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A collaborative planning process to develop future scenarios for wastewater systems

Maria Neth [a,b,*], Ann Mattsson [a,b], David I'Ons [a], Susanne Tumlin [a], Magnus Arnell [c,d], Lena Blom [b,e], Britt-Marie Wilén [b], Oskar Modin [b]

[a] Gryaab AB, Box 8984, 402 74, Göteborg, Sweden
[b] Division of Water Environment Technology, Department of Architecture and Civil Engineering, Chalmers University of Technology, SE-41296, Göteborg, Sweden
[c] Unit of Urban Water Management, RISE Research Institutes of Sweden, Gjuterigatan 1D, SE-58273, Linköping, Sweden
[d] Division of Industrial Electrical Engineering and Automation (IEA), Department of Biomedical Engineering, Lund University, PO Box 118, SE-22100, Lund, Sweden
[e] City of Gothenburg, Department of Sustainable Waste and Water, Box 123, SE-424 23, Angered, Sweden

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ABSTRACT

Wastewater infrastructure has a long lifetime and is subject to changing conditions and demands. When plans are made to upgrade or build new infrastructure, transdisciplinary planning processes and a robust analysis of future conditions are needed to make sustainable choices. Here, we provide a stepwise collaborative planning process in which future scenarios are developed together with local stakeholders and expert groups. The process was implemented at one of the largest wastewater treatment plants (WWTPs) in Scandinavia. With a combination of workshops and the use of a web-based digital tool, future scenarios including flows, pollutant loads, and treatment requirements could be created. Furthermore, sustainability prioritizations affecting the WWTP, were identified. The future scenarios developed for the WWTP in the case study, predict stricter and new regulations, constant or lower future loads and ambiguous future flows. The highest ranked sustainability priority was low resource and energy consumption together with low CO_2 footprint. The quantified future scenarios developed in the planning process were used as input to a process model to show the consequences they would have on the WWTP in the case study. Applying this collaborative process revealed future scenarios with many, sometimes conflicting, expectations on future WWTPs. It also highlighted needs for improvements of both the collection system and the WWTP.

1. Introduction

Wastewater treatment (WWT) systems represent a large economic value for society and take a long time to replace (Lienert et al., 2015). Although there is no consensus on how to define sustainable WWT (Grönlund, 2014), climate emissions, impacts on the environment, and costs are important parameters, which are affected by the physical structures, chemicals, electricity, and other resources needed for the operation of a wastewater treatment plant (WWTP) (Wang et al., 2018). The choices made when new investments and upgrades are carried out will affect the sustainability of a WWT system for a long time, but how do we know today what are the most sustainable choices for the coming fifty years?

Future scenario analysis is one way of dealing with an uncertain future, serving as an applicable tool to support systematic thinking (Schoemaker, 1995). The outcome is an account of a plausible future (Peterson et al., 2003). Future scenario analysis has a long history in fields such as business strategy and politics and has also been applied to energy provision, climate change, and water scarcity (Lienert et al., 2006). The purpose of a scenario method is to outline a range of possible future states. The actual future may lay somewhere within that range (Dominguez et al., 2009).

In the planning of future WWT systems, there are many conditions and aspects that are important to consider. Predictions for treatment requirements, wastewater flows and loads of pollutants are crucial. These predictions are affected by changes in legislation, population and how people choose to live and eat (Dominguez and Gujer, 2006). Aspects such as precipitation patterns, climate change and the need of climate adaption must also be considered (Butler et al., 2017). The availability, affordability and sustainability view of electricity and

* Corresponding author. Gryaab AB, Box 8984, 402 74, Göteborg, Sweden.,
E-mail addresses: neth@chalmers.se, maria.neth@gryaab.se (M. Neth).

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chemicals can affect the choice of future WWT processes dramatically (van der Hoek et al., 2018; Wang et al., 2018). Crucial decisions about improving stormwater handling and the renovation or restructuring of a sewer system will have a large impact on future wastewater flows and are therefore important to include in future scenario analysis.

Historically, WWTPs are subject to many changes during their operational lifetime, such as changes in catchment area, discharge requirements and available technology (Dominguez and Gujer, 2006). Based on this cognizance, it is important to take a wide range of aspects into account to be able to design flexible wastewater systems that can handle changing conditions.

A complicating factor is that many of the important aspects for future WWTPs are to a large extent dependent on stakeholders external to a WWTP (Dominguez and Gujer, 2006). Stakeholders such as authorities that decide upon treatment requirements, managers of sewers and city infrastructure, and property owners often manage water in different ways, causing higher or lower future flows and costs for a WWTP (Seifert et al., 2019). Often, upstream stakeholders have limited insight into the challenges facing the WWTP and have a different systems perspective. Seifert et al. (2019) noted that this can lead to a bystander effect when stakeholders assume that WWTPs will ensure that safe water is discharged into the recipient, which leads to a reduced sense of responsibility for the quantity of water and pollutants flowing to the WWTP. To address sustainable wastewater management more holistically, WWTPs must therefore engage with stakeholders along the entire water cycle (Seifert et al., 2019). A shift to include stakeholders more frequently in engineering planning work is also recommended by Zheng et al. (2016) in their scenario-based framework for wastewater infrastructure planning.

Combining involvement of stakeholders and future scenario analysis in the field of water and wastewater planning is one approach to handle an uncertain future. A few examples are available in the scientific literature. Dominguez et al. (2009) presented a participatory approach to strategic planning that aimed to elucidate the multiple priorities imposed by different stakeholders and to address uncertainties. The approach involved multiple themed workshops with stakeholders and decision-makers and was applied to three wastewater utilities in Switzerland (Dominguez et al., 2009, 2011). Harris-Lovett et al. (2019) developed a collaborative decision-making process for nutrient management in the San Francisco Bay Area that they called a mixed-methods approach, including stakeholder analysis, multi-criteria decision analysis and scenario planning.

Another structured decision-making procedure aimed at increasing the sustainability of water infrastructure planning is described by Lienert et al. (2015). They focused on the initial steps of the structured decision-making procedure (Gregory et al., 2012): (1) clarify the decision context; (2) define objectives and attributes; (3) develop alternatives. By carrying out stakeholder interviews and workshops they identified objectives and created strategic decision alternatives that could be compared with the objectives. The work of Lienert et al. (2015) was continued by Zheng et al. (2016) in a multi-criteria decision analysis framework with involvement of stakeholders to compare alternative developments of a WWT system. Yet another example for involving many different stakeholders in planning is the design charrette, where people from different disciplines and backgrounds are brought together in a hands-on workshop to collaborate, explore, and create design options for a certain area. The idea is that all affected stakeholders participate in the workshop and together they create plans for a sustainable community (Roggema, 2014).

The studies described above are all examples of processes involving various stakeholders and future scenarios. They are primarily about the decision-making processes and work with pre-defined scenarios or scenarios with a wider focus that do not specify flows and pollutant loadings. Future loadings are determining factors for the design and operation of a WWTP, and they need to be set for the final sizing of a WWTP (Dominguez et al., 2011). The focus of the previously mentioned studies is on how to work out future strategies in line with the scenarios and to find the strategies that best match most stakeholders' interests. They do not focus on the process of developing the future scenarios and do not include both stakeholders and experts from different fields in the development of the future scenarios. For an actual WWT system, before discussing strategies, a robust analysis of the future conditions is needed to be able to know which strategy that best fulfils future demands. Further examples showing how future scenarios can be developed for an individual WWTP in collaboration with relevant stakeholders and experts from different fields are, therefore, needed in the scientific literature.

Once future scenarios have been developed, it is also important to understand how they would affect the existing WWTP to determine if major upgrades are needed. Therefore, future scenario analysis for WWTPs should include quantitative measures of flows, pollutant loads, and treatment requirements. To foresee what effects different future scenarios would have on a WWTP, one possibility is to use process modelling (Rieger et al., 2013). Process modelling is a common and established tool for different purposes when it comes to planning of WWTPs, such as for design and system upgrades, optimization, forecasting effects of changes in flows, loadings, or more stringent discharge treatment requirements (Andersson et al., 2020; Arnell et al., 2017).

The aim of this study was to integrate WWTP process modelling in future scenario analysis to determine the need for future plant upgrades. We developed a collaborative process that takes a wide range of aspects into consideration to create future scenarios that can serve as a basis in the planning of a future WWT system. By involving both stakeholders and experts with different competences in the development of the future scenarios, we improve the quantitative estimates of the future conditions. The predicted future scenarios were used as input to a process model, which enabled detailed predictions of performance of the existing WWTP in the case study and highlighted the need for upgrades. The sustainability priorities predicted in the future scenario analysis provided information about how conflicting sustainability targets should be weighted when such upgrades are carried out. The process was applied at Gryaab AB, which operates one of the largest WWTPs in Scandinavia, in the planning of possible expansions and upgrading of the plant.

2. Method

2.1. The case study

The company Gryaab, co-owned by 8 municipalities in the Gothenburg region in western Sweden, owns and operates the Rya WWTP and a 130 km of tunnel sewer system. The local sewer systems are owned by each of the municipalities. The Rya WWTP treats wastewater from a population of 780 000 people or 970 000 person equivalents (pe). The water process includes screening, grit removal, primary settlers, high-loaded activated sludge for pre-denitrification and simultaneous precipitation, trickling filters for nitrification, secondary settlers, nitrifying moving bed bioreactors (MBBRs), post-denitrifying MBBRs and disc filters. The sludge process consists of belt gravity thickeners, anaerobic digesters with biogas production and dewatering with sludge screw presses. The inflow to the WWTP is high and varies greatly, between 2 and 16.5 m^3/s with an average flow of 4.5 m^3/s corresponding to about 500 L per person per day, consisting of sanitary and industrial wastewater and infiltration and inflow. For process schematic of the Rya WWTP, see Fig. S1, supplementary material.

During the process of developing future scenarios, most of the authors of this paper participated with different roles in the core and expert groups. Our role as researchers was to develop and implement the methodology at the case study and observe the results.

2.2. Future scenario analysis

The purpose of the future scenario analysis was to outline future flow, pollutant loads, treatment requirements, and sustainability priorities for a WWTP. This was accomplished using a stepwise process of workshops with local stakeholders and expert groups (Fig. 1).

Step 1. A local assessment of future conditions

The first part of the process was a local assessment of future conditions. This was conducted through three workshops, that were led by an external process leader and involved a core group of persons from the WWTP and various stakeholders responsible for water and city planning in the region. The workshops had three different themes: "The WWTP and its future and environmental impacts", "The water in our cities and the WWTPs' role in city development", and "Future priorities, challenges and economic conditions for the community".

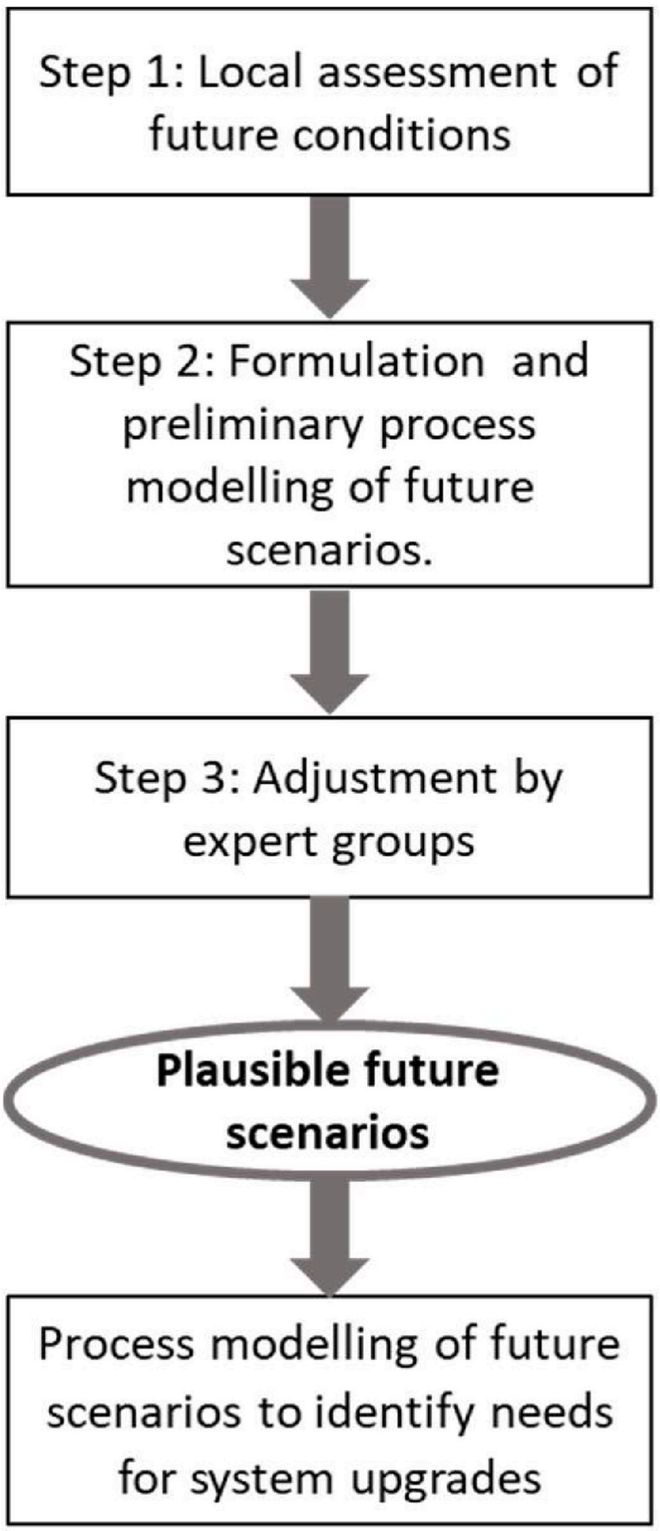

Fig. 1. An overview of the collaborative planning process to develop future scenarios.

The structure of the workshops was a mix of informative presentations, discussions in smaller groups, and collection of individual answers with a web-based digital tool. Conditions for designing and operating future wastewater systems were explored and discussed. The main aim with the workshops was to provide a broad basis from which the future scenarios could be formulated in the next step of the process.

Through the web-based digital tool, the participants of the workshops answered individually to statements about the future (time period 2030–2070) compared to today (see supplementary material). Based on the answers from the workshop participants, the statements about the future were divided into three categories: consensus on, a majority believe in, and disagreement on.

Step 2. Formulation of future scenarios

Based on the results from the local stakeholder groups, future scenarios for the loads and flows to the WWTP and treatment requirements were formulated by the core group from the WWTP. Quantified scenarios were created to represent two extremes for the year 2050, within the boundaries established by the local stakeholder group. The consequences of the future scenarios on the WWTP were simulated in a process model. This was done to demonstrate the breadth of the effects that the future scenarios could have on the existing plant.

Step 3. Adjustment of future scenarios in collaboration with expert groups

The next step of the process was to let three expert groups assess and refine the future scenarios. The first expert group (Swe1, n = 17) met in a one-day workshop and consisted of Swedish expertise from utilities, academia and environmental authorities, a core group of persons from the WWTP and an external process leader. The experts were selected to represent different relevant fields of expertise and experienced individuals were prioritized. The workshop for the Swe1 group involved presentations, group discussions and collection of individual responses using a web-based digital tool. In the group discussions, the participants were divided based on their field of expertise: authorities, wastewater treatment, water, and city planning. The groups were assigned different topics and asked to predict specific discharge limits for pollutants, specific loadings of nitrogen (N), phosphorous (P) and organic material (Biochemical Oxygen Demand 7 days, BOD_7) and different types of improvements in the sewer system for the year 2050. The groups were asked to give quantitative answers to the most possible extent. The individual responses from the Swe1 group concerned future flows, loads, regulations, and treatment requirements.

The second expert group (Swe2 group, n = 29) consisted of Swedish expertise mainly from utilities and the academia. The third expert group (Nordic, n = 140) consisted of Nordic expertise attending the NordIWA conference in Helsinki, Oct. 2019. The Nordic group had members from academia, utilities, technology providers, and consultants. The interaction with the Swe2 group and the Nordic group had the same format. Both groups were given a short presentation about the project and then asked to express their opinions about future flows and load conditions, regulations and treatment requirements, and sustainability priorities by answering individually using a web-based digital tool.

Using the web-based digital tool, all three expert groups (Swe1, Swe2 and Nordic) were asked to provide individual opinions about future flows and loadings to the WWTP in the year 2050. Specifically, questions were posed about stormwater to combined sewers, stormwater to separate sewers, flows due to climate change, potable water consumption, organic loading, nitrogen (N) loading, and particle and sludge loading. They also answered individually about regulations and demands on the WWTP year 2050, divided into the categories: effluent N limit, effluent BOD limit, effluent phosphorous (P) limit, regulated removal of pharmaceuticals, mandatory nutrient recycling, regulated climate and environmental impact, mandatory energy efficiency and mandatory chemical use efficiency. The scale used was 1–10 where 5 was set to be the level of today. A value higher than 5 meant a higher load or a more stringent requirement than today, and a value below 5 meant a lower load or a less stringent requirement than today. If the question concerned an area with no regulation today, a value higher than 5 means that there will be regulations.

The Swe2 and Nordic expert groups were also asked to prioritize four targets based on what is most important for a sustainable WWTP. The targets were: low costs for the WWTP, low effluent concentrations of pollutants from the WWTP, low effluent mass of pollutants from the WWTP and low consumption of resources and energy in combination with low carbon footprint for the WWTP. The results of the workshops were used by the core group from the WWTP to adjust the two quantified future scenarios for year 2050.

2.3. Data collection and statistical analysis

A web-based digital tool for polling and participant interaction (mentimeter.com) was used to collect individual answers anonymously during the workshops and expert evaluations. The answers were given in numbers, and mean averages and standard deviations were calculated for each statement or question for each of the groups. Statistical analysis of the scores was done using a one-sample *t*-test in Scipy (Virtanen et al., 2020). Comparison of means from multiple groups was carried out using ANOVA and Tukey's Honest Significant Differences (HSD) test implemented in the Python package statsmodels (Seabold and Perktold, 2010). Questions in which participants ranked four alternatives were converted to normalized scores by giving 4 points to rank 1, 3 points to rank 2, etc. and then dividing the points given to each alternative by the total number of points.

2.4. Simulation of future scenarios in a WWTP process model

The two quantified future scenarios for year 2050 were simulated using a dynamic process model (GPS-X 7.0, Hydromantis, Hamilton, ON, CA) to show the ability of the current WWTP to cope with future loads. The biological model used was Mantis, which is an extended Activated Sludge Model No.1 (Henze et al., 2006) that includes nitrogen and organic parameters. The used process model covers the water line of the Rya WWTP, except for the screening and filtering steps which were calculated together with the sludge line. The model includes the processes primary settling, activated sludge, trickling filters, secondary settling, and MBBRs. The calibration of the process model followed the steps described in Rieger et al. (2013) starting with model structure and followed by influent fractionation, calibration of nitrification and denitrification parameters, and then calibration of other models such as aeration models. For calibration and validation, one year of daily resolution historical data for a typical year were used and effluent nitrogen concentrations were predicted.

For BOD_7 and P, reduction calculations were performed in Excel. Input to both the process model simulations and to the Excel calculations of the future scenarios for year 2050 were daily average concentrations of BOD_7, N, and P for one year. The daily averages were calculated based on the quantified future specific loads of N, P, and BOD_7 in year 2050 and with todays' daily flow variations for a high flow year (estimated to come every 10th year). The high flow year used was based on historical data of rain flows and inflow to the WWTP and to re-calculate the flows into future flows a hydraulic model by the company DHI was used. In that model, DHI used future rain series, climate impacts, and considered different improvements in the sewer system based on the future scenarios (Johnson et al., 2021). The results from the simulations and calculations were presented as yearly average effluent concentrations (mg/l) and mass flow (kg/d) from the WWTP for Total N, Total P and Total BOD_7.

3. Results

3.1. Local assessment of future conditions

The first part of the collaborative process to create future scenarios was a local assessment of future conditions. The workshop participants' individual answers to the future statements were compiled and the overall answers for each statement were divided into 1) Consensus on, 2) A majority believe in, and 3) Disagreement on. The results are summarized in Table 1.

The load of pollutants and the flow to the WWTP are affected by aspects such as implementation of source separation of urine, implementation of separate sewer systems for wastewater and stormwater, and potable water consumption. In general, there was little consensus in the group on these aspects. The only point of consensus was that separate collection of urine will not be implemented. A majority did also not believe in separate black water collection. A lack of source separation in the future would suggest that we should not expect drastic reductions in the specific nutrients loads reaching the WWTP. Most of the participants believed in some progression towards lower water consumption, local recycling of grey water, and improved storm water management. These are measures that can possibly contribute to reduced flows. The participants had greater consensus about aspects related to future treatment requirements. They believed in stricter effluent limits for BOD and N, new regulation on pharmaceuticals in the effluent, and on recovery of P from sludge.

3.2. Future scenarios

Initial quantitative future scenarios representing two extremes for the year 2050 were created by a core group from the WWTP based on the

Table 1
Local stakeholder groups' answers to statements about the future divided into Consensus on, A majority believe in, and Disagreement on.

	Consensus on	A majority believe in	Disagreement on
Regulations and demands	-Stricter limits on effluent BOD and N -New regulation on removal of pharmaceutical residues and recovery of P	-Stricter limits on effluent P -Required recovery of organic fertilizer from wastewater	-New regulation on removal of virus, bacteria and other new micropollutants -Required recovery of N and micronutrients from wastewater
Exterior	-Requirements on odour from WWT -The appearance of the WWTP, i.e., its architecture and how it fits into the surroundings, will be prioritized	-Covered basins at the WWTP -Multifunctional use of covered basin surfaces	-High requirements on decreasing noise from WWT -Limitations on heavy traffic coupled to WWT
Storm-water	-Overflow protection from the sea is still not implemented by 2070	-Management of stormwater runoff will be implemented	-Climate safe cloudburst management plan is implemented
Separation of the sewer system	-Separate collection of urine is not implemented	-Separate collection of black water is not implemented -Local recycling of grey water is implemented -Lower potable water consumption	-Completely separated sewer system is implemented -Local heat recovery from wastewater upstream WWTP is implemented

boundaries established by the local stakeholder group. The scenarios considered population size, specific load of N, P and BOD_7, daily flow of wastewater and daily flow of infiltration and inflow. The scenarios were adjusted during the workshop with the Swe1 expert group. The adjusted future scenarios were the results of the group discussions with the participants divided into groups based on field of expertise. The adjusted future scenarios are presented in Table 2.

The population was set equal in both scenarios based on a combination of local, regional, and national predictions of population growth. The specific load of N per person was set lower than today in scenario 1, which could occur because of lower meat consumption or source separating systems in parts of the catchment area; although, the experts did not believe in major effects of source separating systems in a big city such as Gothenburg. The experts stated that N is foreseen to be a valuable asset in the future, where the energy consumption will determine where and how the recovery will take place (van der Hoek et al., 2018). The specific load of P will, according to the expert group, most likely decrease. Since P is a limited resource, discharges into wastewater will probably be minimized. The specific load in scenario 2 is a bit higher than today for both N and P, which could be explained by higher meat consumption or just to take height for other non-foreseeable reasons. Regarding the specific load of organic material (BOD_7) the experts assumed it to be as today or a bit higher. Some large WWTPs in Sweden, including the Rya WWTP, have seen a trend of increasing amount of BOD_7 in the influent the last years (Tumlin et al., 2019) but no one has been able to explain it yet.

The wastewater flow per person is lower than today in scenario 1, which could occur because of lower potable water consumption or more internal grey water recycling. The two scenarios also have different speed of improvements in the sewer system, resulting in different flows of infiltration and inflow. The organisation that operates the sewer system in the region has developed two improvement plans for the sewer system, where scenario 2 is the one with a slower implementation and scenario 1 represents a faster implementation of the improvement plan. It is assumed that improvements give the expected effect in lowering the flow. Climate effect can be set as a climate factor affecting different types of flows in different ways. In scenario 1 the climate factor was set to have the same effect on flows as today while in scenario 2 the climate factor was set higher.

Regarding future treatment requirements the limits in 2050 are predicted to be more stringent than today for P, N and BOD_7. This was the outcome of the local assessment (Table 1) and also what the representatives from authorities in the Swe1 expert group believed in. The specific numbers of predicted limits in 2050 from the Swe1 group are presented in Table 3. More results about future treatment requirements can be found in the section Expert evaluations.

Table 2
Scenarios for year 2050 for the case study Rya WWTP.

	2050 Scenario 1	2050 Scenario 2	Present
Load			
Population, persons (+0.8% per year)	1 100 313	1100 313	763 064
Specific loads (g/p.d)			
N	11	14	13.6
P	1.3	1.8	1.7
BOD_7	80	100	84
Flows			
Average daily flow (m^3/s)	4.48	5.85	4.38
Domestic wastewater flow (l/p.d)	140	190	170
Improvements in combined sewer system			
Conversion to separated system	20%	7%	0%
Surface stormwater retention	17%	1%	0%
Improvements in separated sewer system			
Amendment of incorrect connections	27%	6%	0%
Repair or relining of pipes	36%	10%	0%
Climate effect			
Leakage and drainage	As today	As today	–
Peak flows	As today	Higher than today	–

3.3. Expert evaluations

The participants in all expert groups, Swe1, Swe2 and Nordic, answered individually to questions about future flows, loads and regulations for WWT systems. Predictions of future flows and loads to the WWTP can be seen in Fig. 2. The results are generally close to 5, which suggest similar loads as today. Lower water consumption and increased effects of climate change are the issues that for all three groups most clearly departs from today's levels, and statistically significant differences from 5 were observed ($p < 0.05$, one-sample *t*-test).

The predictions from the participants of the three expert groups (Swe1, Swe2 and Nordic) regarding future treatment requirements are summarized in Fig. 3. All groups believed that the future holds stricter limits on N, P and BOD, as well as new regulations on removal of pharmaceutical residues, demands on resource recovery, and reduced climate- and environmental impacts with chemical and energy use mentioned specifically.

The Swe2 and Nordic expert groups were also asked to prioritize sustainability targets for WWTPs. Both groups ranked low consumption of resources, energy, and low carbon footprint the highest followed by low effluent mass of pollutants from the WWTP (Fig. 4). Low cost for the WWTP was ranked the lowest by both groups.

3.4. Factor affecting responses by expert groups

During the interaction with the Nordic expert group, the participants also provided information about the country they mainly work in and their profession. When the results for future conditions were split up according to country and profession, significant differences were observed only for the expected future regulations of effluent N (Fig. S2-S5, supplementary material). The participants from Norway gave somewhat lower scores than the participants from the other countries ($p < 0.05$, Tukey's HSD). However, participants from all countries did expect stricter regulations in the future. The sustainability prioritization differed somewhat between participants from different countries and professions (Fig. S6-S7, supplementary material).

3.5. Simulated effluent results of future scenarios

The results from the process model simulations (for N) and calculations (for P and BOD_7) of the two scenarios (specified in Table 2) are shown in Table 3. The Swe1 expert group estimated specific numbers for expected future limits of N, P and BOD_7 that are presented together with the results of the scenarios in Table 3. The results show that it will not be possible with the existing plant to manage the expected limits for neither

Table 3
Simulated effluent concentrations for the 2050 scenarios. Today's discharge limits and predicted limits for the year 2050 are also shown.

Parameter	Scenario 1	Scenario 2	Today's limits	Predicted limits[a]
Total N (mg/l)	7.1	11.8	8	2-6 (5)
Total P (mg/l)	0.22	0.25	0.3	0.05–0.2 (0.1)
Total BOD_7 (mg/l)	8.2	11.7	10	4-8 (6)
Total mass of N (kg/d)	2700	5900	–	–
Total mass of P (kg/d)	85	126	–	–
Total mass of BOD_7 (kg/d)	3200	5900	–	–

[a] Predicted range with the most likely value in parenthesis.

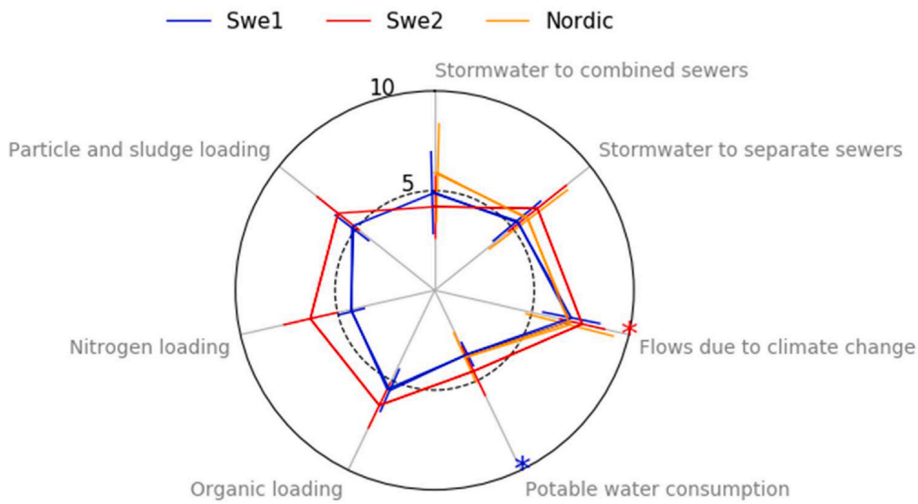

Fig. 2. Future flow and load conditions according to three expert groups. The range is from 1 (center point) to 10 (solid black line), where 5 (dashed line) was set to be the value of today. A higher value means a higher load than today. Average values and standard deviations for the three expert groups are shown. Asterisk (*) indicates that the average score is significantly different from 5 for at least one of the groups ($p < 0.05$, one-sample *t*-test).

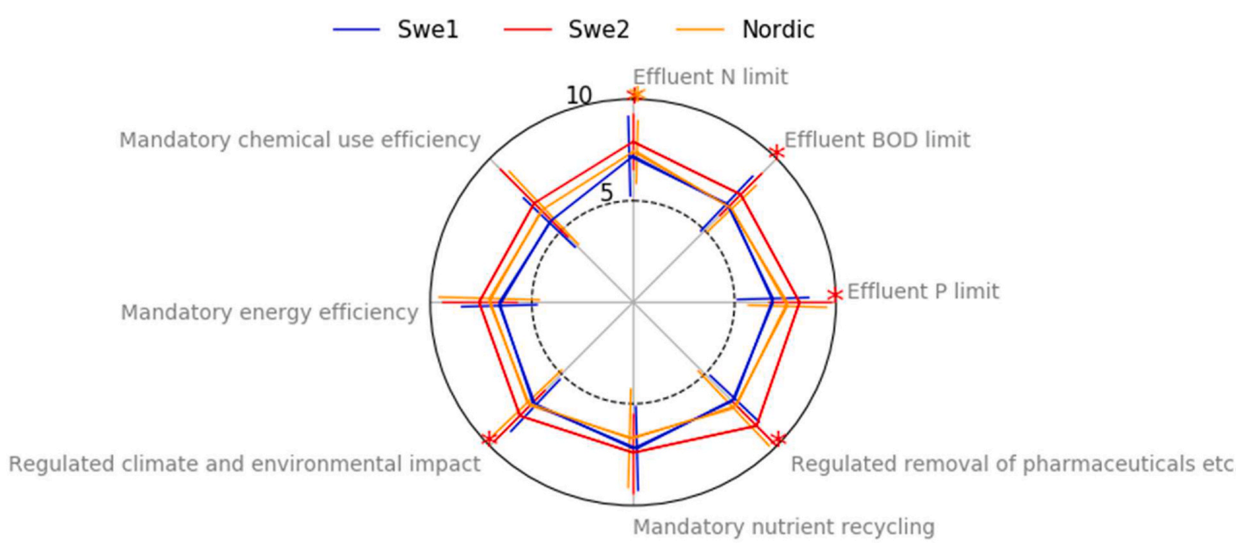

Fig. 3. Future regulations and demands according to the three expert groups. The range is from 1 (center point) to 10 (solid black line), where 5 (dashed line) was set to be the value of today. Average values and standard deviations for the three expert groups. Asterisk (*) indicates that the average score is significantly different from 5 for at least one of the groups ($p < 0.05$, one-sample *t*-test).

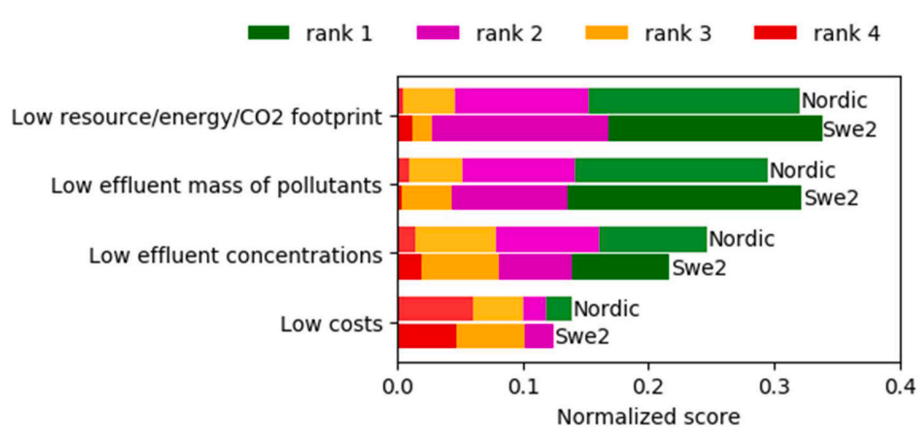

Fig. 4. Ranking of responses to the question: For sustainable WWTPs, what is most important? A high normalized score means that the response was prioritized by the participants. The colors show the proportion of the score associated with each rank. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

of the scenarios.

4. Discussion

4.1. The future scenarios

For the WWTP in the case study, detailed quantitative future scenarios focusing on currently regulated parameters (BOD_7, N, and P) are shown in Table 2. A complement to the quantified future scenarios is the data collected with the web-based digital tool that identified areas where there was consensus as well as areas where the participants disagreed (Figs. 2 and 3). Overall, the results show that in addition to stricter requirements on BOD_7, N, and P, the expert groups believed in new regulations on pharmaceutical residues and climate and environmental impact. Regulations on removal of some defined micropollutants, whereof many pharmaceutical residues, have already been implemented in Switzerland, and monitoring programs are conducted in other countries (Miarov et al., 2020). Taking that into account, to predict that regulations on pharmaceutical residues in the future is very plausible. It is therefore logical to suggest that WWTP managers take steps to prepare for future requirements on pharmaceutical residues monitoring and removal.

Although, stricter and new regulated pollutants are positive for recipients, better pollutant removal often means that new structures need to be built, which leads to increased energy and resource consumption and environmental impact both for the construction and operative phase (Åmand et al., 2015). The belief in stricter limits on N, P and BOD, and new regulations on removal of micropollutants, in combination with reduction of climate emissions and reduced energy and resource consumption is contradictory. Tools such as life cycle assessment and multi-criteria can be useful tools to compare the environmental impact of different alternatives (Angelo et al., 2017), but sooner or later prioritizing is inevitable.

Reflection about the multiple objectives that stakeholders have is an important step in the decision-making procedure. Different stakeholders have different priorities when it comes to environmental, social, governance and economic issues (Dominguez et al., 2009). In our study, the Swe2 and Nordic expert groups prioritized future sustainability targets for WWTPs. The results showed that both groups ranked low resource and energy consumption the highest (Fig. 4). Low effluent pollutant levels, which is the WWTPs' core business is only ranked second. One possible explanation to this response from the expert groups is that meeting the effluent limit is seen as a non-negotiable requirement and the question was interpreted as what to do next: Reduce pollutants even more or focus on doing it in a way that consumes less resources or less money. The groups prioritized reducing resources, while low costs had the lowest priority.

Not prioritizing low costs is in line with the study by Zheng et al. (2016). However, this is contradictory to one of their earlier studies (Lienert et al., 2013) with more open interview questions. Zheng et al. (2016) recommend using trade-off judgements to get underlying values and to make questions more case-specific rather than general. An interpretation of the low priority of low costs in this study could be that as though the goal is to meet stricter requirements and reduce resource consumption, the cost must be allowed to increase. A limitation with the prioritization results could be that the participants in the expert groups mainly represented utilities, academia, technology providers, and consultants while decision makers with economic responsibility for the overall wastewater systems were poorly represented.

The combination of stakeholder-, and expert group workshops and process modelling revealed other discrepancies between future conditions and prioritizations. The local stakeholder group believe in some development towards lower water consumption, and local recycling of grey water, but not a large systematic transformation. They did not expect that the collection systems for stormwater and heavy rainfall will be much different from today. The expert groups expected future consequences due to climate change. According to the hydraulic model (Johnson et al., 2021) of the catchment area for the case study this would mean higher flows, especially by higher peak flows because of heavier rainfalls.

On the other hand, the process model showed that infiltration and inflow in the wastewater collection system has a large effect on the mass of pollutants discharged from the WWTP (Table 3) which means that the future status of the wastewater collection system (e.g., whether it is a combined or separate system and whether the pipes are leaking or not) has a decisive impact on the discharges of pollutants. In addition, combined sewer overflows contribute with discharges of untreated wastewater directly to the recipient. Low effluent mass of pollutants in combination with low resource consumption is likely difficult to realize with wastewater containing a high fraction of infiltration and inflow. To meet these sustainability prioritizations, we believe that sustainable management of stormwater and minimization of infiltration and inflow water in the wastewater collection system is a key target.

Another prediction for future WWT systems, that could not be quantified, came from the local stakeholder groups. The local stakeholder groups were given the most time for discussions in three workshops. This made it possible to discuss water in the city more holistically. The stakeholders believed that in the future, there will be more demands on space requirements, appearance, and smell of the WWTP (Table 1). This raises interesting questions about the WWTPs role in the city. Should we have long tunnels that transport wastewater to remote WWTPs, underground WWTPs, or should we find ways of incorporating WWTPs in the city's infrastructure in an appealing way and not only focus on a functional design? These are issues that must be considered when future WWTPs are planned.

4.2. The collaborative planning process

Decision-making for WWT systems is complex as it involves multiple stakeholders, uncertain future conditions, and conflicting sustainability targets. Clarifying the decision context is an important first step in the decision-making procedure (Gregory et al., 2012) and an identification of possible future scenarios is needed. The collaborative planning process presented in this study shows a method to develop plausible, quantitative scenarios for the parameters that are most relevant for the WWTP: future flows, pollutant loads and treatment requirements, and sustainability priorities. The plausibility was improved by involving stakeholders and experts in different steps of the process and the scenarios could thereby stepwise be adjusted or confirmed. We suggest that to have predictions made independently by several different stakeholders and expert groups is a good way to give more confidence in the results. Another strength with this approach is that specific factors affecting group dynamics, such as a single dominating person, does not have a decisive effect on the outcome of the planning process.

The contribution from the first step of the process, the local assessment of future conditions by a stakeholder group, was a broad basis for the future scenarios. A few in the stakeholder group expressed an insecurity about their own competence to predict the future development for the issues raised. However, in this stepwise process the local assessment only contributes with the initial estimates that are then further developed into future scenarios. Yet another purpose with this step was to engage stakeholders in the planning process (Zheng et al., 2016). To let a stakeholder group, discuss many issues affecting the future WWT system is a way to improve their understanding and support for future changes and reduce the bystander effect (Seifert et al., 2019).

Another advantage with the collaborative planning process used in this study was that the expert group in the second step, the Swe1 group, got tangible data to critique and revise. The assessment of future conditions by the local stakeholder groups was already in the following step of the process translated into specific numbers for e.g., pollutant loads and wastewater flows. With this approach, the experts' knowledge and time could be used to directly adjust the scenarios. A limitation with this procedure is that it requires that the core group driving the process has enough knowledge and experience to be able to translate the results of the local assessment into specific numbers. However, to have the future scenarios in specific numbers makes it possible to connect the collaborative planning process to a WWTP process model. The consequences of different future scenarios can be shown and needs for extensions, improvements, and re-designs of the WWTP can be highlighted.

The outcome for the WWT organisation where this collaborative process was applied was a range of possible future states in which the organisation will have to operate, which is the purpose of a scenario method (Dominguez et al., 2009). Knowing that range, the organisation can move on to discuss future strategies.

5. Conclusions

A collaborative stepwise planning process to establish future scenarios and priorities for sustainable wastewater treatment was developed and implemented at the Rya WWTP, serving the Gothenburg region in Sweden. The collaborative process involved stakeholders and expert groups in several steps over a period of more than one year, which made it possible to gradually build and refine the future scenarios. An important benefit from this process was that key stakeholder groups gained an increased understanding of the entire WWT system, in particular how the configuration of the collection system and the amount of infiltration and inflow affect future discharges of nutrients. The integration of process modelling, and future scenario analysis enabled us to quantify the impact of future scenarios on plant performance and treatment results. This showed that it will be very difficult or impossible to manage the expected discharge limits with the existing WWTP and therefore upgrades are inevitable.

The future scenarios developed in this study hold stricter requirements on the currently regulated effluent parameters BOD_7, N, and P, and likely also new regulations on climate impact and removal of pharmaceutical residues. Future loads to the WWTP in the case study are expected to remain the same or be lower. Future flows can vary widely because some aspects likely lead to increases (climate effect and stormwater) while others lead to decreases (potable water consumption). According to the expert groups, low resource and energy consumption and low CO_2 footprint is the number one priority for future sustainable WWTPs in general.

These future scenarios show that WWTPs need to be adaptable for a range of conditions and demands. For example, they need to prepare for potential requirements on pharmaceutical residues. The appearance and integration of wastewater systems in infrastructure is also likely to be an aspect to consider. Overall, the results of this study show that there will be many expectations on future sustainable WWTPs with stricter and new regulations in combination with reduced resource and energy consumption, and climate impact. A combination of high amounts of infiltration and inflow and strict discharge limits is a serious obstacle for the WWTP in this case study if the aim is to create a future resource effective WWTP with a low climate impact. This will require thorough evaluations of different alternatives to find the most sustainable steps forward.

Credit author statement

Conceptualization [Ann Mattsson, David I'Ons]. Data collection [David I'Ons, Magnus Arnell, Maria Neth]. Data analysis [Maria Neth, Oskar Modin, Susanne Tumlin, David I'Ons]. Software [Maria Neth, Susanne Tumlin, Oskar Modin]. Writing – original draft [Maria Neth]. Writing – review & editing [All authors].

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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