Restoring Bällstaån

Exploring Nature-Based Solutions for Eutrophication Remediation

Project Sustainable Urban Planning - Assessments, Plans and Processes
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Summary

In an era of growing urbanization, maintaining clean and sustainable water environments is crucial for ecosystem health and human well-being. Bällstaån, a stream in Järfälla municipality, faces ecological and chemical challenges due to eutrophication, toxins, and physical factors, hindering the attainment of sustainable development goals. Nature-based solutions (NbS) have gained recognition as an effective approach to addressing eutrophication and as a means to achieving the SDGs. The aim of this project is therefore to explore possible NbS for eutrophication remediation in Bällstaån. The exploration involves identifying what type of NbS can contribute to mitigating eutrophication effects and examining the factors influencing their implementation and suitability for Bällstaån through literature reviews, site analysis and interviews. The results show that various NbS can effectively address eutrophication in Bällstaån. Explored solutions include constructed wetlands, buffer strips, phytoremediation, and biomanipulation. Constructed wetlands and buffer strips emerge as more tested options, with phytoremediation and biomanipulation requiring further investigation. Due to limited space in and around Bällstaån, buffer strips are deemed preferable. The study also concludes that there are several implementation factors that are important to consider for successfully implementing NbS. These include considering site-specific complexities, ensuring stakeholder participation and collaboration, prioritizing and planning for maintenance and evaluation, as well as reviewing costs, multi-functionality, and alternative solutions.

Sammanfattning

I en tid av ökande urbanisering är det avgörande att upprätthålla rena och hållbara vattenmiljöer för ekosystemens hälsa och mänskligt välbefinnande. Bällstaån, en å i Järfälla kommun, står inför ekologiska och kemiska utmaningar på grund av övergödning, gifter och fysiska faktorer, vilket hindrar uppnåendet av hållbarhetsmål. Naturbaserade lösningar (NbS) har erkänts som ett effektivt tillvägagångssätt för att hantera övergödning och som ett medel för att uppnå de Globala målen. Syftet med detta projekt är därför att undersöka möjliga NbS för att åtgärda övergödning i Bällstaån. Undersökningen består av att identifiera vilken typ av NbS som kan bidra till att mildra övergödningseffekter och undersöka faktorerna som påverkar deras implementering och lämplighet för Bällstaån genom litteraturstudier, platsanalyser och intervjuer. Resultaten visar att olika NbS effektivt kan hantera övergödning i Bällstaån. Utforskade lösningar inkluderar konstruerade våtmarker, buffertzoner, fytoremediering och biomanipulering. Konstruerade våtmarker och buffertzoner framstår som mer beprövade alternativ, medan fytoremediering och biomanipulering kräver ytterligare undersökning. På grund av begränsat utrymme i och omkring Bällstaån anses buffertzoner vara att föredra. Studien drar även slutsatsen att det finns flera genomförandefaktorer som är viktiga att överväga för att framgångsrikt implementera NbS. Dessa inkluderar att beakta platsspecifika komplexiteter, säkerställa deltagande och samarbete med intressenter, prioritera och planera för underhåll och utvärdering samt granska kostnader, multifunktionalitet och alternativa lösningar.

Acknowledgements

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1. Introduction

Water is an indispensable resource upon which all living organisms depend. Its quality and availability are not only essential for sustaining ecosystems but also for ensuring the well-being of human societies. In an era of increasing urbanization, the maintenance of clean and sustainable aquatic environments is vital for ensuring drinking water of good quality and for the preservation of biodiversity and ecosystem services (Ansari and Singh Gill, 2014; Teurlincx et al., 2019). Bällstaån is a stream in Järfälla municipality, in north-western Stockholm, Sweden, that faces challenges regarding its ecological and chemical status due to eutrophication (a process of excessive plant and algal growth due to increased nutrient loading), toxins, and physical aspects (Stockholms stad & Stockholm vatten och avfall, 2022). The issue of eutrophication has many direct links to several of the United Nations' sustainable development goals, particularly Goal 6: Clean water and sanitation, Goal 11: Sustainable cities and communities, and Goal 14: Life below water.

Nature-based solutions (NbS) have gained recognition as an effective approach to addressing urban water challenges, including eutrophication, as well as a means to achieving the SDGs (United Nations, 2018). Researching possible NbS for eutrophication issues can for example contribute to SDG 6 by promoting the restoration and preservation of water quality (United Nations, 2018). Regarding SDG 11, NbS for eutrophication mitigation can support sustainable urban development through the promotion of green infrastructure and improved ecosystem services. Lastly, SDG 14 can benefit from NbS as it helps protect aquatic ecosystems by mitigating the impacts of eutrophication on the world's water bodies and their biodiversity (ibid.). This report focuses on the issue of eutrophication in Bällstaån and explores the potential of NbS to mitigate it. Initially, the aim, research questions, scope, background, and the case of Bällstaån are presented, followed by the methodology and results. Lastly, an analysis and discussion take place with proposed recommendations presented to conclude the report.

1.1 Aim and research questions

This project aims to explore possible nature-based solutions for eutrophication remediation in Bällstaån, with the goal of inspiring strategies for tackling the challenge. The exploration involves identifying what type of nature-based solutions can contribute to mitigating eutrophication effects and examining the factors influencing their implementation and suitability for Bällstaån. Identifying feasible solutions for eutrophication is important to reach established goals and standards for clean water in Bällstaån. To achieve the aim, the following research questions have been formulated:

- What type of nature-based solutions can contribute to mitigating eutrophication effects in Bällstaån?
- What factors should be considered when implementing nature-based solutions to mitigate eutrophication in Bällstaån?

1.2 Scope and Delimitations

This research project explores nature-based solutions for eutrophication in Bällstaån. The unit of analysis is eutrophication with a geographical limitation of Järfälla municipality and Bällstaån (see Figure 1). The study is restricted to urban contexts, thus excluding agricultural and marine environments. Remediation strategies, specifically “end-of-pipe” solutions, rather than source reduction methods, are the focus of this project. This allows for a targeted examination of solutions applied at the later stages of eutrophication mitigation. The study considers explicit nature-based solutions and excludes non-explicit nature-based solutions combined with gray solutions. This distinction provides a clear investigation of solutions rooted in natural processes. Following these delimitations, the project's objective is to explore nature-based solutions for remediating eutrophication in the specified urban context.

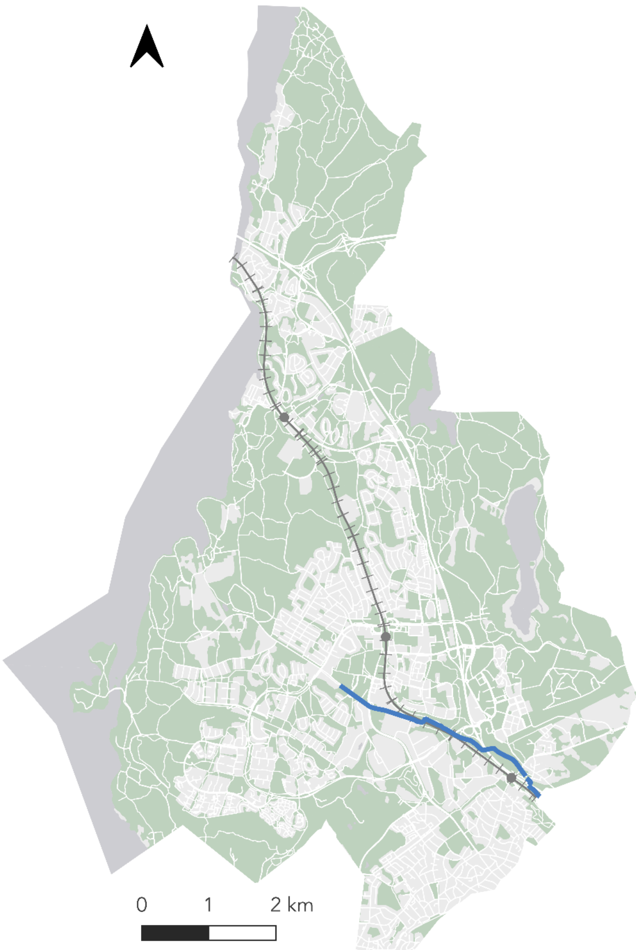

Figure 1. Järfälla municipality and Bällstaån (layout by authors, data from Lantmäteriet, 2022).

2. Background

This chapter provides an overview and contextual background relevant to the research project. Firstly, an introduction to the environmental challenges of eutrophication is presented. Secondly, the concept of NbS is introduced, followed by a background to the case of Bällstaån and current efforts and initiatives.

2.1 Eutrophication

Eutrophication stands as a significant sustainability challenge as it leads to the degradation of freshwater ecosystems (Ansari and Singh Gill, 2014; Teurlincx et al., 2019). Water bodies are changing due to the excessive influx of nutrients, specifically phosphorus (P) and nitrogen (N). This nutrient overload predominantly comes from a variety of human activities such as sewage discharge, household detergents, industrial effluents, agricultural runoff, construction site pollution, and urban expansion (Glibert et al., 2005; Ansari and Singh Gill, 2014; Teurlincx et al., 2019). Climate change is also a catalyst for eutrophication, as increased temperatures promote more rapid algal growth, and changed precipitation patterns intensify nutrient discharge into aquatic habitats (Rodgers, 2021).

Eutrophication poses a multifaceted threat and causes an increased growth of cyanobacteria and aquatic macrophytes, which leads to decreased oxygen levels and decomposition of aquatic flora and fauna. The excess influx of nutrients creates conditions for rapid algal growth where cyanobacteria, also known as blue-green algae, outcompetes other algae and aquatic plants (Glibert et al., 2005; Ansari and Singh Gill, 2014; Teurlincx et al., 2019). Some species of cyanobacteria can produce harmful toxins that pose a threat to aquatic organisms, animals, and even humans if contaminated water is used for drinking or recreation. The repercussions of eutrophication extend globally, affecting lakes, reservoirs, estuaries, and wetlands located near densely populated regions, thereby altering their ecological structure and causing heightened nutrient levels at the same time as other chemical pollutants are present (Ansari and Singh Gill, 2014; Teurlincx et al., 2019).

Eutrophication is a pervasive issue throughout Sweden. Despite implemented measures, the national environmental quality goal of "no eutrophication" has not been achieved and is unlikely to be reached with the existing and decided regulatory measures and actions (Havs- och vattenmyndigheten, 2022). It is thus important to further explore potential solutions for mitigating the issue.

2.2 Nature-Based Solutions

The concept of nature-based solutions (NbS) was introduced by the International Union for Conservation of Nature (IUCN) to meet the challenges of climate vulnerabilities through benefits from nature (Kumar Gupta et al., 2020). NbS is often defined as measures that harness the potential of natural resources by using natural and constructed systems inspired by nature to improve ecosystem services while maintaining or restoring biodiversity (Kumar Gupta et al., 2020; Triest et al., 2016; Bridgewater, 2018; Dondajewska et al., 2018; O'Hogain and McCarton, 2018). The concept includes a variety of elements such as green infrastructure, ecological engineering, and ecosystem-based adaptation, and it is often regarded as the counterpart of "grey infrastructure", which consists of engineering measures, facilities, and installations designed to support or replace functions typically carried out by ecosystems (Souliotis & Voulvoulis, 2022). The aim of NbS is to mitigate issues such as climate change, water security, food security, and disaster resilience while presenting a cost-effective and environmentally friendly approach (Triest et al., 2016; Kumar Gupta et al., 2020). Restoration of degraded ecosystems is a central goal of NbS, which highlights the transformative power of nature in promoting innovative approaches to global challenges (Bridgewater, 2018; O'Hogain and McCarton, 2018). Furthermore, it is important to implement policies that prioritize the protection and restoration of water-related ecosystems together with the implementation of NbS, if they are to reach the desired results (Germann et al., 2023).

An important challenge within the concept of NbS lies in the ambiguity surrounding the terms "nature" and "natural", which can lead to implications for the development of sustainable approaches (Bridgewater, 2018). Therefore, it is important to consider the human context of NbS by for example incorporating local and indigenous knowledge, which can lead to more effective solutions (Bridgewater, 2018; Kumar Gupta et al., 2020). Worth noting is also that there are diverse definitions for the term NbS which can create a conceptual complexity and make the term somewhat subjective. Therefore, there is a need to ensure enough time to cautiously assess its application on the ground level and identify how the term can be further refined (Kumar Gupta et al., 2020). There are also arguments that even if NbS will form an integral component of a future water infrastructure there is still a need for human-built engineered infrastructure, gray infrastructure, as NbS may not be able to solely tackle all challenges (O'Hogain and McCarton, 2018).

When navigating the concept of NbS it becomes evident that clarity in terminology and understanding is crucial. As mentioned above there are several definitions of the concept. However, among the definitions proposed in the literature, those presented by the International Union for Conservation of Nature (IUCN) and the European Commission (EC), are among the most frequently used and will therefore be used for this report. The IUCN defines NbS as actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits (IUCN, 2012). The European Commission defines NbS as actions inspired by, supported by, or copied from nature, either using and enhancing existing solutions to challenges or exploring more novel solutions, for example, mimicking how non-human organisms and communities cope with environmental extremes (European Commission, 2015).

2.3 The Case of Bällstaån

Bällstaån starts in Järfälla and flows through Stockholm municipality and Sundbyberg municipality before reaching its end point at Bällstaviken, which is the innermost part of Ulvsundasjön, a bay within Lake Mälaren, see figure 2. The stream's total drainage area covers 39 sqkm, of which 56% belongs to Järfälla municipality, 41% to Stockholm, and 3% to Sundbyberg (Stockholms stad et al., 2022).

The stream has a length of approximately 10,5 km and a drop of only 10 m, with only a few stretches of rapid flow. About 3,5 km of the stream's course are within Järfälla. Long stretches of the stream have been straightened and there are several culverts. There are two inflows into Bällstån from the southwest, one being Veddestabäcken in Järfälla. The stream's average water flow is between 270 and 300 l/s (ibid.).

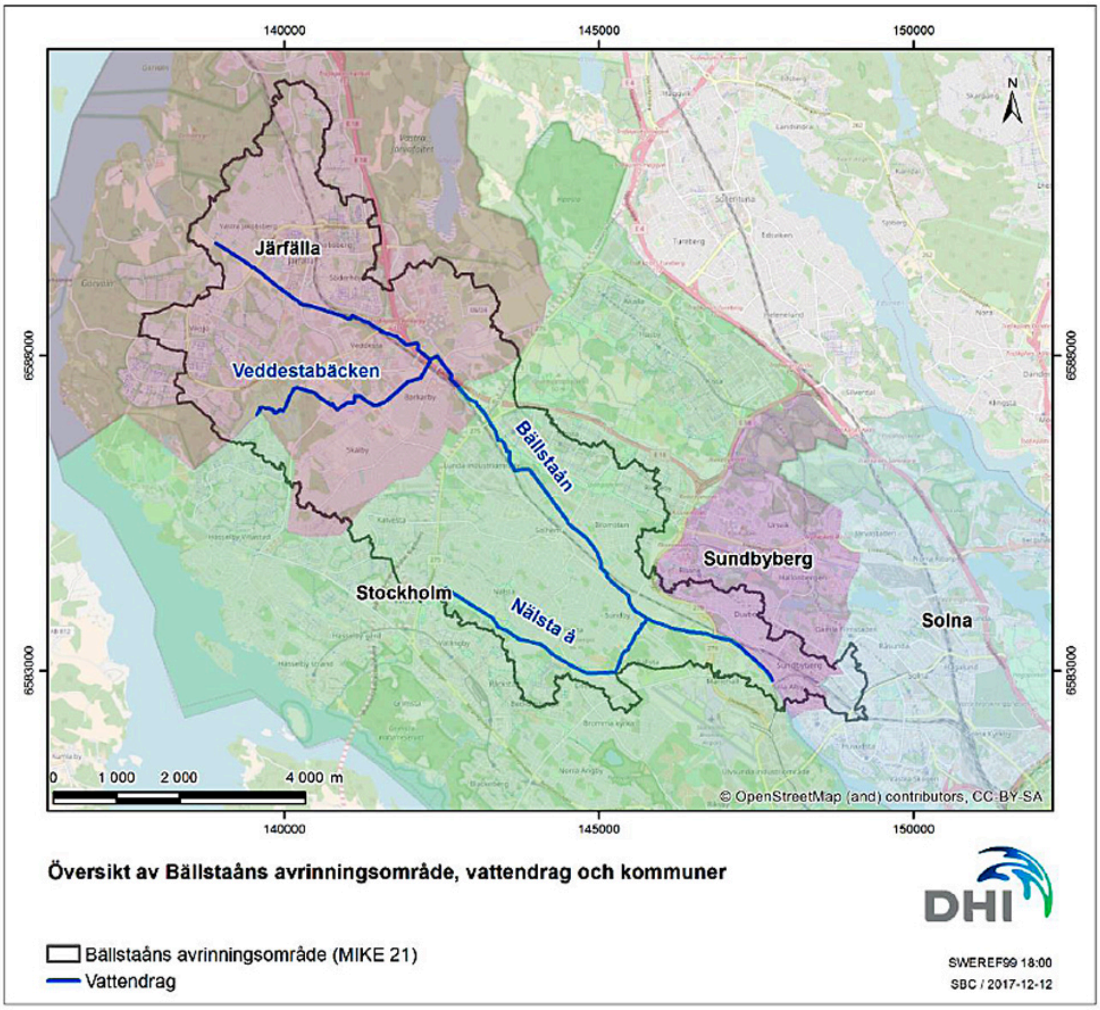

Figure 2. Översikt av Bällstaåns avrinningsområde med ingående vattendrag och kommuner (DHI & Stockholm Vatten och Avfall, 2017)

Eutrophication is a challenge for Bällstaån, as well as an increasing amount of toxins and affected shorelines (Stockholms stad & Stockholm vatten och avfall, 2022). A significant portion of the pollution load comes from nutrients and environmentally hazardous substances in stormwater, which carries pollutants from various activities and roads to Bällstaån. Green spaces make up only one-third of the drainage area, with the remainder occupied by residences, roads, industrial areas, and central districts. Ongoing developments and infrastructure projects are causing the hardening of once permeable land, which increases the risk of pollutants being transported into the stream (ibid.). Due to these challenges, the ecological status of Bällstaån is inadequate, and good chemical status is not achieved (VISS, Länsstyrelsen, n.d.). The total phosphorus value for Bällstaån was on average 109 µg/l in 2021 and the target value for achieving good ecological status is 46 µg/l (Stockholm stad, 2023). Per the EU Water Framework Directive, Bällstaån should have achieved such status by 2021 but has been granted an extended timeframe until 2027. To reach the goal by 2027, actions need to be taken (Stockholms stad & Stockholm vatten och avfall, 2022).

2.3.1 Current Efforts and Initiatives for Bällståan

Bällstaågruppen functions as an information and coordination group for targeted efforts concerning Bällstaån, its catchment area, and Bällstaviken. The group consists of Järfälla municipality, Stockholm municipality, Sundbyberg municipality, Trafikverket (Swedish

Transport Administration), Stockholm Vatten och Avfall (Stockholm Water and Waste), Sundbyberg Avfall och Vatten (Sundbyberg Waste and Water), and Solna Vatten (Solna Water), and aims to connect actors and stakeholders to share information and coordinate actions for improving the water quality (Stockholms stad, 2019). See Table 1 for the goals and proposed actions of Bällstaågruppen.

Table 1. Bällstaågruppens goals for Bällstaån and proposed actions for achieving them

Goals
Wastewater should not reach Bällstaån except in extreme situations (long-term power failures for example)
Bällstaån will not cause floods in nearby areas during high flows
Bällstaån and surrounding areas will be used to create attractive environments with Bällstaån as a central element
Bällstaviken and Ulvsundasjön will have approved water quality for swimming
Actions
Minimize wastewater emissions from leakage etc
Improve stormwater quality through cleaning and systemic supervision of environmentally hazardous operations in the catchment area
Identify sources of pollution
Delaying stormwater through ponds and flooding areas in connection to Bällstaån
Erosion mitigation and biotope improvement actions in connection to Bällstaån
Sampling and supervision of the water quality to identify pollution and evaluate actions

The municipalities that are part of Bällstaågruppen take responsibility for actions or measures pertinent to their municipality, meaning that Järfälla municipality has responsibility for their shares of Bällstaåns catchment area and necessary actions or measures there. Even if a local action program specifically for Bällstaån in Järfälla could not be found, Järfälla's comprehensive plan for 2030 emphasizes the importance of Bällstaån along with actions to enhance and preserve it (Järfälla Municipality, 2014). Ecosystem services provided by the undeveloped land in connection to Bällstaån are described as necessary and in need of continuous consideration given their importance regarding flood mitigation. The areas with the potential to handle flooding to prevent flooding downstream are described as specifically important on both a local and regional level. In addition to being important for flooding prevention and recreation, Bällstaån also serves as a green corridor between the nature reserves Görväln and Järvafältet (ibid.). The municipality also emphasizes in the comprehensive plan that the stream is polluted and actions are needed to improve the water quality and that they are collaborating with Sundbyberg municipality and Stockholm municipality to reach the goals. Järfälla municipality also emphasizes that efforts are currently underway to develop measures and strategies aimed at reducing the environmental impact on the municipality's lakes and waterways, to achieve water quality targets. The ongoing work is being conducted concurrently with the development of a new comprehensive plan (Järfälla Municipality, 2023).

Based on the goals and actions set for Bällstaågruppen, Stockholms Stad, Stockholm Vatten och Avfall, and Sundbybergs Stad have collaboratively developed a local action program for

Bällstaån within their municipal borders (Stockholms stad, 2022). The goals and initiatives within the action program aim to improve water quality, with a focus on habitats for water-living organisms. Specific goals include reducing phosphorus from land-based sources by approximately 530 kg/yr (Stockholms stad, 2022). The action program emphasizes the importance of developing place-specific actions within municipal borders to minimize the historical and current strain on Bällstaån. It also emphasizes the necessity of including supervision and sustainable stormwater management within comprehensive plans and detailed plans, directing attention to the treatment of stormwater runoff from impermeable surfaces, as well as protecting natural areas and flood plains from negative impacts from potential urban development (Stockholms stad, 2022). Improvements along the bank of Bällstaån are also suggested to enhance biotopes and hydromorphology through the protection of existing vegetation or the introduction of new vegetation along the stream. Furthermore, the program emphasizes the importance of cooperation with residents and others within the watershed to reach an increased understanding of how they can contribute to enhancing Bällstaån's water quality (Stockholms stad, 2022). Lastly, environmental monitoring measures are also included in the program to identify possible polluted areas as well as causes. Environmental monitoring is also important when evaluating the outcomes of implemented measures (ibid.).

3. Methodology

In this chapter, the way the research was conducted is described. The chosen research approach is introduced first, followed by an explanation of the primary method employed for data collection: literature reviews. Subsequently, two supplementary data sources, comprising a site visit and two interviews, are presented. The methodology for data analysis is described within the respective sub-chapter corresponding to each applied method, providing an explanation of the analytical approaches employed.

3.1 Research approach

This study is empirically grounded in a qualitative, case study approach. This means that it is grounded in a single case and conducted within a particular setting, motivated by the aspiration to gain a better understanding of a specific issue and phenomenon in a particular context (MacCallum et al., 2019). The case study approach restricts the generalizability of the findings. Still, it offers a nuanced understanding of the specific context and allows for in-depth exploration of unique factors influencing the phenomenon and the study (ibid.). As mentioned previously, the phenomenon or unit of analysis is the stream Bällstaån, limited to within the administrative borders of Järfälla municipality. For a more detailed description of the case, see Chapter 2.3.

Qualitative research generates non-numeric information, which is good for describing individual cases where it is hard to identify specific measurable variables. It is also suitable for generating in-depth descriptions and understanding the context, thus an appropriate approach for achieving the aim of this study. Interpretation of findings is an intrinsic part of the analytical process within qualitative research (ibid.). To minimize subjectivity, efforts have thus been undertaken to apply systematic and replicable procedures and to describe the research methods applied as transparently as possible.

3.1 Literature Review

A literature review is a systematic approach to gathering and synthesizing previous research. The review establishes a foundation for knowledge advancement and integrates findings and perspectives from several empirical findings to address relevant research questions (Snyder, 2019). For this report, three separate literature reviews were conducted to address specific aspects corresponding to the two research questions.

The first review explored NbS for eutrophication remediation and aimed to identify what types of NbS are most beneficial or effective for addressing eutrophication, with a specific emphasis on lakes in urban contexts. The choice to concentrate on lakes rather than in-stream solutions stems from the early recognition of the limited available results for NbS remediation measures in stream environments. The literature was searched for in Google Scholar, initially using the keywords “nature-based solutions”, “eutrophication”, and “lake”, which yielded 1200 results. The second search included the keywords “eutrophication”, “nature-based solutions”, and “phosphor” which yielded 37 results. A third search included “eutrophication”, “nature-based solutions”, “urban”, and “lake”. The third search yielded 1060 results. The results from the three searches were assessed based on their relevance to the scope and their publication dates, where more recent literature within the scope was selected. Results that did not fit within the scope of the paper, such as literature focusing on solutions for agricultural causes of eutrophication, were excluded from the review. A fourth search was conducted after reading the selected papers from the previous three searches. The fourth search included the keywords "phytoremediation", "eutrophication", and "lake" and yielded 5320 results which were also assessed based on relevance to scope and publication date. After the search and collection process, the literature was synthesized and thematically analyzed based on the arguments and solutions appearing in the material. The main themes identified were remediation outside of the lake, restoration treatments within the lake, and biomanipulation. The data within these themes were subsequently reorganized into new themes that correspond to specific solutions: constructed wetlands, buffer strips, phytoremediation, and biomanipulation.

The second review sought to explore the factors shaping the implementation process of NbS for eutrophication remediation and outline challenges that could impede the implementation's efficacy and success. The literature was similarly searched for in Google Scholar initially using the keywords “nature-based solution”, “eutrophication”, “purification or remediation”, and “implementation”. This generated a total of 414 results which were then assessed. Similarly to the first review, this review had an urban focus and excluded results related to agriculture or marine environments. For this review, results addressing tropical climates were also omitted to maintain a focus on temperate regions. Additionally, results indicating an explicit focus on other types of NbS for issues not related to water management were also excluded. Another search was made later using only the search words “nature-based solution”, “implementation”, and “eutrophication”. A few additional articles were identified through a process of citation chaining from other articles. Due to a limited number of articles addressing implementation dynamics explicitly concerning eutrophication remediation, a broader scope was necessary to comprehensively explore the factors influencing the implementation of NbS. Literature on NbS implementation in general was therefore also taken into account. After the search and initial assessment, this body of literature was also synthesized and thematically analyzed based on repeating topics and arguments. The main themes identified were processes of implementation, the interplay between NbS and gray infrastructure, the right solution for the right place, economic shortcomings, stakeholder engagement, and evidence and assessment.

The third literature review was conducted after the others, due to an identified gap that limited the applicability of the results to the case of Bällstaån. This search used the keywords “eutrophication”, “(stream or river)”, “nature-based solutions”, and “remediation”, to explore NbS used specifically for flowing water bodies. This search yielded 279 results, which were similarly assessed based on their relevance and thematically analyzed, where the identified themes mirrored those discerned in the initial review.

3.2 Site Analysis

Site analysis is a qualitative evaluation of specific sites, which contributes to the understanding of the opportunities and constraints of a site. It provides a detailed examination of the relevant features of the site, such as topography, vegetation, and infrastructure, and is often a necessary step when proposing new land use or developments (MacCallum et al., 2019). For this study, a site visit was conducted at Bällstaån on the 1st of November 2023 to gain detailed and site-specific information about the stream and its surrounding area. The list of features that should be considered during a site analysis is extensive and depends on the purpose of the research project. Based on the relevant features suggested by MacCallum et al. (2019), the following features were the main considerations during the visit to Bällstaån: major features of the site (e.g. built elements and their location and size), surrounding land uses and visible activities, access paths to and from the site, characteristics of water bodies, and vegetation.

In preparation for the visit, information about Bällstaån was reviewed, and five locations within the area were selected for exploration along the stream, based on map examination. The criteria for site selection prioritized accessibility and the feasibility of walking along the stream to ensure thorough coverage. Selecting the locations in advance was deemed the most effective approach to gaining a comprehensive understanding during the visit, given the challenging terrain that made it difficult to walk along the entire stream. Only four of the five sites could be visited during the visit due to construction (see Figure 3). This could potentially have led to significant features of the site being overlooked. Nevertheless, the four sites that were visited allowed for comprehensive coverage of the majority of Bällstaån within Järfälla. Photographs were taken to document the observations, and written notes were taken to record the experiences and perceptions of the area.

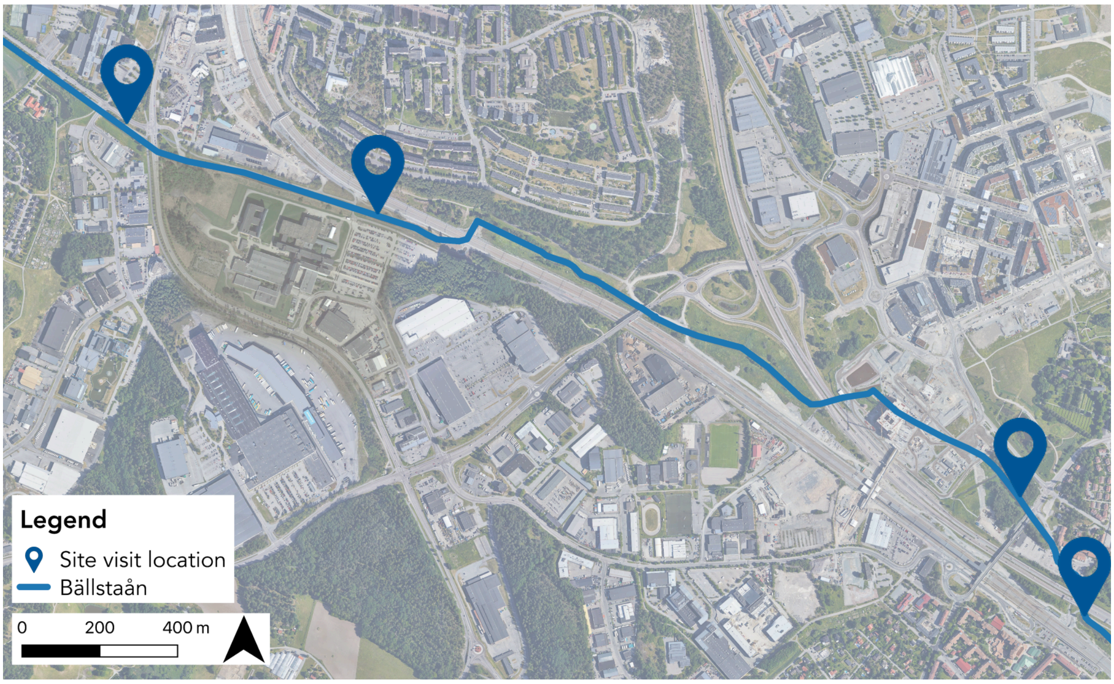

Figure 3. Selected sites visited during the site visit (layout by authors, data from Lantmäteriet, 2022)

After the site visit, the material collected primarily served two purposes. Firstly, it functioned as a base to guide subsequent interviews, enabling discussions on the physical environment and its impact on potential solutions. Through these discussions, the material could thus also be analyzed and evaluated in terms of what physical features were particularly important to consider in relation to NbS implementation. Secondly, the material also enabled triangulation of evidence, meaning that information sourced from the visit and the interviews could be compared and cross-verified. Furthermore, the images help provide a more tangible representation of the site features, aiding in the communication of the findings.

3.3 Interviews

A semi-structured interview is a research method based on an interview guide containing predetermined questions and topics to be addressed during the interview. The interview format is flexible, allowing the interviewer to adapt and develop questions or change the order of the questions, based on the responses and reasoning provided by the interviewee (Denscombe, 2018).

A total of two semi-structured interviews were conducted for this research project. The first interview was conducted on the 15th of November 2023 with Katarina Ekestubbe, a municipal ecologist from Järfälla municipality. The selection of the municipal ecologist was deliberate, aiming to gain information regarding the municipality´s way of working with green spaces, water management, and NbS. The second interview was conducted on the 17th of November 2023 with Emma Hammarström, a landscape architect from the consulting firm Ekologigruppen. Ekologigruppen is experienced in green and blue infrastructure and served as the project manager for the entire consultant group in the planning and construction of Kyrkparken, which is a local park adjacent to Bällstaån with a connected water system.

Before the interviews, two separate interview guides were formulated in consideration of the study's aim and research questions, see appendices 1 and 2. Written consent for participation, recording, and the use of interviewees' materials and names in the project report was obtained from both participants at the start of each interview. The interviews were recorded and then transcribed into written form for analysis. The transcribed material was then thematically analyzed where emerging patterns and themes were noted, coded, and grouped. The themes identified were physical environment, challenges, cooperation, multi-functionality, green-blue infrastructure and nature-based solutions, gray solutions, and work procedures and processes.

4. Results

This chapter presents the results obtained from the study. The results are organized in themes to provide a comprehensive overview of key outcomes, including NbS for eutrophication remediation and the implementation process of NbS. Through analysis of the collected data, the research questions are addressed in the different sub-chapters. The results presented in this chapter contribute valuable insights and serve as a foundation for the following discussion and analysis.

4.1 Nature-Based Solutions for Eutrophication Remediation

Various researchers and experts have explored innovative strategies for mitigating excess nutrients in urban water bodies and improving wastewater management as a way to tackle eutrophication (Germann et al., 2023; Wendling and Holt, 2019; Dondajewska et al., 2018; O'Hogain and McCarton, 2018). This chapter presents the potential solutions for remediating eutrophication in water bodies. Since Bällstaån has unique characteristics as a stream, part of the literature review also focused on investigating tailored NbS for remediating eutrophication in streams specifically. The solutions for remediating eutrophication in water bodies presented in this chapter are constructed wetlands, buffer strips, phytoremediation, and biomanipulation, see figure 4. These are all examples of bioremediation, one of the best-known NbS to reduce, eliminate, or control a multitude of pollutants from both water and soil (Kumar Gupta et al., 2020). Worth mentioning is that these separate NbS in some cases have overlapping functions to a certain extent. Bioremediation involves the controlled degradation or transformation of pollutants into less toxic forms, by employing various living organisms that include bacteria, fungi, and plants. Bioremediation is a widely accepted approach to treating contaminated water in rivers and other types of water bodies. However, bioremediation, while highly targeted, relies on parameters that are unique to each case, including environmental conditions, site characteristics, microbial populations, contaminant concentrations, and nutrient levels (Shishir et al., 2019). Additionally, the time required for bioremediation is typically longer compared to alternative treatments like excavation. Furthermore, addressing mixtures of contaminants with a single microorganism is seldom feasible. The challenge increases when pollutants exist in various forms—solids, liquids, and gasses— which makes the selection of suitable microbes challenging due to their survival being dependent on specific environmental conditions (ibid.).

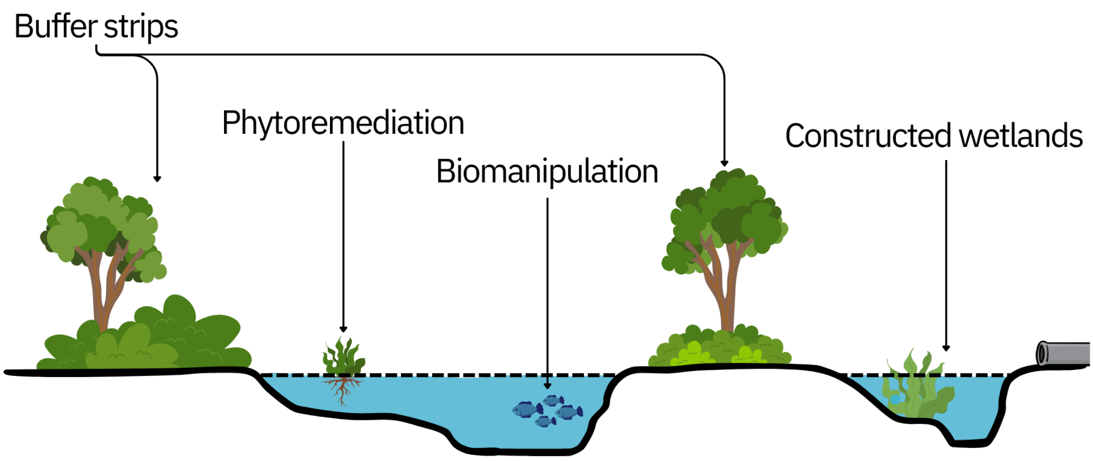

Figure 4: Illustration of key bioremediation solutions: Buffer strips, phytoremediation, biomanipulation, constructed wetlands (by authors)

4.1.1 Constructed wetlands

A method for remediation is the use of constructed wetlands for wastewater treatment (O'Hogain and McCarton, 2018; Kumar Gupta et al., 2020). Pistocchi (2022) proposes wetlands as a NbS for mitigating excess nutrients in rivers specifically. Wetlands distributed along the capillary drainage network of the river catchment can mitigate excess nutrients and pollutants, specifically nitrogen, which is a cause of eutrophication. The wetlands can help filter sediments and nutrients in connection to the river, which prevents nutrient-rich runoff from entering it. It can also facilitate denitrification, which is a microbial process that converts nitrates into nitrogen gas that can be harmlessly released into the atmosphere. Furthermore, wetlands act as natural buffers that regulate the flow of water, which helps prevent nutrient-rich runoff from reaching the river by allowing natural processes to filter nutrients (ibid.). There are several variants for constructed wetlands that mainly differ by the grain sizes in the soil (Stottmeister et al., 2003). Domestic wastewater, agricultural wastewater, and mine drainage water are mainly treated in constructed wetlands, but treating industrial effluents and contaminated groundwater in constructed wetlands is also receiving increased attention (ibid.).

A ring of wetlands around Lake Ljsselmer, located in the Netherlands, was implemented as a pilot project to improve the lake's water quality by optimizing ecosystem services (O'Hogain and McCarton, 2018). The innovative design concept serves as a helophyte filter (a helophyte is a perennial marsh plant that grows in areas that are partly submerged in water) to improve the water quality by reducing nutrients and suspended solids, in addition to combining ecosystem services with water treatment and hydraulic infrastructure. Since a helophyte is a marsh plant, it regrows from buds below the water surface. *Phragmites Australis* and *Typha* are two other examples of plants typically used in constructed wetland systems with positive results on water quality (O'Hogain and McCarton, 2018).

Small floating islands are another form of constructed wetlands that have proven effective for managing water quality and enhancing ecological restoration (Kumar Gupta et al., 2020). The floating islands of wetland plants have been applied in lakes either as islands or along lake shorelines instead of stone pitching or concrete lining (Kumar Gupta et al., 2020). Constructed wetlands can play a key part in treating sewage and wastewater, enhancing the quality, and remediating excess nutrients before discharging into lakes (Kumar Gupta et al., 2020).

Ekestubbe (2023) discusses that Järfälla works with remediating eutrophication issues within the municipality in various ways, mainly by implementing NbS such as ponds and wetlands to absorb and infiltrate nutrients naturally, outside of existing water bodies. Although, as discussed by Hammarström (2023), such solutions require adequate space, which might be difficult to obtain in an urban environment.

4.1.2 Buffer strips

Buffer strips, also known as buffer zones, can be implemented to remediate wastewater and stormwater to prevent eutrophication and maintain the ecological balance of the lake's ecosystem (Germann et al., 2023; Dondajewska et al., 2018; Kumar Gupta et al., 2020). Buffer strips perform different functions by intercepting runoff before it is discharged to the water body, such as maintaining channel stability, providing terrestrial and instream habitat, filtering sediment and nutrients, purifying bacteria and pathogens, and providing a nondisturbance zone for runoff-producing areas (Barling and Moore, 1994; Pistocchi, 2022). The buffer strips can for example be made up of two rows of trees planted within a higher portion of the bank, while also including spontaneous vegetation between the river and tree rows (Pistocchi, 2022). Buffer strips and revegetation can be beneficial as it does not necessarily require a lot of space. Roots and plants from the buffer strips absorb excess nutrients and help bind soil particles, preventing erosion and reducing the transport of nutrients attached to soil particles into the river. Vegetation in the buffer strip can also act as a natural filter for pollutants by trapping and absorbing contaminants from runoff before they reach the river (Pistocchi, 2022). Revegetation along streams or floodplains is a form of buffer strip focusing on catchment treatment as well (Kumar Gupta et al., 2020).

Pistocchi (2022) explains two cases where buffer strips have been implemented in Italy. One buffer strip was implemented in the catchment of Venice lagoon in northern Italy and the other in the catchment of the Scandolara stream in central Italy. As part of a strategy to tackle eutrophication by removing pollutants, particularly nitrogen, buffer strips were distributed along the capillary drainage network of the catchment of the Venice Lagoon. The Scandolara stream was in 2007 equipped with an 11 m wide buffer strip as part of a wider river restoration project. The buffer strip was constructed to remove nitrogen in the sub-surface flows to the adjacent cultivated areas (Pistocchi, 2022). Worth mentioning is that the buffer strips were a part of large-scale strategies including multiple NbS targeting a variety of environmental challenges.

4.1.3 Phytoremediation

Similarly to buffer strips, phytoremediation is a subset of bioremediation that focuses on green technology that utilizes the natural abilities of plants and their associated microorganisms to remove, stabilize, and transform pollutants in soil and water (Ansari and Singh Gill, 2014; Ansari et al., 2015; Kumar Gupta et al., 2020). Phytoremediation is a method that encompasses the following main mechanisms (Ansari and Singh Gill, 2014; Ansari et al., 2015):

- Phytoaccumulation: where plants accumulate contaminants in their leaf or root tissues
- Phytodegradation: which is a plant-microbe symbiotic relationship that degrades organic pollutants within the rhizosphere (the soil in the vicinity of plant roots)
- Phytovolatilization: A process where plants take up and convert water-soluble contaminants into a gaseous form that is released through the stomata of plants

Aquatic plants such as *Spirodela*, *Eichhornia*, *Lemna*, *Salvinia*, and *Wolffia* have demonstrated a high potential for phytoremediation of nutrient-rich lakes – particularly nitrates and phosphates. Multispecies phytoremediation systems have proven to be more efficient in nutrient removal than mono-species systems (Ansari and Singh Gill, 2014; Ansari et al., 2015).

Shishir et al. (2019) emphasize that phytoremediation is one of the most proficient tools to manage polluted environments and recover contaminated river water. Specifically for eutrophication, phytoremediation in rivers using plants and their associated microorganisms can remove phosphorus and nitrogen from contaminated water. Treatments using phytoremediation are more stable, cheaper, and easier with better results in comparison to conventional grey treatments when implemented successfully (Shishir et al., 2019; Ansari and Singh Gill, 2014; Ansari et al., 2015). Nevertheless, the success of phytoremediation depends on the tolerance of the plants used to treat pollutants, as well as being limited by the depths the roots can reach while still effective with respect to the surface area covered. There is also a need to evaluate which plants to use in certain places and climates to achieve expected results since the response of plants and microbes varies under different growth conditions i.e., temperature, light intensity, climate, altitude, etc. (Ansari and Singh Gill, 2014; Ansari et al., 2015).

4.1.4 Biomanipulation

Biomanipulation is a nature-based approach within water bodies that can counter eutrophication and restore ecological integrity (Triest et al. 2016; Dondajewska et al., 2018; Kumar Gupta et al., 2020; Jeppesen et al., 2012;). It involves the manipulation of key components of the ecosystem, such as introduction or removal of animal and plant species. Both in larger deeper lakes and shallow water bodies, biomanipulation is considered a relatively cost-effective means of addressing eutrophication. Biomanipulation can shift the ecological integrity in favor of stable states that are characterized by non-cyanobacteria phytoplankton dominance (Triest et al., 2016; Dondajewska et al., 2018; Kumar Gupta et al., 2020). The literature review shows that there are multiple strategies for biomanipulation to prevent cyanobacterial blooms in lakes and large ponds with the primary goal of controlling eutrophication and enhancing biodiversity. Common biomanipulation solutions include fish removal, the addition of piscivorous fish, and the addition of filter-feeding planktivorous fish (Triest et al. 2016; Dondajewska et al., 2018; Kumar Gupta et al., 2020). Fish removal and fish stocking are popular tools for directly manipulating the food web, enhancing water transparency, and improving water quality (Jeppesen et al., 2012; Triest et al., 2016; Dondajewska et al., 2018). The addition of filter-feeding planktivorous fish directly reduces the abundance of cyanobacteria. Worth mentioning is the need for careful method and species consideration, to minimize the risk of maladaptation and ensuring the long-term ecological balance within the ecosystem, as well as continuous maintenance required in order to ensure desired results of the chosen method. Some of the restoration methods as part of biomanipulation are compiled in Table 2.

Table 2. Biomanipulation methods based on Jeppesen et al.'s (2012) overview of key biological restoration methods and main targets.

Method	Processes involved
Predatory fish stocking to control phytoplankton	Adding fish-eating fish to decrease the number of zooplankton-eating fish and improve phytoplankton grazing and zooplankton numbers
Benthic omnivorous fish removal to control phytoplankton	Removing benthic filter-feeding omnivorous fish (common carp, tilapia for example) to decrease sediment bioturbation and internal nutrient recycling
Zooplankton-eating fish removal to control phytoplankton	Removing zooplankton- and/or benthic invertebrate eating fish to increase number of large zooplankton and their grazing on phytoplankton
Pelagic herbivorous fish stocking to control phytoplankton	Stocking pelagic filter-feeding herbivorous fish (bigheaded carp and silver carp for example) to remove phytoplankton, specifically cyanobacteria
Macrophyte transplantation and protection	Establishing and protection of submerged macrophytes from plant-eating birds or fish to maintain high macrophyte coverage
Herbivorous fish stocking to control macrophytes	Adding plant-eating fish (grass carps for example) to reduce excessive growth of submerged macrophytes
Introduction of mussels	Introducing mussels to increase water filtration and create clearer water

Occasionally, the introduction of alien fish species has been used as a restoration tool, even though its impact on local native biodiversity may not always be fully understood (Triest et al., 2016). In addition to addressing eutrophication, biomanipulation has also been applied to address invasive aquatic weeds in India, such as water hyacinth, *Salvinia molesta*, and the alligator weed by introducing host-specific insects with success in controlling water hyacinth in certain lakes (Kumar Gupta et al., 2020). Even if this control method may require ongoing efforts due to the need for breeding these insects regularly it shows the potential of exploring various kinds of biomanipulation for remediating eutrophication in lakes.

No results for biomanipulation specifically in streams were found in the literature. However, Hammarström (2023) emphasizes the different conditions running water provides, given the presence of fish, frogs, and other protected living organisms. In combination with running water, such elements provide another form of complexity in comparison to working with other types of water bodies.

4.2 The Implementation Process of Nature-Based Solutions

The literature indicates that working with NbS can present challenges, as there is a lack of clear and coordinated guiding principles. Consequently, various efforts within the literature have been dedicated to clarifying the process and developing guidelines (e.g. Cohen-Shacham et al., 2019; Raymond et al., 2017, Kumar et al., 2020; Naturvårdsverket, 2021). The core principles are closely interconnected, with some overlapping elements, and collectively contribute to accelerating the broader adoption of NbS. In general, the principles involve setting objectives, understanding local conditions, designing NbS, and selecting assessment approaches (Kumar et al., 2020). This approach encompasses several key steps (Naturvårdsverket, 2021):

1. identifying place-specific risks and challenges,
2. understanding the local ecological and social conditions,
3. identifying possible solutions tailored to the local context,
4. comparing the consequences of different options to prioritize the most suitable one,
5. effectively implementing the chosen NbS solution, and
6. ongoing monitoring and evaluation to ensure goal attainment or identify the need for adjustments

Participation and engagement of stakeholders is underlined as particularly important in all phases of NbS projects and is crucial for a successful implementation and policy integration (Raymond et al., 2017; Kumar et al., 2020). While these principles offer general guidelines to facilitate the implementation of NbS, the specific actions for each stage depend on the context. Thus, an important step toward successful NbS implementation involves reviewing the stages of the process and formulating a comprehensive action plan at an early stage. The following sub-chapters present the aspects and hindrances that are particularly important to consider in the implementation process.

4.2.1 Identifying Locations

The literature review underlines that NbS must be site- and context-specific (Souliotis & Voulvoulis, 2022). This means that they should be designed to correspond to local issues and characteristics and that they might not necessarily be replicable in other places (O'Hogain & McCarton, 2018). However, selecting and identifying suitable and context-specific NbS is a key practical challenge when it comes to working with NbS as it requires a specific skillset and expertise. Furthermore, frameworks and guidelines specifically developed for selecting NbS and characterizing the local context are uncommon in the literature (Anderson et al., 2023). Some general aspects that are important to consider have been discovered. These include slope and vegetation, size, soil conditions, type of water body, quantity and quality of water, climate, weather, and socio-cultural factors (Sandin et al., 2022; Volkan Oral et al., 2020). Regarding climatic conditions, constructed wetlands have for example been demonstrated to work efficiently in different climatic conditions, but are the most efficient in tropical conditions (Volkan Oral et al., 2020). This emphasizes the importance of an iterative decision-making process, in which identifying the optimal implementation location is contingent upon selecting the most appropriate solution for addressing the specific problem, and at the same time reviewing what solutions best fit the specific site.

Based on these highlighted aspects, the site observation of Bällstaån revealed several features that warrant consideration in the context of NbS implementation. The stream's characteristics include numerous relatively straight stretches, with only a few shorter segments exhibiting rapid flow. Furthermore, Bällstaån runs through several culverts, encompassing both shorter ones beneath walkways and smaller roads, as well as longer ones beneath the railway and motorway. In Järfälla, the stream exhibits a narrow profile, with certain segments measuring approximately 3–4 m in width. Particularly during these stretches, vegetation overgrowth was observed, notably dominated by the prevalence of reeds and bulrushes. However, no systematic inventory of plant species was conducted during the site observation. As stated by Hammarström (2023), excessive and unintended vegetation beyond initial plans and in unexpected places can influence the function and efficiency of NbS. Unplanned vegetation growth can for example harm water flow dynamics, but simultaneously prove beneficial in other aspects, such as for the uptake of contaminants.

Figure 5. Images from site visit on 2023-11-01 (By authors)

The consideration of features surrounding the stream and its vicinity is also important when considering and planning for the implementation of NbS. As depicted in Figure 5, the stream runs beneath and alongside various infrastructural elements, such as smaller roads, walkways, larger roads, motorways, bridges, and railway tracks. It runs in proximity to residential housing, particularly the recently established Barkarbystaden while maintaining a minimum distance of 100 m from residential housing in other locations. Additionally, the stream flows adjacent to a sizable industrial area characterized by diverse industrial activities. This type of landscape and limited space restricts what type of NbS are suitable to implement, and for example limits the possibilities for creating wetlands, meandering, or expanding the stream. It also influences the feasibility of siting a solution in proximity to inflows, which can be particularly important to keep excess nutrients from reaching the water body (Hammarström, 2023). Although close to urban activities, the area adjacent to the stream is mostly made up of grass or other types of open nature areas with unclear land use.

Beyond visible attributes, the implementation of NbS is also impacted by non-visible physical features. Insights gained from Kyrkparken revealed that the area has loose and porous soil, attributed to the site´s historical background as a former seabed. This poses a significant geotechnical challenge that needs to be taken into consideration. Furthermore, excavation activities can bring forth other unanticipated elements, such as outcrops or pipelines whose precise locations were not fully ascertained beforehand (Hammarström, 2023). In summary, any NbS solutions considered for Bällstaån need to be suitable for these site-specific features, such as the limited space, present and planned infrastructure and land uses, soil conditions, and hydromorphology.

4.2.2 Stakeholder Engagement, Participation, and Cooperation

Participation and stakeholder engagement are central to successful NbS implementation, and collaboration across various sectors and levels is required to inform the process (Raymond et al., 2017; Kumar et al., 2020). Cooperation between actors was for example proven to be one important success factor in the Kyrkparken project, where a broad range of competencies within the project group played an important role in identifying solutions, not only during the planning phase but also throughout the construction process (Hammarström, 2023). Active engagement and on-site visits by project participants further contributed to the project's adaptive capacity in responding to unforeseen events or discoveries during construction. As Bällstaån runs through and affects several municipalities, inter-municipal collaboration in this case is particularly important in all efforts toward achieving the environmental targets for the stream (ibid.).

The literature shows that there are, however, several challenges related to stakeholder engagement that might impact the implementation of NbS. For example, a greater level of participation entails a greater risk of conflict, which might lead to undesirable outcomes where different stakeholders hold opposing interests. This is influenced by a general lack of knowledge on how to create, use, and institutionalize collaborative structures to facilitate NbS implementation, thus underlining the need for further investigation on how such collaboration can be reinforced at an early stage (Anderson et al., 2021; Sandin et al., 2022).

Negative public perceptions have been identified as another potential barrier to NbS uptake (Anderson et al., 2021). While NbS generally garner local acceptance, the extent to which they are perceived to enhance or degrade local history, identity, and places, can influence public acceptance. Consequently, understanding the factors driving public acceptance is crucial for ensuring successful implementation (Volkan Oral et al., 2020; Anderson et al., 2021). For instance, Kyrkparken, which was built on predominantly unused land away from any major culturally important elements, stands as a case with little public resistance (Hammarström, 2023). It exemplifies how strategic site selection can mitigate negative perceptions. Raising awareness and disseminating positive outcomes of NbS to citizens can also contribute to increased acceptance and compensate for perceived negative impacts, such as aesthetic concerns. Proving the effectiveness is, however, a subsequent hurdle due to for example challenges in measuring NbS performance (Laikari et al., 2021; Anderson et al., 2021).

4.2.3 Maintaining and Evaluating Nature-Based Solutions

Maintenance and evaluation of NbS have been identified as important elements of successful implementation and establishment of long-lasting solutions (e.g. Souliotis & Voulvoulis, 2022; Kumar et al., 2020; Sandin et al., 2022). Despite their importance, the results also indicate that it is two particularly challenging elements to address and achieve. The literature suggests that this is partly due to NbS frequently being implemented and analyzed in small–scale projects, which has created a knowledge gap regarding evidence and in assessing their performance. This gap hinders the scaling up and implementation of NbS (ibid.). As a result, a preference for gray solutions regardless of their higher cost persists, since there generally is a higher competence regarding such solutions, and their effectiveness may be easier assessed (ibid.). The uncertainty regarding NbS performance may also lead to maladaptation, where improvements in one part of the system risk negatively impacting other components, and potential benefits or drawbacks may be overlooked or misunderstood. (Souliotis & Voulvoulis, 2022; Van Rees, 2023). Additionally, most of the research on NbS for water management, specifically for eutrophication remediation, has been concentrated outside urban areas. This creates uncertainties regarding the specific implementation dynamics in urban settings. Considering the need for stakeholder engagement and the large number of actors in urban areas, this can substantially slow down implementation processes (Volkan Oral et al., 2020). Lastly, NbS evaluations have predominantly focused on environmental aspects and impacts, often neglecting to adequately address the economic, social, and health impacts (Sandin et al., 2022). To enable the scaling up of NbS, the knowledge about them and their benefits to water resource management must be further explored, synthesized, and adapted to be usable for policy and decision-makers. It is also important to train technical and maintenance staff on the use and value of the NbS (UNEP, 2018; Laikari et al., 2021).

In practice, the issues surrounding responsibility for the management and funding of NbS can significantly hinder their maintenance and evaluation. In the case of Kyrkparken for example, no follow-ups or sampling of the water quality have been conducted and no dredging has been done since the construction. According to insights from Hammarström (2023), this pattern is prevalent in many stormwater management pond projects, primarily due to constraints in both time and financial resources. These limitations make it challenging for municipalities to ensure the sustained implementation of maintenance and evaluation efforts necessary to preserve the functionality of NbS and assess their effectiveness.

Furthermore, as stated by Hammarström (2023), municipalities encounter a notable challenge in delineating responsibilities among various maintenance contractors. For instance, one department or contractor is often tasked with overseeing aspects above the water surface, while another is responsible for those below it. This makes it difficult to determine which entity is responsible for different aspects of maintenance, particularly in areas or for solutions characterized by unclear boundaries (e.g., plants and vegetation both in and above water, overseeing the execution of work, and addressing fluctuations in water surface levels). Finding a new way of working, specifically with maintenance and task allocation, is thus an important challenge to address when it comes to implementing NbS or other types of newer solutions (ibid.). To facilitate post-implementation maintenance and evaluation of NbS or similar innovations, it is also important to incorporate considerations for these tasks at an early stage in the planning and design process. Ensuring accessibility for removing sediment accumulations is one example of how this could be done (Hammarström, 2023).

4.2.4 Costs, Multi-functionality, and Considering Other Options

Funding of management and maintenance of NbS can be a challenge for municipalities to overcome. The literature suggests, however, that considering and accounting for such costs over time is crucial to avoid the gradual deterioration of the solutions (Sandin et al., 2022). Additionally, the implementation costs are another economic factor to consider that might pose a challenge to the implementation of NbS, as financing NbS has proven more challenging than financing conventional infrastructure (UNEP, 2018). For example, financial models often require readjustment and further research to fully evaluate the costs and benefits of NbS over time. The lack of information about the costs and benefits of NbS also creates challenges in estimating revenue streams and formulating suitable investment plans. Moreover, profit margins are often limited, negatively impacting the profitability and attractiveness of NbS investments (Sandin et al., 2022; O'Hogain & McCarton, 2018). Despite these challenges, using NbS to improve water quality has also resulted in significant cost savings compared to gray infrastructure measures in several cases (Souliotis & Voulvoulis, 2022).

Comparing NbS with conventional gray infrastructure measures also reveals that NbS possesses a greater level of flexibility to adjust system performance in response to substantial changes caused by factors like climate change and economic development. Moreover, NbS often demonstrates considerably lower carbon emissions during construction compared to gray measures (Souliotis & Voulvoulis, 2022; Kumar et al., 2020). However, NbS implementation is associated with challenges concerning for example design standards, regulation, and financing. Furthermore, NbS may require a longer timescale to be successfully implemented, which means that the need for immediate action might necessitate adopting more traditional approaches to avoid further damage. NbS also has the weakness of being less tested than gray measures and may require more space (ibid.). NbS should thus not be considered a universal remedy and prioritizing NbS over traditional approaches without thorough planning and implementation may result in adverse effects (Souliotis & Voulvoulis, 2022). The literature instead suggests that NbS, when not implemented alone, can improve the performance of existing infrastructure, and combining NbS with gray elements can provide important co-benefits (Souliotis & Voulvoulis, 2022; Mubi Zalaznik et al., 2023). By themselves, NbS inherently exhibit a greater degree of multi-functionality compared to conventional gray solutions, thereby motivating the municipality to actively pursue such alternatives (Ekestubbe, 2023; Hammarström, 2023). Achieving co-benefits and multi-functionality is important for all types of measures implemented in the municipality due to limited resources and broad, interconnected challenges. Consequently, the municipality is required to invest in solutions that not only address singular issues, but also contribute concurrently to the attainment of multiple sustainability objectives, such as climate adaptation, biodiversity, and recreation (ibid.).

4.3 Implementation roadmap

Based on the implementation guidelines introduced at the beginning of chapter 4.2 and the implementation considerations presented in the ensuing sub-sections, a roadmap delineating the implementation process has been designed, see Figure 6. The roadmap summarizes the results and illustrates how NbS can be operationalized.

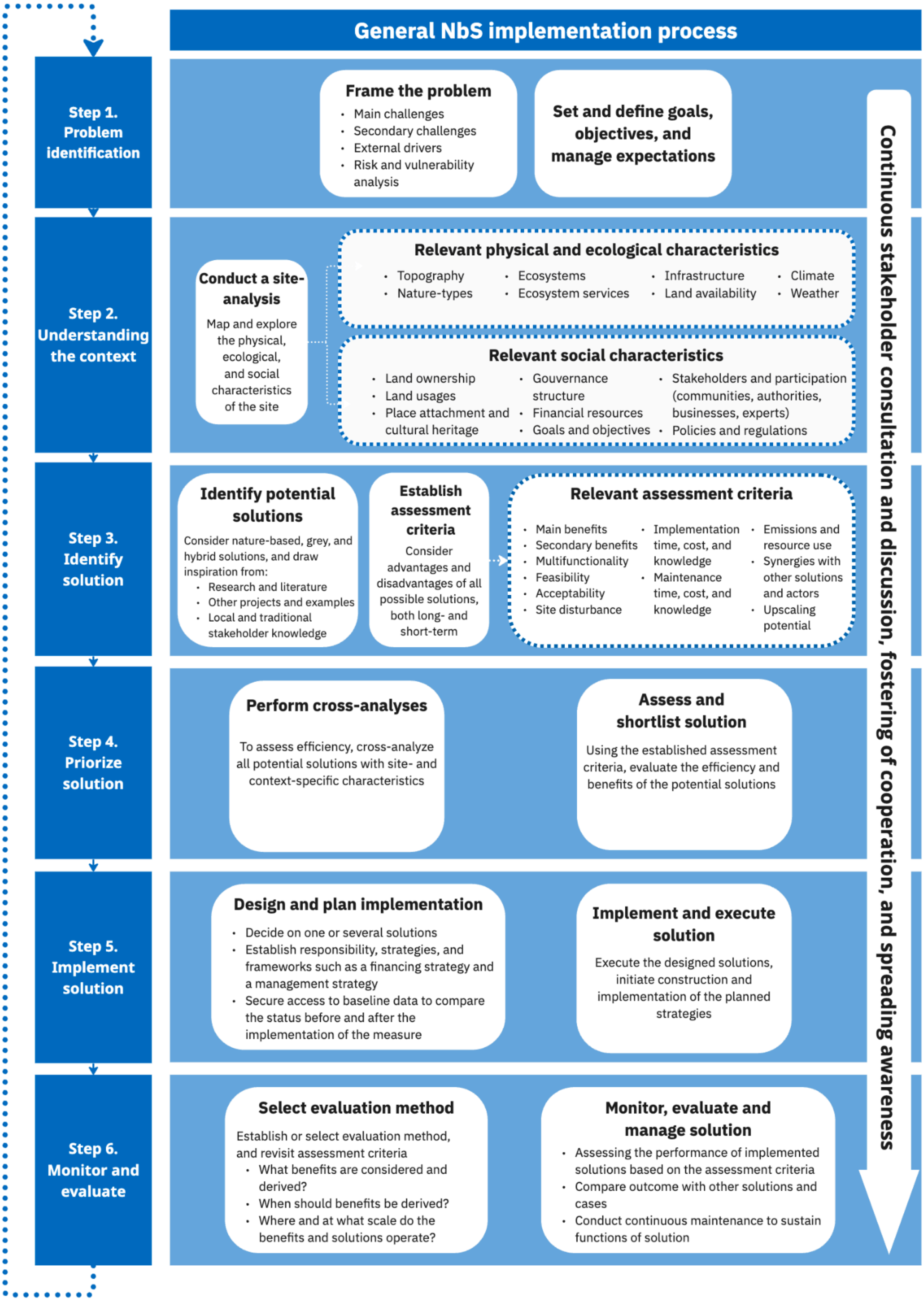

Figure 6. Summary of the key processes involved in the operationalization and implementation of nature-based solutions (illustration by authors, based on Naturvårdsverket, 2021; Raymond et al., 2017 & Gonzalez-Ollauri et al., 2023)

Figure 6 illustrates a general NbS implementation process and the roadmap can be applied and followed for various environmental challenges where NbS is or should be considered. To exemplify this implementation process for Bällstaån, data from the results has been integrated into steps 1-3, as illustrated in Figure 7. Followingly, Table 3 presents an introduction to step 4 from Figure 6, where each identified NbS is evaluated based on the assessment criteria from step 3. The evaluation of each NbS, in Table 3, is based on the data presented in the results, which are currently limited to steps 4–6. Consequently, a few assessment criteria could not be evaluated for the specific NbS. It is also important to note that since the results are qualitative, the criterias are assessed accordingly and not based on precise measurements. It should thus be regarded as a first indicator requiring further investigation. Nevertheless, the combined insights from Figure 7 and Table 3 provide an illustrative example of how the implementation process can be conducted for Bällstaån in the context of eutrophication mitigation.

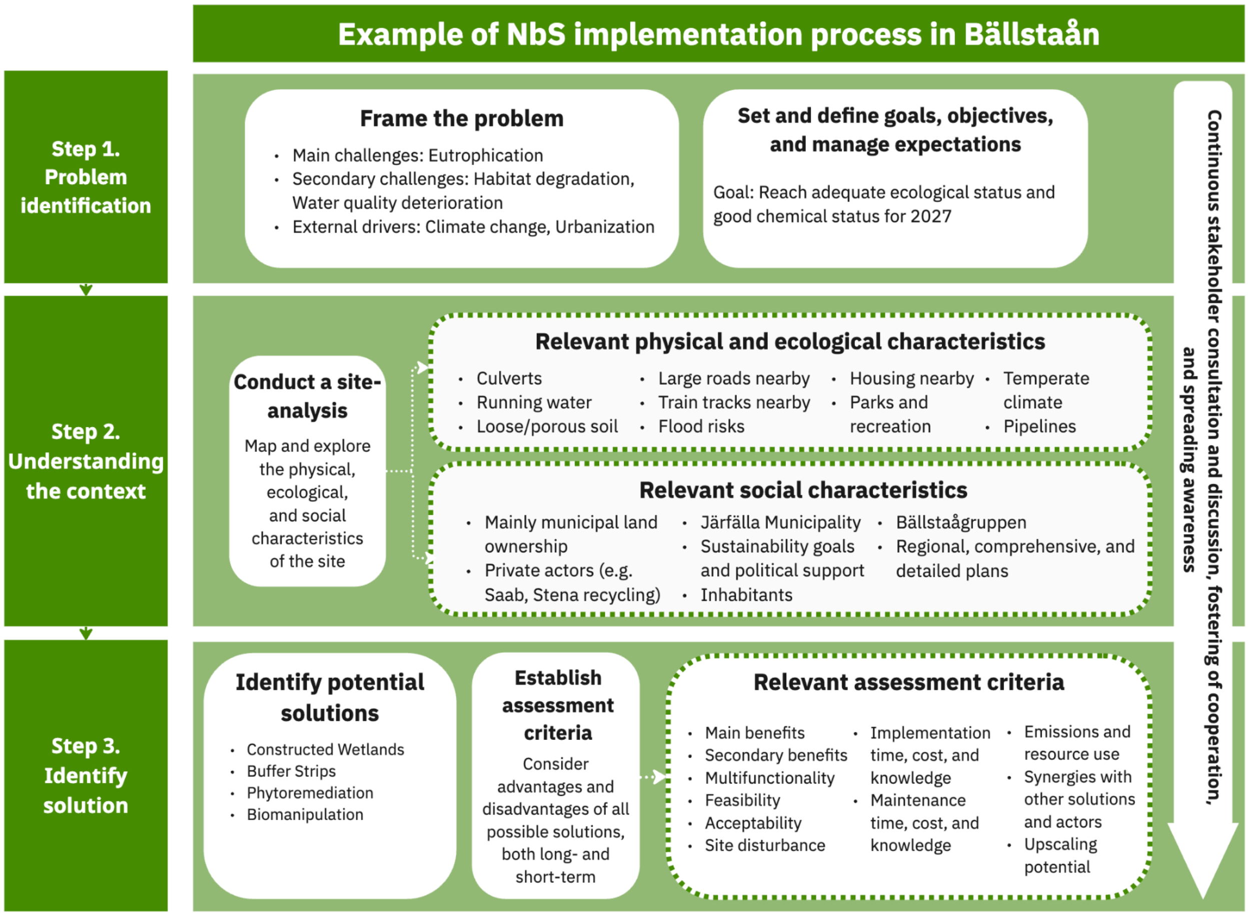

Figure 7. Example of NbS implementation process in Bällstaån, steps 1–3 (By authors, based on illustrations from Naturvårdsverket, 2021; Raymond et al., 2017 & Gonzalez-Ollauri et al., 2023, with content informed by various articles included in the results section)

Table 3. Evaluation of each NbS based on assessment criteria from step 3 in figure 6.

	Constructed wetlands	Buffer Strips	Phytoremediation	Biomanipulation
Main benefits	• Infiltration - removes excess nutrients • Effectively targets eutrophication	• Purifying bacteria and pathogens • Filtering sediments from nutrients	• Removing, stabilizing, and transforming pollutants • Excess nutrient removal	• Controlling excess nutrients • Enhancing biodiversity
Secondary benefits/multifunctionality	• Can add recreational values • Can enhance aesthetics • Flood mitigation	• Maintaining channel stability • Providing terrestrial and in-stream habitats • Can enhance aesthetics • Flood mitigation • Heat mitigation	• Can enhance aesthetics • Treatment of various kinds of pollutants, such as metals	• Aesthetically unobtrusive • Enhancing water transparency
Feasibility	• Less space-efficient • Fixed solution - specific location	• Space-efficient • Fixed solution - specific location	• Very space-efficient • Multispecies proven more efficient than monospecies	• Very space-efficient
Acceptability				
Site disturbance	• Risk of impacting current activities due to space requirement	• Risk of impacting current activities due to restricted access	• Risk of impacting current activities due to restricted access • Risk of impacting current ecosystems	• Risk of impacting current activities due to restricted access • Risk of impacting current ecosystems
Implementation cost/time				
Implementation knowledge	• Explored solution	• Explored solution	• Less explored solution	• Least explored - some uncertainties for implementation in smaller streams
Maintenance cost/time	• Requires ongoing maintenance: dredging etc	• Low maintenance requirements, minimal intervention	• Some maintenance to ensure continued presence of wanted plants	• Requires continuous maintenance to ensure desired results
Maintenance knowledge				
Emissions and resource use				
Synergies with other solutions	• Possible to combine with other solutions	• Possible to combine with other solutions	• Possible to combine with other solutions	• Possible to combine with other solutions
Upscaling potential				
Evaluation potential				

5. Analysis and Discussion

The findings underscore bioremediation as a comprehensive umbrella term and the primary category within NbS for tackling eutrophication in aquatic ecosystems. Notably, the study identifies four specific types of bioremediation most frequently explored and used for eutrophication remediation: constructed wetlands, buffer strips, phytoremediation, and biomanipulation. These solutions all have the potential to contribute to eutrophication remediation, however, their success is dependent on a variety of implementation factors. Particularly important is the aspect of cross-analyzing the solutions with site-specific characteristics, to make sure that the solutions are suitable to implement on the site in question to achieve the desired outcomes.

Based on the results acquired, it is possible to give a first indicator of what type of NbS would be possible and suitable to implement, and that is worthy of further investigation. Constructed wetlands are the most explored solution and have been shown to have positive effects on mitigating eutrophication. Buffer strips have also been proven effective, but there are larger uncertainties concerning their performance when implemented alone as they are often combined with other solutions. Both constructed wetlands and buffer strips are examples of fixed solutions, meaning that they can be implemented in specific locations where they provide the most benefits, such as in the proximity of nutrient entry points. However, constructed wetlands often require more space than buffer strips, limiting their feasibility in more dense areas. In contrast, buffer strips are more space-efficient and can be implemented in more narrow strips alongside watercourses. Furthermore, constructed wetlands require ongoing maintenance such as the dredging of sediments for sustained effectiveness, whereas buffer strips entail lower maintenance requirements as the vegetation often requires minimal intervention.

Phytoremediation works similarly to buffer strips and has proven to be an efficient action targeting eutrophication. The use of multiple plant species in phytoremediation has demonstrated a higher efficacy compared to monospecies interventions. However, the success of phytoremediation depends on evaluating plant species tailored to the specific context of implementation, taking into account variables such as climate, temperature, and local ecosystem characteristics. Biomanipulation was the least researched solution for remediating eutrophication specifically in smaller streams and introduces some uncertainties for implementation. Similarly to phytoremediation, the selection of the most beneficial type of biomanipulation, whether it involves fish stocking or removal and the choice of fish species, adds layers of complexity to its implementation. Furthermore, the dynamic nature of biomanipulation, not necessarily place-specific, raises difficulties in its application, particularly in moving water bodies like streams.

Based on these factors, it can be concluded that constructed wetlands and buffer strips are more tested and secure options for implementation, as they require less specific investigations relying on expert knowledge. Due to the identified limited space available in and around Bällstaån, as well as challenges in ensuring implementation maintenance strategies and allocating responsibilities within current work and implementation processes, constructed wetlands might be particularly difficult to implement and sustain. In this regard, buffer strips emerge as a preferable alternative, despite some lingering uncertainties about the outcome. The greatest uncertainties pertain to phytoremediation and biomanipulation, warranting further and more meticulous investigations to determine their potential in Bällstaån specifically. Nonetheless, these methods have shown promise as solutions, justifying continued investigation and small-scale pilot testing. Future efforts should then primarily focus on refining plant and species selection criteria and assessing long-term impacts and maintenance to enhance the reliability of phytoremediation and biomanipulation.

The implementation processes and factors presented in this report primarily concern the general implementation of NbS, although taking into consideration some context-specific aspects of Bällstaån and Järfälla municipality. Following the implementation roadmap presented in Chapter 4.3 (Figure 6), the primary focus of this project has been on steps 1–3. These steps involve framing the problem, understanding the local context, and identifying potential solutions. These initial stages serve as the foundation for NbS implementation for eutrophication remediation in Bällstaån, shedding light on crucial aspects and serving as an inspirational starting point for future investigations.

However, due to limited results and the absence of measurements and sampling related to for example eutrophication or water levels, steps 4–6 have received less attention and were not addressed in this project, with the exception of table 3. These later steps are equally pivotal and warrant thorough consideration in future investigations and potential implementation processes. Additionally, they acknowledge the significance of continuous stakeholder engagement and cooperation, involving consultation, discussions, and awareness-building throughout the implementation process. While this aspect has not been extensively explored in this study, specifically concerning NbS implementation, it is suggested that future efforts give particular attention to examining how such practices can be effectively fostered and realized. This is particularly important among actors and stakeholders within the municipality, as larger-scale cooperation among municipalities is already established.

6. Recommendations

This chapter presents recommendations regarding NbS for remediating eutrophication and considerations for implementation.

1. Utilize established implementation guidelines

For a successful NbS implementation, it is recommended to establish an early-stage action plan grounded in core principles and guidelines outlined in the literature and presented in the implementation roadmap provided in this report. These elements collectively form a cohesive framework, with proposed steps including problem identification, understanding the context, identifying solutions, prioritizing solutions, implementing solutions, monitoring and evaluating, and ensuring continuous dialogue with a relevant network of stakeholders.

2. Prioritize and plan for long-term maintenance

The challenge of maintenance responsibility and funding hindering maintenance processes requires attention, especially given the time and financial constraints faced by the municipality. To address this, stakeholders concerned with remediating Bällstaån should prioritize resource allocation for post-construction maintenance and assessment of NbS. By incorporating considerations for maintenance tasks at an early stage in the planning and design process the success and functionality of NbS for Bällstaån can be ensured.

3. Prioritize and broaden evaluations

To overcome the challenges of evaluation of NbS it is crucial to address knowledge gaps stemming from small-scale projects. Relevant stakeholders should prioritize comprehensive assessments, particularly in larger-scale and urban projects, to counteract the prevailing preference for conventional solutions. By broadening evaluations beyond environmental aspects to include economic, social, and health impacts a more holistic understanding of NbS can be obtained as well as continued learning, providing the foundation for adaptability.

4. Ensure participation and stakeholder engagement

It is recommended to adopt established implementation guidelines for NbS that prioritize robust and long-term stakeholder engagement and co-management between and within municipalities concerned with Bällstaån. Active participation across sectors and ongoing participant involvement are recommended to enhance adaptive capacity. To bolster public acceptance, strategic site selection and awareness campaigns can play pivotal roles. Lastly, by cultivating a collaborative environment and addressing conflicts earlym future NbS initiatives can navigate challenges and increase their overall success.

5. Conduct further exploration of NbS for Bällstaån

As presented in the results there are potential NbS for remediating eutrophication in streams. However, there is a need for further exploration of how and where to implement them to tackle the challenge of eutrophication in Bällstaån specifically. It is therefore recommended to initiate small-scale pilot testing focused on investigating specific species and plants for biomanipulation and phytoremediation, locations of influx where constructed wetlands could potentially be implemented, and favorable locations and plant types for buffer strips.

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Appendices

Appendix 1. Interview guide, ecologist at Järfälla Municipality

Samtycke och information

- ~~Interviewee has received information about the project~~
- ~~Interviewee has given consent to participate, being recorded for transcription purposes, and for the material to be used in the project report~~

Kort om projektet

- Projektet syftar till att utforska naturbaserade lösningar som en åtgärd för att hantera övergödningsproblematik, framför allt i Bällstaån. Vi ska därför utreda om NBS kan tillämpas för att tackla övergödning, om det är lämpligt att implementera dem i det här fallet, och hur en sådan implementeringsprocess kan se ut i just Järfälla. Fokuset idag är att få en uppfattning om hur kommunen jobbar med t.ex. vattenfrågor, övergödningsproblematik, och naturbaserade lösningar, och vad ni har för tankar kring en eventuell implementering av naturbaserade lösningar för övergödning i Bällstaån.

Introduktionsfrågor

- Kan du berätta lite mer om dig själv och vad din roll är inom kommunen?
- Hur kommer du i kontakt med vattenfrågor i ditt arbete?
- Hur kommer du i kontakt med förorenings- eller övergödningsfrågor i ditt arbete?

Övergödning

- Hur arbetar ni i Järfälla med övergödningsfrågor? (både i sjöar och vattendrag)
    - Vilka specifika lösningar har ni jobbat med?
- Vilka problem eller hinder stöter ni på när det kommer till att implementera eller genomföra olika lösningar för att hantera övergödningen?

Naturbaserade lösningar

- Känner du till begreppet naturbaserade lösningar? Vad innebär det för dig?
- Har du stött på eller arbetat med naturbaserade lösningar i din roll hos kommunen?
    - Om ja, kan du berätta lite om dessa och dina upplevelser kopplat till det arbetet?
- Känner du till om kommunen har andra erfarenheter av projekt med NBS, som du inte varit med och jobbat på? (det nämns t.ex. kort i klimatanpassningsplanen)
    - Om ja, hur har ni arbetat med NBS tidigare? (t.ex. i vilka projekt, för vilka syften? har det använts i eller runt om vattendrag?)
    - Om nej, varför? (t.ex. begränsat intresse, saknar kunskap, andra utmaningar eller hinder?)
- På vilket sätt och i vilka sammanhang upplever du att man pratar om och diskuterar naturbaserade lösningar idag i kommunen (men även kanske i regionen, nationellt etc)? Är det något man försöker inkorporera och är intresserad av?

- Hur ser du på att implementera naturbaserade lösningar inom kommunen för att hantera problem med övergödning eller andra vattenföroreningar (t.ex. fördelar, nackdelar)
- Hur ser du på skalbarheten hos NBS? Tror du att sådana lösningar kan tillämpas på en bredare skala inom kommunen?
    - Varför eller varför inte?
    - Vilka hinder tror du finns för att implementera NBS på en bredare skala? (målkonflikter, sociala aspekter, kostnader, kunskapsbrist)
    - Hur ska man kunna möta det/vad tror du krävs för att NBS ska få en större utbredning eller kunna implementeras i kommunen? (t.ex. mer kunskap, mer ekonomiska eller tidsmässiga resurser, andra aspekter?)
        - Vad har kommunen för möjligheter att jobba med dessa aspekter?
- Vilka krav ser ni är särskilt viktiga att en naturbaserad lösning lever upp till? (gällande hållbarhet, långsiktighet, flexibilitet, effektivitet, kostnader etc)
- Hur ser arbets- och implementeringsprocessen ut inom kommunen när det gäller implementering av NBS, eller andra liknande lösningar för den delen? Finns det några tydliga steg kring hur man går tillväga?

Samverkan

- Hur ser samarbetet ut för vattensamverkan i Järfälla - vilket ansvar har kommunen/Järfälla? Vilka utomstående aktörer är inblandade?

Bällstaån

- Vad har du för upplevelser kring arbetet med just Bällstaån (och föroreningar och övergödning)
- Vilken kapacitet har kommunen att arbeta med Bällstaån och dess föroreningsproblematik?

Appendix 2. Interview guide, Ekologigruppen

Samtycke och information

- ~~Interviewee has received information about the project~~
- ~~Interviewee has given consent to participate, being recorded for transcription purposes, and for the material to be used in the project report~~

Kort om projektet

Vårt projekt syftar till att utforska naturbaserade lösningar som en åtgärd för att hantera övergödningsproblematik, framför allt i Bällstaån. Vi ska därför utreda om NBS kan tillämpas för att tackla övergödning, om det är lämpligt att implementera dem i det här fallet, och hur en sådan implementeringsprocess kan se ut i just Järfälla. Det vi hoppas få ut av den här intervjun är att få höra lite mer kring hur ni jobbade med Kyrkparken och hur arbets- och implementeringprocesserna såg ut, samt hur ni jobbar med grönblå strukturer och ekosystemtjänster mer generellt, gärna kopplat till olika vattenfrågor.

Introduktionsfrågor

- Kan du berätta lite mer om Ekologigruppen men också om dig själv och vad din roll är inom företaget?

Kyrkparken

- Kan ni berätta om ert arbete med Kyrkparken i Järfälla kommun?
  - Vad var starten för projektet och vilka var de övergripande målen?
  - Vilka olika typer av lösningar är det ni jobbade med i Kyrkparken?
    - Jobbade ni med några lösningar gällande föroreningar eller övergödning, med tanke på hur nära parken är till Bällstaån till exempel? (sen vet jag inte men kan vara så att även marken var förorenad?)
    - Läste en artikel där det stod att man i parken kan "följa vattnets väg från stenstaden, via en slingrande bäck till en vattenträdgård och sedan vidare till dammen och ut i Bällstaån. Genom bäckens slingrande renas dagvattnet innan det rinner ut i ån" → Kan du berätta lite mer om den här reningsprocessen?
    - Hur kommer det sig att man landade just i den typen av åtgärd? Tittade man på andra alternativ?
    - (Hur anpassar ni era lösningar till olika typer av vattenmiljöer och ekosystem?)
- Hur såg arbetsprocessen ut när ni planerade och genomförde Kyrkparken-projektet, framför allt i samarbetet med kommunen? (vilken ände börjar man i, när kom ni in, hade kommunen en plan osv?)
- Stötte ni på några utmaningar under arbetet?
  - Vilka och hur hanterades de?
- Vet inte riktigt status på parken just nu, är ert arbete där färdigt eller är det fortsatt pågående?

- Har ni än så länge märkt av om parken fungerar som planerat och kunnat mäta hur det bidrar till de olika målen?
    - Hur går sådan uppföljning till?
    - Är det ni som gör det eller är det kommunen? redan sagt

Övergödning

- Känner du till några andra projekt som Ekologigruppen genomfört med fokus på framförallt vattenrening och övergödningsproblematik?
    - Har ni några insikter eller lärdomar från de projekten när det kommer till att tillämpa naturbaserade lösningar för att hantera övergödning?
    - Har ni något material kring det som vi kan ta del av?
- Hur ser du på möjligheten att implementera naturbaserade lösningar inom kommunen för att hantera problem med övergödning? (t.ex. fördelar, nackdelar)?
    - Vad krävs för att lyckas med implementeringen av NbS?
    - Finns det några specifika utmaningar eller möjligheter som ni ser när det gäller att applicera naturbaserade lösningar i Bällstaån?

Blågröna strukutrer eller naturbaserade lösningar

- Generella tankar/upplevelser kring att arbeta med blågröna strukturer eller naturbaserade lösningar (inte bara kring övergödning)? Utmaningar?