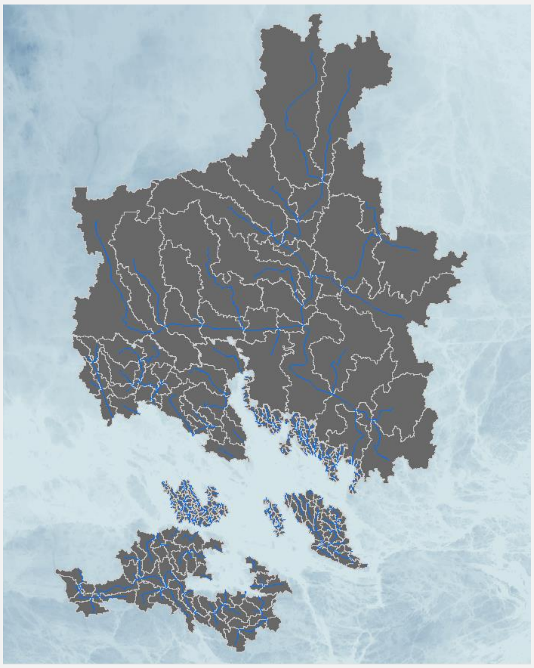

Modeling the effects of socioeconomic development and climate change on the microbial water quality in the catchment of Lake Mälaren

Master's thesis in Infrastructure and Environmental Engineering

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MASTER’S THESIS ACEX30

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Cover:
Modeled catchment area surrounding Lake Mälaren.

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Abstract

Surrounding catchment areas can influence drinking water suppliers negatively. The anthropogenic activities from the catchment areas contribute with fecal contamination to surface water. These activities are expected to change in the future due to socioeconomic development but also due to climate change, which alters hydrological parameters. To assess the effect of future changes on microbial concentrations related to hydrological processes, a useful method could be to use Shared Socioeconomic Pathways (SSP) together with Representative Concentration Pathways (RCP) and a hydrological modeling programme such as ArcSWAT, which other recent studies have begun to use.

In this report, the potential impact of socioeconomic and climate changes on the microbial water quality in the catchment of Lake Mälaren was investigated. This was done by identifying fecal contamination sources, setting up a baseline scenario, and developing and including future scenarios. The baseline scenario was simulated in ArcSWAT for the period 2010-2020, and the future scenarios were simulated for two time periods, 2040-2050 and 2090-2100.

The performance of the model with respect to water flow in three selected subbasins ranged from fair to good and was overall acceptable. The simulated concentrations of *E. coli* and *Cryptosporidium* in the outlet of Stäket were in general high in contrast to the observed or modeled concentrations in previous studies. The concentrations in two other subbasins had a greater similarity with the observed or modeled concentrations in previous studies. According to the model, the most critical contributors to *E. coli* concentrations were wastewater treatment plants and on-site wastewater treatment systems, while for *Cryptosporidium* it was wastewater treatment plants and agriculture. Wastewater treatment plants contributed to the majority of the *E. coli* and *Cryptosporidium* concentrations when present in a water course. According to the modeling results, a scenario with high level of adaptations (improved wastewater treatment, buffer zones and reduced water use) would generally reduce the *E. coli* and *Cryptosporidium* concentrations, while a scenario with lower level of adaptations would generally have similar *E. coli* and *Cryptosporidium* concentrations compared to the baseline scenario. Scenarios with climate change alone would also generally have similar *E. coli* and *Cryptosporidium* concentrations compared to the baseline scenario.

Contents

Preface

This master thesis was carried out at Chalmers University of Technology, Sweden during the Spring 2021. The thesis was conducted within the research project “ClimAQua – Modeling climate change impacts on microbial risks for a safe and sustainable drinking water system” grant number 2017-01413 funded by Formas – the Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning. Supervisors were Ekaterina Sokolova and Mia Bondelind, at Chalmers University of Technology, which we would like to thank for valuable feedback, brainstorming and support throughout the entire project. We would also like to thank Viktor Bergion, at Chalmers University of Technology, for his previous work with the Stäket catchment area and for valuable support for our project. We would moreover like to thank all interviewed persons for providing us with important data for this project. Finally we thank Helene Ejhed at Norrvatten for good information about fecal contamination in the study area and for providing us with relevant literature.

Gothenburg, May 2021
Erik Söderlund
Mathias Lennartsson

1. Introduction

A big challenge today is the ongoing climate change (WHO, n.d) where both human and natural activities are contributory parts of the problem (Ring et. al, 2012). Only the activities from humans are estimated to have caused a temperature rise of almost 1°C globally since the pre-industrial era. If nothing is changed and this rate continues, global warming has a potential to reach a level of 1.5°C between 2030 and 2052 (IPCC, 2018). Due to these temperature changes an international agreement was created called the Paris Agreement, where the goal is to limit global warming below 2°C relative pre-industrial levels. To reach this long-term goal countries work towards lowering their contribution to global warming regarding reduction of greenhouse gas emissions (Cabrera et.al, 2018). If the temperature is not decreased in the near future we will see harmful results on the hydrological cycle in forms of extreme rain events, flooding, longer dry and rainy seasons. Simultaneously, the world is undergoing socioeconomic development with for example changes in population, land use, technology and consumption. This socioeconomic development may bring an intensified resource use with increased food production, water consumption and land use which will increase the environmental stress (Coffey et al., 2016). Climate change and socioeconomic development could consequently lead to an accelerating transport of fecal contamination to water bodies (Rose et al., 2001; Hofstra, 2011) and increase the risk of waterborne disease. Hydrological predictive tools, used to simulate fate and transport of pathogens, can hence be adopted to effectively investigate the impact on water quality (Cuceloglu et.al, 2017). Such models can be used to find solutions in order to improve the present water quality (Mannina et.al, 2006) and to forecast effects of climate change and socioeconomic development on water quality, hence making early water quality improving adaptations possible.

A common and widespread pathogen is *Cryptosporidium* which can occur in public water supplies. The contaminant is more frequent in surface water than groundwater due to surface water being more exposed to run-off and sewage discharges and is therefore more vulnerable to contamination. *Cryptosporidium* is a known waterborne disease that can infect humans at low doses and result in serious health effects. Healthy people will recover in weeks after exposure but if they have a weakened immune system it can persist for a long time and even cause death (epa, 2001). In Östersund in 2010, an outbreak of *Cryptosporidium* occurred in the city's water system and infected 27 000 inhabitants. The source of the pollution is not known and the pathogen remained in the water source for over 3 months (Folkhälsomyndigheten, 2014a).

The bacteria *Escherichia coli* (*E. coli)*, which is excreted by warm-blooded organisms, is commonly present in waters affected by agriculture and sewage. Some strains of *E. coli* may cause disease such as diarrhoeal diseases and urinary tract infections, but in general *E. coli* is harmless (WHO, 2017). Instead, *E. coli* is often included in water quality studies as an indicator of recent fecal contamination and potential presence of pathogens (WHO, 2001). The *E. coli* bacterium is most often found in natural water bodies along with a fecal contamination source, hence it can indicate if there is an increased risk of pathogens (Odonkor and Ampofo, 2013). The concentration of *E. coli* should however not be used as a deciding factor on the actual pathogenic presence. The presence of *E. coli* does not directly mean that other pathogens are present (Odonkor and Ampofo, 2013) and the absence of *E. coli* does not directly mean that other pathogens are absent (WHO, 2017). Pathogens more or less resistant to environmental factors or disinfection can for example affect the correlation of presence between *E. coli* and other pathogens (WHO, 2017).

1.1 Aim and objectives

The aim of this thesis is to use the Soil and Water Assessment Tool (SWAT) to assess the effects of socioeconomic development and climate change on the microbial water quality in the catchment of Lake Mälaren– a drinking water source for approximately two million people.

The objectives are to:

- set-up a hydrological model to simulate the fate and transport of *Cryptosporidium* and *E. coli;*
- formulate a baseline scenario, using current statistical data, for the time period 2010-2020 to investigate and simulate the current water quality conditions and the sources of contamination;
- define future climate and socioeconomic scenarios for the two time periods, 2040-2050 and 2090-2100, for the catchment of Lake Mälaren;
- combine different climate and socioeconomic scenarios to investigate and simulate future microbial water quality.

1.2 Limitations

The study will not include hydrodynamic conditions in larger water bodies and will only consider the north eastern part of Mälaren. Further, the study will only simulate the fate and transport of *E. coli* and *Cryptosporidium* and therefore not consider other contaminants. The duration of the simulations in SWAT will be a time-span of 10 years, and future scenarios will include years 2040-2050 and 2090-2100.

1.3 Research questions

- Which are the major fecal contamination sources within the catchment area?
- How is today's water quality in the catchment area affected by fecal contamination?
- How will socioeconomic development and climate change affect the water quality in the catchment area?

2. Background

The following chapter presents Lake Mälaren and nearby areas, with focus on the investigated subbasins, as well as a review of microbial organisms relevant in the drinking water context. Furthermore, projected future changes regarding climate change and socioeconomic development are explained, and how the combined impact can affect *Cryptosporidium* and *E. coli*. Thereafter, several recent studies on hydrological modeling of climate change and socioeconomic development are reviewed. Lastly, there is a review of studies on modeling fecal contamination sources with focus on methods and assumptions.

2.1 Lake Mälaren and nearby areas

Mälaren is the third largest lake in Sweden with its surface area of 1073 km². The catchment area is approximately 22 600 km². The lake is surrounded by 23 municipalities (Mälarens vattenvårdsförbund, n.d) which use Mälaren for drinking water supply, transportation, recreation and as a sewage recipient (SMHI, 2021). There are five intakes for drinking water located in Mälaren which bring water to the drinking treatment plants. The two largest drinking water treatment plants (DWTP) in the eastern part are Lovö and Norsborg, which together supply 1 240 000 users with clean water. The third largest DWTP is Görväln which treats water for 520 000 users (Johansson, 2014). The area around the lake is dominated by urban areas, forests and bogs, fields and meadows and lakes. Mälaren has several large tributaries which bring 80 % of the inflowing water to the lake. The primary outlet of Lake Mälaren is Norrström, where the water is let out in the Baltic Sea (Sonesten, 2018).

Figure 1. A map of the catchment area surrounding Lake Mälaren (Sonesten et al., 2013).

Since Lake Mälaren consists of many bays and islands it can be divided into several smaller delimited water basins (Figure 2). The water quality is different due to natural causes between the basins, difference in soil composition and water exchange. The lake can be seen as shallow since its mean depth is 12.8 meters, and the depth is less than 3 m in approximately 20 % of the lake (Sonesten, 2018), but the deepest part is up to 66 meters (SMHI, 2021). The difference in volume and in combination with inflow of water makes retention time of the basins vary. Basin A in the western part of Figure 2 is receiving almost 50 % of the inflowing water which results in a fast exchange of water. In the eastern part where the larger and deeper basins are located, the exchange parameter and the retention time is important. Due to a slow water exchange and a long retention time the basins can function as a sedimentation basin (Sonesten, 2018).

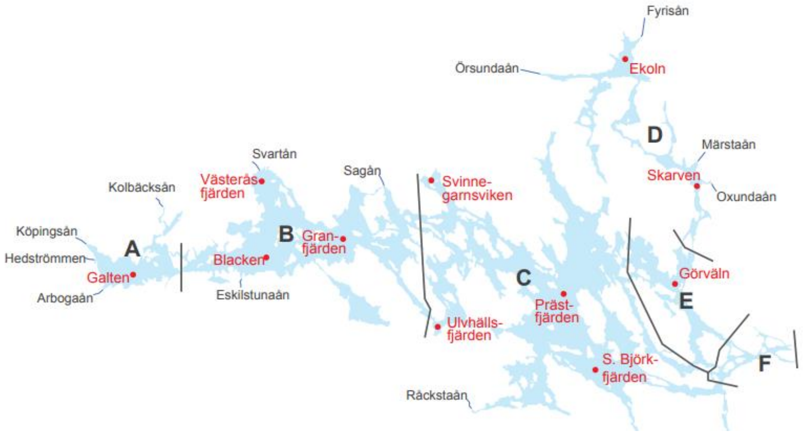


Figure 2. Map of Lake Mälaren divided into smaller water basins (Sonesten et al., 2013).

The western part of the catchment area is different to the northern part regarding the composition of soil which is a major cause to the imbalance of the chemical water composition between the basins. In the northeast the moraine is relatively rich in nutrients and has a small amount of peat. The water is then able to counteract acidification. However, in the northwestern part of the catchment area the conditions are the opposite. The soil in the northwest has a low content of nutrition and a high proportion of peat which makes the water poorly buffered (Sonesten, 2018).

The water quality of Lake Mälaren is vulnerable due to its surrounding environment. Leakages of nitrogen, phosphorus and organic material from the sewage systems and arable and pasture lands are creating undesirable disturbances of the aquatic life and environment (Ejhed, 2020). Disturbances such as algae blooms can become a big problem which will both make the water low on oxygen but it can also be a problem for the DWTPs (Norrvatten, n.d). The water from the surrounding activities does not only contain nitrogen, phosphorus and organic material, it also contains microorganisms such as pathogens and fecal indicators. The source of pathogens and indicators is often excreta and these therefore seen as fecal contamination. The feces often come from humans, grazing animals and wildlife (Johansson, 2014). The most common pathogens related to drinking water are *Campylobacter*, *E. coli*, *Salmonella*, *Shigella*, *Norovirus*, *Cryptosporidium*, *Entamoeba histolytica* and *Giardia* (Säve-Söderbergh, 2013), where *E. coli* often is seen as fecal indicator which can give an indication if there are other fecal contaminants in the water (Ottosson, 2007).

2.2 Microorganisms

Two common microbial organisms related to drinking water are *Cryptosporidium* and *E. coli* (Säve-Söderbergh, 2013). *Cryptosporidium* is seen as a pathogen and *E. coli* is frequently seen as a fecal indicator which can indicate if there are other pathogens present.

2.2.1 *Cryptosporidium*

Cryptosporidium is a protozoan which can cause infections in humans, cattles, lamb and other animals (Folkhälsomyndigheten, 2019). The pathogens are excreted through oocysts in human and animal feces and are transmitted via contaminated water or food (Folkhälsomyndigheten, 2019). Gastrointestinal diseases caused by *Cryptosporidium* is a worldwide issue (Khalil et al., 2018). The severity of infection varies among people, where infections in healthy adults usually resolve within a week, while infections in severely immunocompromised human beings and infants and children of developing countries can be life-threatening (Huang et al., 2004; WHO, 2017). In 2016, there were between 24 600 and 81 900 cases of diarrheal related mortality globally for children under five years old, caused by *Cryptosporidium*, with the majority of the cases (between 14000 and 50400) occurring in Western sub-Saharan Africa (Khalil et al., 2018). Historical *Cryptosporidium* outbreaks in Sweden include events in Östersund in 2010 and Skellefteå in 2011 where 27 000 (Folkhälsomyndigheten, 2014a) and 20 000 (Folkhälsomyndigheten, 2014b) people respectively became infected by *Cryptosporidium* in the drinking water.

Cryptosporidium can only reproduce inside a host, in other words a human or an animal (Folkhälsomyndigheten, 2019), whereas other pathogens, for example *Legionella* can reproduce in water (WHO, 2011). *Cryptosporidium* can however persist in water for several months (WHO, 2011), which compared to other protozoa or bacteria is a long time (WHO, 2011). The protozoa will yet gradually lose viability and ability to infect in water, and the decay rate is usually exponential (WHO, 2011).

Cryptosporidium reaching DWTPs is effectively removed with UV-treatment (WHO, 2011; Svenskt Vatten, 2011) where 99.99% or more of the oocysts can be removed depending on the UV intensity (Svenskt Vatten, 2011). Other treatment techniques include filtration which can remove up to 99.99% (WHO, 2008) and coagulation/flocculation which can remove between 95-99.9% of the oocysts (Svenskt Vatten, 2011). *Cryptosporidium* in wastewater treatment plants (WWTPs) is reduced by sedimentation of oocysts bound to particles (Svenskt Vatten, 2011) and about 90-99% oocysts is removed in four investigated Swedish WWTPs (Ottoson et al., 2006). Sufficient information on the ability of Swedish WWTPs to reduce *Cryptosporidium* is however lacking (Socialstyrelsen, 2014). There is also a lack of information on the ability of Swedish on-site wastewater treatment systems (OWTSs) to reduce *Cryptosporidium* (Socialstyrelsen, 2014) as it is difficult to control outgoing concentrations, and many households have insufficient OWTSs (Socialstyrelsen, 2014).

2.2.2 *E. coli*

Coliforms are members of bacteria groups which can be found in both human and animal feces. Coliform bacteria, such as *E. coli*, are often used as indicators of the presence of potential sewage discharges or diffuse sources such as grazing animals. The bacteria can indicate if there are possible presence of disease-causing viruses, bacterias and protozoans which also are present in the human and animal digestive systems (USEPA, n.d). A water without indicator bacteria does however not necessarily mean that there are no other pathogens in the water, since indicators often have less survival time (Gertzell, 2017).

The persistence of *E. coli* in open environments such as soil, manure and water, is complex, and it depends on physical, chemical and biological factors. Some groups of *E. coli* can resist pH-values of 2.5, that allows them to pass through the stomach, and if it invades the tissues it can cause death. The ability of *E. coli* to grow and survive in an open environment is restricted. It is dependent on the environmental conditions and the availability of nutrients and energy sources, or else it will starve (Elsas et.al, 2010). *E. coli* can be attached to suspended particles in open water and settle to bottom sediments and survive for months, meanwhile in open water without suspended particles it does only survive for a few days (Brinkmeyer et al., 2015).

2.3 Projected future changes

Projections regarding climate change and socioeconomic changes are presented in the following chapter. The chapter also introduces the different representative concentration pathways (RCPs) and shared socioeconomic pathways (SSPs) and how these can be combined.

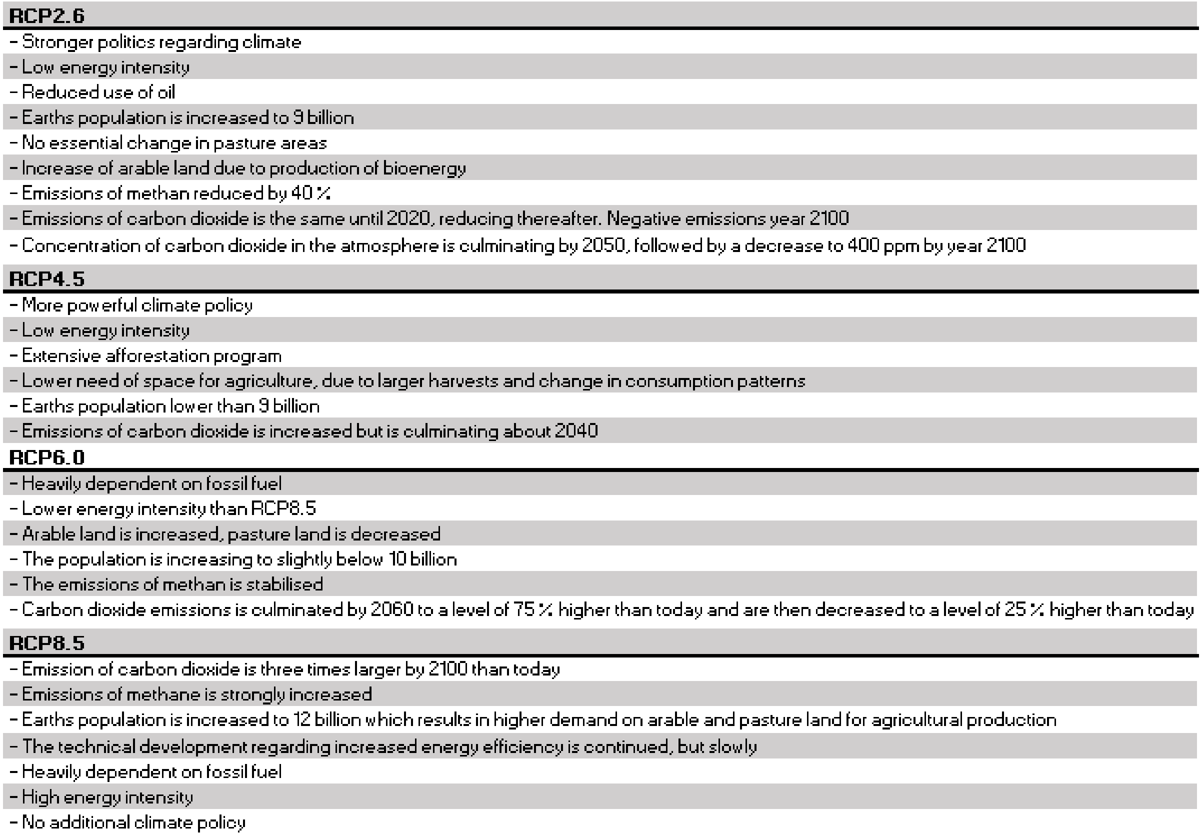
2.3.1 Climate change scenarios

A major global challenge today is climate change. It is known to be caused by the greenhouse gases (GHG), mostly from industrialization and economic growth (Schellnhuber, 2006). In line with the growth of the economy, the world population has increased six times over the last two centuries, which has caused an unsustainable global warming (Zhu & Peng, 2012). According to Schellnhuber (2006) the global temperature has risen by 0.2°C since 1990 and there is evidence that most of it is due to human activities. Projections are telling us that the warming of this century will be between 1.5 and 6°C as a result of the increase of GHG (Schellnhuber, 2006).

The impacts of the ongoing and the forthcoming climate change can alter the hydrological cycle, ecosystems and human health. According to the Intergovernmental Panel on Climate Change (2007) (IPCC) in areas at high latitudes and in wet tropical climates, projections show that there may be an increase by 10-40% of the annual average river runoff. But in dry areas the runoff can decrease by 10-30%. The resilience in the ecosystems will be disturbed by the increased risk of floods, drought, wildfires, land use change, pollution and overexploitation of resources. The health status of humans can be decreased as a result of climate change. Deaths, diseases and injuries are expected to increase due to heat, floods, fires, storms and droughts (IPCC, 2007).

To investigate various scenarios regarding climate change different representative concentration pathways (RCP) have been derived by IPCC and the future projections are calculated from Global Climate Models (GCM), see Table 1 (IPCC, 2014; SMHI, 2019). The RCPs are derived to support research regarding the impact of GHG concentrations and emissions and potential policy responses (Kim et.al, 2013). The RCPs are named by the levels of anthropogenic radiation which are projected before the year 2100. Different radiative forcings mean different increases of GHG in the atmosphere. For example the worst case, RCP8.5, means that there is a projected level of radiative force of 8.5 W/m^2 up to the year 2100. The radiative force is compared with levels at the pre-industrial time, mid 17th century (SMHI, 2018).

Table 1. Explanation of the four different RCPs derived by IPCC (SMHI, 2018).



RCP2.6
- Stronger politics regarding climate
- Low energy intensity
- Reduced use of oil
- Earths population is increased to 9 billion
- No essential change in pasture areas
- Increase of arable land due to production of bioenergy
- Emissions of methan reduced by 40 %
- Emissions of carbon dioxide is the same until 2020, reducing thereafter. Negative emissions year 2100
- Concentration of carbon dioxide in the atmosphere is culminating by 2050, followed by a decrease to 400 ppm by year 2100
RCP4.5
- More powerful climate policy
- Low energy intensity
- Extensive afforestation program
- Lower need of space for agriculture, due to larger harvests and change in consumption patterns
- Earths population lower than 9 billion
- Emissions of carbon dioxide is increased but is culminating about 2040
RCP6.0
- Heavily dependent on fossil fuel
- Lower energy intensity than RCP8.5
- Arable land is increased, pasture land is decreased
- The population is increasing to slightly below 10 billion
- The emissions of methan is stabilised
- Carbon dioxide emissions is culminated by 2060 to a level of 75 % higher than today and are then decreased to a level of 25 % higher than today
RCP8.5
- Emission of carbon dioxide is three times larger by 2100 than today
- Emissions of methane is strongly increased
- Earths population is increased to 12 billion which results in higher demand on arable and pasture land for agricultural production
- The technical development regarding increased energy efficiency is continued, but slowly
- Heavily dependent on fossil fuel
- High energy intensity
- No additional climate policy

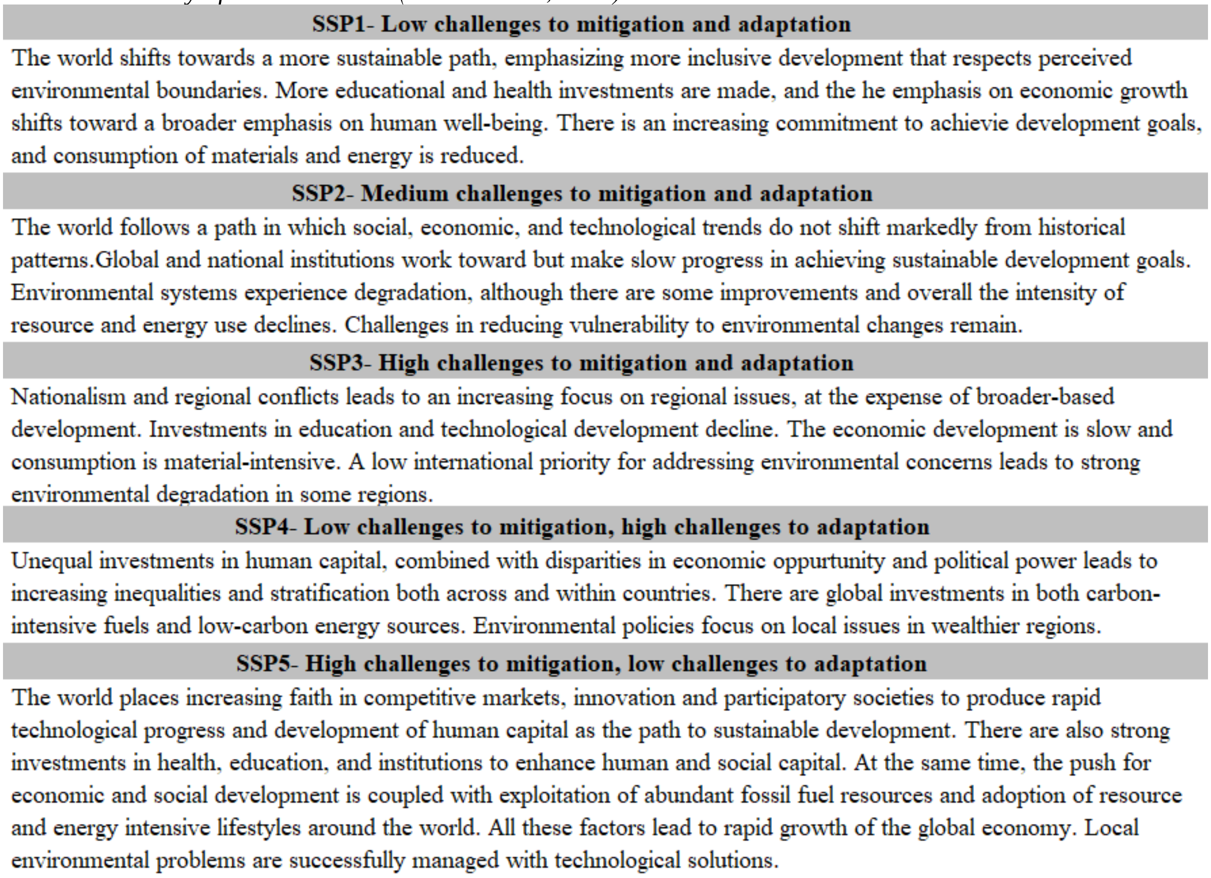
The change in climate will have an impact on Sweden. It will cause higher temperatures and the levels of precipitation will be increased, above all during the winter. The Swedish Meteorological and Hydrological Institute (SMHI) have made simulations in the Stockholm area regarding the mean annual temperature for year 2100 during the winter, for RCP4.5 it will increase with 3°C and for RCP8.5 with 6°C. The rise of temperature will result in a longer vegetation period and an expectation of more consecutive days with a temperature above 20°C. The annual mean precipitation is expected to increase with 20-30%, mostly during winter and spring. The amount of precipitation will be larger in the eastern part of Stockholm area compared to the western. The increased number of consecutive days with higher temperature will have an effect on the snow in forms of less snowfalls and less accumulation on the ground (SMHI, 2015).

SMHI is estimating the discharge of water in the Stockholm area is expected to increase with 10% until the mid-century and thereafter decrease. The streams around the area will be relatively unchanged except for Oxundaån, where the flow will increase with 10%. As a result of the increased temperature, the discharge of water during the winter period will increase drastically compared to the summer period whereas it will decrease. The inflow during the winter with RCP4.5 and RCP8.5 will increase with 40-75% from the levels of today to 2100, and during summer it will decrease with approximately 30% (SMHI, 2015).

2.3.2 Socioeconomic development scenarios

Socioeconomic development scenarios are used in climate research to provide plausible descriptions on how the future may unfold with respect to socioeconomic factors such as birth rate, land use change, consumption pattern and technological and economic development (Jin et al., 2018; Iqbal et al., 2018; Islam et al., 2017; Zandersen et al., 2019). These factors can for example lead to population growth, urbanization and agricultural intensification with increased microbial contamination of aquatic systems as a consequence (Rose et al., 2001; Hofstra, 2011). The current level of scientific understanding in the area is limited, and socioeconomic development may unfold in different and unpredictable ways (Bartosova et al., 2019), meaning that the effect on for example water quality is uncertain, where extending current socioeconomic trends may neglect unpredicted changes in current development from policies, political developments or other events (Bartosova et al., 2019). Shared Socioeconomic Pathways (SSPs) have therefore been developed, by scientific communities on behalf of IPCC (van Vuuren et al., 2011) with five different development scenarios (SSP1-SSP5) used to reflect plausible future developments (Table 2). The goal of applying scenarios is however not to create exact future predictions but rather to discover different plausible developments to make more robust and informed decisions (Berkhout et al., 2002).

Table 2. Summary of SSP narratives (O'Neill et al., 2017)



SSP1- Low challenges to mitigation and adaptation
The world shifts towards a more sustainable path, emphasizing more inclusive development that respects perceived environmental boundaries. More educational and health investments are made, and the he emphasis on economic growth shifts toward a broader emphasis on human well-being. There is an increasing commitment to achievie development goals, and consumption of materials and energy is reduced.
SSP2- Medium challenges to mitigation and adaptation
The world follows a path in which social, economic, and technological trends do not shift markedly from historical patterns.Global and national institutions work toward but make slow progress in achieving sustainable development goals. Environmental systems experience degradation, although there are some improvements and overall the intensity of resource and energy use declines. Challenges in reducing vulnerability to environmental changes remain.
SSP3- High challenges to mitigation and adaptation
Nationalism and regional conflicts leads to an increasing focus on regional issues, at the expense of broader-based development. Investments in education and technological development decline. The economic development is slow and consumption is material-intensive. A low international priority for addressing environmental concerns leads to strong environmental degradation in some regions.
SSP4- Low challenges to mitigation, high challenges to adaptation
Unequal investments in human capital, combined with disparities in economic oppurtunity and political power leads to increasing inequalities and stratification both across and within countries. There are global investments in both carbon-intensive fuels and low-carbon energy sources. Environmental policies focus on local issues in wealthier regions.
SSP5- High challenges to mitigation, low challenges to adaptation
The world places increasing faith in competitive markets, innovation and participatory societies to produce rapid technological progress and development of human capital as the path to sustainable development. There are also strong investments in health, education, and institutions to enhance human and social capital. At the same time, the push for economic and social development is coupled with exploitation of abundant fossil fuel resources and adoption of resource and energy intensive lifestyles around the world. All these factors lead to rapid growth of the global economy. Local environmental problems are successfully managed with technological solutions.

With the new development of SSPs, projections using both RCPs and SSPs are suggested (Van Vuuren et al., 2012), where RCPs cover the climate forcing dimension of different possible futures (Van Vuuren et al., 2011), while SSPs provide narratives of possible socioeconomic developments (O'Neill et al., 2017). According to Berkhout et al. (2002) it is only possible to evaluate full climate change impact on future societies when combining climate change factors with socioeconomic factors. Scientists performing water quality assessments have therefore started to include socioeconomic scenarios (for example change in land use, population, and technology) within their climate change scenarios. The results show that the socioeconomic dimension has a substantial impact, and it may have a similar or even greater impact compared to climate change (Borris et al., 2016; Bartosova et al., 2019; Olesen et al., 2019; Guo et al., 2020; Jin et al., 2018; Islam et al., 2018; Iqbal et al., 2019; Coffey et al., 2016).

There are different possible combinations of SSPs and RCPs depending on the amount of radiative forcing that a specific SSP is expected to generate. SSP1 (with low mitigation and adaption challenges) is consistent with RCP4.5 (as it adheres the “below 2°C target”) and the two are hence frequently combined (Islam et al., 2018; Iqbal et al., 2018). SSP5 (high mitigation and low mitigation challenges) is consistent with RCP8.5 and these two are therefore also frequently combined (Olesen et al., 2019; Jin et al., 2018; Bartosova et al., 2019). SSP3 (high mitigation and adaption challenges) is also consistent with RCP8.5 for developing countries, as it is unrealistic that low-income countries will contribute to the amount of greenhouse gases generated in SSP5 (Islam et al., 2018; Iqbal et al., 2018). SSP2 (intermediate mitigation and adaptation challenges) can also be combined with RCP8.5 (Olesen et al., 2019; Jin et al., 2018; Bartosova et al., 2019), but is only consistent up to the year 2050.

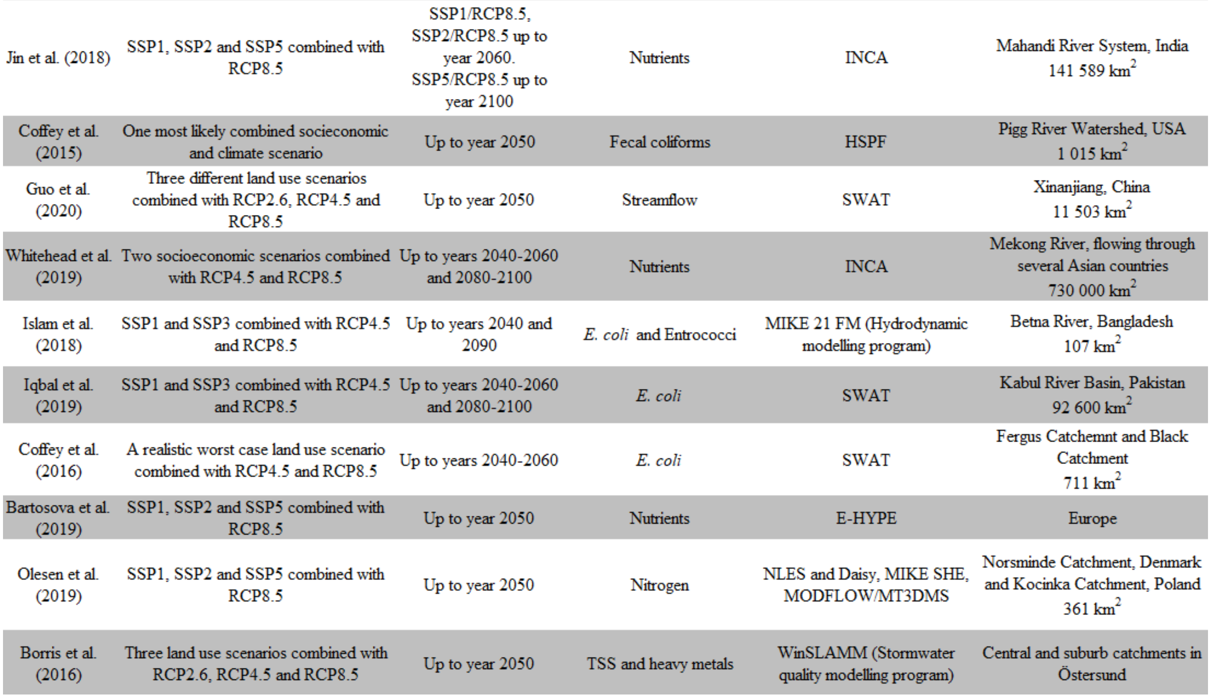
2.3.3 Effects of climatic and socioeconomic factors on microbial water quality

Climatic and socioeconomic factors can have an effect on *Cryptosporidium* and *E. coli*. Higher flows in sewers generated from increased rainfall and population growth can for example contribute to more sewer and WWTP overflows (Svenskt Vatten, 2011; Socialstyrelsen, 2014; Iqbal et.al, 2019). Increased precipitation may further contribute to more surface runoff and therefore increased mobilisation and higher concentrations of *Cryptosporidium* and *E. coli* (Socialstyrelsen, 2014; Pandey et.al, 2012; Vermeulen and Hofstra, 2014). Droughts have also been associated with increased risks of *Cryptosporidium* outbreaks (Lal and Konings, 2018), dry weather usually decreases the survival rate of *Cryptosporidium*, nonetheless it may increase the concentrations of *Cryptosporidium* in relation to water flow (Pozio, 2020). Dry weather also increases the amount of pathogens and indicators that can build up on land before being mobilized by rain (Khan et al., 2015). Studies have found that the decay rate of *Cryptosporidium* and *E. coli* is dependent on temperature, where increasing temperature is making the decay rate increase (King and Monis, 2007; Vermeulen and Hofstra, 2014).

2.4 Previous modeling of climate change and socioeconomic development

As there are potential impacts of climate change and socioeconomic development on microorganisms but also other pollutants, researchers have started to include projections of these factors in hydrological modeling studies. The methods used in ten different studies (Table 3) to generate future projections, mostly for hydrological modeling purposes, are described in chapter 2.4.1 and 2.4.2.

Table 3. Studies including SSP and RCP scenarios in their models.



Source	Projection scenarios	Projection Span	Investigated parameter	Modelling Program	Study Area and Size
Jin et al. (2018)	SSP1, SSP2 and SSP5 combined with RCP8.5	SSP1/RCP8.5, SSP2/RCP8.5 up to year 2060. SSP5/RCP8.5 up to year 2100	Nutrients	INCA	Mahandi River System, India 141 589 km^2
Coffey et al. (2015)	One most likely combined socieconomic and climate scenario	Up to year 2050	Fecal coliforms	HSPF	Pigg River Watershed, USA 1 015 km^2
Guo et al. (2020)	Three different land use scenarios combined with RCP2.6, RCP4.5 and RCP8.5	Up to year 2050	Streamflow	SWAT	Xinanjiang, China 11 503 km^2
Whitehead et al. (2019)	Two socioeconomic scenarios combined with RCP4.5 and RCP8.5	Up to years 2040-2060 and 2080-2100	Nutrients	INCA	Mekong River, flowing through several Asian countries 730 000 km^2
Islam et al. (2018)	SSP1 and SSP3 combined with RCP4.5 and RCP8.5	Up to years 2040 and 2090	*E. coli* and Entrococci	MIKE 21 FM (Hydrodynamic modelling program)	Betna River, Bangladesh 107 km^2
Iqbal et al. (2019)	SSP1 and SSP3 combined with RCP4.5 and RCP8.5	Up to years 2040-2060 and 2080-2100	*E. coli*	SWAT	Kabul River Basin, Pakistan 92 600 km^2
Coffey et al. (2016)	A realistic worst case land use scenario combined with RCP4.5 and RCP8.5	Up to years 2040-2060	*E. coli*	SWAT	Fergus Catchemnt and Black Catchment 711 km^2
Bartosova et al. (2019)	SSP1, SSP2 and SSP5 combined with RCP8.5	Up to year 2050	Nutrients	E-HYPE	Europe
Olesen et al. (2019)	SSP1, SSP2 and SSP5 combined with RCP8.5	Up to year 2050	Nitrogen	NLES and Daisy, MIKE SHE, MODFLOW/MT3DMS	Norsminde Catchment, Denmark and Kocinka Catchment, Poland 361 km^2
Borris et al. (2016)	Three land use scenarios combined with RCP2.6, RCP4.5 and RCP8.5	Up to year 2050	TSS and heavy metals	WinSLAMM (Stormwater quality modelling program)	Central and suburb catchments in Östersund

2.4.1 Climate change

Investigated studies that have included climate change in water quality modeling have used downscaled General Circulation Models (GCMs) to project future climate data, as the GCMs themselves are too coarse and cannot provide high-resolution information for water resources and water quality studies undertaken at a catchment scale (Jin et al., 2018). The number of climate scenarios, RCPs, varies between studies where some studies use one, today most likely (Coffey et al., 2015) or worst case (Jin et al., 2018), scenario. One study has included three scenarios to assess the impact of low, medium and high greenhouse gas emissions developments (Guo et al., 2020). The most common method however, also in line with IPCCs and Paris Accord recommendations for two climate futures (Whitehead et al., 2019), is to use the RCP4.5 and RCP8.5 scenarios (Islam et al., 2018; Iqbal et al., 2019; Coffey et al., 2016; Whitehead et al., 2019). Both scenarios are possible but also contrasting and can therefore frame some of the uncertainties that are linked to modeling with future climate projections. Previous studies have used RCPs mostly only for precipitation and temperature (Coffey et al., 2015; Coffey et al., 2016; Guo et al., 2020; Whitehead et al., 2019; Jin et al., 2018; Iqbal et al., 2019) but also for sea level rise (Islam et al., 2018).

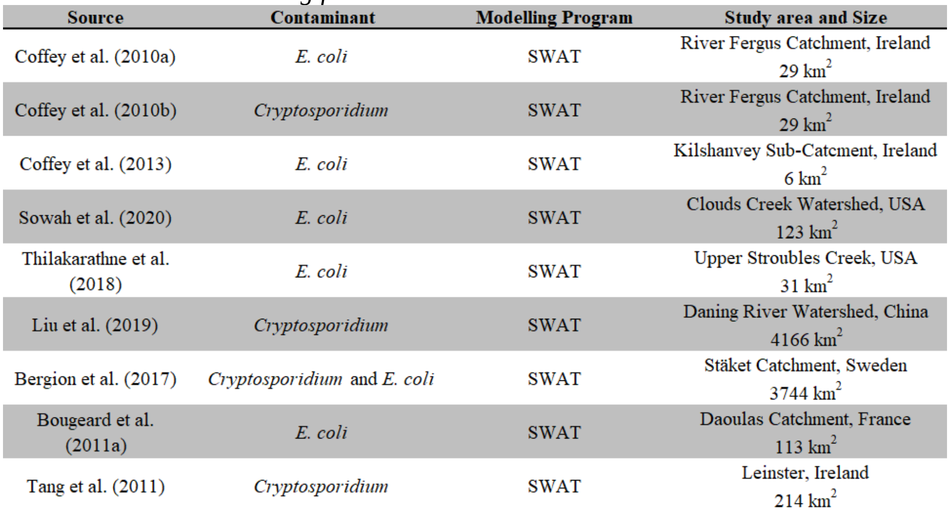
2.4.2 Socioeconomic development

Water quality modeling studies that have included socioeconomic development and have modeled nutrients or pathogens (these are assumed to have similar contamination sources) have covered socioeconomic changes in population, land use, livestock, wastewater treatment and manure management (Coffey et al., 2015; Coffey et al., 2016; Coffey et al., 2020; Jin et al., 2018; Whitehead et al., 2019; Islam et al., 2018; Iqbal et al., 2019; Bartosova et al., 2019; Olesen et al., 2019; Borris et al., 2016). Quantitative changes for these factors have in previous studies mostly been made using relevant sources and best judgement in line with the qualitative narratives presented in each SSP scenario, and/or by directly using numerical projections presented in the IIASA SSP Database (IIASA, 2018). Variables such as population growth and urban share for specific countries as well as land cover area (built-up area, cropland, forest and pasture), demand and production of crops and livestock for specific world regions are projected up to year 2100 in the IIASA SSP Database. Most studies have used two or more socioeconomic scenarios in order to simulate different and contrasting possible pathways. Some studies have moreover combined SSPs and RCPs in pairs (Islam et al., 2018; Iqbal et al., 2019) while other studies have combined several SSPs with one (Olesen et al., 2019; Bartosova et al., 2019; Jin et al., 2018) or several RCPs (Whitehead et al., 2019; Borris et al., 2016) as it is not certain which socioeconomic scenario that will evolve and several SSPs may be consistent with one RCP (Van Vuuren et al., 2013) especially for short term projections (up to 2050).

2.5 Previous modeling of fecal contamination

In order to simulate fecal contamination parameters in hydrological modeling programs, different fecal contamination sources with accompanying contamination loads need to be defined. The methods used in nine different studies (Table 4) to define these parameters are described in chapters 2.5.1, 2.5.2 and 2.5.3.

Table 4. Studies on modeling fecal contamination sources



Source	Contaminant	Modelling Program	Study area and Size
Coffey et al. (2010a)	*E. coli*	SWAT	River Fergus Catchment, Ireland 29 km^2
Coffey et al. (2010b)	*Cryptosporidium*	SWAT	River Fergus Catchment, Ireland 29 km^2
Coffey et al. (2013)	*E. coli*	SWAT	Kilshanvey Sub-Catcment, Ireland 6 km^2
Sowah et al. (2020)	*E. coli*	SWAT	Clouds Creek Watershed, USA 123 km^2
Thilakarathne et al. (2018)	*E. coli*	SWAT	Upper Stroubles Creek, USA 31 km^2
Liu et al. (2019)	*Cryptosporidium*	SWAT	Daning River Watershed, China 4166 km^2
Bergion et al. (2017)	*Cryptosporidium* and *E. coli*	SWAT	Stäket Catchment, Sweden 3744 km^2
Bougeard et al. (2011a)	*E. coli*	SWAT	Daoulas Catchment, France 113 km^2
Tang et al. (2011)	*Cryptosporidium*	SWAT	Leinster, Ireland 214 km^2

2.5.1 Wastewater treatment plants (WWTPs)

Previous studies involving WWTPs have mostly used information on WWTP average discharges, from measurements in WWTPs (Liu et al., 2019; Bergion et al., 2017; Coffey et al., 2010a; Coffey et al., 2010b) or estimations from the total number of connected people (Thilakarathne et al., 2018; Bougeard et al., 2011a) together with an assumed *Cryptosporidium* and/or *E. coli* concentration (Coffey et al., 2010a.; Coffey et al., 2010b; Liu et al., 2019; Bergion, 2017) to calculate the total microbial load. To calculate the load of *Cryptosporidium* and/or *E. coli* in the WWTP effluent a reduction efficiency has been assumed (Coffey et al., 2010b; Coffey et al., 2010a; Bergion et al., 2017), one study has also included direct measurements of *Cryptosporidium* loads in treated sewage (Liu et al., 2019). Both methods resulted in similar *Cryptosporidium* loads.

Overflows, from WWTPs and sewers, can be an important contributor to high pathogen concentrations in water bodies (Svenskt Vatten, 2011; Socialstyrelsen, 2014), this has however only been included in one study using reported daily means over a span of several years (Åström and Johansson, 2015). In one of two simulated areas, mostly consisting of urban land, sewer overflows were an important contributor to temporary peak concentrations of *E. coli* (Åström and Johansson, 2015).

2.5.2 On-site wastewater treatment systems (OWTSs)

Previous studies have used statistics to directly find the total number of OWTSs in the catchment area (Coffey et al., 2010a; Coffey et al., 2010b; Coffey et al., 2013; Sowah et al., 2020) or by assuming that addresses not connected to WWTPs in the catchment area have OWTSs (Thilakarathne et al., 2018; Liu et al., 2019) or that each detached house contains one OWTS (Bergion et al., 2017). Based on the total number of detached houses (SCB, n.d-a) and OWTSs (SCB, n.d-b) in Sweden there are more than twice as many detached houses compared to OWTSs, hence the OWTS contribution of microorganisms may vary greatly depending on used assumption.

The OWTS discharge has in previous studies been calculated by assuming an average household size and a sewage discharge contribution from each person in the household (Coffey et al., 2010a; Coffey et al., 2010b; Coffey et al., 2013; Bergion et al., 2017; Sowah et al., 2020; Thilakarathne et al., 2018; Liu et al., 2019). A raw sewage sludge concentration of *Cryptosporidium* (Coffey et al., 2010b; Liu et al., 2019; Bergion et al., 2017) and *E. coli* (Coffey et al., 2010a; Sowah et al., 2020; Bergion et al., 2017) has been estimated together with an assumed OWTS treatment efficiency (Bergion et al., 2017; Coffey et al., 2010a; Coffey et al., 2010b) and/or a septic tank failure rate (Thilakarathne et al., 2018; Sowah et al., 2020; Coffey et al., 2010a; Coffey et al., 2010b; Coffey et al., 2013). The septic system water quality database in SWAT only accounts for *E. coli* (Åström and Johansson, 2015) and nutrient loads (Sowah et al., 2020). Hence, to, for example, include *Cryptosporidium* loads one need to assume a septic system failure rate (Sowah et al., 2020) which is difficult to assume (Coffey et al,, 2010a; Coffey et al., 2010b). Some studies have therefore recommended (Coffey et al., 2010a; Coffey et al., 2010b) or used (Bergion et al., 2017) a continuous fertilisation management operation to model the influence from OWTSs as a non-point source. This method however also has limitations as some OWTSs, for example OWTSs with sand filters, should rather be characterised as point sources (Bergion et al., 2017).

2.5.3 Agriculture

In earlier studies, local statistics on livestock numbers have been used to find the amount of livestock in investigated catchment areas (Coffey et al., 2010a; Coffey et al., 2010b; Coffey et al., 2013; Thilakarathne et al., 2018; Liu et al., 2019; Sowah et al., 2020; Bergion et al., 2017). Liu et al. (2019) have also used a reproduction factor for the existing livestock. The studies assume that grazing lasts for a certain period where manure of grazing animals is directly deposited in the catchment area, either only as a diffuse source on the ground (Coffey et al., 2010a; Coffey et al., 2010b; Bergion, 2017; Liu et al., 2019; Thilakarathne et al., 2018), or also as a point source directly into streams (Coffey et al., 2013; Coffey et al., 2015; Coffey et al., 2016; Sowah et al., 2020). Animal deposition directly into streams have had considerable impact on the water quality in these studies (Coffey et al., 2013; Coffey et al., 2015; Coffey et al., 2016; Sowah et al., 2020). When previous studies have included *Cryptosporidium*, a prevalence scenario in livestock has also been assumed, which is varying depending on age, type of animal and geographical location (Coffey et al., 2010b; Liu et al., 2019; Bergion et al., 2017). When livestock are not grazing, for example, during winter months, it is assumed that the manure is stored and later used as a fertilizer on arable land. *Cryptosporidium* and *E. coli* will degrade during this storing period, hence some studies have included a "die-off" rate to take this into account (Bougeard et al., 2011a; Tang et al., 2011; Liu et al., 2019). Bergion et al. (2017), did not include a "die-off" rate in stored manure, and suggested that this could be one reason for high microorganism concentrations in their model compared to observations.

3. Method

The following chapter presents the study area and the setup of the SWAT-model which includes model inputs and fecal contamination parameters. Furthermore, the sources of fecal contamination are presented and quantified for the baseline scenario as well as the projected socioeconomic and climate changes. At last, calibration and validation of the model are described.

3.1 Study area

The investigated area is the part of Norrström catchment area that drains water to Prästfjärden, Ekoln, Skarven and Görväln (basin C, D and E in Figure 3) which potentially can affect the Görväln drinking water treatment plant (Figure 4). Upstream areas with flow deviating from the Görväln DWTP (as illustrated in Figure A1 in appendix) are outside of the scope of the thesis. The delineation of basins C, D and E was performed and can be justified by hydrodynamic information, where in basin C the retention time is 1.8 years (Sonesten et al., 2013), hence degradation and sedimentation will reduce the impact of pathogens added to basin A and B. The delineated area was further interesting as it contains several urban areas, for example Uppsala which is Sweden's fourth largest city, but also a lot of rural areas and agriculture. Uppsala County, which covers the majority of the land in the delineated catchment area, has had an increase in agricultural land between 1995-2010 unlike the rest of Sweden (Boverket, 2012).

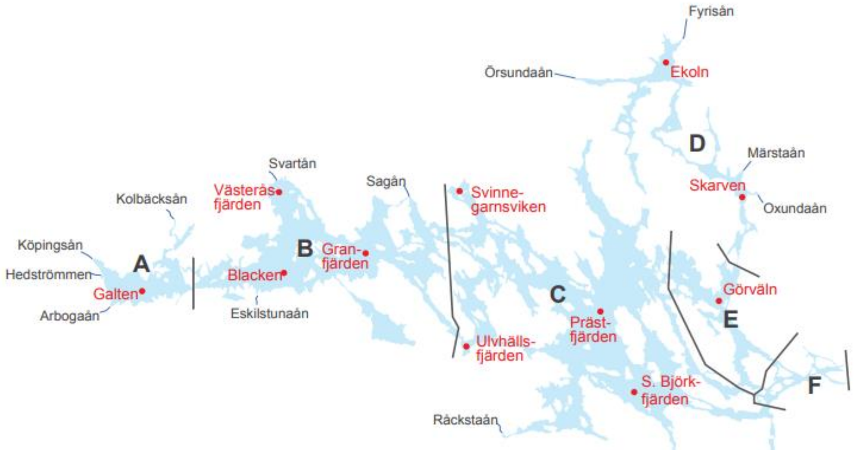


Figure 3. Different basins (basin A, B, C, D, E and F) in Mälaren (Sonesten et al., 2013).

Figure 4. Delineated catchment area (within the bold black boundaries). Map edited from Sonestet et al. (2013).

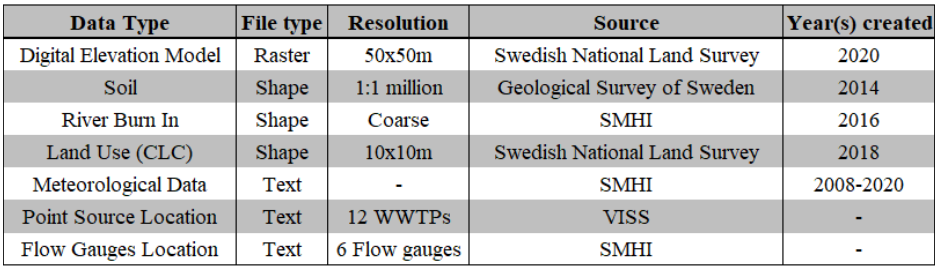
3.2 SWAT

Soil and Water Assessment Tool (SWAT) was formerly developed for the USDA Agricultural Research Service to model hydrological changes. The tool was created to see how different land uses impact water and sediments in larger catchment areas over time (Nietsch et al, 2011). The model includes rain, wind, relative humidity, solar radiation, temperature, soil, hydrology, plant growth, pesticides and land management. The catchment area in SWAT is divided into numerous subbasins, which later are sub-divided into smaller Hydrologic Response Units (HRU) with similar physical properties and can be seen as homogeneous. The HRUs consist of soil characteristics, land use and management (Gassman et al., 2007).

3.2.1 Model setup

ArcSWAT version 2012.10.5.24 was used as a hydrological modeling program in this study. Seven separate models were used in order to include the influence of all areas that are assumed to have a pathogenic impact on Görväln DWTP (Figure 5). Of these models the Stäket catchment area (model 1) was by far the largest while the islands of Strängnäs (model 4) and Ekerö (model 5 and 6) were the smallest. The models were built with topographic conditions, geologic conditions, land use, meteorological conditions, and point sources (wastewater treatment plants) to imitate realistic hydrological conditions. Flow gauges were further added to the models to calibrate and validate the hydrological conditions. The topographic conditions in the models were defined using a digital elevation model (Table 5) retrieved from Swedish National Land Survey (Lantmäteriet, 2020). Geologic conditions were defined using soil data (Table 5), that was used to describe different soil types, from Geological Survey of Sweden (SGU, 2014) and a river burn in model (Table 5) from SMHI that was used to delineate water courses (SMHI, 2016a). Land uses were defined using the "Corine Land Cover" (Table 5) retrieved from Swedish National Land Survey (Lantmäteriet, 2019). Meteorological conditions were defined using meteorological data (Table 5), between 2008 and 2020, retrieved from SMHI (SMHI, n.d-a). Wastewater treatment plants (Table 5) were added as point sources using positions from the VISS database (VISS, n.d). Flow gauges (Table 5) were added as subbasin outputs in the models and the positions were retrieved from SMHI (SMHI, 2020a). Drainage basins and subbasins, retrieved from SMHI, were moreover used to crop the digital elevation model to better fit each model and reduce simulation time. The subbasins from SMHI were also used to see how well the produced subbasins in the model corresponded in size to actual subbasins.

Table 5. Input files used to describe hydrological conditions in the SWAT models or to calibrate and validate the SWAT models.



Data Type	File type	Resolution	Source	Year(s) created
Digital Elevation Model	Raster	50x50m	Swedish National Land Survey	2020
Soil	Shape	1:1 million	Geological Survey of Sweden	2014
River Burn In	Shape	Coarse	SMHI	2016
Land Use (CLC)	Shape	10x10m	Swedish National Land Survey	2018
Meteorological Data	Text	-	SMHI	2008-2020
Point Source Location	Text	12 WWTPs	VISS	-
Flow Gauges Location	Text	6 Flow gauges	SMHI	-

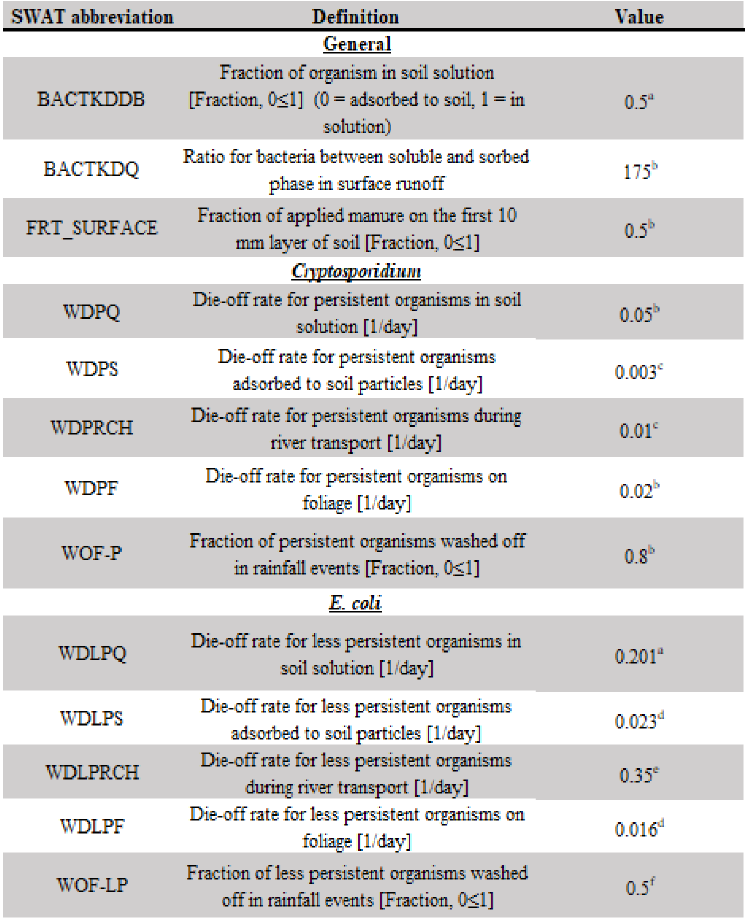
The land uses defined in the Corine Land Cover (CLC) data were redefined to SWAT codes using literature (El-Sadek and Ivrem, 2014; Kostra and Büttner, 2019) together with descriptions of the SWAT codes. Soil data defined by the Geological Survey of Sweden was also redefined to SWAT codes using literature (Johansson, 2014). Both the land use and soil shape data were merged and converted to raster data in ArcMap. The slopes in the model were defined using three slope classes: 0-1%, 1-10% and 10-99.99%. Six rain stations (Skjörby, Vattholma, Vittinge, Mariefred, Södertälje and Vallentuna), three temperature stations (Uppsala, Stockholm and Södertälje), two wind stations (Adelsö and Stockholm) and one relative humidity station (Adelsö) with data from 2008 to 2020 (SMHI, n.d-a) were used as meteorological input. Solar radiation was assumed to be the same as the one present in the SWAT weather database, this assumption was also made by Bergion et al. (2017).

Figure 5. SWAT models in a collected representation. Red triangles represent WWTPs, yellow triangles represent flow gauges, and orange circles represent meteorological stations. WWTPs also have numbers colored with red, connected to the WWTPs listed in Table 10. Numbers colored with black show the different models. In this report model 1 is named Stäket, model 2 Enköping, model 3 Stäket Under, model 4 Strängnäs Island, model 5 and 6 Ekerö, and model 7 Strängnäs.

3.2.2 Fecal contamination parameters

Cryptosporidium is assumed to be the persistent organism and *E. coli* is assumed to be the less persistent organism in the models. The fecal contamination parameters in Table 6 were updated in the SWAT models for both persistent and less persistent organisms.

Table 6. Fecal contamination parameters for SWAT.



SWAT abbreviation	Definition	Value
	General	
BACTKDDB	Fraction of organism in soil solution [Fraction, 0≤1] (0 = adsorbed to soil, 1 = in solution)	0.5[a]
BACTKDQ	Ratio for bacteria between soluble and sorbed phase in surface runoff	175[b]
FRT_SURFACE	Fraction of applied manure on the first 10 mm layer of soil [Fraction, 0≤1]	0.5[b]
	Cryptosporidium	
WDPQ	Die-off rate for persistent organisms in soil solution [1/day]	0.05[b]
WDPS	Die-off rate for persistent organisms adsorbed to soil particles [1/day]	0.003[c]
WDPRCH	Die-off rate for persistent organisms during river transport [1/day]	0.01[c]
WDPF	Die-off rate for persistent organisms on foliage [1/day]	0.02[b]
WOF-P	Fraction of persistent organisms washed off in rainfall events [Fraction, 0≤1]	0.8[b]
	E. coli	
WDLPQ	Die-off rate for less persistent organisms in soil solution [1/day]	0.201[a]
WDLPS	Die-off rate for less persistent organisms adsorbed to soil particles [1/day]	0.023[d]
WDLPRCH	Die-off rate for less persistent organisms during river transport [1/day]	0.35[e]
WDLPF	Die-off rate for less persistent organisms on foliage [1/day]	0.016[d]
WOF-LP	Fraction of less persistent organisms washed off in rainfall events [Fraction, 0≤1]	0.5[f]

a) Bergion (2017)
b) Tang et.al (2011)
c) Coffey et.al (2010b)
d) Bougeard et.al (2011b)
e) Kim et.al (2010)
f) Bougeard (2011a)

The decay rate in SWAT is based on the first order of Chick's law (Baffaut & Sadeghi, 2010), see Equation 1.

$$C_t = C_0 e^{-K_{20} t \theta^{(T-20)}} \qquad \text{(Eq. 1)}$$

C_t [count/100ml], the microbial concentration at time t; C_0 [count/100ml], the initial microbial concentration; K_{20} [day^{-1}], first order of die-off rate at a temperature of 20°C; t [days], is exposure time; θ, temperature adjustment factor; T [°C], temperature.

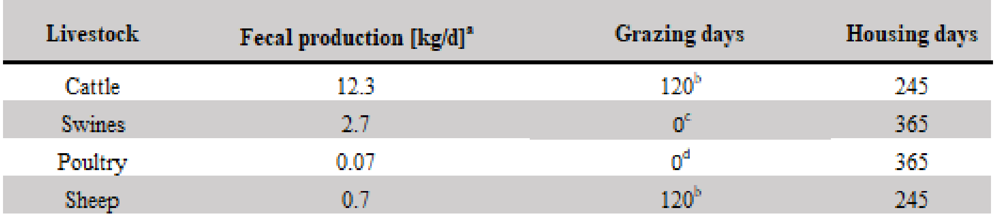
3.3 Fecal contamination sources

The following sub-chapter presents the different sources of fecal contamination which were a part of the input in the SWAT model. The chapter on livestock and fertilization with manure describes the contribution from pasture and arable land. The chapters on municipal wastewater treatment plants and on-site wastewater treatment systems describe the contribution from urban land and detached house properties.

3.3.1 Livestock and fertilization with manure

The contribution of microbial loads from the livestock in the catchment area is through fecal dropping, which is assumed to be only on the pasture land during grazing. Another contribution is the stored feces from the housing period which is used as manure fertilizer. The load from the pasture area was based on the quantity of the livestock in each municipality. Each municipality's pasture area (Table AA1) and the number of livestocks were gathered from Jordbruksverket (2020). The data on the available pasture area and the number of the different animals were used to calculate a density of animals per hectare (Table AA2). The fecal production was based on mean values for the different livestocks and the fecal production per day was calculated, see Table 7. The fecal production for each type of livestock in each municipality during grazing and housing is seen in Table 8. In the bracket called “cattle" different kinds of cows were included such as cows for production of milk, breeding, heifers, beef and calves under one year. The bracket called “swines” includes boars and sows for breeding, pigs for slaughter above 20 kg and piglets under 20 kg. The “poultry”-bracket combines hens for both layering and slaughter. The last bracket “sheep” includes lambs, bags and ewes.

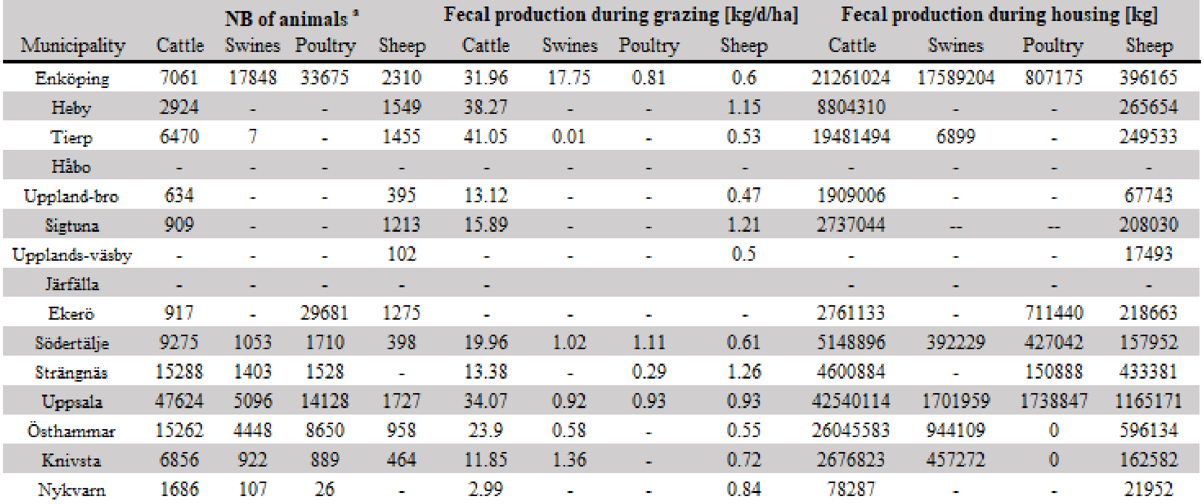
Table 7. Amount of feces produced by each type of livestock each day and days of grazing and housing.



Livestock	Fecal production [kg/d][a]	Grazing days	Housing days
Cattle	12.3	120[b]	245
Swines	2.7	0[c]	365
Poultry	0.07	0[d]	365
Sheep	0.7	120[b]	245

a) Atwill et.al (2012)
b) Jordbruksverket (2021b)
c) Jordbruksverket (2021c)
d) Jordbruksverket (2021d)

Table 8. Number of animals in each municipality, and the fecal production during grazing and housing.

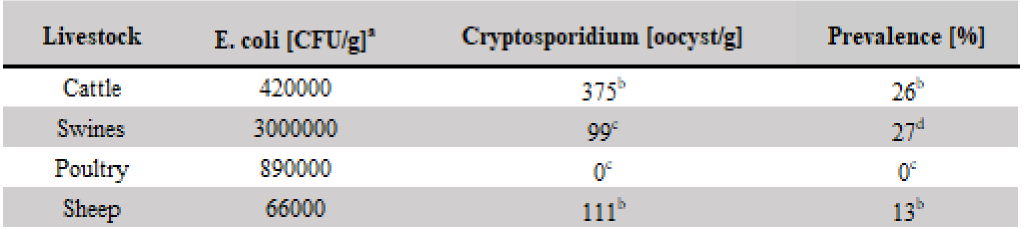


	NB of animals [a]				Fecal production during grazing [kg/d/ha]				Fecal production during housing [kg]			
Municipality	Cattle	Swines	Poultry	Sheep	Cattle	Swines	Poultry	Sheep	Cattle	Swines	Poultry	Sheep
Enköping	7061	17848	33675	2310	31.96	17.75	0.81	0.6	21261024	17589204	807175	396165
Heby	2924	-	-	1549	38.27	-	-	1.15	8804310	-	-	265654
Tierp	6470	7	-	1455	41.05	0.01	-	0.53	19481494	6899	-	249533
Håbo	-	-	-	-	-	-	-	-	-	-	-	-
Uppland-bro	634	-	-	395	13.12	-	-	0.47	1909006	-	-	67743
Sigtuna	909	-	-	1213	15.89	-	-	1.21	2737044	--	--	208030
Upplands-väsby	-	-	-	102	-	-	-	0.5	-	-	-	17493
Järfälla	-	-	-	-	-				-	-	-	-
Ekerö	917	-	29681	1275	-	-	-	-	2761133	-	711440	218663
Södertälje	9275	1053	1710	398	19.96	1.02	1.11	0.61	5148896	392229	427042	157952
Strängnäs	15288	1403	1528	-	13.38	-	0.29	1.26	4600884	-	150888	433381
Uppsala	47624	5096	14128	1727	34.07	0.92	0.93	0.93	42540114	1701959	1738847	1165171
Östhammar	15262	4448	8650	958	23.9	0.58	-	0.55	26045583	944109	0	596134
Knivsta	6856	922	889	464	11.85	1.36	-	0.72	2676823	457272	0	162582
Nykvarn	1686	107	26	-	2.99	-	-	0.84	78287	-	-	21952

a) Jordbruksverket (2020)

To attain the fecal production per hectare for each municipality (Table 8) from grazing animals the density was multiplied with the feces produced, which was later added in the fertilizer database in SWAT. To consider the concentration of *Cryptosporidium* and *E. coli* in livestock feces a literature study were made and the obtained values (Table 9) was added in the fertilizer database in SWAT. Since only the infected organisms excrete pathogens the infected part of the population was important to consider. Prevalence is the relationship between the infected and the healthy individuals in a population (Åström, 2013). The relationship was considered through a factor to correct the concentration of *Cryptosporidium* (Table 9). For the future scenarios it was assumed that the concentration of *Cryptosporidium* and *E. coli* for each livestock and the prevalence of *Cryptosporidium* remains the same.

Table 9. Concentration of E. coli and Cryptosporidium for each livestock and the prevalence of Cryptosporidium.



Livestock	E. coli [CFU/g][a]	Cryptosporidium [oocyst/g]	Prevalence [%]
Cattle	420000	375[b]	26[b]
Swines	3000000	99[c]	27[d]
Poultry	890000	0[c]	0[c]
Sheep	66000	111[b]	13[b]

a) Bergion (2017)
b) Coffey et.al (2010b)
c) Cox et.al (2005)
d) Åström (2013)

The days when the livestocks is not outside, livestock is assumed to be housing and all feces are collected and stored. It was assumed that the housing livestock produce the same amount of feces as when grazing outside. During the manure storing period the concentration of *E. coli* in feces was assumed to decay with a 3-log reduction rate (Bougard et.al, 2011) and the concentration of *Cryptosporidium* was reduced with a die-off factor of 50 % (Tang et.al, 2011; Liu et.al, 2011). The stored manure (Table AA3) was assumed to be fully applied on the arable land (Table AA1) as fertilizer during two periods, 1st March and 1st October (Jordbruksverket, 2021a).

3.3.2 Municipal wastewater treatment plants

Municipal WWTPs (>2000 connected people) were included in the models and can be seen in Table 10. The WWTPs were identified using the map "Vattenkartan" in the VISS database (VISS, n.d), where a map layer only containing WWTPs was filtered out using the sectoral code "90.10" in the map layer "Environmental hazardous activities". The position of each WWTP (VISS, n.d) was also assumed to be the position of WWTP discharge, these positions were further controlled against the discharge positions used by Bergion et al. (2017) for the Stäket model or environmental reports for Strängnäs, Mariefred, Enköping and Bålsta WWTPs. The wastewater flow was either assumed to be constant, using values from environmental reports, or vary daily using data retrieved from personal communication with WWTPs (Table 10). For the five treatment plants with daily variation, it can be seen that the flows can have significant daily variation (Figure AB1), no seasonal trends can however be seen (Figure AB1). No discharge data could be found for Örsundbro WWTP, hence it was assumed that it had the same discharge as Skokloster WWTP based on the number of connected people. For the baseline scenario, Enköping was assumed to have two WWTPs (Örsundsbro and Enköping), while for future scenarios the municipality was assumed to only have one newly built WWTP (Löten) (Länsstyrelsen Uppsala Län, 2020).

Table 10. Average daily wastewater flow and number of connected people at each WWTP. The wastewater flow is either constant or varying with a time resolution of 1 day. For the baseline scenario Enköping is served by two WWTPs while for the future scenarios the municipality is served by only one newly built WWTP (Löten).

Municipality	WWTP name	Average daily flow (m^3/d)	Connected people	Position (in Figure 5)
Östhammar	Österbybruk	1213	2335	1
Uppsala	Björklinge	950*	3687	2
Uppsala	Storvreta	1600*	6291	3
Uppsala	Uppsala	51000*	185900	4
Heby	Heby	732	2709	5
Enköping	Örsundbro**	575	2000	6
Enköping	Enköping**	7670	22000	7
Enköping	Löten***	-	45000	7
Håbo	Bålsta	5997	16000	8
Håbo	Skokloster	575	1911	9
Knivsta	Knivsta	3100	13000	10
Strängnäs	Strängnäs	8100*	16176	11
Strängnäs	Mariefred	1670*	3831	12

* Varying flow with time resolution of 1 day was used in the model
**For baseline scenario
***For future scenarios

To estimate outgoing *E. coli* and *Cryptosporidium* loads from the WWTPs, a raw wastewater concentration and treatment efficiency were assumed. The concentration of *E. coli* in raw wastewater was reported in ranges from 10^4 to 10^9 CFU/100 ml (Chahal et al., 2016; Barrios-Hernandez et al., 2019; Rose et al., 2004; Ohlsson et al., 2011; Dienus et al., 2016) hence a concentration of $10^{5.6}$ CFU/100 ml, which also was measured as a mean concentration during a long-term monitoring project in a Swedish WWTP (Dienus et al., 2016), was assumed. The concentration of *Cryptosporidium* in raw wastewater was reported in ranges from $10^{-1.3}$ to $10^{2.8}$ oocysts/100 ml (Rose et al., 2004; Ottoson et al., 2006; Eregno et al., 2016), hence a concentration of $10^{0.3}$ oocysts/100ml, which also has been measured as a mean concentration in four Swedish WWTPs (Ottoson et al., 2006), was assumed. The treatment efficiency was assumed to be 1.2 $\log_{10}$ for *Cryptosporidium* and 2.4 $\log_{10}$ for *E. coli* (Ottoson et al., 2006).

3.3.3 On-Site wastewater treatment systems

OWTSs are treatment systems that are used to treat sewage from detached houses, which are free-standing residential buildings. The number of OWTSs and detached house properties in each investigated municipality was retrieved from SCB (2021a). In our study only permanent housing, hence a constant loading over the year, was assumed. It was also assumed that 12% of holiday homes in Södermanland County and 14% of holiday homes in Stockholm and Uppsala County were permanently inhabited (SCB, n.d-c). The amount of OWTSs and detached house properties were subsequently used to get OWTS-density factors (OWTSs divided by detached house properties) for all municipalities (Table 11). The corresponding OWTS-density factor was multiplied with the number of detached house properties in each subbassin (retrieved by using the "Property Map" from Lantmäteriet and the map layer "Housing: Detached Houses'') to obtain a geographical distribution of OWTSs in SWAT.

Table 11. OWTS-density factors. OWTS-density is calculated as "OWTSs" divided by "Detached houses".

Municipality	**Östhammar**	**Uppsala**	**Upplands-Bro**	**Tierp**	**Strängnäs**	**Sigtuna**	**Knivsta**	**Håbo**	**Heby**	**Enköping**	**Ekerö**	**Upplands Väsby**	**Nykvarn**	**Södertälje**
Detached houses	11804	30197	5305	8361	10691	6461	4365	6007	6076	11731	9438	5833	3166	12273
OWTSs	3009	9161	874	2637	2593	1648	1801	572	2160	4247	2278	196	981	2532
OWTS-density factor	0.25	0.30	0.16	0.32	0.24	0.26	0.41	0.10	0.36	0.36	0.24	0.03	0.31	0.21

To calculate sewage discharge, all households in the study area were assumed to consume 140 litres per person per day (Svenskt Vatten, 2019) and consist of 2.5 persons (Bergion et al., 2017 Coffey et al., 2010b). To simulate sewage discharge, the "Continuous fertilization" function in SWAT was used. This is a way of treating OWTSs, as adopted by Coffey et al. (2010b) and Bergion et al. (2017). This function however only accepts units of kg per hectare per day, hence the sewage discharge in litres per person per day was converted by assuming a sewage density of 1kg/dm^3 (Bergion et al., 2017; Coffey et al., 2010b) and by dividing by the respective subbasin area. It was estimated that the OWTS sewage discharges were spread evenly over the entire subbasin. Subbasins with ±25% similarity in sewage discharge were moreover categorized, and average discharges for these grouped subbasins were assumed. This categorization enabled us to apply the same sewage discharge to more subbasins instead of applying a separate sewage discharge to all 442 subbasins in the study area and for all scenarios. Even if some accuracy is lost, this method still captures considerable variations in different subbasins. In figure AB2 (which includes the three largest models Stäket, Enköping and Strängnäs) it can be seen that differences in subbasins with exact sewage discharges and with categorization are small.

The concentration of *E. coli* in raw sewage was assumed to be 10^6 CFU/100 ml based on OWTS specific analyzes (Ottoson, 2013). The higher *E. coli* concentration for OWTSs compared to WWTPs may be attributed to that WWTPs also are influenced by additional flows from for example storm water. No OWTS specific *Cryptosporidium* concentration could be found, hence the same concentration as for WWTPs was assumed (10$^{0.3}$ oocysts/100 ml) (Ottoson et al., 2006). The wastewater in OWTSs is to some extent treated. These treatment methods can for example be infiltration plants, soil beds, septic tanks, cleaning wells and closed tanks (Naturvådsverket, 2003). The treatment at each OWTS is not known. Naturvårdsverket (2003) has, however, reported that the treatment among OWTSs in Sweden is distributed according to Table 12. The treatment efficiency for fecal contaminants is known for infiltration plants, closed tanks, sand filters and septic tanks (Naturvårdsverket, 2003; Bergion et al., 2017) and this was assigned according to Table 12. No specific treatment efficiency for *E. coli* or *Cryptosporidium* was however found, hence the same treatment efficiency was used for both *E. coli* and *Cryptosporidium*. Based on the percentage of OWTSs and assigned treatment efficiencies, an average treatment efficiency, of about 0.8log$_{10}$ removal, was assigned and was assumed to be evenly distributed over the study area.

Table 12. OWTS types and treatment efficiencies for E.coli and Cryptosporidium.

Treatment method	Percentage of OWTSs (%)*	Assigned treatment efficiency	Treatment efficiency (%)**
Infiltration plant	37	Infiltration plant	99
Cleaning well	7	Infiltration plant	99
Soil bed	17	Sand filter	95
Closed tank	10	Closed tank	100
Septic tank	26	Septic tank	50
Unknown	3	Septic tank	50

*Naturvårdsverket (2003)
**Naturvårdsverket (2003); Bergion et al. (2017)

3.4 Projected socioeconomic scenarios

For future socioeconomic projections, the three SSP scenarios SSP1, SSP2 and SSP5 were used. SSP1 and SSP5 were used as they are the only scenarios that are consistent with the climate pathways RCP4.5 and RCP8.5 respectively up to 2100, and could hence be simulated up to 2090-2100. However, both SSP1 and SSP5 are relatively extreme scenarios and both these scenarios involve low challenges to adaptation to local environmental problems and health issues. Hence, a business-as-usual scenario, SSP2, with higher challenges to adaptation to local and environmental problems was also used. SSP2 is consistent with RCP8.5 but only up to year 2050 (Van Vuuren et al., 2013; Jin et al., 2018; Olesen et al., 2019; Bartosova et al., 2019), thus SSP2 was simulated only for 2040-2050. In part, the socioeconomic projections in the study area were assumed by interpreting the narratives for each SSP scenario (Tables 13-15), this was used for projections in wastewater treatment, water consumption and buffer zones. In part, the socioeconomic projections in the study area were assumed by using projections from the IIASA database (IIASA, 2018), this was used for projections in population, urbanization, land use and livestock. All quantified socioeconomic changes can be seen in Table 17.

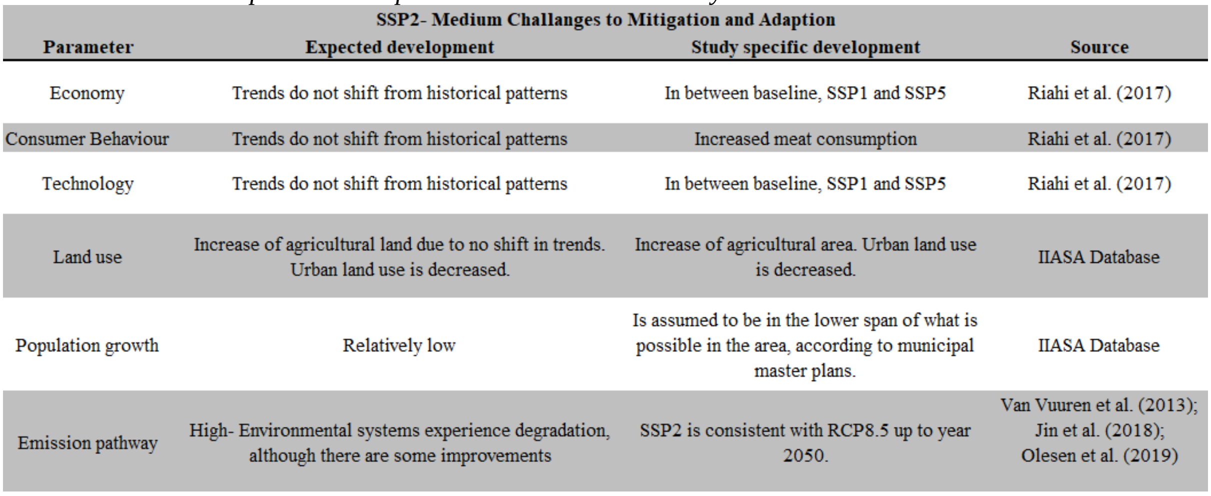
SSP1 is a scenario where the world easily adapts to local environmental and health issues and has low challenges to mitigation, hence this scenario is overall the most sustainable of the three chosen scenarios. In this study, it was assumed that the SSP1 scenario would mean changed consumer behaviour, improved technology, relatively low population growth and low emissions of carbon dioxide (Table 13).

Table 13. SSP1 with expected development downscaled to the study area.

SSP1- Low Challanges to Mitigation and Adaption			
Parameter	**Expected development**	**Study specific development**	**Source**
Economy	Emphasis on economic growth shifts toward a broader emphasis on human well-being. Investments in education and health	Improved consumer behaviour and technology. Increased political instruments to improve environment and human well being	Riahi et al. (2017)
Consumer Behaviour	Reduced resource use from education and awareness	Reduced household water use. Reduced meat consumption	Riahi et al. (2017)
Technology	Technology is improved in order to achieve development goals and improve health	Improved wastewater treatment. Reduced household water use	Riahi et al. (2017)
Land use	Reduced need of agriculture due to changed consumption patterns. More extent afforestation. Urban land is expected to increase parallelly with the population.	Reduced agricultural area. Increase of forest areas. Increased urban land use.	IIASA Database
Population growth	Relatively low	Is assumed to be in the lower span of what is possible in the area, according to municipal master plans.	IIASA Database
Emission pathway	Low	RCP4.5	Islam et al. (2018); Iqbal et al. (2018)

SSP2 is a scenario where trends do not shift from historical patterns, hence this scenario is assumed to be an intermediate scenario with in general less drastic changes than in the SSP1 and SSP5 scenarios. In this study, it was assumed that the SSP2 scenario would mean increased meat consumption, somewhat improved technology and water use, relatively low population growth, and high emissions of carbon dioxide up to 2050 (Table 14).

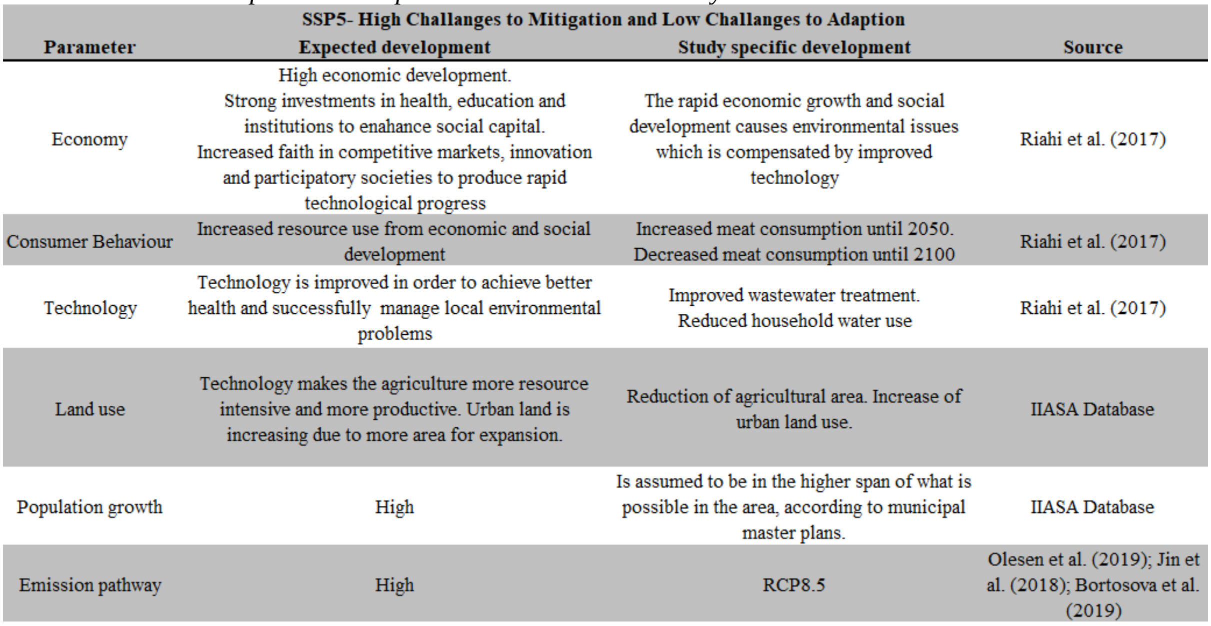
Table 14. SSP2 with expected development downscaled to the study area.



SSP2- Medium Challanges to Mitigation and Adaption			
Parameter	**Expected development**	**Study specific development**	**Source**
Economy	Trends do not shift from historical patterns	In between baseline, SSP1 and SSP5	Riahi et al. (2017)
Consumer Behaviour	Trends do not shift from historical patterns	Increased meat consumption	Riahi et al. (2017)
Technology	Trends do not shift from historical patterns	In between baseline, SSP1 and SSP5	Riahi et al. (2017)
Land use	Increase of agricultural land due to no shift in trends. Urban land use is decreased.	Increase of agricultural area. Urban land use is decreased.	IIASA Database
Population growth	Relatively low	Is assumed to be in the lower span of what is possible in the area, according to municipal master plans.	IIASA Database
Emission pathway	High- Environmental systems experience degradation, although there are some improvements	SSP2 is consistent with RCP8.5 up to year 2050.	Van Vuuren et al. (2013); Jin et al. (2018); Olesen et al. (2019)

SSP5 is a scenario where the world, from innovations, easily adapts to local environmental and health issues, but has high challenges to global warming mitigation. In this study, it was assumed that the SSP5 scenario would mean increased meat consumption up to 2050, but decreased meat consumption up to 2100, improved technology, high population growth, and high emissions of carbon dioxide (Table 15).

Table 15. SSP5 with expected development downscaled to the study area.



SSP5- High Challanges to Mitigation and Low Challanges to Adaption			
Parameter	**Expected development**	**Study specific development**	**Source**
Economy	High economic development. Strong investments in health, education and institutions to enahance social capital. Increased faith in competitive markets, innovation and participatory societies to produce rapid technological progress	The rapid economic growth and social development causes environmental issues which is compensated by improved technology	Riahi et al. (2017)
Consumer Behaviour	Increased resource use from economic and social development	Increased meat consumption until 2050. Decreased meat consumption until 2100	Riahi et al. (2017)
Technology	Technology is improved in order to achieve better health and successfully manage local environmental problems	Improved wastewater treatment. Reduced household water use	Riahi et al. (2017)
Land use	Technology makes the agriculture more resource intensive and more productive. Urban land is increasing due to more area for expansion.	Reduction of agricultural area. Increase of urban land use.	IIASA Database
Population growth	High	Is assumed to be in the higher span of what is possible in the area, according to municipal master plans.	IIASA Database
Emission pathway	High	RCP8.5	Olesen et al. (2019); Jin et al. (2018); Bortosova et al. (2019)

3.4.1 Projected agriculture

The decrease of land use regarding arable and pasture land in SSP1 is assumed to be due to a more educational awareness of the results of over-consumption and lower resource use (Table 13). The reduced need of resources makes agricultural productivity more efficient (Rakovic et.al, 2020) which results in an increased yield for crops on a smaller amount of area. Since SSP1 has a lower demand on agricultural land and an increased yield on the production it leaves a lot of area for forestland (Rakovic et.al, 2020), which in the model was described as a high increase for both periods 2040-2050 and 2090-2100 (Table 17). The decrease in livestock is motivated with low-meat diets and policies for mitigation (Kriegler et.al, 2017). The change regarding the contribution from livestock is seen in Tables AA4-AA5 and AA9-AA10.

The SSP2 scenario is mostly following the present behaviour with intermediate challenges considering mitigation and adaptation (Riahi et.al, 2017; Kriegler et.al, 2017). The trends do not shift so the increase in livestock, arable and pasture land is following the growth of population and food demand (Table 17). The decrease in urban land in combination with the major increase in population will make the cities more dense. Minor regulations will lead to a slight increase in forestation (Krigler et.al, 2017). The contribution from the livestock is seen in Table AA6 and AA11.

The agricultural land for SSP5 will decrease during the whole century (Table 17). The enhanced technology is assumed to make agriculture more resource-intensive and increase in productivity (Rakovic et.al, 2020). This makes the manure treatment more efficient, lower usage per area, and thereby reduces the number of microorganisms in the applied manure. The input from the livestock is seen in Tables AA7-AA8 and AA12-AA13. The manure application is following the progress of livestock. The livestock is assumed to increase at first but then in the later part of the century it is supposed to decrease. The increase can be assumed to be parallel with the population and the meat-rich diet (Kriegler et.al, 2017). Reason for the decrease is assumed to be due to changing consumption patterns and diets in the later part of the century which results in agriculture having to redirect their focus.

Since one can obtain environmental support from the European Union to construct buffer zones along watercourses within the agricultural land (Mälarens vattenvårdsförbund, 2000), it is assumed that the construction of buffer zones will increase over the next decades. In Västmanland county support was distributed for construction of 600 km buffer zones and in Stockholm county there is currently 250 km buffer zones (Mälarens vattenvårdsförbund, 2000). The manure management/treatment-values (Table 17) which are used as input in the model are based on values from the USA and are motivated with a mean value of the loading reduction efficiency of *E. coli* and fecal coliforms. The SSP1 and SSP5 are assumed to have 30 % loading reduction implemented by 2040-2050 and 60 % by 2090-2100, the SSP2 2040-2050 is assumed to have 15 % loading reduction.

3.4.2 Projected population

Changes in population were assumed to affect the total wastewater loads from WWTPs and OWTSs in the study area. The population in the area is, according to projections from municipalities, expected to grow fast compared to projections of the total population of Sweden. Projections of the total population of Sweden shows an increase of 7% and 15% until 2030 and 2050 respectively (SCB, 2021b). However, Uppsala municipality, which is the largest municipality in the study area, is estimated to have a population increase of 13% and 30% until 2030 and 2050 respectively (Figure 6). Sigtuna and Knivsta are moreover expected to have increases of about 60% until 2050 (Figure 6). There are however uncertainties in these local projections, and there are few long term projections. Hence, to make long term projections and frame different scenarios, a relatively low population scenario consisting of SSP1 and SSP2 projections and a high population scenario consisting of SSP5 projections for the Swedish region were used to make future population projections in this study (Figure 6 and Table 17).

In Figure 6 it can be seen that most population projections for municipalities and counties lie within or close to the span of the SSP1/SSP2 and SSP5 projections from the IIASA database (IIASA, 2018). Two municipalities, Uppsala and Enköping (which together contain about 60% of the population in the study area) have moreover presented uncertainty intervals for their population projections (Uppsala Kommun, 2016; Enköpings Kommun, 2018). These intervals are on the border of the SSP1/SSP2 and SSP5 projections which further emphasises the use of SSP projections as high/low population scenarios. The municipalities Knivsta and Sigtuna do however have higher population rates until 2050 compared to the SSP5 scenario (Figure 6). Hence, to take this into account in the high population scenario, the population rates for Knivsta and Sigtuna were assumed to follow local projections until 2050 and the SSP5 projections until 2100. All other municipalities were assumed to only follow the SSP projections (Figure 6 and Table 17).

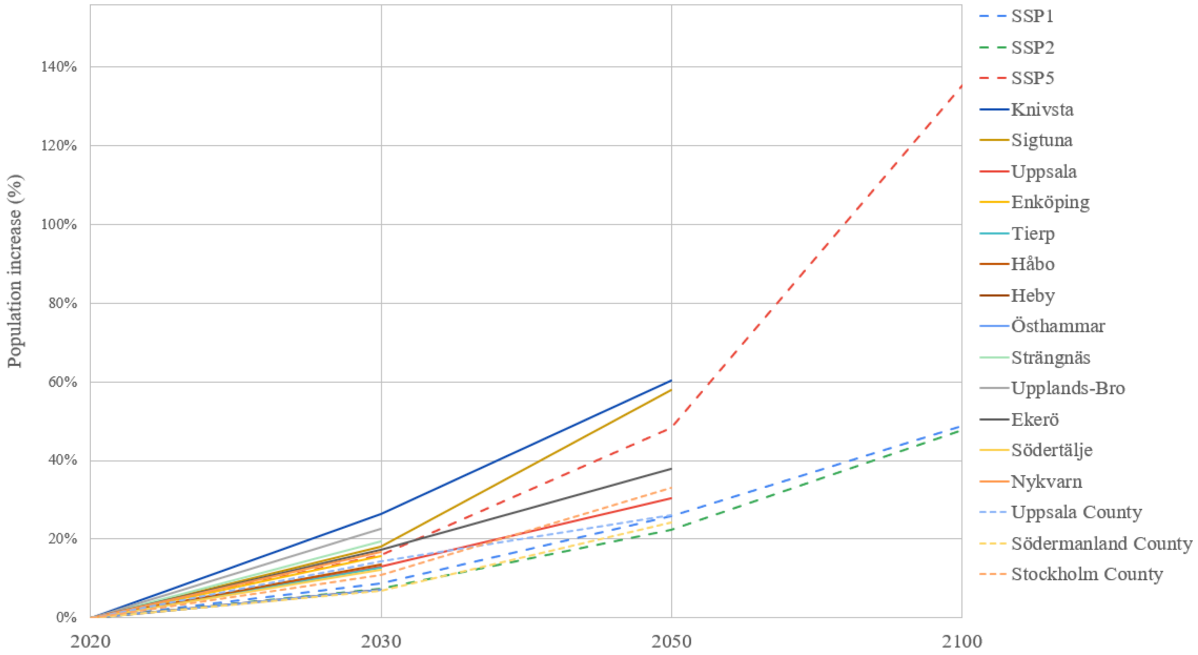


Figure 6. Population increases in the SSP (dashed lines), municipality (continuous lines) and county projections (dotted lines). The municipality and county projections are retrieved from municipal master plans and/or regional specific population forecasts.

Higher population rates are seen and expected in urban areas compared to rural areas. The IIASA database (IIASA, 2018) shows that the urban population share (in comparison to the rural population share) will increase by 10-15% up to 2050 and 20-25% up to 2100 (Table 17). To allow for this inhomogeneity in the model it has been assumed that people connected to WWTPs also live in urban areas while people with OWTSs live in rural areas and that each municipality in the study area is an isolated unit. However, although it is possible to have 100% urbanization in a municipality, which is the case in for example Sundbyberg (SCB, 2018), it was assumed that the urbanization stagnates if reaching 90-99% as rural areas are assumed to continue to be important with agriculture, forestry etc. and as many people prefer rural housing. This stagnation, at around 90%, can also be seen in projections for Sweden up to 2050 (Our World in Data, n.d) and in the SSP projections for the OECD region. In the estimations it was assumed that 2.5 people in general are connected to each OWTS, and for municipalities without WWTPs that are included in this study it was assumed that the urban share is the total number of people in the municipality subtracted by the amount of people with OWTSs (Table AB1-AB2).

For future OWTS flows, the changed population factor (Table AB3) was added directly to the total baseline OWTS flow. For future WWTP flows (Table AB4-AB5), the changed population factor (Table AB3) was only added to the wastewater fraction of the total baseline flow into the WWTPs, whereas additional water (for example stormwater that infiltrates the sewage pipes) was assumed to be constant.

It is however probable that increased precipitation increases the amount of additional water, but it is also probable that the sewer network will be refurbished. It was hence, for this calculation, assumed that increased rain and refurbished sewers would compensate each other. The wastewater share of the total flow into the WWTPs was in part assumed using reported wastewater shares from WWTPs (this has been done for the WWTPs at Östhammar, Uppsala, Heby and Strängnäs). For the other WWTPs, this share was assumed using the mean wastewater share from 26 Swedish municipalities (Clementson et al., 2020). The latter assumption also corresponds well to a scenario where households, influencing the WWTPs in our study, use the mean swedish water consumption of 140 liters per person per day (Svenskt Vatten, 2019).

3.4.3 Projected water consumption

The water consumption in Swedish households is currently about 140 liters per person per day (Svenskt Vatten, 2019) which is high compared to the 50-100 liters per person per day that is considered to be enough to ensure human needs (WHO, 2003). The access to water in Sweden is normally good, but dry weather has lately (for example in 2016, 2017 and 2018) generated water depletion in several Swedish regions during the summer months (SMHI, 2020b). This phenomenon is expected to be more common, especially in Southern Sweden, in the future (Bernes, 2016). To ensure future water supply it was therefore assumed that households would reduce their water consumption.

In the SSP1 scenario, it was assumed that the citizens, from education, become more aware of their general resource management. This awareness together with campaigns to reduce water consumption, political instruments (Chonewicz, 2019; Katz et al., 2016) and new technology, such as individual water meters, which (with some exceptions) are required in new or reconstructed buildings in Sweden (Boverket, 2014), was assumed to lower the household water consumption by 20% by 2050. From following this path, it was estimated that the water consumption would be lowered to 100 liters per person per day (or 30%) by 2100, which is in the upper range for what is necessary to ensure human needs (WHO, 2003).

In the SSP5 scenario it was assumed that new technology and innovation would reduce water consumption. Studies have shown that reusing greywater can reduce the total household water consumption by 30% (Opher & Friedler, 2016) and can be performed using greywater reusing toilets. Other technologies include for example low-water-consuming shower heads and faucets, which can lower the water use from showers and faucets by 20-30% (Conservation Mart, 2016; Hydrao, n.d; VVS Forum, 2018). It was further assumed that these technologies would become widely used in the SSP5 scenario, hence similarly to the SSP1 scenario, a 20% reduction was assumed by 2050 and a 30% reduction was assumed by 2100.

In the SSP2 scenario, it was assumed that the consumption would continue to decrease, following the trend in Sweden for about the last 40 years (SCB, 2017). The decrease was however not assumed to be as great as in the SSP1/SSP5 scenarios, hence a 10% decrease was estimated until 2050.

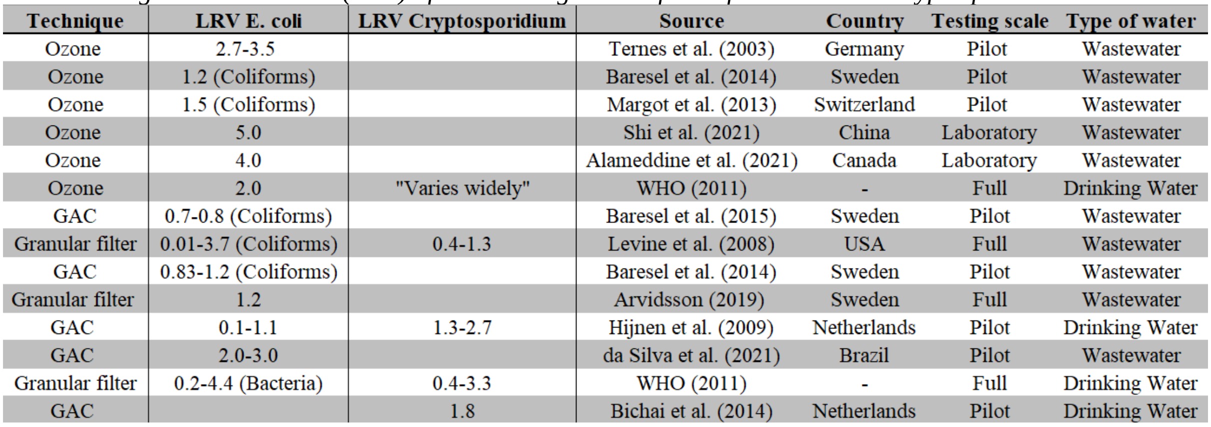
3.4.4 Projected WWTP treatment

Swedish WWTPs are currently mainly focused on removing oxygen consuming substances, nitrogen, and phosphorus (Naturvårdsverket, 2017) and are therefore often constructed with biological and flocculation processes (Naturvårdsverket, 2018). These treatment steps also reduce other substances than the ones targeted, but some substances need more treatment steps to be removed. One example is pharmaceutical substances. Pharmaceuticals that are used by humans are currently transported via wastewater to water bodies without adequate treatment. As pharmaceuticals are slow or even non degradable and biologically active they can accumulate in the biosphere and cause pharmacological effects in organisms (UN, n.d), meaning for example effects on development, growth and reproduction, but also lead to an accelerating resistance to antimicrobials (OECD, 2019). In a study involving a selection of Swedish WWTPs, it could be seen that the levels of several pharmaceutical substances in downstream water bodies exceeded recommended levels (Wallberg et al., 2016). A need for advanced treatment of pharmaceuticals in WWTPs is therefore motivated in order to achieve environmental quality standards in water bodies (Ejhed, 2020; Svenskt Vatten, 2017a).

There are currently no formal requirements to remove pharmaceuticals in Sweden, but it is likely that several larger WWTPs will be required to install techniques to remove pharmaceuticals in the future (Svenskt Vatten, 2017a). Naturvårdsverket has since 2018 distributed investment grants for installation of techniques to remove pharmaceuticals at Swedish WWTPs (Vattenmyndigheterna, n.d). In Linköping, there is already today large-scale treatment of pharmaceuticals (Naturvårdsverket, 2017). The treatment technique that is most promising, and also the one used in Linköping, is by using ozone together with biological active filtration (BAF), for instance via an activated coal or sand filter (Svenskt Vatten, 2017b). Relevant to our study area, Uppsala WWTP will during 2021 try to use ozonation and filtration in order to remove PFAS and pharmaceuticals (Sveriges Radio, 2020). Fyrisån which is downstream the Uppsala WWTP has Sweden's highest loads of PFAS and Diclofenac (a pharmaceutical residue) today (SVT, 2020). Knivsta WWTP has used ozone and a biological filter to remove pharmaceuticals within the framework of a research project (Cimbritz and Mattsson, 2018). In Strängnäs and Enköping there are plans to add ozone and/or biological filters to remove pharmaceuticals if new requirements are set (Armandsson et al., 2015; Länsstyrelsen Uppsala Län, 2020).

To meet environmental quality standards and ensure human health, the WWTPs with reported plans, which include the larger WWTPs in the area, were assumed to adapt their treatment processes to also include pharmaceutical removal in the SSP1 and SSP5 scenarios. Technologies in these scenarios were assumed to improve in order to achieve environmental goals and ensure human health (Table 13 and 15). The treatment techniques were estimated to involve both ozonation and BAF with granular material such as sand or active coal. Ozonation was assumed to mainly remove *E. coli*, as *Cryptosporidium* needs ozonation with a significantly higher CT-value (ozone concentration and time) compared to *E. coli* (WHO, 2009; Svenskt Vatten, 2015; Ødegaard et al., 2014), especially during colder temperatures (WHO, 2009). Treatment efficiency in studies for ozone on *E. coli* and other bacteria varies between 1.2 and 5 log removal (Table 16). Granular filters were assumed to remove both *E. coli* and *Cryptosporidium*, but the treatment efficiency was estimated to be higher for *Cryptosporidium* as the *Cryptosporidium* size is larger than the *E. coli* size. The treatment efficiency in studies for granular filters on *E. coli* and other bacteria varies between 0.1 and 4.4 log removal and on *Cryptosporidium* between 0.4 and 3.3 log removal (Table 16). The differences in efficiency for filters are assumed to be caused by different hydraulic loads and chemical pretreatment and backwashing regimes (Levine et al., 2008). It was therefore further assumed that these parameters would be optimized until 2100.

Table 16. Log Reduction Value (LRV) of ozone and granular filters for E. coli and Cryptosporidium.



Technique	LRV E. coli	LRV Cryptosporidium	Source	Country	Testing scale	Type of water
Ozone	2.7-3.5		Ternes et al. (2003)	Germany	Pilot	Wastewater
Ozone	1.2 (Coliforms)		Baresel et al. (2014)	Sweden	Pilot	Wastewater
Ozone	1.5 (Coliforms)		Margot et al. (2013)	Switzerland	Pilot	Wastewater
Ozone	5.0		Shi et al. (2021)	China	Laboratory	Wastewater
Ozone	4.0		Alameddine et al. (2021)	Canada	Laboratory	Wastewater
Ozone	2.0	"Varies widely"	WHO (2011)	-	Full	Drinking Water
GAC	0.7-0.8 (Coliforms)		Baresel et al. (2015)	Sweden	Pilot	Wastewater
Granular filter	0.01-3.7 (Coliforms)	0.4-1.3	Levine et al. (2008)	USA	Full	Wastewater
GAC	0.83-1.2 (Coliforms)		Baresel et al. (2014)	Sweden	Pilot	Wastewater
Granular filter	1.2		Arvidsson (2019)	Sweden	Full	Wastewater
GAC	0.1-1.1	1.3-2.7	Hijnen et al. (2009)	Netherlands	Pilot	Drinking Water
GAC	2.0-3.0		da Silva et al. (2021)	Brazil	Pilot	Wastewater
Granular filter	0.2-4.4 (Bacteria)	0.4-3.3	WHO (2011)	-	Full	Drinking Water
GAC		1.8	Bichai et al. (2014)	Netherlands	Pilot	Drinking Water

In the SSP1 and SSP5 scenarios, additionally to conventional treatment, log removal of *Cryptosporidium* from filtration was hence estimated to be 0.6 until 2050, which was measured as the average log removal in a study using six different types of filters at full scale WWTPs (Levine et al., 2008). Log removal of *E. coli* until 2050 was estimated to be 1.2 from ozonation, which was measured in pilot scale with water from a Swedish WWTP, and a log removal of 0.2 from filtration which is lower than the *Cryptosporidium* removal and in the span of three studies (Levine et al., 2008; Hijnen et al., 2009; WHO, 2011). Until 2100, it was estimated that log removal of *Cryptosporidium* and *E. coli* from filtration would increase. A log removal of 1.3 of *Cryptosporidium*, which is in the higher span in the study of Leivne et al. (2008), was hence assumed. For *E. coli*, it was assumed that the treatment efficiency from filtration would be increased with 1 $\log_{10}$. A log removal of 1.2 from filtration, which also has been recorded in measurements in a Swedish WWTP (Arvidsson, 2019) and is in the higher span in four studies (Baresel et al., 2014; Baresel et al., 2015; Hijnen et al.,2009; Levine et al., 2008), was hence assumed. Based on reported plans on pharmaceutical removal and the total WWTP flows in the study area, it was assumed that 80% of the wastewater would be treated with advanced treatment by 2050 and 90% would be treated by 2100 (Table AB6). Total log removal, also including conventional treatment, can be seen in Table 17.

Additional treatment steps for pharmaceutical treatment are however expensive in terms of investment costs and many municipalities have other ongoing important investments where for example sewage pipes need to be improved at a high rate and higher demands are placed on already existing treatment (Naturvårdsverket, 2017). This puts municipalities with a small investment budget for water and sewage works in a difficult economical position (Naturvårdsverket, 2017). In the SSP2 scenario it was therefore assumed that treatment of pharmaceuticals has lower priority in relation to the high investment costs and other prioritized developments. Hence, it was assumed in this scenario that none of the WWTPs in the study area would use advanced treatment.

3.4.5 Projected OWTS treatment

There are 700 000 OWTSs in Sweden, about 400 000 or 58% of these are in need of refurbishment, either because they only have septic tanks as a treatment method which is illegal according to The Swedish Environmental Code (1998:808) or because they have turned older than 20 years which can affect the treatment efficiency (Havs- och Vattenmyndigheten, 2013; Palm et al., 2012; Naturvårdsverket, 2003). Measures are therefore taken to improve these OWTSs. For the Norrström basin these measures include supervision, increased connection of OWTSs to WWTPs, and OWTS upgrading when properties are to be constructed or reconstructed, this is for example a requirement in the Uppsala County (Sonesten et al., 2013).

The remediation rate of OWTSs, which includes replacement and upgrade, is today about 1-3% each year why it would take about 70 years to remediate all OWTSs in a business as usual scenario (Havs- och Vattenmyndigheten, 2013). This pathway was assumed to be reasonable in the SSP2 (or business as usual) scenario. The national target is however to increase the remediation rate, up to 5% each year, which means that it would take about 23 years to remediate all OWTSs (Havs- och Vattenmyndigheten, 2013). This pathway was assumed to be reasonable in the SSP1 and SSP5 scenarios which are associated with high levels of adaptations.

For the quantified projections (Table 17 and AB7) it was assumed that replacing septic tanks would affect the *E. coli* and *Cryptosporidium* concentrations. The age of the OWTSs was however not considered, as it was assumed to mainly affect the OWTSs ability to remove phosphorus (Palm et al., 2012; Naturvårdsverket, 2003). 29% of the OWTSs in the baseline scenario were estimated to be served by only septic tanks and have a treatment efficiency of 50% (Table 12). For septic tanks being replaced, it was assumed that the new treatment would be performed by an infiltration plant with a treatment efficiency of 99%. The new treatment efficiencies were added as mean treatment efficiencies for the whole study area (Table 17).

3.5 RCP

In this study, the RCP scenarios RCP4.5 and RCP8.5 were assumed. This assumption is motivated by the contrasting radiative forcings which are assumed in these scenarios. This gives two different climate futures that are separate from each other. The two RCP scenarios can also be combined with the assumed socioeconomic scenarios (SSP1, SSP2 and SSP5) which also motivates the use of these scenarios.

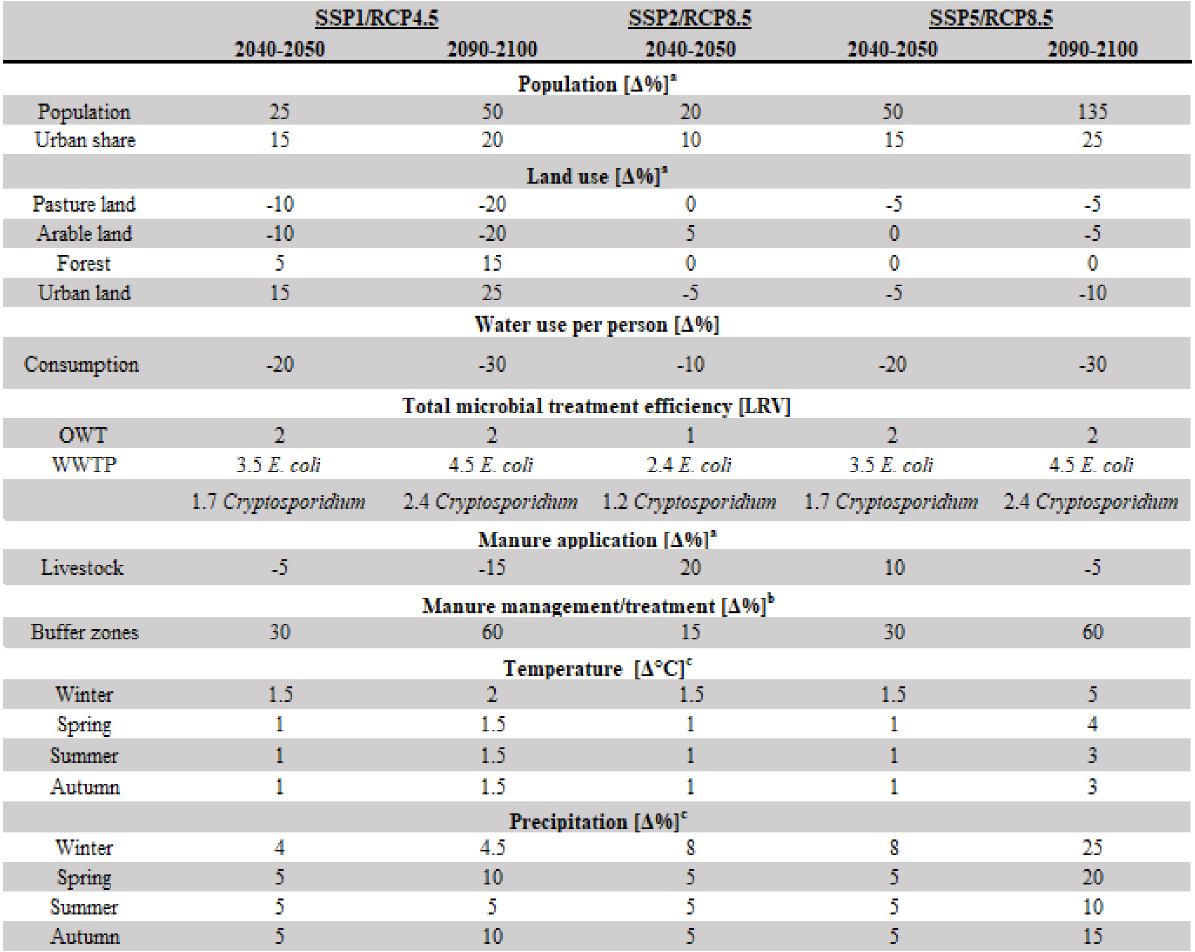
The RCP4.5 scenario is driven by more powerful climate politics, hence the lower increase of temperature compared to the RCP8.5 scenario. The emissions of carbon dioxide increases but culminates at about year 2040 and the low energy intensity can be explained by the low increase of global population. The lowered areas for agriculture, which relies on the larger harvests and altered diets, enhances the afforestation (SMHI, 2018). The precipitation is following the pattern of temperature since there is more water vapor accessible at higher temperatures (SMHI, 2020c).

On the other hand, the RCP8.5 scenario lacks additional climate policy. The carbon dioxide emissions will be three times higher in 2100 than today, methane emissions will be strongly increased, and the society will be heavily dependent on fossil fuel. The global population will be increased by a lot, the areas for pasture and arable land will be in high demand (SMHI, 2018). As a result of the increased GHG emissions the temperature will be highly increased (Solomon et.al, 2010) and parallelly the precipitation will also be increased (SMHI, 2020c).

3.6 Projected socioeconomic development and climate change

Table 17 presents the projected socioeconomic development and climate change for the three modeled scenarios. Future changes in population, urban share, land use, livestock (retrieved from the IIASA database), temperature and precipitation (retrieved from SMHI) were calculated as mean values of the different ten-year time periods. Changes in population were retrieved as projections for Sweden. Changes in urban share, land use and livestock were retrieved as projections for the OECD region. Projected temperature and precipitation were based on a regional climate model which is downscaled for the Norrström catchment area (SMHI, n.d-b). The percentage change (Δ%) in Table 17 is relative to the baseline scenario. Total microbial treatment efficiency in Table 17 is the current treatment efficiency and the potentially enhanced future treatment efficiency combined.

Table. 17. The three modeled scenarios projected socioeconomic development and climate change.



	SSP1/RCP4.5		SSP2/RCP8.5	SSP5/RCP8.5	
	2040-2050	**2090-2100**	**2040-2050**	**2040-2050**	**2090-2100**
Population [Δ%][a]					
Population	25	50	20	50	135
Urban share	15	20	10	15	25
Land use [Δ%][a]					
Pasture land	-10	-20	0	-5	-5
Arable land	-10	-20	5	0	-5
Forest	5	15	0	0	0
Urban land	15	25	-5	-5	-10
Water use per person [Δ%]					
Consumption	-20	-30	-10	-20	-30
Total microbial treatment efficiency [LRV]					
OWT	2	2	1	2	2
WWTP	3.5 *E. coli*	4.5 *E. coli*	2.4 *E. coli*	3.5 *E. coli*	4.5 *E. coli*
	1.7 *Cryptosporidium*	2.4 *Cryptosporidium*	1.2 *Cryptosporidium*	1.7 *Cryptosporidium*	2.4 *Cryptosporidium*
Manure application [Δ%][a]					
Livestock	-5	-15	20	10	-5
Manure management/treatment [Δ%][b]					
Buffer zones	30	60	15	30	60
Temperature [Δ°C][c]					
Winter	1.5	2	1.5	1.5	5
Spring	1	1.5	1	1	4
Summer	1	1.5	1	1	3
Autumn	1	1.5	1	1	3
Precipitation [Δ%][c]					
Winter	4	4.5	8	8	25
Spring	5	10	5	5	20
Summer	5	5	5	5	10
Autumn	5	10	5	5	15

a) IIASA (2018)
b) Richkus et.al (2016)
c) SMHI (n.d-b)

3.7 Calibration and validation

The Nash-Sutcliffe Efficiency (NSE) and R² were used to evaluate the performance of the models. The NSE-value is a measure of how well the simulated data agrees with measured data (Equation 2). The NSE-value has a range of -∞ to 1, where unsatisfactory is below 0, poor 0-0.24, fair 0.25-0.49, good 0.5-0.74, very good 0.75-0.89 and excellent is above 0.9 (Coffey et. al, 2010b; Moriasi et al, 2007).

$$NSE = 1 - (\frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - P)^2} \qquad \text{(Eq. 2)}$$

Whereas O_i is the observed value at time i, P_i is the simulated value at time i and P is the mean of the observed values.

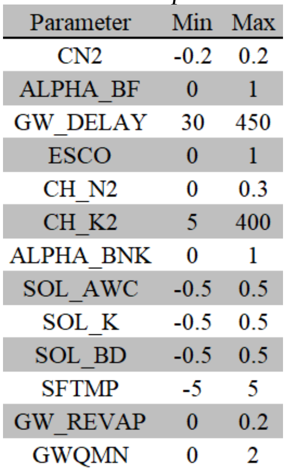
R² is a statistical measure to estimate how well the variance between observed values and the model corresponds (Fernando, 2020) (Equation 3). The range for the R²-value is between 0 and 1, where 0 gives an indication of no correlation and 1 is full correlation, acceptable results of R² is above 0.50 (Coffey et. al, 2010b; Moriasi et. al, 2007).

$$R^2 = \left(\frac{\sum_{i=1}^{n}(O_i - O)(P_i - P)}{\sqrt{\sum_{i=1}^{n}(O_i - O)^2 \sum_{i=1}^{n}(P_i - P)^2}} \right)^2 \qquad \text{(Eq. 3)}$$

Whereas the O_i is the observed value at time i, O is the mean of observed values, P_i is the simulated value at time i and P is the mean of the simulated values.

The software SWAT-Calibration and Uncertainty Program (SWAT-CUP), with the SUFI- 2 analysis routine, was used to calibrate the hydrological models based on monthly averaged water flow. The SMHI water flow stations “2247 Ränsta”-Stäket Sub. 19 and “2248 Härnevi”-Stäket Sub. 29 were used for the Stäket model (see positions in Figure 7). Other flow gauges at Stäket were not used due to differences in subbasin area definition between the SWAT-model and SMHI (Johansson, 2014). The flow station “2249 Åkers Krutbruk”- Strängnäs Sub. 22 was used for the Strängnäs model (see position in Figure 7). Both the Stäket and the Strängnäs model were calibrated with the parameters and ranges in Table 18, these parameters were assumed to affect the hydrological cycle, and were also used by Bergion et al. (2017). The calibration period for Stäket was 2010-2013 and for Strängnäs 2010-2014. The calibration periods were chosen given that they should have similar average and standard deviation of the flow as the validation period. For Stäket, 500 simulations were performed and for Strängnäs 2000 simulations were performed. More simulations were used for the Strängnäs model as the initial observed and modeled values had a greater divergence compared to the Stäket model. Validation period for flow was 2014-2019 for Stäket and 2015-2019 for Strängnäs. NSE and R² values were retrieved using Agrimetsofts calculators (Agrimetsoft, 2020) which uses the same equations as Equation 2 and 3.

Table 18. Flow parameters and ranges used for calibration



Parameter	Min	Max
CN2	-0.2	0.2
ALPHA_BF	0	1
GW_DELAY	30	450
ESCO	0	1
CH_N2	0	0.3
CH_K2	5	400
ALPHA_BNK	0	1
SOL_AWC	-0.5	0.5
SOL_K	-0.5	0.5
SOL_BD	-0.5	0.5
SFTMP	-5	5
GW_REVAP	0	0.2
GWQMN	0	2

Validation of *E. coli* was performed using observed concentrations from Norrvatten (personal communication) and Havs- och Vattenmyndigheten (n.d). *E. coli* gauges were chosen based on that they should be close to a subbasin outlet and that they should not be too affected by downstream processes, for example dilution in water bodies downstream the subbasin. Hence, *E. coli* concentrations observed at the Stäket outlet/Stäket Sub. 38 (Norrvatten), Bonäsbadet/Stäket Sub. 38, Vårdsätrabadet/Stäket Sub. 16 and Taxingebadet/Strängnäs Sub. 40 (Havs- och Vattenmyndigheten) were used (see positions in Figure 7). No observed *Cryptosporidium* concentrations at any of the subbasin outlets in our study could be found. The concentrations of *Cryptosporidium* were hence compared to results from other studies that used hydrological modeling to simulate fate and transport of *Cryptosporidium* (Coffey et al., 2010b; Tang et al., 2011) and one study that has observed *Cryptosporidium* concentrations at nine observation points in Sweden (SVU, 2011). The concentrations by Coffey et al. (2010b) and Tang et al. (2011) were modeled in catchment areas in Ireland. Ireland lies within the same climate zone as our study area (UK Meteorological Office, 2015), hence the modeled environments were assumed to be similar and the concentrations therefore somewhat comparable to the ones in our study.

4. Results

In this chapter the calibration and validation results are first presented followed by results of microbial organism concentrations in the baseline and future scenarios. The most influential sources to *E. coli* and *Cryptosporidium* concentrations in the SWAT-models are also presented. The results are presented with mean concentrations, as it was assumed that mean concentrations better could enable us to see trends and reasons for certain concentrations, compared to for example maximum concentrations which to a higher degree were assumed to occur irregularly with more elusive reasons. All subbasins, flow gauges, *E. coli* gauges and WWTPs used and mentioned in the results can be seen in Figure 7. Average *E. coli* and *Cryptosporidium* concentrations for all subbasins over 10-year time spans, used for Figures 11, 16 and A17-A18 can be seen in Figure A2-A15.

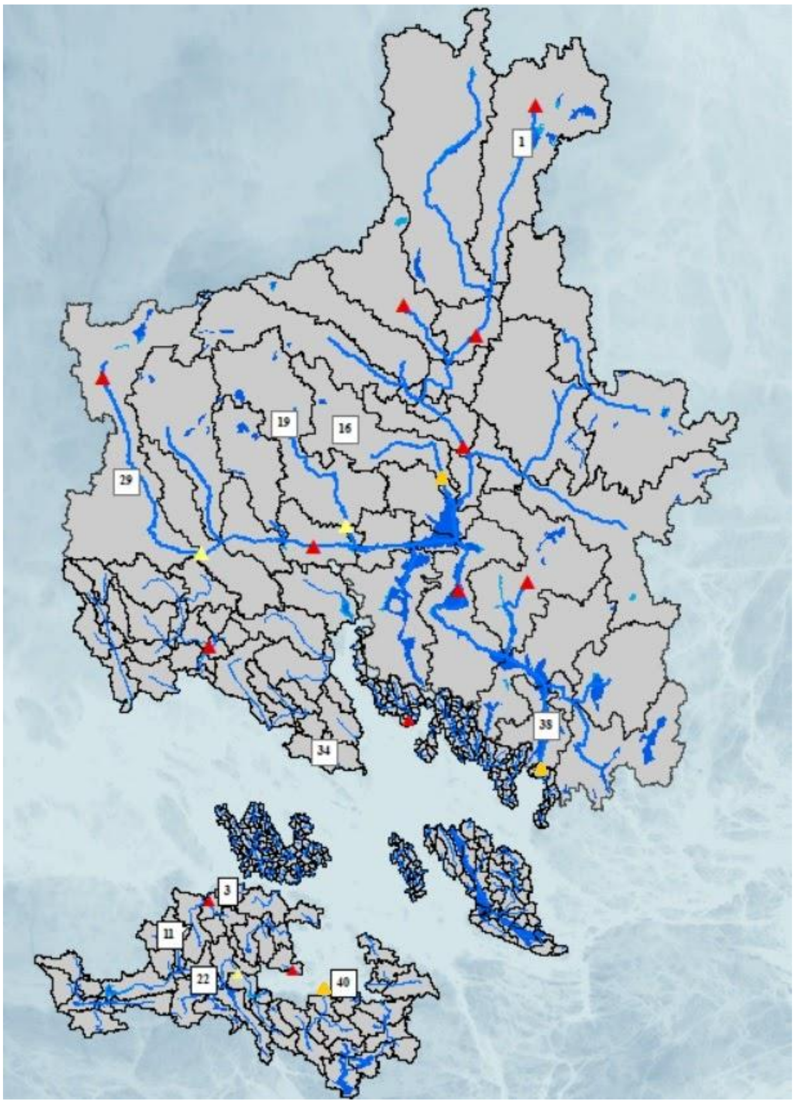
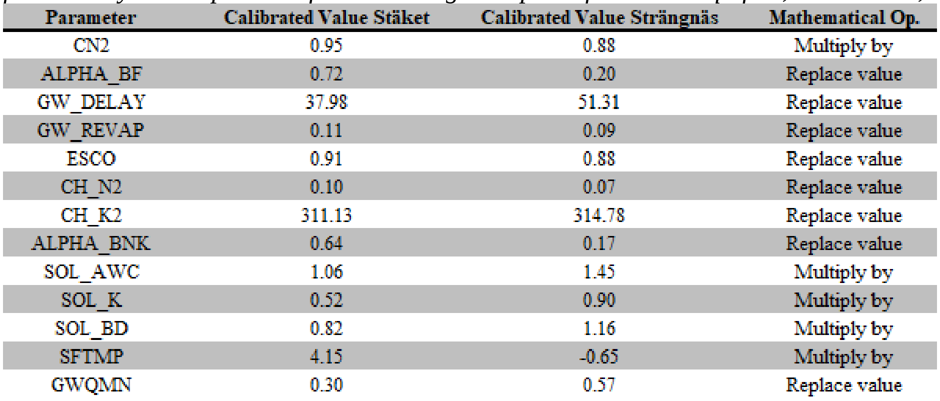


Figure 7. Overview image of the study area with subbasin numbers, flow gauges (yellow triangles), E. coli gauges (orange triangles) and WWTPs (red triangles) mentioned in the result. Rivers, water bodies and wetlands are also included in the figure.

4.1 Water flow calibration and validation

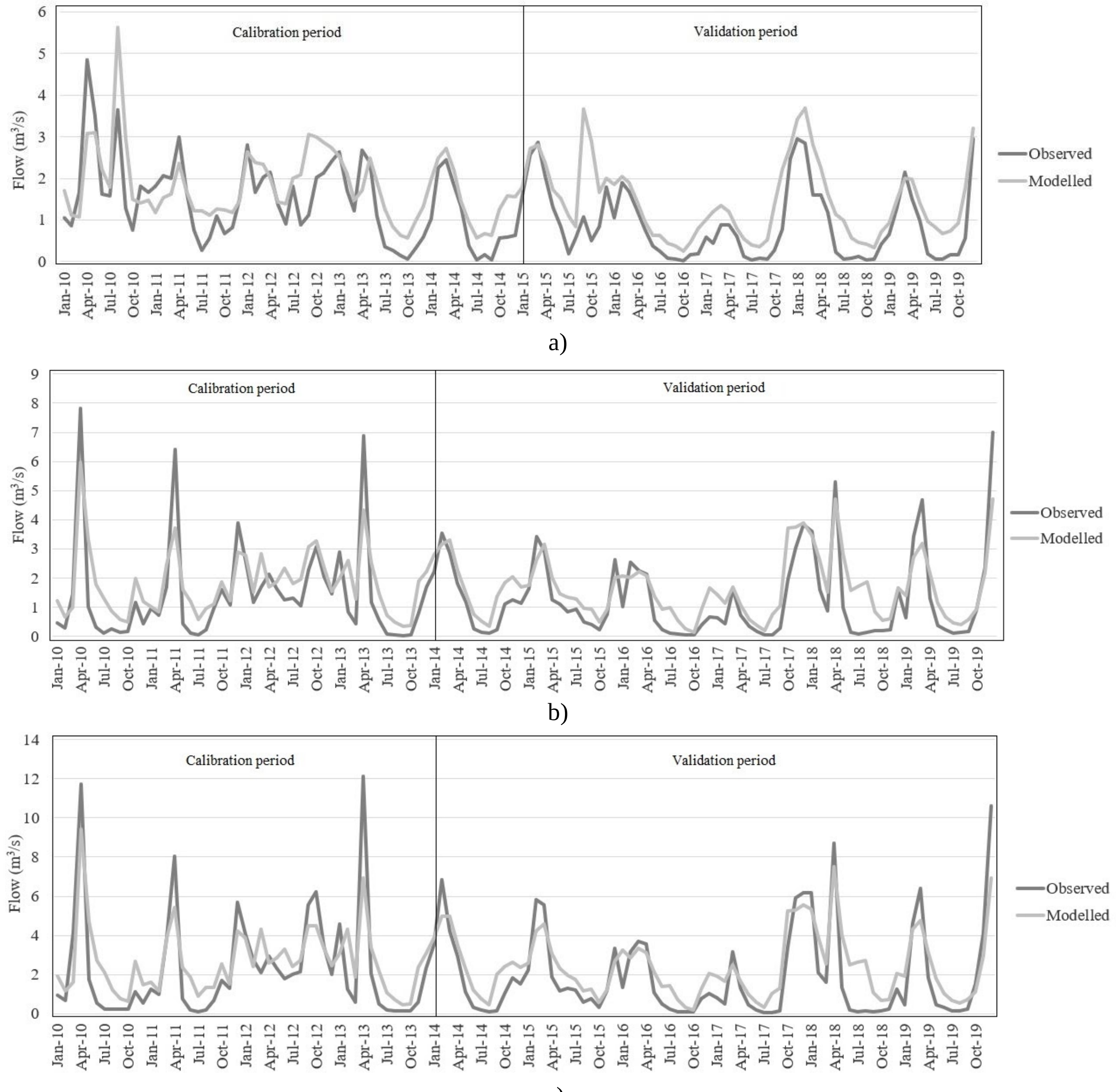
Flow calibrations for Strängnäs Sub. 22 and Stäket Sub. 19 and 29 resulted in the calibrated parameter values presented in Table 19.

Table 19. Calibrated parameter values for Stäket and Strängnäs. These parameters were assumed to affect water flow as they are responsible for describing transport of water in aquifers, in channels, in soil and on land.



Parameter	Calibrated Value Stäket	Calibrated Value Strängnäs	Mathematical Op.
CN2	0.95	0.88	Multiply by
ALPHA_BF	0.72	0.20	Replace value
GW_DELAY	37.98	51.31	Replace value
GW_REVAP	0.11	0.09	Replace value
ESCO	0.91	0.88	Replace value
CH_N2	0.10	0.07	Replace value
CH_K2	311.13	314.78	Replace value
ALPHA_BNK	0.64	0.17	Replace value
SOL_AWC	1.06	1.45	Multiply by
SOL_K	0.52	0.90	Multiply by
SOL_BD	0.82	1.16	Multiply by
SFTMP	4.15	-0.65	Multiply by
GWQMN	0.30	0.57	Replace value

Calibration and validation for the Strängnäs and Stäket area (Figure 8) resulted in NSE and R^2 values as shown in Table 20. The NSE values range from fair in Strängnäs Sub. 22 to good in Stäket Sub. 19 and 29, and R^2 values are all acceptable.



a)

b)

c)

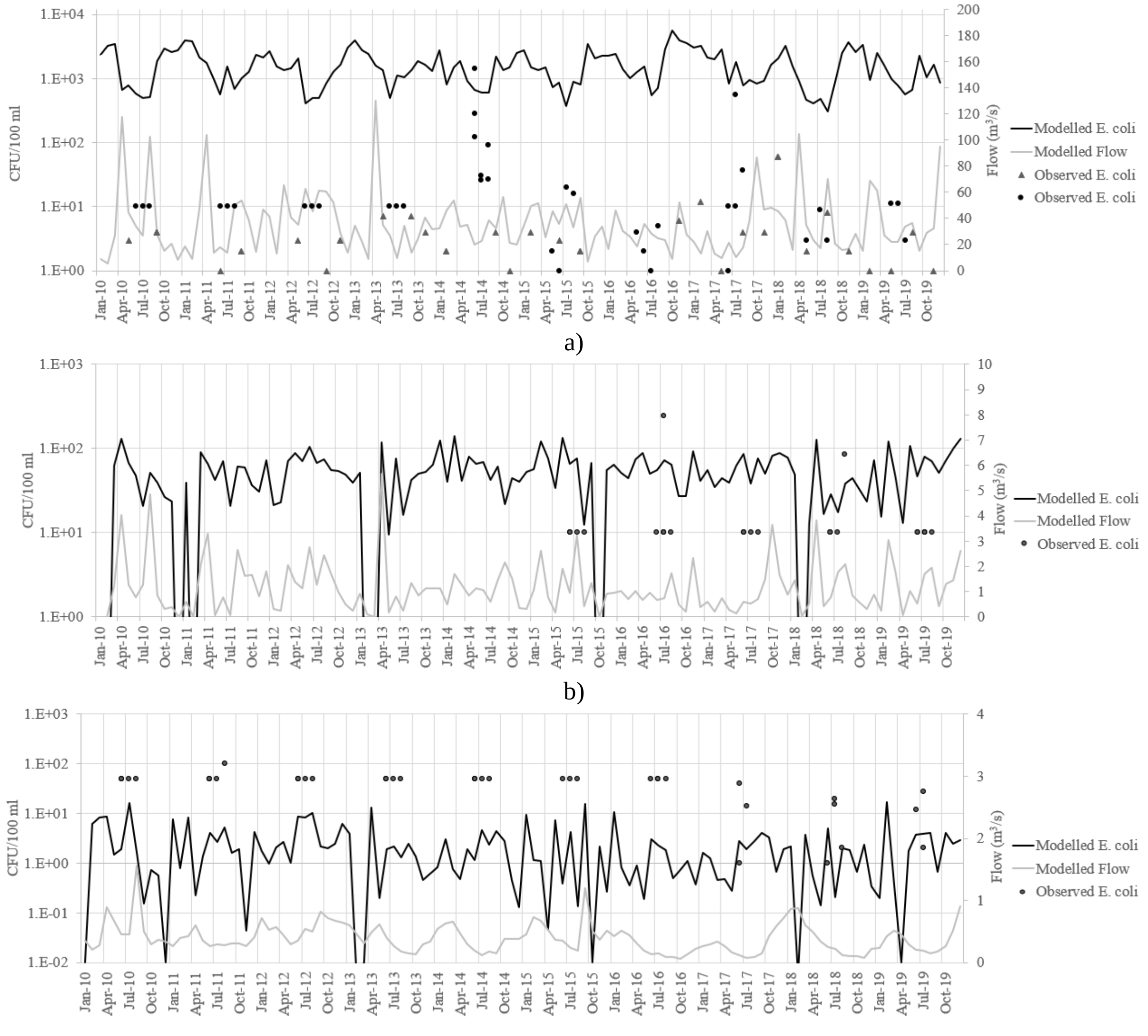
Figure 8. Modelled flow after calibration compared to observed flow for Strängnäs Sub. 22 a), Stäket Sub. 19 b) and Stäket Sub. 29 c).

Table 20. NSE and R^2 values for the different areas and for the calibration and validation periods.

	Calibration		Validation	
Area	**NSE**	**R^2**	**NSE**	**R^2**
Strängnäs Sub. 22	0.250	0.560	0.293	0.733
Stäket Sub. 19	0.570	0.730	0.705	0.798
Stäket Sub. 29	0.620	0.740	0.733	0.812

4.2 Water quality validation

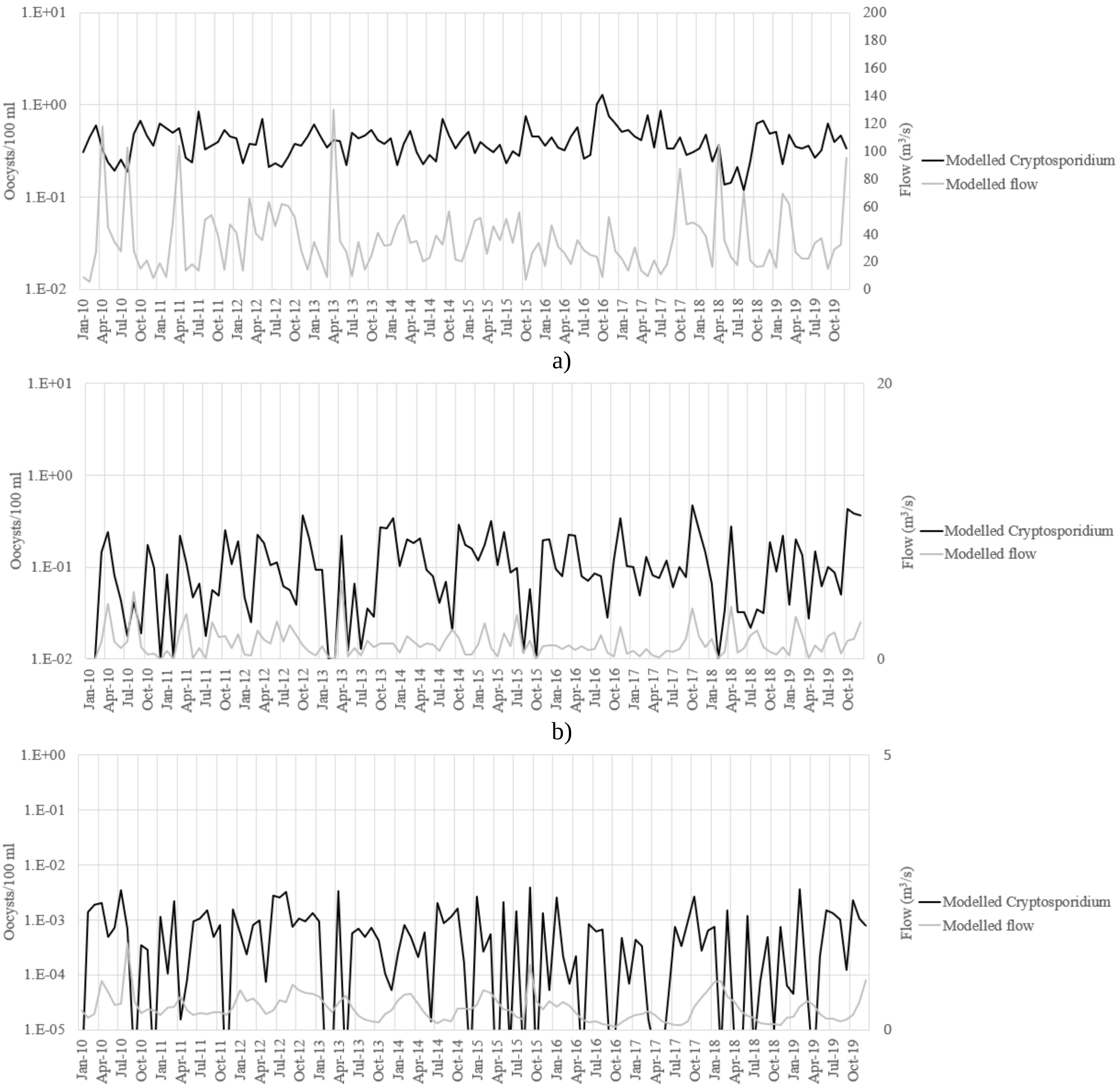
Modeled *E. coli* concentrations compared to observed *E. coli* concentrations in Stäket Sub. 38, 16 and Strängnäs Sub. 40 are presented in Figure 9. Comparison for Stäket Sub. 38 shows that modeled *E. coli* concentrations are on average about 1.5 $\log_{10}$ units larger compared to observed *E. coli* concentrations. Comparison for Stäket Sub. 16 shows that the concentrations on average are of the same $\log_{10}$ magnitude as the observed values. In Strängnäs Sub. 40 the *E. coli* concentrations are about 1 $\log_{10}$ magnitude higher for the first half of the simulation period but in the same $\log_{10}$ magnitude for the second part.



c)

Figure 9. E. coli validation for Stäket Sub. 38 a), Stäket Sub. 16 b) and Strängnäs Sub. 40 c). Dots in the diagrams are observations from Havs- och Vattenmyndigheten (n.d) and triangles are observations from Norrvatten.

Cryptosporidium concentrations for Stäket Sub. 38, 16 and Strängnäs Sub. 40 are shown in Figure 10. Compared to modeled concentrations by Coffey et al. (2010b) and Tang et al. (2011), of 0-4.8 oocysts/l (mean 0.9 oocysts/l) and 0-4 oocysts/l respectively, and measured concentrations in Sweden SVU (2011) of 0.1-2 Oocysts/l, the modeled concentrations are higher for Stäket Sub. 38 (between 1.2 and 12.7 oocysts/l) but have greater similarity for Stäket Sub. 16 and Strängnäs Sub. 40 (between 0 and 4.7 oocysts/l).



a)

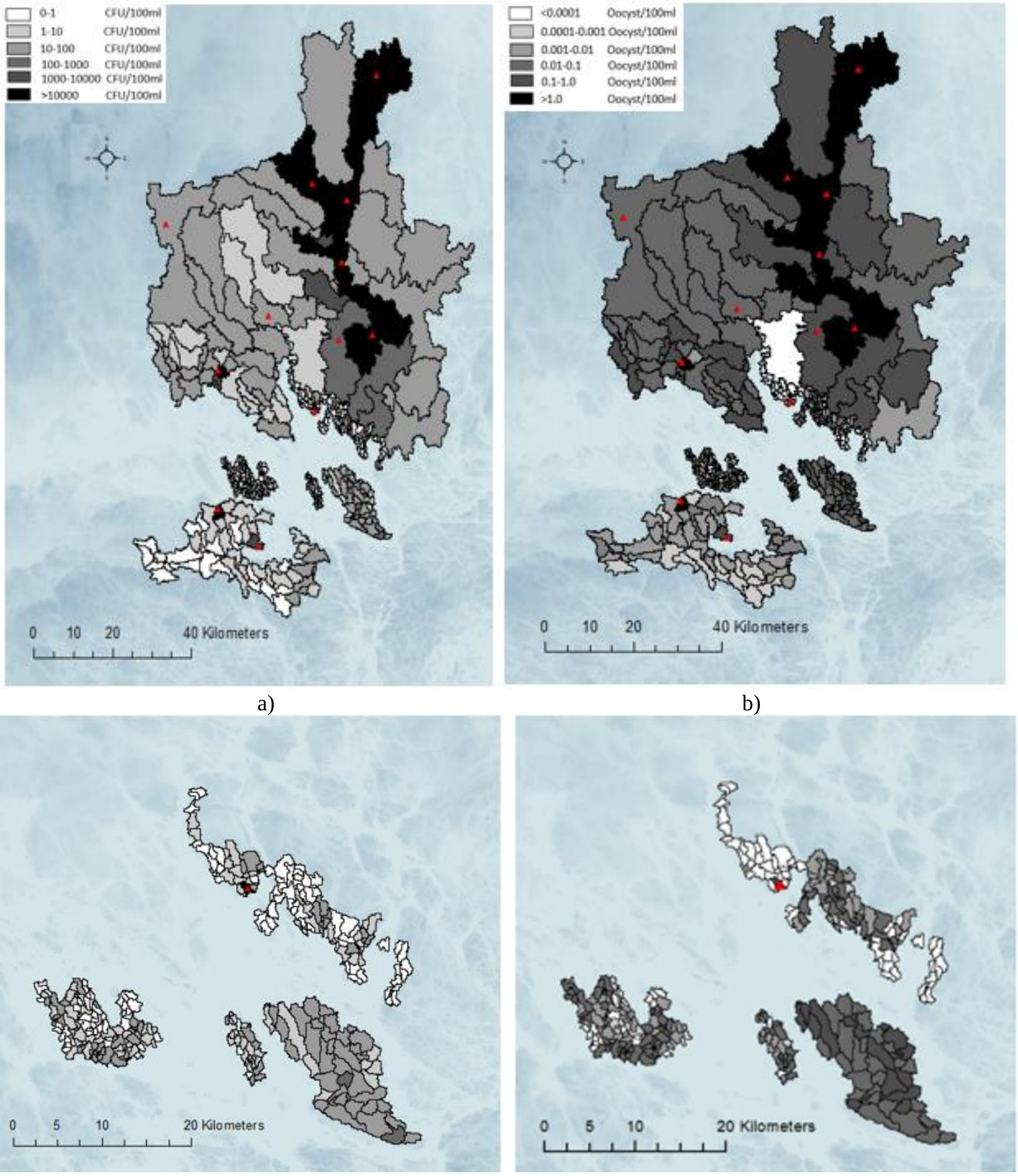
b)

c)

Figure 10. Cryptosporidium concentrations for Stäket Sub. 38 a), Stäket Sub. 16 b) and Strängnäs Sub. 40 c).

4.3 Baseline scenario

A geographical distribution of average *E. coli* and *Cryptosporidium* concentrations for the baseline scenario is visualized in Figure 11. One trend that can be seen is that *E. coli* and *Cryptosporidium* concentrations are high when WWTPs are present within or upstream a certain subbasin (Figure 11). The concentrations are otherwise somewhat homogeneously distributed.



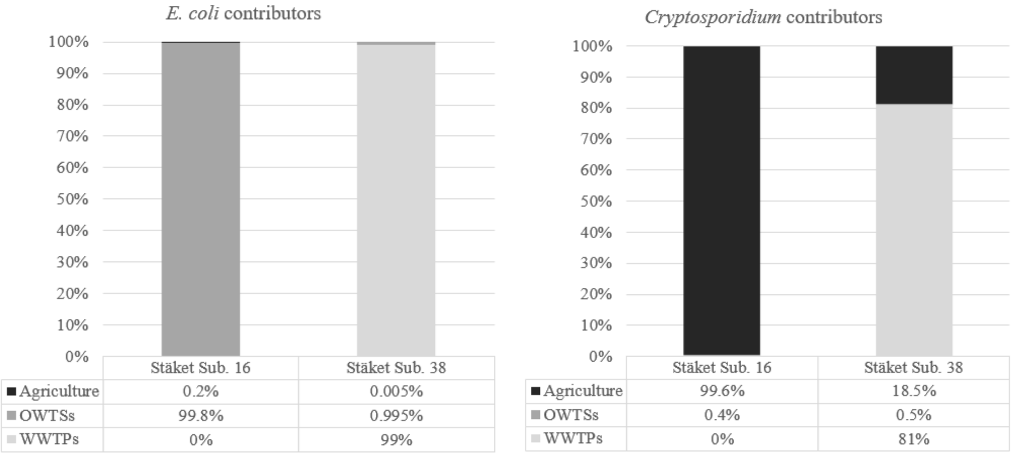
a) b)

c) d)

Figure 11. Average E. coli concentrations for the 10-year time span are visualized in full scale a) and smaller scale to visualize smaller subbasins c) in $\log_{10}$ magnitudes of CFU/100ml. Average Cryptosporidium concentrations in $\log_{10}$ magnitudes of Oocyst/100ml for the 10-year time span are visualized in full scale b) and smaller scale to visualize smaller subbasins d) in oocyst/100ml. Red triangles designate WWTPs.

The greatest contributors to *E. coli* and *Cryptosporidium* monthly average concentrations in Stäket Sub. 16 and 38 can be seen in Figure 12. Stäket Sub. 16 and 38 are analyzed based on that they are assumed to have high influence on *E. coli* and *Cryptosporidium* concentrations reaching Görväln DWTP. These subbasins have been validated for *E. coli* and *Cryptosporidium* and have contrasting sources of influence where Stäket Sub. 38 have more WWTPs influencing the subbasin compared to Sub. 16 (Figure 7) and different upstream hydrological conditions where Stäket Sub. 38 have larger water bodies upstream compared to Sub. 16 (Figure 7).

The *E. coli* concentrations are in general more influenced by OWTSs and WWTPs while the *Cryptosporidium* concentrations in general are more influenced by agriculture and WWTPs (Figure 12). Stäket Sub. 16 which has no WWTP upstream is not influenced by WWTP discharges, while Stäket Sub. 38 which has WWTPs upstream is highly influenced by WWTP discharges (Figure 12).



	Stäket Sub. 16	Stäket Sub. 38
■ Agriculture	0.2%	0.005%
■ OWTSs	99.8%	0.995%
■ WWTPs	0%	99%

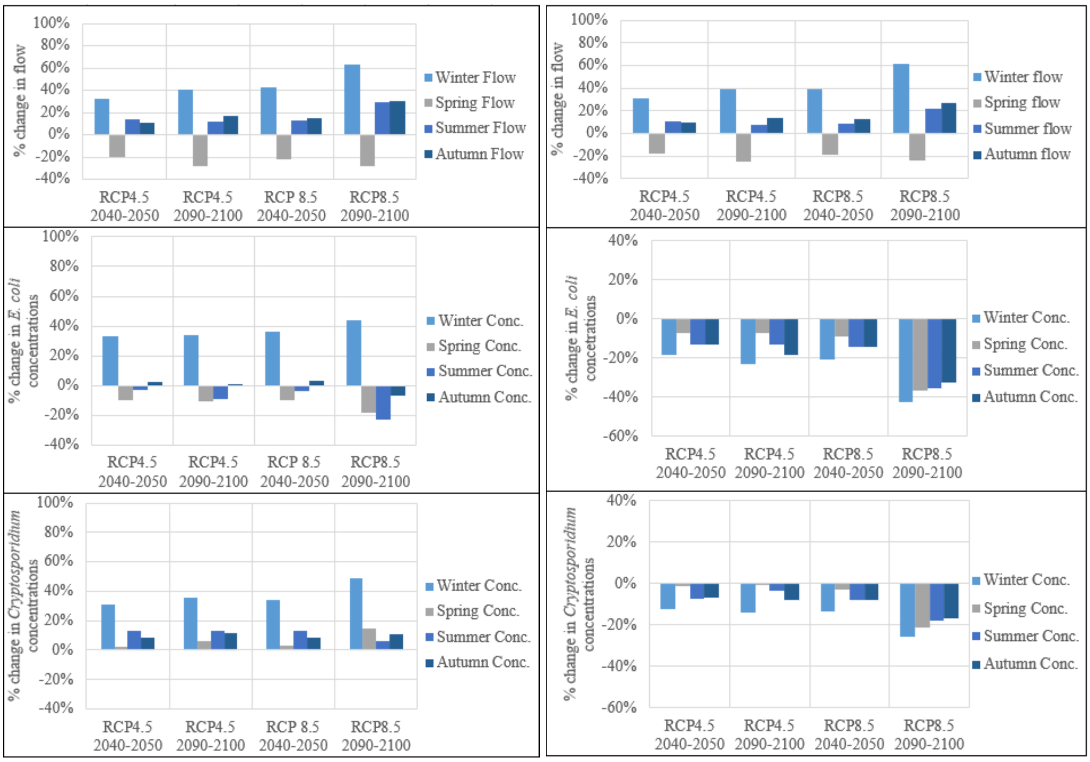
	Stäket Sub. 16	Stäket Sub. 38
■ Agriculture	99.6%	18.5%
■ OWTSs	0.4%	0.5%
■ WWTPs	0%	81%

Figure. 12. Largest contributors for E. coli (left) and Cryptosporidium (right) to average concentrations in Stäket Sub. 16 and 38.

4.4 Climate change

Climate change alone has a low total impact on the *E. coli* and *Cryptosporidium* concentrations. Results for each subbasin are presented in Appendix Figures A2-A15. Results from Stäket Sub. 16 and Stäket Sub. 38 are selected and shown in this chapter. Figure 13 visualizes future percentual changes in flow and *E. coli* and *Cryptosporidium* concentrations for climate change, compared to the baseline scenario. The percentual change was calculated using the mean future flow or concentration over a ten-year span (the time span simulated in SWAT) for winter, spring, summer or autumn. This future mean flow or concentration was subtracted and divided by the mean baseline flow or concentration over a ten-year span for the correlating season. The seasons were based on calendar definitions. Hence, winter, spring, summer and autumn includes the sum of concentrations or flows for December-February, March-May, June-August and September-November respectively.

When including climate changes, the results show some differences compared to the baseline scenario (Figure 13). One difference between the future and the baseline scenarios in Stäket Sub. 16 is that the *E. coli* and *Cryptosporidium* concentrations are higher during the winter season for the future scenarios. The higher concentrations correlate with increased precipitation (Table 17) and flows that are expected in the future (Figure 13). In Stäket Sub. 38, the concentrations are instead lower during the winter season for the future scenarios compared to the baseline scenario even though the flows are increased (Figure 13). The concentrations are also reduced during spring, summer and autumn for the future scenarios compared to the baseline scenario. However, climate change alone has a lower impact on *E. coli* and *Cryptosporidium* concentrations, compared to scenarios combining socioeconomic development with climate change (Figure 14 and 15).



a) b)

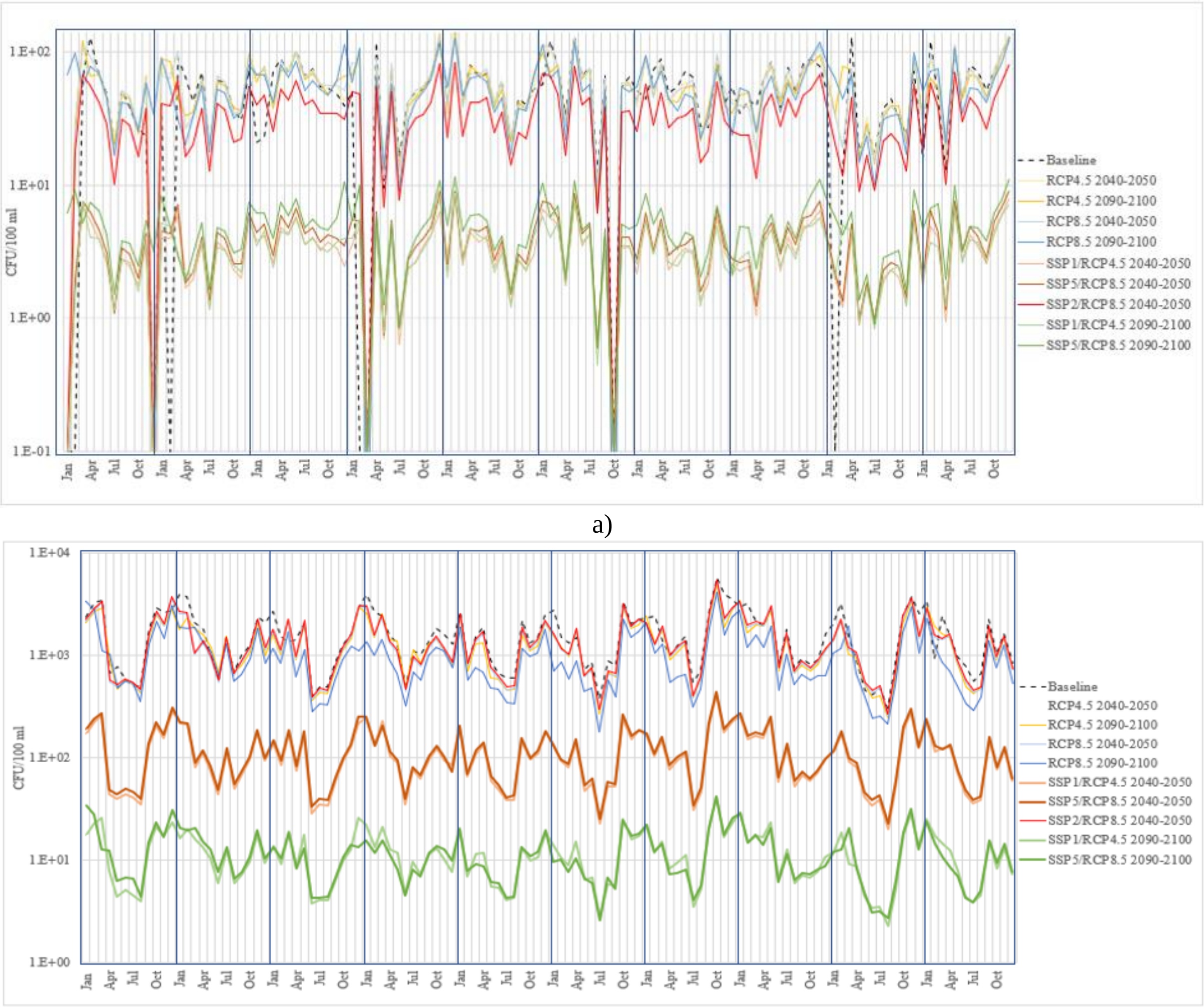
Figure 13. Percentage change of climate change scenarios in relation to the baseline scenario- effect on average E. coli and Cryptosporidium concentrations and flow in winter (Dec-Feb), spring (Mar-May), summer (Jun-Aug) and autumn (Sep-Nov) (seasons are based on calendar definitions) over ten year spans. Stäket Sub. 16 is visualized in figure a) and Stäket Sub. 38 is visualized in figure b).

4.5 Climate change and socioeconomic development combined

Monthly averages of *E. coli* and *Cryptosporidium* concentrations for Stäket Sub. 38 and Sub. 16 were used to see seasonal changes. Subbasin averages of *E. coli* and *Cryptosporidium* for SSP1/RCP4.5, SSP2/RCP8.5 and SSP5/RCP8.5 are visualized under the investigated time-intervals to find geographical variations in concentrations from combined climate change and socioeconomic development scenarios.

4.5.1 Monthly averages

Averages of monthly *E. coli* concentrations are visualized in Figure 14 for baseline, scenarios with climate change and scenarios combining climate changes and socioeconomic changes. Results are shown for Stäket Sub. 16 and 38. The results shows that the highest *E. coli* concentrations are found for baseline, climate change only and SSP2/RCP8.5 2040-2050 scenarios. For Stäket Sub. 16 the SSP1/RCP4.5 and SSP5/RCP8.5 scenarios for the time span 2040-2050 and 2090-2100 all generate about 1 $\log_{10}$ lower concentrations compared to the baseline, climate change only and SSP2/RCP8.5 2040-2050 scenarios (Figure 14). For Stäket Sub. 38 and the SSP1/RCP4.5 and SSP5/RCP8.5 scenarios for the time span 2040-2050 about 1 $\log_{10}$ lower concentrations compared to the baseline, climate change only and SSP2/RCP8.5 2040-2050 scenarios were retrieved (Figure 14). For the same subbasin and the same scenarios but for the time span 2090-2100 about 2 $\log_{10}$ lower concentrations compared to the baseline, climate change only and SSP2/RCP8.5 2040-2050 scenarios were retrieved (Figure 14).

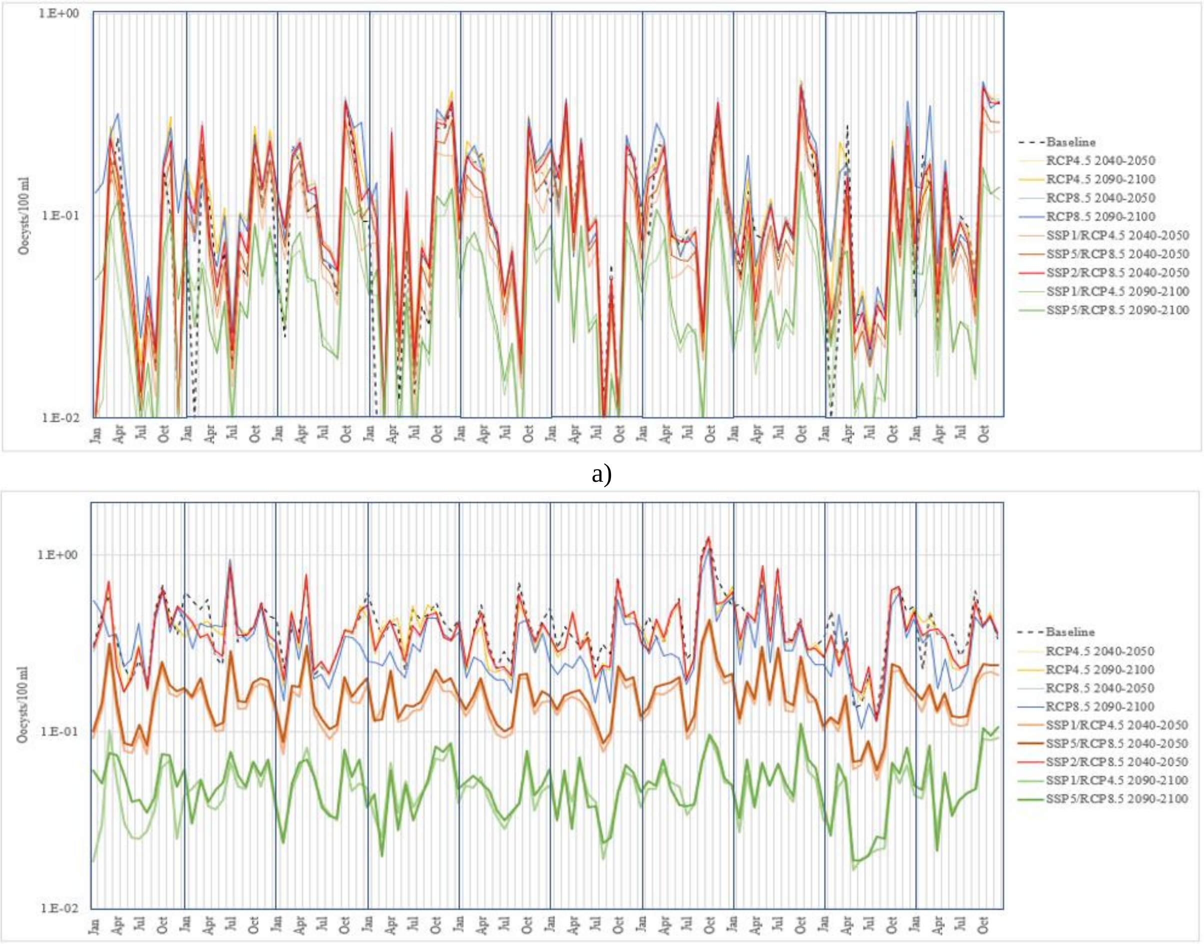


a)

b)

Figure 14. Monthly averages of E. coli over a ten year span for Stäket Sub. 16 a) and Stäket Sub.38 b).

Averages of monthly *Cryptosporidium* concentrations are visualized in Figure 15 for baseline, scenarios with climate change and scenarios combining climate changes and socioeconomic changes. Results are shown for Stäket Sub. 16 and 38. The results again show that the baseline, climate change and SSP2/RCP8.5 2040-2050 scenarios have the highest concentrations of *Cryptosporidium*. For Stäket Sub. 38 the SSP1/RCP4.5 and SSP5/RCP8.5 scenarios for time span 2040-2050 have approximately a 0.5 $\log_{10}$ reduction of *Cryptosporidium* concentration compared to the baseline, climate change only and SSP2/RCP8.5 2040-2050 scenarios. The SSP1/RCP4.5 and SSP5/RCP8.5 scenarios for the time span 2090-2100 results in about 1 $\log_{10}$ reduction compared to the baseline, climate change only and SSP2/RCP8.5 2040-2050 scenarios.



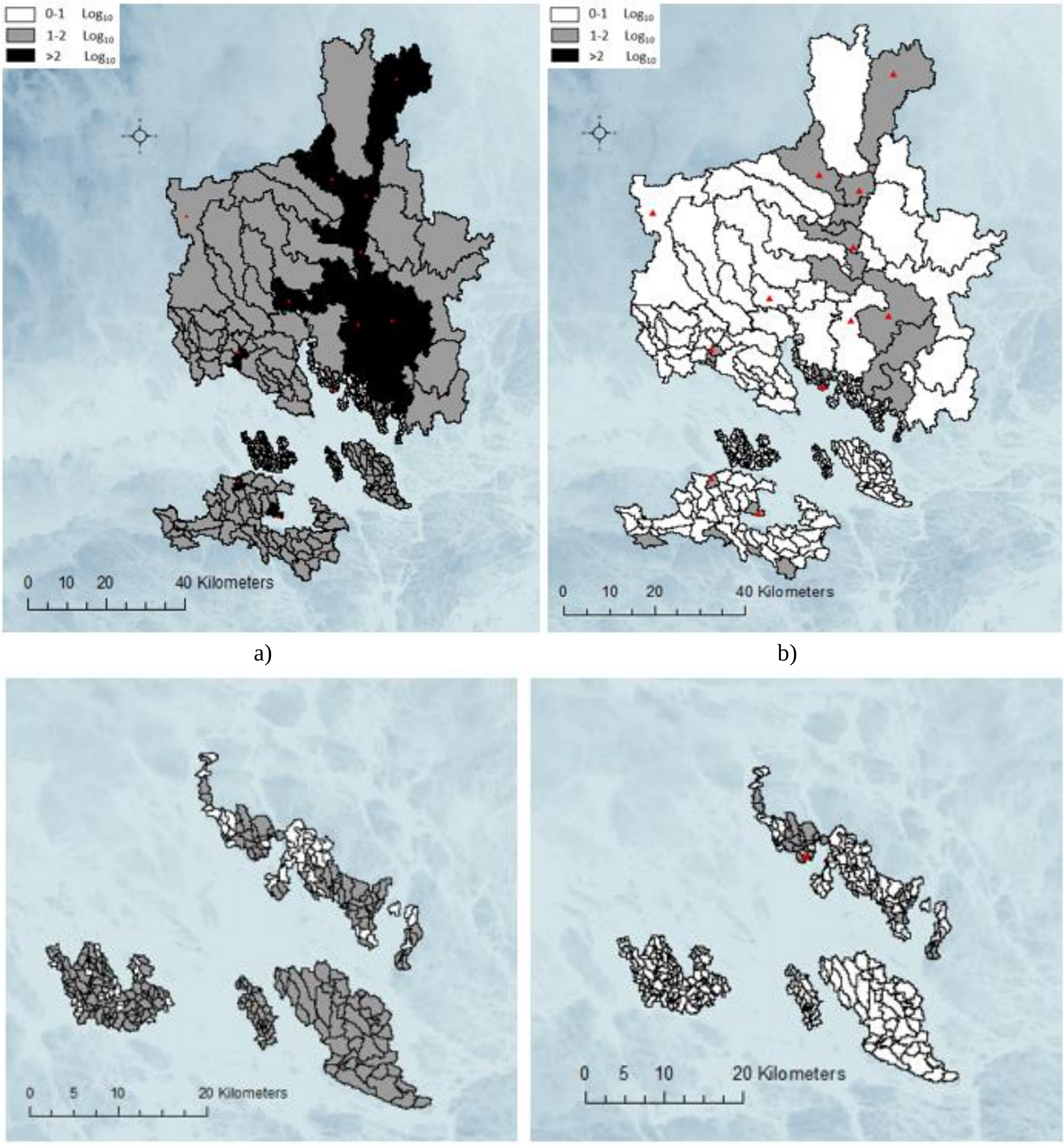
a)

b)

Figure 15. Monthly averages of Cryptosporidium for Stäket Sub. 16 a), Stäket Sub.38 b).

4.5.2 Subbasin averages

Average subbasin *E. coli* and *Cryptosporidium* reductions compared to the baseline scenario for the SSP1/RCP4.5 and SSP5/RCP8.5 scenarios up to year 2040-2050 are visualized in Figure A17. For these scenarios, concentration reductions for *E. coli* of 1-2 $\log_{10}$ and for *Cryptosporidium* of 0-1 $\log_{10}$ were retrieved over the whole area (Figure A17). SSP2/RCP8.5 2040-2050 did have a concentration reduction compared to the baseline scenario for both *E. coli* and *Cryptosporidium* of 0-1 $\log_{10}$ for the whole investigated area (Figure A18). Figure A17-A18 are not visualized in the results as no significant changes of reduction between different subbasins could be seen. Average subbasin reduction of *E. coli* and *Cryptosporidium* for the SSP1/RCP4.5 and SSP5/RCP8.5 scenarios up to year 2090-2100 are visualized in Figure 16. The two scenarios are displayed in the same figure due to similar average reductions. The area is approximately retrieving a decrease in concentration between 1 and >2 $\log_{10}$ for *E. coli* and 0-2 $\log_{10}$ for *Cryptosporidium* (Figure 16). The largest reductions are detected in the subbasins where WWTPs are present or upstream (Figure 16).



a) b)

c) d)

Figure 16. Average subbasin reduction relative to the baseline scenario for SSP1 and SSP5 for a time span between year 2090-2100 of E. coli for the 10-year time span are visualized in full scale a) and smaller scale to visualize the smaller subbasins c), Cryptosporidium are visualized in full scale b) and smaller scale d). Red triangles designate WWTPs.

5. Discussion

In the following sub-chapters the obtained results regarding the current and future water quality of lake Mälaren will be discussed. Uncertainties regarding assumptions, methods and results will also be discussed and suggestions for future research in the area will be mentioned

5.1 Baseline microbial water quality

The NSE and R^2 values regarding flow showed fair to good and acceptable results respectively (Table 20). Strängnäs Sub. 22 had the lowest NSE and R^2 values, which presumably was because of differences in subbasin area definition between SMHI and the SWAT model, as the modeled flow almost consistently was higher than the observed flow (Figure 8). Only three subbasins could be calibrated and validated for flow due to lack of flow gauges and the differences in subbasin area definitions between SMHI and the SWAT models. There was also a lack of usable observation points for *E. coli* concentrations and there were no observation points for *Cryptosporidium* concentrations why the modeled concentrations should be considered to have high uncertainty. The reliability and quality of the model could hence be increased with more observation points.

The simulated concentrations were compared to observed concentrations and/or previous modeling studies. For Strängnäs Sub. 40 the simulated *E. coli* concentrations were about 1 $\log_{10}$ magnitude higher than observed concentrations for the first half of the decade, thereafter the concentrations were in the same magnitude. The differences in the first half of the decade can be due to temporary changes in loads which the model is not able to catch, where if looking at the time period 2000-2010 in the observation data the majority of the measured concentrations are in the same magnitude as the simulated concentrations. For Stäket Sub. 38 (Stäket outlet) the simulated *E. coli* and *Cryptosporidium* concentrations both were high. This has also been seen in an earlier modeling study regarding Stäket (Bergion et al., 2017). The reason for the high concentrations could presumably be that SWAT is not fully able to reflect realistic hydrodynamic conditions in larger water bodies (Bergion et al., 2017). Hence, processes such as sedimentation, dilution, degradation, and transportation which are expected to differ in for example Lake Ekoln (which is upstream the outlet at Stäket Sub. 38) compared to other smaller watercourses may be misinterpreted in the model. Therefore the high fecal contamination concentrations, mostly generated from WWTPs near Lake Ekoln, does presumably not reduce as much in the SWAT model as in reality. The same misinterpretation was presumably the case for other WWTPs that discharged water directly into larger water bodies, for example in Stäket Sub. 1 where the discharged wastewater from Österbybruks WWTP passes Lake Dannemora, hence it is therefore probable that the model in general overestimated the WWTP contribution. It is nonetheless possible to modify existing watercourses and/or add reservoirs or ponds in SWAT to improve the hydrodynamic processes. This does however mean that extensive amounts of data for parameterization of these processes are needed (Bergion et al., 2017) which was not obtained within this study.

The simulated *Cryptosporidium* concentrations in the baseline scenario were mostly affected by agriculture and WWTPs (where WWTPs were present) and least affected by OWTSs (Figure 12). One reason for this can be that *Cryptosporidium* prevalence for domestic animals is higher than for humans. This relationship for *Cryptosporidium* between agriculture and OWTSs has also been reported by Coffey et al. (2010b). The *E. coli* concentrations were mostly affected by OWTSs and WWTPs (where WWTPs were present) and least affected by agriculture (Figure 12). In previous studies on the other hand also *E. coli* concentrations have been reported to be more affected by agriculture compared to OWTSs (Sowah et al., 2020; Coffey et al. 2010c). This distinction between our study and previous studies can be due to differences in the amount of OWTSs and agriculture in the catchment areas. It may also be due to the fact that we have assumed die-off factors for *Cryptosporidium* and *E. coli* in stored manure, and that we have not assumed any direct stream deposition of manure. These assumptions deviate from these two earlier studies (Sowah et al., 2020; Coffey et al., 2010c).

5.2 Projected future water quality

The effects of climate change alone and climate change and socioeconomic development combined on *E. coli* and *Cryptosporidium* concentrations can be seen in Figure 14 and Figure 15. Climate change alone in our models mostly had a low positive or low negative effect (Figure 14 and 15). The concentrations were however clearly increasing for winter months in Stäket Sub. 16 (Figure 13). The increased winter concentrations could be attributed to the fact that the flows for this subbasin during the baseline scenario, especially under winter periods, were low to none (Figure 9 and 10). Hence, less days under 0°C for the future scenarios and consequently more runoff presumably increased the transportation and caused higher concentrations of microbial organisms (Vermeulen and Hofstra, 2014). Increased microbial loads for future winter scenarios has also been reported in an earlier study (Coffey et al., 2015). For Stäket Sub. 38, where the flows under the baseline scenario already were high (Figure 9 and 10), the concentrations were on the other hand reducing for future winter months. Even higher future winter flows could possibly have caused dilution of microbial organisms in this part of the catchment (Vermeulen and Hofstra, 2014). Increased winter temperatures for future scenarios could also have contributed to a lower survival rate of *E. coli* and *Cryptosporidium* compared to the baseline scenario (King and Monis, 2007; Vermeulen and Hofstra, 2014), why the concentrations were reduced. Dilution of microbial organisms, for future scenarios with increased preciptations, has also been reported in an earlier study (Islam et al., 2018). Socioeconomic scenarios in combination with climate change mostly caused a decrease of fecal contamination concentrations in our models (Figure 16). It could in general be said that the total *E. coli* and *Cryptosporidium* concentrations were more affected by the SSP scenarios whereas the total effect of climate change alone was not nearly as significant (Figure 14 and 15). This observation was also reported in an earlier study (Islam et al. 2018).

Low fecal contaminant concentrations compared to the baseline scenario were most pronounced for the SSP1/RCP4.5 and SSP5/RCP8.5 scenarios. The SSP5/RCP8.5 scenario generally generated somewhat higher concentrations than the SSP1/RCP4.5 scenario (Figure 14 and 15) which could be attributed to higher population and livestock rates in the SSP5/RCP8.5 scenarios. These differences were however small compared to the differences between the SSP1/RCP4.5 and SSP5/RCP8.5 scenarios and the other scenarios. The SSP1 and SSP5 scenarios both had similar adaptation assumptions (wastewater treatment, buffer zones and water use) hence it is reasonable to assume that adaptations were decisive in generating the low concentrations. It is therefore also reasonable to assume that it was the enhanced adaptations in the 2090-2100 scenarios that were decisive in generating even lower concentrations compared to the 2040-2050 scenarios. The SSP2/RCP8.5 2040-2050 scenario on the other hand resulted in similar concentrations compared to the baseline scenario. The SSP2 scenario was composed of assumptions of relatively high increase in livestock and low willingness to adapt. This high sensitivity to adaptation means that the results are only valid under the conditions that the SSPs follow the narratives in Table 13-15 and that the adaptations described in Table 17 therefore will be implemented for each specific scenario.

E. coli concentrations, which were mostly affected by OWTSs and WWTPs (Figure 12), were reduced in scenarios with more wastewater treatment adaptations whereas *Cryptosporidium* concentrations, which were mostly affected by agriculture and WWTPs (Figure 12), were reduced in scenarios with more buffer zones and WWTP adaptations. As the wastewater treatment efficiency has potential to improve much with fewer inadequate OWTSs and additional pharmaceutical treatment in WWTPs, the reductions in especially the SSP1/RCP4.5 and SSP5/RCP8.5 scenarios for *E. coli* were high (Figure 14) The assumed agricultural improvements with buffer zones did not generate such significant changes for *Cryptosporidium* concentrations, for example in Stäket Sub. 16 (Figure 15). However, in Stäket Sub. 38 that was also influenced by WWTPs the *Cryptosporidium* concentrations were reduced more significantly (Figure 15).

5.3 Uncertainties in model input data

In our models, only data for WWTPs with more than 2000 connected people was used, hence smaller WWTPs were not included. There are about 830 WWTPs dimensioned for 200-2000 people (Naturvårdsverket, 2007) compared to 416 WWTPs dimensioned for more than 2000 people (Naturvårdsverket, 2018) in Sweden, hence it is possible that a substantial amount of WWTPs were omitted in our models. However, no information on the amount of WWTPs with fewer than 2000 people in the study area could be obtained. It is reasonable to believe that the WWTP discharges, hence also the total microbial organism contribution, are significantly lower for WWTPs with fewer than 2000 people compared to WWTPs with more than 2000 people. Other uncertainties are that, for seven out of twelve included WWTPs, constant discharge were assumed, while in reality the discharges may vary over time. All WWTPs were moreover assumed to have the same incoming fecal contamination concentration and treatment efficiency while in reality the incoming fecal contamination concentration in raw wastewater, treatment efficiency and consequently the fecal contamination discharge from WWTPs would vary. The assumed raw sewage concentrations of *E. coli* and *Cryptosporidium* are furthermore very uncertain as they can vary with several $\log_{10}$ magnitudes, and could hence mean that the loads of *E. coli* and/or *Cryptosporidium* from WWTPs are over- or underestimated. As WWTPs had a high influence on *E. coli* and *Cryptosporidium* concentrations in the study area, the use of more detailed data from WWTPs could be justified. Overflows, from WWTPs and sewers, were furthermore not included in our models due to lack of data and that many areas (for example Uppsala, Enköping, Knivsta and Östhammar municipality) almost solely have separate sewer systems (Helander, 2011); overflows are therefore occurring erratically due to factors such as broken pipes. In combination with lack of data, no obvious trends could hence be observed why estimations, regarding overflows, for the 10-year simulation span in SWAT and for future scenarios could not be performed. This exclusion means that the model does not capture significant temporary discharges that could arise from overflows, and therefore no future scenario includes events with increased WWTP and sewer overflows which could occur with climate change and more precipitation. From a previous hydrological modeling study (including agriculture, OWTSs, WWTPs and sewage overflows) it was reported that sewer overflows were important as they contributed to temporary peak concentrations of *E. coli* (Åström and Johansson, 2014).

Continuous fertilization function was used to simulate OWTSs, this function spreads the loading over the land surface like a nonpoint source. Some OWTSs like OWTSs with sand filters could however rather be characterized as point sources (Bergion et al., 2017) and their discharge would in reality occur underground instead of on land surface in the models. These discrepancies could affect the fate and transport of fecal contamination from OWTSs. Other uncertainties regarding OWTSs are: the loading is spread evenly over the entire subbasins; the same sewage flow, sewage concentration and treatment efficiency is used for all OWTSs; and only contribution from permanent housing is assumed. These are simplifications of reality and means that the precise loading for a certain geographical location and variations in OWTS discharge is not represented in the model, and only assuming permanent housing presumably contributed to some underestimation of fecal contamination concentrations.

The loading from the livestock is assumed to be dropped directly on the ground, which then can be seen as an overestimation of the concentration of *E. coli* and *Cryptosporidium* compared to the reality since small amounts of feces do disperse in diffuse ways. Mean values of the daily fecal production were used which might not represent the actual value for each of the species. This can result in either an underestimation or overestimation which can affect the contribution from the agricultural sector. It is assumed for all scenarios that the *E. coli* and *Cryptosporidium* in the stored manure is exposed to a die-off rate which is fixed. In reality it could be assumed that it would vary between the scenarios regarding temperature changes and storage equipment. Presumably this assumption might lead to either an underestimation or an overestimation of the concentration of *E. coli* and *Cryptosporidium*. Furthermore, a simplification was made as the stored manure was assumed to be applied on all of the arable land during two days a year. It is more reasonable that it is applied on smaller parts of the area for a longer time (Coffey et.al, 2010a; Coffey et.al, 2010b). The result of this assumption might lead to an overestimation of the concentration of *E. coli* and *Cryptosporidium* during the months when the manure is applied. Overall the loads from agriculture are highly uncertain regarding the microbial concentration. This since the modeled values are chosen from other studies which have given a range of values whereas we chose a mean value from the interval. This can imply the microbial concentration from agriculture could be much higher but also much lower.

The database produced by IIASA (2018) was used to project socioeconomic developments in population, urbanization, land use and livestock. The used data was at best downscaled for Sweden (for population), but in some cases data for the OECD region was used (for urbanization, land use and livestock) as no further downscaled data could be found and applied homogeneously over the whole study area. Assumed socioeconomic developments with treatment efficiency, water use and buffer zones were also applied homogeneously over the whole study area. These simplifications mean that we get a more general outcome compared to if more local values would have been used. Data from the IIASA database and assumed socioeconomic development could hence be supported with more local data to improve the resolution of the model.

In our models the data regarding climate change was retrieved from the RCA4 climate model with several climate scenarios in SMHI. There is however variability within this climate model and the projections within the RCA4 climate model might deviate from projections in other climate models why there are uncertainties here. More climate models could be added to increase the robustness of the assumed climate projections, but this requires more knowledge about climate projections, hence it was not regarded in this study. The used inputs from this climate model data was further calculated as a mean value for each day, but since the data varies over the days it might not be fully representative. Data considering wind, solar radiation and relative humidity was not changed for the future scenarios, instead the data from the baseline scenario was used. How these parameters will change in the future is somewhat unclear and/or hard to predict and no projections for the Norrström catchment basin could be found.

5.4 Future research

For further improvements of the models regarding the loads of *E. coli* and *Cryptosporidium* entering lake Mälaren it is recommended to connect the hydrological models to a hydrodynamic model. This is recommended in order to analyze the fate and transport of *E. coli* and *Cryptosporidium* in larger water bodies. It would also mean that the actual impact from the catchment area to the location of the drinking water intake at Görväln could be modeled. Overflows, from WWTPs and sewers, are moreover assumed to have a significant impact on momentaneous microbial organism loading and the loadings could be increased in the future with more precipitation, a future study could therefore further investigate if it is possible to involve the impact of overflows.

Much of the input data for the models was retrieved from other studies which were conducted in other cities or in other countries, and much of the input data was homogeneously applied to the whole study area. It would therefore be useful to enhance the inputs with more detailed local parameters, to generate more accurate results. Lastly, only a few observation points could be used for flow and *E. coli* and no observation points were available for *Cryptosporidium*, it is therefore recommended to conduct measurements considering flow and concentrations from the different outlets in lake Mälaren. This would result in further calibration and validation data and consequently more reliable modeling results.

6. Conclusions

Setting up the SWAT models showed difficulties regarding the lack of data to describe hydrodynamic conditions in larger water bodies and the lack of observation stations that could be used to calibrate and validate the models. The NSE values in three selected subbasins ranged from fair to good and the R^2 values were acceptable, with respect to water flow. The *E. coli* and *Cryptosporidium* concentrations in the outlet of Stäket (Stäket Sub. 38) were in general high compared to observed concentrations or modeled concentrations in previous studies. The concentrations in Stäket Sub. 16 and Strängnäs Sub. 40 had a greater similarity with observed concentrations or modeled concentrations in previous studies. The most important contributors to *E. coli* concentrations were WWTPs and OWTSs while the most important contributors to *Cryptosporidium* concentrations were WWTPs and agriculture, according to the modeling results.

To simulate future scenarios, climate change (RCP4.5 and RCP8.5) was modeled alone and in combination with three socioeconomic scenarios (SSP1, SSP2 and SSP5) to represent possible future development pathways (SSP1/RCP4.5, SSP2/RCP8.5 and SSP5/RCP8.5). Based on the results, climate change alone would generally bring similar *E. coli* and *Cryptosporidium* concentrations compared to the baseline scenario. The SSP2/RCP8.5 scenario with relatively low level of adaptations would also bring similar *E. coli* and *Cryptosporidium* concentrations compared to the baseline scenario. The SSP1/RCP4.5 and SSP5/RCP8.5 with high levels of aptations (improved wastewater treatment, buffer zones and reduced water use) would on the other hand generally bring clear reductions of *E. coli* and *Cryptosporidium* concentrations compared to the baseline scenario. It can hence be said that these results indicate a relatively hopeful future regarding microbial water quality in the catchment of Lake Mälaren, with similar or reduced concentrations compared to the baseline scenario. That is however only under the conditions that the development follows the projected changes within this research, and that assumed adaptations for each specific SSP scenario therefore will be implemented.

For future improvements it is recommended to connect the hydrological models to a hydrodynamic model to better simulate fate and transport of *E. coli* and *Cryptosporidium* in larger water bodies. This would not only improve the results but would also mean that the actual impact on Görväln could be modeled. More measurements of flow and water quality would also improve and furthermore increase the validity of the results. Quality and resolution of input data could moreover in general be upgraded to for example better isolate areas where water quality should be improved or where certain future changes in water quality are expected to occur.

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8. Appendix

Figure A1. Flow directions of eastern Mälaren. (Ekvall, 2019)

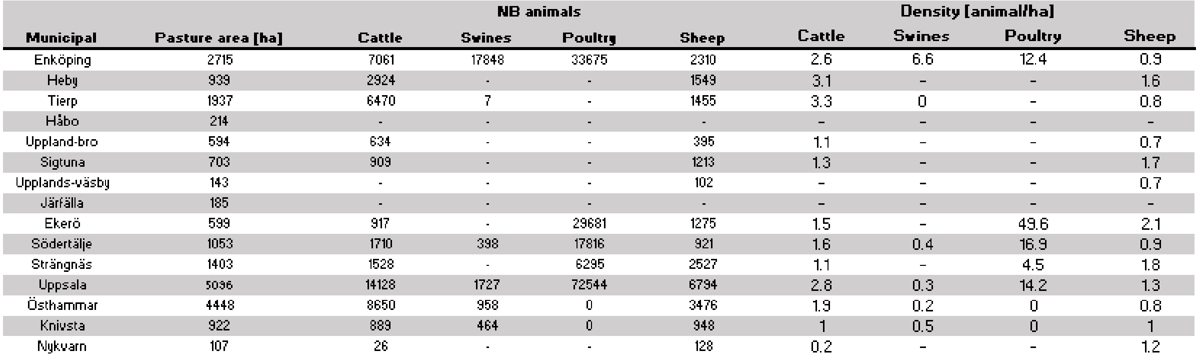
8.1 Agriculture

The data provided in the appendix “Agriculture” is used to calculate microbial loads from livestock through fecal dropping and manure spread on agricultural land. Table AA1 provides data on each municipality’s total arable and pasture land. Table AA2 presents the density of animals per hectare for each municipality and Table AA3 the amount of stored feces for each fertilization occasion. Table AA4-AA8 shows the fecal production with buffer zones implemented for each scenario and Table AA9-AA13 shows the amount of stored feces for each municipality for the different scenarios.

Table AA1. Each municipality’s total arable and pasture land (Jordbruksverket, 2020).

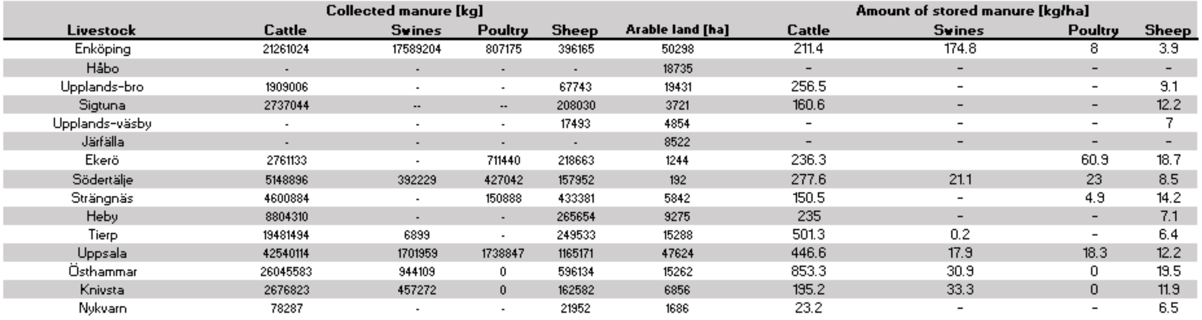
Municipality	Arable land [ha]	Pasture land [ha]
Enköping	50298	2715
Heby	18735	939
Tierp	19431	1937
Håbo	3721	214
Uppland-bro	4854	594
Sigtuna	8522	703
Upplands-väsby	1244	143
Järfälla	192	185
Ekerö	5842	599
Södertälje	9275	1053
Strängnäs	15288	1403
Uppsala	47624	5096
Östhammar	15262	4448
Knivsta	6856	922
Nykvarn	1686	107

Table AA2. Density of animals per hectare for each municipality (Jordbruksverket, 2020)



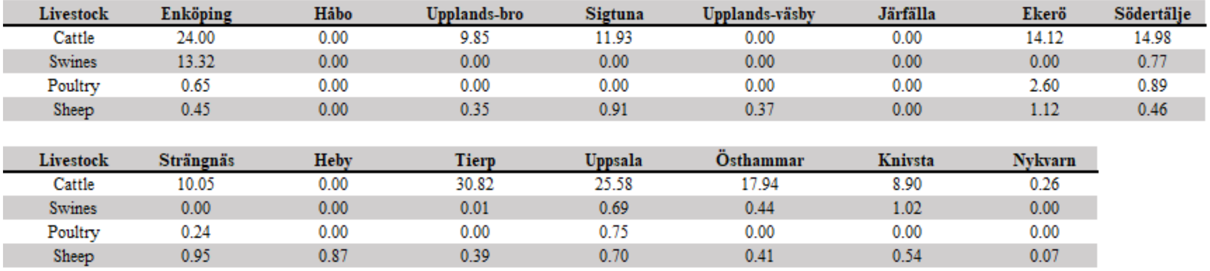
		NB animals				Density [animal/ha]			
Municipal	**Pasture area [ha]**	**Cattle**	**Swines**	**Poultry**	**Sheep**	**Cattle**	**Swines**	**Poultry**	**Sheep**
Enköping	2715	7061	17848	33675	2310	2.6	6.6	12.4	0.9
Heby	939	2924	-	-	1549	3.1	-	-	1.6
Tierp	1937	6470	7	-	1455	3.3	0	-	0.8
Håbo	214	-	-	-	-	-	-	-	-
Uppland-bro	594	634	-	-	395	1.1	-	-	0.7
Sigtuna	703	909	-	-	1213	1.3	-	-	1.7
Upplands-väsby	143	-	-	-	102	-	-	-	0.7
Järfälla	185	-	-	-	-	-	-	-	-
Ekerö	599	917	-	29681	1275	1.5	-	49.6	2.1
Södertälje	1053	1710	398	17816	921	1.6	0.4	16.9	0.9
Strängnäs	1403	1528	-	6295	2527	1.1	-	4.5	1.8
Uppsala	5036	14128	1727	72544	6794	2.8	0.3	14.2	1.3
Östhammar	4448	8650	958	0	3476	1.9	0.2	0	0.8
Knivsta	922	889	464	0	948	1	0.5	0	1
Nykvarn	107	26	-	-	128	0.2	-	-	1.2

Table AA3. Amount of stored manure for each fertilization occasion (Jordbruksverket, 2020)



	Collected manure [kg]					Amount of stored manure [kg/ha]			
Livestock	**Cattle**	**Swines**	**Poultry**	**Sheep**	**Arable land [ha]**	**Cattle**	**Swines**	**Poultry**	**Sheep**
Enköping	21261024	17589204	807175	396165	50298	211.4	174.8	8	3.9
Håbo	-	-	-	-	18735	-	-	-	-
Upplands-bro	1909006	-	-	67743	19431	256.5	-	-	9.1
Sigtuna	2737044	--	--	208030	3721	160.6	-	-	12.2
Upplands-väsby	-	-	-	17493	4854	-	-	-	7
Järfälla	-	-	-	-	8522	-	-	-	-
Ekerö	2761133	-	711440	218663	1244	236.3		60.9	18.7
Södertälje	5148896	392229	427042	157952	192	277.6	21.1	23	8.5
Strängnäs	4600884	-	150888	433381	5842	150.5	-	4.9	14.2
Heby	8804310	-	-	265654	9275	235	-	-	7.1
Tierp	19481494	6899	-	249533	15288	501.3	0.2	-	6.4
Uppsala	42540114	1701959	1738847	1165171	47624	446.6	17.9	18.3	12.2
Östhammar	26045583	944109	0	596134	15262	853.3	30.9	0	19.5
Knivsta	2676823	457272	0	162582	6856	195.2	33.3	0	11.9
Nykvarn	78287	-	-	21952	1686	23.2	-	-	6.5

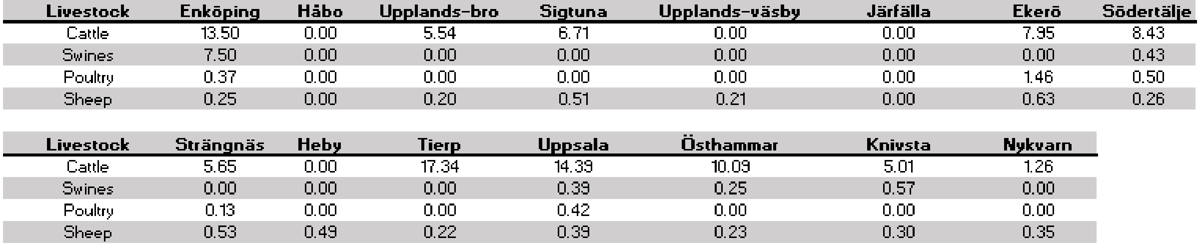
Table AA4. Fecal production with buffer zones for SSP1 year 2040-2050.



Livestock	**Enköping**	**Håbo**	**Upplands-bro**	**Sigtuna**	**Upplands-väsby**	**Järfälla**	**Ekerö**	**Södertälje**
Cattle	24.00	0.00	9.85	11.93	0.00	0.00	14.12	14.98
Swines	13.32	0.00	0.00	0.00	0.00	0.00	0.00	0.77
Poultry	0.65	0.00	0.00	0.00	0.00	0.00	2.60	0.89
Sheep	0.45	0.00	0.35	0.91	0.37	0.00	1.12	0.46

Livestock	**Strängnäs**	**Heby**	**Tierp**	**Uppsala**	**Östhammar**	**Knivsta**	**Nykvarn**
Cattle	10.05	0.00	30.82	25.58	17.94	8.90	0.26
Swines	0.00	0.00	0.01	0.69	0.44	1.02	0.00
Poultry	0.24	0.00	0.00	0.75	0.00	0.00	0.00
Sheep	0.95	0.87	0.39	0.70	0.41	0.54	0.07

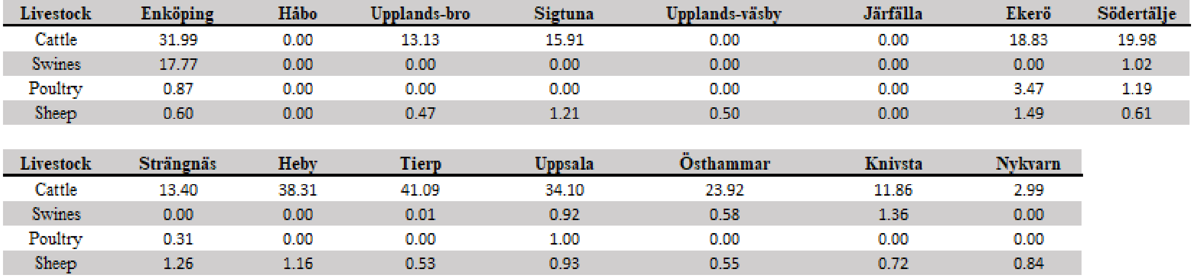
Table AA5. Fecal production with buffer zones for SSP1 year2090-2100.



Livestock	**Enköping**	**Håbo**	**Upplands-bro**	**Sigtuna**	**Upplands-väsby**	**Järfälla**	**Ekerö**	**Södertälje**
Cattle	13.50	0.00	5.54	6.71	0.00	0.00	7.95	8.43
Swines	7.50	0.00	0.00	0.00	0.00	0.00	0.00	0.43
Poultry	0.37	0.00	0.00	0.00	0.00	0.00	1.46	0.50
Sheep	0.25	0.00	0.20	0.51	0.21	0.00	0.63	0.26

Livestock	**Strängnäs**	**Heby**	**Tierp**	**Uppsala**	**Östhammar**	**Knivsta**	**Nykvarn**
Cattle	5.65	0.00	17.34	14.39	10.09	5.01	1.26
Swines	0.00	0.00	0.00	0.39	0.25	0.57	0.00
Poultry	0.13	0.00	0.00	0.42	0.00	0.00	0.00
Sheep	0.53	0.49	0.22	0.39	0.23	0.30	0.35

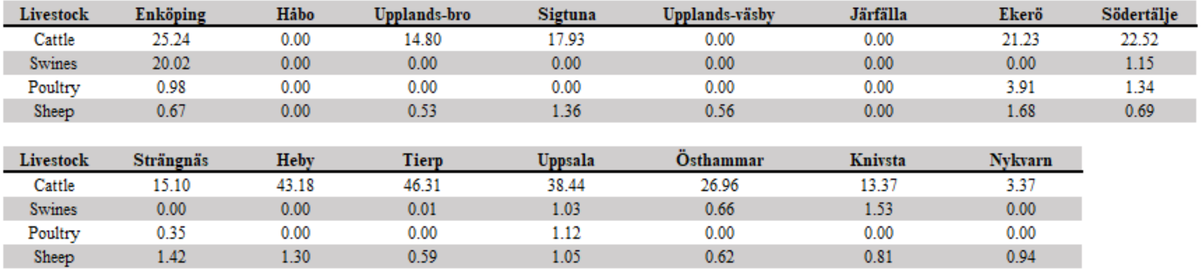
Table AA6. Fecal production with buffer zones for SSP2 year 2040-2050.



Livestock	**Enköping**	**Håbo**	**Upplands-bro**	**Sigtuna**	**Upplands-väsby**	**Järfälla**	**Ekerö**	**Södertälje**
Cattle	31.99	0.00	13.13	15.91	0.00	0.00	18.83	19.98
Swines	17.77	0.00	0.00	0.00	0.00	0.00	0.00	1.02
Poultry	0.87	0.00	0.00	0.00	0.00	0.00	3.47	1.19
Sheep	0.60	0.00	0.47	1.21	0.50	0.00	1.49	0.61

Livestock	**Strängnäs**	**Heby**	**Tierp**	**Uppsala**	**Östhammar**	**Knivsta**	**Nykvarn**
Cattle	13.40	38.31	41.09	34.10	23.92	11.86	2.99
Swines	0.00	0.00	0.01	0.92	0.58	1.36	0.00
Poultry	0.31	0.00	0.00	1.00	0.00	0.00	0.00
Sheep	1.26	1.16	0.53	0.93	0.55	0.72	0.84

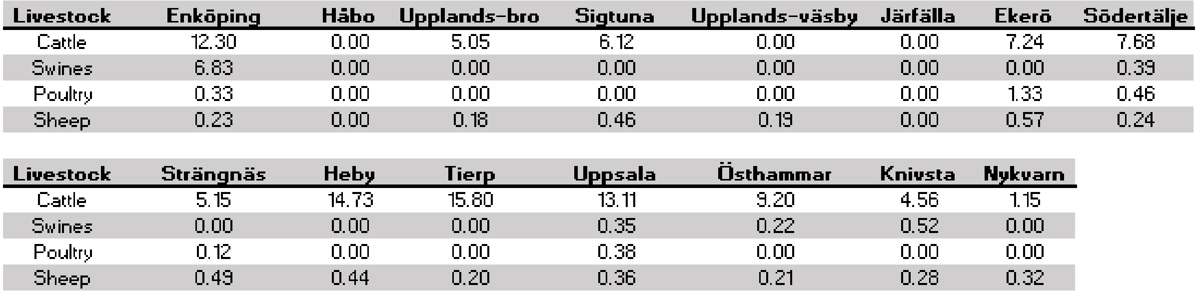
Table AA7. Fecal production with buffer zones for SSP5 year 2040-2050.



Livestock	Enköping	Håbo	Upplands-bro	Sigtuna	Upplands-väsby	Järfälla	Ekerö	Södertälje
Cattle	25.24	0.00	14.80	17.93	0.00	0.00	21.23	22.52
Swines	20.02	0.00	0.00	0.00	0.00	0.00	0.00	1.15
Poultry	0.98	0.00	0.00	0.00	0.00	0.00	3.91	1.34
Sheep	0.67	0.00	0.53	1.36	0.56	0.00	1.68	0.69

Livestock	Strängnäs	Heby	Tierp	Uppsala	Östhammar	Knivsta	Nykvarn
Cattle	15.10	43.18	46.31	38.44	26.96	13.37	3.37
Swines	0.00	0.00	0.01	1.03	0.66	1.53	0.00
Poultry	0.35	0.00	0.00	1.12	0.00	0.00	0.00
Sheep	1.42	1.30	0.59	1.05	0.62	0.81	0.94

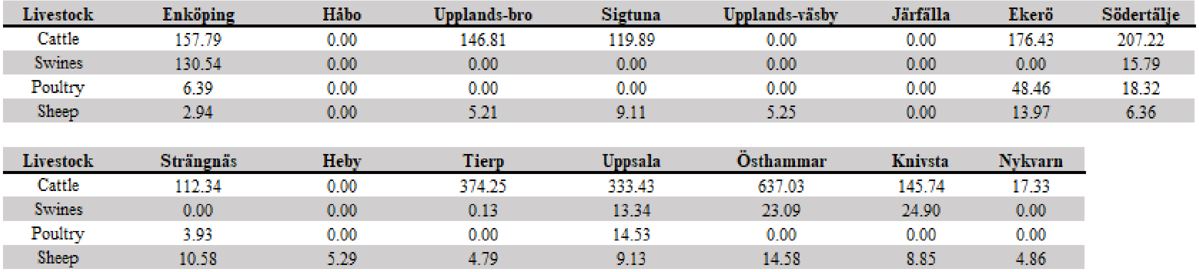
Table AA8. Fecal production with buffer zones for SSP5 year 2090-2100.



Livestock	Enköping	Håbo	Upplands-bro	Sigtuna	Upplands-väsby	Järfälla	Ekerö	Södertälje
Cattle	12.30	0.00	5.05	6.12	0.00	0.00	7.24	7.68
Swines	6.83	0.00	0.00	0.00	0.00	0.00	0.00	0.39
Poultry	0.33	0.00	0.00	0.00	0.00	0.00	1.33	0.46
Sheep	0.23	0.00	0.18	0.46	0.19	0.00	0.57	0.24

Livestock	Strängnäs	Heby	Tierp	Uppsala	Östhammar	Knivsta	Nykvarn
Cattle	5.15	14.73	15.80	13.11	9.20	4.56	1.15
Swines	0.00	0.00	0.00	0.35	0.22	0.52	0.00
Poultry	0.12	0.00	0.00	0.38	0.00	0.00	0.00
Sheep	0.49	0.44	0.20	0.36	0.21	0.28	0.32

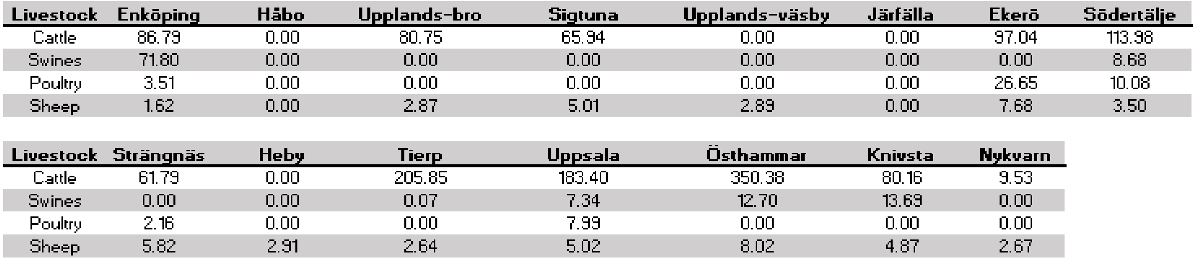
Table AA9. Stored manue [kg/ha] for SSP1 year 2040-2050.



Livestock	Enköping	Håbo	Upplands-bro	Sigtuna	Upplands-väsby	Järfälla	Ekerö	Södertälje
Cattle	157.79	0.00	146.81	119.89	0.00	0.00	176.43	207.22
Swines	130.54	0.00	0.00	0.00	0.00	0.00	0.00	15.79
Poultry	6.39	0.00	0.00	0.00	0.00	0.00	48.46	18.32
Sheep	2.94	0.00	5.21	9.11	5.25	0.00	13.97	6.36

Livestock	Strängnäs	Heby	Tierp	Uppsala	Östhammar	Knivsta	Nykvarn
Cattle	112.34	0.00	374.25	333.43	637.03	145.74	17.33
Swines	0.00	0.00	0.13	13.34	23.09	24.90	0.00
Poultry	3.93	0.00	0.00	14.53	0.00	0.00	0.00
Sheep	10.58	5.29	4.79	9.13	14.58	8.85	4.86

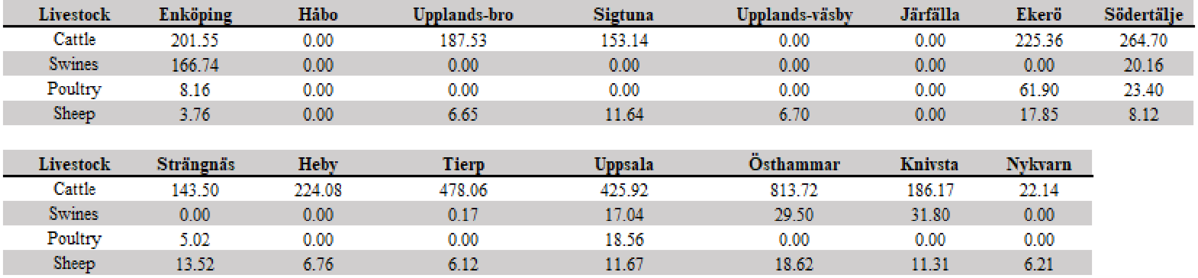
Table AA10. Stored manue [kg/ha] for SSP1 year 2090-2100.



Livestock	Enköping	Håbo	Upplands-bro	Sigtuna	Upplands-väsby	Järfälla	Ekerö	Södertälje
Cattle	86.79	0.00	80.75	65.94	0.00	0.00	97.04	113.98
Swines	71.80	0.00	0.00	0.00	0.00	0.00	0.00	8.68
Poultry	3.51	0.00	0.00	0.00	0.00	0.00	26.65	10.08
Sheep	1.62	0.00	2.87	5.01	2.89	0.00	7.68	3.50

Livestock	Strängnäs	Heby	Tierp	Uppsala	Östhammar	Knivsta	Nykvarn
Cattle	61.79	0.00	205.85	183.40	350.38	80.16	9.53
Swines	0.00	0.00	0.07	7.34	12.70	13.69	0.00
Poultry	2.16	0.00	0.00	7.99	0.00	0.00	0.00
Sheep	5.82	2.91	2.64	5.02	8.02	4.87	2.67

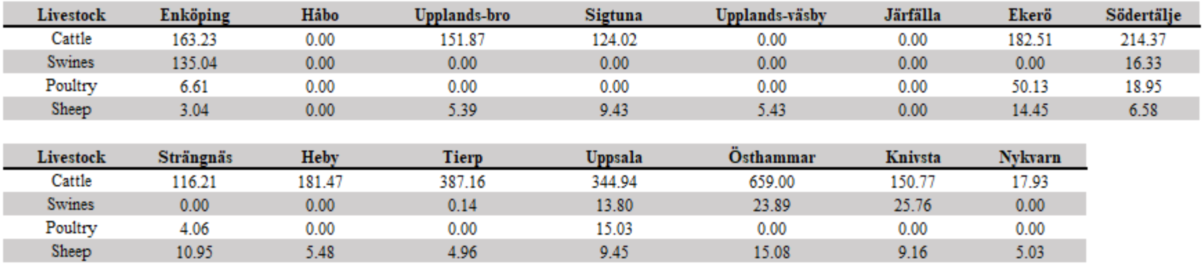
Table AA11. Stored manure [kg/ha] for SSP2 year 2040-2050.



Livestock	Enköping	Håbo	Upplands-bro	Sigtuna	Upplands-väsby	Järfälla	Ekerö	Södertälje
Cattle	201.55	0.00	187.53	153.14	0.00	0.00	225.36	264.70
Swines	166.74	0.00	0.00	0.00	0.00	0.00	0.00	20.16
Poultry	8.16	0.00	0.00	0.00	0.00	0.00	61.90	23.40
Sheep	3.76	0.00	6.65	11.64	6.70	0.00	17.85	8.12

Livestock	Strängnäs	Heby	Tierp	Uppsala	Östhammar	Knivsta	Nykvarn
Cattle	143.50	224.08	478.06	425.92	813.72	186.17	22.14
Swines	0.00	0.00	0.17	17.04	29.50	31.80	0.00
Poultry	5.02	0.00	0.00	18.56	0.00	0.00	0.00
Sheep	13.52	6.76	6.12	11.67	18.62	11.31	6.21

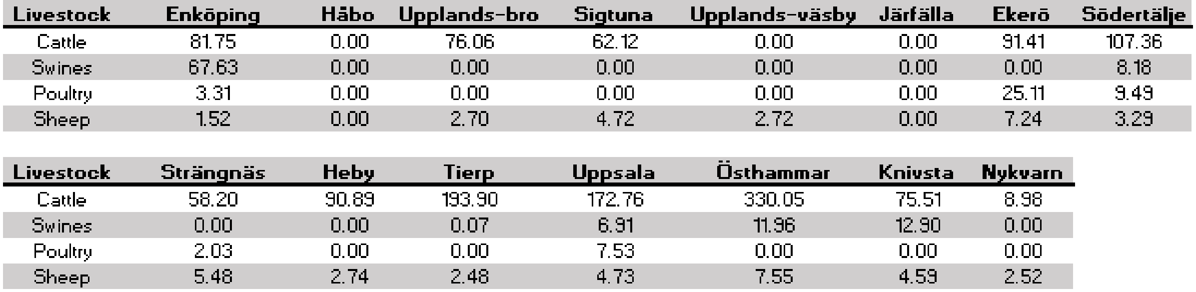
Table AA12. Stored manure [kg/ha] for SSP5 year 2040-2050.



Livestock	Enköping	Håbo	Upplands-bro	Sigtuna	Upplands-väsby	Järfälla	Ekerö	Södertälje
Cattle	163.23	0.00	151.87	124.02	0.00	0.00	182.51	214.37
Swines	135.04	0.00	0.00	0.00	0.00	0.00	0.00	16.33
Poultry	6.61	0.00	0.00	0.00	0.00	0.00	50.13	18.95
Sheep	3.04	0.00	5.39	9.43	5.43	0.00	14.45	6.58

Livestock	Strängnäs	Heby	Tierp	Uppsala	Östhammar	Knivsta	Nykvarn
Cattle	116.21	181.47	387.16	344.94	659.00	150.77	17.93
Swines	0.00	0.00	0.14	13.80	23.89	25.76	0.00
Poultry	4.06	0.00	0.00	15.03	0.00	0.00	0.00
Sheep	10.95	5.48	4.96	9.45	15.08	9.16	5.03

Table AA13. Stored manure [kg/ha] for SSP5 year 2090-2100.



Livestock	Enköping	Håbo	Upplands-bro	Sigtuna	Upplands-väsby	Järfälla	Ekerö	Södertälje
Cattle	81.75	0.00	76.06	62.12	0.00	0.00	91.41	107.36
Swines	67.63	0.00	0.00	0.00	0.00	0.00	0.00	8.18
Poultry	3.31	0.00	0.00	0.00	0.00	0.00	25.11	9.49
Sheep	1.52	0.00	2.70	4.72	2.72	0.00	7.24	3.29

Livestock	Strängnäs	Heby	Tierp	Uppsala	Östhammar	Knivsta	Nykvarn
Cattle	58.20	90.89	193.90	172.76	330.05	75.51	8.98
Swines	0.00	0.00	0.07	6.91	11.96	12.90	0.00
Poultry	2.03	0.00	0.00	7.53	0.00	0.00	0.00
Sheep	5.48	2.74	2.48	4.73	7.55	4.59	2.52

8.2 Urban areas and detached house properties

The data provided in the appendix “Urban areas and detached house properties” is used to describe fecal contamination from WWTPs and OWTSs. Figure AB1 shows flow from WWTPs with retrieved data on flow with daily variation. Figure AB2 shows the difference between exact OWTS discharges and OWTS discharges with a categorization made in our study. Table AB1-AB5 concerns future effect from population changes on discharges from OWTSs and WWTPs. Table AB6-AB7 concerns future OWTS and WWTP treatment efficiencies.

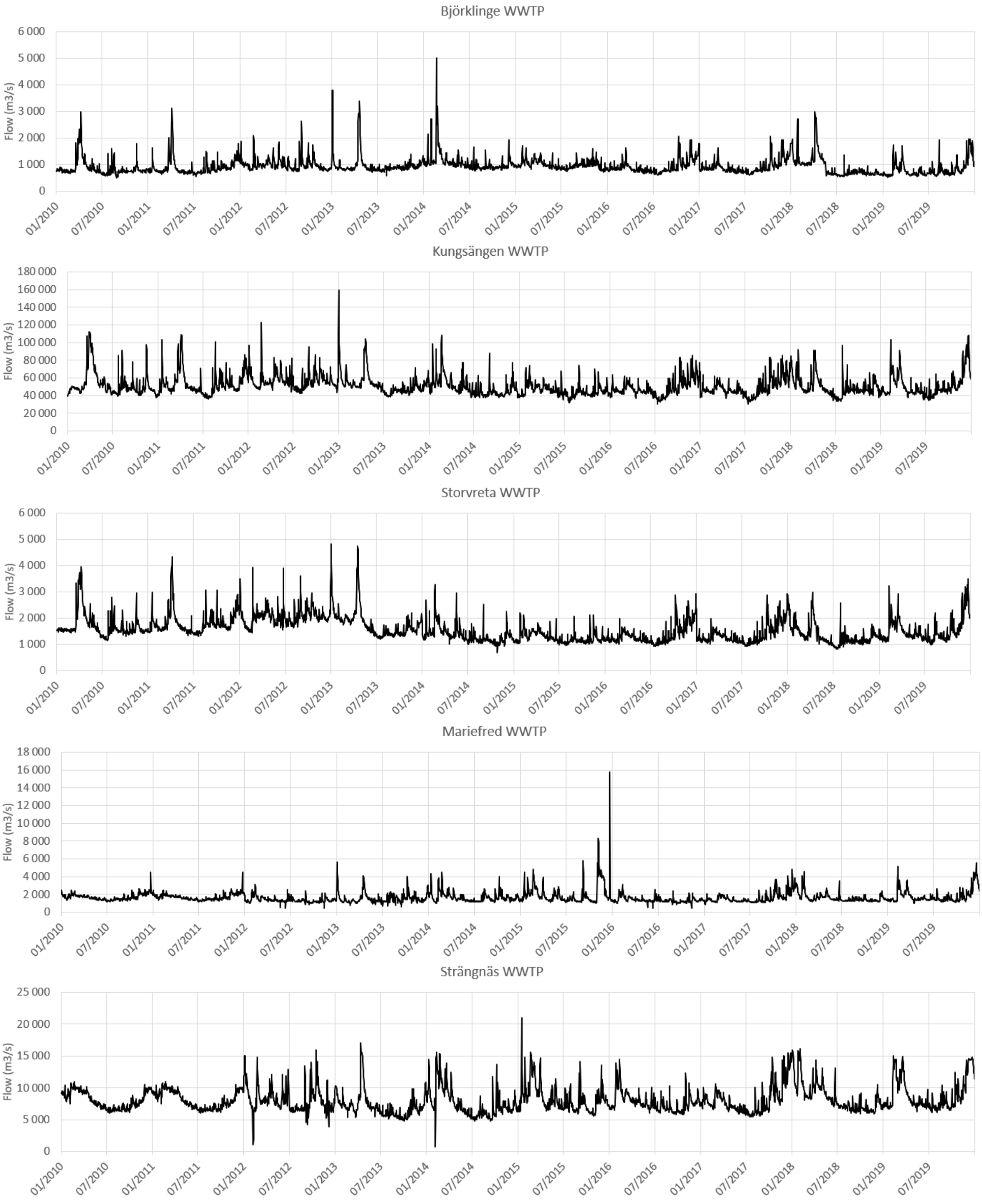


Figure AB1. WWTP flows with daily variation for five different WWTPs in the study area. For Mariefred and Strängnäs WWTPs, only flows from 2012 and 2013 respectively could be retrieved, hence the flows for these years and WWTPs were extrapolated back to 2010.

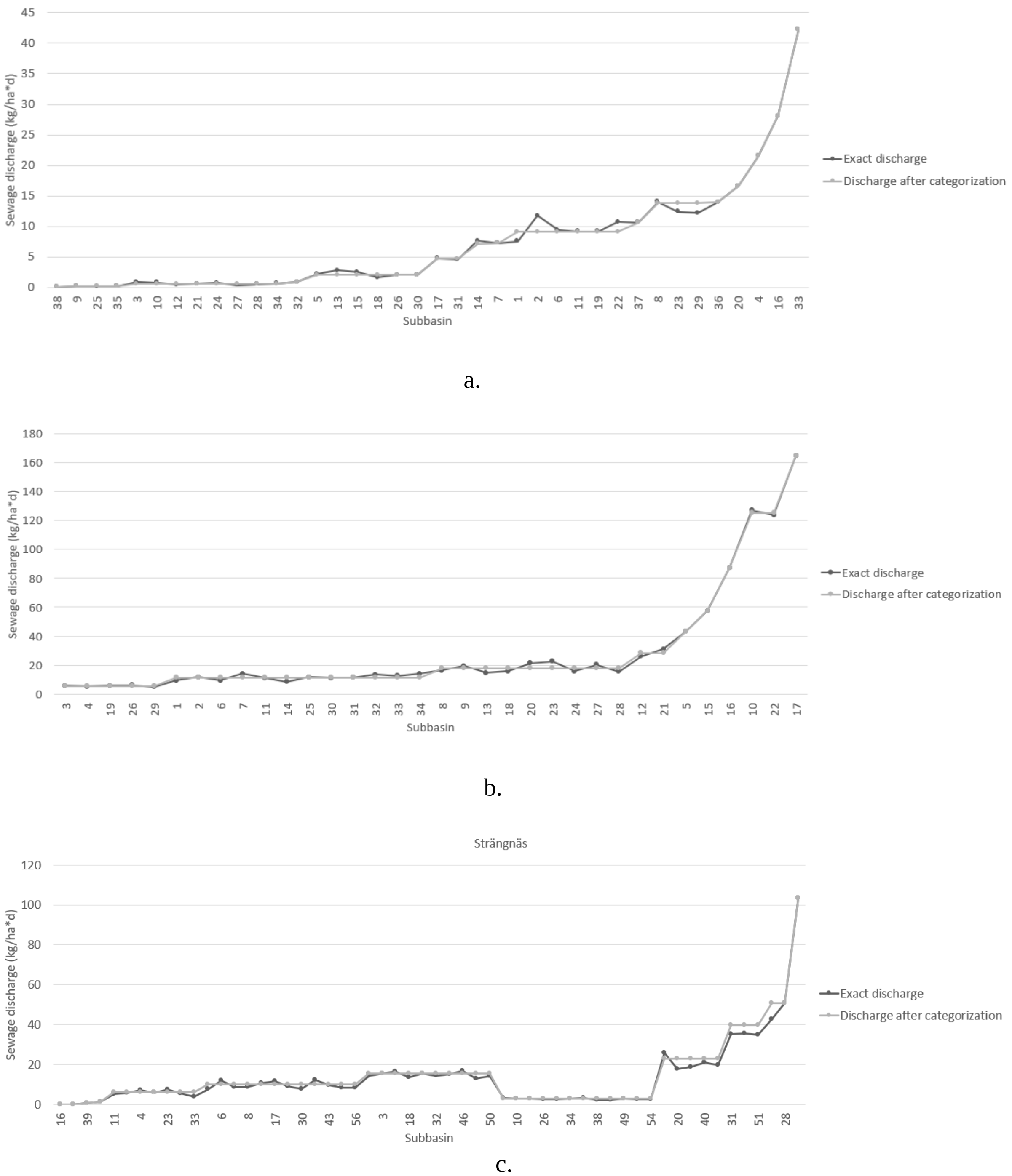


Figure AB2. Exact sewage discharge in the baseline scenario compared to sewage discharge with a categorization of subbasins with ±25% similarity. a) represent Stäket, b) Enköping and c) Strängnäs.

Table AB1. Urban and OWTS share based on the number of people (PE) connected to WWTPs and with OWTSs. The sum of estimated people connected to WWTPs and with OWTSs is validated against the measured population in each municipality based on literature, with an estimation error.

Municipality	Pe connected to WWTP	Pe with OWTSs	Sum of estimated pe	Urban share	OWTS share	Measured pop	Estimation Error
Östhammar	12699	7522	20221	63%	37%	22500	-10%
Uppsala	195878	22904	218782	90%	10%	230000	-5%
Upplands-Bro	28815	2185	31000	93%	7%	31000	-
Tierp	13451	6593	20044	67%	33%	20044	-
Strängnäs	28750	6482	35232	82%	18%	36000	-2%
Sigtuna	45879	4121	50000	92%	8%	50000	-
Knivsta	13350	6000	19350	69%	31%	19765	-2%
Håbo	19911	1430	21341	93%	7%	22000	-3%
Heby	7809	5400	13209	59%	41%	14000	-6%
Enköping	30000	12500	42500	71%	29%	46000	-8%
Ekerö	23306	5694	29000	80%	20%	29000	-
Södertälje	92669	6331	99000	94%	6%	99000	-
Upplands Väsby	44511	489	45000	99%	1%	45000	-
Nykvarn	8546	2454	11000	78%	22%	11000	-

Table AB2. The effect of urban share and population increase on the number of people (PE) connected to WWTPs and OWTSs. PE1 is calculated based on the effect from urban share and PE2 is calculated based on the effect of urban share and population increase combined. Baseline scenario can be seen in Table AB1.

	SSP1 2040-2050						SSP2 2040-2050					
Municipality	Urban Share	OWTS Share	PE1 WWTP	PE1 OWTS	PE2 WWTP	PE2 OWTS	Urban Share	OWTS Share	PE1 WWTP	PE1 OWTS	PE2 WWTP	PE2 OWTS
Östhammar	71%	29%	14443	5778	18170	7269	70%	30%	14100	6122	17244	7487
Uppsala	90%	10%	195878	22904	246415	28813	90%	10%	195878	22904	239559	28011
Upplands-Bro	93%	7%	28815	2185	36249	2749	93%	7%	28815	2185	35241	2672
Tierp	76%	24%	15299	4745	19246	5970	75%	25%	14934	5110	18265	6249
Strängnäs	93%	7%	32699	2533	41136	3186	91%	9%	31921	3312	39039	4050
Sigtuna	92%	8%	45879	4121	57716	5184	92%	8%	45879	4121	56110	5040
Knivsta	78%	22%	15184	4166	19101	5241	77%	23%	14822	4528	18128	5537
Håbo	93%	7%	19911	1430	25048	1799	93%	7%	19911	1430	24351	1749
Heby	67%	33%	8882	4327	11173	5443	66%	34%	8670	4538	10604	5550
Enköping	80%	20%	34121	8379	42924	10541	78%	22%	33309	9191	40736	11241
Ekerö	91%	9%	26508	2492	33346	3136	89%	11%	25876	3124	31647	3820
Södertälje	94%	6%	92669	6331	116578	7964	94%	6%	92669	6331	113334	7743
Upplands Väsby	99%	1%	44511	489	55995	615	99%	1%	44511	489	54437	598
Nykvarn	88%	12%	9720	1280	12228	1610	86%	14%	9489	1511	11605	1848

	SSP5 2040-2050						SSP1 2090-2100					
Municipality	Urban Share	OWTS Share	PE1 WWTP	PE1 OWTS	PE2 WWTP	PE2 OWTS	Urban Share	OWTS Share	PE1 WWTP	PE1 OWTS	PE2 WWTP	PE2 OWTS
Östhammar	71%	29%	14457	5764	21426	8542	77%	23%	15605	4616	23252	6878
Uppsala	90%	10%	195878	22904	290291	33943	90%	10%	195878	22904	291858	34127
Upplands-Bro	93%	7%	28815	2185	42704	3238	93%	7%	28815	2185	42935	3255
Tierp	76%	24%	15313	4731	22694	7011	82%	18%	16529	3515	24628	5237
Strängnäs	93%	7%	32730	2502	48506	3708	93%	7%	32730	2502	48768	3728
Sigtuna	92%	8%	45879	4121	72489	6511	92%	8%	45879	4121	68360	6140
Knivsta	79%	21%	15198	4152	24317	6643	85%	15%	16405	2945	24444	4388
Håbo	93%	7%	19911	1430	29508	2119	93%	7%	19911	1430	29667	2130
Heby	67%	33%	8890	4318	13175	6400	73%	27%	9596	3612	14298	5383
Enköping	80%	20%	34153	8347	50615	12370	87%	13%	36865	5635	54929	8396
Ekerö	91%	9%	26533	2467	39321	3657	91%	9%	26508	2492	39496	3714
Södertälje	94%	6%	92669	6331	137335	9383	94%	6%	92669	6331	138077	9433
Upplands Väsby	99%	1%	44511	489	65966	724	99%	1%	44511	489	66322	728
Nykvarn	88%	12%	9730	1270	14419	1883	95%	5%	10502	498	15648	742

	SSP5 2090-2100					
Municipality	Urban Share	OWTS Share	PE1 WWTP	PE1 OWTS	PE2 WWTP	PE2 OWTS
Östhammar	83%	17%	16763	3459	39443	8138
Uppsala	90%	10%	195878	22904	460901	53892
Upplands-Bro	93%	7%	28815	2185	67802	5141
Tierp	89%	11%	17755	2289	41778	5385
Strängnäs	93%	7%	32730	2502	77015	5887
Sigtuna	92%	8%	45879	4121	115156	10344
Knivsta	85%	15%	16414	2936	41856	7486
Håbo	93%	7%	19911	1430	46851	3364
Heby	73%	27%	9601	3607	22592	8488
Enköping	87%	13%	36886	5614	86792	13210
Ekerö	91%	9%	26533	2467	62431	5806
Södertälje	94%	6%	92669	6331	218050	14897
Upplands Väsby	99%	1%	44511	489	104735	1150
Nykvarn	96%	4%	10508	492	24725	1158

Table AB3. Population change factor: PE2 (from Table AB2) divided by baseline population (Table AB1).

	SSP1 2040-2050		**SSP2 2040-2050**		**SSP5 2040-2050**		**SSP1 2090-2100**		**SSP5 2090-2100**	
Municipality	**Urban**	**OWTS**	**Urban**	**OWTS**	**Urban**	**OWTS**	**Urban**	**OWTS**	**Urban**	**OWTS**
Östhammar	1.43	0.97	1.36	1.00	1.69	1.14	1.83	0.91	3.11	1.08
Uppsala	1.26	1.26	1.22	1.22	1.48	1.48	1.49	1.49	2.35	2.35
Upplands-Bro	1.26	1.26	1.22	1.22	1.48	1.48	1.49	1.49	2.35	2.35
Tierp	1.43	0.91	1.36	0.95	1.69	1.06	1.83	0.79	3.11	0.82
Strängnäs	1.43	0.49	1.36	0.62	1.69	0.57	1.70	0.58	2.68	0.91
Sigtuna	1.26	1.26	1.22	1.22	1.58	1.58	1.49	1.49	2.51	2.51
Knivsta	1.43	0.87	1.36	0.92	1.82	1.11	1.83	0.73	3.14	1.25
Håbo	1.26	1.26	1.22	1.22	1.48	1.48	1.49	1.49	2.35	2.35
Heby	1.43	1.01	1.36	1.03	1.69	1.19	1.83	1.00	2.89	1.57
Enköping	1.43	0.84	1.36	0.90	1.69	0.99	1.83	0.67	2.89	1.06
Ekerö	1.43	0.55	1.36	0.67	1.69	0.64	1.69	0.65	2.68	1.02
Södeertälje	1.26	1.26	1.22	1.22	1.48	1.48	1.49	1.49	2.35	2.35
Upplands Väsby	1.26	1.26	1.22	1.22	1.48	1.48	1.49	1.49	2.35	2.35
Nykvarn	1.43	0.66	1.36	0.75	1.69	0.77	1.83	0.30	2.89	0.47

Table AB4. Flow from houses (charged) and additional flow from for example drainage.

WWTP	**Tot flow (m3/d)**	**Flow from houses (based on charged amounts) (m3/d)**	**Additional flow (m3/d)**	**Charged share of tot flow**
Österbybruk	1213	425	788	35%
Björklinge	950	380	570	40%
Storvreta	1600	1168	432	73%
Uppsala	51000	37549	13451	74%
Heby	732	486	246	66%
Löten	8713	3995	4718	46%
Bålsta	5997	2750	3248	46%
Skoklosters	575	264	312	46%
Knivsta	3100	1421	1679	46%
Strängnäs	8100	4698	3402	58%
Mariefreds	1670	969	701	58%

Table AB5. Flow from WWTPs assuming population and water use change.

	Flow (m3/d)					
WWTP	**Base scenario 2010-2020**	**SSP1 2040-2050**	**SSP1 2090-2100**	**SSP2 2040-2050**	**SSP5 2040-2050**	**SSP5 2090-2100**
Österbybruk	1213	1274	1333	1307	1361	1711
Björklinge	950	952	966	988	1021	1196
Storvreta	1600	1607	1650	1718	1817	2356
Uppsala	51000	51240	52615	54781	57969	75298
Heby	732	802	869	840	902	1230
Löten	8713	9291	9838	9600	10110	12808
Bålsta	5997	6015	6115	6274	6508	7776
Skoklosters	575	577	587	602	624	746
Knivsta	3100	3306	3500	3416	3750	4798
Strängnäs	8100	8780	8980	9143	9743	12211
Mariefreds	1670	1810	1852	1885	2009	2518

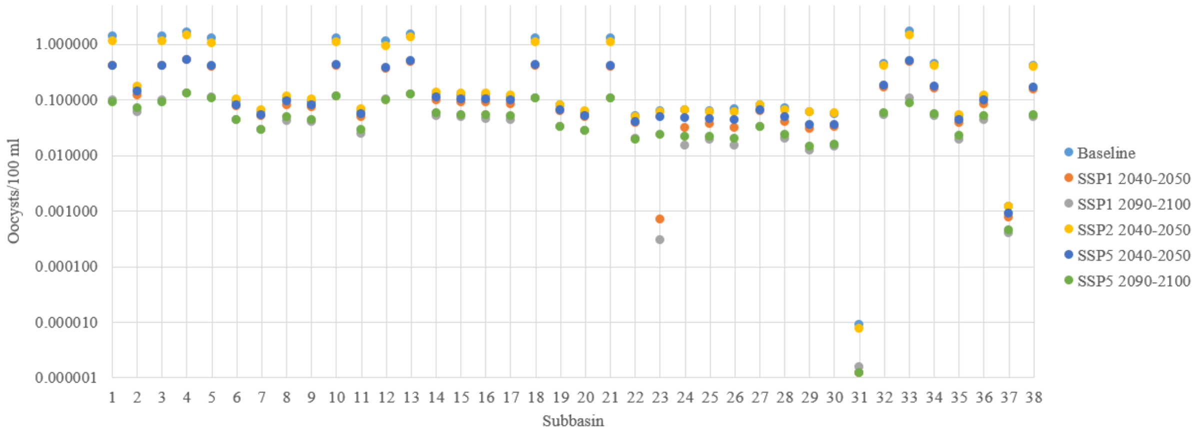
Table AB6. Treatment efficiencies from ozonation and filtration multiplied by the share of WWTPs with advanced treatment.

SSP1 2040-2050	**SSP1 2090-2100**	**SSP2 2040-2050**	**SSP5 2040-2050**	**SSP5 2090-2100**
Share of WWTPs with advanced treatment				
80%	90%	0%	80%	90%
LRV *E.Coli* (Advanced treatment efficiency*Share)				
1.1	2.2	0.0	1.1	2.2
LRV *Cryptosptoridium* (Advanced treatment efficiency*Share)				
0.5	1.2	0.0	0.5	1.2

Table AB7. Treatment efficiencies in OWTSs over time. Shares and efficiencies are based on Naturvårdsverket (2003). "SSP2 2040-2050" is calculated assuming that 45/70 (based on the number of years to replace malfunctioning OWTSs) septic tanks are still present. "SSP1/SSP5 2040-2050 and 2090-2100" is calculated assuming that no septic tanks are still present.

	Baseline scenario		**SSP2 2040-2050**		**SSP1/SSP5 2040-2050 and 2090-2100**	
Type of OWTS	**Share**	**Efficiency**	**Share**	**Efficiency**	**Share**	**Efficiency**
Infiltration plant	44%	99%	54%	99%	73%	99%
Closed tank	10%	100%	10%	100%	10%	100%
Soil bed	17%	95%	17%	95%	17%	95%
Septic tank	29%	50%	19%	50%	0%	50%
		Avarage efficiency		**Avarage efficiency**		**Avarage efficiency**
		84%		90%		99%

8.3 Result



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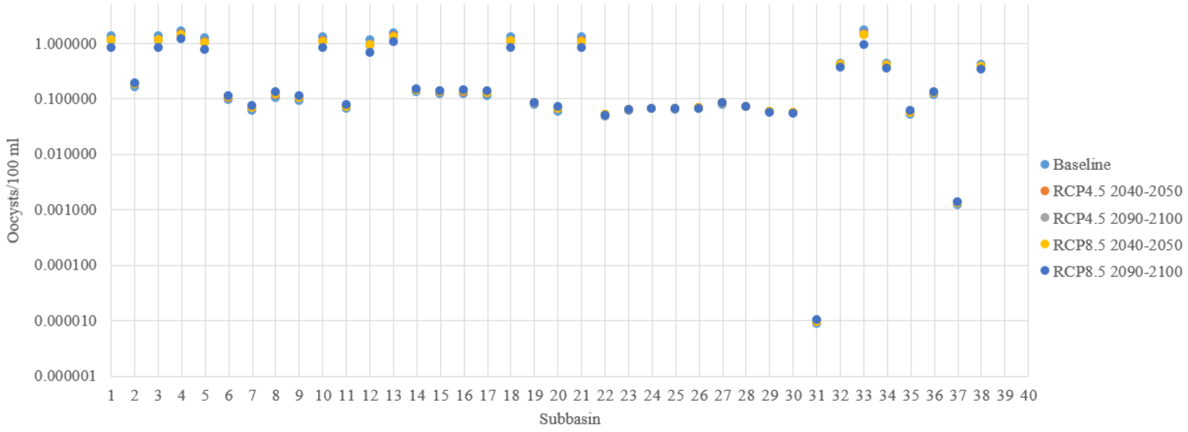
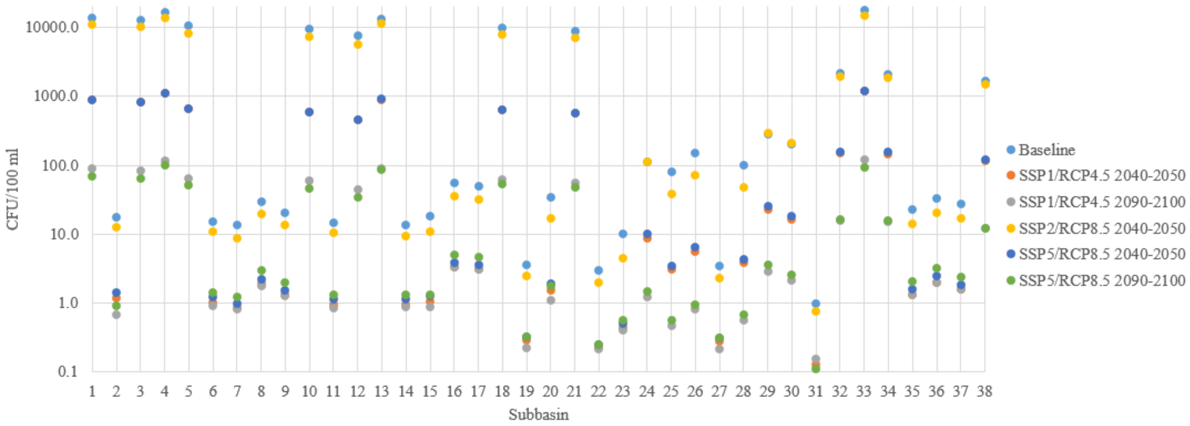


b)

Figure A2. Stäket- Cryptosporidium, total average concentrations. Socioeconomic development and climate change a), climate change alone b). All subbasin numbers can be seen in figure A16.



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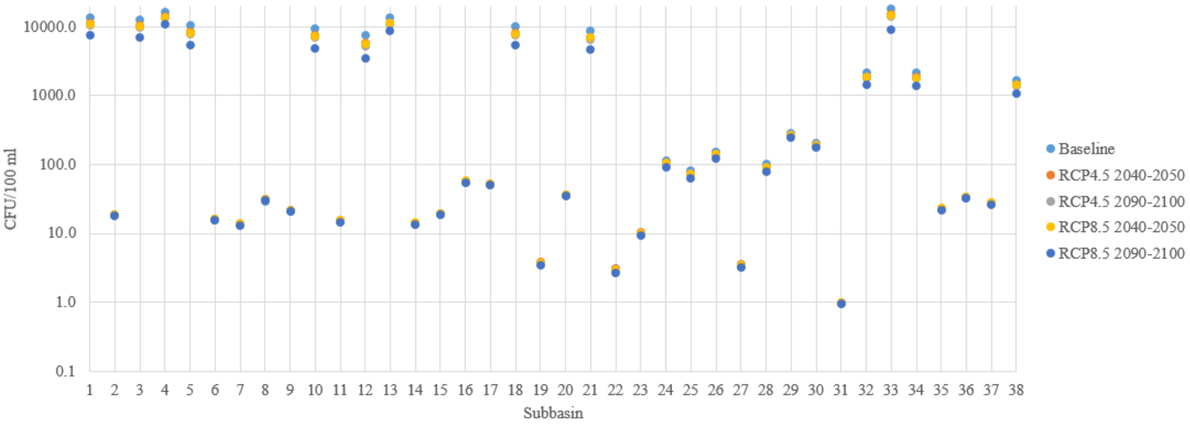
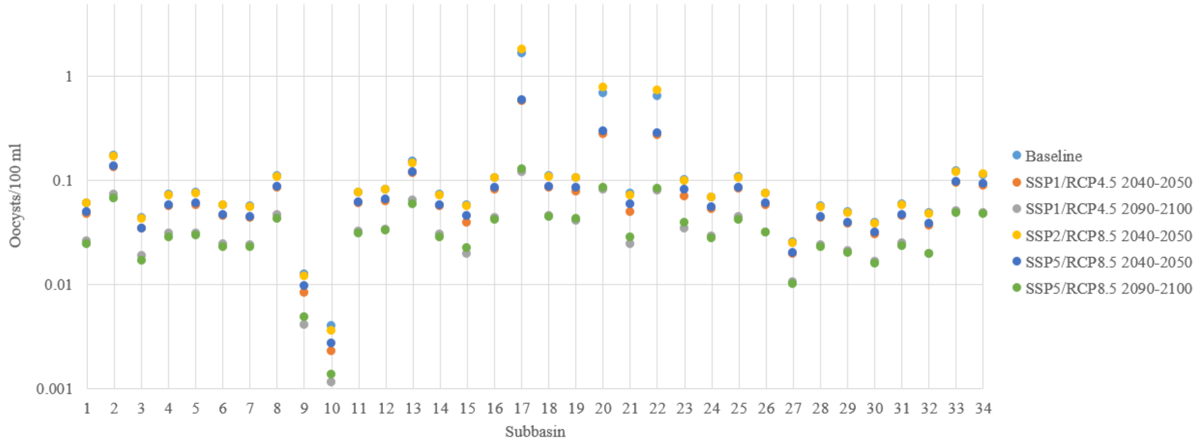


b)

Figure A3. Stäket- E. coli, total average concentrations. Socioeconomic development and climate change a), climate change alone b). All subbasin numbers can be seen in Figure A16.



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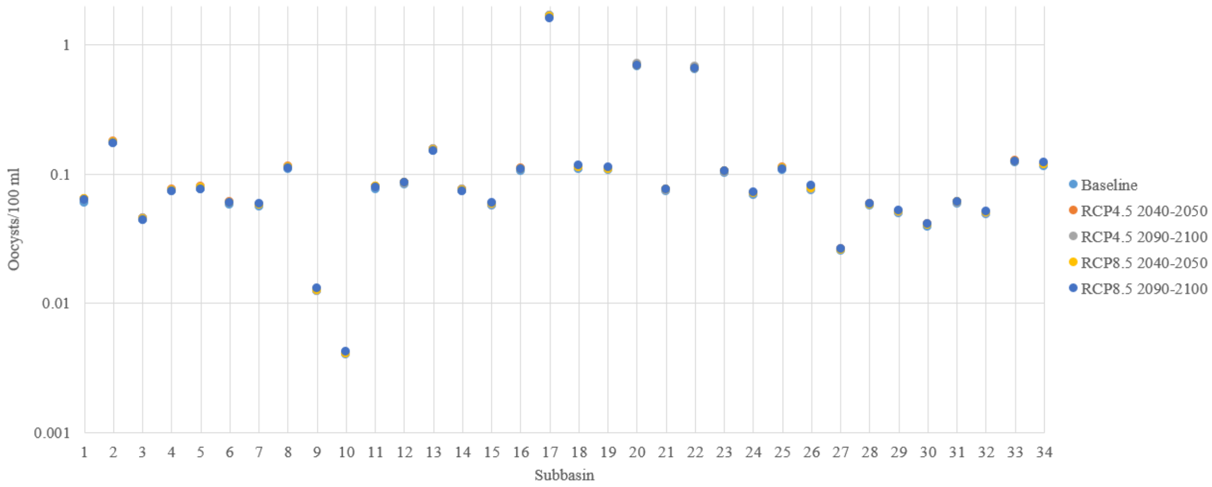
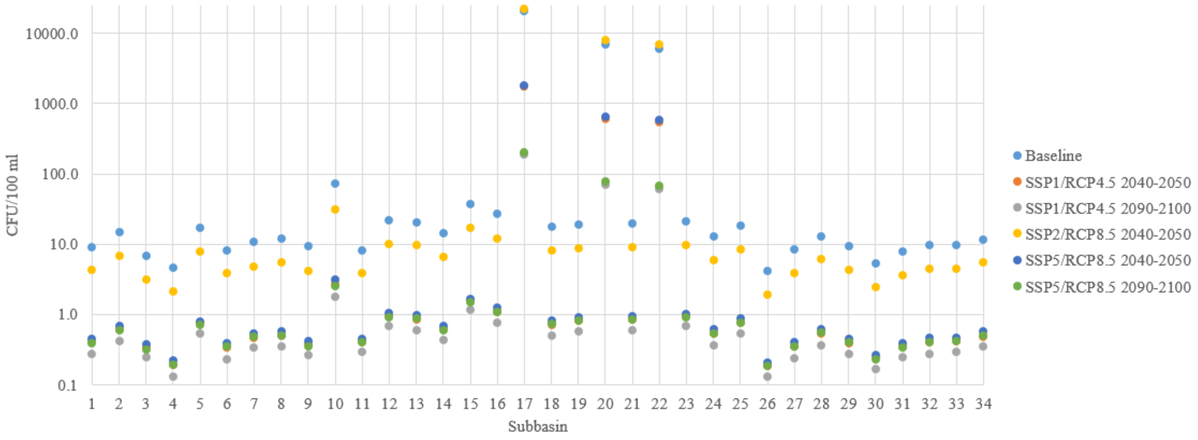


b)

Figure A4. Enköping- Cryptosporidium, total average concentrations. Socioeconomic development and climate change a), climate change alone b). All subbasin numbers can be seen in Figure A16.



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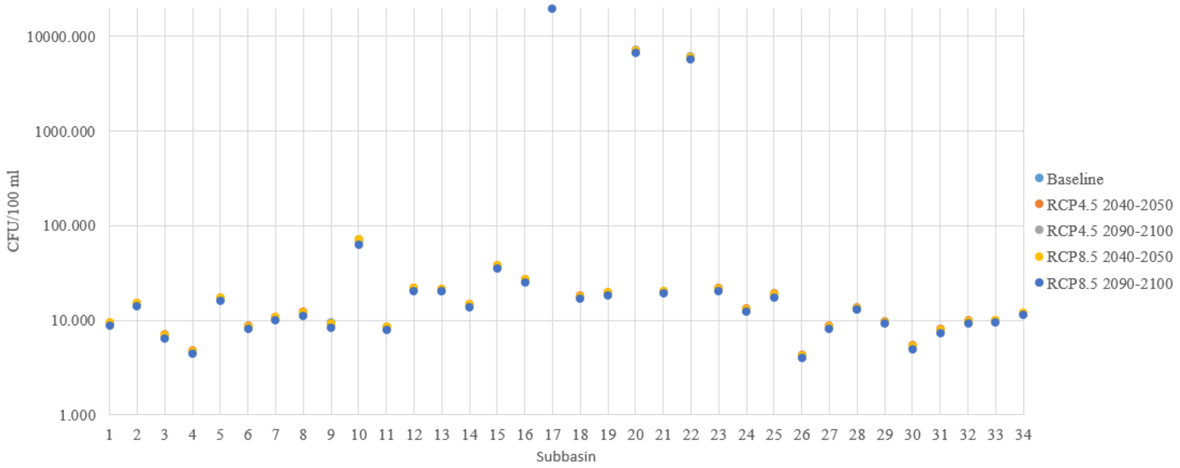
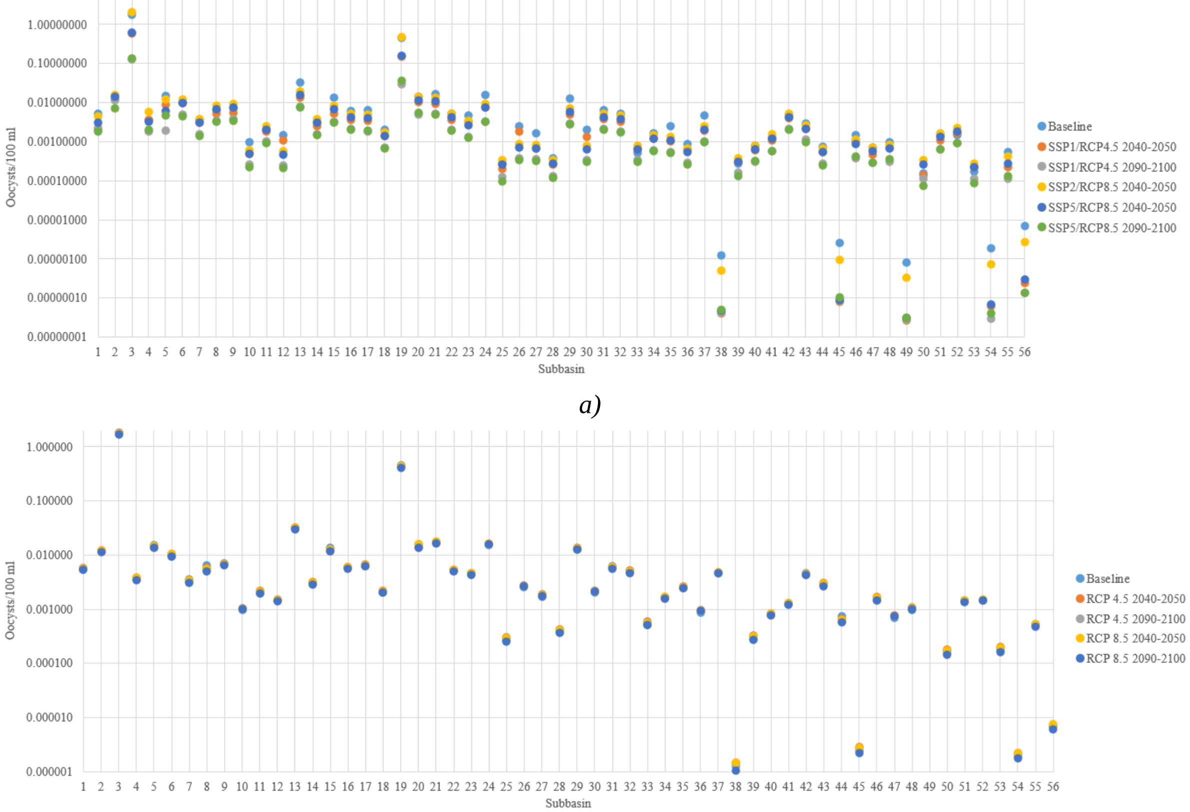


b)

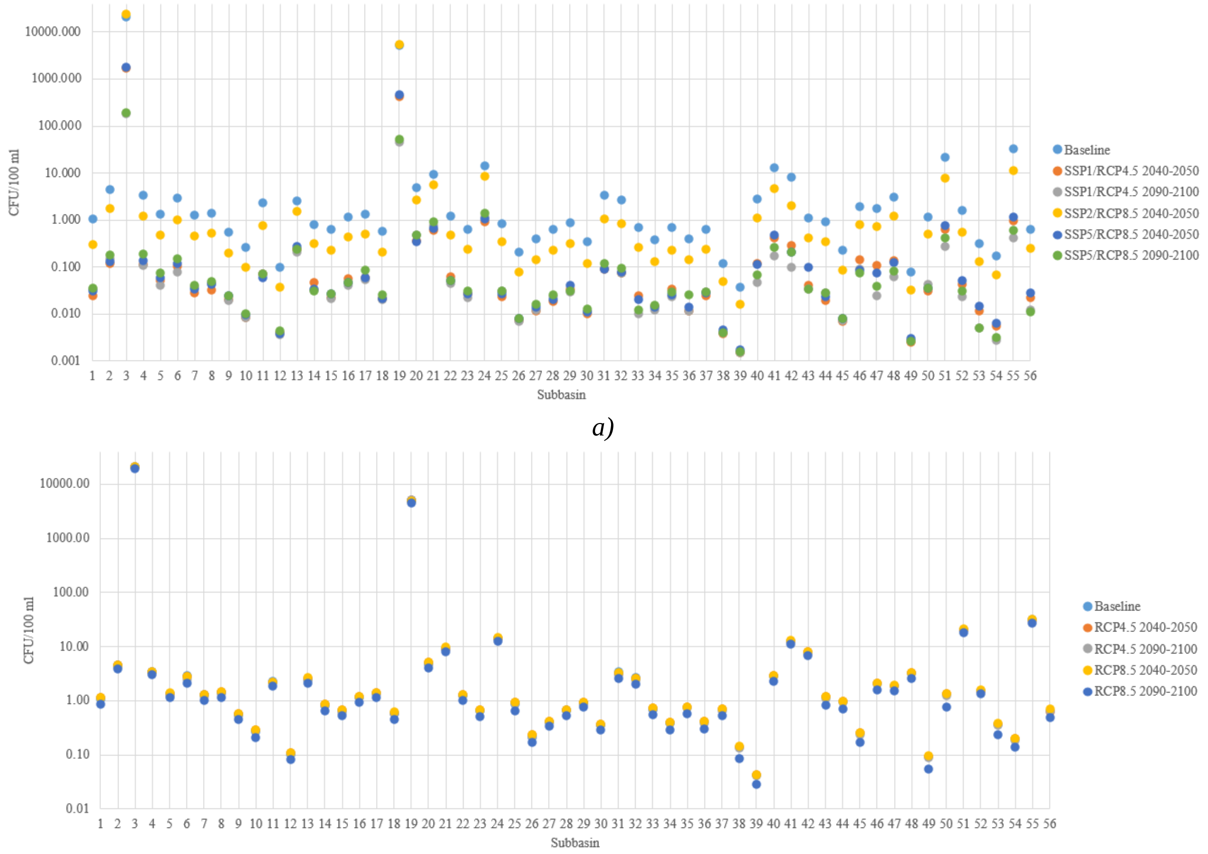
Figure A5. Enköping- E. coli, total average concentrations. Socioeconomic development and climate change a), climate change alone b). All subbasin numbers can be seen in Figure A16.



a)

b)

Figure A6. Strängnäs- Cryptosporidium, total average concentrations. Socioeconomic development and climate change a), climate change alone b). All subbasin numbers can be seen in Figure A16.



a)

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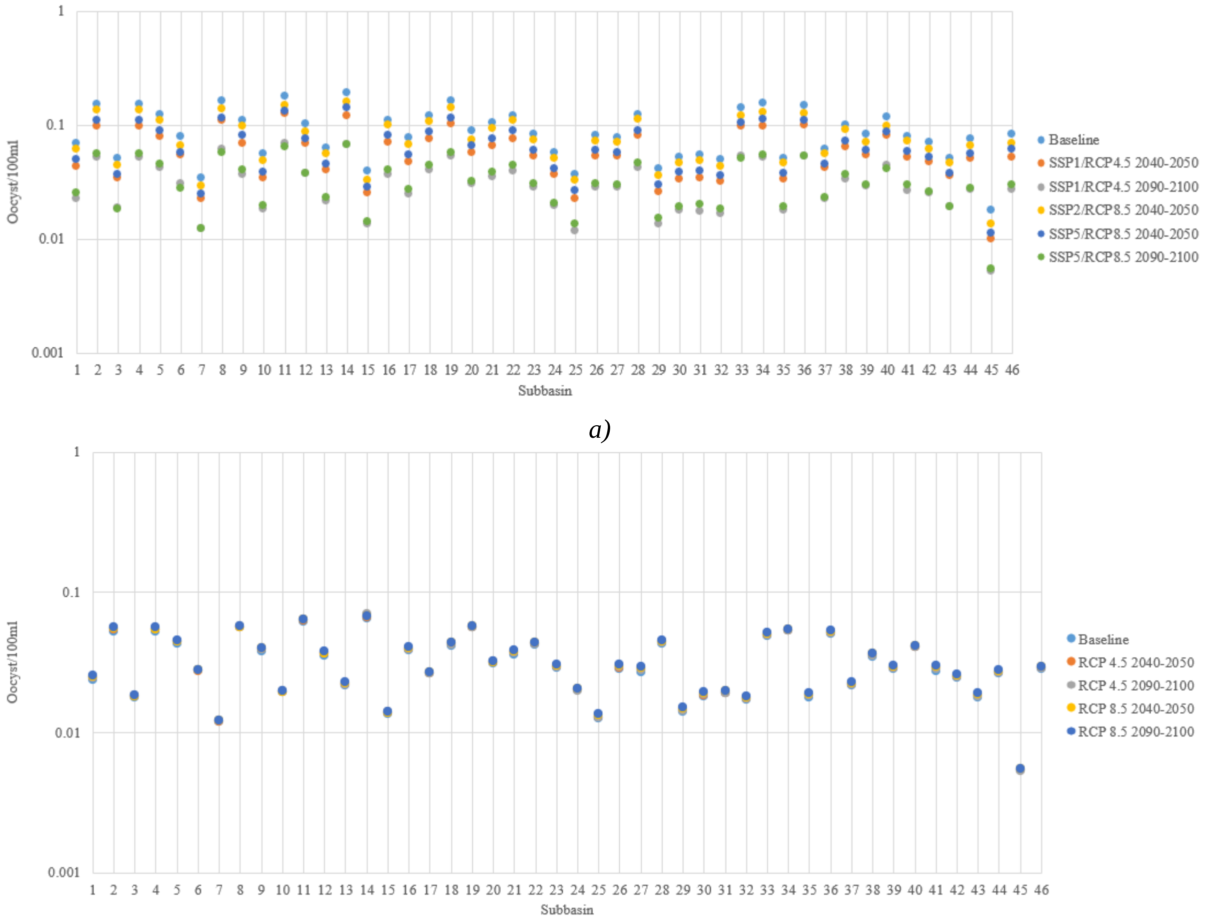
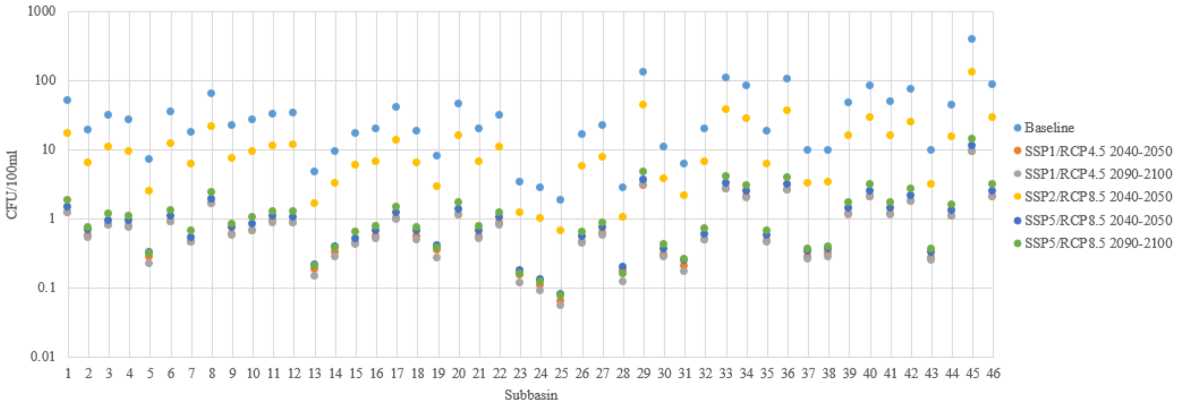
Figure A7. Strängnäs- E. coli, total average concentrations. Socioeconomic development and climate change a), climate change alone b). All subbasin numbers can be seen in Figure A16.



a)

b)

Figure A8. Ekerö Model 6- Cryptosporidium, total average concentrations. Socioeconomic development and climate change a), climate change alone b). All subbasin numbers can be seen in Figure A16.



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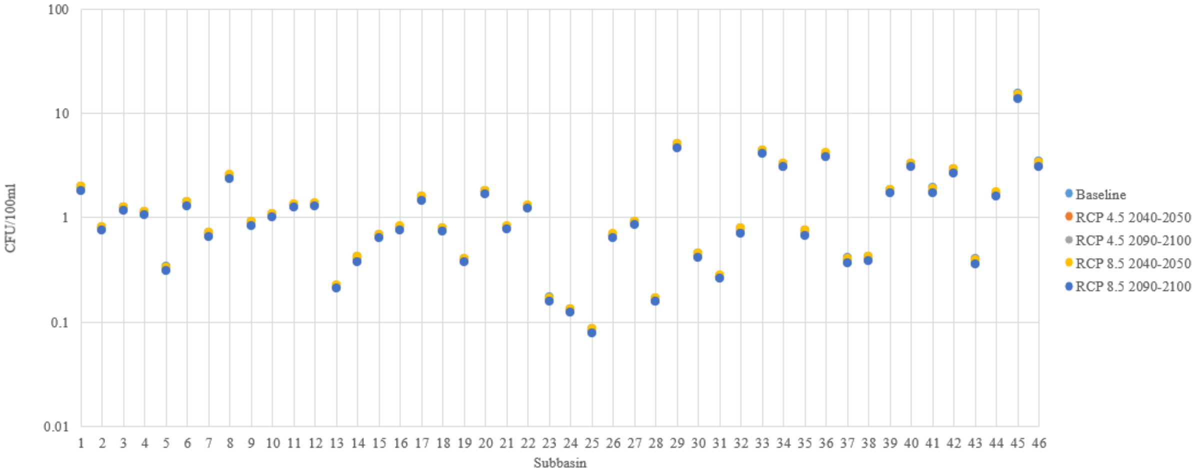
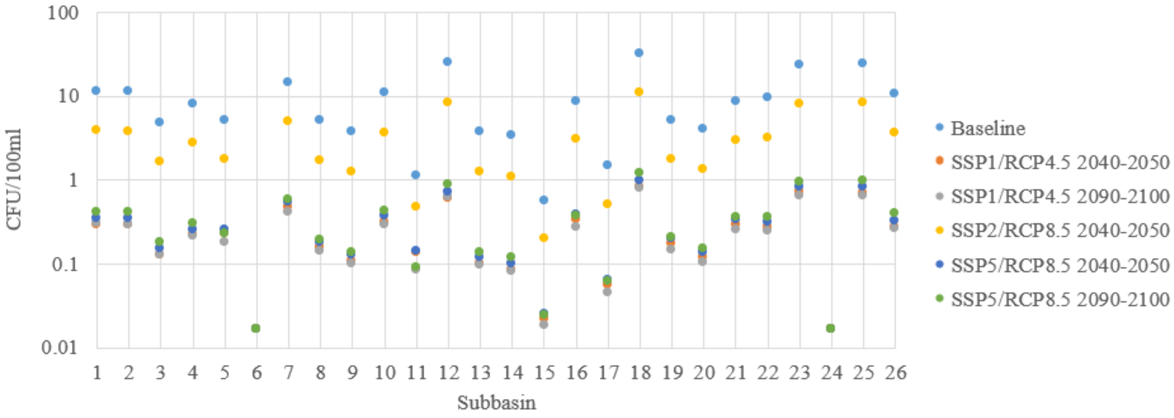


b)

Figure A9. Ekerö Model 6- E.coli, total average concentrations. Socioeconomic development and climate change a), climate change alone b). All subbasin numbers can be seen in Figure A16.



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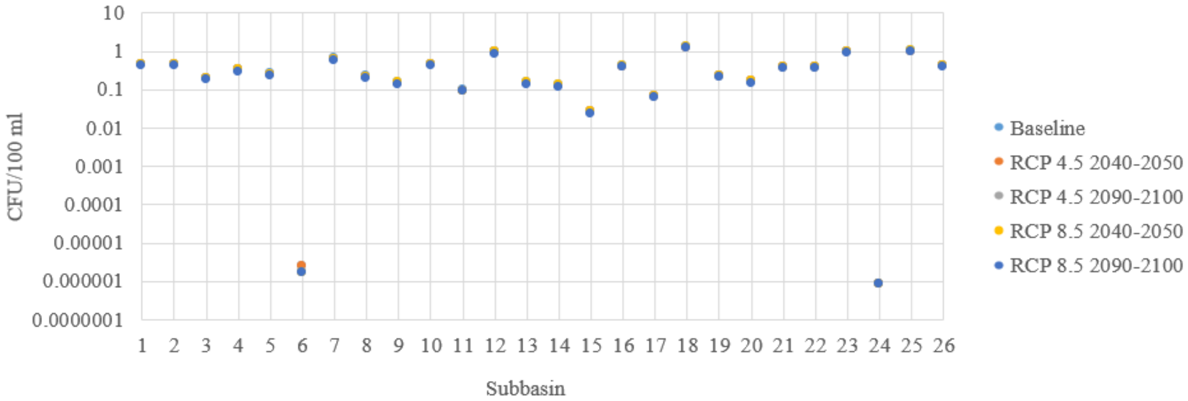
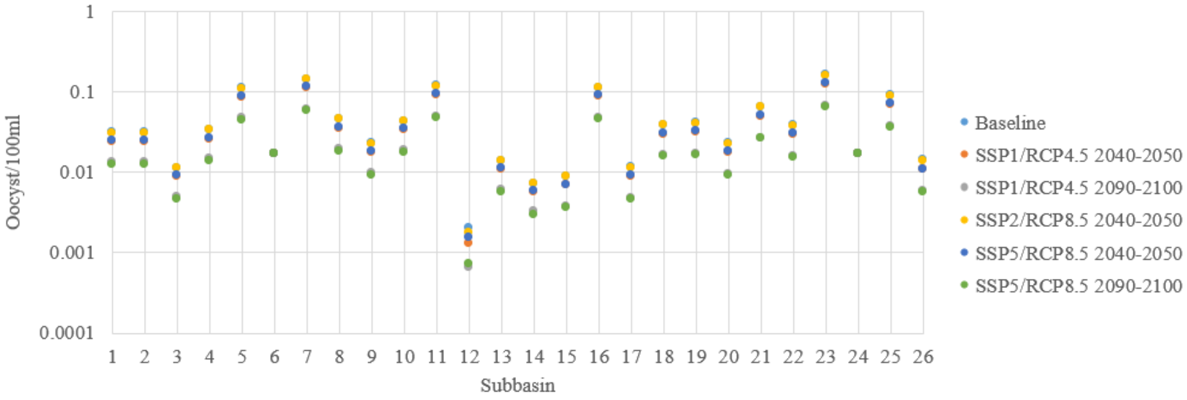


b)

Figure A10. Ekerö Model 5- E. coli, total average concentrations. Socioeconomic development and climate change a), climate change alone b). All subbasin numbers can be seen in Figure A16.



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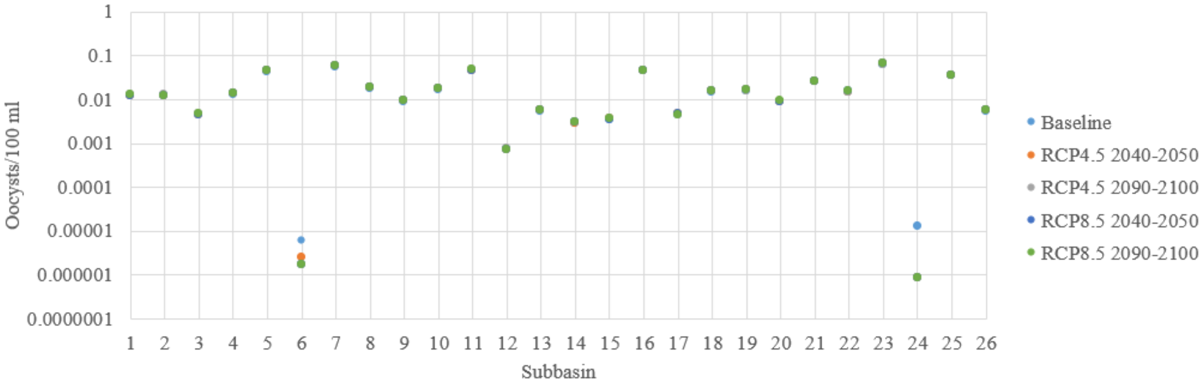
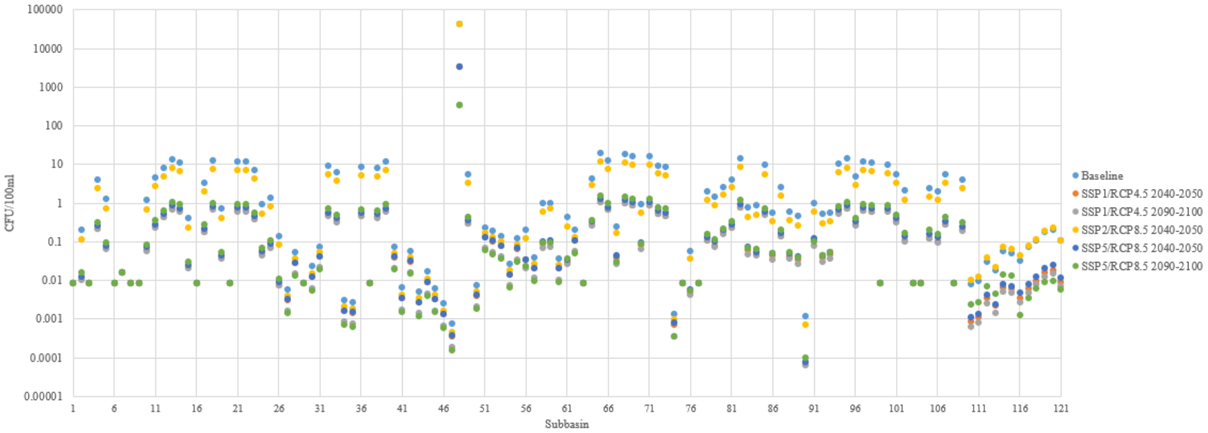


b)

Figure A11. Ekerö Model 5- Cryptosporidium, total average concentrations. Socioeconomic development and climate change a), climate change alone b). All subbasin numbers can be seen in Figure A16.



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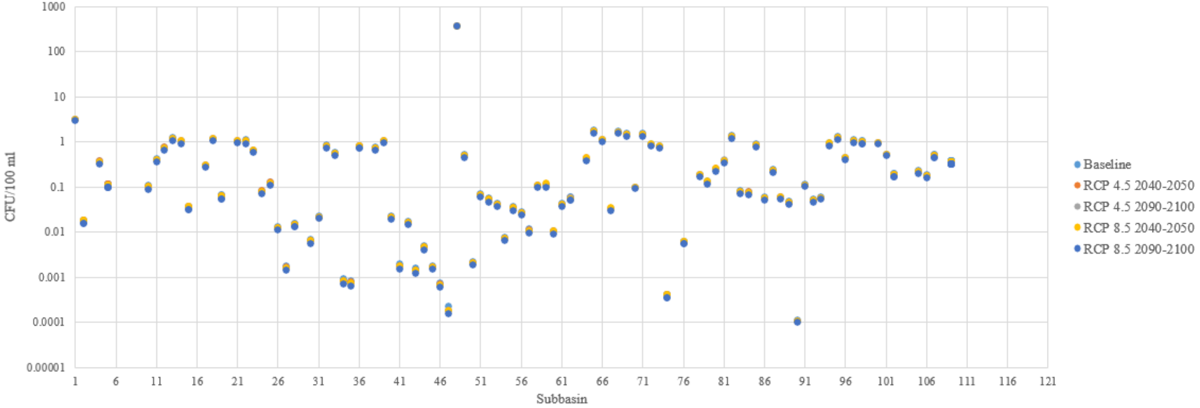
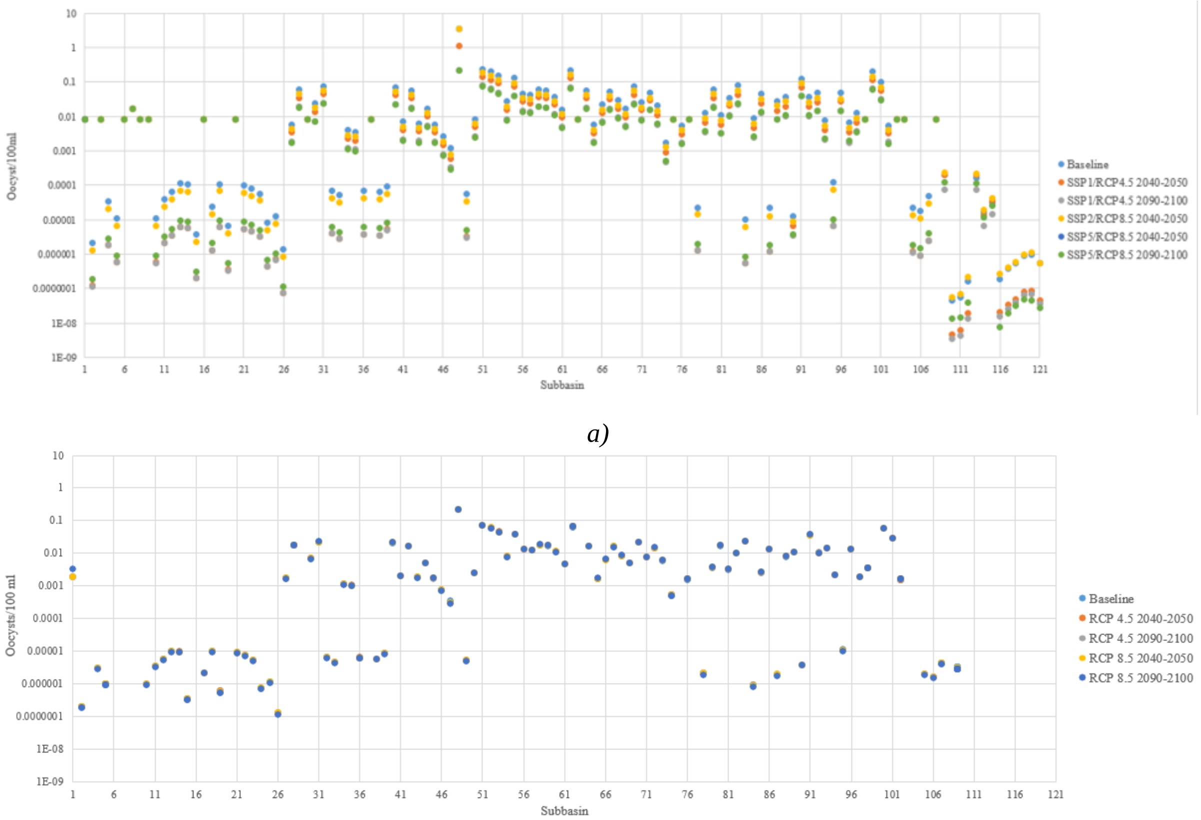


b)

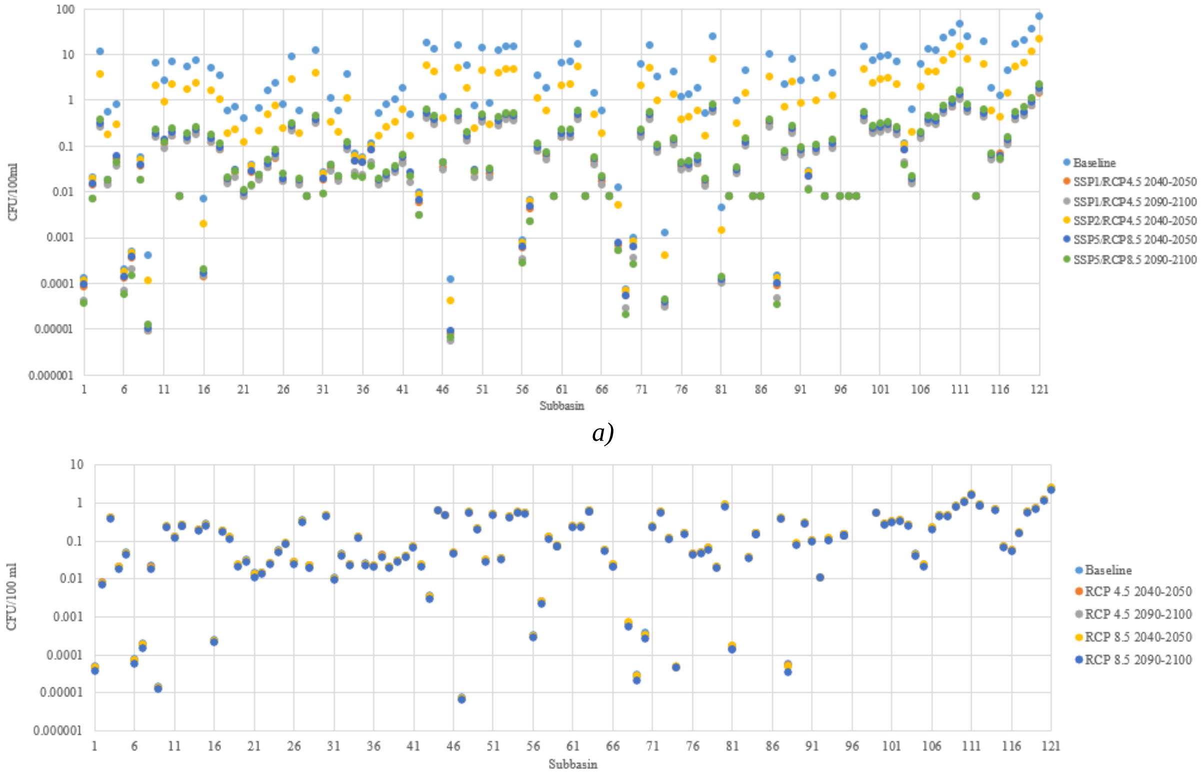
Figure A12. Stäket Under- E. coli, total average concentrations. Socioeconomic development and climate change a), climate change alone b). All subbasin numbers can be seen in Figure A16.



a)

b)

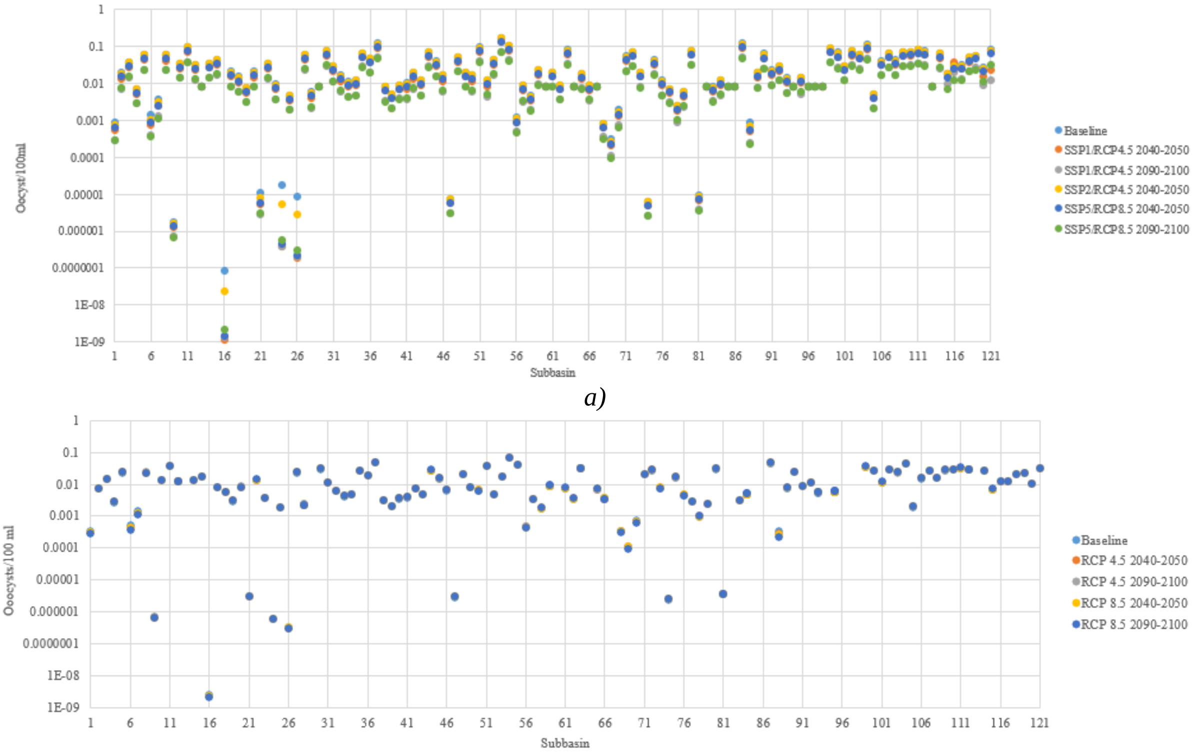
Figure A13. Stäket Under- Cryptosporidium, total average concentrations. Socioeconomic development and climate change a), climate change alone b). All subbasin numbers can be seen in Figure A16.



a)

b)

Figure A14. Strängnäs Island- E. coli, total average concentrations. Socioeconomic development and climate change a), climate change alone b). All subbasin numbers can be seen in Figure A16.



a)

b)

Figure A15. Strängnäs Island- Cryptosporidium, total average concentrations. Socioeconomic development and climate change a), climate change alone b). All subbasin numbers can be seen in Figure A16.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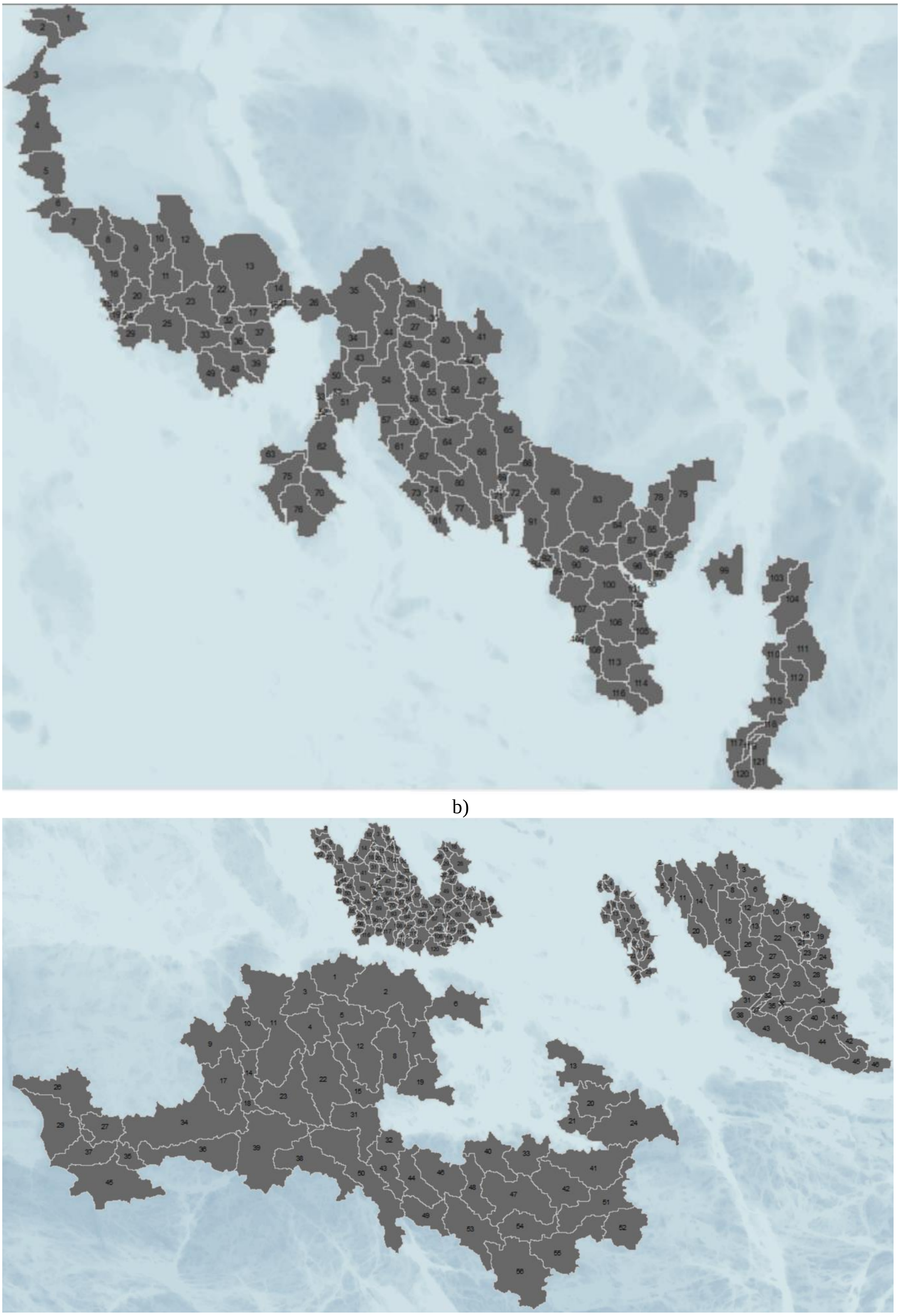
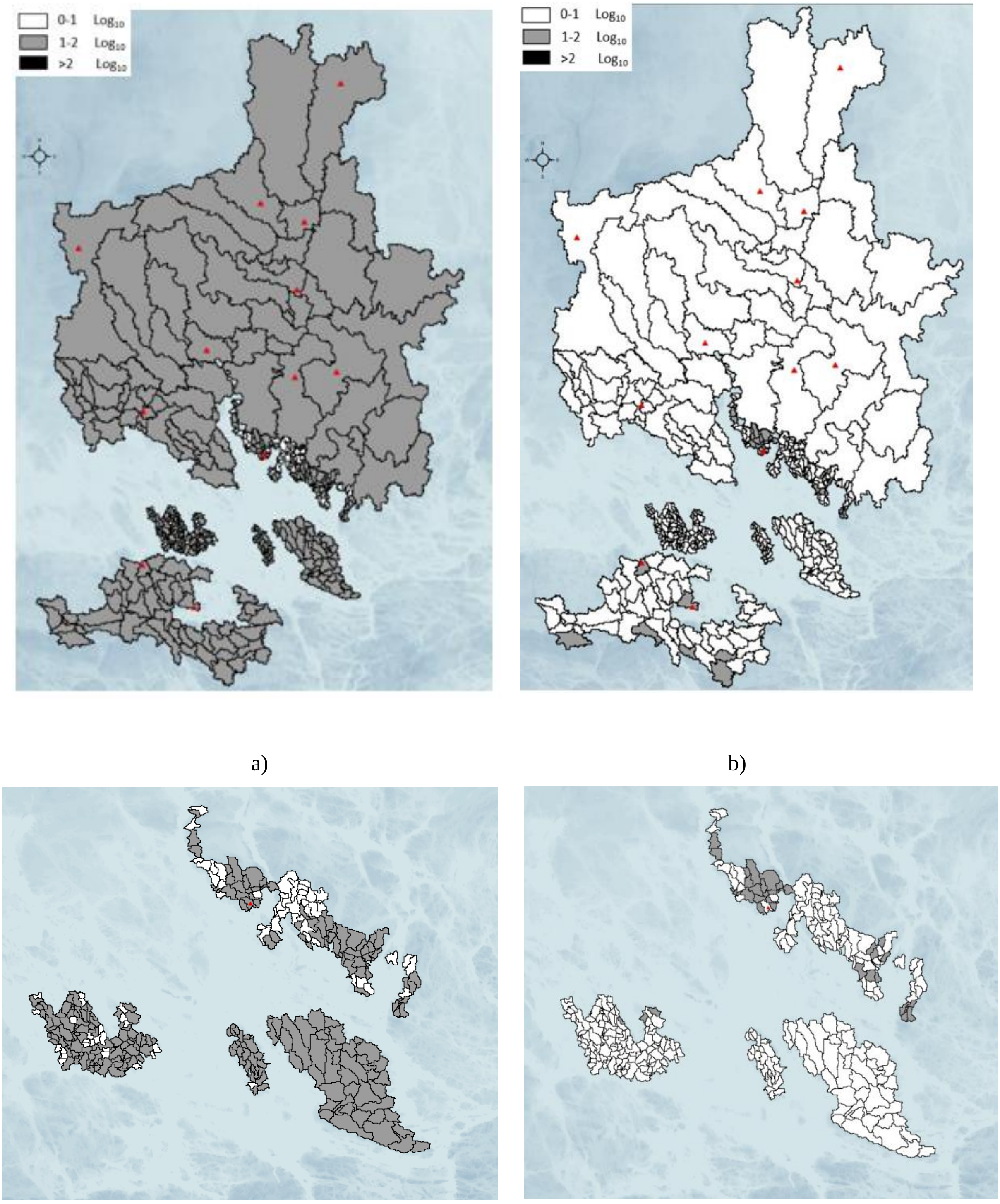
a)



b)

c)

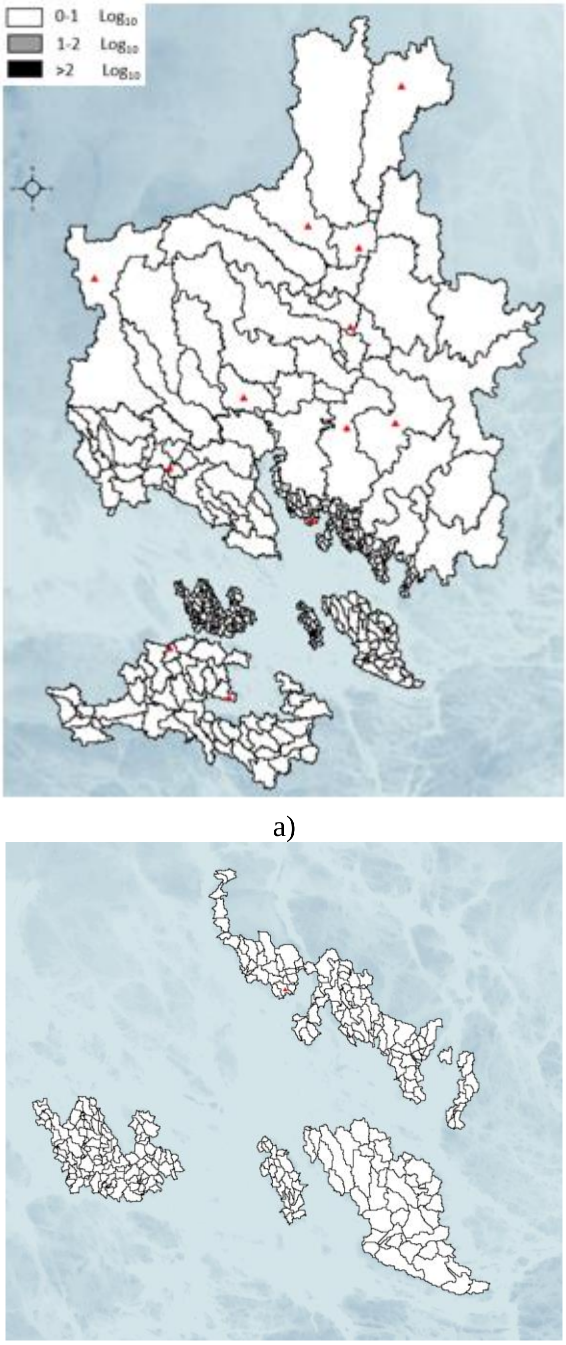
Figure A16. Subbasin numbers for Stäket and Enköping a), Stäket under b), Strängnäs and Ekerö c).



a) b)

c) d)

Figure A17. Average subbasin reduction of E. coli are visualized in a) and c) and Cryptosporidium in b) and d) for SSP1 and SSP5 up to year 2040-2050. Red triangles designate WWTPs.



a)

b)

Figure A18. Subbasin averages of E. coli and Cryptosporidium in a) and b) for SSP2 up to the year 2040-2050. Red triangles designate WWTPs.

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