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Status improvement in water and wastewater fixed facilities: Success and challenges of 11 Swedish water utilities as case studies

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ABSTRACT

Reinvestment in water and wastewater (WW) facilities is a challenge for Swedish water utilities. Nationwide, 4% of 184 organizations meet the requirements for a sustainable WW facility status according to the sustainability index (SI), the Swedish benchmark system. Eleven Swedish municipal WW organizations that had improved the status of their facilities were examined and are presented as good learning examples. Managers/strategists of nine of the organizations were interviewed in depth. Our aims were to concretize the used strategies and to clarify success factors and challenges, as well as to support WW organizations that want to improve their results. The nine surveyed organizations showed a clear desire to move toward sustainability. For example, setting aside 1% of the whole replacement value per year for reinvestment (which is embedded in the policymakers' business plan) and the use of its own staff for construction work significantly aided the Arvika company's goals. All organizations were found to have a 10-year plan for renewal at the strategic, tactical, and operational levels. Five organizations that had made more significant progress also had more specific 3-year plans and were linked to robust economies. New investments came at the expense of reinvestments because all municipalities are expanding.

Key words: Reinvestment, Renewal, Sustainability index, Swedish water utilities, Water and wastewater facilities

HIGHLIGHTS

- Decision-making process and a flexible budget are an explanation for the success of Ronneby.
- The business plan is a success factor for the organization in Umeå.
- A political decision on a renewal plan is a success factor in Mölndal.
- The lack of possibility to create reinvestment funds is a financial challenge.
- Prioritizing between renewing existing pipelines and building new ones is also a financial challenge.

1. INTRODUCTION

Investing in the wastewater (WW) business is about reinvesting to maintain status, add new connections, expand capacity as needed, and meet various requirements (Svenskt Vatten, 2020a). Historically, the first expansion of municipal WW systems in Sweden took place in the 1950–1970s with the help of government grants. Fixed assets have often depreciated faster than they have been replaced. This means that current subscribers pay less than the real cost of providing water and WW infrastructure to their municipalities (Svenskt Vatten, 2020c). This is because fully depreciated assets that are still in use do not contribute to financing investments. The average depreciation period for the pipeline network is 53 years. Also, depreciation periods of up to 80 years occur (Haraldsson, 2019). Also, actual useful life is generally over 70 years (Malm & Svensson, 2011). According to the study by Mårtensson *et al.* (2018), the WW pipe systems installed today should have a service life of at least 100 years.

Thus, the WW infrastructure functioned for several decades under advantageous conditions with long service life, competent operating organizations, low fees, and satisfied users (Svenskt Vatten, 2020a). Operational problems in the form of supply interruptions or unusable water are uncommon in Sweden (Svenskt Vatten, 2015), and WW services consistently rank high in various citizen satisfaction surveys (Sveriges kommuner och Regioner, 2019). The depreciation costs of WW facilities built with government subsidies cannot be financed by fees, since only the posted costs can be covered by fees under the Water Services Act (Svenskt Vatten, 2020a). Thus, the gradual replacement of today's water facilities with new investments will be financed by loans in the usual way. This will require significantly increasing interest costs to maintain today's performance, and WW charges will have to double in today's monetary value over the next 20 years due to the necessary investment increases (Svenskt Vatten, 2020c). The infrastructure in Sweden currently includes 197,000 km of municipal water and WW pipelines, as well as about 1,500 water treatment plants (WTPs) and 1,600 wastewater treatment plants (WWTPs) of various sizes (Svenskt Vatten, 2021b). The replacement cost of the WW infrastructure is estimated at SEK 820 billion for all parts of all assets. This corresponds to approximately SEK 80,000/inhabitant (Svenskt Vatten, 2020a).

Most facilities that are 'out of sight' and therefore less noticed by the public than other forms of infrastructure have a direct impact on the economic vitality of the state (Collins, 2014). An ageing infrastructure poses a major challenge for the state because it suggests uncertain future development, which requires important economic decision-making (Urich & Rauch, 2014).

Reinvestment in the existing WW infrastructure has not been able to occur at the required rate because the organizations are not designed for the higher rate of required investment (Svenskt Vatten, 2020a). The WW organizations were designed at a time when the investments were already made, and the focus since then has been on operating the facilities (Svenskt Vatten, 2020c).

As a result, tariffs will have to be significantly increased in the coming years. However, a tariff is not an implemented measure; it is only a consequence of them. Tariff increases in recent years have been far too low in relation to investment needs for long-term, robust WW operations (Svenskt Vatten, 2020c).

Several municipalities in Sweden need to review their investment needs and establish investment plans for long-term, sustainable WW management. The need to invest in ageing infrastructure and build a future-proof urban water management (UWM) system also applies to municipalities worldwide (Pot, 2019).

A network's pipelines must be tight to function properly. If they are leaky, leakage (additional water) can occur, increasing the load on the networks and treatment plants and thus causing basement flooding (Lidström, 2020). Overloaded WWTPs with insufficient capacity and thus inadequate treatment are another consequence of such extra water (Damvergis, 2014). Leaks can also cause fill material around the pipeline to enter the network and clog it, as well as undermine the surrounding soil and cause landslides (Lidström, 2020). Inflowing groundwater and rainwater thus lead to failures of hydraulic capacity (Malek Mohammadi *et al.*, 2019) and dilute contaminated water, leading to a greater need for overflows. Both overflows and WW leakage into the natural environment are further important consequences of leaking, cracked, and crushed pipes in a deteriorating pipeline network that can lead to enormous environmental consequences. WW that leaks from a piping system can contaminate both groundwater and surface water. According to Schleyer *et al.* (1991), approximately 300 million m^3 of WW leaks into groundwater in Germany each year. The effects of pollution can last a long time over several generations because groundwater moves slowly (Commission, 2008).

A lack of proper renovation and maintenance leads to the reduced performance of water and WW systems (Damvergis, 2014). The renovation and repair of WW systems represents a significant investment for WW administrations (Kaushal *et al.*, 2020). Moreover, it guarantees the proper proactive maintenance of the network and prevents many problems, thus protecting the environment (Malek Mohammadi *et al.*, 2019). According to Section 10 of the Swedish Water Services Act, water supply systems must be managed so that they continue to perform their intended function in a sustainable manner. Achieving this requires long-term financial and resource planning and thinking to ensure preventive maintenance (Svenskt Vatten, 2021b).

WW operations in Sweden are investing in a more sustainable society in many ways through their core business. Swedish water services are also linked to many of the global Sustainable Development Goals, and they are supposing Sustainable Development Goal number 6 'Clean water and sanitation for all' as their own local goal (Kvarnström *et al.*, 2021). In addition to other common metrics for WW operations, the sustainability index (SI) is used as the dominant benchmark tool to steer WW businesses toward sustainability in both the short- and long-term (Kvarnström *et al.*, 2021). The SI was developed in 2014 by the Swedish Water and Wastewater Association (SWWA) and is applied via an annual survey answered by participating WW organizations. It consists of 14 parameters that represent three sustainable pillars. Each parameter has a series of questions, for a total of 82 questions (Najar & Persson, 2021).

The questions reflect links between WW activities and the corresponding national and EU requirements, as well as links to the global Sustainable Development Goals via the corresponding sub-goals of the 2030 Agenda (Svenskt Vatten, 2021a). The parameters and questions in SI are also linked to nine other Sustainable Development Goals-SDG 2030 (Svenskt Vatten, 2021a). Based on the responses to the questions, the results are assessed as green when sustainability requirements are met, yellow when sustainability should be improved, and red when sustainability needs to be addressed. Individual parameters are scored by weighting the color index of the results to the questions associated with the parameters (Svenskt Vatten, 2015).

The national results of the 2020 SI showed that 84% of the total 184 participating municipalities were classified as red and only 4% (seven out of 184 organizations) were classified green for the 'status of WW facilities' parameter (Svenskt Vatten, 2021a). Municipalities thus require major investments 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). Growing populations and changing settlement patterns, along with a great need for infrastructure renewal, have changed the conditions for municipalities (Jonsson & Thomasson, 2019). However, this situation has led municipalities to invest much more in expanding WW infrastructure to accommodate growth than in renewing WW systems (Malek Mohammadi *et al.*, 2019). Renewal and maintenance R&M and improvement works in the 'status of WW facility' parameter (as well as in other ongoing areas) vary, and all municipalities have different conditions for carrying out their works (Svenskt Vatten, 2021a). One reason for the differences in WW organizations' sustainable development is the freedom that organizations have in planning WW activities according to the Municipal Act (SFS 2018: 1350) (Najar & Persson, 2021). The size, area, and geography of municipalities can also lead to different difficulties in WW organizations' sustainable development (Svenskt Vatten, 2021a).

Thus, there is a need to both highlight some municipal WW organizations 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. In this study, 11 WW organizations were selected with the goal of examining, analyzing, and using them as good learning examples. The primary aim was to show how these organizations have improved their facility status by concretizing the organizations' working methods, planning tools, and strategies, as well as clarifying success factors and challenges. Another aim was to support WW organizations in Sweden and abroad that want to improve the status of their WW facilities. The study was guided by the following research questions: (1) What are the SI results of the parameter 'status of WW facilities' for the studied organizations? (2) What strategies have the studied organizations used and what factors have been crucial in implementing improvements? (3) What challenges have they encountered and how can they be minimized? (4) How far have they come, and can they maintain a sustainable rate of renewal?

2. MATERIALS AND METHODS

This section explains the research strategy approach and how the research method, i.e., the multiple-case studies, was planned and conducted. It also describes the data collection techniques used, i.e., literature reviews, document analysis, and interviews. The section also introduces the structure of the study and explains how the study is presented.

2.1. Survey strategies and methods

The research approach used for this study was case studies because case studies are appropriate when a deeper understanding of a situation or event is sought. Eleven water utilities were studied in their real-time context. This means that it was possible to make direct observations and analyze the causes and effects of the issues studied (Säfsten & Gustavsson, 2021). The study was embedded as a multiple-case design as it included multiple contexts (Yin, 2018). The context was 11 water utilities studied as good learning examples. An advantage of a multiple-case design is that it is possible to compare different cases, and it also increases the possibility of generalization (Yin, 2018). The approach used to identify the reality of water utilities – is mainly characterized by a qualitative approach: interviews, document analysis, and literature studies.

To select good learning examples between WW organizations, we needed help from the SWWA. The SWWA acts as an umbrella organization for municipal WW organizations and gathers information about its members through a static database (VASS) and an SI survey – the Swedish benchmark system. All members feed their data into the VASS database and SI survey, and the SWWA can access their results.

In a letter to the SWWA, we stated our intention to conduct a study of WW organizations that have improved their WW facility performance and could be presented as good examples of water management at the national and international levels. In its response, the SWWA proposed 12 organizations. They were of different organizational forms and sizes. We contacted the selected organizations with a digital letter. In the letter, we explained the idea, purpose, and goal of the study and asked them if they wanted to participate as good examples and contribute not only their experiences and explanations of their success but also the challenges they had faced. We also explained that we would conduct in-depth interviews with them and additionally asked them for their annual SI detailed evaluation documents if they agreed to participate in the study. Eleven organizations responded positively and provided their annual SI detailed evaluation documents for all years in which they participated in the survey.

We received a total of 58 documents from 11 organizations. The documents were examined, and the results for the 'status of the WW facility' parameter were compiled in tables and charts at both the query and parameter levels. The improvement trends in the organizations' performance for the studied parameter were compiled in line graphs for all years in which the organizations participated in the survey. Managers/strategists from nine of the 11 organizations were interviewed in depth. Responses were compared to each other, the organizations' reported results from the SI detailed documents, and the national SI results.

In summary, the empirical data for the study was obtained through the literature review (Section 2.2). It was conducted to provide a theoretical framework, write the introduction, and prepare the interview questions. Thus, the literature studies (Section 2.2) include (subsection 2.2.1) a literature review on the renewal and maintenance (R&M) of WW pipeline networks and (subsection 2.2.2) a description of the condition of WW facility status in the SI survey. Further data were gathered from 11 case studies (Section 2.3), i.e., via the analysis of the 58 SI detailed evaluation documents for the 11 studied organizations (subsection 2.3.1), and through interviews with WW managers and strategists from nine organizations out of 11 (subsection 2.3.2).

Section 3 presents the results, analysis, and discussion of the study. To illustrate the comprehensive results and analysis of nine case studies, Section 3 is divided into four subsections: 3.1, 3.2, 3.3, and 3.4. Subsection 3.1 presents the SI results and trends for the 'status of WW facilities' parameter. Section 3.2 presents the strategies and explanations for the success of the organizations studied. To better understand the results of this study, the strategies used were divided into several categories, which are presented in the following subsections: 3.2.1, 'Application of Renewal Plans at Different Levels'; 3.2.2, 'Application of Life-Cycle Perspective to WW Investments'; 3.2.3, 'Application of Digital Technologies'; and 3.2.4, 'Other Strategies and Success Factors.' Section 3.3 presents the challenges during the organizations' development journey. Section 3.4 presents the renewal rate, its calculation, and replacement costs.

2.2. Literature studies

This section presents the background material that, along with other methods of data collection, is necessary to answer the research questions and partially support the results of the study.

2.2.1. Renewal and maintenance (R&M) of the WW network

The deterioration of a WW network can be divided into two main groups: lack of capacity and poor structural conditions (Lidström, 2020). Problems with the structural conditions of pipelines are due to many factors such as pipe material, groundwater, and soil moisture causing corrosion, external load, temperature, and construction work (Lidström, 2020), and all these factors are aggravated by the age of the pipes (Opila, 2011; Malek Mohammadi *et al.*, 2019; Lidström, 2020).

There are two types of maintenance in WW networks: remedial maintenance and preventive maintenance. Remedial maintenance is reactive maintenance, and preventive maintenance is proactive maintenance (Svenskt Vatten, 2021b). In addition, the term corrective is used for the reactive type of maintenance, and the term aggressive preventive is used for proactive maintenance (Damvergis, 2014). Reactive maintenance always results in poor system performance, especially as a system ages (Damvergis, 2014). In a proactive maintenance culture, analysis, renewal, improvements, and long-term planning are a large part of the work and culture (Svenskt Vatten, 2021b). Preventive maintenance programs should therefore be applied by WW organizations to maintain WW systems, meet specific requirements, and protect the environment (Damvergis, 2014).

Both renewal and maintenance are integral parts of the asset management of WW operation and include policies, goals, strategies, and plans for managing WW assets, so they comprise a structured way of working to optimally manage assets over their lifetime (Svenskt Vatten, 2021b).

To assess longer-term renewal needs, one needs to know what one has (Malm & Svensson, 2011), and information about a network, recorded in a database, can be considered a prerequisite for planning effective renewal work (Malm *et al.*, 2011). In addition, collecting cost statistics from a number of different projects can provide decision support for planned budget work and can be used to evaluate the cost of future projects (Malm *et al.*, 2011). The use of geographic information system (GIS)-based databases is recommended for data inventory and management. In a GIS, multiple layers of data can be simultaneously linked, updated, and analyzed (Malek Mohammadi *et al.*, 2019).

Effective renewal planning should include a renewal strategy and a specific action plan that, among other things, forms the basis for the annual budget. A renewal plan should also include a current situation analysis consisting of three basic pillars: a description of the facility, a condition assessment of the facility, and a gross needs list that is adjusted to form a priority list (Svenskt Vatten, 2021c). The renewal strategy, in turn, provides an estimate of long-term renewal needs, staffing requirements, the basis for the annual budget, and costs, including capital costs (Svenskt Vatten, 2021b).

Several models have been developed to identify pipelines that need renewal and maintenance (Malek Mohammadi *et al.*, 2019). By using information from databases and an appropriate mathematical technique, conditions regarding the deterioration or remaining life of pipelines can be predicted (Malek Mohammadi *et al.*, 2019). The accuracy of model prediction depends on the choice of a proper modeling technique for pipeline deterioration (Tran, 2007; Malek Mohammadi *et al.*, 2019).

Therefore, the availability of pipe inspection and soil data is the basis for model development. Unfortunately, most cities and agencies do not have an integrated database with all the required information, and available databases are usually subject to uncertainties and missing values (Salman & Salem, 2012). Therefore, there is a great need for systematic documentation of damage to existing WW networks with mandatory reporting of malfunctions directly to the water utility map database to support intelligent renewal planning (Mårtensson *et al.*, 2018).

The prediction of expected renewal needs was calculated in a 2009 study using the Long-Term Planning-s (LTP-s) tool. The tool was developed as part of the EU project Care-W (Sægrov, 2005). The results of the study showed that the renewal rate for water pipes and WW pipes should be 0.7 and 0.6% of the total length respectively or the replacement cost of the entire network. However, since the study was conducted, the renewal rate has remained at about 0.4% (Malm & Svensson, 2011).

2.2.2. 'Status of the WW fixed facilities' parameter

The 'status of WW fixed facilities' parameter is one of 14 parameters in the SI survey that belong to the basic pillar 'sustainable resources'. It 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 (Najar & Persson, 2021). The studied parameter is described in the SI with nine phases over nine questions (Rs1–Rs9) that can be used by municipal WW organizations 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) address the existence of a financial forecast, a multi-year budget and long-term financial plan for capital expenditures, and a plan for pipeline network replacement needs over the next 10 years (Supplementary material, Table S1 in S1). Supplementary material, Table S1 shows the questions (Rs1–Rs9) and the states of green, yellow, and red for the 'status of WW fixed facilities' parameter.

Water supply networks and WW 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 much about the condition of water pipes (Rs4). For a WW network, conditions are best assessed based on not only comprehensive television inspections but also operational problems and maintenance needs (Rs6). For WTPs and WWTPs, there is no established method to assess reinvestment needs. Instead, a separate assessment is required (Supplementary material, Table S1). 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, i.e., a water supply network is assessed as green if Rs4 is green and Rs7 is green or yellow (Svenskt Vatten, 2020b).

2.3. Case studies

Municipalities in Sweden are divided into three main groups according to the municipal grouping in 2017. These groups are Group A for big cities, which applies to municipalities with at least 200,000 inhabitants; Group B for larger cities, which applies to municipalities with at least 50,000 inhabitants; and Group C for smaller cities, which applies to municipalities with at least 15,000 inhabitants In addition, there is a group of 123 municipalities with less than 15,000 inhabitants of which 73 municipalities have less than 10,000 inhabitants (Sveriges kommuner och Regioner, 2021) The 11 WW organizations selected for this study belong to the two most common groups of importance in Sweden, i.e., Groups B and C. This is because they represent most municipalities in Sweden, namely 173 out of 290 municipalities, while group A includes four municipalities. The selected WW organizations are located in 11 different municipalities and 10 different counties and each county consists of a number of municipalities (Världens Häftigaste, 2021).

The organizations were selected in consultation with the SWWA, based on the performance of organizations in the SI survey. The intention was to propose several organizations that had set good priorities and had succeeded in improving the status of their facilities. The selected organizations that met the requirements happen to belong to groups B and C.

The 11 municipal organizations that were surveyed in this study, as well as their locations on a Swedish map, and the counties in which they are located are shown in Figure 1.

Four of the selected organizations are in municipalities of Group C, smaller cities: Arvika (25,865 inhabitants), Ljungby (28,521), Ronneby (29,346), and Ängelholm (43,030). The remaining organizations are located in municipalities of Group B, larger cities: Mölndal (68,152), Luleå (78,487), Växjö (94,884), Umeå (130,224), Jönköping (142,630), Västerås (155,858), and Linköping (164,684). For an overview of the type, associated municipalities, and population of the studied organizations, see Supplementary material, Table S2 in S2. Further information about the case studies was not considered particularly valuable to the study. The selected communities were studied in two steps. In the first step, we compiled all 11 communities' results from the detailed SI evaluation documents (Section 3.2.1). In the second step, we interviewed VA managers/strategies in these organizations (Section 3.2.2).

2.3.1. Detailed SI evaluation documents for 11 studied organizations

The detailed SI evaluation documents include all 14 parameters of the SI survey, the associated questions, and the organizations' responses to all questions for each year in which the organizations participated in the survey (Najar & Persson, 2022). They also show the rating of each question based on the conditions given in Supplementary material, Table S1 in S1. A green rating is assigned if the requirement is met, a yellow rating is assigned if compliance needs to be improved, and a red rating is assigned if action needs to be taken. A total of 58 documents were submitted by the 11 surveyed communities. The number of years the organizations participated in the SI survey varied; Ljungby participated in 2020, Ängelholm participated in 2017–2020, Ronneby participated in 2016–2020, and the remaining eight organizations participated in all years, i.e., from 2015 to 2020.

Thus, the results from the 58 reports were compiled for the 'status of WW fixed facilities' parameter, the focus of this study (Figure 2). The results of the studied parameter were generated with a weighting method. The weighting limit (WL) was calculated to assign a weight of 2 to each green response to the questions, a weight of 1 to each yellow response, and a weight of 0 to each red response (Najar & Persson, 2021). Supplementary material, Figure S1 in S3 illustrates the color index scores for all questions in the 'status of WW facilities' parameter for 2020 for all participating 11 municipalities. The calculated weighting limits for the 'status of WW facilities' parameter are also shown in the second row of Supplementary material, Figure S1 in S3 for the 11 organizations in 2020. The weighting limits were calculated in the same way for all years in which the organizations participated in the SI survey.

2.3.2. Interviews

Although their WW fixed facility status parameter was scored differently (green, yellow, and red) and their weighting limits for the studied parameter ranged from 1.3 to 2, all suggested 11 organizations were selected

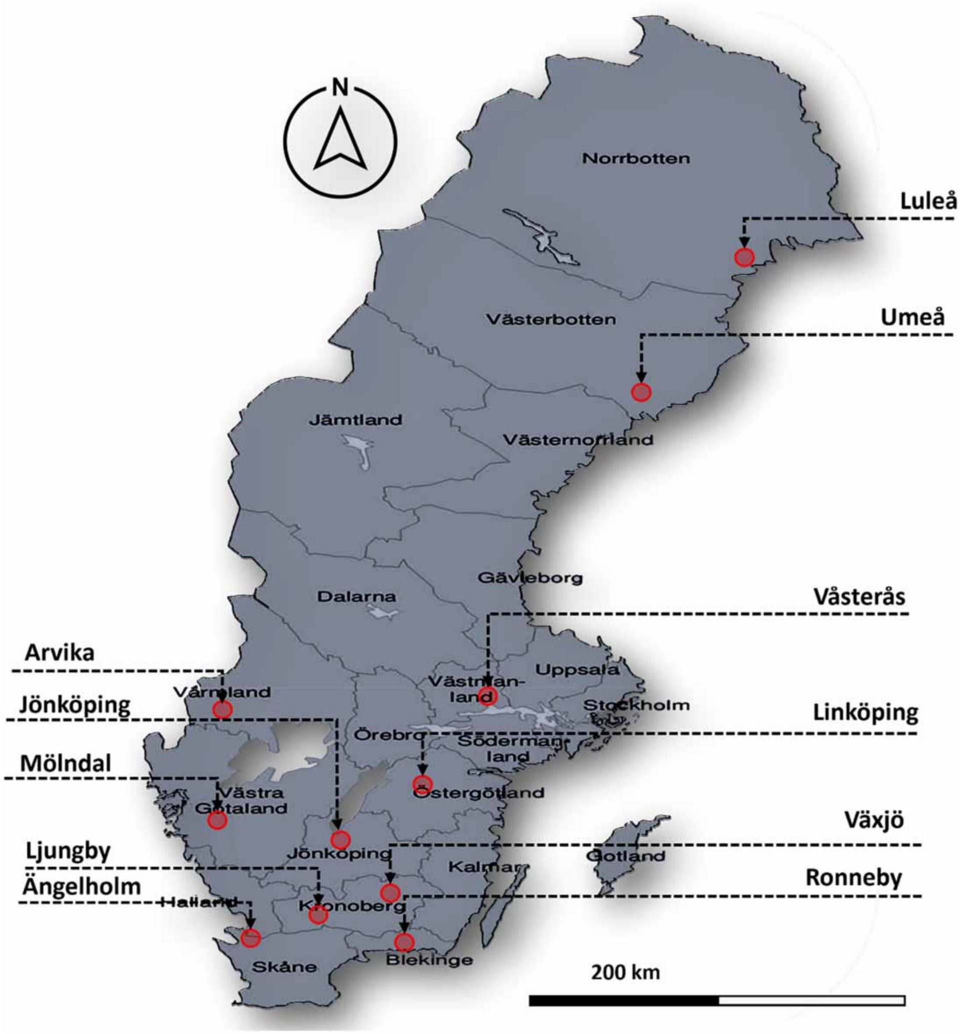

Fig. 1 | Swedish map with all counties and municipalities (●) that were examined in this study.

for interviews. Four of these organizations, namely, Arvika, Ljungby, Ängelholm, and Umeå, had a green rating for the studied parameter with different weighting limits of 1.8, 2, 1.6, and 1.4, respectively. Six organizations were yellow, with weighting limits of 1.3 and 1.4. Växjö, which was assigned a red rating, had a weighting limit of 1.4. However, Växjö was nevertheless selected because five of nine questions were rated green and only question Rs2 was rated red. Supplementary material, Figure S1 shows the results for all studied municipalities in 2020 at the question and parameter level.

Semi-structured interviews were conducted with managers/strategists of nine of the 11 WW organizations in this study. Linköping and Ljungby did not have the opportunity to participate in the interview. Based on the purpose and objectives of the study, the questions were compiled in a file and sent to the managers of the organizations along with a schedule for the interviews. Attached to the file were the organizations' compiled results from the detailed SI evaluation documents at the parameter level (Figure 3) and the question level for

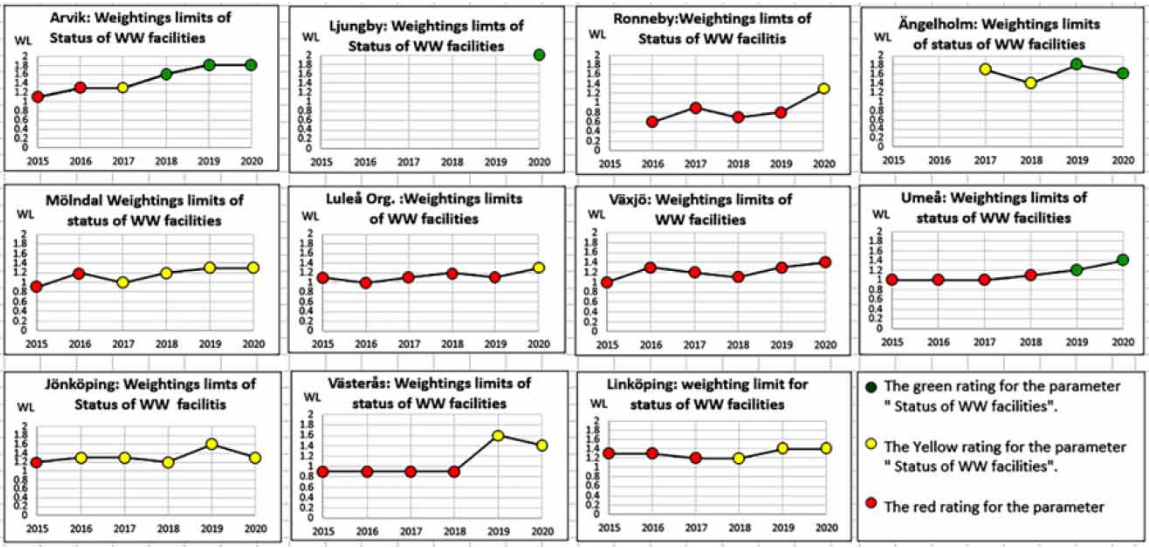

Fig. 2 | Results of the 'status of WW facilities' parameter for all studied WW organizations in 2015–2020.

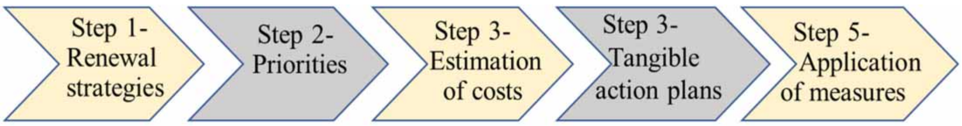

Fig. 3 | The steps of the renewal plan.

the year 2020 (Supplementary material, Figure S1). There was a total of 25 interview questions, as well as follow-up questions. The questions were divided into three topics based on the objectives of the study and the research questions. Many of the interview questions began with a brief background based on collected data from the studied literature and research reports.

Interviews were conducted and recorded in October 2021 via the ZOOM program. They lasted approximately 1 hour per organization.

Supplementary material, Table S2 in S2 provides information on the nine surveyed organizations, including the counties in which they are located, the size of their municipalities, and the type of the organizations. Five of the nine surveyed organizations (Arvika, Ängelholm, Luleå, Jönköping, and Västerås) participated in another survey in a previous study conducted by the same authors (Najar & Persson, 2022) during the same period, in which they also presented good learning examples for sustainable climate adaptation and flood safety.

3. RESULTS AND DISCUSSION

This section presents the results, analysis, and discussion of the study. The section is divided into four subsections (3.1, 3.2, 3.3, and 3.4) to illustrate the comprehensive findings and analyses of the nine case studies. In Section 3.1, the results, and trends of the organizations (SI) for the 'status of WW facilities' parameter are presented. To better understand the results of the study, the strategies used were divided into several categories, which are presented in the following subsections: 3.2.1, 'Application of Renewal Plans at Different Levels'; 3.2.2, 'Application of Life-Cycle Perspective to WW Investments'; 3.2.3, 'Application of Digital Technologies'; and 3.2.4, 'Other Strategies and Success Factors.' Section 3.3 presents the challenges along the organizations' development journey. Section 3.4 presents the definition of renewal rate, its calculation, replacement costs, and the performance of the organizations studied.

3.1. The SI results and trends of the 'status of WW fixed facilities' parameter

The graphs in Figure 2 and Figure S1 in Appendix S3 of Supplementary material show the different performance levels of the studied organizations, 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. The graphs in Figure 2 show that four organizations – Arvika, Ljungby, Ängelholm, and Umeå – had improved their results to the green rating with different weighting limits from 2 to 1.4. Three of the green organizations, namely, Arvika, Ljungby, and Ängelholm, belong to the group of smaller municipalities. These findings are in line with the study by Najar & Persson (2022) that six out of 10 studied utilities had good results with high waiting limits of 1.7 in the parameter 'Climate adaptation and flood security' of which three were small municipalities.

However, the findings are in contrast with the conclusion of a previous study (Malm *et al.*, 2011), in which the authors stated that 'in many smaller municipalities, almost no time is spent on renewal planning because it is difficult to exclude daily work and deal with these issues', and also in contrast to Sörelius & Svensson (2016) who found that small municipalities have difficulty maintaining the good status for WW facilities in the long term and do not have sufficient resources and the necessary skills to accomplish this task. We found that although the large municipalities have better resources in the form of fees revenue and staff, some factors other than size may have a greater impact on the organizations' results. These factors include organizations having active ownership (Najar & Persson, 2021), the role of the manager and significant events such as major floods (Najar & Persson, 2022). Umeå, on the other hand, belongs to the group of larger municipalities, which is in line with the finding of Svenskt Vatten (2020b), that municipalities with more than 50,000 inhabitants scored better and had lower proportions of red parameters than municipalities with less than 20,000 inhabitants. A green rating of the 'status of the WW facilities' parameter means that all conditions for a green score are met and that they have prepared a multi-year budget (Rs1), have a 10-year financial plan (Rs2), and have a plan for the renewal needs of their pipeline network over a 10-year period (Rs3) (Supplementary material, Figure S1 in S3).

The other municipalities of Ronneby, Mölndal, Luleå, Jönköping, Västerås, and Linköping were rated yellow for their results with a weighting limit between 1.3 and 1.4. Växjö lacked a 10-year economic plan (Rs2) to finance renewal needs and was therefore rated red for the studied parameter despite many green ratings for its answers (five out of nine questions). This is in line with the findings of Sörelius & Svensson (2016), that one reason for the high percentage of red scores at the national level is that WW organizations do not meet the financial foresight requirements for investments. Växjö also had a weighting limit of 1.4 (Supplementary material, Figure S1 in S3).

3.2. Strategies and explanations for organizational success

This section presents the strategies that the organizations studied used, the explanation, and the factors that were critical to implementing the improvements.

3.2.1. Application of renewal plans at different levels

Maintenance and renewal plans are usually divided into three levels: strategic, tactical, and operational (Svenskt Vatten, 2021c). A renewal plan can be defined in five steps (Figure 3). At the strategic level, step (1), the goal is to show a long-term direction and maintain a long-term robust economy. The tactical level, step (2), concerns the balancing of different priorities and the prioritizing of actions to be implemented. Both the strategic and tactical levels should be politically decided in a plan. In connection with the budget, in step (3), a decision regarding the action level, i.e., the operational level that is presented in steps (4) and (5), must be made (Mistra InfraMaint, 2020).

Having an approved renewal plan would also help in dealing with politics, according to the interviewed WW strategist from Mölndal, and is in agreement with findings by Sörelius & Svensson (2016).The national SI results for all the years showed that the percentage of municipalities that had a renewal plan and conducted work based on that plan was 15%, which is a remarkably low figure considering that the WW network accounts for about 80% of fixed assets (Svenskt Vatten, 2020a). In this study, five of the 11 studied organizations, namely, Arvika, Ljungby Ängelholm, Umeå, and Linköping, had renewal plans.

Arvika, Ängelholm, and Umeå showed green results for the 'status of WW fixed facilities' parameter. The studied parameter is considered green when Rs1 and Rs2, among others, are rated green (Supplementary material, Figure S1 in S3), meaning that a multi-year budget has been established and a 10-year financial plan in consistent with step 3 in Figure 3 (Mistra InfraMaint, 2020), showing how the identified investment and renewal needs in the WW network and WW treatment plants will be financed is in place. The results of the interviews showed that these three organizations have renewal plans in place and are considering the involved strategic, tactical, and operational levels when creating their renewal and maintenance plans (Figure 3). 'We have a good picture of our renewal needs in at least 10 years,' said the WW manager in Umeå. 'On a strategic level, we have used the renewal plans to develop the tariff so that it is linked to sound finances thus supporting previous findings by Sörelius & Svensson (2016), the development of WW fees for a community is closely related to future reinvestment in WW facilities . On a tactical level, we have a basis for a renewal plan for the different types of lines,' the Umeå manager added. The WW organization has also weighted its different needs regarding the risks and consequences of pipelines, including the number of defects, the age, and the material.

Arvika has a 10-year plan that includes the most important matters. It also has a more specific 3-year plan. The 3-year plan is left to politicians, who only make decisions for the next year. At the tactical level, politicians give them more money each year for certain events. 'For example, we rebuilt the water treatment plant a few years ago, and at that time it cost 50 million over three years,' said the WW manager in Arvika. This is considered an advanced step (step 5 in Figure 3), in connection with the plan or implementation phase and also according to Svenskt Vatten (2021c).

Växjö (green for Rs1 and red for Rs2) (Supplementary material, Figure S1 in S3) also uses the three levels, though mainly the operational and strategic levels. The strategic level concerns policy, budget, and long-term decisions said the WW manager in Växjö. The tactical level is used when the organization feels that it must make a political decision or set priorities. This was also mentioned by the VA manager in Arvika (green for Rs1 and Rs2), e.g., when planning what the Växjö WWTP should look like in 2050. 'This is a very tactical matter, where many decisions have to be made. Then we talk to the politicians about the possible ways we can go,' said the WW director in Växjö.

Like Luleå (yellow for Rs1 and Rs2), the strategist in Mölndal (yellow for Rs1 and Rs2) said that the 10-year strategic plan defines what needs to be achieved based on the age, material, and condition of the pipeline network (Supplementary material, Figure S1 in S3). The tactical level includes prioritization between operational disruptions and pipeline replacement, as explained by Mistra InfraMaint (2020). The plan in Mölndal was developed and politically approved by the board in 2016.

WW organization in Jönköping (green for Rs1 and yellow for Rs2) also followed these levels, according to its manager. Most recently, the organization started financial planning related to strategic work. 'We have received investment funds to do what we can and want to do. But that means that the debt is increasing very quickly. We currently have a loan debt of SEK 1.3 billion. But we have a target that our loan debt will be reduced by 2027 through an action plan,' said the manager of the WW organization in Jönköping.

The action plan includes the following items: (1) Increase consumption fees to increase the allocation to the Investment Fund. (2) Increase connection fees to cover at least the actual cost of installation. (3) Reduce the volume of investment. (4) Charge for services not regulated by the Public Water Services Act, such as sprinkler connections. (5) Reduce costs through smart savings.

The results of the study also showed that the organizations use the operational level through concrete measures that are decided and implemented each year in the investment budget. The company at Arvika, for example, made a policy decision at the operational level to annually allocate 1% of the replacement value for reinvestment and renewal plans. This is in line with the findings of Sörelius & Svensson (2016) who stated that for planning future reinvestment, the replacement value of the municipal WW facilities and the replacement needs for the facilities should be known.

3.2.2. Application of the life-cycle perspective as a strategy for investments in WW facilities

A life-cycle perspective must be considered when selecting and applying renewal measures. A life-cycle perspective for WW investments addresses how maintenance is performed or planned to keep the asset functioning throughout its life. In other words, it is about whether the company has the qualifications to deal with changing economic, environmental, and demographic conditions. In this case, the company must be resilient, i.e., able to deal with change and external pressures (Jonsson & Thomasson, 2019).

The main pillars or dimensions of urban water system sustainability are environmental, economic, and social (Lehmann *et al.*, 2013; Opher *et al.*, 2019). Life-cycle perspective is one of the approaches used to analyze the sustainability of WW systems (Alejandrino *et al.*, 2021). Also, the life-cycle sustainability assessment (LCSA) is a sustainability assessment technique that considers the three pillars mentioned above (environmental, economic, and social) (Costa *et al.*, 2019). The tool used in this study to analyze the short- and long-term sustainability of urban WW systems and thereby the life-cycle perspective is the SI (Svenskt Vatten, 2015). The SI is also based on the three pillars of sustainability and relies on 14 parameters that capture sustainability and 82 questions that explain the parameters in more detail. The three basic pillars are 'Sustainable services for users', 'Environmental sustainability', and 'Sustainable resources'. They take into account the ecological, economic, and social aspects (Najar & Persson, 2019). SI reflects the ambitions and requirements of the WW industry, and WW organizations are the ones ultimately responsible for the assessments made through SI (Svenskt Vatten, 2019).

In this study, the surveyed companies reported that they consider a life-cycle perspective when selecting and applying renewal measures to ensure that fixed assets remain functional throughout their lifespan.

Six out of nine WW organizations, namely, Arvika, Ängelholm, Mölndal, Växjö, Umeå, and Västerås, also reported feeling that they have a strong organization that can handle change. In Mölndal, conscious renewal and reinvestment comprise a large part of this aspect, according to the WW manager, even though there are challenges on the climate side, such as investments in the piping system and so on. But we have included this as a criterion in our renewal plan, i.e. to determine the order in which we should expand the network to be ready for climate adaptation as well, says the WW strategist in Mölndal. Växjö is resilient enough in both facilities and systems. 'But there are always considerations for improvements and investments that we are constantly working with,' says the WW manager in Växjö. Umeå has had a stable system for a long time, but the local population has dramatically increased, almost doubling in the last 40 years. This means that a WW organization should upgrade and replace the pipelines, even if they have not yet reached their technical lifetime. When it comes to demographics, the Ängelholm organization is sizing and building ahead based on the growth of the municipality. They use new techniques and new materials. They use a lot of re-lining, replacing concrete pipes with plastic pipes, which they consider to be denser, lighter, a better working material, and create a better working environment for the workers laying the pipes. Another feature of large diameter plastic pipes used for sewer networks is that they are white on the inside. This is of great importance and allows any defects in the filming to be clearly seen after 50 years. This increases the life-cycle perspective, said WW manager in Ängelholm. The WW manager in Västerås said that they have a requirement to be resilient. Thus, they cope with demographic and economic challenges and invest in the facilities so that they will last in the long term. The WW investigator in Västerås also emphasized that they need to build the piping system so that they can last in the future, because WW systems have such a long-life span. The company in Arvika not only has a strong organization that can handle environmental, and demographic conditions but also economic changes as it has room for tariff increases if it needs more money. 'We could probably handle a lot,' pointed out the WW manager in Arvika.

In Ronneby, Jönköping, and Luleå, however, the situation regarding operation resilience is different. According to the manager in Ronneby, the WW business is rather conventional, and all changes take a long time, which means that it is not very resistant to large or fast changes and therefore not strongly resilient. The interviewees of Jönköping and Luleå also reported that their operations are not yet resilient. However, Luleå is on a good path, according to the manager: 'We are working in this direction and see an upswing. We have started to create structures for reinvestment'.

The manager in Jönköping said, 'It will take a few more years of investment, and we need to balance the economy here, too, so that credit debt does not skyrocket. It will certainly need more tariff increases to reach a reasonable level that balances both the economy and the environment.' The need for investments in Ronneby, Jönköping, and Lulea in one or both treatment plants is the reason why the business is not yet resilient.

3.2.3. Application of digital technologies

Fiber optics can be used to monitor pipelines in real time, and a metal indicator wire can be used to monitor leaks by measuring resistance (Persson *et al.*, 2016). There are a number of different technologies on the market where the technology is built into the wall of the pipeline. In the last decade, digitization has been a growing trend worldwide when it comes to creating smart pipeline networks. A water network according to Davis *et al.* (2013) can be transformed into a smart system that can be monitored from within, with the goal of improving the ability of the WW sector to optimize operations in real time and make more informed decisions about network renewal and maintenance. Measured data can be used and analyzed on a much larger scale than before and smart meters that can sound an alarm at the right time can facilitate operations and reduce the risk of emissions to the environment (Malm *et al.*, 2019). In this study, all nine surveyed organizations reported the extensive use of digital technology for control and monitoring, e.g., flow meters that generate their own voltage, digital water meters, cameras used to monitor wells, and various pressure measurement devices. This is consistent with the statement by Malm *et al.* (2019) that the benefits of digitization are beginning to emerge for the Swedish water network. For example, the WW organization in Mölndal measures flow rates and is considering various ways to use the 'Internet of Things (IoT)'. IOT is a collective term for the development that machines, vehicles, etc. are equipped with small built-in sensors and computers that are able to perceive and communicate with their environment. They also use tools with minds of their own. For example, the organization at Mölndal has installed 50 water meters that can communicate with each other, and 500–600 more are intended to be installed in the city. The organization previously had radio meters. The organization at Jönköping uses digital technology for the operational monitoring of the WW network. This technology is connected to the booster stations and pumping stations. It also has some points in the network used for flow and pressure measurement. There are also plans in Jönköping to collect pressure measurements from the water meters and to analyze this information with software to gather a different view of the leaks.

According to the Ronneby company's director, the WW organization is trying to stay on top of digital technology. 'Technology has helped us a lot. Especially when it comes to locating leaks, for example, or figuring out how much extra water has flowed into certain pipes, which means we can locate such a pipe later to repair it by relining or replacing it.' The WW manager in Ronneby continued, 'Through the water meter, we can see if there is an unusually high consumption in the pipe network and thus locate a leak, or if a property owner has a leak in his house, if it is an unusually high consumption in relation to normal consumption.' This is in line with Malm *et al.* (2019) that the main needs of drinking water networks are to increase robustness by better controlling the functioning of the networks and to reduce water losses. It is also consistent with Laspidou (2014) that digitalization offers great potential to improve WW infrastructure in a cost-effective way. The organization at Västerås also uses meters in its network and is working on optimizing operations. One specific example addressed by the WW investigator in Västerås concerned digital water meters: 'Because we can see what we are using and what we have produced in the different zones, we can, for example, locate leaks and focus on fixing them instead.'

The WW manager in Umeå said, 'We use LoRa meters in sewer systems (wastewater and rainwater), to monitor additional water and overflow water.' LoRa is a radio technology used for collecting meter data that is currently being used in several municipalities. One advantage is that it is easy to set up meters, connect them, and then collect metering data. For example, different types of sensors can be connected together and powered by batteries. The system can have a range of about 10–15 km. The IoT can communicate via this type of platform (Lora-alliance.org, 2023). The organization at Västerås also uses meters in its network and is working on optimizing operations.

All nine surveyed organizations in this study are good examples of digital technology adoption, showing the direction and changing the way they work to create smart pipeline networks, while the WW-sector in Sweden is digitalized to a lesser extent than other industries according to Malm *et al.* (2019).

Eight out of nine studied organizations cited a lack of time and financial resources, as well as a lack of employees with the right skills, as barriers to increased use of digital technologies. However, the WW investigator in Västerås said, 'Time will be replaced in the long run when a lot of data can be obtained via the network, enabling us to analyze values and use them as a basis. This will make it easier for us to make informed decisions about what actions to take.' WW managers in Umeå, Jönköping and Västerås reported seeing the security aspect as a challenge when using digital technologies. They said that many solutions and applications offered today upload data to cloud servers that are often not located in Sweden. That should not happen if the information is secret. 'So, it's difficult to draw a line on what kind of data we can classify as secret and what we cannot. The technology is under development and there will be big changes in the next few years,' said the WW manager in Jönköping. The WW manager in Växjö wondered, 'Are we measuring correctly and interpreting correctly? How do we deal with all the measurement data we get? And do we have a use for everything we measure?' She also said that 'Someone has to take care of everything we measure, and that is sometimes quite an inflation.' The barriers related to security and lack of expertise and finances cited by most organizations are consistent with the findings of the study by Malm *et al.* (2019) which suggested that IT strategic skills, several IT technicians with knowledge of IT security, GIS, automation, and communications need to be recruited in the water utilities. If digitization is used intelligently, it will save costs for water utility operations in the long run.

3.2.4. Other success factors

Other success factors for reinvestments to improve the status of WW were also compiled from the interviews with WW managers. WW managers in Umeå, Växjö, and Västerås emphasized employee engagement. The WW manager in Växjö stated that there has been a lot of focus on the working environment and methodical work to improve the status of the working environment in many ways, which has resulted in a high level of commitment from the operating staff. WW managers in Arvika, Luleå and Umeå emphasized good skills as one of the key factors in line with the results of the study by Haraldsson (2019) which states that access to skills seems to be a key factor for success.

In Umeå, competence and commitment are thus the main probably factors in the company's success according to the manager. 'Competence and education are linked in some way,' the manager said. With the expansion of the city, the company knew that it needed significant developments and therefore resources and competencies were needed. A business plan for Umeå WW was created, and with it, challenges were identified. An estimate of what kind of skills and resources would be needed in the next few years was included in the budget. Then, maintenance and renewal plans were developed considering the needed capabilities and resources: 'Increasing water tariffs became a solution and we have increased the fees for our facilities by 10% annually for the last three years and for the consumption part we have increased 6% for 5–6 consecutive years. Therefore, in Umeå, we have a high tariff for both the consumption and the construction part.' The measure is consistent with the results of the study of Haraldsson (2019) that there is a significant positive correlation between the amount of fees and the amount of investment, as well as the investment result.

One explanation for the success in Västerås is the commitment of the employees, who strategically work while considering the long term. 'We have various plans, but we do not currently have a document that we call a renewal plan. However, we are thinking about creating a concrete document to renew the pipeline network and link it to new investments that need to be made,' said the WW director in Västerås. The company has also proposed additional decisions in the budget for WW operations to receive earmark funds for reinvestment.

The organizations at Växjö, Jönköping and Västerås have worked well in the long term. The head of WW in Jönköping said, 'We have long-term planning in the renewal strategy and the measures we are implementing are very helpful. This has had an impact on the reduction of wastewater stops per kilometer and water leaks per kilometer of pipe, as well as the number of overflows.'

One clear explanation for the Arvika company's success is that it has professionals who have been working for a long time and know their plants well, including where the weak points are. The company at Arvika works with its own management, has conducted significant filming with its own cameras, and has extensive maps in the WW database. In terms of resources, setting 1% of replacement cost for reinvestment was the starting point for moving forward and completing the necessary tasks at Arvika. The fact that the company conducts much of its tasks in-house with its own labor and machinery is also crucial according to the manager. The organization has its own construction managers, pipe layers, and three teams that are basically on the job year-round, though it rents some machinery to complete the work. It does not have to procure any work for projects. 'That's what keeps us going,' the Arvika manager said. Also they overcome the biggest challenge facing many organizations, as the WW manager in Ängelholm explained, 'It's going to be a big problem when more municipalities in Sweden renew and renovate their WW facilities at the same time, where are we going to get contractors from?' he said.

The WW manager of Luleå said that 'the explanation for our success is absolutely the competence and a strategic way to adapt to the current situation.' One 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, said the WW strategist. 'In connection with the plan, we 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. We have also received SEK 56 million for the construction of a large new wastewater pumping station', added the Mölndal strategist.

A fast-decision-making process and a loose budget are among the explanations for the success of Ronneby. A loose budget means that it has a budget that allows it to transfer certain investment funds to other projects. For example, if it decides to invest 5,000,000 in the pipeline network but there is a water leak that requires the replacement of a longer pipe, 'We do not tie the money to the projects, which means we can reprioritize our renewal plan ourselves and make good progress that way,' said the WW manager. The company has also had a significantly high level of expertise in WW for the last 5–6 years, with employees who feel pride in being able to work with WW issues.

The company at Ängelholm like Jönköping and Växjö 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 sewage treatment plant. This shows that the organizations studied work in the long term, in contrast to the national results from SI since 2014, which show that water utilities have deficits in long-term work (Svenskt Vatten, 2020b).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. In Ängelholm, employees who have been working there for at least 15 years or from the beginning have shown strong competence.

3.3. Faced challenges

Different challenges have been faced by WW managers on their way to sustainability. According to the manager in Arvika, politicians who do not understand the technology and do not want to change their minds are a significant challenge, because it is them who make decisions regarding the economy.

The implementation of remediation measures is a challenge because they require a lot of time and cause problems for the population, road users on busy roads, and the economy. The manager in Jönköping said, 'A big challenge is when people think we are digging everything up or when a store gets smaller customers, even though we try to explain and inform why we are digging.' Additionally, if coordination with other pipeline owners (electricity, district heating, and telephone) does not work well, the problem grows, both socially and economically. 'That not everyone goes along and then they come a year later and want to put their lines in the newly laid asphalt after they refused when we asked if we should coordinate,' said the manager in Jönköping.

Another challenge addressed by the manager in Luleå is the difficulty of sticking to construction and priorities. 'We have a lot of growth issues, a lot of new buildings, so the renewal projects are often put on hold.' This is in line with that stated in Svenskt Vatten (2020a) that decisions on new investments in expansion of the network are governed by the legal requirements according to the Water Services Act, while reinvestments in existing infrastructure are entirely based on the principal's decision. When the organization's resources are not sufficient, it is therefore reinvestments that must be held back.

This was also the case in Västerås and Ronneby, though the company in Ronneby has had significant success in renewal (Supplementary material, Figure S1, S3, Rs4, Rs5, and Rs7). This company thus had higher scores than the reported averages shown in Supplementary material, Table S1, Rs5 and Rs7.

The manager at Västerås stated that the issue of finances and priorities is also challenging because there is a financial cap on the entire group. 'There is a cap on how much money we can get each year. So, we cannot get as much as we want to do all the renewals we have planned,' the Västerås investigator said.

This lack of resources, including both time and expertise, to work with the investigations and provide a basis for renewal issues can be challenging.

In Mölndal, the lack of expertise has gradually been addressed by employing engineers and investigators, according to the surveyed manager.

The manager in Växjö also confirmed that the lack of human resources is a major challenge. Access to data that forms the basis for renewal planning can be a major challenge to achieving sustainable results. This is consistent with findings of Salman & Salem (2012) that most of the city do not have an integrated database and by Mårtensson *et al.* (2018) that there is a great need for systematic documentation of damage on existing WW networks directly to map database to support smart renewal planning.

In Umeå, this has been remedied by storing all operational failures and actions taken on the network in the WW database over many years. Information on dimensions and materials of the entire network is also stored there. Furthermore, there is an engineer in Umeå who has been working on the production of the base for several years. Information about the equipment (pumps and all components in a plant) and the efforts undertaken within the plant is stored in the 'Idus' maintenance system for five years, according to the WW manager in Umeå.

Access to contractors is a challenge that is also related to what all the other municipalities in a region are doing at the same time, according to the WW manager in Ängelholm. If contractors are busy with other jobs, the price will certainly go up. 'It's going to be a big problem when more municipalities in Sweden reinvest and renew their WW facilities at the same times, where are we going to get contractors? Who will drive the machines. We do some of the work ourselves, but with our own labour and equipment we would not be able to handle the SEK 800 million of the last 10 years,' said the manager in Ängelholm. The challenges faced by WW organizations are summarized in Figure 4.

3.4. Renewal rate and replacement cost: can the renewal rate be maintained?

The replacement cost of the water and WW infrastructure is SEK 820 billion for all parts of the system. Of this, SEK 680 billion is the replacement costs for pipeline networks, including pumping stations, booster stations, and reservoirs (Svenskt Vatten, 2020a).

Investments in WW infrastructure must be made each year. These include reinvestment to maintain status, new connections for new buildings, climate adaptation, and meeting various requirements. According to a study by Carlsson *et al*. (2017), it was found that municipal organizations will need to invest an average of 16 billion SEK or 1,550 SEK per inhabitant in the period (2018–2027). However, according to a study by Haraldsson (2019), based on real investments for 244 municipalities for the period (2015–2017) and planned investments for the years (2018–2021), the result was higher in both cases than in the study of Carlsson *et al*. (2017). Also, the planned investments for the future were 37% higher (Haraldsson, 2019). Investment expenditures were also estimated at SEK 22.7 billion/year (Svenskt Vatten, 2020a). Of this 56% was for reinvestment, 26% for expansions, 5% for climate adaptation, and the rest distributed among other needs such as increased requirements, adapted infrastructure, etc. Based on the actual renewal needs, expenditure per pipeline meter, the total number of pipeline meters in the country and a general uncertainty analysis, the actual renewal needs of the pipeline network are estimated to be an annual reinvestment of SEK 6.8 billion. This should be compared with the current annual reinvestment in the renewal of the pipeline network of SEK 4.1 billion (Svenskt Vatten, 2020a).

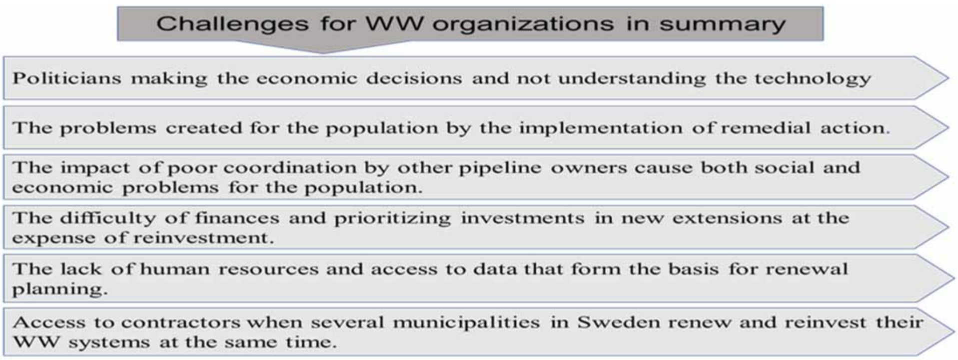

Fig. 4 | The summary of challenges for WW organizations.

The forecast of expected renewal needs was calculated in a study published by Malm & Svensson (2011) using the Long-Term Planning-s (LTP-s) tool. The tool was developed as part of the EU project Care-W (Sægrov, 2005). The results of the study showed that the renewal rate for water pipelines should be >0.7% and for WW pipes >0.6% of the total length (Malm & Svensson, 2011).

The renewal rate in percent = Annual reinvestment/replacement cost of the network.
The age of the pipes in the ground = Replacement cost of the network/Annual reinvestment. Or
The age of the pipes in the ground = the length of the network/length of renewal per year

The replacement cost of renewing the WW pipelines network of SEK 680 billion and the annual reinvestment of SEK 6.8 billion give a renewal rate of 1% and mean that the pipes should remain in the ground for about 100 years before being replaced. This is in line with the requirement that pipes installed today should have a lifetime of at least 100 years (Mårtensson *et al.*, 2018).

It follows that reinvestment in the pipelines network should be either 1% of the replacement value of each municipality or 30% of the investment required in the municipalities, so that the pipes are sustainable and remain in the ground for about 100 years before being replaced (Mårtensson *et al.*, 2018).

In SI, the limit for the renewal rate according to the LTP tool (Sægrov, 2005; Malm & Svensson, 2011) was set at >0.7% for water pipes and >0.6% for sewage pipes (Svenskt Vatten, 2015) (see Supplementary material, Table S1 in S1). This means that pipes must be in the ground for about 165 years before they are replaced (SEK680 billion/SEK 4.1billion), and that reinvestment in the pipe network is set at about 0.6% of the replacement cost (4.1/680). Thus, SEK 4.1 billion is the annual reinvestment for current renewal needs.

This study shows that although Arvika and Ronneby belong to the group of 'smaller cities' (Sveriges kommuner och Regioner, 2021) and are the smallest among the studied participating organizations, the renewal rate in both municipalities was above the limits of SI and averages about 1% (Supplementary material, Figure S1 in S3). The company in Arvika also had a green rating for the 'status of WW facilities' parameter and a weighting rate of 1.8. Arvika and Ronneby are thus exceptions to the conclusions of Malm *et al.* (2011a) that smaller municipalities spend almost no time on renewal planning because it is difficult to work with reinvestment without neglecting day-to-day operations. They are also an exception to the findings of Haraldsson (2019) which showed a strong correlation between small municipalities making lower investments per inhabitant.

Arvika's infrastructure has been determined to have a replacement value of SEK 2 billion for its pipe network. Furthermore, according to its WW manager, Arvika has reinvested about SEK 20 million, or 1% of the replacement cost of the pipeline network, over several years. This is in line with Arvika's business plan, which stipulates that the WW company reinvest 1% of the replacement value and the rest of the investment must be added. The decision is approved by the politician and is valid every year. This means that the pipes will remain functional for at least 100 years, which is in line with what Mårtensson *et al.* (2018) says about the lifetime of pipelines. This strategy is unique and one of Arvika's key success factors. The manager of WW in Ronneby stated that the strategy the company uses for water mains has helped to achieve a high renewal rate of 1.3%. He described the strategy the company uses as follows: 'If we have a lot of leaks in a pipe, we replace a longer section instead of just patching and repairing. Eventually, we change from valve to valve.'. The high level of reinvestment in both Arvika and Ronneby, which have the organizational form of a municipal enterprise, is consistent with the findings of Haraldsson (2019) that there is a strong positive correlation between the choice of the organizational form of a municipal enterprise and the investment outcome and implementation rate. However, the replacement rate in Ronneby will not be maintained at this level, as other major investments in WWTPs and waterworks have priority, according to the WW manager.

The Umeå WW company was also struggling to maintain its renewal rate for three reasons, according to the WW director. The first reason is that the WW business is heavily dependent on the rehabilitation of the city's roads. It is thus uneconomical to renew pipes if a road is not renewed at the same time, according to the Umeå director. 'We do not want to burden the WW collective with laying new asphalt and new superstructures on roads, but that should be financed from public funds. However, we are trying to carry out joint projects with the city's roads and parks department,' said the WW chief. The second reason is that the city of Umeå is expanding, and an extensive road network is being built, so many resources are being exploited. Additionally, the Road and Park Administration will build new roads and new bike paths at the expense of reinvesting in roads. The third reason is that Umeå has a high utilization rate of WWTPs. 'We have to expand at least two waterworks and two wastewater treatment plants. So, there is a risk that this will be a bit at the expense of reinvestment in the pipeline network,' said the WW manager in Umeå.

In Luleå, reinvestment is currently 0.6% of the replacement value and demand is 0.9% for water and 0.7% for WW. Though the WW company cannot currently reach these levels, it has plans to reach them by 2030 and therefore have an increasing renewal rate, according to the WW director.

Mölndal has a renewal rate of about 0.7% in the pipeline network and has a budget for reinvestment that is about 50% of the total investment budget, the WW director said. However, the organization lacks key personnel who can lead renewal projects. The case was also found to be similar in Jönköping and Växjö in terms of resources.

The company in Växjö almost maintains its SI renewal rate, but its manager did not believe it could currently reach 1%. The interviewees from the organizations in both Växjö and Jönköping did not believe they could maintain the renewal rate percentage they have today. According to the WW manager in Jönköping, it is a matter of resources and the age of the pipeline network. 'There is also a lot of new construction,' the manager in Växjö said. 'We are building three huge expansion areas at the same time, which will take several years. That ties up all the machinery, all the contractors and everything else. So, we do not have any resources left, and the contractors do not have time for reinvestment either."

Ängelholm was rated green for the WW facility status parameter and was one of four organizations that were rated green in this study. Although the renewal rate for water pipes was rated yellow (0.65%) and that for WW lines was rated red (0.2%), the head of WW in Ängelholm stated that he thinks the renewal rate is quite good because the company has a renewal plan that it follows and therefore renew two large areas every year at a cost of SEK 20–30 million per year. The company recently built a new WWTP at a cost of SEK 120 million, and their WTP was built in 2005. However, this plant will be supplemented by water wells and boreholes. 'I cannot say how much we are renewing in percentage because we are expanding the pipeline network, and it will be bigger than last year. Then the percentage is relative to everything else,' said the director of WW in Ängelholm.

The organization in Jönköping has invested heavily in all categories in recent years, meaning 'we have gone from an investment budget of just over 100 million 10 years ago to over 300 million a year now. That's a lot, but the need is great,' the WW chief said. The need for renewal accounts for more than half of the total investment needs, the manager in Jönköping continued.

The company in Västerås wants to increase the pace of renewal, but it is rapidly expanding, and new investments come at the expense of reinvestment. The WW director said, 'The renewal needs are bigger than what I get money for because I have a cap. So, I have to cut renewal because I cannot cut utilization.'

The renewal rate for the WW pipe network and treatment plants is indicative of the degree of implementation of reinvestment in WW facilities. The results of this study show that the renewal rate of the WW network for five years is green on average in seven out of 11 organizations (>0.6%), while it is green for the water networks in three organizations (>0.7%) (Supplementary material, Figure S1 in S3). The results also show that the level of implementation in the three smallest organizations, Arvika, Ljungby and Ronneby, is significantly better than in the other organizations. Of these, two are municipal enterprises and Ljungby has a traditional administration. Ljungby is rated green on all nine SI questions on the parameter 'status of WW facilities' and it would have been interesting to interview the director of the WW organization, but there were obstacles. The other eight organizations surveyed have set specific priorities for reinvestment between the pipeline network and WW facilities, so the degree of implementation varies, but most have made great progress. The strategies and factors that led to success in the organizations studied and described in Section 3, Results and Discussion, should be explored by all water utilities.

The results of this study have shown that four organizations were green in the parameter (status of WW facilities), of which three were small municipalities: Arvika, Ljungby, and Ängelholm. This means 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 organizations' results. These factors include organizations having active ownership (Najar & Persson, 2022) and the role of the manager.

3.5. Limitations

The case study conducted in this paper was designed as an embedded multiple-case design that included more than one unit of analysis (Yin, 2018). Eleven WW organizations were selected with the aim of studying, analyzing, and using them as good learning examples, of which nine were interviewed and studied in depth. One advantage of the multiple-case design is that it is possible to compare different cases, which increases the possibility of generalization, although it is time-consuming (Yin, 2018).

However, we could not accommodate all the topics we had in our interview guide in the results of the study, i.e., we had to exclude some parts of the impact of the economy due to the scope of the topic, although we received interesting responses from the respondents. However, we had explained parts of what was excluded in another article (Najar & Persson, 2021). We could have selected a medium number of case studies (WW organizations), but to be able to generalize the results, we decided to survey all nine that wanted to participate. We could have selected a smaller number of topics to answer our research questions, but we chose all of them to fulfill our purpose and achieve the deep understanding we sought.

4. CONCLUSIONS

This study examined the performance of 11 selected organizations with good results regarding the status of WW fixed facilities parameter. Our objective was to analyze the success factors and to flesh out their working methods, the strategies they use, and the challenges they face. The calculated weighting limits, reflecting the evolution of the performance of the 11 studied organizations, ranged from 1.3 to 2.0.

The following factors and explanations for the success of organizations could be identified:

- The organizations' managers demonstrated a drive to achieve their goals and have made varying degrees of significant progress. All of the organizations surveyed reported having renewal plans in place for at least10 years, and five of the organizations that made greater progress reported having more specific 3-year plans that can be used to develop WW charges that lead to sound finances.
- The strategic, tactical, and operational levels considered when creating renewal and maintenance plans were seen as success factors by all organizations surveyed.
- Another success factor emphasized by the companies was that they consider a life-cycle perspective when selecting and applying renewal measures to ensure that their facilities remain functional throughout their lives.

- Six out of nine companies also reported having strong organizations and the ability to deal with the changing economic, environmental, and demographic conditions under the life-cycle perspective concept.
- All nine surveyed organizations make extensive use of digital technologies for control and monitoring. Also, they are good examples of the direction they are working in to create intelligent WW systems.
- Competent and experienced staff, a focus on the work environment and improving the employee outcomes, using in-house staff instead of contractors, quick decision-making processes, a loose budget, and changing the pipeline from valve to valve when there are multiple leaks in the network, are some of the success factors.
- The small municipality can succeed with excellent achievement if it has active ownership and drive managers who dare to do things.
- 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 organization with active ownership.

Some of the challenges facing WW organizations include the following:

- Economic challenges and the need to prioritize between the renewal of water and WWTPs or pipelines.
- Growth in population, many new buildings, and difficulty accessing contractors.
- Difficulties in coordinating with other pipeline owners.

In this study, 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 excellent results and overcome some challenges. For example, Arvika (population 25,865) is overcoming the challenge of strong growth and construction of many new buildings by setting aside 1% of replacement costs per year for reinvestment, making it economically independent of expansion work and the economic challenges. Thus, an accurate estimate of the total cost of replacing WW facilities can help companies determine their budget for reinvestment at a given replacement rate. Arvika also became independent of contractors and labor availability by using its own employees, workers, and machinery. Ronneby (population 29,346) also adopted a loose budget strategy, meaning money is not tied to a specific project, but investment funds can be transferred to other projects as needed. Added to this is 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 one pipe, rather than just patching and repairing.

FUTURE STUDIES

Both investments and reinvestments in WW infrastructure are financed by depreciation, surpluses, and interest-bearing loans. Depreciation and capital costs in the form of interest and amortization are thus financed through the water utility's operating budget; that is, WW charges. However, it should be further investigated how water utilities will finance their investments and reinvestments in WW infrastructure with the current interest rates. At the time of writing, society has seen an increase in current interest rates from about 1.5 to >4%, 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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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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