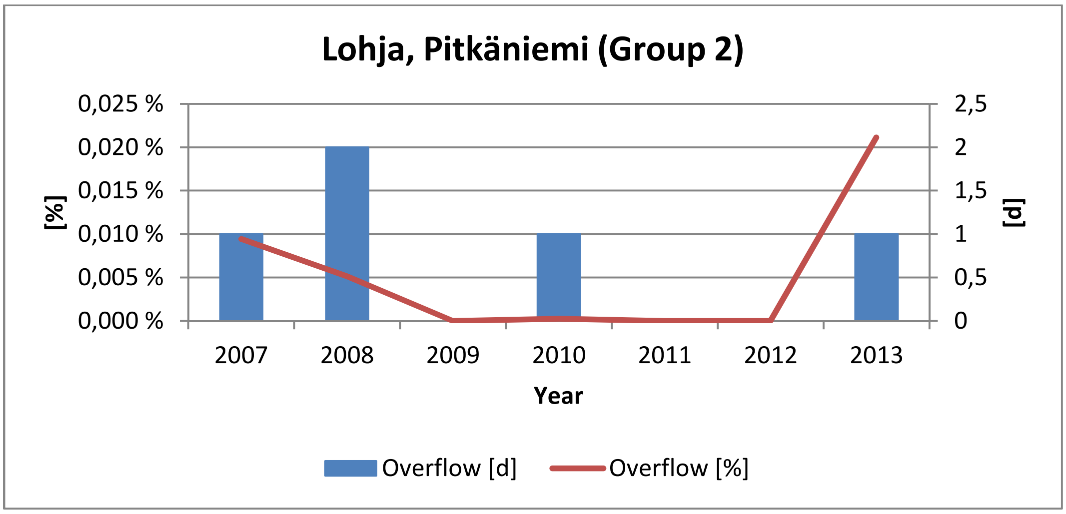
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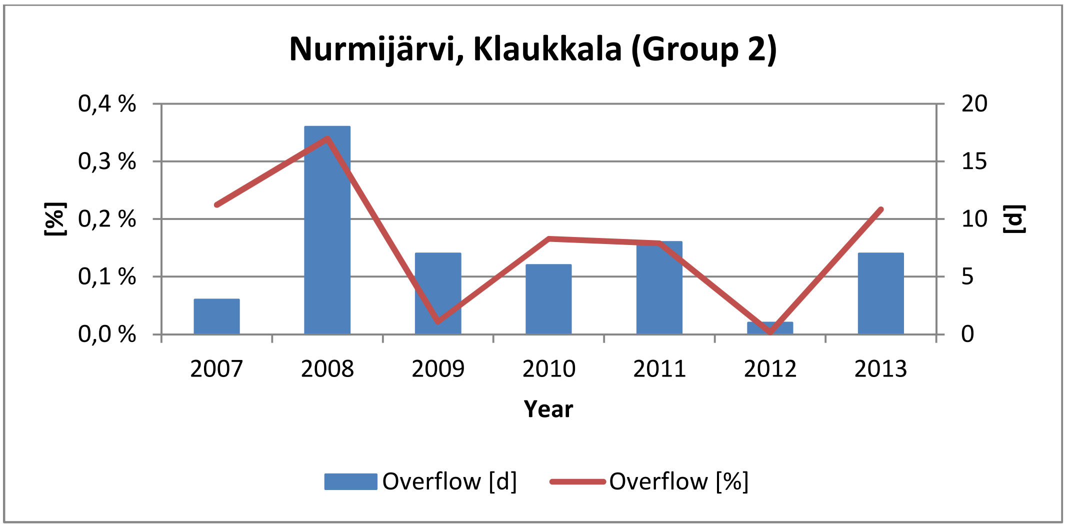
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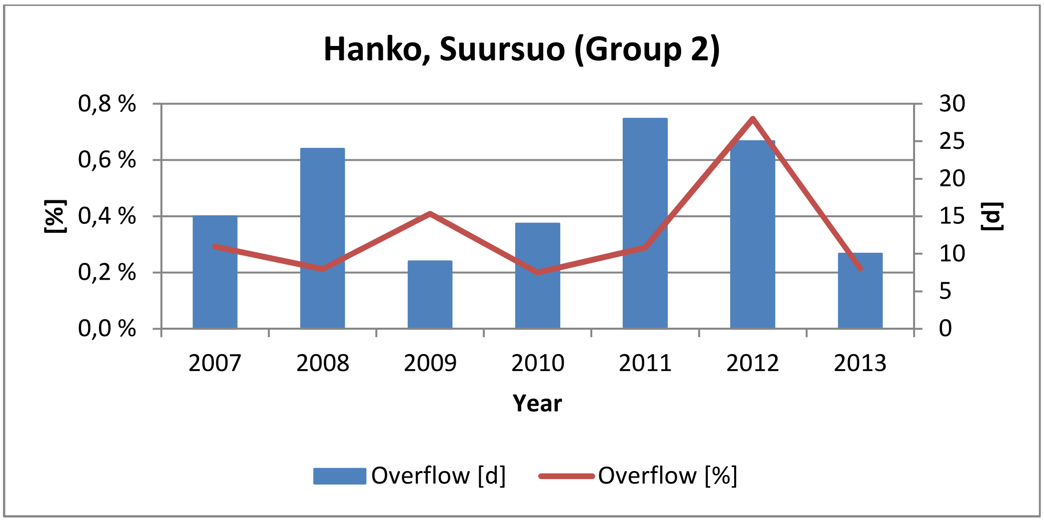
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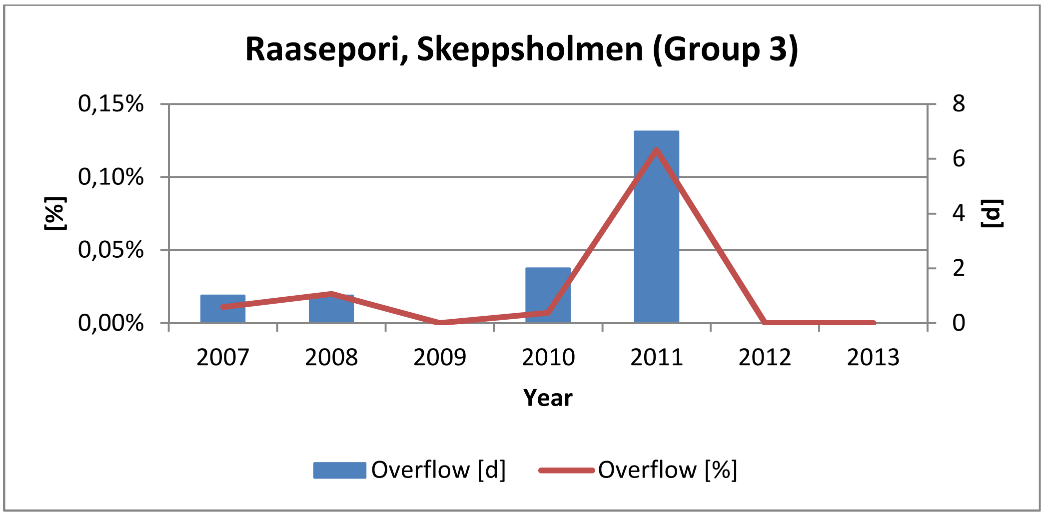
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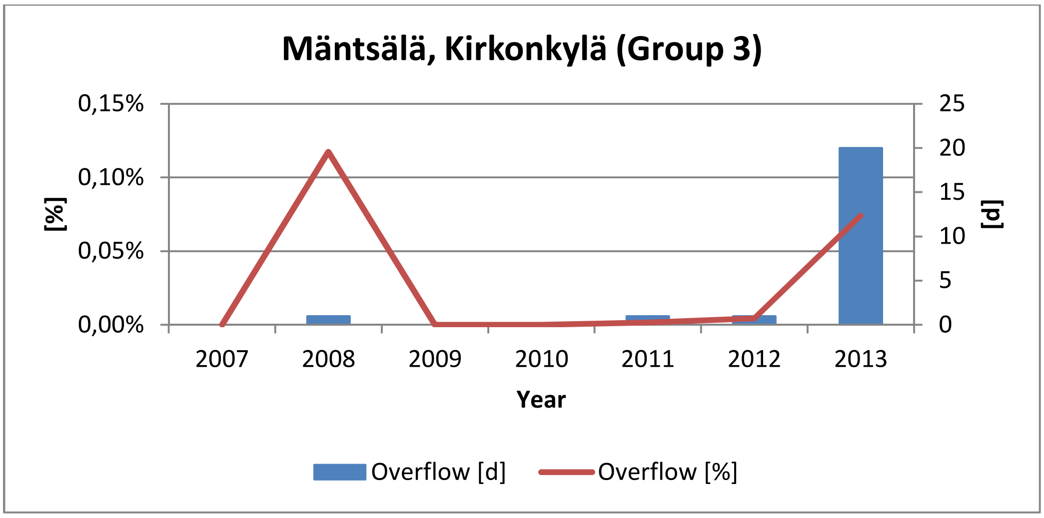
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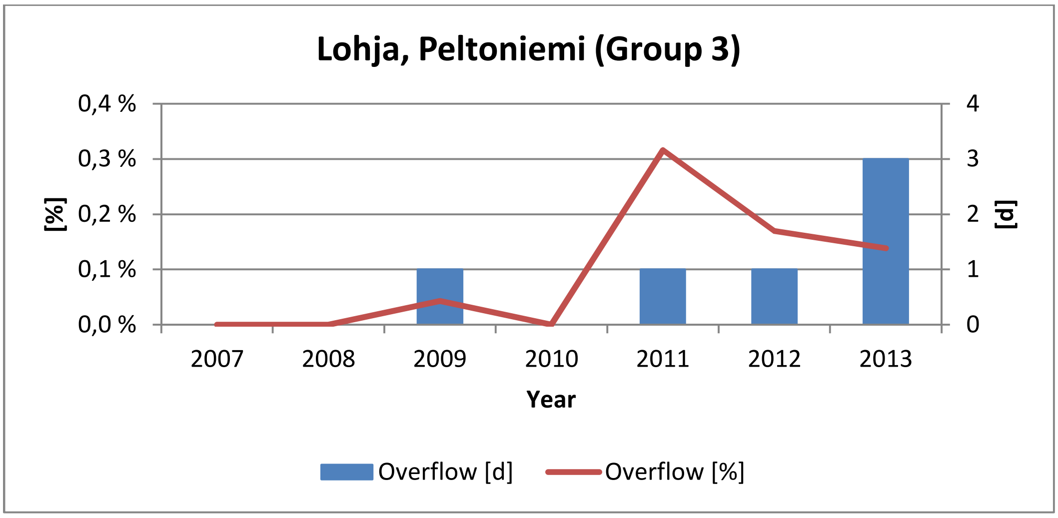
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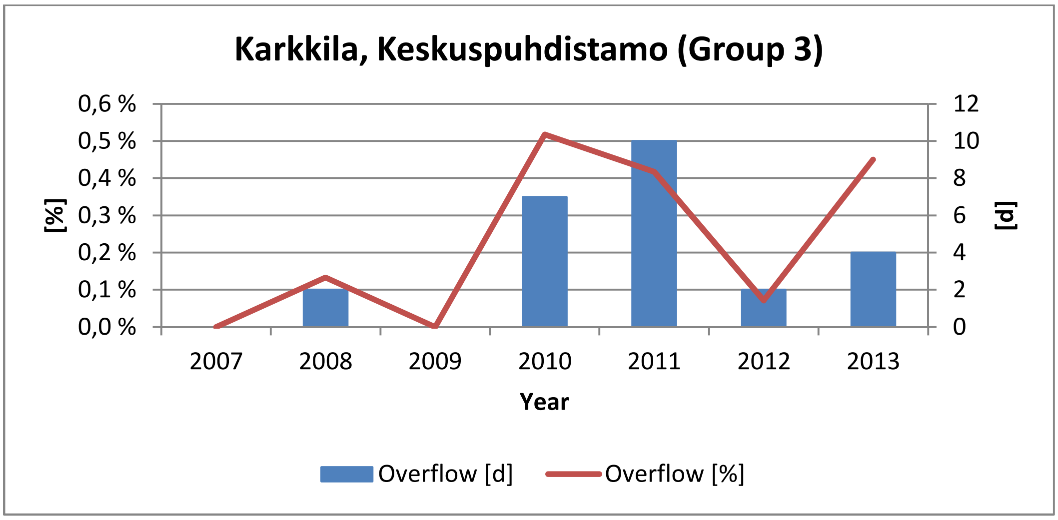
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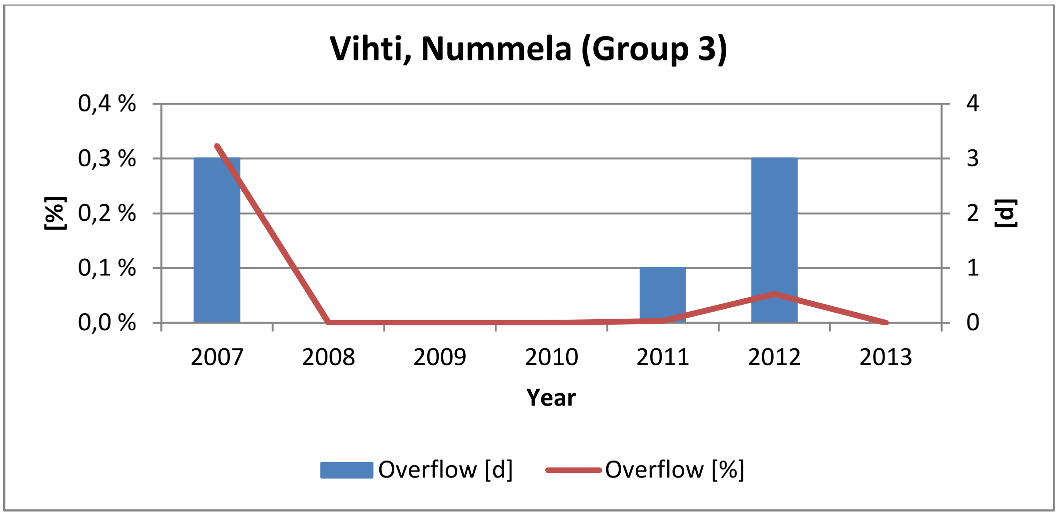
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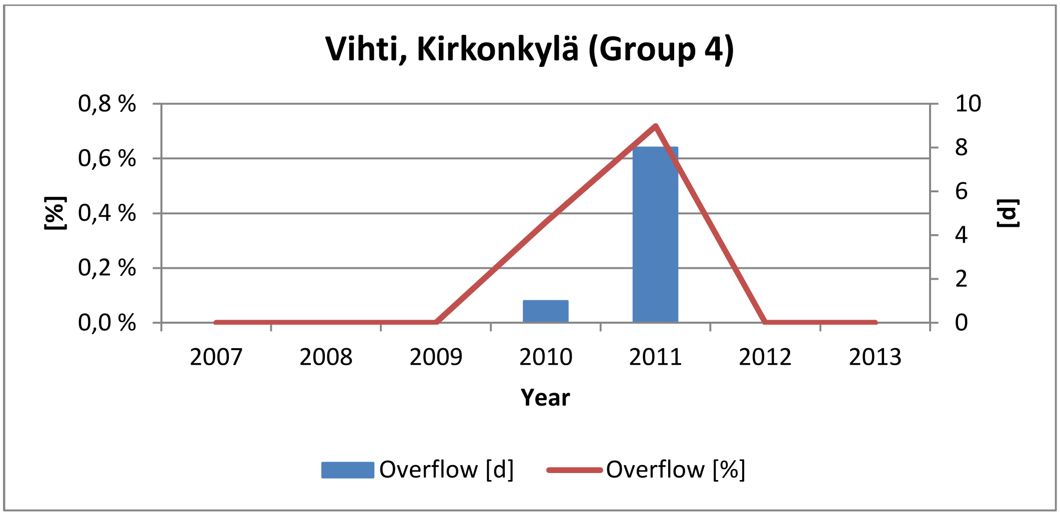
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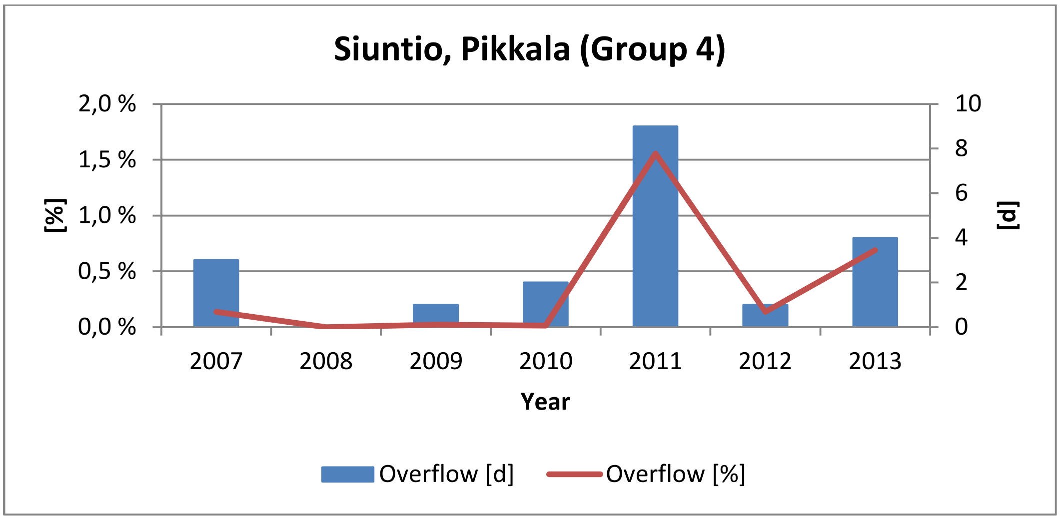
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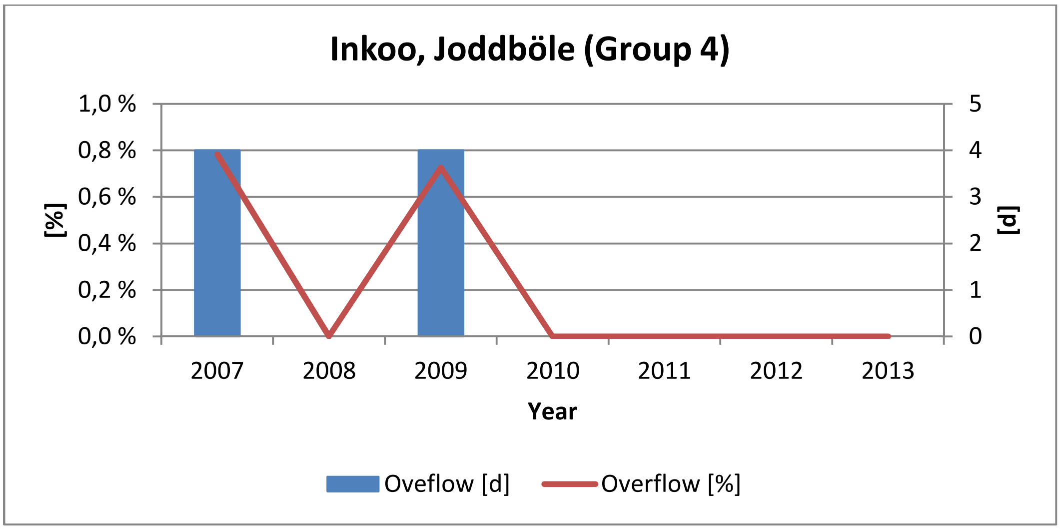
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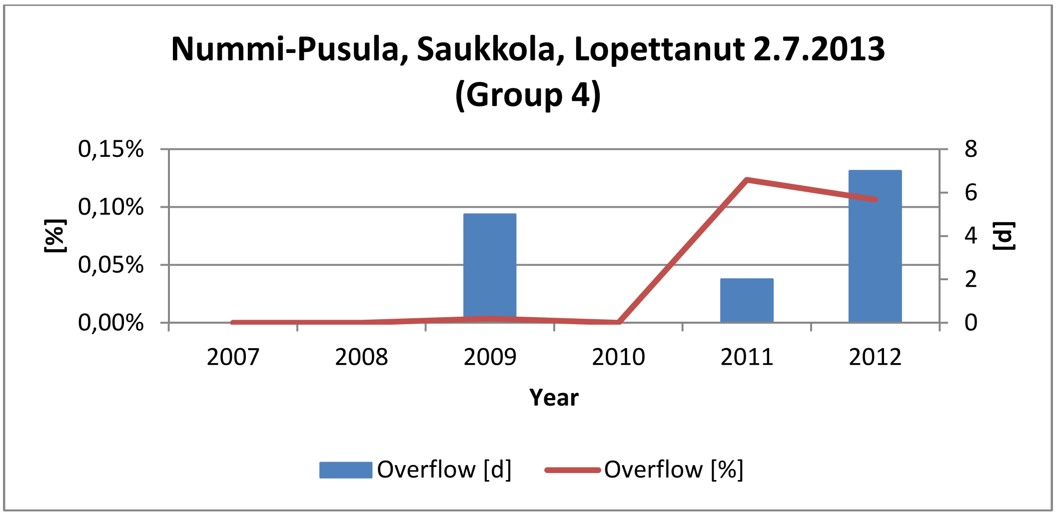
Nummi-Pusula, Saukkola, Lopettanut 2.7.2013 (Group 4)
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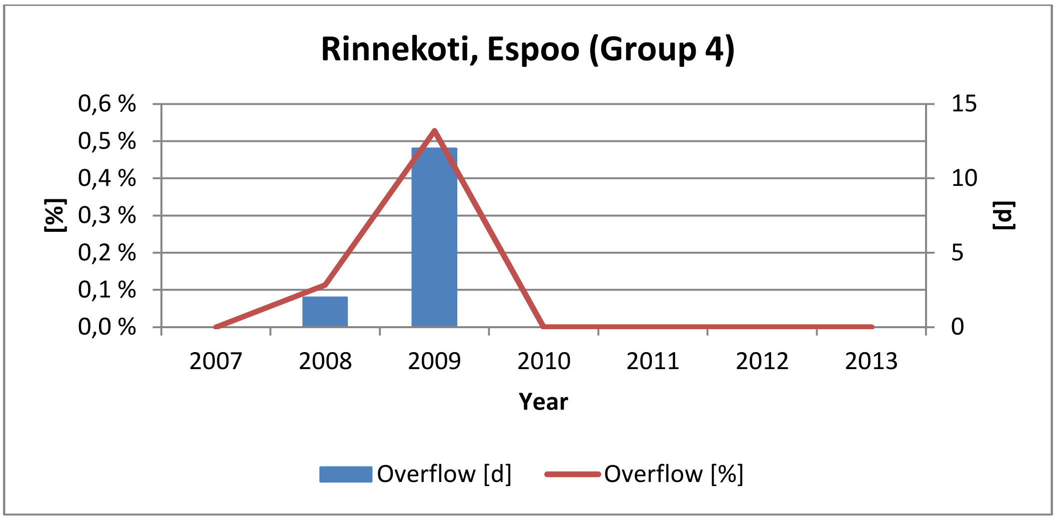
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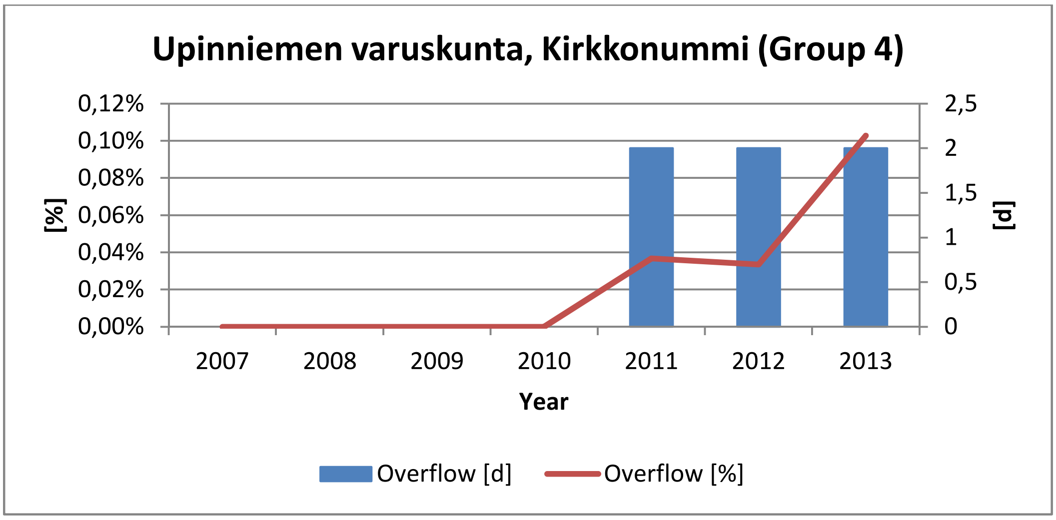
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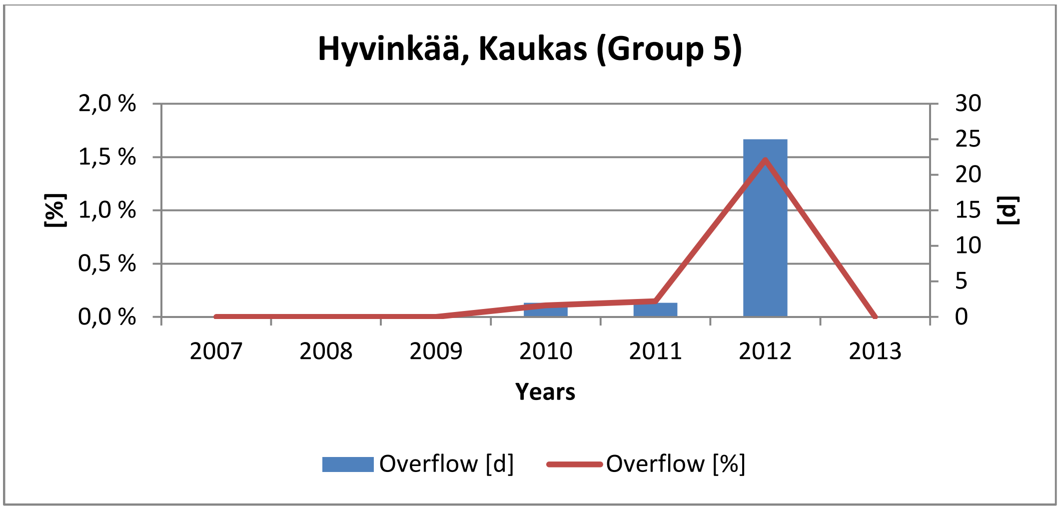
Hyvinkää, Kaukas (Group 5)
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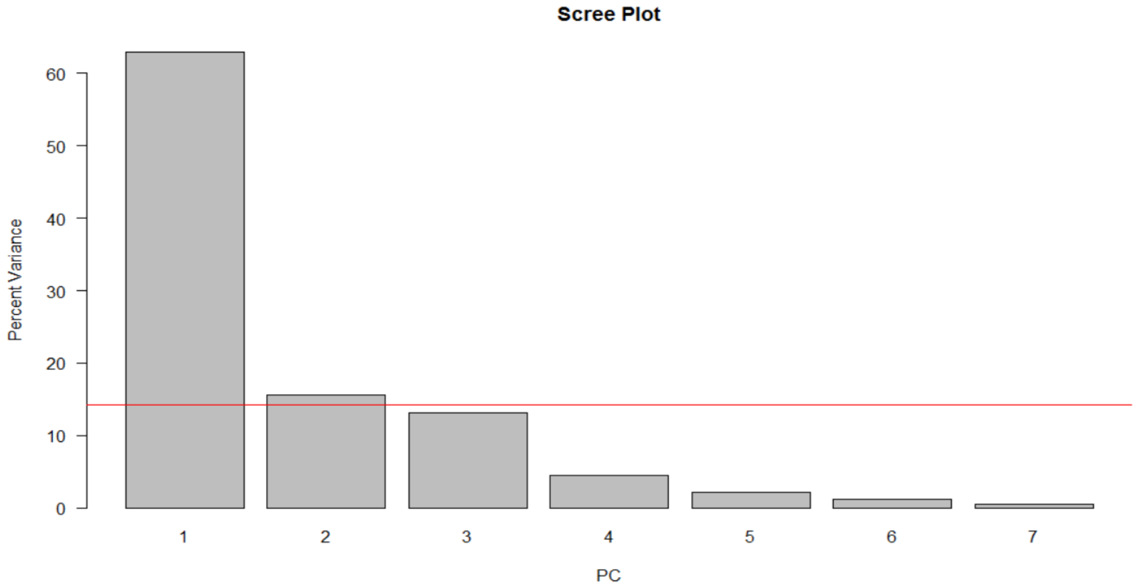
Statistics

Below, a scree plot presents principal components, while red line indicates the Kaiser's criterion, i.e. Eigen values over one.



The next figure displays a regular biplot, before modifying it into a ggbiplot.