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Sustainability Analysis of Swedish Performance

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NASIK NAJAR
WATER RESOURCES ENGINEERING | FACULTY OF ENGINEERING | LUND UNIVERSITY

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Nasik Najar

DOCTORAL DISSERTATION

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Abstract:

In Sweden, a sustainability index (SI) has been used since 2014 as an internal benchmark management tool to analyse and steer municipal water and wastewater (WW) activities toward sustainability. A consistent trend in national results from SI across all years is that while day-to-day operations are working well, there are deficiencies in strategies for long-term planning. The national results show that only 2 per cent of the 184 participating water utilities in the 2020 SI results have a good level of performance (green) and meet the requirements for sustainable climate adaptation and flood security, and only 4 per cent of 184 were green and meet the requirements for sustainable status of the WW facilities". Therefore, the present work investigates and focuses on water utilities that demonstrate good ability to improve their long-term sustainability outcomes.

The goal of the thesis was to present these utilities as good learning examples to inspire other utilities seeking to improve their outcomes, and to clarify and flesh out the driving factors, strategies, and important explanations for their success, as well as the challenges they face.

Four studies were conducted. The first study addressed the project of future water supply in Växjö after 10 years of operation as an evidence-based case study for long-term planning. The second addressed the evaluation of the use of the SI tool through eight case studies. The third study examined in depth 10 selected WW organisations that improved their "climate adaptation and flood security" parameter. The fourth study examined 11 selected organisations that have improved the status of their WW facilities.

Document analysis and semi-structured interviews with managers of the organisations were conducted in all four studies.

It was found that WW organisations need a complete picture when using their results for discussions with policy makers or for benchmarking. It was also found that the role of the farsighted manager was important and evident throughout the process, as was the investment in quality and innovative technology; that the current WW fee system does not cover future maintenance costs; and that there is intergenerational inequity due to the current low level of reinvestment. Some unique strategies that had a major impact on the organisations' success were: the formation of an interdisciplinary group in two organisations, setting aside 1 per cent of replacement value annually for reinvestment, a quick decision-making process and loose budget, and more specific renewal plans (namely three- to five-year plans). Some of the challenges cited are division of responsibility, economic challenges, and the need to prioritise. Most respondents expressed a desire for reinvestment funds to be established. They also complained about the inadequacies of WW legislation and called for changes. They also stressed the importance of clarifying the division of responsibilities in the legislation.

Key words: Sustainability index; reinvestment; facilities status, climate adaptation and flood security; water utility in Sweden.

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MADE IN SWEDEN

To my beloved family and the spirit of my father

Table of Contents

Abstract

A sustainability index (SI) has been used as an internal benchmark management tool since 2014 to analyse and steer the activities of municipal water and wastewater (WW) organisations towards sustainability. A consistent trend in the SI national results across all years is that day-to-day operations are working well, but long-term planning strategies are flawed. The national SI results show that only 2 per cent of the 184 participating water utilities in the 2020 SI results have a good level of performance (green) and meet the requirements for sustainable climate adaptation and flood security, and only 4 per cent of 184 were green and meet the requirements for sustainable status of the WW facilities. The present work examines and focuses on water utilities that demonstrate good capabilities to improve their long-term sustainability outcomes. The aim was to present these utilities as good learning examples to inspire other utilities looking to improve their outcomes and to clarify and concretise the drivers, strategies and key explanations for their success, as well as the challenges they face.

Four studies were conducted. The first study addressed the project of future water supply in Växjö after 10 years of operation as an evidence-based case study for long-term planning. The second study dealt with the evaluation of the use of the SI tool by eight case studies. The third study examined in depth 10 selected WW organisations that have improved their "climate adaptation and flood security" parameter. The fourth study examined 11 selected organisations that improved the status of their WW assets. In all four studies, document analysis and semi-structured interviews were conducted with managers of the organisations.

It was found that WW organisations believe in the SI tool and agree that SI has good potential but did not use their results for discussions with policy makers or for benchmarking. the SI results should be mapped more clearly and give a better overview of the current situation and the developing trend. Therefore, the Swedish Water and Wastewater Association (SWWA) should provide WW organisations with a tool to produce a more meaningful report on their results from the VASS system (see Section 5.2).

It was also found that the role of the farsighted manager has a significant impact on the success of organisations, regardless of the size or type of organisation. In addition to forming an interdisciplinary group in two organisations, which also created great opportunities for interdepartmental collaboration, setting aside 1 per cent of replacement value per year for reinvestment, establishing more specific renewal plans (that is, five- to three-year plans), developing cloudburst maps, applying measures to the most vulnerable existing buildings in low-lying and confined areas, using the strategy of changing pipelines from valve to valve when there were multiple leaks in a pipeline, and performing tasks with in-house labour and machinery.

The challenges mentioned include financing, division of responsibilities and inadequacies of legislation, and the need to prioritise. There was a desire to change legislation, establish reinvestment funds, and clarify the division of responsibilities in legislation.

Populärvetenskaplig Sammanfattning

I strävan efter att skapa ett hållbart samhälle är kommunala VA-verksamheter väsentliga delar av konceptet och kraven på VA-organisationer är därför höga. VA-Infrastrukturen byggdes ut i Sverige under 1950-, 60- och 70-talen och är en komplex uppgift med flera system, och många olika aspekter. Den omfattar för närvarande 195 400 km kommunala vatten- och avloppsledningar och cirka 3 500 verk av olika storlek för att producera dricksvatten och rena avloppsvatten. En växande utmaning är att VA- infrastrukturen med tiden börjat bli alltmer ålderstigen och reinvesteringar har inte kunnat genomföras i den omfattning som behövts.

Baserat på studier och den tillgängliga erfarenheten är VA-nätverket delvis i dåligt skick och är i stort behov av underhåll och renovering. Bristen på underhåll orsakar förlust av dricksvatten från ledningarna samt avloppsläckage, vilka påverkar ekonomin och kommande generationer.

Avloppsvatten som läcker ut ur rörsystemet kan förorena både mark, ytvatten och grundvatten. Det är dock en stor uppgift att hantera de system som ska användas på bästa möjliga sätt så att de klarar de utmaningar de kommer att ställas inför. Osäkerhet om klimatförändringar, även inom en relativt kort tid fram till 2050, innebära en ytterligare utmaning för att öka säkerhetsnivåerna mot översvämningar och andra miljö- och mänskliga effekter.

Branschorganisationen Svenskt Vatten har sedan 2014 utvecklat verktyget hållbarhetsindex (HBI) för att hjälpa kommunala VA-organisationer att analysera och utveckla hållbarheten i sin verksamhet på kort och lång sikt. Och även att identifiera utmaningar som VA-verksamheten står inför. Det är framtaget för att möta flera olika strategiska behov inom VA-verksamheten. HBI skulle bl.a. underlätta diskussioner mellan verksamhetsansvariga och politiska beslutsfattare, samt att systematiskt kunna följa upp förbättringsarbete inom en kommun.

HBI är en undersökning som VA- organisationerna deltar i frivilligt genom att svara på 82 frågor om verksamheten. Svaren på frågorna beskriver statuset på verksamheten och hållbarhetsgraden på organisationen. Svenskt Vatten redovisar resultaten årligen på nationell nivå.

HBI-resultat år 2020, liksom tidigare år, visade att den dagliga driften fungerar bra men att det generellt sett saknas resurser för långsiktig planering. De visade också att de parametrar som utgör de största utmaningar för VA-verksamheten är” Klimatanpassning och översvämningssäkerhet”, där bara 2% av 184 organisationer uppfyllde hållbarhetskraven. För parametern ”Va-anläggningens status”, uppfyllde bara 4% hållbarhetskraven. Resultaten av HBI sedan starten 2014 visar också att den nationella prestationsförbättringen är svagare och långsammare än man hade hoppats

Kommunallagen (SFS 2018:1350) ger frihet till VA-organisationerna i Sverige för att planera sin VA-verksamheten. De har därför kommit olika långt i sin hållbara utveckling. I denna avhandling har de organisationer som gjort tydliga förbättringar och framsteg i de område som andra inte har lyckats göra det studerats och analyserats.

Fyra studier genomfördes (**Paper I, II, III och IV**), med syfte att studera dessa organisationers prestationer och analysera orsaker till deras succés via djupintervjuer med VA-cheferna och dokumentanalyser mm. I tre sista studierna analyserades dessutom deras HBI-redovisning i detalj för samtliga år de deltog i HBI. Fokus för samtliga studier var att visa hur dessa organisationer har förbättrat sina resultat genom att konkretisera arbetssätt, planeringsverktyg och strategier samt tydliggöra framgångsfaktorer men också de utmaningar som de har mött. Målet var att använda dem som goda lärande exempel för att inspirera andra Va-organisationer som vill arbeta hållbart.

Studiernas resultat visade att organisationer med politiskt inflytande och aktivt ägande kan initiera framgångsrika strategier och långsiktiga planer med ett utmärkt resultat, oavsett typ och storlek av organisation.

Det visade sig att VA-organisationer tror på HBI-verktyget, håller med om att HBI har god potential, men de använde inte sina resultat för diskussioner med beslutsfattare eller för benchmarking i någon större omfattning. HBI-resultat bör därför kartläggas och kommuniceras tydligare för att ge en bättre överblick över nuläget och utvecklingstrenden. Svenskt Vatten bör därför förse VA-organisationer med ett verktyg för att göra en mer meningsfull rapport om sina resultat från VASS - systemet**.**

Ledarskapet hade stor betydelse. Den framsynta chefens roll var viktig och tydlig genom hela processen och för succés, liksom investeringen i kvalitet och innovativ teknik. Några unika strategier som hade stor inverkan på organisationernas framgång var: bildandet av en tvärvetenskaplig grupp i två organisationer, avsättning av 1 % av återanskaffningsvärdet årligen för reinvestering, en snabb beslutsprocess och lös budget samt mer specifika förnyelseplaner, det vill säga fem- till treårsplaner.

Ekonomiska utmaningar, behovet av att prioritera och att samarbete och ansvarsfördelning vid hantering av översvämningsrisker är några av de utmaningar som nämndes.

Resultaten visades även att det nuvarande VA-avgiftssystemet inte täcker framtida underhållskostnader och är en av orsakerna till de låga reinvestering som i sin tur kan leda till en ökad ojämlikhet mellan generationerna.

De flesta intervjuade uttryckte en önskan om att re-investeringsfonder skulle inrättas som tillät periodisering av medel mellan åren. De lyfte fram brister i VA-lagstiftningen och efterlyste ändringar. De betonade dessutom vikten av att förtydliga ansvarsfördelningen i lagstiftningen

About the Author

I am a Kurd from the Autonomous Region of Kurdistan/Iraq. I lived most of my life in Baghdad and studied civil engineering at Mosul University. My first job in Sweden was as a water and wastewater engineer at the multi-utility company Tekniska Verken in Linköping AB. At that time, I was a 33-year-old mother of a six-year-old daughter, and I had five years of work experience in construction engineering and two years as a water supply engineer. I quickly became fascinated by the way the company worked, which made it a great environment for a curious young engineer who wanted to learn and develop. In parallel, during my work I took some courses in soil mechanics, hydraulics, AutoCAD, and so on, and also three courses in business economics. In the 10 years I spent there, I worked independently in many fields, including planning, designing of water piping-systems, investigations, renewal planning, and simulation with networks models. I really enjoyed working with all fields of water management. However, after 8 years, I felt that I had learned a lot in practice and wanted to develop myself academically. I also dreamed of one day helping to pass on some of Sweden's experience in water technology to developing countries.

In 1995, I applied to the Royal Institute of Technology (KTH) in Stockholm, Sweden, to get a Master of Science in civil engineering. Sitting down on a school chair after so many years of working was fantastic. It was a pleasure to read advanced courses in water and wastewater technology, geotechnology, road technology and design, as well as on sustainability, and also to learn about the Brundtland Report, Agenda 21 at the local level, and the globally formulated Millennium Development Goals.

In 1997, I obtained the degree of Master of Science in civil engineering from KTH, Stockholm, Sweden. At that time, I had three daughters, the youngest of whom was seven years old.

In 2002, I started a new job as a university Lecturer in a full-time at Linnaeus/Växjö University, where I worked until 2011, teaching water and wastewater engineering, road construction and design, geotechnology (soil mechanics), and hydraulics.

In parallel with my 100 per cent teaching, I also conducted research for about 10–20 per cent over my fulltime work because I also was registered as an industry PhD student at KTH. However, I completed all the PhD compulsory courses, amounting to 69 higher education credits (ECTS). I also published two articles in the journal *Water* and presented two other articles at two conferences and wrote the scientific essay for my technology licentiate thesis.

In 2010, I obtained my Degree of Technology Licentiate at KTH Stockholm. The title of my thesis was "Water Management & Performance in Global to Local Scales. A Comparison and Knowledge Transfer."

The technology licentiate degree is awarded after completion of studies at postgraduate level in one of the higher education institution's subjects. Studies encompass 120 credits. In addition to a scientific essay worth at least 60 credits, the Licentiate degree also includes courses of at least 30 credits at postgraduate level.

The technology licentiate work was a starting point for future work on how to transfer knowledge and experience in water technology to those who need it most, and to help achieve global sustainability.

In 2011, I started my new position as assistant professor (senior lecturer) at the School of Engineering, Jönköping University, Sweden. My 100 per cent employment included teaching in courses (Water and Wastewater Technology, Geotechnical Technology, and Hydraulics), as well as supervising and examining BSc theses.

The teaching workload in Jönköping was such that I did not have the opportunity to complete my doctorate, although I had to write only two more articles after my technology licentiate degree. I continued applying to get time for research, which I received for the first time in 2018, and I then was offered a 25 per cent of full-time position from January 2019. The offered time was not significant, but I was satisfied.

I was also very fortunate that Professor Kenneth Persson from the Department of Water Resources Engineering at Lund University agreed to be my PhD supervisor. However, it had been eight years since I had done my technology licentiate degree, so I had to change the research project, and conduct four new studies. I choose the new research project in consultation with Professor Persson.

Prof. Persson is a well-known and active researcher in water resources engineering. We knew each other through the examination phase of my technology licentiate exams. He was my opponent and the examiner at that time, and I continued followed his scientific articles after that. At the end of 2018, I received a written acceptance for the PhD programme at Lund University.

Now, as I write this, I am done with everything (four studies done, three papers published, and the fourth submitted and in the review process) and I will defend my dissertation on April 28, 2023. So, my PhD degree will be complete before I turn 70, four months after I defend my dissertation.

Acknowledgement

Twenty-five per cent of my full-time position as senior lecturer in the Department of Construction Engineering and Lighting Science was allocated to research from 2019–2022. The time was spent on conducting four studies, writing and publishing four articles, and writing the dissertation essay. Other duties required for the PhD, such as doctoral courses, had been completed previously. The Department of Construction Engineering and Lighting Science also covered all other costs, such as publication costs, language editing, conferences, and travel. This is in addition to funding 25 per cent of the full-time position from 2019–2022. The research programme Mistra InfraMaint also funded 25 per cent for 2021.

The work was mainly funded by Jönköping University and partly by Mistra InfraMaint.

I would like to express my great gratitude to Dr Ingrid Wadskog, the executive director of the School of Engineering at Jönköping University, and Thomas Olsson, the former head of the Department of Construction Engineering and Lighting Science, for giving me this wonderful opportunity to realise my dream. Without your funding decision, my PhD journey would never have begun. My special thanks go to Nina Andersson, the new head of the Department of Construction Engineering and Lighting Science, who supported me administratively in every way.

I would like to thank Mistra InfraMaint for their financial support in 2021 to conduct my study on the application of the sustainability index.

To Prof. Kenneth M Persson, you are exactly the supervisor every graduate student wants. You have always responded promptly to my emails and phone calls, which I greatly admired. Also, you read and commented on my work within a week or less, which made me very happy because I am always in a race against time, especially during my PhD. You have usually commented on my work and responded to my email with praise and words of encouragement. Therefore, I would like to express my boundless gratitude to you for all of this and not least for your dedication, support, and guidance during my doctoral work.

I would like to express my great gratitude to the managers and strategists of the Swedish municipal water utilities that I interviewed for my four studies for their time and very valuable responses. I can only say that this work would not have been possible without you.

I would also like to express my great gratitude to Magnus Bäckström, an expert from the Swedish Water and Wastewater Association (SWWA), for his efforts and work in contacting water utilities, SWWA members, and selecting those who were more advanced in my research areas. Without you, Magnus, it would have been very difficult, if not impossible, to conduct three of the studies included in this thesis.

I would also like to thank my co-supervisor and friend Dr Ibrahim Yitmen for his support and being there when I needed him.

Very special thanks go to my friend and colleague, Dr Amjad Al-Musaed, who helped me at all times with the Photoshop program to improve my figures.

My gratitude also extends to all my colleagues and friends at the Department of Construction Engineering and Lighting Science for being such wonderful people. All of you gave me such unforgettable, wonderful moments during our coffee break times.

I would also like to give a big thanks to the wonderful Carina Littrén. We had many pleasant conversations when I called you and asked for practical help with the administration.

Obtaining and collecting unpublished data important for research is not always an easy task, especially in Kurdistan. It requires a special position and a large network of contacts. Therefore, I would like to express my belated but very special thanks to my wonderful friend Engineer Majid Koji, the managing director of Almuhandis consulting engineering company in Kurdistan. He helped me a lot in obtaining various data when I was writing my TEC /LIC Thesis. I am eternally grateful for his great contribution to my LIC dissertation.

A very special thank you to my best friend Dr Islah Habib for painting such a beautiful cover for my dissertation. I am so grateful for that.

My very special gratitude goes to my mother and my father's spirit for their eternal encouragement and support throughout my life and for being such wonderful and phenomenal parents.

My love and gratitude go to my sisters and brothers and their families, who make my life full of joy, meaning and happiness through their support, their pure and irreplaceable relationships, and through the pleasant company we have together.

Rizgar, my partner and best friend, you entered my life in 2016, when there was little room for a few short vacations, a few outings together and evenings in front of the TV and meetings with friends and family. However, since 2019 you have been living almost alone, long days and evenings, no outings, no vacations. I was busy teaching during the day and doing research and sitting in front of the computer in the evenings. But you have been wonderful the whole time, never complaining and helping me in any way you could. I am so grateful for everything, for your patience, your efforts to create such an incredibly calm and problem-free environment.

To my daughters, Midia, Aman and Jenna, you have supported me along the way and also been the true joy and inspiration in my life. You have stood by me, by my ambitions and by my studies, which have never stopped until now. You have been so reasonable, wonderful, and just as ambitious, if not more so, all along, which makes me so proud of you all. To my grandchildren, Kevin, Ava and Céline, you have also put up with me being so busy all the time. You often said to me, "Nono, when are you going to retire and stay with us longer?" I want to apologise to you and tell you that from now on I will do my best to be there for you. Thank you to my daughters, my wonderful sons-in-law Adnan and Milad and my dearest grandchildren, I love you all more than anything.

Finally, I also want to thank all my good friends for being part of my social and meaningful life. And I want to apologise to them for being busy these past two years, but better times will soon come.

Appended Papers

Paper I

Najar N. and Persson K. M. (2019) Strategies, Processes, and Results for the Future Water Supply of the Växjö Municipality: Evaluation of an Evidence-Based Case Study of Long-Term Strategies within the Water and Wastewater Sector in Sweden. Water 2019, 11(10), 2150; https://doi.org/10.3390/w11102150

Paper II

Najar N., and Persson K. M. (2021) A Sustainability Index within Water and Wastewater Management in Sweden: An Evaluation of Eight Case Studies. Water 2021, 13(14), 1879; https://doi.org/10.3390/w13141879

Paper III

Najar N. and Persson K. M. (2022) Assessing Climate Adaptation and Flood Security Using a Benchmark System: Some Swedish Water Utilities as Good Learning Examples. Water 2022, 14(18), 2865; https://doi.org/10.3390/w14182865

Paper IV

Najar N. and Kenneth M Persson. Status Improvement of Water and Wastewater Fixed Facilities: Success and Challenges of Eleven Swedish Water Utilities as Case Studies. (Submitted – under revision)

Author's contribution to the appended papers

Paper I – IV

The author initiated, planned, and conducted the study; developed the methodology; conducted the survey by creating, collecting, and distributing the questionnaire; analysed and processed the responses and other data; analysed and discussed the results; and developed the conclusions for all papers included in this thesis. The author also wrote the manuscripts, submitted the papers to appropriate journals, and revised the manuscripts based on the peer-reviewed feedback. The co-author supervised all studies included in the thesis, contributed several valuable viewpoints, and supported the entire research process.

Conference abstracts

- **"Application Of Sustainability Index in Municipal Water and Wastewater Organizations in Sweden for Improved Asset Management: *Some Case Studies As Good Learning Examples".***
IWA World Water Congress & Exhibition. 11-15 Sep 2022. (Accepted with oral presentation).

Related publications

- **Nasik Al-Najjar. "The Future Water Supply of Växjö Municipality-** ***Evaluation of different alternatives".*** Vatten 63:299-311. Lund 2007 and as **article III**: in the Licentiate thesis in Land and Water Resources Engineering/ School of Architecture and Built Environment, Royal Institute of Technology (KTH) 2010: "**Water Management and Performance on Local and Global Scale**. *A comparison between two Regions and their possibilities of Knowledge Transfer".*

Related Conference Proceedings.

- **Nasik Najar & Bengt Hultman." COST-EFFECTIVE WATER SUPPLY AND SANITATION"** in Proceeding of 2nd Environmental conference- Water (KECW007), 22-24, April 2007 I Dohuk, Kurdistan Region I Iraq. And as **article II.** Published in the Licentiate thesis in Land and Water Resources Engineering/ School of Architecture and Built Environment, Royal Institute of Technology (KTH) 2010: "**Water Management and Performance on Local and Global Scale**. *A comparison between two Regions and their possibilities of Knowledge Transfer".*

- **Nasik Najar & Bengt Hultman." Water Management and Technology in Swedish Municipalities- Assessment of possibilities of exchange and transfer of experiences".** In proceeding of "The international conference on an International Perspective on Environment and Water Resources, Bangkok, Thailand. 5-7 January 2009. Arranged by EWRI, ASCE and Asian Institute of Technology (AIT)". And as **article IV.** Published in the Licentiate thesis in Land and Water Resources Engineering/ School of Architecture and Built Environment, Royal Institute of Technology (KTH) 2010: "**Water Management and Performance on Local and Global Scale**. *A comparison between two Regions and their possibilities of Knowledge Transfer".*

Abbreviations

BMPs	Best Management Practices
CA and FS	Climate adaptation and flood security
GAAP	Generally Accepted Accounting Principles.
HBI	Hållbarhetsindex (In Swedish)
ISM	Innovative Stormwater Management
LAV	The General Water Services Act (2006)
L-TUWM	Long-Term Urban Water Management
SI	Sustainability Index
SIUWP	Sustainable Integrated Urban Water Planning
SUD	Sustainable Urban Drainage
SUDS	Sustainable Urban Drainage Systems
WSSD	World Summit on Sustainable Development,
SWW	Swedish Water and Wastewater Association.
WW	Water and Wastewater

1 Introduction

Water utilities in Sweden's 290 municipalities provide water to the residents and dispose their wastewater in a long-term and sustainable manner, considering the environment and human health. The water utilities are self-sufficient, meaning that profits are not allowed under the Public Water Supply Act (2006:412)(Strandhäll and Jonsson 2022).

Water and wastewater (WW) infrastructure has been developed in Sweden by competent municipal organisations. Much of this infrastructure was built using government grants in the 1950s, 1960s and 1970s. Combined sewers were built until the middle of the 20th century, and today approximately13 per cent of the sewage pipes in Sweden are combined systems (Svenskt Vatten 2020). Many of the facilities are currently fully depreciated but still in operation. WW operations have worked well for several decades, with satisfied users and low charges. Operational problems in the form of supply interruptions or unusable water rarely occur in Sweden (Svenskt Vatten 2015). Today, the WW infrastructure comprises 195,000 km of water and wastewater pipelines and approximately 3500 water and wastewater treatment plants (Svenskt Vatten 2020).

Many older sewer systems may be in poor condition due to their age. Poor condition of the piping systems can lead to leakage of sewage and pollutants, as well as water intrusion into the pipes. Climate change has increased the load on wastewater systems, caused many problems, and revealed significant deficiencies in the systems, especially in the combined system. Houses connected to combined sewer systems are exposed to basement flooding risk more often than those connected to separated systems (Sörensen 2018, Mobini 2021). In addition, climate scenarios mapped for the next 100 years show that precipitation will increase and become more intense for society. Hence, the pipelines are not designed for these volumes (Matschke Ekholm and Nilsson 2021) .

Municipal WW organisations have high ambitions and demands for their services because their work is of great importance for the sustainable development of society (Svenskt Vatten 2017). Their mission also has a direct or indirect link to many of the United Nations' 17 Sustainable Development Goals, especially Goal 6 "Clean water and sanitation for all" (Svenskt Vatten 2022).

Well-functioning utilities and facilities that meet today's environmental requirements are needed to provide safe water and wastewater services to the citizens (Jonsson 2017). Water utilities must also have the skills and capacity to meet the challenges of the future, as well as the technical expertise to increase the use of digital technologies (Malm, Mårtensson et al. 2019). They also need to be able to make strategic investments to modernise the wastewater system and bring it to long-term sustainable levels (Svenskt Vatten 2021a). There is also a growing need and expectation for stormwater management to be included in municipal planning, rather than just as municipal expansion occurs (Svenskt Vatten 2020). Accordingly, WW utilities must analyse and improve the sustainability of their activities, both in the short and long term, to meet the above mentioned and future challenges.

To this end, the Swedish Water and Wastewater Association (SWWA) has developed an internal benchmark management tool, the Sustainability Index (SI), which was launched in 2014 (Svenskt Vatten 2015). SI is a key to aligning WW activities with sustainability in the future, as well as a tool for analysing and developing the sustainability of WW activities in the short and long term. National results for SI for all years since implementation show that improvements in water utility performance have not been as desired, but that operational functions are still working well (Svenskt Vatten 2022). SI national results also show that the majority of water utilities do not have long-term planning in place and that only 2 per cent of the 184 participating water utilities in SI results 2020 meet the requirements for sustainable climate adaptation and flood security, and only 4 per cent meet the requirements for sustainable status of the WW facilities (Svenskt Vatten 2021a). According to the Municipal Law (SFS 2018:1350), WW utilities are free to plan their activities, which means that their success in the pursuit of sustainability is different (Najar and Persson 2019).

1.1 Research objectives

The specific objective of this work was to present practices of some water utilities that have made progress in improving their activities towards sustainability in the three challenging areas where the majority of water utilities have deficiencies – (1) long-term development, (2) climate adaptation and flood security (CA and FS), and (3) the status of WW-fixed facilities – and to show why they succeeded and how they addressed the challenges.

To achieve this specific goal, the following objectives were established through four main studies (Papers).

Paper I presents the Future Water Supply (FWS) project for Växjö municipality as evidence of the application of successful long-term sustainable plans. The objectives were (1) to show how strategies were developed and applied to meet sustainability requirements and inspire other municipalities to develop their long-term plans and strategies; (2) to show whether Växjö's FWS project ensured water quality and quantity after 10 years of operation; and (3) to show whether the investment in the FWS project had an economic impact on consumers.

Paper II gives an overview of how WW management is carried out in Sweden. In particular, the study aimed to assess the application of the SI tool through eight case studies to (1) clarify the strategies used to eliminate the shortcomings defined by SI, (2) clarify who is responsible for ensuring sustainability within the WW sector, and (3) identify the principles and methods of financing and assess whether they are sufficient to meet sustainability requirements.

Paper III analyses and presents 10 Swedish municipal WW organisations that have improved their CA and FS towards sustainability. The goal was to study these organisations in depth and present them as good learning examples to inspire other utilities that want to improve their results. The study clarifies (1) the influence of organisational form on utility performance, (2) the factors and strategies that have contributed to progress and the main explanations for their success, and (3) how they deal with the various challenges, difficulties in sharing responsibilities, and finances when it comes to stormwater management.

Paper IV shows the status improvement of fixed facilities of 11 WW utilities and tracks their performance on SI. The aim was to study, analyse and use these utilities as good learning examples to support other organisations in Sweden and internationally that want to improve the status of their aging WW facilities. The focus was on clarifying the organisations' working methods, planning tools, strategies, success factors and challenges, and also on showing how far they have come and whether they can maintain the sustainable rate of their reinvestment.

2 Theoretical background

2.1 The sustainability index survey

The Sustainability Index (SI) is key to guiding WW operations toward sustainability in the future and is thus part of the work towards continuous improvement. SWWA developed the SI in 2014. The SI survey consists of a questionnaire that municipal WWS organisations have responded to since 2014. The survey consists of 82 questions grouped into three groups under 14 parameters. These groups form the three pillars that interpret the aspects of the Brundtland Commission's definition (BCD) of sustainability. The three pillars, 14 parameters and the code for the 82 questions are presented in Figure 1, and the 82 questions are presented in A1–A3 in Appendix A (**Paper II**). For more details on the structure of SI and the national annual result, see Sections 3.1.2 and 3.2 of **Paper II.**

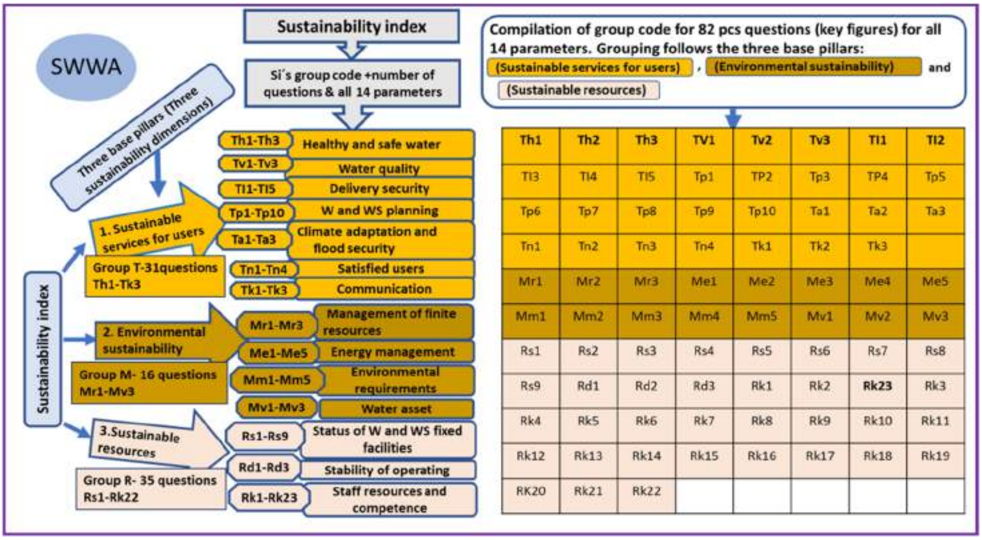

Figure 1. The structure of SI consists of three base pillars, fourteen parameters, and group code compilation for questions (key figures) of each base pillar and its parameters.

The SI tool was designed to contribute to supporting many essential strategic needs of municipal WW organisations including discussions among organisations managers and policymakers, water-tax adjustments, improvement work, long-term sustainability, preparation of strategic documents, analysis of the organisations, etc. The number of participating municipal WW organisations in the SI survey increased steadily in the first seven years, from 97 in 2014 to 184 in 2020, but then decreased to 181 in 2021(Svenskt Vatten 2022).

2.2 National SI results for 2020

The 2020 SI results, like the results of previous years' surveys, show that WW organisations are generally well positioned to deliver water services with high quality, delivery reliability and customer satisfaction in the short term (Figure 2). Figure 2 summarises the parameter results for all 184 municipalities participating in the SI 2020.

In many cases, the lack of long-term planning is the cause of the red rating. Twenty-six per cent of participating organisations have no WW plan at all and about 13 per cent have a clear distribution network renewal plan and are green (see WW planning parameter in Figure 2). Figure 2 also shows that the biggest challenge for WW organisations, as in previous years, is improving the status of the WW facilities. A lack of long-term plans and insufficient renewal rate are the main reasons for the high per centage of red ratings (Svenskt Vatten 2021a). The results also show that only 2 per cent of the 184 organisations were green in the parameter climate adaptation and flood security (CA and FS).

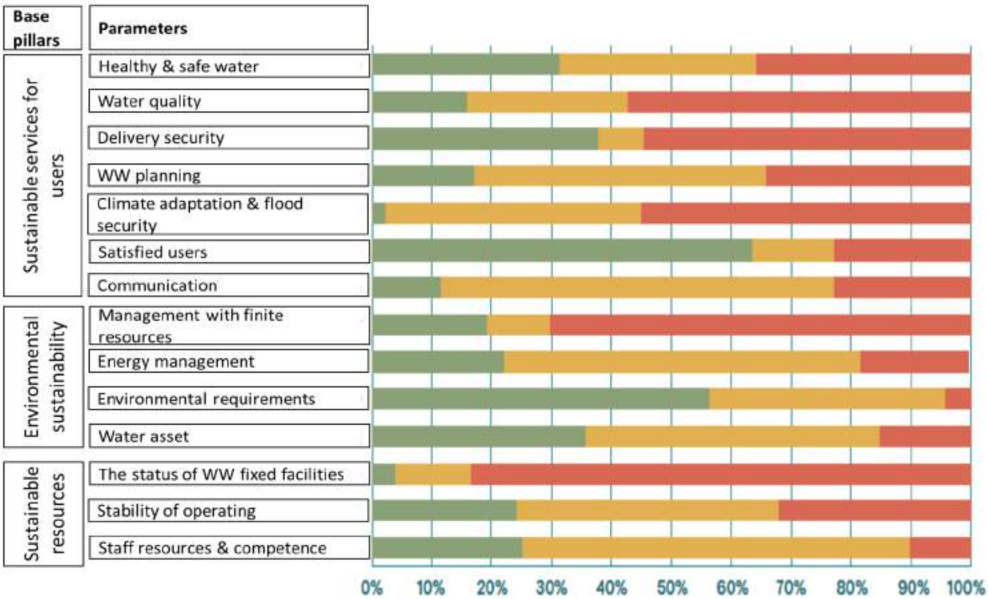

Figure 2. Parameter results for 184 participating municipalities in SI 2020 (Svenskt Vatten 2021a)

Money, staff competence and organisation are three critical factors that must be in place for WW organisations to be able to plan and implement the necessary investment projects for the development of contemporary WW systems (Svenskt Vatten 2020). The results of the sustainability index show that the provision of competencies related to long-term planning, investigations, and the capacity to implement projects are perceived as the most difficult. The result proves that competence and organisational issues are key areas to focus on in order for WW organisations to be able to fulfil their mission in a long-term and sustainable manner (Svenskt Vatten 2021a).

2.3 The "CA and FS" parameter

Climate adaptation and flood security "AC and FS" is one of 14 parameters in the survey SI that belong to the base pillar ""sustainable services for users". This parameter provides an overview of the municipality's status and the work being done to secure its future in terms of climate adaptation. "CA and FS" is defined at SI survey by three questions (Ta1–Ta3) (Table 1). Table 1 shows the questions for the parameter "CA and FS" and the conditions required for their evaluation (Svenskt Vatten 2015). The questions refer to all measures that must be taken to protect and adapt both existing and newly planned buildings from flooding associated with torrential rains. These measures include (1) conducting the necessary vulnerability assessments with an action plan for existing buildings to improve long-term safety; (2) having a clear strategy for new construction and reconstruction for flood-proof elevation to prevent damage to homes when stormwater system is overloaded; (3) identifying the number of basement floods in a community, as this can provide information on how well municipal drainage systems are functioning for existing buildings.

The SI, national results for the parameter "CA and FS" in 2020 show that 55 per cent of the total 184 participating municipalities are red on this parameter and only 2 per cent are green (that is, four organisations out of 184) (Figure 2). The fact that a large part of the municipalities are red on this parameter is mainly due to the lack of a vulnerability analysis and a flood protection strategy for new and renovated buildings (Svenskt Vatten 2021a).

Table1. The questions for the parameter “CA and FS” and the conditions required for their evaluation (Svenskt Vatten 2015).

The Code	Parameter: Climate Adaptation and Flood Security	Conditions for. “CA and FS”		
		Green	Yellow	Red
Ta1	Is there an investigation with an action plan examining society’s vulnerability due to more extreme rainfall and rising levels in seas, water courses, and lakes?	Yes, there is an action plan, and work is being conducted according to this.	Yes, but there is no action plan.	No
Ta2	Is there a clear strategy for the new construction/reconstruction of flood-safe houses and correct height adjustment so that there is no damage to houses when the stormwater systems are overloaded?	Yes, and no floods Can occur in new areas due to rain or water levels.	Yes, but they should have been sharper.	No
Ta3	Basement floods within business areas as a 5-year average (the number per the coupling pipes in 1000 houses)	< 1	1-2	>2

2.4 The parameter “status of WW fixed facilities”

The “status of WW fixed facilities” parameter is one of 14 parameters in the SI survey that belong to the base pillar “sustainable resources”. This parameter concerns the status of all parts of WW facilities (pipeline networks, waterworks, treatment plants, and pumping stations) and how they can be preserved in an economically sustainable manner (Svenskt Vatten 2019). The studied parameter is described in the SI with nine phases over nine questions (Rs1–Rs9) (Table A1, Appendix A, **Paper IV**) that can be used by municipal WW organisations to obtain an overview of the status of their assets. These nine questions cover all conditions required for a sustainable WW fixed facility status. Three of these questions (Rs1–Rs3) relate to the existence of a financial forecast, a multi-year budget, and a long-term financial plan for capital expenditures, as well as a plan for pipeline network replacement needs over the next 10 years (Table A1, Appendix A, **Paper IV**), which lists the questions (Rs1–Rs9) and the conditions required to score them as (green, yellow, or red). Water supply networks and wastewater networks are treated separately in various questions, some of which are joint questions. The conditions of water supply networks are assessed with Rs3, Rs4, and Rs5, while the conditions of sewerage networks are assessed with Rs3, Rs6, and Rs7.

A low renewal rate (Rs5 and Rs7) does not lower the score of the studied parameter if it is based on a fixed plan (Rs3). Leaks in water pipes indicate a lot about the condition of water pipes (Rs4). For a wastewater network, conditions are best assessed based on not only comprehensive television inspections, but also on operational problems and maintenance needs (Rs6). A sewer network is rated green if Rs3 is green and Rs6 is green or yellow. The same assessment applies to a water supply network; that is, a water supply network is assessed as green if Rs4 is green and Rs7 is green or yellow. For water and wastewater treatment plants, there is no established method to assess reinvestment needs. Instead, a separate assessment is required (Table A1, Appendix A, **Paper IV**).

2.5 The detailed SI evaluation documents

The documents are annual and show all 14 parameters and the associated questions (all 82 questions) that make up the SI survey. Each parameter is shown as the main heading for a table, and below the main heading there are four columns with the following headings: the code for the questions, the questions themselves for the associated parameter, the WW organisations’ responses to each question, and their colour index score (Table 2). Table 2 shows as an example of one of the 14 parameters in a typical detail in an SI evaluation document. Thus, it shows the code, the questions and the answers with their colour index score for the parameter "CA and FS" of the municipality of Arvika for 2020. It also shows the colour index score for the parameter itself, based on the conditions of the evaluation (Table1). So, in Table B1, the rating of the parameter is yellow because one of the answers is yellow.

Table 2. Part of a typical detailed document of the SI evaluation for the parameter "CA and FS" of the Arvika Municipality in 2020 (Arvika Municipality 2020).

Parameter: Climate Adaptation and Flood Security (CA and FS).		
Code	**The Questions**	**Answer with Color Index**
Ta1	Is there an investigation with an action plan examining society's vulnerability due to more extreme rainfall and rising levels in seas, watercourses, and lakes?	Yes, but no action plan
Ta2	Is there a clear strategy for new construction/ Reconstruction in terms of flood safety and correct height adjustment so that there is no damage to houses when the stormwater systems are overloaded?	Yes, and no floods can occur in new areas due to rain or water levels.
Ta3	Basement floods within business areas as a 5-year average (the number per the coupling pipes of 1000 houses)	0.21

2.6 Laws and regulations for WW operations

The main regulations governing WW operations are found in the Public Water Services Act (2006:412), the Environmental Code, the Swedish Food Agency's Drinking Water Regulations (SLVFS 2001:30 with supplement), and in several EU directives that regulate WW operation.

According to the Water Services Act, the municipality is responsible for the development of public WW facilities. The law also regulates the rights and obligations of the WW principal and subscriber, respectively. The Water Services Act also stipulates that the municipality must have its own accounting system for WW operation, separate from other municipal finances. This is necessary in order to verify that the income from WW charges does not exceed the necessary costs, which is not allowed by law (Lidström 2020).

The Environmental Code specifies the requirements for emissions from environmentally hazardous activities, and under the Environmental Code, wastewater treatment plants (WWTPs) are classified as environmentally hazardous activities. WWTPs are also subject to licencing or notification requirements (Sveriges Riksdag 1999).

SLVFS 2001:30 is the law that regulates that drinking water is of the right quality. The regulations set maximum levels of contamination of drinking water in terms of microbiological and chemical parameters (Lidström 2020, Svenskt Vatten 2020 d). According to SLVFS 2001:30 (with supplement) a water distribution system shall be designed, maintained and managed so that drinking water meets the requirements of these regulations when it reaches consumers (Svenskt Vatten 2020 d).

2.7 Organisational forms of municipal WW in Sweden

Municipal WW organisations can be operated as:

a) Own municipal administration (traditional organisations form) (65 per cent)

b) Own municipal enterprise for WW (3 per cent)

c) Multi-utility, an enterprise that also handles other services such as waste and energy (13 per cent)

d) Regional cooperation through an inter-municipal enterprise, an association of municipalities, or a joint committee (19 per cent) (Lidström 2020).

The organisational forms studied in this thesis **(Papers I, II, III** and **IV)** are a mixture of the first three types mentioned above (a, b, and c). The traditional form is the most common form of WWS organisation in Sweden (Jonsson 2017) and they “self-regulate” their WW activities and have political influence and active ownership. The politicians in a municipal board are ultimately responsible for the activity carried out by the organisation. Information channels are clear and there is an elaborate system by which citizens can hold politicians responsible for the way they manage municipal activities (Thomasson 2013 a).

Active ownership constitutes an internal relationship, which means that it is the municipality on its own that can create conditions for long-term sustainable responsibility (Jonsson 2017) and includes both political and administrative leadership (Jonsson and Jannesson 2014). The traditional form is one of several administration parts under the responsibility of the technical board within the municipality. The technical board usually has several issues to deal with that belong to all administrations. The structure and impact of this form of organisation has shown and discussed in **(Paper I)** and the impact is further shown in (**Papers III** and **IV**).

Regardless of the organisational form of WW management, knowledgeable personnel are required in a variety of different disciplines. Process engineers, investigative engineers, systems engineers and operations engineers, along with laboratory personnel, construction workers, maintenance personnel, survey and mapping technicians, designers, project managers, economists, are examples of people with skills required to provide WW services to users (Lidström 2020).

When a public activity is incorporated (own municipal enterprise), the operational and financial responsibility for the activities is transferred to a company. This means that there is a separation of ownership and control, so the role of the municipal council is limited to deciding on shareholder policies and appointing a board of directors and auditors for the company. However, they do not set the overall goals and policies and do not approve the company's budget (Grossi and Reichard 2008, Mattisson and Thomasson 2011). The CEO is responsible for the municipal company and strategic responsibility lies with the board of directors. In Swedish municipal companies, the board is often formed by elected politicians. The role of the company's board member is different from the role of a municipal board member or a council member. It is no longer possible to act primarily as a politician. Board members must act in accordance with the provisions of the Swedish Companies Act (Thomasson 2013 b). One of the main motives for corporatisation is the pursuit of greater efficiency in the operation of the enterprise. Studies on the corporatisation of public activities have shown that corporatisation makes financial and operational management clearer and more structured (Mattisson and Thomasson 2011). Studies have also shown that corporatisation creates clearer financial accountability, makes decision-making paths shorter, and allows staff to be deployed more efficiently. The company also becomes a more attractive employer and favours employees' competence development (Hellström and Ramberg 2004). The impact of organisational form on water utilities' performance was investigated specifically in **Paper III** when assessment of climate adaptation and flood security was conducted through evaluating 10 Swedish water utilities as good learning examples. The impact of organisational form was also shown in **(Paper IV)** when the successes and challenges of 11 Swedish water utilities within status improvement of WW facilities were studied as case studies.

Multi-utility is a term for a company that carries out several activities in the field of technical infrastructure. The company is divided into several business units, so water and wastewater form a separate business unit (Farsi and Filippini 2009). The performance of this type of organisation was studied in **Papers II, III** and **IV** in this thesis. A study from Italy has shown that there are economic benefits of integrating several businesses (Guerrini, Romano et al. 2011). Since the multi-utility company is run in the form of a corporation, the same effects occur in these companies as reported for the corporate form (Thomasson 2013 b).

2.8 Modern reforms in the public sector

Modern public sector reforms, collectively known as New Public Management reforms (NPM reforms), assume that the public sector can be improved by transferring concepts from the private sector to the public sector (Dunleavy, Margetts et al. 2006, Pollitt and Dan 2011). The main goal was to increase customer orientation and cost efficiency of the public sector (Dunleavy, Margetts et al. 2006). According to (Agevall 2005), NPM has five characteristics: disaggregation, competition, governance, control, management roles, and citizen empowerment. Two forces may have driven politicians' desire to reform the public sector (Power 1997, Pollitt and Bouckaert 2004). Gaining more political influence and also an emphasis on goal management; that is, politicians need to develop their ability to formulate follow-up goals for the activities they are asked to manage (Liff 2015).

Public sector organisations are regarded as if they were companies, and their management strives to equate their organisations with enterprises.

The fact that public sector organisations are corporatized (Brunsson 2011) has created a condition where comparison with private sector governance is relevant and possible (**Papers II, III,** and **IV**) to enhance the legitimacy of public sector organisations. Corporatisation has influenced the way goals are formulated and pursued (Hasselbladh, Bejerot et al. 2008). It has also led to organisational leadership taking on the meaning that good general management skills are needed for managers in operational units (Hood 1995), and that established forms of evaluation can and should be used (Power 1997). This has led to the development of management systems, economic measures, and data and information systems (Liff and Andersson 2009).

2.9 WW fees for financing the annual costs.

According to the General Water Services Act (2006) (LAV), each municipality is free to choose how to finance WW services, either with collective tax, WW charges, or a mixture of both (Lidström 2020). The operation of the Swedish WW sector since the 1970s has been financed by user charges regulated by the cost price principle (Malmer 2003). To protect users from monopoly pricing, LAV mandates that the result and financial position of the operation must be determined according to generally accepted accounting principles (GAAP) and should be reported separately for the WW business (Haraldsson and Tagesson 2014). Water charges are used to produce potable water, maintain and replace pipes and related facilities, and maintain and treat wastewater and stormwater. The charges also cover the cost of capital loans (interest and amortisation), depreciation and investments in water and wastewater systems and treatment plants, as well as administration.
Together, these areas and services result in total annual costs that must be covered by revenues from fees collected as the municipality's WW organisation charges. The annual revenue (turnover) of the Swedish municipal water utilities is approximately SEK 20 billion. The capital costs amount to about SEK 5 billion,

which represents approximately one-quarter of the total revenues (Svenskt Vatten 2020).

WW fees generally consist of two parts (**Paper I**): Consumption fees and connection fees. Connection fees are paid once by the property owner for connecting the property to the municipal water supply and sewer system. Consumption fees consist of (1) the fixed basic fee, the amount of which depends on the water demand of the property and thus on the number and size of water meters; (2) the variable fee, which depends on the water consumption of the property. According to LAV, the fees may not be higher than the costs necessary for the establishment and operation of the WW systems (Lidström 2020).

The level of the WW tariff is proposed by the WW organisation and decided by the municipal politicians (municipal council) (Jonsson 2017) and should be based on the costs known at the present time, but also on the costs expected in the future so that the necessary costs are distributed as fairly as possible in time and space, which is also a requirement according to LAV **(Paper II)**. The WW tariff varies between the different municipalities due to the different conditions that the municipalities must fulfil for LAV (Lidström 2020).

In **Paper I**, the impact of investment on water fees for the project of future water supply for Växjö and Alvesta municipalities is studied.

Since WW fees are based on budgeted assumptions that are predetermined, it is not surprising that these fees sometimes exceed the costs incurred to perform those services. (Carlsson, Haraldsson et al. 2017) showed that, out of 34 municipalities, 80 per cent had a surplus in their operations.

According to (Jonsson and Syssner 2017), it is difficult to raise the tariff for WW operations, even though municipal WW organisations have complete responsibility for the operations. The principles and methods of financing WW operation for the studied WW-organisations were identified in **Paper II** to evaluate whether they were sufficient to meet the sustainability requirements and if it is difficult to raise the tariff.

2.10 Financing investment and reinvestment expenses

Aging infrastructure poses a major challenge by creating uncertain future development for the status of WW-facilities and leading to the need to make important economic decisions (Urich and Rauch 2014). Reinvestment in the existing WW infrastructure has not been able to occur at the required rate because the WW organisations are designed for a time when the investments have already been made and the focus has been on operating the facilities (Svenskt Vatten 2020 c). Consequently, several municipalities in Sweden need to review their investment needs and establish investment plans for long-term sustainable WW management (Jonsson and Syssner 2017).

Investments within WW are financed by depreciation, investment grants, connection fees, deposits and surpluses from tariff increases, and external interest-bearing financing. Depreciation costs for WW facilities are chargeable; that is, they can be financed through fees.

Reinvestments in WW infrastructure are financed through depreciation, surplus, and interest-bearing loans (Svenskt Vatten 2020). Thus, depreciation and capital costs in the form of interest and amortisation are paid through the WW operating budget – that is, the WW tariff – which means that tariff increases often become a reality (Svenskt Vatten 2020). Depreciation of WW facilities can take different amounts of time for different components of the facility. For example, the average depreciation period for the pipe network is 53 years (Haraldsson 2019), while the actual useful lives are usually over 70 years (Malm and Svensson 2011-b). WW pipelines installed today should have a service life of at least 100 years (Mårtensson, Malm et al. 2018). An important feature of depreciation is that as long as depreciation charges are to be taken into account, the assets contribute to the financing of the year's investments. Fully depreciated assets that are still in use (a situation that characterises today's WW situation) do not contribute to the financing of investments.

Excess withdrawals – surpluses from tariff increases – according to LAV must be returned to the collective after three years via a reduction in the WW tariff (Svenskt Vatten 2020).

The cost price principle makes it possible to set aside funds for new investments but not reinvestment and exploitation. Excess withdrawals may also be put on these investment funds for specific investments. The return of the surplus occurs when the projects are depreciated after they are used (Jonsson and Syssner 2017). The problem is that the forms for projects or the specific use of investment funds are unclear. Under the proposed legislation, the fund must be used for future new investments that should benefit the entire WW collective; that is, direct improvement investments. Reinvestment and expansion investments are excluded (Jonsson and Syssner 2017). LAV has caused some uncertainty among WW principals regarding how to establish a fund. The principals have expressed the desire to use a fund for reinvestments, not just for new investments (Bashir and Mohamud 2021). LAV (2006) and its regulations lack specifications about which investment objects can be allocated to funds. The impact of this lack in the regulations and the uncertainty caused among WW principals are also investigated in **Papers II, III** and **IV**.

According to current legislation and today's situation of depreciation, it is the level of the current tariff that governs both investment and reinvestment costs.

To eliminate the risks of contamination, water loss, etc., it is important that reinvestment be made in the form of pipeline renewal (Jonsson and Syssner 2017).

To make this happen, WW organisations must be able to plan, track and implement a specific renewal rate.

Therefore, the renewal rate is one of the dimensions that SI uses to measure whether the status of WW facilities meets sustainability requirements in WW organisations. **Paper IV** showed the renewal rates and replacement costs and explained how far the organisations studied have come in reinvesting and improving their asset status and whether they can maintain sustainable renewal rates.

The WW infrastructure in Sweden consists of 1,559 WTPs, 1,661 WWTPs, 195,400 km of pipelines, pumping and booster stations, and reservoirs.

The replacement cost of WW infrastructure is SEK 820 billion for all parts of the system. Of this, SEK 680 billion is for replacement costs for the pipeline networks, including pumping and booster stations and reservoirs (Svenskt Vatten 2020). According to new calculations, the total investment level in Sweden is SEK 22.7 billion/year, of which 56 per cent will be used for reinvestment (pipelines and treatment plants etc.), 26 per cent for expansion, 5 per cent for climate change adaptation, and the rest for other needs such as increased requirements, adapting infrastructure, etc. Of the SEK 22.7 billion, the actual renewal (reinvestment) needs for the pipeline network are estimated at SEK 6.8 billion per year (Svenskt Vatten 2020), which equates to 1 per cent of the replacement value and 30 per cent of the 22.7 billion (the investment level). The replacement cost of 680 billion for pipeline networks and with annual reinvestment of 6.8 billion gives a renewal rate of 1 per cent and means that the pipelines should be in the ground for 100 years before they are replaced.

In SI, the specific renewal rate limit was set at > 0.7 for water pipes and > 0.6 for wastewater pipes according to the long-term plans (LTPs) used in a 2009 study (Malm and Svensson 2011-b). This means that pipes should be in the ground for approximately 165 years before they are replaced and that reinvestment in the pipe network is set at about 0.65 per cent of the replacement cost (Svenskt Vatten 2015). The LTP tool was developed as part of the EU project Care-W (Sægrov 2005).

A forecast for the development of interest costs 2020–2040 was carried out based on the assumed interest rate development 2020–2040 (Svenskt Vatten 2020). "The interest rate used in the calculations is 1% in 2020 - 2024, 1.5% in 2024 - 2030, and then 2% by 2040. With these interest rates, interest costs increase from 1.2 billion per year today to 7.8 billion per year in 2040. i.e. almost seven times higher. The interest rate is very uncertain, which is why a sensitivity analysis of different interest rates was also performed. Calculations of interest costs with scenarios differing by ± 0.5%. Made. With the lower interest rate, the interest costs for 2040 are 5.8 billion and with the higher rate 9.7 billion (compared with the estimated value of 7.8 billion). That is, it has been shown that even a small shift in the interest rate results in a difference of about SEK 2 billion" (Svenskt Vatten 2020).

Further calculations of interest costs for the situation that characterises the current situation of interest rates that have risen to over 4 per cent and the expectation of further interest rate increases in the coming years need to be examined. The actual impact on WW organisations should also be studied.

2.11 Stormwater management in Sweden

WW organisations are responsible for sizing up and operating new stormwater pipes until the stormwater pressure level reaches the ground surface (Figure 3). This means that a level of safety must be established with respect to different return periods of rain for different types of buildings. Rain with a return time of 10 years is specified for the capacity of stormwater pipelines in downtown and commercial areas. Rain with a return time of two and five years is specified as the capacity for sparse residential and dense residential buildings, respectively. When the capacity of the stormwater system is fully utilised, the excess runoff is discharged to and managed on the ground surface (Figure 3). The return period for rain with a pressure line at ground level is sized for a maximum rainfall of 30 years in downtown and commercial areas, and 20- and 10-year rainfalls for sparse residential and dense residential area, respectively. This level for sizing the ground follows the European standard SS-EN 752: 2008. (SIS 2008) (Svenskt Vatten 2016.). Protecting communities from severe consequences and flooding caused by torrential rains, rising water levels in lakes, seas and watercourses is the responsibility of all community planning. Therefore, the safety level for rain with a more than 100-year intensity should be taken, and the work must be carried out in close cooperation between the administrations of municipal planning, building permits, parks, roads, the environment, and WW organisations to achieve effective solutions (Svenskt Vatten 2016).

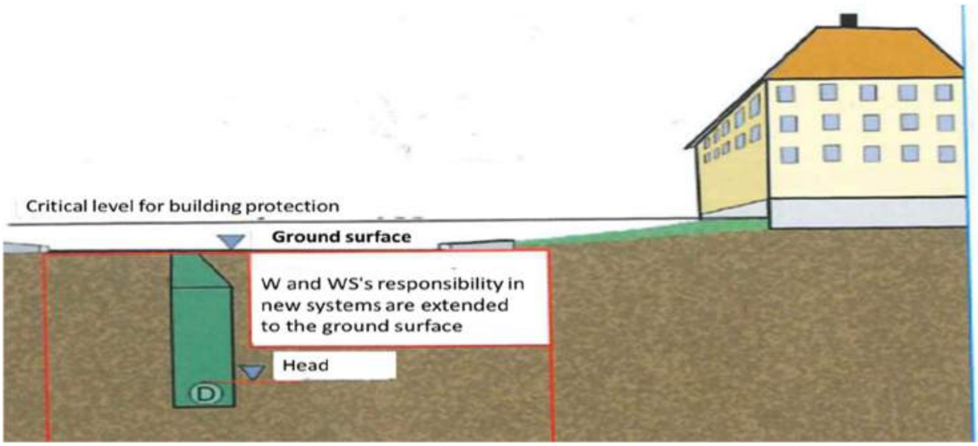

Figure 3. The responsibility of WWS organisations for stormwater management on new pipelines (Svenskt Vatten 2016).

2.12 Towards sustainable approaches of stormwater management

Designing the underground pipe networks (combined or separated sewer) to collect and convey the stormwater away from urban area was the traditional engineering solution for stormwater management before the 1970s in Sweden and in many other countries (Stahre 2006, Stahre 2008). However, the capacity of the existing drainage systems eventually became insufficient, and many areas were inadequately protected during heavy rainfall (Woltjer and Al 2007). As urban areas have grown the impermeable surfaces have increased, the amount of the stormwater increases and the vulnerability to flooding increases as a result (Ståhle 2008). In the 1970s, concern about the impact of the stormwater on the quality of the receiving water also increased (Stahre 2008) and a strong correlation was found between urbanisation and the deterioration of the quality of lakes and watercourses (Alm 2010).

The local disposal and detention of the stormwater runoff were the measures taken and were complementary to the traditional solutions of slowing down and reducing the hydraulic load on the system, improving the quality of stormwater runoff and to achieving better protection against expected climate change effect. The social dimension of the urban drainage came into focus after the introduction of the concept of sustainable development in the 1990s by Agenda 21 and the Rio Declaration (2002) (Stahre 2008) and the UN-organised World Summit on Sustainable Development, (WSSD) in Johannesburg in 2002 (Hultman and Levlin 1998) Accordingly, the new concept of sustainable urban drainage from 1995 included quantity, quality and social dimensions (Stahre 2008).

Many studies have shown that climate change has led to the development of new knowledge, thinking, strategies, and technologies, and that the application of these strategies presents new challenges. These challenges, in addition to the challenges posed by the cloudbursts themselves, are a major barrier to progress in climate (IPCC 2022). To achieve better protection against expected climate change and cloudbursts, there should be a shift from a purely sectoral approach to a sustainable approach of integrating urban planning (Woltjer and Al 2007), which involves reducing the piping of stormwater, creating floodplains, and other open solutions that can absorb excess stormwater during floods without major consequences (Regeringskansliet 2017). Hence, several approaches for decentralised solutions have been developed. They have different values according to where they were first developed (Barbosa, Fernandes et al. 2012). Sustainable Urban Drainage (SUD) is the term used for the multidimensional approach to urban drainage in Europe (Stahre 2006). Other labels for the new approach in different parts of the world are: best management practices (BMPs) (Niemczynowicz 1999, Villarreal 2004), sustainable urban drainage systems (SUDS) (Poustie 2015) and innovative stormwater management (ISM) (Marsalek and Schreier 2009). The ISM concept includes innovative approaches to mitigate the risk of flooding and reduce pollution impacts, while the term BMPs usually refers to structures that imitate the natural hydrologic processes (Marsalek and Schreier 2009). The concept of SUD is realised by using open or partly open drainage systems that utilise nature's own way of handling stormwater (Marsalek and Schreier 2009). The concept included open systems as surface flow, wetlands, and detention ponds, besides infiltration and percolation as ground stone in the system (Stahre 2008).

The traditional flood control approach, from the 1960s to the 1980s, involved the concept of resistance; that is, reducing the effects of flooding through physical flood protection (Sayers, Yuanyuan et al. 2013) (Sayers, Yuanyuan et al. 2013). The strategy is about keeping water away from land, such as by building embankments and raising them continuously (Restemeyer 2015). Since the damage can be catastrophic if flood controls fail (Restemeyer 2015), traditional flood control measures are an inadequate method to prevent the growing risks of floods (Hooijer 2004). The newer approach is about resilience; that is, focusing on risk management instead of on hazard control (Vis 2003) and taking the possibility of flooding into account, thus aiming at minimising the consequences of flooding. Hence, resilience adapts land use to reduce flood damage potential; elevating housing structures is an example of its application. Thus, in the context of urban flooding, resilience means robustness, adaptability, and transformability (Scott and O'Neill 2013). Adaptation is often organised around resilience as bouncing back and returning to a previous state after a disturbance (IPCC 2022).

The approach of flood risk management includes a shift from purely sectoral to integrated thinking; or, in other words, from pure water management to a more resilience-based approach of integrated urban planning to keep vulnerable land uses out of flood-prone areas (Woltjer and Al 2007). This can be viewed as a promising approach to deal with the unpredictability of climate change and future flood risk in cities.

The application of the concept of sustainable integrated urban water planning (SIUWP) or long-term urban water management (L-T UWM) and climate adaptation planning depends not only on access to technical solutions, but also on understanding how to manage them (Van de Meene 2011).

L-T UWM and climate adaptation planning is only lightly regulated in Swedish national policy and is thus mainly applied by individual water utilities (Cettner 2013, Glaas 2018). Therefore, few municipalities in Sweden are working in L-T UWM (Glaas 2018). Many cities have explored the possibilities of multifunctional stormwater management that integrates multiple components to manage runoff (Rodak 2020). However, to create the conditions for multifunctional management, decisions on how to manage stormwater must be made at an early stage; that is, in the general plan and in the detailed plan (Widarsson 2007).

In **Paper III,** 10 WW organisations were selected, six of which were studied in depth and presented as good learning examples. These utilities had demonstrated good capabilities in improving their sustainability outcomes within climate adaptation and flood security (CA and FS) by working with SIUWP and creating conditions for integrating multiple components that were specified in the sustainability index (SI).

2.13 Collaboration with planning for SIUWP

The design and construction of the traditional stormwater facilities (pipes and detention tanks) has been the responsibility of municipal WW utilities as they are located underground (Stahre 2008). These systems were developed on different principles than those used today and were designed for lower rainfall intensities. However, rainfall intensity has increased in the last 15 years and has led to flooding in many industrial cities, such as Copenhagen (2011), New York (2012), and Malmö (2014), with serious social consequences (Sörensen 2018, Mobini 2021).

There is a lack of a national strategy and action plan for working with climate adaptation planning in Sweden (Glaas 2018). Many ministries and agencies are involved, but no one has overall responsibility for climate adaptation. The main responsibility for implementing concrete measures lies with municipalities and individual property owners (Försäkring 2015).

Flood risk management in these systems is a societal task and cannot be controlled without cross- disciplinary cooperation (Restemeyer 2015) between the relevant municipal administrations; that is, the parties responsible for building permits, municipal planning, parks, roads, environment, and WW (Svenskt Vatten 2016.) and involvement of different experts from these different administrations in the planning and design of the facilities. Examples of such expertise are landscape and planning architects, WW, and street, traffic and park engineers. This means collaboration, sharing responsibilities and involvement of different experts from different municipal administrations in the planning and design of the facilities is essential (Svenskt Vatten 2016). Experiences and several studies have shown that managing of collaboration and sharing responsibilities is difficult to handle and is a major challenge. The lack of clarity of roles and responsibilities and as each municipal department has their own budget, interest and responsibilities makes cooperation between them difficult (Sörensen 2018) and a major challenge is overcoming the institutional barriers that exist between the different city departments (Stahre 2008, Sörensen 2018). Possibilities and obstacles of sharing responsibility have been investigated in **Papers II** and **III**.

To create the conditions for multifunctional management of storm water, decisions on how to manage it must be made at an early stage; that is, in the general plan and in the detailed plan (Widarsson 2007).

2.14 Study area and the case studies

Sweden is divided into 21 counties and each county is divided into several municipalities, which form a total of 290 municipalities.

Municipalities in Sweden are divided into three main groups – A, B and C – according to the number of inhabitants. Group A are major municipalities with a population of 200,000 or more; Group B are large municipalities with a population of 50,000 or more; Group C are small municipalities with a population of 15,000 or more (SKR 2017). In addition, there is a group of 123 municipalities with fewer than 15,000 inhabitants.

The WW organisation studied in **Paper I**, seven of the eight organisations studied in **Paper II**, five of the 10 organisations studied in **Paper III**, and seven of the eleven organisations studied in **Paper IV** belong to Group B communities. They are among the 50 largest municipalities in Sweden. One of the remaining organisations studied in **Paper II**, five in **Paper III** and four in **Paper IV** belong to Group C of small municipalities.

Seven of the eight (Orgs 1–8) selected municipalities in **Paper II**, had populations in the range of 70,000–170,000. The eighth had a range of 30,000–35,000 inhabitants.

The following 12 organisations were selected for both **Paper III** and **Paper IV**: Arvika (25,865 inhabitants), Ljungby (28,521), Ronneby (29,346), Värnamo (34,030), Ängelholm (43,030), Mölndal (68,152), Luleå (78,487), Växjö (94,884), Umeå (130,224), Jönköping (142,630), Västerås (155,858) and Linköping (164,684 inhabitants). However, they were divided in both studies (Figure 4) and some of them were deepened with interviews based on their performances obtained from the document analysis. Figure 4 shows the location of all WW organisations studied in **Papers II, III** and **IV** on the map of Sweden. (See the original figures in the respective papers.)

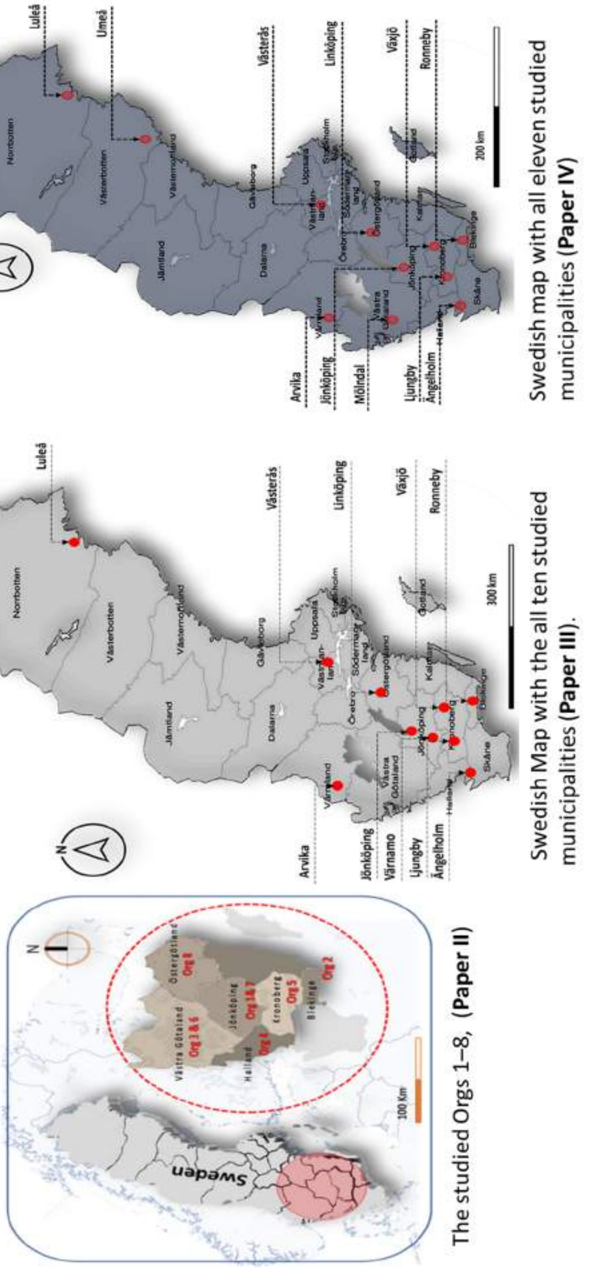

Figure 4. Map of Sweden showing the name and/or location of all organisations studied in Papers II, III, and IV.

3 Methodology

This chapter provides an overview of the methodology used in the appended papers. Further details on the methods and the data used are found in the papers.

3.1 The survey strategy and approaches

The research approaches used for this work in all articles are case studies in their two forms: a single case design and a multiple case design. Case studies are appropriate when a deeper understanding of a situation or event is sought (Säfsten and Gustavsson 2021), which was the case with this work. Most of the case studies conducted were embedded multiple-case designs **Papers II, III** and **IV** that included multiple contexts and more than one unit of analysis (Yin 2018) or required a deep understanding of their unit of analysis (Säfsten and Gustavsson 2021). **Paper II** dealt with eight WW organisations**, Paper III** with 10 organisations, and **Paper IV** with 11 organisations. The context of the case must be an independent entity with clear boundaries, such as an organisation **Papers I, II, III** and **IV,** a project and process **(Paper I)** (Yin 2018).

Paper I was a holistic single case design, for which the context was the WW organisation in Växjö and the unit of analysis was the Future Water Supply (FWS) project for Växjö. A holistic case design can be used when what is to be studied is unique, which was the case in **Paper I** as the FWS of Växjö is one of the most significant, developed long-term planning projects in Sweden. According to (Yin 2018), even if a study is a single-case design, it can include multiple units of analysis if a truly deep understanding of the phenomenon is sought; this was the case with **Paper I**, as a deep understanding was required, and multiple themes were explored in the WW organisation.

An advantage of a multiple case design is that it is possible to compare different cases, and it also increases the possibility of generalisation (Yin 2018). A disadvantage of the multiple-case design is that it is time-consuming and does not provide the same opportunities for in-depth investigation as a single-case design (Säfsten and Gustavsson 2021).

The specific objective of this work was to present practices of some public water utilities in Sweden that have improved their activities toward sustainability in the three challenging areas (long-term development, climate adaptation and flood security, and the condition of WW fixed facilities) in which the majority of water utilities have deficiencies (Svenskt Vatten 2021a).

The water utilities surveyed were mostly case studies in their real-time context. **Papers II, III** and **IV**. In **Paper I**, the FWS project of Växjö municipality was studied as a retrospective case study in addition to real-time to show a clear case for evidence-based management in the case of Växjö's FWS, after 10 years of operation. One of the goals was to show how strategies were developed and applied in a long-term project to meet sustainability requirements. The same project was studied by the author of the present work in 2007 in its real-time context (**Related Publication**) (Najar 2010). In that study, we investigated the decision-making process and the evaluation criteria used to assess the capacity of the selected alternative and the motivations for choosing one of seven different alternatives were analysed. With case studies in real time, it is possible to make direct observations and to study cause and effect, which was very sought after in all interviews in all appended **Papers** (**I, II, III** and **IV**) **(Säfsten and Gustavsson 2021)**. A disadvantage of retrospective case studies is that the researcher is referred to the participants' experiences with the project. However, in the case of FWS in Växjö, the project was also studied in real time because it was studied while the use of the project and the treatment process were still ongoing and would continue for several years. Still, it was a retrospective case, as the implementation of the project was completed when **Paper I** was conducted.

Therefore, the disadvantage of retrospective case study in **Paper I** does not apply and the reliability of the results in the case of Växjö FWS is very high because the outcome of the project is based on the experience of the citizens with the outcome of the implementation 10 years later, on how the purpose of the project is fulfilled and how it was possible to implement the project and also because the reasons for the successful implementation were clear and valid.

In this work, the approach used to identify data and information – or, in other words, parts to identify the reality of water utilities – is mainly characterised by a qualitative approach. There are also some types of a quantitative approach in all papers of this work, especially **Papers I** and **IV**. The reason for using this approach is that, in qualitative methods, the context under study is seen as dynamic and the focus is on the whole rather than individual parts, and also to establish some interaction between the cases under study and the researcher (Säfsten and Gustavsson 2021).

3.2 Data collection sources

In a case study, different techniques can be used to collect data (Säfsten and Gustavsson 2021), and in order to strengthen the quality of research, triangulation is used; that is, combining different techniques to collect data (Yin 2018), so that the weaknesses of one technique can be compensated by the strengths of another technique. In this work, literature review, document analysis, and interview techniques were mainly used. Statistical processing and analysis methods were used to process the data using quantitative methods.

Interviews and analysis of annual SI detailed evaluation documents were the main sources of primary data for **Papers I, II, III** and **IV**. Primary data (that is, direct observations of a phenomenon) were collected with the aim of answering the research questions (Säfsten and Gustavsson 2021). Secondary data were not based on direct observations of the phenomenon under study, but on primary data from other surveys and from literature review. The following sources of secondary data were used in **Papers II, III** and **IV**: the background material for the study, as well as the SI and the annual SI results reports and all literature reviews on the topic, which also formed the basis for the creation of the questionnaires for the interviews. Sources of secondary data for **Paper I** included previously published articles (Najar 2010), internal documents, reports and permits, regional and local water plans, water protection and national interest regulations, previous surveys, previous interviews, and the water tariff system, in addition to some of those mentioned above.

The interview technique was chosen for data collection based on the research questions, and for two other reasons: the ability to access the desired data and the ability to include people's perceptions and experiences (Kvale 2014). Thus, the interviews were conducted with managers of WW organisations who have many years of experience in water management and are directly responsible for the development of the organisation. This choice provided the desired answers to all research questions.

3.3 Primary data

The main sources of primary data were interviews and document analysis of the annual SI detailed evaluation documents.

3.3.1 Document analysis

Data from a document study are usually referred to as secondary data. Secondary data are supplementary to primary data and are useful when the researcher wants to know how someone else has interpreted a situation (Merriam and Tisdell 2015). However, it was different when analysing data from the SI detailed evaluation documents. They were used in **Papers II, III** and **IV** in addition to the interviews as primary data sources. This is because they contain raw qualitative data in the form of organisations' responses to all 82 questions from SI, for all 14 parameters and in all years in which the organisations participated in the SI survey (**Paper II**), and for one parameter and its associated questions and responses each (**Papers III** and **IV**). The SI detailed evaluation documents also show the rating of the questions and parameters with traffic light colours: green if the sustainability requirement is met, yellow if it needs improvement, and red if action is needed to meet the requirement. For this extensive qualitative data, matrices and charts (line graphs) were used to represent the data (Miles 2019).

To allow and facilitate comparisons in the matrices between organisations and trends in the charts for each organisation, the statistical weighting method was used to score the overall results. Green responses were given a weighting limit of 2, yellow responses were given a weighting limit of 1, and red responses were given a weighting limit of 0. The weighting limit for each parameter was determined by calculating the average weighting limits of all questions (Figure 8 in **Paper II**, Figure 3 in **Paper III** and Figure A1 in **Paper IV**).

In **Paper I**, five SI detailed evaluated document for Växjö municipality for 2015–2019 were reviewed and analysed. In **Paper II**, 32 SI detailed evaluated documents for the eight organisations surveyed for 2015, 2017, 2018 and 2019 were reviewed and analysed at both the parameter and question levels to illustrate each organisation's performance and how the results have evolved over the years. In **Paper III**, 52 SI detailed evaluation documents for the climate adaptation and flood resilience parameter and related questions were reviewed and analysed for the 10 organisations studied and for all years in which they participated in the SI survey between 2015 and 2020. In **Paper IV,** 58 SI detailed evaluation documents for the parameter "Status of WW fixed facilities" and related questions were reviewed and analysed for the 10 organisations studied and for all years in which they participated in the SI survey between 2015 and 2020.

3.3.2 Interviews

A research interview is a professional conversation that has a specific purpose and follows a specific structure. In **Papers I, II, III** and **IV)** of this work, semi-structured interviews were conducted with the managers of several water utilities. which is the most common type of interviews in engineering studies (Säfsten and Gustavsson 2021). Some advantages of using semi-structured interviews are the high validity (as their relevance can be verified in the context of the interview), the fact that deep and detailed information was obtained about the subject of the study, and the flexibility to adapt the interview questions while conducting the study (Säfsten and Gustavsson 2021).

In **Paper I**, the interviews were conducted between the corresponding author and a technical assistant on one side, and two key persons in the municipality of Växjö. The first was the former head of the WW department, who was responsible for the decision-making, planning and implementation of the EWS project. The second interviewee was the current head of the department, who is responsible for managing the project within the desired standards and goals. To prepare the interviewees, a list of questions was sent to them prior to the interview. Each question included brief background information based on the literature and documents studied. The interview questions were compiled into an interview guide and divided into four main areas: (1) organisation and decision-making strategies, (2) impacts on water prices, (3) quality assurance, and (4) lessons and advice. Finally, the interview transcripts were carried out by the author.

The eight municipalities selected for (**Paper II**) are located in southern Sweden. Seven of them are among the 50 largest municipalities in Sweden, since participation in the SI survey in this size category is about 94 per cent nationwide, and they reflect the national results better than other sizes. The eighth has approximately 35,000 inhabitants and was selected to also shed light on performance within the organisation at this size.

Interview questions were divided and categorised into three main areas based on the objectives of the study and the research questions. Many of the questions included a brief background based on the literature studied. A matrix and two charts (Figures 8, 9, and 10 in **Paper II**) developed by the authors based on analysis of SI detailed evaluation documents for each municipality, were also sent with the interview questionnaire. The matrix and two charts showed the SI results, the differences in development, and the trend of change for the eight organisations studied in 2015, 2017, 2018, and 2019. The interview guide also included explanations of how the weighting method was applied and how the results were obtained. The interview guide was emailed to managers two weeks before the first interview to inform and prepare them for the interview. Interviews were conducted and recorded digitally via Zoom. Transcripts and summaries of interview results were emailed to interviewees for content review. Research questions guided the interviews. The first question was answered through document analysis. The other four questions were answered by managers in the interviews.

In **Papers III** and **IV**, 12 organisations were selected to be studied through case studies in consultation with SWWA. These organisations had good priorities and improvements in their pursuit of sustainability in the SI parameters “CA and FS” and the “status of WW fixed facilities,” which are the two biggest challenges facing WW organisations across the country. A text explaining the purpose and intended study methodology was sent to the selected organisations asking for their consent to participate in the study. Ten organisations in **Paper III** and 11 in **Paper IV** gave their consent. In addition, upon request, we received the detailed documents of their SI annual detailed evaluation for 2015–2020. Based on these documents, the organisations’ results in the two parameters at the question and parameter levels were compiled in matrices and in graphs (Figures 3 and 4 in **Paper III** and Figures A1, Appendix A, and Figure 2 in **Paper IV**) to identify the trend of improvement over the years. Based on these results, the seven **(Paper III)** and nine (**Paper IV)** organisations that had achieved the most improvement in the two parameters were selected for further investigation in the form of in-depth interviews. Interviews with six of seven WW managers in (**Paper III**) and with nine of 11 managers (**Paper IV**) took place in October–December 2021. The final step was to transcribe, summarise, and analyse the interviewees’ responses. For more details on the methodological approach, see **Papers III** and **IV**.

4 Results and analysis

All of the results of this work and their discussion are presented in detail in the appended papers. In this chapter, the main results are presented in the following four sections of the four papers.

4.1 Driving factors and strategies for developing and implementing long-term planning (**Paper I**)

In **Paper I**, the whole process of developing the Future Water Supply (FWS) of the municipality of Växjö was presented in this paper as a case study. The main objective was to show how strategies can be developed and applied to meet sustainability requirements in long-term planning and to show if the FWS project ensures water quality and quantity after 10 years of operation and if it had an economic impact on residents.

The decision-support strategies, the entire process, and the driving force for developing FWS of Växjö – the Bergaåsen project – were investigated and the results show that the decisions are typically made based on many factors and criteria. One of the main factors is the traditional type of the WW organisation at Växjö with politician influence and active ownership. Active ownership constitutes an internal relationship, which means that it is the municipality on its own that can create conditions for long-term sustainable planning in line with some other studies (Jonsson 2017, Pahl-Wostl 2017, Glaas 2018).

Another factor was the poor condition of the previous WTP and several daily complaints from users about water quality. These complaints worked as an alarm and raised politicians' awareness for the need to act and finance. This took 12 years to get full attention. A new WW manager, Pehr Andersson, has attracted the attention of politicians and his role was significant and evident throughout the whole process.

Andersson began to study and evaluate seven different alternatives in an area 80–100 km from the centre of Växjö, and the Bergaåsen project was selected. The choice was based on the results of all investigations, test pumping and the groundwater model to simulate the flow and level fluctuations at different proportions of abstraction and infiltration.

Investment in quality and innovative technology was a typical strategy used throughout the process.

The project functioning and operation processes to ensure the desired quality and quantity were also studied; they showed that Bergaåsen became the first fully computerised gravel formation in Sweden. The groundwater level inside, outside and in the terrain between each well can be followed exactly and its level could be seen online, and the amount of water in the magazine could be controlled by over 100 analogue level meters.

Bergaåsen was designed for 30 years based on forecasts made in 1999–2001. However, via planned measures, an extension of the withdrawal capacity for a 50-year perspective became possible.

One of the planned measures was to divide the area of Bergaåsen into several zones. Zones for raw water abstraction and zones for managing aquifer recharge, and two zones are kept as future reserve areas.

Moreover, inducing water from the Lagan River to the groundwater was applied from the beginning to guarantee the quantity of supplied water in the long term.

All results from the collected data indicate that expectations will be achieved,

The water quality is good, and almost all parameters are under the accepted limits with very good margins (Table 8, **Paper I**). Moreover, there is no chlorine in the drinking water of Växjö because there is no bacterial growth in the pipelines due to less organic content and a low water temperature compared to surface water.

The choice not to chlorinate in Bergaåsen was mainly based on the experiences that exist in Sweden that biologically stable water is gained after the infiltration of water through gravel formation.

The results of the SI survey for the WW organisation in Växjö for parameters that deal with drinking water showed that “safe healthy water,” “security of delivery,” and “satisfied customers” had a green colour for all the years that Växjö participated in the survey. The results show that over 90 per cent of water users were satisfied, and less than 3 per cent were dissatisfied (Table 1 **Paper I**).

The economic impact on water users could be explained by analysing the rate of increases in the fees paid for water consumption before the start of Bergaåsen until this study was conducted. The rate of increase in the fixed portion of the consumption fees from 2008 to 2018 was 3.5 per cent per year. This rate is marginal and mostly due to inflation. Meanwhile, the average of annual consumption fee in the Växjö municipality for a typical Type A house was 8 per cent less than the average of the annual consumption fee for Swedish municipalities in 2018 for the same house type, (Tables 4 and 5, **Paper I**). This means that this significant investment of 450 million SEK (the total price) did not cause an immediate increase in water fees for users in the Växjö municipality.

The explanation for this is first a well-deliberated financial plan. The plan was for the fee to begin to increase by 4 per cent in addition to inflation for five years in a row when the project was already under the decision-making process.

Another factor that had a positive effect on keeping down the costs of the project was market interest rates, which gradually dropped to below 2 per cent; they were 7–8 per cent during the calculation of the project. This downturn reduced annual costs by up to 20 million SEK.

Based on what the manager, Pehr Andersson, has accomplished and learned, he was asked to provide some advice to the WW managers to start a long-term planning project. The first piece of advice was to tell the politicians the truth about the current state of the facilities. They should make the decisions because they are the ones who make the decisions for the voters. The second recommendation was for managers to try to find consultants who can innovate and find new ways to make improvements. The third was that managers should not try to cut corners at the expense of quality and should instead strive for the best possible outcome.

4.2 Evaluation of the application of the Sustainability Index (**Paper II**)

Paper II provided an overview of WW management in Sweden by presenting the SI tool. The study specifically aims to evaluate the use of the SI tool through eight case studies. The findings of the study included the strategies used to address the shortcomings, clarify who is responsible for ensuring sustainability within the WW sector, and the principles and methods and challenges of financing WW operations.

The SI results for organisations 1–8 were compared with each other (Figures 5 and 6) and with national results for 2019 (Table 3).

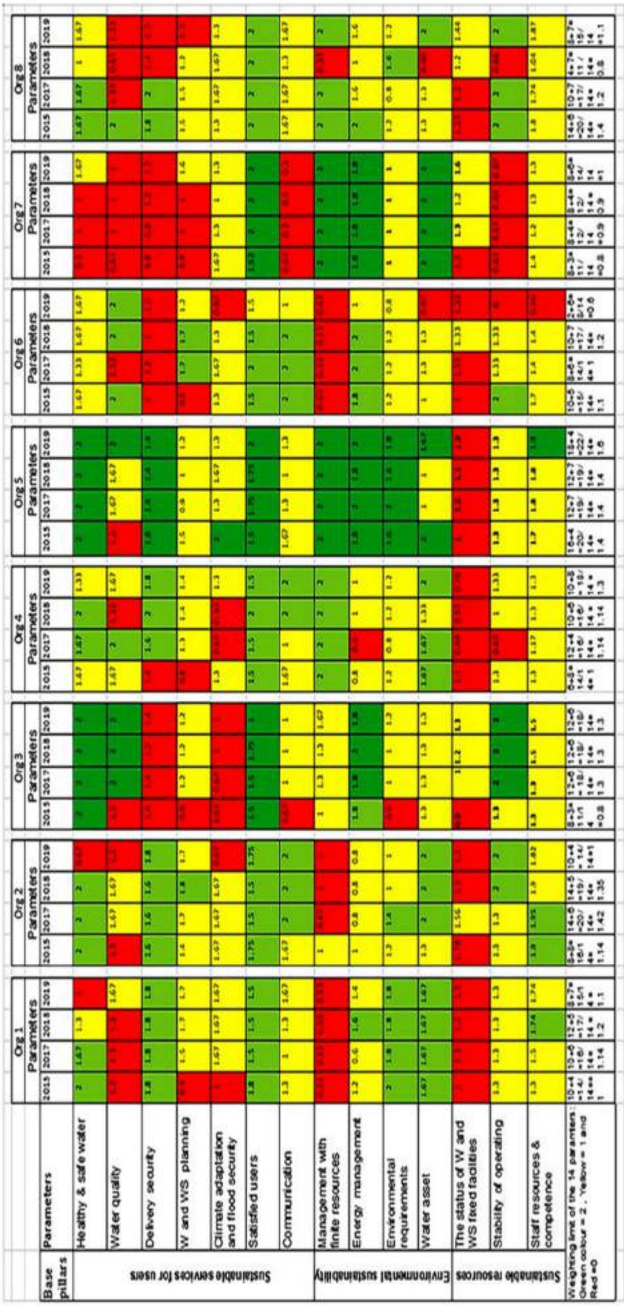

Figure 5. Compilation of results of SI parameters for Orgs 1–8 during 2015, 2017, 2018 and 2019.

The results generally reflect low, unchanged, or deteriorated development except Org 5 (Figure 6). The results show that Orgs 4, 5, and 7 had an improved results trend during 2017–2019, to varying degrees. The improving change in results for Org 5 was the largest among the eight organisations, and the trend pointed upward during 2018–2019. Org 7 also had improved results during 2015–2019 and the trend is positive. However, it started from a low level in 2015 (0.8) to (1.1) 2019. Many parameters were still not given green status over the years, but the results improved for them. The trend for Orgs 1, 2, and 6 is downward, is basically unchanged for Org 3, and the weighting limit is at the same level as Org 4 for 2019.

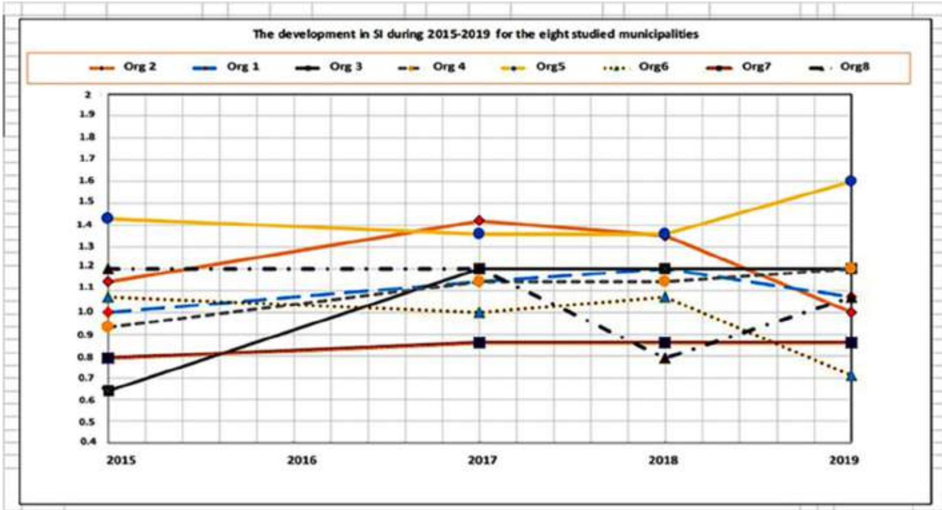

Figure 6. Alteration trend for all fourteen SI parameters during 2015 and 2017–2019 for Orgs 1–8.

Table 3. proportion in precent of red and green parameters for Orgs 1–8 and 171 organisations that participated nationally.

Base Pillar	Parameters	Proportion of Red Parameters for Orgs 1–8 in 2019	Proportion of Red Parameters for 171 Orgs Nationally in 2019	Proportion of Green Parameters for Orgs 1–8 in 2019	Proportion of Green Parameters for 171 Orgs in 2019
Sustainable services for users	Healthy and safe water	2/8 = 25%	44%	25%	31%
	Water quality	3/8 = 38%	60%	38%	21%
	Delivery security	4/8 = 50%	59%	50%	34%
	W and WS planning	1/8 = 13%	41%	0%	18%
	Climate adaptation and flood security	3/8 = 38%	58%	0%	3%
	Satisfied users	0%	21%	85%	59%
	Communication	1/8 = 13%	21%	25%	12%
Environmental sustainability	Management with finite resources	3/8 = 38%	67%	50%	21%
	Energy management	0%	19%	38%	20%
	Environmental requirements	0%	6%	25%	54%
	Water asset	0%	15%	6/8 = 75%	32%
Sustainable resources	Status of W and WS fixed facilities	5/8 = 63%	78%	0%	5%
	Stability of operation	1/8=13%	33%	38%	28%
	Staff resources and competence	1/8= 13%	10%	13%	21%

Table 3 shows that Orgs 1–8 had a smaller proportion of red results in all parameters compared to the national results of all 171 participants. This is in line with (Svenskt Vatten 2020 a), who found that municipalities with more than 50,000 inhabitants had improved results, with a smaller proportion of red parameters than municipalities with fewer than 20,000. The proportion of green parameters for Orgs 1–8 was not larger for all parameters, and was even lower for some of them, especially those parameters that require long-term strategies and planning. The parameters “WW planning”, “Climate adaptation and flood security (CA and FS)”, and “Status of WW fixed facilities” are three examples where none of the eight organisations have green status. This is in line with SI results reports for 2015–2019 for the parameters with the largest red proportion nationally.

The factors that caused the significant proportion of red on the top two challenge parameters, “climate adaptation and flood security” and “status of WW fixed facilities” were explored in depth through interviews for six of eight organisations in this study (**Paper II**).

The results for the CA and FS parameter for Orgs 1–8 are shown in Figure 7. Three questions, Ta1–Ta3 (Table 1), were answered by each organisation to assess the parameter. The conditions for achieving the green, yellow, and red values are explained in detail in Table 1. Orgs 3, 4, 5, 7 and 8 answered that they did not have green value for the CA and FS parameter because this is a cross-administrative issue involving many administrations that must provide resources; consequently, it is difficult to produce an action plan.

Org 1, the smallest of the surveyed organisations, with approximately 35,000 inhabitants, has managed its stormwater. According to its manager, it took three to four years to get to where it is today (1.7 in waiting limit) (Figure 7), and the organisation’s action plan was intended to be ready in 2020. Contrary to what was reported in (Svenskt Vatten 2020 a), “larger municipalities, regardless of organizational form, have significantly better results than small municipalities”.

	Org 1				Org 2				Org 3				Org 4			
	Parameter resultat				Parameter resultat				Parameters resultat				Parameter resultat			
	2015	2017	2018	2019	2015	2017	2018	2019	2015	2017	2018	2019	2015	2017	2018	2019
Climate adaptation & flood security	1	1.7	1.7	1.7	1.7	1.7	1.7	0.67	0.67	0.67	1	1	1.3	0.67	0.67	1.3

	Org 5				Org 6				Org 7				Org 8			
	Parameters resultat				Parameters resultat				Parameters resultat				Parameters resultat			
	2015	2017	2018	2019	2015	2017	2018	2019	2015	2017	2018	2019	2015	2017	2018	2019
Climate adaptation & flood security	2	1.3	1.7	1.3	1.3	1.7	1.3	0.67	1.7	1.3	1	1.3	1.3	1.7	1.7	1.3

Figure 7. The result of the parameter “Climate adaptation and flood security” of the Orgs 1-8.

The results for the “Status of WW fixed facilities” parameter for Orgs 1–8 is presented in Figure 8. Nine questions, Rs1–Rs9 (**Appendix A, Figure A3 Paper II)** and (Table A1 Appendix A, **Paper IV**) were answered by the eight organisations to assess the parameter. The conditions for achieving green, yellow, and red values are compiled in detail in Table A1, Appendix A in **Paper IV**.

	Org 1				Org 2				Org 3				Org 4				Org 5				Org 6				Org 7				Org 8			
	Parameters				Parameter resultat				Parameters				Parameter resultat				Parameters				Parameters				Parameters				Parameters			
	2015	2017	2018	2019	2015	2017	2018	2019	2015	2017	2018	2019	2015	2017	2018	2019	2015	2017	2018	2019	2015	2017	2018	2019	2015	2017	2018	2019	2015	2017	2018	2019
The status of W and WS fixed facilities	1	1.2	1.2	1.3	1.78	1.56	1.3	1.3	0.9	1	1.2	1.3	1.1	0.44	0.55	0.78	1	1.2	1.1	1.3	1	1.33	1.33	1.33	1.2	1.3	1.2	1.6	1.33	1.2	1.2	1.44

Figure 8. Results for parameter "Status of W and WS fixed facilities" for Orgs 1–8.

Orgs 3, 7 and 8 have 2019 yellow status with weighting limits of 1.3, 1.6, and 1.44, respectively, and they were satisfied that they had tackled the problem and were in good standing. The other five organisations still have red status for the parameter.

According to (Svenskt Vatten 2020), the investment level is too low because WW organisations lack internal capacity. Therefore, the national results for the parameter "Personnel resources and competence" in SI show that 21 per cent were rated green and 10 per cent were rated red. In **Paper II** five out of six surveyed organisations have sufficient competence to carry out most of the work by their own staff; an exception is Org 1, which expressed a need for more competent staff. Figure 9 shows the result for parameter "Personnel resources and competence" for Orgs 1–8. Org 6, which has a communal corporate form, is red in the parameter and has a weighting limit below 1, indicating a clear lack of internal capacity. Thus, the effect of Org 6's low staff capacity is clearly shown in the results of the two parameters "CA and FS" and "WW facility status" (see Figures 7 and 8) (Svenskt Vatten 2020).

	Org 1				Org 2				Org 3				Org 4				Org 5				Org 6				Org 7				Org 8			
	Parameters				Parameter resultat				Parameters				Parameter resultat				Parameters				Parameters				Parameters				Parameters			
	2015	2017	2018	2019	2015	2017	2018	2019	2015	2017	2018	2019	2015	2017	2018	2019	2015	2017	2018	2019	2015	2017	2018	2019	2015	2017	2018	2019	2015	2017	2018	2019
Staff resources & competence	1.3	1.5	1.74	1.74	1.9	1.95	1.9	1.82	1.3	1.3	1.5	1.5	1.3	1.2	1.3	1.3	1.7	1.8	1.8	1.9	1.7	1.4	1.4	0.96	1.4	1.2	1.3	1.3	1.8	1.74	1.04	1.87

Figure 9. Result for parameter "Personnel resources and competence" for Orgs 1–8

Paper II also showed that five out of six WW organisations use simple strategies to address deficiencies identified by the SI. For example, some of the organisations create a list of deficiencies that need improvement, while others review what is relevant and what is easy to fix and select specific issues to improve their results. Org 5 conducts an annual review of the SI results and includes the deficiencies as priorities in their activity plan. They prioritise the issues that are most important and where it is appropriate to take action. So, if the status of the results is either red or yellow, they determine what should be improved, etc. Org 5 has also established a central finance function with accounting economists and controllers. This function's job is to make sure the business is developing, which means they are constantly evaluating whether they have the resources and are using the money wisely. Org 8 does not use the SI tool to analyse and plan its activities, nor does it use the tool to compare itself with others or to look at its results, but it uses the strategy of the company's business area and their activities plan.

Five out of six interviewed organisations believe in the SI tool, agree that SI has good potential, and want to use the results for all purposes for which they are intended. They also have confidence in the SI tool's positive role if used as a basis for discussion with policymakers and have used their results reports to varying degrees but not as much as they would like. However, they do not believe that SI has influenced much strategic work between leadership and the municipality board at the political level, because they have not used it to a large degree. Two out of six organisations feel that they do not have a complete picture when they show how their results are related to other municipalities, and think it is too complicated to set up.

In addition, not all of the organisations studied use benchmarking to get inspiration on the indications on SI because, according to the head of Org 1, they did not have time for benchmarking. The head of Org 5 said that the SWWA website was difficult to use for benchmarking with other municipalities and suggested that a background like Figure 5 in this study and Figure 8 in **Paper II** should be available at the national level. However, they use established and modern methods to motivate staff and increase participation in work improvements, such as setting specific goals and deadlines for projects, using contributions for work improvement, as part of their salary discussion, ensuring that employees feel they are treated fairly, etc.

Paper II also investigated financing methods, financing challenges, and the responsibility for ensuring sustainability. All interviewed organisations noted that there is a link between long-term sustainability and active demands to raise tariffs. The heads of all six interviewed organisations raised tariffs according to their assessment of needs. Org 1, which scored highest among Orgs 1–8 studied in the CA and FS parameter, has been steadily increasing fees for many years to cover new investment costs and future operational maintenance and capital costs for its facilities. Org 1 has a relatively high tariff; its manager said, "If we had not raised the tariff, we could not handle the basic maintenance and future investments."

Orgs 3, 4, and 7 have locked money in investment funds from the overdrafts in the consumption charge. The cost price principle makes it possible to set aside funds for new investments but not for reinvestment and exploitation. Funding by those organisations is in line with what Växjö municipality did successfully when SEK 120 million of a total SEK 450 million was put in an investment fund for investing in its FWS project in 2009 (**Paper I**).

Investment funds may not be used for renewal; the Water Service Act has a deficiency here, according to four of the six managers interviewed.

The head of Org 7 emphasised that money for renewal must come in, and one way to do that is to create funds for reinvestment. Three managers also argued that a legal change in the Water Services Act is required.

The heads of Orgs 8 and 7 stated that there are significant risks with the large loans they have because an interest rate increase would mean a sharp increase in fees, thus increasing the injustice.

The main responsibility for ensuring that the technical office meets the sustainability objective lies with the technical committee for Orgs 1, 3, 4, 5, and 7, which have a traditional form of organisation. However, it is the heads of the WW organisations, together with their employees, who do the work.

For Org 8, which has a multi-utility organisational form, the main responsibility lies with the CEO, and those who ensure sustainability are business area managers, together with their staff.

4.3 Driving factors and explanation for success of climate adaptation and flood security (**Paper III**)

Via the SI survey, the parameter of "climate adaptation and flood security" (CA and FS) was identified as one of the two top challenges facing municipal water utilities nationally and in **Paper II**. Ten WW organisations were selected and studied; seven of these, which had waiting limits of 1.7 to 2.0, were selected as good learning examples. They have made improvements and great progress in their work on CA and FS. Six of the seven were interviewed in depth in the autumn of 2021 to highlight driving factors, strategies, the influence of organisational form and other important explanations for success. The study also highlighted the challenges faced by the organisations and the reasons why few organisations have an action plan for society's vulnerability due to more extreme rainfall, as outlined in the documents examined in this study (see Ta1, Figure 10) and **Paper III**.

Figure 10 shows that only Jönköping had a green score on the CA and FS parameter, and thus has a waiting limit of 2 because it had a green score for all three questions. The other nine organisations were yellow, with a waiting limit of 1.3–1.7, and none were red. At the national level, as many as 55 per cent were red and only 2 per cent were green (Svenskt Vatten 2021a).

The reason for those who had 1.7 is that they had a vulnerability analysis but no action plan (Figure10).

The significant events as a major flood and flooding of basements are one of the driving factors for success. Arvika in 2000 and 2006, Värnamo in 2004 and Jönköping in 2013 were exposed to such events and were the reason for applying climate adaptation measures. These incidents have also revealed the vulnerability of the existing stormwater management systems. Many strategies were developed and applied by the municipalities to avoid the flooding consequences on the societies. For example, Arvika developed the EU Climate-Proof Area project (CPA). The project conducted sizing and capacity calculations for stormwater pipes throughout the centre of Arvika and provided insights into the capacity and condition of the network. Measures included replacing pipes with larger ones, but not replacing pipes that were 20 years old, even if they were small. Half of the consulting costs for the (CPA) were covered by the EU.

Parameter: Climate Adaptation and Flood Safty "CA and FS"	Arvika 2020	Ljungby 2020	Ronneby 2020	Värnamo 2020	Ängelholm 2020	Luleå 2020	Växjö 2020	Jönköping 2020	Västerås 2020	Linköping 2020
Calculating the weighting limits. Green answer = 2 waigh, yellow = 1 and red = 0	(2*2)+(1*1)=5/3 = 1.7	(1x2)+(2x1)=4/3 = 1.3	(1*2)+(2*1) = 4/3 = 1.3	(2x2)+(1x1)=5/3= 1.7	(2x2)+ (1x1) =5/3 =1.7	(2x2)+(1x1)=5/3= 1.7	(1x2)+(2X1)=4/3 =1.3	(3x2) = 6/3= 2	(2x2)+(1x1)= 5/3 = 1.7	(2x2)+(1x2)= 5/3 = 1.7
Ta1:Is there an investigation with an action plan on society's vulnerability due to more extreme rainfall and rising levels in seas, watercourses and lakes?	Yes, but no action plan	Yes, but no action plan	Yes, but no action plan	Yes, but no action plan	Yes, but no action plan	Yes, but no action plan	Yes, but no action plan			Yes, but no action plan
Ta2:Is there a clear strategy for new construction, reconstruction, for flood-safe and correct height adjustment that there is no damage to houses when the stormwater systems are overloaded?	Yes and no floods can occur in new areas due to rain or water levels.	the strategy should have been sharper.	the strategy should have been sharper.				the strategy should have been sharper.		the strategy should have been sharper.	
Ta3: Basement floods within business areas as a 5-year average (The number per 1000 house coupling pipe)	0.41 (4 in 5 years)	0.51	0.57	0.976	0.37	0.779	0.07	<1	0.32	0.57

Figure 10. Evaluation of all the questions for the CA and FS parameter, as well as the calculation of the weighting limits of the parameter for the 10 studied organisations in 2020.

One of the main reasons for the success in Arvika was that they had formed a technical team after moving to corporate in 2011. Moreover, it had applied different solutions depending on the conditions on the ground it had; for example, rehabilitated the two low-lying areas in Arvika.

The formation of an interdisciplinary climate adaptation group within the municipality of Ängelholm as in Arvika was another reason for its success. Climate adaptation actions were overseen through the working group, which included representatives from the WW side, as well as the city planning, street, park, environment, and building permit sides.

In Värnamo, a crucial factor for success was the creation of data modules on stormwater pipe networks and the level of the Lagans River, which flows through the city. In these data modules, measures were simulated to see what impact a measure could have. In addition, Värnamo attributed their success to the understanding and curiosity of politicians and to the fact that the WW organisations had been good at applying for external funding.

The factors that helped the WW organisation in Luleå was that they adopted the climate guidelines from 2015 and the development of the SI, which was very helpful for showing the current situation. SI has also allowed the organisation to prioritise and focus on what others are doing. In addition to building competence in the WW organisation, cooperation with Luleå University of Technology and other research institutions explained its success.

Jönköping's success in become green in the parameter was partly due to developing cloudburst mapping of the central city area and another different area and its focus on locating low-lying areas in it to determine how runoff would appear in the event of a 100-year rainfall and on flooding. In connection with this work, a northern storm was counted in Lake Vättern when it was pouring in with heavy rain. There was a prediction that Lake Vättern will tip because the land uplift in the northern part (approximately 2.7 mm/year) is greater than in Jönköping at the southern part of Lake Vättern (approximately 1.3 mm/year). This means that the level of Lake in Jönköping increases by 1.4 mm per year.

In addition, measures had been taken for the most vulnerable existing buildings in low-lying and confined areas. Jönköping had also succeeded in creating a long-term plan and gaining full political support by informing politicians about what exactly the organisation needed to do and why.

Västerås set sustainability goals in the strategic and development plans they worked with and followed. The main explanation for their success was that they had been working with long-term plans for many years and dared to try things. The manager in Västerås also sees the size of the municipality as an explanation for their success, because with around 156,000 inhabitants they can generate a good amount of revenue in the form of WW fees.

WW organisations are attempting to convert their combined systems to separate systems, as a protective measure against future climate change." It is also a measure that belongs to flood risk management to reduce flooding. Today, 13 per cent of the sewers in Sweden are still combined sewers (Svenskt Vatten 2020).

Eighteen per cent of the sewers in Jönköping, 10 per cent in Luleå, 3 per cent in Västerås and 3–4 per cent in Värnamo are still combined systems. Arvika and Ängelholm have separated their entire systems.

Managers of four organisations felt that their organisational form was of great importance to their positive outcomes, although they had different organisational forms. These organisations were Ängelholm and Luleå which have traditional form on the one hand, and Arvika and Västerås on the other hand, which have a municipal enterprise and a multi-utility form, respectively.

The organisational form, according to the manager in Ängelholm, is a driving force behind their success in working for the long term, retaining their employees for a long time, and forming the climate adaptation group, which has created good opportunities for contacts and cooperation across organisational boundaries.

The managers of Arvika and Västerås experienced that they can easily enhance the competence and ensure more resources and efficient use of them, that they had a clearer place in the community, and that part of the political board, which also sat on the municipal council, focuses on the right thing. They can create clearer financial accountability. They also have the ability and flexibility to borrow externally (not only from the municipality) if it is difficult to borrow from the municipality for investments.

Most of the WW managers surveyed in 2020 (**Paper II**) considered responsibility sharing to be a major challenge and a complex issue, with many conflicts of interest that required large resources to address strategically. Managers indicated that there was an unclear division of responsibilities for stormwater in the built area, and that there were questions about who should be responsible for both investigation and cost, and what the requirements were. (**Paper II**).

Therefore, it was interesting to examine this issue again with the good learning examples in this study **(Paper III**) to show if and how they could deal with the difficulty of dividing tasks.

It turned out that Arvika and Ängelholm felt that they could handle task sharing well, partly due to their organisational form. They both had formed groups – the technical staff in Arvika and the climate adaptation group in Ängelholm – that worked across organisational boundaries and encompassed many disciplines.

The manager in Arvika also explained that the two events that affected Arvika – the cloudburst events in 2000 and 2006 – made people in Arvika aware of the division of responsibilities and how to work together, and also who should pay for what.

Värnamo said they also had no problem sharing responsibility when it came to new investments because they had money in an investment budget that is covered by the tax collective. The Värnamo manager also explained that the cost of the measures implemented by the WW department to mitigate the impact of torrential rains on existing areas would be borne by the community tax. The WW department would cover the costs if the stormwater network is undersized.

The managers of the other three WW organisations surveyed – namely Luleå, Jönköping and Västerås – believed that the division of responsibilities is the biggest challenge they encountered on their way to make improvements. It is especially difficult when it comes to cloudburst management.

The manager at Jönköping believed that other departments of the municipality should require the municipality to use tax revenues for the actions for which they are responsible. Thus, WW fees would be reserved to fund the work that was the responsibility of the WW organisation. Measures that cost approximately 80 million SEK were allocated and paid for by the municipality with tax funds during the flood event 2013 in Jönköping. The manager at Jönköping said that, despite this incident, it was not easy to overcome other difficulties in the division of responsibilities and funding.

The other challenges that been mentioned by the manager at Jönköping was that there are overlaps in the legislation, in the Environmental Code and the Water Services Act, and there are gaps in the legislation regarding stormwater management. Although they have a stormwater group at management level that is trying to find a common line, the manager said that they need clearer legislation to make this work.

The investigator in Västerås, similarly to the manager in Jönköping, also emphasised the importance of clarifying the division of responsibilities in legislation to create clear incentives for the work, so that it did not depend solely on the commitment of the individual.

SWWA has called for the creation of an action plan in addition to a vulnerability analysis for existing and newly planned buildings. However, without having an action plan, the organisations cannot become green in the CA and FS parameter Nationwide, only four out of 184 municipalities have an action plan and are thus green in this parameter (Svenskt Vatten 2021a). The results for eight out of 10 municipalities in this study show (Ta1, Figure 10) that they had produced an investigation (vulnerability analysis) but no action plan.

The managers interviewed in **Paper II** explained that there are three reasons why it is difficult to develop an action plan: (a) the unclear division of responsibilities, which leads to uncertainty about who is responsible for developing the action plan; (b) difficulty finding all the actions to create an action plan; and (c) a lack of clarity regarding who will fund the actions once you have an action plan (Najar and Persson 2021). The reasons given by the six good learning examples interviewed in (**Paper III**) also included other explanations. Three of the interviewees – those from Arvika, Ängelholm, and Luleå – believed that they did not need to create an action plan because it was difficult to create a detailed action plan as it involved a lot of work and needed to be adjusted frequently. Instead, they had used the time to implement several improvement actions. This means that they did not have the intention to develop an action plan. Ängelholm and Luleå are also coastal municipalities, so they had good possibilities for discharging water into the sea. All the reasons for the ineffectiveness of developing an action plan are elaborately explained in Section 5.6 in **Paper III**.

The other three organisations – Västerås, Värnamo and Jönköping – are located inland and have different geographic conditions than the coastal communities and fewer opportunities to drain large amounts of water during heavy and torrential rains. Therefore, it is even more urgent for them to have an action plan.

Västerås did have an action plan, but it was 10 years old and had many shortcomings. Värnamo was in the process of developing an action plan but still lacked much basic material. Jönköping was the only municipality in this study that had an action plan, but also had special geographical conditions because of Lake Vättern. Some base conditions and actions taken in the Jönköping action plan are briefly explained in Section 5.6 in **Paper III**.

4.4 Driving factors and explanation for the success of status improvement of fixed facilities (**Paper IV**)

The parameter "Status of WW fixed facilities" is the one of the top challenges for WW organisations. The other is "CA and FS". The "Status of WW fixed facilities" parameter also has a large proportion of red results, both nationally and in the study of **Paper II** (See Figure 8 in **Paper II**). Thus, municipalities require major investments in order to be able to deliver WW services with the same quality and reliability in the future, and it is important that these investments are conducted in a socio-economic and appropriate way (Svenskt Vatten 2017). This parameter demands financial foresight in the form of a multi-year budget and a long-term financial plan for investment, in addition to improving the status of all parts of the WW system (pipe network, waterworks, sewage treatment plants and pumping stations (Table A1, **Paper IV**). The large proportion of red results is due to not meeting the requirement for financial foresight for investments, and many municipalities have not analysed their need for renewal while the rate of renewal is low (Svenskt Vatten 2021a). Growing populations and changing settlement patterns, along with a great need for infrastructure renewal, have changed the conditions for municipalities (Jonsson and Thomasson 2019). This situation has led municipalities to invest much more in expanding WW infrastructure to accommodate growth than in renewing WW systems (Malek Mohammadi 2019).

In **Paper IV**, 11 municipal WW organisations that have implemented and demonstrated a particular ability in terms of the status improvement of their facilities and to track their performance according to the SI were selected, with the goal of examining, analysing, and using them as good learning examples. The managers of nine of these organisations were interviewed and studied in depth. The primary aim was to show how these organisations have improved their facility status by concretising the organisations' working methods, planning tools, and strategies, as well as clarifying success factors and challenges.

The results and trends of the organisations (SI) for the "status of WW facilities" parameter is presented for all of the years they participated in the SI survey (Figure 11 and Figure 12). Figures 11 and 12 show different performance levels of the studied organisations, as well as the trends in changes toward sustainability for the "status of the WW fixed facility" parameter over the years. All trends were found to be largely positive. Three of the green organisations – namely, Arvika, Ljungby, and Ängelholm – belong to the group of smaller municipalities. A green rating of the "status of the WW facilities" parameter means that all conditions for a green score are met (Appendix A, Table A1 **Paper IV).**

Organizations, results in 2020 and population size	Arvika 25865	Ljungby 28521	Ronneby 29346	Ängelholm 43030	Mölndal 68152	Luleå 78487	Växjö 94886	Umeå 130224	Jönköping 142630	Västerås 155858	Linköping 164664
Parameter: VA - anläggningens status -2020	1.8	2	1.3	1.6	1.3	1.3	[illegible]	1.4	1.3	1.4	1.4
Rs1: Is there a multi-year budget (3-4 years) established											
Rs 2: Is there a ten-year financial plan showing how the identified investment and renewal needs under Rs3, Rs8 & Rs9 will be funded?											
Rs 3: Is there a plan for renewal-needs pipeline networks in 10 years or longer linked to both the facilities' status and challenges in the form of climate adaptation. Mm											
Rs 4: Status of the water supply network measured as calculated leakage (m3 / km, day).	2.3	0	3.6	0	6.05	6.73	3.42	5.6	9.64	11.18	3.66
Rs 5: Renewal rate water-pipes network 5-year average (>0.7)	0.73	>0.7	1.3	0.65	0.59	0.5-0.7	0.63	[illegible]	0.62	0.66	[illegible]
Rs 6: What is the condition of the sewage network? Answer the question using TV inspections, stops, flushing needs, and line breaks.											
RS 7: Renewal rate wastewater network 5-year average (>0.6)	1.18	>0.6	0.78	[illegible]	0.81	>0.6	0.73	0.81	0.31	0.59	0.49
Rs 8: What is the investment need for WTP, and Pumpstations? Make a general assessment for all facilities based on periodic inspections, risk assessment, maintenance plans and operational disruptions/emergency repairs.											
Rs 9: What is the investment need for WWTP and pumping stations? Make a general assessment for all facilities based on periodic inspections, risk assessment, maintenance plans and operational disruptions/emergency repairsr.											

Figure 11. Results of the "status of WW fixed facilities" parameter for the year 2020 for 11 studied organisations

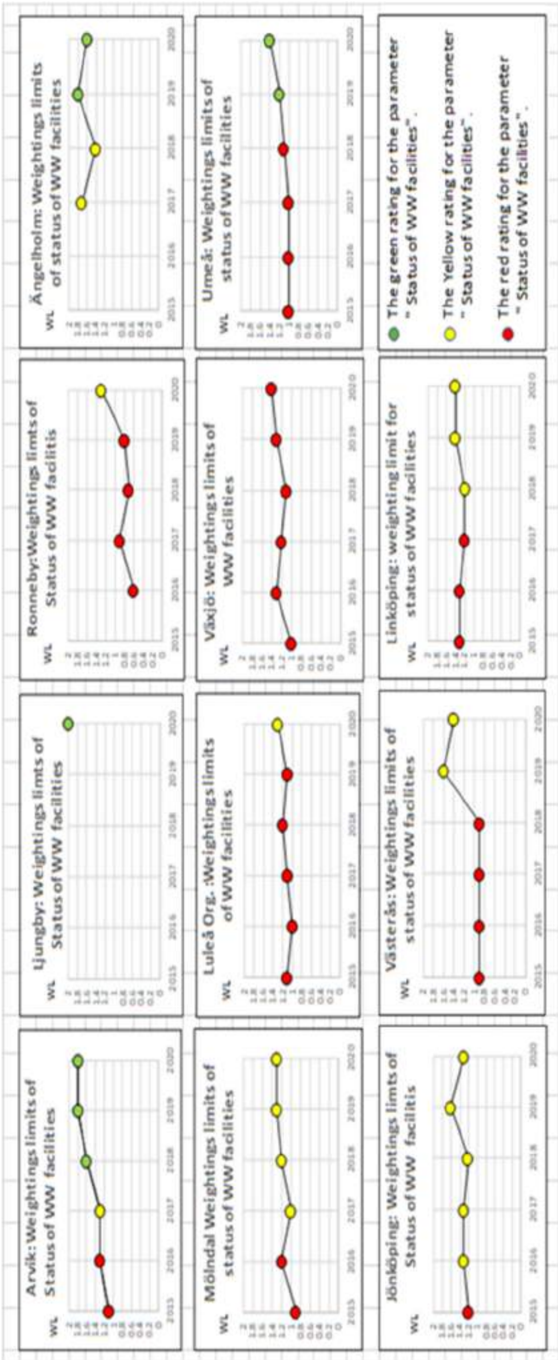

Figure 12. Results of the "status of WW facilities" parameter for all studied WW organisations in 2015–2020.

Maintenance and renewal plans are usually divided into three levels: strategic, tactical, and operational (Svenskt Vatten 2021c). A renewal plan can be defined through the five steps shown in Figure 13; the per centage of municipalities that had a renewal plan and conducted work based on that plan was 15 per cent at the national level (Svenskt Vatten 2021a). In the present study, five of the 11 studied organisations (Arvika, Ljungby Ängelholm, Umeå and Linköping) had renewal plans (Rs2 Figure 11). The results of this study showed a significant improvement in the possession and use of renewal plans compared with the national results. Arvika has a 10-year plan that includes the most important matters. It also has a more specific three-year plan. The other six organisations had a general renewal plan or various plans and were therefore yellow in RS2 (Figure 11); the exception was Växjö, which was red for Rs2 and was therefore red in the parameter. Nevertheless, like other studied organisations, Växjö involved strategic, tactical, and operational levels when creating its renewal and maintenance plans. The WW strategist said that a clear explanation for the success in Mölndal was the political decision regarding the renewal plan for the network in 2016 after a long dialogue with the technical board about the need for a plan. For more details on how they apply innovation strategies at different levels and apply the five steps of the renewal plan, see Section 4.2.1 in **Paper IV**.

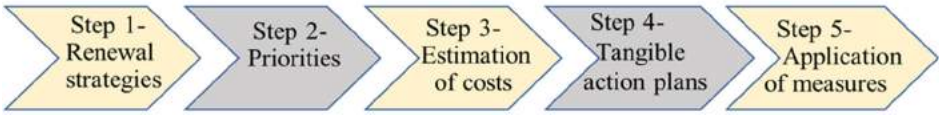

Figure 13. The steps in a renewal plan

Respondents also indicated that they take a life-cycle perspective when selecting and applying renewal measures to ensure that fixed assets remain functional throughout their lifespan. Six of them also said they feel they have a resilient organisation that can handle financial, environmental and demographic changes, as described by (Jonsson and Thomasson 2019). In the other three – namely, Ronneby, Jönköping, and Luleå – the situation regarding operation resilience is different. The need for investments in one or both treatment plants is the reason why the business is not yet resilient.

For more details on the application of life cycle perspective as a strategy for investments in WW facilities, see Section 4.2.2 of **Paper IV**.

In addition, all nine surveyed organisations reported the extensively use of digital technology for control and monitoring. As digital technology is increasing the ability of the WW sector to optimise operations in real time and make more informed decisions about network renewal and maintenance, measured data can be used and analysed on a much larger scale than before (Malm, Mårtensson et al. 2019). A water network can be transformed into a smart system that can be monitored from within (Davis, Sullivan et al. 2013). The benefits of digitalisation are beginning to emerge for the Swedish water network (Malm, Mårtensson et al. 2019).

For more details on the extent and nature of digital technologies used by the organisations studied as strategies and explanations for their success, see Section 4.2.3 of **Paper IV**.

Other success factors were also compiled from the interviews with the WW managers, with most emphasising good competence and employee commitment.

WW in Växjö focuses on improving the status of the working environment, which has resulted in considerable commitment from the operational staff.

In Arvika, setting 1 per cent of replacement cost for reinvestment was the starting point for further development. The company also operates with its own management and performs most of its tasks in-house with its own labour and machinery. They have not had to procure any work for projects, which has kept them going and, according to WW managers, has also been a key factor in their success.

Success in Luleå can be explained by the competence and a strategic way of adapting to the current situation.

In connection with the political decision regarding the renewal plan for the network in 2016, Mölndal also received additional support to bring funds into the investment budget to increase the pot that was earmarked for the renewal of the pipeline network.

A fast-decision-making process and a loose budget are among the explanations for the success of Ronneby. A loose budget means that it can transfer certain investment funds to other projects besides using the technique of replacing a longer sections of pipe network instead of just patching and repairing. They replace from valve to valve. The company at Ängelholm has been planning for the long-term since 2010, has a huge project called “the large WW”, and has built many new things, including a new network and a new WWTP. The many meters of newly constructed pipelines that have been put into operation have resulted in a large part of the entire pipeline network being relatively new. The company has received support from politicians because they understand that much is happening and improving.

Increasing water tariffs became a solution in Umeå. Construction fees for facilities have increased by 10 per cent annually for 2019, 2020 and 2021 and the consumption have increased by 6 per cent for the five to six consecutive years.

The WW managers interviewed faced several challenges on their path to sustainability. One of the most difficult challenges is prioritising between plant or pipeline network renewal. Prioritisation leads to the expansion of one sector at the expense of the other. Also, a lot of growth and a lot of new buildings mean that renewals are not prioritised and access to contractors becomes a major problem.

Another challenge is the difficulties coordinating with other pipeline owners (electricity, district heating, etc.), which causes both social and economic problems.

The renewal rate, its calculation, and replacement costs were also studied. The renewal rate in Arvika and Ronneby was above the limits of SI and averages about 1 per cent (Figure 11). Arvika was shown to have a replacement value of SEK 2 billion for its pipe network and has reinvested approximately SEK 20 million, or 1 per cent of the replacement cost of the pipeline network, over several years. This is because of the decision in the politicians' business plan to reinvest 1 per cent of the replacement value annually.

Ronneby have achieved a high renewal rate of 1.3 per cent (Figure 11) because of its strategy of changing the valve the company uses when there are a lot of leaks. The company then generally replaces a longer section instead of repairing.

The renewal rate in several other organisations was the same as the percentage reported by the SI. This means that pipes should be in the ground for about 165 years before they are replaced.

Ängelholm was one of four organisations that rated green for the WW facility status parameter in this study. The renewal rate for water pipes was rated yellow (0.65 per cent) and that for wastewater lines was rated red (0.2 per cent) (Figure 11). The manager of WW in Ängelholm was not able to say how much the company is renewing, as a in percentage, because it is expanding the pipeline network. The manager insisted that the renewal rate is quite good in Ängelholm because the company has a renewal plan that it follows and thereby renews two large areas every year at a cost of SEK 20–30 million per year.

The organisation in Jönköping has gone from an investment budget of just over SEK 100 million 10 years ago to over SEK 300 million a year now. The need for renewal accounts for more than half of the total investment needs. "That's a lot, but the need is great," the manager said.

5 Discussion

5.1 Driving forces for long-term planning

Paper I showed that the WW organisation in Växjö succeeded in planning and implementing the FWS-Bergaåsen water supply project for Växjö and Alvesta. The project, which started in 2009, has a long-term, sustainable character. The entire process from planning to commissioning took approximately 10 years.

Since the project's inception, it has met all the requirements that are made today in terms of desired quality, quantity, delivery security and user satisfaction. Moreover, the investment impact of the Bergaåsen project has not led to an immediate increase in water charges for users. Investing in quality and innovative technology was the usual strategy throughout the process. As a result, the project became the first computer-controlled gravel plant in Sweden.

The FWS project was initiated and implemented based on three driving forces:

- The poor condition of the former WTP and several daily complaints from users about water quality
- The traditional type of the WW organisation with political influence and active ownership, which means that the municipality can create the conditions for long-term sustainable planning through its internal relationships.
- The role of the newly hired WW manager, Pehr Andersson, who has a lot of experience and drive.

The following are some of Andersson's accomplishments:

1. He attracted the attention of politicians.
2. He dared to extend the investigation radius for finding a suitable raw water supply from 30 km to approximately 200 km from the centre of Växjö.
3. He invested in quality and innovative technology.
4. He implemented the first fully computerised gravel extraction in Sweden.
5. He adapted a well-thought-out financial plan that did not result in fee increases.
6. He extended extraction from 30 to 50 years.
7. More than 90 per cent of water users were satisfied.

8. During his leadership, he implemented three major projects: the 1994 wastewater treatment plant, the 2009 water treatment plant FWS, and the application of new technologies for stormwater. These projects benefited the residents of Växjö and were also recognised at the national level.
9. His achievement was very appreciated by the new WW manager, Steve Karlsson, who started in 2015 when Andersson retired. Karlsson said that he had considerable benefits from the top quality of the WWTP and the WTP that Pehr Andersson had built (Interview 2018, **Paper I**).

Based on the three driving forces for the implementation and success of the FWS project, it is not difficult to see that the most important driving factor was the initiatives and the role of the manager, Pehr Andersson. One might think that user complaints about the poor quality of the water from the old treatment plant should have attracted the attention of politicians, since the problem started in the mid-1980s, but politicians did not react, and the problems were only temporarily addressed by the management team at the time (Section 4.2 **Paper I**). It took 12 years before full attention was given to these problems, when Pehr Andersson was hired as head of the WW organisation in 1987. He told the political how urgent the situation was, and only then was he given the green light to find solutions to the problem. The third factor – active ownership – includes both political and administrative leadership (Jonsson and Jannesson 2014). Again, the role of the manager as an administrative leader seems to be crucial, because in a traditional type of organisation, politicians are responsible for various matters of community-owned administrations such as education and healthcare. In such an organisation, WW issues are often neglected (Jonsson 2017).

5.2 Implementation of SI by WW utilities

The SI is a benchmark for analysing and guiding the activities of municipal WW toward sustainability in the short and long terms (Svenskt Vatten 2017). In **Papers II, III** and **IV**, SI was used for analysing the sustainability of WW operations in eight Swedish water utilities. In **Paper II** the implementation of SI was examined in general, and in **Papers III** and **IV** SI was used to show how some good learning examples have managed to improve their operations in the two most challenging areas – CA and FS – and the status of WW fixed facilities. SI supposed among other things, facilitate discussions between business leaders and policymakers, thus supporting the key strategic issue around investment, planning, prioritisation, and rate adjustment that business leaders and elected policymakers must decide (Svenskt Vatten 2019).

Paper III showed that Luleå believes that the development of SI has been very helpful to present the current situation and has therefore been one of the factors contributing to their success at CA and FS. One of the six organisations interviewed in **Paper II** (Org 8) does not use the SI tool to analyse and plan its activities, nor to compare itself with others or to look at its results, but it uses the strategy of the company's business area and its activities plan. The other five organisations believe in the SI tool, agree that SI has good potential, and want to use the results for all purposes for which they are intended. They also have confidence in the positive role of the SI tool when used as a basis for discussion with policy makers, but they could not use it for that purpose because they lack an adequate basis suitable for discussions and for some other purposes. Managers of these five organisations also did not feel that SI influenced strategic work between leadership and the community board at the policy level. Two of the managers said that they did not have a complete picture of how their results related to those of other communities and that they thought the setup was too complicated. It can be concluded that the report and compilation of results generated from the survey through the VASS system are critical for achieving the desired SI goal, and that the foundation currently provided by these reports is not good enough to be used for discussions with policymakers or for benchmarking with other organisations.

Based on my last three studies of the SI tool (**Papers II, III,** and **IV),** I strongly believe that the SI tool has excellent potential to be used much more than it has been and for all the purposes for which it was developed. This can probably be accomplished at minimal cost by making it easier for already overburdened WW organisations to generate a more informative report of their results from the VASS system. In this way, the reports can better illustrate the results and also form the basis for comparisons between different groups of organisations and thus be used in their discussions with policy makers. One way to do this is to have the organisations, when conducting the SI survey, evaluate the results of their parameters with weighting limits, as used and explained in studies (**Papers II, III** and **IV**) and also shown in Figures 5, 10 and 11. These figures were sent to all organisations interviewed along with the interview guides. They were greatly appreciated by the managers and Org-s 5 and 7 said that it would be very helpful for their discussions with policy makers and for benchmarking with other organisations if they could obtain similar documents from VASS. The reports currently generated by the VASS system can be used by organisations to list their own deficiencies or to conduct an annual review of SI results, including deficiencies. For example, Org 5 in (**Paper II**) conducts an annual review of SI results and includes deficiencies as priorities in their activity plan.

I also recommend that organisations making improvements should be mentioned in the annual SI results reports so that all organisations understand that what is being done is mentioned, as this is likely to inspire others. If possible, the comments section should also explain how the improvements were made.

5.3 The influence of organisational form on success

The influence of organisational form on success was discussed intensively in the case of four organisations. All four organisations felt that their organisational form was of great importance to their positive outcomes, although they had different organisational forms. Two of the organisations, Ängelholm and Luleå, have a traditional form where politicians on a municipal board are ultimately responsible for the organisation's activities (Thomasson 2013 a). The other two are Arvika and Västerås, which have a municipal company and a multi-utility company, respectively, where the CEO is responsible for operational activities and strategic responsibility lies with the company's board (Thomasson 2013 a). All four organisations believe that their decision-making paths were much shorter than in the other form. Both Ängelholm and Arvika have succeeded in forming an interdisciplinary group that can work across organisational boundaries and have created good opportunities for collaboration. Furthermore, Ängelholm can keep its staff and Arvika and Västerås can easily expand their competences and provide for more resources. This is also in line with (Hellström and Ramberg 2004, Mattisson and Thomasson 2011, Thomasson 2013 a) and (Jonsson and Jannesson 2014). Even though the only organisation in **Paper II** that was red on the "staff resources and competence" parameter was Org 6 with a municipal company, I believe that the explanation for the success is that the four organisations have active ownership that includes both political and administrative leadership (Jonsson and Jannesson 2014). Again, the manager's role as administrative leader seems to be a key factor, in addition to the role of the interdisciplinary groups in Arvika and Ängelholm, which their WW managers were also involved in forming.

5.4 The influence of municipal size

According to (Svenskt Vatten 2020 a), "large municipalities with 50,000 or more inhabitants have significantly better results than small municipalities, regardless of the organizational form." The research results in this thesis show that smaller municipalities can also deliver good results. In **Paper II**, the small Org 1, with about 32,000 inhabitants, had a weighting limit (WL) of 1.1- on average for all 14 parameters (Figure 5). Its results were similar to those of large Orgs 2, 7, and 8, which had populations in the range of 70,000–170,000, and better than those of Org 6 (WL 0.6), which had a population of more than 114,000. In **Paper III**, six out of 10 studied organisations had waiting limits of 1.7 in the parameter (CA and FS), of which three were small municipalities, namely Arvika, Värnamo and Ängelholm, with populations of 25,865–43,030 (Figure 10). In **Paper IV**, four organisations were green in the parameter (status of WW facilities), of which three were small municipalities: Arvika, Ljungby and Ängelholm (Figure 11).

The results of this work have shown that although the large municipalities have better resources in the form of fee income, some factors other than size may have a greater impact on the organisations' results. These factors include organisations having active ownership, the role of the manager (**Papers I, II, III,** and **IV**), and significant events such as major floods (**Paper III**).

5.5 Collaboration management and the size of municipalities

Experiences and several studies have shown that managing collaboration and sharing responsibilities is a major challenge (Sörensen 2018). The results from **Papers II** and **III** have also shown that sharing responsibility with other administrations is one of the biggest challenges facing municipalities when it comes to managing and vulnerability analysis for heavy rain events. This is also likely related to a lack of resources, both in terms of staff capacity and available budget (Svenskt Vatten 2021a). According to (Svenskt Vatten 2021a), planning that requires cooperation with other administrations tends to work worse in small communities, regardless of organisational form. The managers of five out of six large organisations interviewed in **Paper II**, with 70,000–170,000 inhabitants, and three out of six managers of large organisations in **Paper III**, namely Luleå (population 78,487), Jönköping (142,630) and Västerås (155,858), felt that shared responsibility with other administrations was a major challenge when it comes to managing rainfall.

The small municipalities of Arvika (25,826 inhabitants), Värnamo (34,030), and Ängelholm (43,030) (**Paper III)** had no problem sharing responsibility. In Värnamo this was partly because the investment budget was covered by the collective tax. In Arvika and Ängelholm this was partly because they both formed an interdisciplinary group – known as "the technical staff" in Arvika and "the climate adaptation group" in Ängelholm – working across organisational boundaries and spanning many disciplines. This again shows that applying the concept of SIUWP and L-T UWM and planning for climate adaptation depends not only on access to technical solutions, but also on understanding how to manage them (Van de Meene 2011).

Jönköping's stormwater management group has not yet found a common line, and Jönköping (142,630 inhabitants) still finds shared responsibility with other administrations to be a major challenge, even though Jönköping is one of only four out of 184 organisations in Sweden that have rated the parameters CA and FS as green in SI. As noted in (Cettner 2013, Glaas 2018), this is mainly because climate adaptation planning is poorly regulated in Swedish national policy and is therefore mainly applied by individual water utilities. Consequently, the urgent need for clearer legislation is enormous.

The lack of clarity of roles and responsibilities and the fact that each municipal department has its own budget, interests and responsibilities, makes cooperation between them difficult (Sörensen 2018) and the major challenge is to overcome the institutional barriers that exist between the different municipal departments (Stahre 2008, Sörensen 2018). The unclear conditions and requirements for the division of responsibilities also create uncertainty about who is responsible for developing the action plan and who will finance the actions once an action plan is in place (**Paper II**); this hinders the development of an action plan, which is the main reason why only 2 per cent of the 184 municipalities are green in the CA and FS parameter.

5.6 The challenges with legislation

The WW fees should only be used to fund the work for which the WW organisation is responsible (30 years rainfall as maximum) (see Section 2.11), and tax revenues must be used by other administrations for the actions for which they are responsible to protect the communities from severe consequences and flooding caused by torrential rain. The factor that is mainly responsible for the inadequacies and red score of "status of WW fixed facilities" and "CA and FS" parameters is money. This became clear and was underlined by the respondents' complaints about shortcomings in legislation and the need for reinvestment funds (**Papers II, III** and **IV**).

The importance of clarifying the division of responsibilities for dealing with torrential rains in legislation was emphasised to provide clear incentives for the work so that it does not depend solely on individual commitment. The lack of clear legislation regarding the division of responsibilities is also a barrier to creating an action plan, as it is unclear who will be responsible for developing the action plan and who will fund the actions once the plan is in place.

Other challenges that were mentioned were overlaps in the legislation, in the Environmental Code and the Water Services Act, and gaps in the legislation regarding stormwater management.

The shortcomings in the use of investment funds were highlighted in **Papers II** and **IV**. The need to establish reinvestment funds was the greatest desire, repeatedly expressed by most respondents in **Papers II, III** and **IV**).

5.7 Challenges that could be overcome with strategies.

In **Paper IV**, many success factors and explanations for improving the status of WW facilities were presented, and managers pointed out several valuable strategies that have helped them achieve their excellent results and overcome some challenges, such as the challenge of strong growth and the construction of many new buildings. This resulted in renewal work being less of a priority and access to contractors becoming a major issue. In Arvika (which has a population of 25,865), 1 per cent of replacement costs per year were set aside for reinvestment, making it economically independent of expansion work and the economic challenges. An accurate estimate of the total cost of replacing WW facilities can also help companies determine their budget for reinvestment at a given replacement rate. Arvika also became independent of the availability of contractors and labour by using its own employees, workers and machinery. Ronneby (population 29,346) also had a loose budget strategy, meaning that money is not tied to a specific project, but investment funds can be transferred to other projects where they are needed. This is complemented by the extensive use of digital technology and the technique of replacing a longer section of pipeline from valve to valve when there are multiple leaks in a pipe, rather than just patching and repairing. All of these strategies have helped Ronneby achieve a 1.3 per cent replacement rate in water main, which is about 0.6 per cent above the established rate in SI. Some other examples include the challenges of sharing responsibility **(Paper III)**. Arvika, Värnamo and Ängelholm had no problem with this. In Värnamo, this was partly because the investment budget was covered by the collective tax, while in Arvika and Ängelholm it was partly because they both formed an interdisciplinary group, “the technical staff in Arvika” and “the climate adaptation group in Ängelholm”, working across organisational boundaries and encompassing many disciplines.

6 Conclusion and further studies

This work evaluated the use of the SI tool through eight case studies **(Paper II)** to show, among other things, how strategies were developed to address shortcomings in WW operations. In addition, the performance and successes of some water utilities were presented **(Papers I, III,** and **IV)** in the following three areas where the majority of water utilities have deficiencies: (1) developing long-term planning **(Paper I),** (2) improving climate adaptation and flood security (**Paper III)**, and (3) improving the status of WW fixed facilities (**Paper IV)**. The goal was to show how these utilities have made progress in improving their operations towards sustainability and how they are meeting future challenges.

It was concluded that:

1. The role of driving and visionary managers has been critical and a clear success factor in all processes and studies.
2. Investment in quality and innovative technology were essential for developing long-term sustainable projects (**Paper I**).
3. Interviewed organisations believe in the SI tool and agree that SI has good potential but did not use their results as much as they would like.
4. WW organisations need a complete picture when using their results for discussions with policy makers or for benchmarking with other organisations. Therefore, they should be enabled to produce a more informative report of their results from the VASS system.
5. The result should be mapped more clearly and give a better overview of the current situation and developing trends.
6. To produce a more meaningful report, one suggestion might be for SWWA to ask participating WW organisations in SI to evaluate the results of their parameters with weighting limits when they conduct the survey, so that the results can be presented in the same way as in Figures 5, 10 and 11. The method has been used and explained in **Papers II, III** and **IV**.
7. Another recommendation is that SWWA mention in its national annual report the organisations that have made improvements and, if possible, explain how these improvements were implemented to inspire other organisations.
8. The small municipality can succeed with excellent achievement if it has active ownership and drive managers who dare to do things. Arvika, Ljungby, Ronneby, Värnamo and Ängelholm are examples of successful organisations.

9. Forming interdisciplinary groups in Arvika and in Ängelholm had a positive impact on the challenge of shared responsibility to manage rainfall, but the group in Jönköping needed clearer legislation to overcome the problem.
10. Värnamo managed the problem of sharing the responsibility by using collective tax to cover the investment budget.
11. The large amount of fees revenue in large communities can have an impact on success, but perhaps in conjunction with the presence of a driving manager and an organisation with active ownership. Västerås, Jönköping, Umeå, Växjö, Luleå and Mölndal are examples of successful large WW organisations.
12. The success in improving the status of WW-fixed facilities (**Paper IV**) required the organisations to have strong willingness to achieve their goals and be able to deal with changing economic, environmental, and demographic conditions.
13. The success (**Paper IV**) also required the use of digital technology and considering a life-cycle perspective in organisations' renewal measures to ensure that their facilities remain functional throughout their life as an indicator of sustainability.
14. Political support in the form of investment funds and implementation support was key to success and a crucial factor in the development of improvements.
15. There is a link between long-term sustainability and active demands to raise tariffs.
16. Clarifying the divisions of responsibility in legislations is needed in order to create clear incentives for work so that it does not depend just on the commitment of the individual.
17. Clearer legislation is needed in order to help WW organisations solve the major challenge of cooperation and shared responsibility with other administrations when it comes to managing rainfall.
18. The lack of clear legislation in the division of responsibilities for dealing with torrential rains is also one obstacle for the creation of an action plan (**Paper II**), in addition to other reasons mentioned in **Paper III**.
19. The need to establish reinvestment funds was the greatest desire repeatedly expressed by most respondents in **Papers II, III** and **IV**).
20. The large loans that the organisations have represent a significant risk, since an increase in interest rates would mean a sharp increase in fees, which increases injustice.

The approach used in this work to study the water utilities is mainly characterised by a qualitative approach. However, there are also some types of a quantitative approach.

The water utilities studied in this work were mostly case studies in their real-time context. All of the case studies conducted were designed as holistically embedded multiple-case designs that included more than one unit of analysis.

Although **Papers I, III** and **IV** included only one unit of analysis (the FWS project in **Paper I**, the parameters “CA and FS” in **Paper III**, and the parameter “status of WW fixed facilities” in **Paper IV**), a deep understanding of these phenomena was required and achieved, so these can be considered as multiple-case designs.

In addition, multiple WW organisations were selected to be interviewed and analysed in depth. which increases the possibility of generalisation, although it was time-consuming. We were not able to accommodate all the themes we had in our interview guide in the results of the study. For example, in **Paper IV** we had to exclude some parts of the impact of the economy due to the scope of the topic, even though we had received interesting responses from the interviewees. However, we had explained parts of what was excluded in **Paper IV** in **Paper II**. We could have selected a medium number of case studies (WW organisations), but in order to be able to generalise the results, we decided to interview all of them.

We could have selected a smaller number of topics to answer our research questions, but we also chose to study multiple topics to fulfil our purpose and achieve the deep understanding we sought.

6.1 Further Studies

Complementary studies should be conducted to examine the technical and concrete measures applied by some of studied good learning examples of climate adaptation and flood resilience to achieve practical benefits at the local and international levels.

In addition, a number of “Swedish Public Investigations” (SOU) on stormwater management have suggested changes in legislation and indicated that clearer stormwater legislation is needed (Regeringskansliet 2017). The WW manager in Jönköping emphasised that the government still has not found a solution and that this has been the case for several years **(Paper III**). Further investigation of the current legislation is needed, focusing on all the difficulties and shortcomings mentioned above. In addition, it should be investigated how current legislation in countries such as Denmark or Norway deals with this important issue.

Investments and reinvestments in WW infrastructure are both financed by depreciation, surpluses and interest-bearing loans. Depreciation and capital costs in the form of interest and amortisation are thus financed through the water utility’s operating budget; that is, WW charges (Svenskt Vatten 2020). In **Papers II, III** and **IV** it was stated that the high loans that the organisations have represent a significant risk, as an increase in interest rates would mean a sharp increase in WW charges, which would also increase inequity. At the time of writing, society has seen an increase in current interest rates from about 1.5 per cent to over 4 per cent, and further increases are expected in the coming year. The impact on reinvestment and the collective should be further explored in future research.

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About the Author

NASIK NAJAR is a Swedish (of Kurdish origin) specialist in the field of water management. She has been a senior lecturer at Jönköping University for 12 years. She was also a lecturer at Linnaeus University for 10 years. At both universities, she taught the following subjects: water and wastewater engineering, fluid mechanics and soil mechanics. She also worked for more than 10 years (1987–1999) at the multi-utility company "Tekniska Verken in Linköping AB") as an independent water and wastewater engineer, designer, investigator, and planner. She also worked for five years as a civil engineer in Baghdad and Beirut and two years as a water supply engineer in Damascus.

She studied and researched in parallel with her work and received a Master of Science (1997) and a Technology Licentiate (2010) from the Royal Institute of Technology (KTH) in Stockholm, Sweden.

Nasik started her PhD at Water Resources Engineering, Lund University, in 2019.

Nasik's PhD research focuses on analysing the performance and sustainability of Swedish water utilities in the context of long-term planning, climate adaptation, flood resilience, and the condition of water assets.

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