CHALMERS

Effects of Climate Change;
Flooding in Lake Vänern

-A study on the wastewater treatment plants based on learning and evaluation of previous events

Master of Science Thesis in the Master´s Programme Geo and Water Engineering

IDA MATTFOLK

Department of Civil and Environmental Engineering
Division of Water Environment Technology
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden 2013
Master’s Thesis 2011:19

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Department of Civil and Environmental Engineering
Division of Water Environment Technology Chalmers University of Technology
SE-412 96 Göteborg
Sweden
Telephone: + 46 (0)31-772 1000

Cover:
The wastewater treatment plant in Arvika which flooded in December 2000 (*Arvika municipality)*. No further information on the event will be provided in this report. The experiences gained will however be discussed. The photo is taken by the fire and rescue department in Arvika municipality.

Reproservice / Department of Civil and Environmental Engineering
Göteborg, Sweden 2013

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ABSTRACT

No overall investigation exists about the actual risk profile of the wastewater treatment plants around Lake Vänern in case of flooding. Through study visits, interviews, review of reports etc. the truth is revealed about 7 municipalities' preparedness and the preventative measures subsequently taken following the severe flooding of 2000/2001 which recorded the highest ever water level in Lake Vänern since regulation began. The municipalities are; Grums, Karlstad, Kristinehamn, Lidköping, Mariestad, Vänersborg and Åmål. The aim of this master thesis is to evaluate the vulnerability for all the selected wastewater treatment plants and sewer systems affected by a flooding scenario in Lake Vänern which according to predicted climate changes may happen again soon. Extreme flows in watercourses have a 100-year return period. However, this may underestimate the actual return period, which could be as low as 20 years. When the 2000/2001 flooding occurred, the network of sewer pipes were flooded by heavy precipitation and the untreated wastewater was discharged through overflow functions to the nearest watercourse. The possible environmental effects of the released overflow water were calculated but because of Lake Vänern´s large water mass, no obvious impact was found. The increased water level caused overflow from Lake Vänern through the overflow function points. The flow reversed in the sewage pipes causing flooding in residential basements and a heavy load into the treatment plants. The location of the wastewater treatment plants, which is low-lying and situated close to Lake Vänern, worsened the flooding, and wiped out important treatment processes as a result. Some of the municipalities are not properly prepared for a similar scenario and most of the staff with experience are either already retired or will be in the near future. Furthermore, it is challenging for municipalities to develop adequate response plans for acute flooding situations due to either a lack or excess of documentation. Communication between the different departments and the wastewater treatment plants is not clear or working properly in most of the municipalities (with one exception). Municipalities should consider changes to their organizational structure in order to improve the flow of information internally and to the inhabitants of the community. Finding leaks in the pipe network system may prevent large quantities of water to enter into the network system and the installation of backup power at sensible pumping stations in the municipality could prevent backflow in the system. Politicians should prioritize investments in the piping network and backup power systems in upcoming budgets as part of a prudent flood mitigation strategy. Indeed, the cost of continued flooding in municipalities across Sweden is likely several times that of the infrastructure required to prevent previous events such as the 2000/2001 flood.

Key words: Climate change, Lake Vänern, flooding, wastewater treatment plant, sewer network system

Klimatförändringens effekter; Översvämning i Vänern

-En studie av avloppsreningsverk baserad på lärande och utvärdering av tidigare händelser

Examensarbete inom Geo- och vattenteknikprogrammet

IDA MATTFOLK
Institutionen för bygg- och miljöteknik
Avdelningen för Vatten- och Miljöteknik
Chalmers tekniska högskola

SAMMANFATTNING

Det finns ingen riskprofil för avloppsreningsverken runt Vänern i ett översvämningsscenario. Genom studiebesök, intervjuer, rapportläsning med mera uppdagas här sanningen om de 7 utvalda kommunernas förberedelse och vidtagna åtgärder sedan den svåra översvämningen som inträffade år 2000/2001 när den högsta vattennivån sedan Vänern blev reglerad uppmättes. De undersökta kommunerna är; Grums, Karlstad, Kristinehamn, Lidköping, Mariestad, Vänersborg och Åmål. Syftet med det här examensarbetet var att utvärdera sårbarheten för de utvalda avloppsreningsverken med pumpstationer, avloppsledningar och bräddstationer i ett översvämningsperspektiv som enligt förutspådda klimatförändringar kan hända snart igen. Man brukar räkna med att extrema flöden i vattendrag och sjöar har en återkomsttid på 100 år och i sådana fall skulle det som hände 2000/2001 ligga långt fram i tiden. Oroande nog anses återkomsttiden vara underskattad och höga flöden verkar hända vart 20:e år istället. När översvämningen inträffade år 2000/2001 blev avloppsrören översvämmade av kraftigt regn och orenat avloppsvatten bräddades ut till närmsta vattentäkt. Den möjliga miljöpåverkan av dessa bräddningar ut i Vänern har undersökts och ingen uppenbar påverkan har hittats vilket antagligen beror på Vänerns stora volym. När vattennivån höjdes började vatten från Vänern att flöda in genom bräddningspunkterna i avloppssystemet och flödet gick bakåt i ledningarna vilket orsakade översvämmade källare i städerna och extrema flöden in i reningsverken. Då reningsverken är lågt placerade och i omedelbar närhet till Vänern så svämmade vissa över med utslagna reningssteg som följd. Vissa av kommunerna är inte förberedda för ett liknande scenario, de flesta erfarna anställda har antingen gått i pension eller är på väg att gå i pension. Bristen på dokumentation om tidigare erfarenheter och/eller för mycket röriga anteckningar om händelserna att få grepp om är oroande. De flesta kommuner har gemensamt att kommunikationen mellan olika avdelningar och avloppsreningsverken inte är tydlig eller fungerar alls. Nuvarande organisation bör revideras inför ett översvämningsscenario och informationsflödet förbättras inom organisationen likväl som till kommuninvånarna. Att hitta läckor i avloppssystemet kan förhindra att stora kvantiteter vatten hamnar där och att installera reservelverk vid känsliga pumpstationer kan förhindra bakåtflöde i systemet. Politiker bör revidera den ekonomiska planen så att kommunerna kan bli mer förberedda om liknande händelser skulle inträffa.

Nyckelord: Klimatförändring, Vänern, översvämning, avloppsreningsverk, avloppsledningar

Contents

Preface

In this study, wastewater treatment plants affected by flooding in Lake Vänern due to climate change were investigated. The investigation was carried out between March and December 2009. The work was requested by MSB, the Swedish Civil Contingencies Agency and by CCS, the Centre for Climate and Security research concerning risks what a changed climate may entail. The project was carried out at the Department of Civil and Environmental Engineering, Water and Environmental Technology, Chalmers University of Technology, Sweden. The project was financed partly by CCS, but with MSB as the main financier.

This project was carried out with MSc Ida Mattfolk as a researcher and Assistant Professor Thomas Pettersson as an internal supervisor from Chalmers. External supervisors are Lars Nyberg of CCS and Rainar All of MSB. The investigations were mainly carried out through study visits to wastewater treatment plants in the different municipalities surrounding Lake Vänern. My supervisors Thomas, Rainar and Lars together with the contacts in each municipality are highly appreciated for their time and help with planning and assisting with information for the investigation. I would also like to thank my family and friends, especially Sofia and Fredrik, for their support and involvement.

Finally, it should be noted that the investigation could never have been conducted without the sense of high quality and professionalism of the staff in all the municipalities and authorities.

Göteborg April 2013

Ida Mattfolk

1 Background

Lake Vänern is Sweden's largest and Europe's third largest lake with an area of 5 648 km^2 and a volume of 153,000 million m^3. The drainage area is 46,880 km^2 and reaches from the northern part of the river of Trysilälven in Norway to the city of Vänersborg in the south of Sweden. The river Klarälven is the largest of the waters that discharge into Lake Vänern. The river Göta älv, which is the largest river in Sweden with an average water velocity of 550 m^3/s, convey the water from Vänern to the sea outside of Gothenburg, Kattegatt *(Klimat och sårberhetsutredningen, 2006:94)*. The river Göta älv drainage area is shown in Figure 1.1.

Figure 1.1 The river Göta älv drainage area with Vänern in the middle and the city of Gothenburg down to the left. ***(Bergström et al, 2006)***

1.1 The climate is changing

The Swedish government investigated the Swedish society's vulnerability to global climate changes and the regional and local impacts of these changes. It presented its findings in a report entitled "Climate and vulnerability investigation by the Swedish Government" *(Klimat- och sårbarhetsutredningen, SOU 2007:60)*. The investigation indicates that the increase in temperature in Sweden is expected to be larger than the global average increase. The actual increase in temperature will depend on future global greenhouse gas emissions. Although changes in rainfall patterns are expected, it is uncertain how wind climate will impact water levels (amongst other effects). The climate changes that have been seen so far and that will take place during the next few decades are mainly a reaction to historical emissions. In Figure 1.2, data from the Intergovernmental Panel on Climate Change (IPCC) show the trends from 1961-1990 concerning Global average surface temperature; Global average sea level; and the

Northern Hemisphere snow cover *(IPCC Fourth Assessment Report, 2007)*. IPCC is the scientific, leading body for the assessment of climate change established by United Nations Environmental Programme (UNEP) and the World Meteorological Organization (WMO). IPCC consists of 2500 scientific experts from 130 countries who analysed the likelihood of climate change; the assessment report show what they are mainly in agreement on, concerning the aforementioned three trends *(Hansson, CCS seminar 2008).*

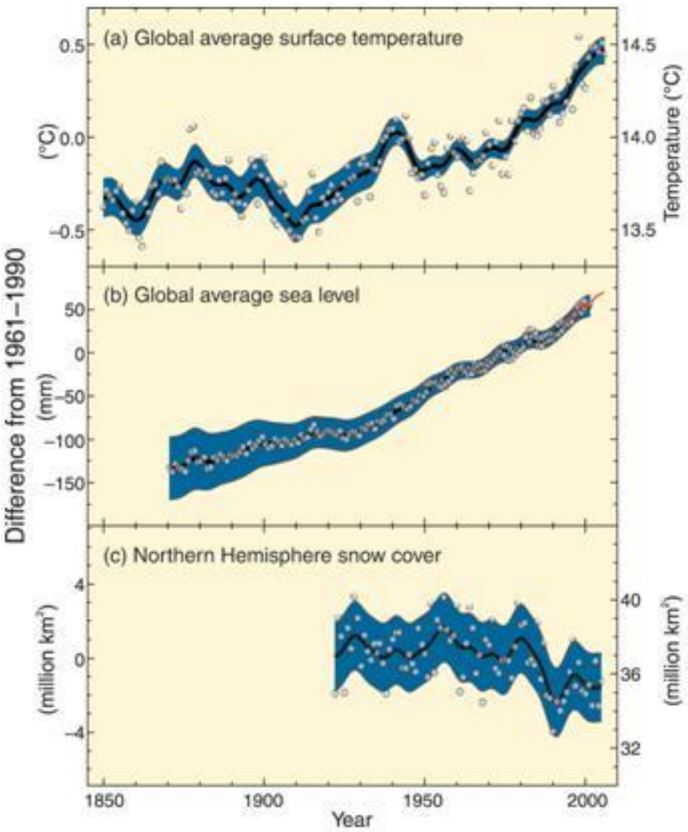

Figure 1.2 Difference from 1961-1990. The shaded areas are uncertainty intervals *(IPCC 2007)*

The trends shown above are an indication of changes that need to be stopped and dealt with. Core sampling and analysis of ice in the Antarctic has shown that since the industrial revolution, levels of carbon dioxide have increased. Those high levels of carbon dioxide have in turn undoubtedly caused the global temperature to rise faster than predicted. Eleven of the twelve warmest years that have been measured by various stations around earth since 1860 were between 1995 and 2005. In Sweden the mean temperature has risen 2°C since then *(SMHI, 2005)*. Many discussions focus on the extent to which man has influenced the *natural* global warming effect, and whether climate change is indeed occurring. Critics claim that there are numerous uncertainties with the models which make them bad/deficient and therefore unreliable. Professor Christian Azar however rejects this criticism in his book entitled "The power over the climate, 2008" with an answer that is worth considering; *"If the models are bad, the reality of the climate sensitivity due to human behaviour can either be higher or lower than predicted. Why should the uncertainty in the models mean that we can feel safe? I think on the contrary; the less control we have over what the consequences might be the stronger the reason to be cautious."*

1.1.1 Climate change scenarios

In its "Special Report on Emissions Scenarios" (SRES) (*IPCC, 2000)*, the IPPC presented different climate scenarios. It is important to note that these are scenarios, not prognoses. These scenarios are based on consistent ways of development for the main factors that are causing Green House Gas emissions (GHG). These factors are; demographic, social, economic and technical development. The scenarios do not include assumptions of precautions to reduce the emissions. The SRES outlines four main directions: A1, A2, B1 and B2 (see Figure 1.3). These are four families of scenarios, each of which has a main alternative. A significant difference between the scenarios is the rate of globalisation which is assumed to affect the emissions due to economic and technical progress. The focus in the A-scenarios is on economic growth, while the B-scenarios show a more sustainable development.

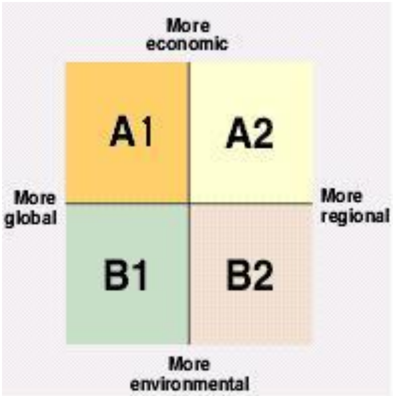

Figure 1.3 The different features of the scenarios *(IPCC, 2000)*

The Swedish Government has chosen to focus on scenarios A2 and B2 in their report *(Klimat- och sårbarhetsutredningen, 2007)*, and these two scenarios will also be the focus of this report. A2 represents a heterogenic world with very different regional development, where the population will continue to increase but the economic growth per capita and technical progress is more fragmented and slower than in the other scenarios. Emissions continue to rise along with temperature which is in average estimated to be 3.4°C higher in 2100.

In scenario B2, local solutions in economic, social and ecological sustainability are introduced. The population is increasing but not as fast as in A2 and economic development progresses along a slow but not remarkable path. Technical progress is not as fast as in A1 and B1, and the focus is on sustainability in both local and regional areas. Emissions are half as high as in A2 and the temperature increase is 2.4°C until 2100. The reason why these two scenarios were chosen is partly because the availability of information, data and results from global and regional models that have been run with these scenarios is extensively investigated. They have also been used in other national studies, for example in Finland and by the European Commission. The release of emissions in these scenarios also represents a reasonable span *(Klimat- och sårbarhetsutredningen, 2007).*

Global models that describe the atmosphere and the oceans' circulation, as well as the interactions between these and land areas, vegetation etc. have been developed. However, regional models offer better analytical capabilities and support for the development of mitigation and adaptation strategies. With regional models the result from the global perspective can be narrowed down to fit the local topography and the distribution between land, ocean and lakes. It also makes it easier to simulate weather events. Combined, the Earth can be divided into a three dimensional grid to include atmosphere, land, ocean, lakes and ice *(Rossby centre, SMHI, 2007)*. One of these global models that have resulted in a regional model is the German model ECHAM4/OPYC3 which was developed by DKRZ, Deutsches Klimarechenzentrum GmbH and the Max-Planck institute. These multi-dimensional grid models have been further refined by researchers at the Rossby Centre in Sweden to a model (RCA3) that encompasses all of Europe at a resolution of approximately 50km^2. As a complement to this model, the RCAO model, which combines an atmospheric and an oceanic model, is used. However, it can only represent the changes in temperature and precipitation from 2071 to 2100. Although there have been some indications during the tests of these models that overestimations and/or underestimations are present within various areas when it comes to climate change effects, the range of the sensibility analysis used on these models should cover most of the model's errors.

1.1.2 Precipitation and flooding

The precipitation will generally increase, mostly in the western part of Sweden and during the winter season. The watercourses in west and southwest Sweden are expected to flood more often in a changed climate. As the climate is changing and extreme weather events are expected, the consequences must be evaluated. Flooding is one of the expected events that may occur more often and with longer intervals in some parts of Sweden. Flooding is defined as "when water is covering spaces of land beyond the normal limitation of a lake, river or ocean" *(Räddningverket, 2004)*. Flooding in rivers and lakes means that more water contributes to the watercourse than they are able to convey without flooding. The land is not able to absorb or drain the water if it is already saturated.

In one of the models (RCA3-EA2), the precipitation in January is predicted to heavily increase until year 2100, see Figure 1.4 below.

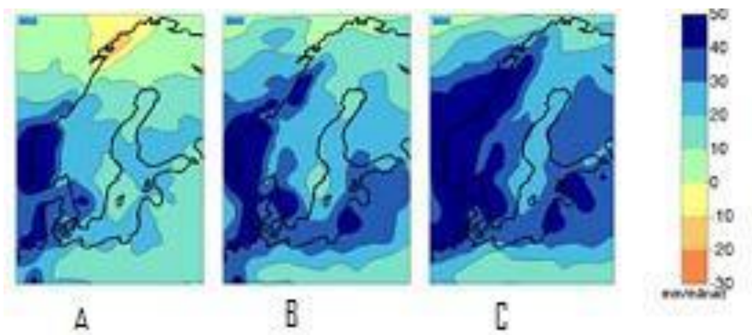

Figure 1.4 Change of average precipitation in January mm/month A) year 2020 B) year 2050 C) year 2080 (*Klimat- och sårbarhetsutredningen, 2007)*

The precipitation is expected to be mostly rain in the wintertime, even in the north of Sweden. By 2080 snowfall will be very rare, except in the middle of the northern part of Sweden where a small increase might be experienced. During summertime, the changes in precipitation are difficult to interpret. Depending on the model that is studied, the areas where it can either be more dry or wet varies. The models that are used in this report show that it is going to be drier in southern Sweden *(Klimat- och sårbarhetsutredningen, 2007).* Both autumn and spring are predicted to be wetter and there is a distinct increase in the number of days with heavy rain (more than 10 mm) in the winter. The intensive rainfalls will also increase predominantly in the western parts of Sweden. This can already be seen when models are run on analysis by observation data from 1991-2005 *(Rossby Centre, SMHI, 2007).* The models are 3-dimensional mathematical calculations of the atmosphere, land area, oceans, lakes and ices. When it comes to extreme flows in watercourses the return period is chosen to be in a 100-year return period –statistically the highest flow in a watercourse during a 100 year period (the flow will come back once every 100 years). However, the return period seems underestimated and the return time for the highest flows now seems to have a return period every 20 years instead.

The normal water level in Lake Vänern RH00 is 44.34 m above sea level which is measured at two different places (Mariestad and Mellerud) but with a fixed point in the municipality of Vänersborg (*SMHI, 2001).* At a 100 (or now 20) year return period the highest water level is measured and predicted to be 46.5 m, the water level which is used for theoretical models in hydro-electric power calculations is 47.4m. If the water level in Lake Vänern will be higher than that, major damage will be the result as by today´s measures.

In a changed climate both the inflow to and outflow from Lake Vänern will be affected. Higher temperature will cause more precipitation during wintertime and so the outflow to the river Göta älv is predicted to have maximum levels more often which could be a security problem for inhabitants and industries along the river. The old strategy and law about regulating the levels in Lake Vänern by releasing water into Göta älv caused a false security so a new strategy for regulating the level in Lake Vänern has been accepted *(SMHI, 2009)* but it will not solve the problems. It will only increase the margins and lower the amount of the extreme outflows to Göta älv but it will not be able to prevent an increase of water level in Lake Vänern at extreme events.

1.2 The wastewater system

The wastewater system in Swedish municipalities consists normally of two different design types. They are either designed as combined sewer systems as shown in Figure 1.5 page 6, or as separate (duplicate) systems. In the combined sewer system, the sewage (sanitary/foul water) and the stormwater (rain etc), share the same pipe network. When a storm event occurs the pipes get flooded and the water is normally discharged untreated into the nearest watercourse through a Combined Sewer Overflow (CSO). The CSO mitigates the quantity load to the wastewater treatment plants in a storm event and makes sure that the water does not flow back into the system to flood basements and other below-grade structures. Another way to prevent (or delay) the discharge is to install a detention tank which mitigates the peak flow before the wastewater treatment plant. The wastewater is temporarily stored during heavy rains and then emptied after the rains have stopped. In the separate (duplicate) system the sewage (sanitary/foul water) and the stormwater are discharged in different pipes. These systems also have overflow installations where the water during heavy rainfall is not lead to a pond or another sustainable urban drainage area but released immediately to a river, lake or the sea because the pipes are full.

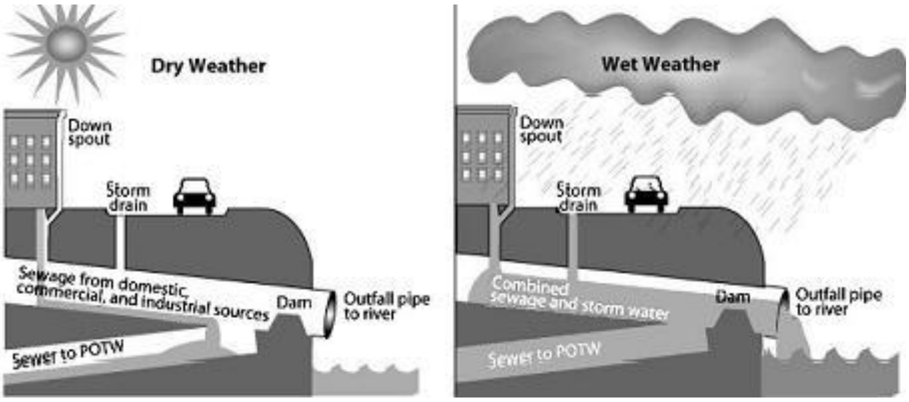

Figure 1.5 Principle of combined sewer system ***(Pettersson T, 2009)***

In the pipes where the sanitary and foul water flows, emergency discharge pipes are installed in pump stations to prevent the water from flowing back into the system due to a pump failure or other scenarios like leakage of stormwater or groundwater into the system. The discharge pipe leads the untreated wastewater directly into a river, lake or the sea. The stormwater systems will be heavily overloaded due to a change in the climate with increased precipitation and a diversifying of the rain to be more frequent during autumn, winter and spring when evaporation is low and the ground is already saturated. As most of the pipes are underestimated for extreme heavy rainfalls the risk of water flowing back into the basement of houses increases. Overflow in the pipes in a combined system and in separated systems (result of bad connections from houses, old pipes, the human factor in opening valves) also discharge sewage into the environment, consequently spreading environmental and health hazards. When designing a wastewater treatment plant a measure of person equivalents are often used. Person equivalent (pe) is a measure of the average amount of wastewater produced by one person during a day *(M.Henze, 2008).*

1.2.1 Pollution caused by discharge of untreated water

Currently there are no microbiological restrictions in Sweden on wastewater that is released to receiving waters. However, municipalities have to report to regional authorities (Länsstyrelsen) on registered released volumes from CSOs *(Klimat- och sårbarhetsutredningen, 2007)*. Untreated wastewater contains different pollutants that cause various environmental problems. It is mostly the elements nitrogen (N) and phosphorus (P) that the wastewater treatment plants focus on reducing before the water is considered clean and can be released from the plant. Un-ionized ammonia (NH_3) is toxic to fish and other aquatic animals. "Phosphate phosphorus is a key nutrient in stimulating excessive plant growth -both weeds and algae- in lakes, estuaries and slow-moving rivers. Cultural eutrophication is the accelerated fertilization of surface waters arising from phosphate pollution associated with discharge of wastewaters and agricultural drainage". *(Viessman W, Hammer M)*. The relationship between flooding and algal blooms has been reported on in the past. The Swedish treatment plants have to meet the criteria, parameters and water quality standards from the Swedish Environmental Protection Agency (EPA). In Table 1.1 the limits for annual average concentration of total nitrogen and total phosphorous are presented *(Naturvårdsverket, 1994)*.

Table 1. Recommended concentrations of P_{tot} and N_{tot} for treated water (Naturvårdsverket, 1994)

Parameter	**Highest allowed value (annual average)**
Total nitrogen	15mg/l
Total phosphorous	0.5mg/l

In Chapter 3, Results, a description is provided of the findings from the brief investigation of the released overflow volumes of untreated water and the possible impact in Lake Vänern.

1.3 The wastewater treatment process

The wastewater treatment plants in Sweden usually combine mechanical, biological and chemical treatment in various ways. A schematic representation of the general treatment procedure is shown in Figure 1.6. .Although, not all wastewater treatment plants follow this procedure.

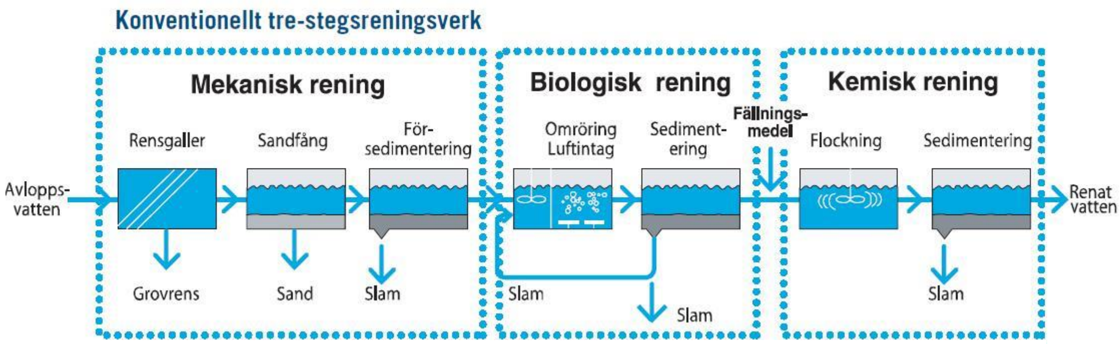

Figure 1.6 General procedure in Swedish over the wastewater treatment in Sweden *(Naturvårdsverket, 2004)*

From the left, in figure 1.6, the wastewater enters the plant to the Mechanical treatment process through a grid or screen (rensgaller) that removes large particles to protect pumps at later stages in the plant. In the next stage, sand and other heavy particles sink to the bottom, because of their weight, and are collected and transported with pumps to a waste disposal site. The water continues to pre-sedimentation. In this stage other material that has not been removed or does not belong in the following treatment procedures are also removed through sedimentation. The sludge at the bottom is removed to a sludge pocket where it is pumped to the sludge treatment. The water now enters the Biological treatment phase where microorganisms (bacteria) break down the organic matter that is dissolved in the wastewater and formed to floc. The floc is separated in the next sedimentation basin and is now called activated sludge. Some of the active-sludge is re-circulated into the first treatment step. The bacteria are sensitive to diluted water that lacks sufficient organic matter. For this reason some of the sludge is re-circulated. The biological step can vary in design and may use anaerobic or aerobic tanks depending on the regulations of nitrogen and biological phosphorous reduction. The water now enters the last step which is Chemical treatment. The steps to remove chemical phosphorous may be done by precipitation with chemicals like iron chloride ($FeCl_3$), coagulation, flocculation and separation.

1.4 Flooding in Lake Vänern during 2000/2001

This study on the wastewater treatment plants affected by the flooding in Lake Vänern is based on learning and evaluation of previous events and mostly focused on the events that occurred in 2000/2001. Lake Vänern is a system that is slow to react to changes due to its large size/scale. The summer of 2000 was characterized by heavy precipitation. All the water reservoirs around Lake Vänern in the different municipalities were full and the surrounding ground was saturated. The rain continued during the autumn causing water levels in Lake Vänern to rise. This has happened before during short periods, but on this occasion a number of factors collectively caused water levels to rise beyond safe levels. In 1937 a law to regulate the level in Lake Vänern through a hydro-electric power plant south of Vänersborg was accepted and this resulted in a lowering of the highest water levels. In Figure 1.7 the levels of Lake Vänern before and after 1937 are shown. Notice the peak of the water level in year 2000/2001.

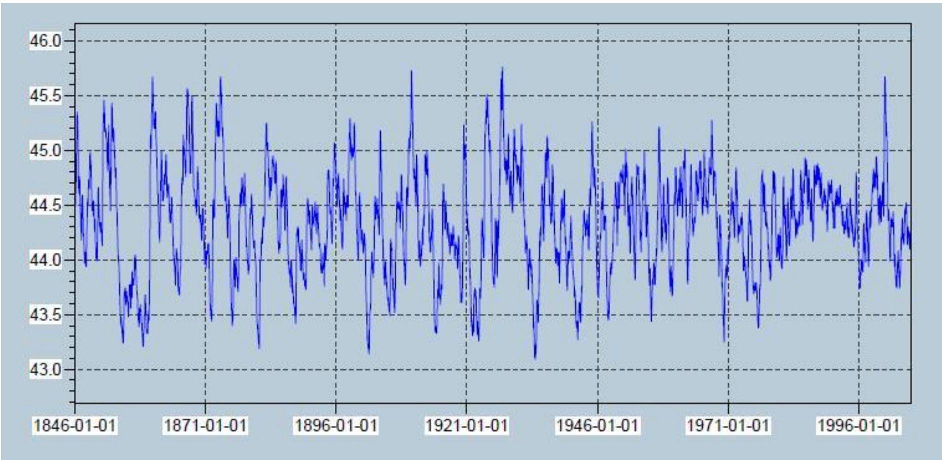

Figure 1.7 The water level in Lake Vänern during the years 1846-2005 ***(Bergström et al, 2006)***

The law contains several decisions on how the regulation should be executed so it does not interfere with the interests of different representatives from the fishing, shipping and agricultural industries. In addition, discharging to the river Göta älv requires qualified calculations since the river banks of Göta älv are sensitive to the flow in the river and might collapse, causing devastating damage to the populated areas and industries along the river *(MSB, 1993)*. During low levels in Lake Vänern, enough water must still be discharged to the river to prevent sea water from rising upstream which in turn could cause problems with salty intrusions at the drinking water intake of the city of Gothenburg. At a certain point in the autumn 2000 (18th of November) when predictions were made about the continuing rising water level in Lake Vänern, the County Administrative Board of Västra Götaland (Länsstyrelsen) took over the responsibility for the regulating with support from the Law about protection against accidents (before: Räddningstjänstlagen) (*Regeringkansliets* *rättsdatabaser)* and increased the outflow to the river Göta älv. The highest water level in Lake Vänern was measured at RH00 45.67 m (1.33 m above normal value). Without this action water levels would likely have increased by an additional 40 cm. In Chapter 7 Appendix Table 7.1 the water level in Lake Vänern from the 1st of Nov 2000 until 28th of Feb 2001 is shown. A lot of preventive actions like building embankments were coordinated around the lake but major damage had already taken place. The Environmental Protection Unit of the County board in Västra Götaland acted fast during the flooding and collected valuable information from all the municipalities around Lake Vänern. The information sought was what effects might be for the municipality if Lake Vänern would rise to +46.00 m (about 80 cm higher than usual) or +46.50 m (about 130 cm higher). In the report *(Hansson S, 2000)* one of the conclusions was that most of the wastewater treatment plants would be flooded and large quantities of untreated water would be discharged into Lake Vänern and the effects for Lake Vänern as a drinking water source should be investigated. A lot of people involved and working with the flooding in year 2000/2001 are retired today and there are basically no documentation left to what happened and how the disaster was dealt with. This report will highlight that in Chapter 3, Results, for all municipalities, to point out the risks of not taking care of valuable experiences.

1.5 Aim

In the present situation of year 2009, no overall investigation exists about the actual risk profile of flooded wastewater treatment plants around Lake Vänern. The aim for this master thesis is to evaluate the vulnerability of all wastewater treatment plants and sewer systems affected by a flooding scenario in Lake Vänern and the measures of prevention taken by the municipalities based on previous events. The primary focus is mainly on the events that occurred year 2000/2001. The report is based on the willingness of the municipalities to be transparent with their information and although the aim is to present as much facts and maps as possible, respect is given to occasional confidential classification. If possible, the contribution from the Swedish Government to manage the costs during this period of flooding will be recited for. The overall costs bound to the flooding for the municipalities will also be asked for.

Drinking water management procedures and policies are not included in this report. Also, wastewater treatment plants that were affected due to flooding of a river connected to Lake Vänern were not investigated. The possible effects of flooded industrial land and any impact on nature reserves are not discussed. The reference system which comes from Swedish Meteorological and Hydrological Institute (SMHI) is called RH00 (Rikets Höjdsystem from year 1900). Because the land uplift since the ice age is higher in the municipality Karlstad (3.5 mm/year) than in Vänersborg (2.66 mm), the Karlstad municipality is using its own system (RH00 Karlstad) for measuring the water level of Lake Vänern. This system lies approximately 0.2 m lower than RH00. Since 2007 Sweden has started to change to a new reference system called SWEREF 99 and since 2005 a new system has been in use that is called RH2000 *(Lantmäteriet)*. Although most of the municipalities around Lake Vänern use different systems, the system from SMHI (RH00) will be used in this report and other systems will be converted to it as the focus is on the events in year 2000/2001.

2 Method

2.1 Procedure

This study is based on a literature review, study visits, seminars and interviews. Different reports and investigations have been studied to get a fair picture of the problematic scenario of flooding in general and in Lake Vänern in particular. The author attended several seminars and one conference in order to inform this discussion on current practices and research.

The interviews performed in this study were partly based on several questions formulated before the interviews but the method used when interviewing people mainly focused on letting them speak freely. Examples of questions asked can be found in Chapter 7 Appendix, Section 7.2. The identities of those interviewed for this study have been kept anonymous. In most of the municipalities representatives from the wastewater treatment plant, the technical office, the security coordinators and the social construction division were included.

Study visits of at least one day were scheduled at seven chosen municipalities affected around Lake Vänern. The municipalities in this study are Grums, Karlstad, Kristinehamn, Mariestad, Vänersborg and Åmål.

2.2 Measurements

In each municipality visited, parameters for the amount of water that had been released untreated as well as laboratory results from the contents of that water were requested for. Not all municipalities could or wanted to share that information. Uncertainties with the results are unavoidable. An approximation is made over how much untreated water was released into Lake Vänern during a year when the flooding occurred and also a calculation of the pollution it caused is presented below. As a reference, the values from the municipality of Kristinehamn are used. An analysis of the impact on Lake Vänern from the release of all untreated waters is presented in Chapter 3 Results.

2.3 Equations

2.3.1 Pollution impact in Lake Vänern of overflow untreated wastewater

The volume of Lake Vänern is estimated to be 153,000 million m^3 *(Lidköping, 2010)*. During the flooding in year 2000 and year 2001 the overflow volumes that were released into Lake Vänern untreated from Kristinehamn was V_{2000}=2,012,100 m^3 and V_{2001}=1,503,264 m^3 respectively *(Kristinehamn Environmental Reports 2000-2001)*. To calculate a monthly average volume ($V_{average}$) released from the seven investigated municipalities:

$$V_{average} = \left(\frac{V_{2000}+V_{2001}}{24}\right) \times 7 \qquad (2.3.1)$$

The total amount of phosphorous, P_{tot} released from Kristinehamn those two years was 3.3243 metric ton. So for all municipalities are then the total amount released per month:

$$P_{average} = \frac{P_{tot} \times 7}{24} \qquad (2.3.2)$$

The total amount of nitrogen, N_{tot} released from Kristinehamn those two years was 41.766 ton/year. So for all municipalities are then the total amount released per month:

$$N_{average} = \frac{N_{tot} \times 7}{24} \qquad (2.3.3)$$

To get the amount of phosphorous and nitrogen in every overflow m^3 the following equation is used:

$$\frac{{}^{ton}/_{month}}{V_{average}} \qquad (2.3.4)$$

When finally calculating the impact of the releases from all seven municipalities of P_{tot} and N_{tot} into all of Lake Vänerns volume, the following equation is used:

$$\frac{{}^{ton}/_{month} \times 7}{V_{total\ Lake\ Vänern}} \qquad (2.3.5)$$

3 Results

In this chapter, all the municipalities are presented and reviewed in alphabetic order.

The result from investigating the effects from releasing untreated water into Lake Vänern shows no obvious relation between the flooding and algal blooms in the following years. The monthly average volume released overflow water from the municipalities is according to the equation (2.3.1), $V_{average}$ = $\underline{1,025,314 \text{ m}^3}$.

The monthly average release of phosphorous is estimated to $P_{average}$ = 0,9695 ton/month according to equation (2.3.2) and the average nitrogen released is $N_{average}$ = 12,18 ton/month using equation (2.3.3).

The estimated amount of nutrients per liter released overflow water is as follows from equation (2.3.4); phosphorous 0,95 mg/l and nitrogen 12 mg/l. Phosphorous levels then exceeds the recommended value and nitrogen levels is below the recommended concentrations for treated water. When using the equation (2.3.5) to summarize the total effect of these concentrations released into the total volume of Lake Vänern, one can easily see that phosphorous is diluted to 0,00015 mg/l and nitrogen to 0,002 mg/l which is far below recommended values and therefore could not have made an obvious imprint.

However, the flooding did affect nature reserves and already polluted soil in areas like industrial areas together with old, abandoned industrial land but the damage and leakage cannot be easily measured.

3.1 Grums

Grums is a small town on the northern (west) part of Lake Vänern, see Figure 3.1.1, with 9,250 inhabitants *(Grums municipality, 2009).*

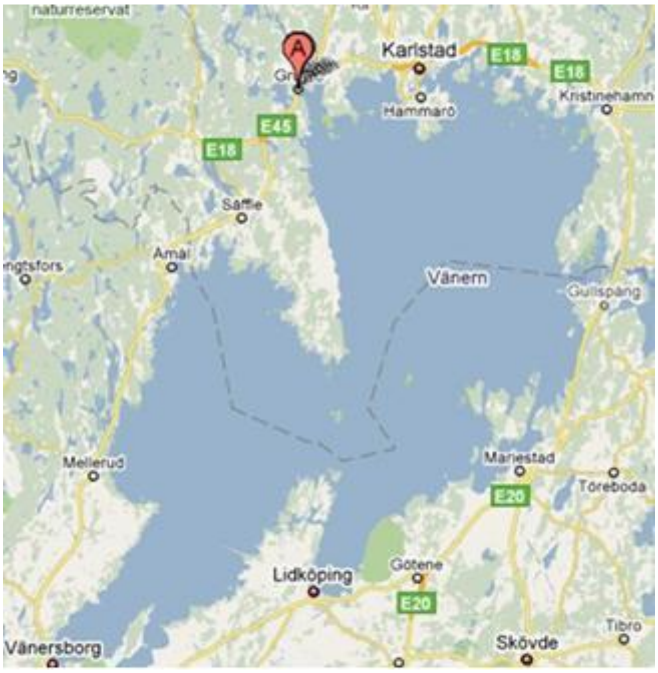

Figure 3.1.1 Grums is located where the red mark with an A is *(Google maps)*

3.1.1 Background

Since Grums is a small municipality there are several small plants treating the wastewater. Three pumping stations were under particular stress during the events. Segmon treatment plant is designed for 1200 pe (person equivalents). The Borgvik´s (Sjöhaget) plant is designed to treat wastewater from up to 350 pe. The treatment plant of Slottsbron is designed for 11,000 pe and was built 1974. There is one more treatment plant in Liljedahl, however; the designed capacity is unknown.

3.1.2 Course of events for Grums year 2000/2001

There were three persons in the staff working during the events 2000/2001 (two of whom are retired today). Very high flows were measured in the Segmon treatment plant. The normal value is about 300 m^3/day and the peak flow then was close to 2300 m^3/day. The water level in Lake Vänern had risen higher than of the CSO´s before the plant causing the water from Lake Vänern to enter the pipes instead of discharging from the pipes to Lake Vänern. To prevent this they had to plug the CSO`s. Lake Vänern also rose over grounds to a level where water started to pour into the basins of the Liljedahl treatment plant. Protection and strengthening with sand bags became necessary. At Borgvik´s treatment plant the flow into the plant rose from 36 m^3/day to 533 m^3/day. The treatment plant at Slottsbron usually has an inflow of 2500-4000 m^3/day but changed to about 9600 m^3/day during this period.

3.1.3 Measures taken

In the Segmon treatment plant some work has been done with new pipes and relining of the old ones to prevent extraneous water from the ground to enter the pipes. Measures are mostly taken in the pumping stations connected to the treatment plant of Borgvik. At some stations extra pumps are available. Today there are four people working with drinking water and the water network system while three people are working with the treatment plants and the pump stations. The worst scenario for today is expected to be a heavy precipitation due to a thunderstorm event and no electricity.

3.1.4 Problems

When visiting Grums municipality the impression was that no one seemed to have the overall responsibility and/or insight in the different activities. The experiences gathered from the two retired persons working 2000/2001 are not properly made. No map was presented over the wastewater treatment plants and their locations. Lab results and measurements over the amount of water released untreated into Lake Vänern at the time was scarcely presented and no material was handed out. No definite plan if worst case scenario would appear seemed to be worked upon. The communication between the maintenance technicians and the administration at the municipality do not seem to be working properly regarding working schedules, transferring of practical knowledge and future plans.

3.2 Karlstad

Karlstad is the largest city around Lake Vänern and is located at the northern part of Lake Vänern, see Figure 3.2.1, with 84,090 inhabitants *(Karlstad municipality, 2009).*

Figure 3.2.1 Karlstad´s location *(Google maps)*

3.2.1 Background

Karlstad is situated in the delta of the outflow of the river Klarälven and it is one of the most exposed cities for flooding around Lake Vänern. The wastewater treatment plant (Sjöstadsverket) in Karlstad is located in the east delta arm of the river Klarälven, see Figure 3.2.2. Sjöstadverket was built 1970. The river Klarälven originates from the Norwegian fjelds and when the temperature rises and the glaciers melt, the water level increases in the river causing problems for the municipality. So in a worst case flooding scenario, the water level in Lake Vänern will rise and Klarälven will have an increased water level and flow. This happened in 2000/2001.

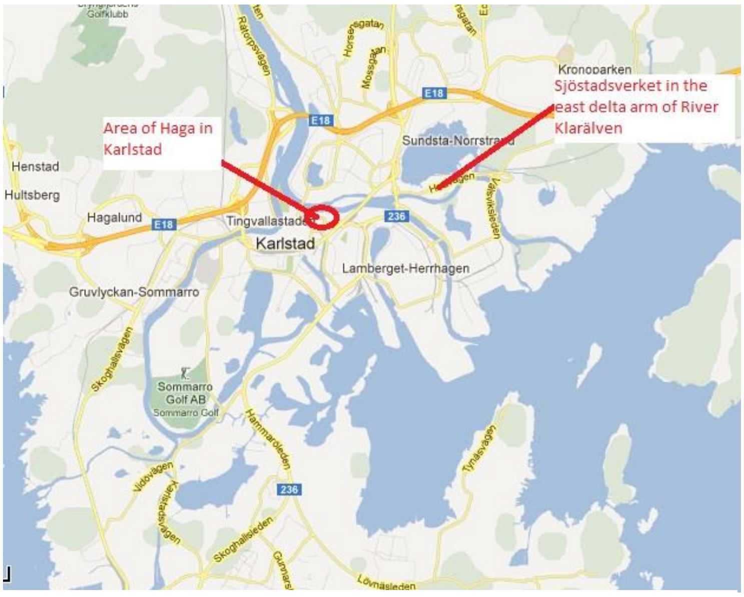

Figure 3.2.2 Sjöstadsverket and Haga pumping station *(Google maps)*

3.2.2 Course of events for Karlstad year 2000/2001

The wastewater system consists of both separated and combined pipe networks. Each pumping station has an overflow function and some also have backup power for the pumps. After multiple days of heavy precipitation in the autumn of year 2000, the water started to flow backwards into the system which was noticed because the lids of the gully pots and other lids were rising around the municipality. One of the most critical areas was Haga pumping station, see Figure 3.2.2. The water from the river Klarälven had risen and entered the pumping station through the overflow function (it came in through the back door so to speak) and the pumping station was soon flooded, cutting the electricity to the pumps. The water flow through the pipes to the wastewater treatment plant was no longer under control. The wastewater treatment plant normally has an inflow of 24,000 m^3/day. During this critical time 2000/2001, the inflow was at the highest flow in December 14th, the flow peaked at 98,000 m^3/day. Before the wastewater treatment plant there is a form of detention tank to store the water before entering the plant and make sure that the inflow is even. It is also equipped with an overflow function, but it was closed due to the high level in the river Klarälven which resulted in too much flow into the plant. The biological treatment in the wastewater plant with active sludge was wiped out and the water also needed to be bypassed after the chemical treatment with a 60 m temporary large culvert in plastic. That arrangement was emergent and so a pipe in the plant was cut open and connected to the culvert that discharged the water directly into the river. This temporary culvert destroyed a nature trail by the water due to erosion. To get the culvert into place took several days. An embankment was built around the plant since the water level was so high in the river Klarälven and Lake Vänern. Temporary pumps were set up in the plant area to get the water on the inside of the embankments at the ground that came from the city, out as well. In Figure 3.2.3 the levels of the treatment plant are marked. Lake Vänern rose to 45.47 m above sea level and since river Klarälven also had risen, the water level must have been around 46.50 m above sea level to start flooding the plant.

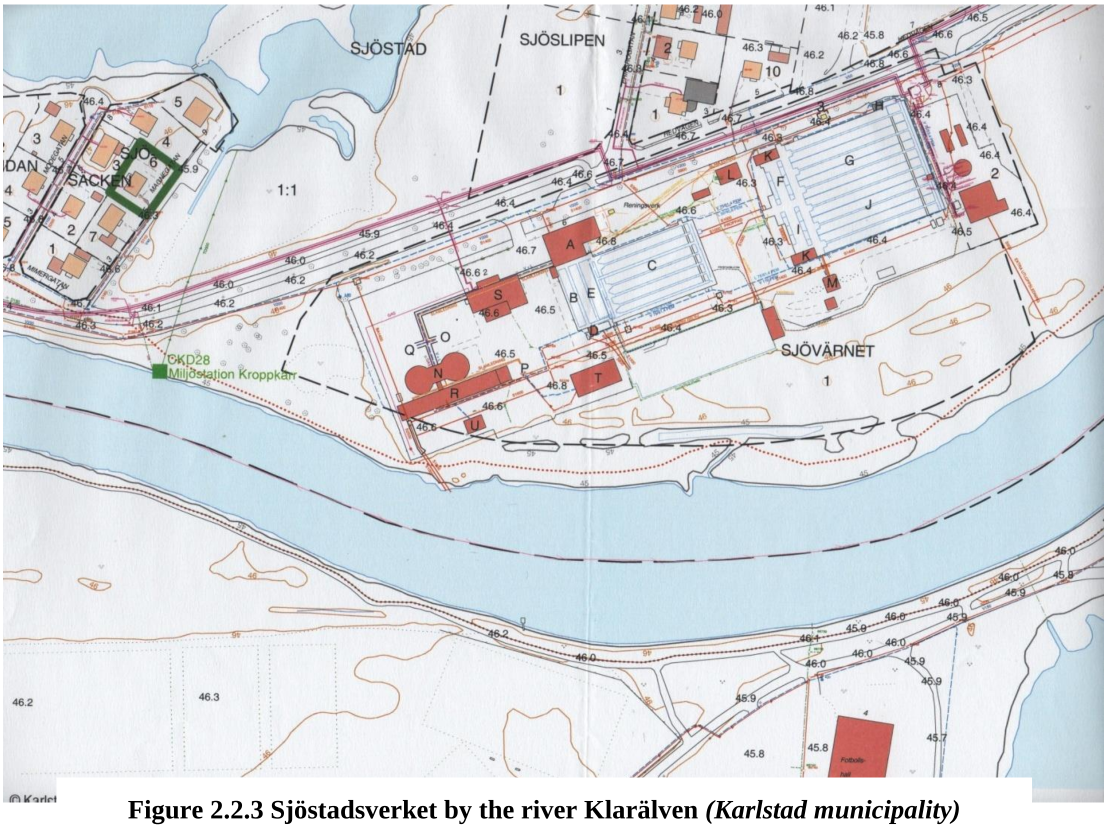

Figure 2.2.3 Sjöstadsverket by the river Klarälven *(Karlstad municipality)*

During the flooding, it was estimated that the treatment plant only managed to treat 60% of the water compared to the usual 98%.

Figure 3.2.4 shows the water level in Lake Vänern RH00 Karlstad during the period 1st June 2000 – 11th September 2001.

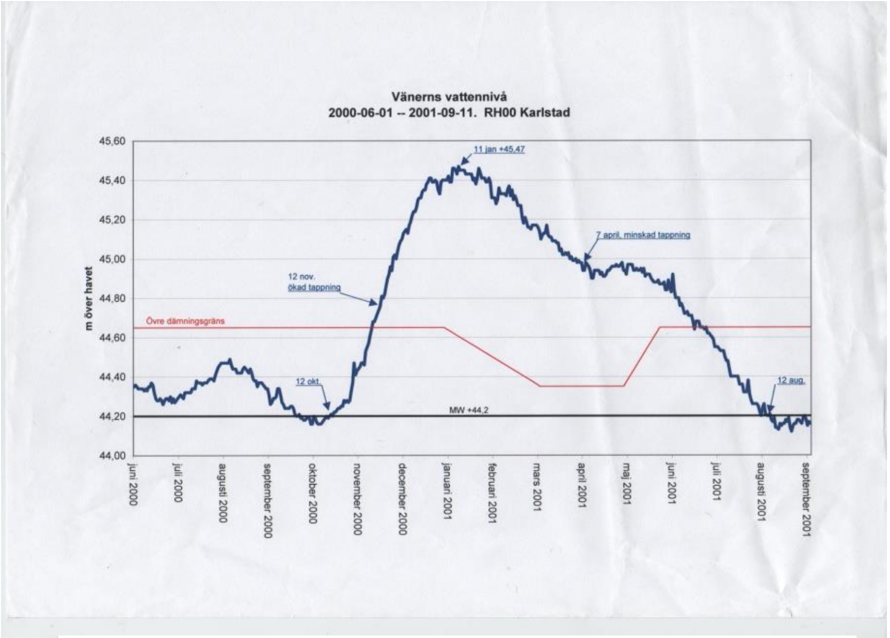

Figure 3.2.4 The water level in Lake Vänern peaked 11th of January 2001 *(Karlstad municipality)*

3.2.3 Measures taken

Haga pumping station has been strengthened by increasing the height of the wall between the river Klarälven and the stormwater. It can now also overflow in two directions. In 2004/2005 some pipes were expanded to be able to handle greater volumes and non-return valves as well as water gates have been installed at critical points. There is a protection wood decking lying to prevent the nature trail from eroding again. A pump is ready to stand by, but it has not been decided whether the culvert should be used again or something else will be used if this happened today. A small wall has been built against the river at the treatment plant but that will have to be reinforced at a similar event. A water plan has been produced by the municipality with goals and procedures in case of flooding. Also a strategy and procedure program for the river Klarälven and its interaction with Lake Vänern has been presented. A lot of reports have been made about flooding in Karlstad from different universities since the city is particularly exposed due to its location.

3.2.4 Problems

In the environmental report of 2007 from the municipality of Karlstad a calculation is made that approximately 25 000 people would be affected at a theoretical level in Lake Vänern of 47.4 m and that is just in the centre of the city. There is a scarce access of available pumps. The water plan and the flooding program have just been initiated and result is still not presented (as of year 2009).

3.3 Kristinehamn

Kristinehamn is located in the northern (east) part of Lake Vänern, see Figure 3.3.1, and has 23,958 inhabitants *(SCB, 2008).*

Figure 3.3.1 Kristinehamn is located where there is an A *(Google maps)*

3.3.1 Background

The wastewater treatment plant (Fiskaretorpets avloppsreningverk) is located in the risk area G of flooding (see Figure 3.3.2). It was built 1964.

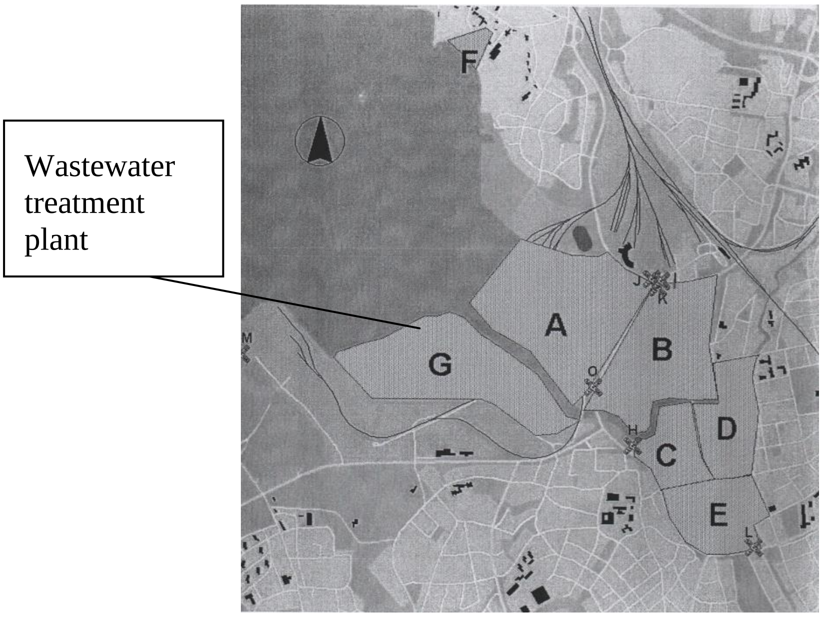

Figure 3.3.2 A map over the centre of Kristinehamn, the wastewater treatment plant is located in area G *(Kristinehamn municipality)*

There are both separated and combined sewer networks in the city. Landa pumping station is an important node in the network since 80% of all wastewater passes through there before the treatment plant. It is in the central part of the city of Kristinehamn.

3.3.2 Course of events for Kristinehamn year 2000/2001

Of the five people in the staff that were working during the flooding in 2000/2001, one has retired. The documentation and experience feedback from this municipality over what happened and where, is very detailed and easy to review. For example, if it would happen again, there is a list of the need for extra pumps and emergency power to Landa pumping station, how and where a rented diver could reinforce the overflow functions in pumping stations to prevent Lake Vänern to fill the station and also how to make arrangements to discharge the wastewater promptly from the sewage network to decrease the pressure on the wastewater treatment plant and the actual pipes. In Figure 3.3.3 is a picture of the diver.

Figure 3.3.3 A diver is on his way down to repair the overflow function to stop the water at Landa pumping station *(Kristinehamn municipality)*

When there was a strong wind from south, south-west on January 9th 2001 the problems got worse since Lake Vänern rose and divers had to plug more overflow functions. Approximately 100,000 m^3 of water was pumped through Landa that day (the normal flow is 10,000-15,000 m^3/day).

3.3.3 Measures taken

Documentation is well prepared with a list of steps of what is needed to deal with in a similar situation and what has to be put in motion work wise and process wise. A decrease in the leakage of stormwater and groundwater into the pipe networks, the possibility to bypass some areas so the water flows directly to the wastewater treatment plant and installation of natural embankments along the water courses are some of the things on that list. Also, Landa pumping station has been rebuilt and new pumps have been installed. Within the organisation there are demands that the preparedness and follow-up should always be active in the analytical team during disasters and the information needed during those times demands a special resource. Today, 10 people are working with drinking water and wastewater in shifts to keep the knowledge and overall insight within the team. The dimensioned flow calculated increased four times the design rain flow when new measures were taken around the city in the sewage pipes and pumping stations. The amount of money from the Swedish Government to manage the costs from the flooding damages was 3.42 million SEK. The overtime costs during that period were around 400,000 SEK.

3.3.4 Problems

There are no obvious problems that have been identified and the organisation as well as the documentation is thorough. The only problem might be the economy. There are some things that still need to be done but right now there are not enough funds to do that.

3.4 Lidköping

There are approximately 37,900 inhabitants in Lidköping (Lidköping municipality, 2009) which is located in the southern part of Lake Vänern, see Figure 3.4.1.

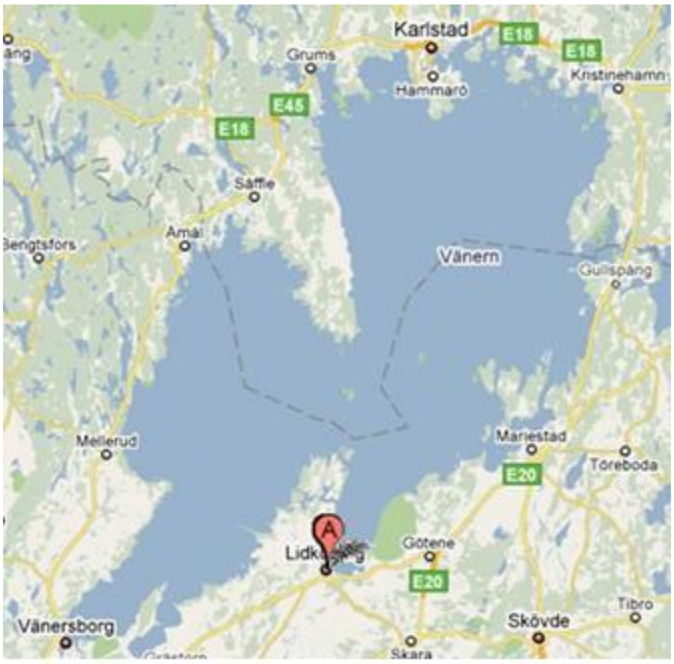

Figure 3.3.1 Lidköping is located at the marked spot with an A *(Google maps)*

3.4.1 Background

Lidköping has mostly a separated wastewater system and has a very flat topography which needs a lot of pump stations. In 1994 an inventory was made on how many CSOs and emergency discharges there are and the findings resulted in about 25-30 that had been unknown. That is not unusual among municipalities and most municipalities do not take the time to make inventories. During the past 20 years, inventory has also been made on the sewer system together with the installation of district heating. This has resulted in the discovery of incorrect connections between houses and the sewer system. For example, the rainwater from the drainpipes on roofs has been connected to the sewer system instead of the stormwater system causing a higher amount of water in to the treatment plant. This has also been the case with the stormwater wells on the courtyards. This decrease of water to the wastewater treatment plant has resulted in a centralised sewage water management and the water taxes are low. There is one small treatment plant named Spiken and Lidköping´s wastewater treatment plant (the large plant) is dimensioned for 45,000 pe and built 1974. Regarding new data of possible climate effects in a future scenario more precipitation may cause a rise of the water level in the Lake Vänern, then the large plant is probably built 1 metre too low. Otherwise mentioned, it is the large plant that is considered in the scenario below.

3.4.2 Course of events for Lidköping 2000/2001

The biological treatment step was wiped out and it took about a month to get it back. All the measured values on the outgoing water held the restricted limits given from Länsstyrelsen (see Chapter 1.2.1, Table 1, page 7). West of the treatment plant was a pump needed to be installed on the inside of the embankments surrounding the plant and a plug was set in the end of the outgoing pipe out in Lake Vänern to prevent the water from flooding the plant. The plug was made of mud and a tarp. Plastic "bladders" were also used to seal off the system in order to prevent the water from flowing backwards into the system. The treatment plants had to be barricaded from the water rising in Lake Vänern and the estimated cost for that together with pumps, "bladders" and overtime etc during the flooding has been approximated to around 500,000 SEK. During the flooding the maximum amount of water entering the treatment plant was 30,000 m^3/day. Lidåker´s pump station was a critical point since the basements in the surrounding area are very low-lying and easily get flooded with wastewater.

3.4.3 Measures taken

A project is now running with the consultant company DHI in Stockholm to find out if and where there are leakages in the pipes and if these points are controlled at high precipitation and water level. There are both pumps and plugs in store and also sand and plastic to build embankments with are not an issue to get hold of. Measures were taken for a lot of CSO´s. At one critical pump station rebuilding was made to handle an increased flow and the three permanent pumps and one overflow pump was changed to two larger pumps and one as a backup.

3.4.4 Problems

Even though the municipality has made a lot of inventory of their needs, there are still some things that are critical to be done and dealt with. For instance, there is no backup power in case of electricity failure so the possibility of a backflow into the basements is quite high at some pump stations. One other problem is that all the experience of what happened 2000/2001 and what needs to be done if it happens again has not been written down, it is just in people's minds. That may cause confusion and slower ability to handle the same scenario if and/or when it happens again.

3.5 Mariestad

This city which is located southeast in Lake Vänern, see Figure 3.5.1, has 23,825 inhabitants (Mariestad municipality, 2008)

Figure 3.4.1 Mariestad is located southeast in Lake Vänern as the map suggests *(Google maps)*

3.5.1 Background

Half of the amount of wastewater is going to a pump station on the treatment plant area and the other half arrives to a station just outside the plant next to a river. There are just a few combined sewer pipes left, the rest is separated. Four of the six staff working on the plant today was working during the 2000/2001 incident. The wastewater treatment plant was built in the 1950´s. No further background information has been given.

3.5.2 Course of events for Mariestad 2000/2001

The wind had a big influence on how severe the scenarios were. Luckily, it was not that windy most of the time. The basements of 170-180 real estate's were flooded. The normal flow into the treatment plant is around 6000-8000 m^3/day, during the events the number increased to 30,000 m^3/day. The biological treatment had to be bypassed to keep the biological sludge intact. The treatment plant did not need to be barricaded this time but may be in the future if the same thing will happen again. The outflow from the treatment plant still had 10 cm to benefit before the treated water had to be manually pumped out because of the pressure from Lake Vänern.

3.5.3 Measures taken

During the interview, no measures were highlighted to have been taken during these years.

3.5.4 Problems

There is a confidence that the municipality will be on time with all the measures that needs to be taken in the event of a similar flooding as of 2000/2001 when it actually occurs. What would happen if the staffs that are working today do not work then? And what if there is no documentation on what to do or how to handle the situation in a “best way”? How well prepared is the treatment plant to manually pump the treated water out if the pressure from Lake Vänern is higher the next time and exceeds the 10 cm? There are so many unanswered questions and to draw the conclusion that if there are no answers then either the municipality will not face the problems or maybe just do not care to share is very close. Either way, it is worrying since the scenario is bound to happen again.

3.6 Vänersborg

In Vänersborg there are approximately 37,000 inhabitants (Vänersborg municipality, 2009) and the city is located south (west) in Lake Vänern, see Figure 3.6.1, where the water flows out into the river Göta älv.

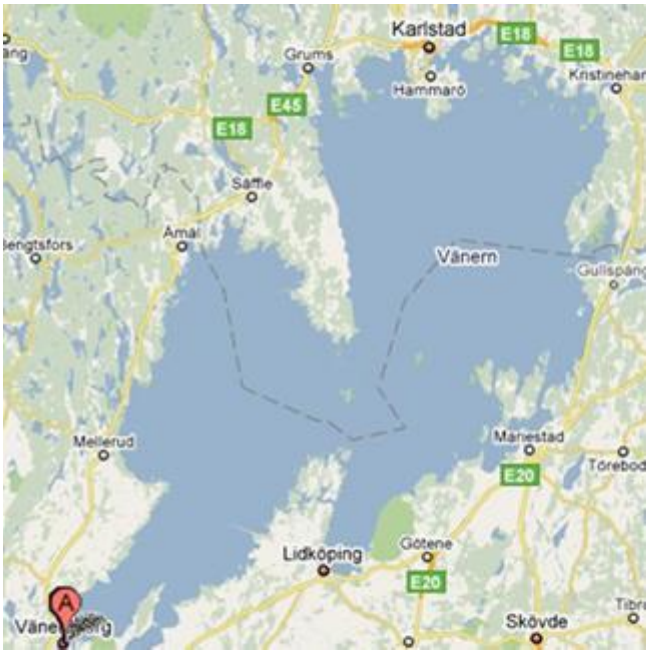

Figure 3.5.1 Vänersborg is located where the mark with an A is *(Google maps)*

3.6.1 Background

Vänersborg has mostly a separated network system and the wastewater treatment plant (Holmängen) has its own accredited chemical laboratory. Holmängen was built 1959. Between the treatment plant and Lake Vänern is a depositing site for the treatment sludge which contains high levels of Chromium (Cr). That is interesting because if Lake Vänern would rise just 50 cm more, the deposit site would be flooded and there would be a huge leakage of that element into the water. The plant is under dimensioned and barely manages to treat the incoming water so that the maximum values for the treated water that is released to the recipients follows the regulations. There is no big pumping station or CSO before the plant. The treatment plant´s lowest point is approximately 46.3 m and it is designed for 28,000 pe.

3.6.2 Course of events for Vänersborg 2000/2001

The usual inflow to Holmängen is approximately 16,000 m^3/day. The highest amount of inflow to the treatment plant was measured in January 9th 2001; the result was 70,000 m^3/day. The grids that is the first step of the treatment plant to take care of the incoming water stopped working during this critical time of 2001 and this resulted in the water flowing back into the system. With Lake Vänern at that high water level made the water that was trying to leave the plant flow backwards instead, back into the wastewater plant. CSO´s had to be made higher and plugs needed to be installed, extra pumps and pipes were also necessary but were not in store. When there was a strong wind from the north, the problems got worse and Lake Vänern rose to above 46 m. That is 1.71 m above the normal water level. The treatment plant did not need to be barricaded. The two pumping stations Smyget and Nabben, each with two pumps of a capacity of 35 m^3, were the most vulnerable during this time. Nabben originally receives foul water from about 5000 people. Estimated cost for the actions is approximately 1.5 million SEK.

3.6.3 Measures taken

Today the plant can handle that level of inflow (70,000 m^3/day), but not without bypassing the biological treatment step to save the active sludge from being wiped out. The grids where the incoming water passes first have been changed. The electricity has been moved from basement level in the plant to the ground level to prevent the electricity to cut off if the plant will get flooded. Some of the CSO´s are rebuilt in the sewage network system and additional material for making them higher and also to plug them are prepared just in case. Non-return valves do exist. If the need for pumps will be critical, a supplier is on standby. Information flyers were sent out to all property owners with buildings in the risk area of flooding during the crisis. There is a computer programme where heights at CSO´s etc and streets that are lying low can be found and localised which is based on experiences from what happened in 2000/2001. A crisis group has been formed to lessen the time between an event occurs and action taken. The group has been active after this event and is collaborating well. There are five small electricity backup sets that can be sent to replace in an emergency and more can be requested/obtained from the city of Trollhättan.

3.6.4 Problems

There might be a problem that there are no extra pumps or pipes in store, the municipality needs to rely on a supplier. Another problem is that the majority of staff members in Holmängen are around 60 years old and is close to retirement. There is only one electrician with vital knowledge and no one to take his place. No documentation is made of what happened 2000/2001 or what should be done if it happens again; it is only in people´s minds. If there is an emergency plan with most of the tasks that needs to be done in case of flooding again it is not shared with the executing staff at the plant. The only plan known is mainly about drinking water yet.

*Every year there are at least 1-5 basements flooding

*There is no known follow up on the water protection area close to the plant, or on the nature reserve Lillån or the reserve for frogs in a swamp close by

3.7 Åmål

There are almost 13,000 inhabitants (Åmål municipality, 2009) in this small town on Lake Vänern´s west side, see Figure 3.7.1.

Figure 3.6.1 Åmål is located where the red mark with an A is *(Google maps)*

3.7.1 Background

There are mostly separated sewer pipes. The treatment plant was built 1965 and is designed for 12,000 pe. The highest point in the treatment plant is 47.4 m and the lowest where the treated water leaves the plant is 44.3 m. The normal water level in Lake Vänern is 44.34 m above sea level and during these events 45.67 m was the highest level without the influence of the wind.

3.7.2 Course of events in Åmål 2000/2001

When the water level increased in Lake Vänern the treatment plant got problems with the outflow of the water. Had the water level in the lake been 17 cm higher, all the basements in the city would probably have been flooded. To build barricades in the city was (and is) not a realistic precaution.

3.7.3 Measures taken

An investigation is underway to check all the valves that to prevent backflow and also that the sewage water will (in case of flooding) go to the stormwater and not the other way. When heavy rain falls or the water level rises like it did 2000/2001 there is supposed to be a preparation/emergency plan on what to do and where to go first, this is something that is on its way but does not have a deadline. In July 2009 the precipitation that was 150 mm/day caused 90 flooded basements which should hurry up the document with the plan. There are pumps and pipes in stock to use. Two new pumps are installed in the treatment plant.

3.7.4 Problems

The experience based knowledge is not written down properly and the "preparation/emergency plan" is not finalised yet. Money is scarce and four people are leaving their jobs.

4 Discussion

Based on the author’s discussions with representatives from the seven municipalities included in this study, there are several areas of concern in regards to flood prevention and emergency preparedness. First, municipal authorities have adopted a reactive approach to flood prevention. In general, respondents indicated a preference for dealing with problems when they occur, rather than taking preventative measures. This may be exacerbated by an organizational culture where subordinates only act when directed to do so by senior management. Such a culture can be inefficient and even dangerous, as low and mid-level employees of municipalities may be best positioned to identify early warning signs of floods and other environmental phenomena. Waiting for direction from above may lead to costly delays in implementing mitigation measures.

It should further be noted that a lack (or excess) of communication, incomplete documentation and non-existent forward-looking strategies in six of the seven municipalities has exacerbated flood damage. Municipalities should have clearly articulated communications procedures between staff and their relevant wastewater treatment plants in the event of flooding. This should include a list of individuals within each organization that should be contacted.

Finally, these procedures and documentation requirements should be formalized in a flood mitigation strategy. Such strategies should follow a similar format and structure across municipalities, thus allowing for consolidation at the regional level. Indeed, future investments in piping and pumping stations (amongst other capital upgrades) could be shared across neighboring municipalities, thus leveraging scale economies.

The lack of consistent data and documentation has made the released volumes during the flooding very difficult to estimate. The amount of chemicals in that water is even more questionable but the concentrations of total nitrogen and total phosphorous measured at the overflow waters from Kristinehamn is used as guiding values.

Some municipalities also reline or change the pipes in the sewage network due to leakage, but this is not always the case. In one municipality the problem was all the wrong or old connections from the houses. Also the knowledge about the capacity of the pumps or the pumping stations is not always known (or at least not shared) and that is strange when they are such important nodes in a flooding scenario. The CSO´s at different points in the network do not have a plan made up for them in the case of flooding. This is problematic as they can be the weakest links in a network.

Not all municipalities could provide a map of the treatment plant with highlighted heights or give the parameters of CSO´s, important pumping stations etc. Some municipalities did not know the capacity of the pumps installed which is surprising when the need for that information is vital if a flooding occurs. When reading about the different events that occurred and the precautions taken by the different municipalities, one may find that there are some differences in detail about the severity of scenarios in 2000/2001, the measures taken and which problems there are in present situation. These differences do not necessarily mean that some municipalities have fewer or a greater number of issues than others. Those municipalities that have shared all the existing and old problems as well as a lot of information and discussions, even if imperfect, are excellent role models. To do the opposite is often worse; ignorance and/or denial can be devastating.

5 Conclusion

After this investigation there are some precautions and conclusions that need to be highlighted/brought to the forefront and shared.

*The municipalities should consider and revise their present organization in a flooding scenario

*The information flow within the organization and also to the inhabitants of the community can always be improved

*Experiences and plans for a flooding scenario should be written down in a manner that is easy to follow

*The work with finding leaks in the pipe network system should be prioritized and continued

*The pump stations capacity should be calculated if it is not known

*Install backup power at sensitive pumping stations in the municipality to prevent backflow into the system

*Try to influence politicians when it comes to economy so the municipalities can be better prepared than before if the previous incident should be repeated.

*A map of the treatment plants with heights should be available, this needs to be established and the function of such a map should be known to all in case of a future flooding

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7 Appendix

7.1 The water level in Lake Vänern 2000/2001

Vattenståndet i Vänern

Table 7.1 Water level in Lake Vänern RH00 *(SMHI, 2001)*

Vattenstånd i Vänern Värdena är angivna i meter över havet (höjdsystem 1900)							
November 2000		**December 2000**		**Januari 2001**		**Februari 2001**	
Datum	m ö h	Datum	m ö h	Datum	m ö h	Datum	m ö h
1/11	44,61	1/12	45,26	1/1	45,61	1/2	45,62
2/11	44,63	2/12	45,27	2/1	45,63	2/2	45,59
3/11	44,64	3/12	45,30	3/1	45,61	3/2	45,58
4/11	44,67	4/12	45,32	4/1	45,60	4/2	45,57
5/11	44,68	5/12	45,33	5/1	45,60	5/2	45,55
6/11	44,69	6/12	45,33	6/1	45,62	6/2	45,54
7/11	44,77	7/12	45,35	7/1	45,62	7/2	45,54
8/11	44,75	8/12	45,37	8/1	45,64	8/2	45,53
9/11	44,78	9/12	45,38	9/1	45,66	9/2	45,54
10/11	44,80	10/12	45,39	10/1	45,67	10/2	45,53
11/11	44,82	11/12	45,40	11/1	45,67	11/2	45,52
12/11	44,85	12/12	45,42	12/1	45,66	12/2	45,53
13/11	44,87	13/12	45,44	13/1	45,67	13/2	45,54
14/11	44,90	14/12	45,46	14/1	45,66	14/2	45,52
15/11	44,92	15/12	45,51	15/1	45,67	15/2	45,51
16/11	44,94	16/12	45,54	16/1	45,66	16/2	45,52
17/11	44,96	17/12	45,55	17/1	45,65	17/2	45,50
18/11	44,97	18/12	45,57	18/1	45,65	18/2	45,51
19/11	44,99	19/12	45,58	19/1	45,64	19/2	45,49
20/11	45,03	20/12	45,59	20/1	45,64	20/2	45,49
21/11	45,04	21/12	45,59	21/1	45,63	21/2	45,49
22/11	45,08	22/12	45,59	22/1	45,62	22/2	45,47
23/11	45,10	23/12	45,60	23/1	45,60	23/2	45,47
24/11	45,12	24/12	45,60	24/1	45,60	24/2	45,44
25/11	45,14	25/12	45,60	25/1	45,60	25/2	45,44
26/11	45,17	26/12	45,59	26/1	45,60	26/2	45,44
27/11	45,18	27/12	45,59	27/1	45,60	27/2	45,42
28/11	45,20	28/12	45,60	28/1	45,60	28/2	45,42
29/11	45,23	29/12	45,63	29/1	45,60		
30/11	45,24	30/12	45,62	30/1	45,60		
x		x		31/1	45,59		

7.2 Questionnaire

How many of you worked during the events year 2000/2001?

How much did Lake Vänern rise?

Which structure has the organization within the municipality?

What happened during the flooding (scenarios) etc?

Is there a combined or separated sewer network system here?

Are the experiences written down?

Is there an action plan in case of similar events?

Is there a map over the wastewater treatment plant with critical heights?

Is there an estimated cost for all the operations during the flooding?

How well prepared do you feel today?

Are there pumps, pipes and other material in store somewhere?

Do you know where to turn if you need assistance?

Which are the normal inflow and outflow to the treatment plant (pump stations etc.) and how did it change during the events?

What are the pump stations, treatment plant, CSO´s etc dimensioned for?

Where there any treatment processes and/or important nodes in the system that stopped functioning and how did you handle that?

Which system of measuring the water level of Lake Vänern do you use?

Do you have any environmental reports or results from the overflow volumes and/or any noticeable effects afterwards to Lake Vänern, nature reserve areas, and similar?

Is there any daily measurements of flow, heights etc available?

Can you provide lab results from the outgoing water (from treatment plant, pump stations, CSO´s etc)?

Is there a risk and/or vulnerability investigation done?

What are the measurements taken since then?

Are there any present problems that you wish to highlight?