FUTURELAKES

For Nature, Climate and People

Optimisation Plans

Strategies to improve restoration success

Deliverable D4.2

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Summary

Since even the best lake restoration programmes have their weaknesses, the six FutureLakes Demonstration Sites have developed individual optimisation plans in order to further progress restoration success. These optimisation plans were made in dialogue with stakeholders and based on the current state of lake management with a view to help shape future lake basin management plans.

To develop their optimisation plan, each Demonstration Site undertook a Strengths-Weaknesses-Opportunities-Threats (SWOT) analysis based on the potential for optimising different elements that could help transform restoration success. The potential of these measures to enhance restoration programmes was evaluated using the IUCN Self-Assessment Tool (SAT). This strategy allowed us to identify gaps and directions for improvement in the current state of lake management in a structured manner. This multistep approach did not just allow for structured learning but also stimulated a deeper dialogue between stakeholders, basin managers and scientific experts.

Individual optimisation plans of the six FutureLakes Demonstration Sites were systematically compared across the following optimisation dimensions: multiple-goals, societal, technical, economic, and policy/regulatory frameworks. Common strengths, evidence gaps, challenges, and transferable lessons were identified to support more effective lake basin management and restoration. The outcomes were synthesised to support learning across the six Demonstration Sites and provide opportunities for replicating and upscaling best practice in Associated Regions and across Europe. The results of this deliverable also serve as a basis for the upscaling dialogues for the Demonstration Sites in T4.3.

Experience from the Demonstration Sites shows that successful lake restoration requires long-term commitment and integrated action across catchments and lakes. All the Demonstration sites highlighted that future programmes should broaden the goals they address to include water quality, biodiversity, climate resilience and societal goals together. Changing policy landscapes with new goals create many new opportunities to strengthen restoration programmes and further implement measures that deliver multiple benefits to water, biodiversity and climate policies, while recognising trade-offs with agriculture, water supply, development and recreation, that may need compensation or careful zoned management around lakes and within their catchments. All programmes indicate climate change is making achievement of water and biodiversity targets harder and all have a need to evaluate the climate-resilience of technical measures and of their management plans as a whole.

Long-term monitoring and scientific evidence are essential for selecting and adapting measures. This was a strength for water quality and ecological data in most of the basin programmes, yet several Demonstration sites face threats to financing on-going environmental monitoring. Despite this, technical optimisation identified the need for monitoring to also cover societal and economic outcomes to identify broader societal and economic benefits of the restoration programmes, and potential trade-offs with key sectors.

New opportunities exist for enhancing monitoring, especially through continuing the citizen science activities developed with communities. The resulting scientific evidence should be made accessible to all stakeholders to systematically guide the design and periodic review of restoration plans. Many Demonstration sites saw opportunities of improved sharing of the data, through open and user-friendly platforms, to support this more evidenced, inclusive and transparent decision-making.

On-going adaptation of restoration programmes was universally considered necessary given climate change, emerging contaminants and the widespread need for greater implementation at scale, as well as the continuing effects of legacy pollution delaying recovery. Success over the long-term, therefore, depends on continuous stakeholder cooperation and inclusive governance supported by strong coordination bodies. Lake restoration does require measures to be implemented at large scale and over the long-term. It, therefore, requires significant up-front financing. A reliance on short-term public funding is both a weakness and a threat to future implementation of measures and long-term

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monitoring. Optimisation of plans should involve better quantification of ecosystem services (such as C sequestration or emission reductions, flood and drought resilience) and the broad societal and economic benefits, especially the potential for nature-friendly recreation and tourism. This knowledge of benefits could open up new financing solutions and investment (e.g. carbon and nature credits, payment for ecosystem services). A more diverse portfolio of public, private and blended financing mechanisms was seen as a way forward to support lake basin management over the long-term.

Synthesis of the six Demonstration Basin optimisation plans was summarised in 12 recommendations to support optimisation of lake basin management plans more generally:

1. Develop integrated restoration strategies that address water quality, biodiversity, climate resilience and societal goals together, while explicitly identifying synergies and trade-offs between objectives.
2. Prioritise measures that have been well evidenced to deliver multiple ecological and societal benefits. Continue to test their effectiveness in new contexts to evaluate their potential for replication in the catchment.
3. Plan restoration at the scale of the whole lake catchment, combining pollution source-control, catchment measures (especially in-field and field edge measures in agricultural areas) and in-lake measures, rather than treating these as isolated interventions.
4. Establish long-term monitoring as an integral and well-funded component of lake restoration programmes, covering water quality and biodiversity responses, as well as societal and economic benefits and trade-offs with key sectors (agriculture, energy, water supply).
5. Use monitoring results within explicit adaptive-management cycles so that measures, objectives and management practices can be adjusted when WFD and biodiversity policy goals are not achieved or in response to climate change or newly emerging pressures.
6. Strengthen the connection between scientific evidence and decision-making by making monitoring information accessible to all stakeholders with interests in the lake and use data systematically to inform management and review of basin management plans.
7. Integrate extreme-event risk management and future climate-change scenarios into the design and periodic review of restoration programmes rather than treating flood and drought management, or climate change more broadly, as a separate issue.
8. Maintain inclusive, transparent and continuous stakeholder engagement with clear coordinating roles essential for basin authorities and actively address gaps in representation, especially of impacted vulnerable groups.
9. Quantify the direct and indirect costs and benefits of restoration, including currently under-valued ecosystem services and societal benefits, including recreation and well-being, to strengthen investment decisions and demonstrate restoration value.
10. Diversify restoration financing beyond reliance on public funding streams by exploring complementary public, private, blended and emerging market finance mechanisms (carbon and nature credits) where appropriate.
11. Improve alignment between water, biodiversity, agriculture, land-planning and climate policies by reducing administrative fragmentation that delays or constrains implementation of measures. Exploit NRR national restoration plan requirements to support this integration.
12. Treat restoration as a continuing learning process by documenting outcomes, sharing lessons and incorporating new evidence, technologies and stakeholder knowledge into subsequent planning and implementation. Support the development of Communities of Practice in basin management at regional, national or international scales.

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Glossary

Biodiversity-focused Solutions (BfS): Solutions focused primarily on active biodiversity restoration, such as habitat creation.

Circular Blue-economy Solutions (CBS): Actions that include recovery of resources (nutrients, biomass) in the restoration process stimulating a blue economy around restoring freshwaters.

Common Agricultural Policy (CAP): a unified European Union program that supports farmers, ensures a stable supply of affordable food, and protects rural economies. Funded through the EU budget, it provides direct income support to growers, stabilizes agricultural markets, and funds rural development projects.

Demonstration Site: (A group of) Lake basins (lake and catchment) in the project that are a focus in WP4 for evaluating an integrated programme of measures (NbS, CBS, BfS, policy, finance, etc.) for lake status, biodiversity, society and economy (Green Deal indicators).

Habitats Directive (HD): a European Union law adopted in 1992 aimed at ensuring biodiversity by conserving natural habitats and wild fauna/flora.

International Union for the Conservation of Nature (IUCN): the world's largest global environmental network. Founded in 1948, it brings together governments and groups to protect nature.

Nature-based Solutions (NbS): Actions to protect, conserve, restore, sustainably use and manage natural or modified ecosystems, which address social, economic, and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services and resilience and biodiversity benefits. This United Nations Environment Programme definition builds on prior definitions from IUCN and the European Commission.

Restoration: the process of assisting the recovery of a damaged or degraded ecosystem towards a target state, such as good status (WFD) or favourable condition (HD).

Self-Assessment Tool (SAT): Used to refer to the SAT from IUCN to analyse NbS. It allows users of the tool to evaluate how well their implemented (or to be implemented) NbS adheres to the golden standard developed by IUCN.

Stakeholder: people/groups with an influence on, or interest in, lake protection and restoration

Strengths-Weaknesses-Opportunities-Threats analysis (SWOT): a tool to analyse a project or strategy. It looks at four areas: Strengths, Weaknesses, Opportunities, and Threats. It is used to analyse what goes well, where areas for growth may lie and what problems might hinder a project.

Urban Waste Water Treatment Directive (UWWTD): European Union law designed to protect the environment and human health from the harmful effects of untreated sewage. It requires member countries to properly collect and treat wastewater from towns and cities before it enters rivers, lakes, or the sea.

Water Framework Directive (WFD): European Directive established in 2000 intended to protect and, where necessary, restore water bodies and to prevent deterioration. Good status means both good chemical and good ecological status.

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Disclaimer

Views and opinions expressed are those of the author(s) only and do not necessarily reflect those of the European Union, European Commission or UKRI. Neither the European Union nor the granting authorities can be held responsible for them.

Artificial Intelligence statement

This report was developed with the help of Artificial Intelligence (AI), in editing and summarizing the findings of the individual optimisation plans. This was done in a closed environment with a special licence which ensured internal-only use of data, and not accessible to other parties. Only data from closed Language models were used, avoiding hallucinations. This information was then verified by reviewing the content involving the authors that provided the original texts.

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1 Introduction

Globally, many lakes are in poor ecological condition, characterised by widespread biodiversity loss and frequent harmful algal blooms (HABs). In Europe, only 54% of lakes achieve the Water Framework Directive (WFD) target of good ecological status. In countries such as the Netherlands, Germany and Poland, more than 60% of surface waters are classified as less than good (European Environment Agency, 2024). This degradation undermines biodiversity, ecosystem functioning and the ecosystem services that support social and economic well-being (e.g., Janssen et al., 2020).

Restoring lake ecosystems is particularly challenging because lakes often act as sinks for pollutants from their catchments (Adrian et al., 2009). Nutrients and contaminants from wastewater, agriculture and industry can accumulate in sediments for decades, sustaining internal loading long after external pressures have been reduced (Søndergaard et al., 2003). Other widespread pressures include water scarcity due to over-abstraction and drought, shoreline degradation and invasive species. Consequently, progress in restoration is often limited or slow. Contributing factors include poorly targeted or insufficient measures, conflicting policy objectives (Carvalho et al., 2019), inadequate financing (Poikane et al., 2024) and long ecological response times that frequently span decades (Abell et al., 2022).

Understanding barriers, recovery lags, emerging challenges and long-term ecological trajectories is therefore essential for designing restoration programmes that can be sustained over time. While Deliverable 4.1 (Kramer et al., 2026) focused on assessing the impacts of past restoration efforts across the six FutureLakes Demonstration Sites (Figure 1), this report aims to identify future opportunities for further improvement of these restoration efforts. Recognizing that even successful restoration plans can be optimised, the report develops six site-specific optimisation plans that aim to maintain and scale-up restoration measures in each basin and support the transformation of future basin management planning.

This optimisation process is timely as Member States are preparing their draft National Restoration Plans for the EU Nature Restoration Regulation (NRR) and will soon be developing the 4th River Basin Management Plans (RBMPs) for the 2028–2033 cycle of the WFD. These provide opportunities to ensure greater policy cohesion between Nature and Biodiversity policy goals. Additional policy initiatives, such as the EU Water Resilience Strategy and recently proposed EU Framework for Climate Resilience also provide new opportunities to influence how lake basin management programmes are taken forward with multiple goals in mind.

The six FutureLakes Demonstration Sites, located in Greece, Finland, the Netherlands, Norway, Poland, and the UK, represent diverse restoration contexts and objectives (Figure 1; Table 1). They experience challenges including eutrophication, biodiversity decline, flood risk, and habitat degradation through combinations of catchment, shoreline, and in-lake restoration measures. Although current objectives are often influenced by legislative frameworks such as the WFD, most restoration programmes originated earlier in response to ecological degradation, declining recreational quality, or water scarcity concerns.

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Figure 1. Location of the six Demonstration Sites of the Future Lakes project.

Table 1. Demonstration Site characteristics.

Demonstration Site	Basin name	Area (km2)	Mean and [max] depth (m)	Direct catchment area (km2)	Country	Primary goals
Lake Vesijärvi	Basin 1 and 2	107	6.8 [40]	514	Finland	Control of eutrophication
Kartuzy Lakes	Mielenko	0.078	1.3 [2]	< 1	Poland	Control of eutrophication
	Karczemne	0.404	1.97 [3]	< 1		
	Klasztorne Duze	0.137	8.1 [20]	22		
	Klastorne Male	0.575	4.8 [9]	103		
Lake IJssel complex	Lake IJssel	1130.7	4.58 [21*]	18770	The Netherlands	Water safety Freshwater supply Well-functioning ecosystem
	Lake Marken	675.2	3.91 [31*]			
Lake Karla		34.9	2.2 [5]	434	Greece	Control of water scarcity Biodiverse ecosystem
Loch Leven		13.3	3.9 [26]	145	Scotland (UK)	Control of eutrophication
Vansjø	Storefjorden	23.8	9.2 [41]	679.91	Norway	Control of Eutrophication

Note: For additional details please refer to Kramer et al. (2026) Annexes a - f).

*The maximum depth in Lake IJssel complex is due to local sandmining.

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Although optimisation opportunities may arise in many aspects of lake restoration, including governance, management, and economics, the plans developed in this deliverable particularly explore opportunities for replicating or upscaling technical solutions evaluated in Deliverables 1.1 (Härkönen et al., 2025a) and 1.2 (Thiemer et al., 2026) where possible. Nature-based Solutions (NbS) are increasingly promoted as approaches that address societal challenges while supporting biodiversity protection and restoration. Circular Blue-economy Solutions (CBS), such as nutrient recovery and biomass reuse, can reduce pollution while generating economic value. Biodiversity-focused Solutions (BfS) explicitly focus on restoring species and habitats and accelerate ecological recovery, thereby strengthening ecosystem resilience.

The site-specific optimisation plans that were developed per Demonstration Site are presented in Chapter 3. The methods by which these plans were developed are presented in Chapter 2. In addition, a synthesis chapter identifies common themes (Chapter 4) across the six plans. From this synthesis, lessons learnt and recommendations for wider uptake in freshwater restoration programmes in other regions are considered (Chapter 5). This deliverable will subsequently provide input to FutureLakes Task 4.3, Upscaling, in which selected optimisation opportunities will be further developed further into more tangible plans and recommendations included in the FutureLakes Blueprint (Task 4.4).

2 Methods

The methods adopted were based on the method used by MERLIN project Deliverable D2.1 Case study optimisation strategies (Buijse et al., 2022). This involved a multistep approach to develop the six individual optimisation plans. These steps were as follows:

1. Filling out the Self-Assessment Tool (SAT) of the IUCN for one or multiple measures taken in each Demonstration Site;
2. Making a Strengths-Weaknesses-Opportunities-Threats analysis based on the SAT answers;
3. Identifying the opportunities for improvement per Demonstration Site based on the results of the SWOTs.
4. Creating the optimisation plans.

During step 1 and 2 of the project, walk-in sessions provided opportunities to discuss any questions arising from the SAT and SWOT analysis amongst the group. Subsequently, during step 3, monthly meetings between Demonstration Site leads and the task leads provided a similar opportunity. Additionally, the Demonstration Site Leads were asked to confer with their stakeholders on the outcomes of the SAT, SWOT and/or the optimisation plans – of which the form and timing of the engagement with the stakeholders was left to the Demonstration Site Leads. More information about each step can be found in the sections below. Steps 3 and 4 also used additional sources of knowledge to the SWOTs including earlier FutureLakes deliverables and local knowledge and experience through conversations with stakeholders.

2.1 IUCN NbS Self-Assessment Tool

To evaluate the strengths and weaknesses of the restoration measures, the IUCN NbS Self-Assessment Tool (SAT) was applied. The SAT was developed by the International Union for Conservation of Nature (IUCN, IUCN 2020) as part of the IUCN Global Standard for Nature-based Solutions and provides a structured framework to assess the quality, effectiveness, and sustainability of interventions against eight criteria and their associated indicators. The tool supports the design, evaluation, and improvement of interventions by considering aspects such as societal relevance, biodiversity benefits,

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stakeholder participation, economic viability, trade-offs, adaptive management, and long-term sustainability.

Although the SAT was originally developed for NbS, in this instance it was also applied to BfS and CBS. Many of the SAT criteria (Table 2) were deemed sufficiently generic to allow assessment of a broader range of restoration measures. For example, criteria related to stakeholder engagement, adaptive management, economic feasibility, governance arrangements, and the evaluation of trade-offs are equally relevant for non-NbS measures. Applying the SAT across all measure types enabled a consistent comparison of their strengths, limitations, and opportunities for optimisation.

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Table 2. Overview of SAT-criteria and indicators.

Theme	Criteria	Indicators	
Societal challenges	1. NbS effectively address societal challenges	1.1	The most pressing societal challenges for rights holders and beneficiaries are prioritised
		1.2	The societal challenges addressed are clearly understood and documented
		1.3	Human wellbeing outcomes arising from the NbS are identified, benchmarked and periodically assessed
Design at scale	2. Design of NbS is informed by scale	2.1	Design of NbS recognises and responds to the interactions between the economy, society and ecosystems
		2.2	Design of NbS integrated with other complementary interventions and seeks synergies across sectors
		2.3	Design of NbS incorporates risk identification and risk management beyond the intervention site
Biodiversity net-gain	3. NbS result in net gain to biodiversity and ecosystem integrity	3.1	NbS actions directly respond to evidence-based assessment of the current state of the ecosystem and prevailing drivers of degradation and loss
		3.2	Clear and measurable biodiversity conservation outcomes are identified, benchmarked and periodically assessed
		3.3	Monitoring includes periodic assessments for unintended adverse consequences on nature arising from the NbS
		3.4	Opportunities to enhance ecosystem integrity and connectivity identified and incorporated into the NbS strategy
Economic feasibility	4. NbS are economically viable	4.1	The direct and indirect benefits and costs associated with the NbS, who pays and who benefits, are identified and documented
		4.2	A cost-effectiveness study is provided to support the choice of NbS including the likely impact of any relevant regulations and subsidies
		4.3	The effectiveness of an NbS design is justified against available alternative solutions, taking into account any associated externalities
		4.4	NbS design considers a portfolio of resourcing options such as market-based, public sector, voluntary commitments and actions to support regulatory compliance
Inclusive governance	5. NbS are based on inclusive, transparent and empowering governance processes	5.1	A defined and fully agreed upon feedback and grievance resolution mechanism is available to all stakeholders before an NbS intervention can be initiated
		5.2	Participation is based on mutual respect and equality, regardless of gender, age or social status, and upholds the right of Indigenous Peoples to Free Prior and Informed Consent (FPIC)
		5.3	Stakeholders who are directly and indirectly affected by the NbS have been identified and involved in all processes of the NbS intervention
		5.4	Decision-making processes document and respond to rights and interests of all participating and affected stakeholders
		5.5	Where the scale of the NbS extends beyond jurisdictional boundaries, mechanisms are established to enable joint decision-making among the stakeholders in those jurisdictions affected by the NbS
Balance trade-offs	6. NbS equitably balances trade-offs between achievement of their primary goal(s) and the continued provision of multiple benefits	6.1	The potential costs and benefits of associated trade-offs of the NbS intervention are explicitly acknowledged and inform safeguards and any appropriate corrective actions
		6.2	The rights, usage of and access to land and resources, along with the responsibilities of different stakeholders are acknowledged and respected
		6.3	Established safeguards are periodically reviewed to ensure that mutually-agreed trade-offs limits are respected and do not destabilise the entire NbS
Adaptive management	7. NbS are managed adaptively, based on evidence	7.1	A NbS strategy is established and used as a basis for regular monitoring and evaluation of the intervention
		7.2	A monitoring and evaluation plan is developed and implemented throughout the intervention lifecycle
		7.3	A framework for iterative learning that enables adaptive management is applied throughout the intervention lifecycle
Mainstreaming	8. NbS are sustainable and mainstreamed within an appropriate jurisdictional context	8.1	NbS design, implementation and lessons learnt are shared for triggering transformative change
		8.2	NbS inform and enhance facilitating policy and regulation frameworks to support its uptake and mainstreaming
		8.3	Where relevant, NbS contribute to national and global targets for human wellbeing, climate change, biodiversity and human rights, including the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP)

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2.2 SWOT

A SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis was conducted for selected restoration measures, or the whole programme, to identify factors that may influence their implementation success and long-term effectiveness. Strengths and weaknesses refer to the internal characteristics of a restoration project that provide advantages or disadvantages relative to alternative approaches. Opportunities and threats represent external factors within the biophysical, social, socio-economic, and institutional environment that may either support or hinder project implementation. To facilitate a systematic assessment across all Demonstration Sites, the Excel-based SWOT template from the MERLIN project (Buijse et al., 2022) was adapted for use within this Task (Table 3). This template guided the experts in identifying and documenting key strengths, weaknesses, opportunities, and threats for their selected intervention(s). While filling out the SWOT template the experts were asked to keep their focus on the relevance of each element for the restoration process.

Table 3. First few rows of the Excel-based SWOT-template used in Task 4.2.

		Internal factors		**External factors**	
		Strengths	**Weaknesses**	**Opportunities**	**Threats**
		characteristics of a project that give it an advantage over others	characteristics that place a project at a disadvantage relative to others	elements in the environment that a project could exploit to its advantage	elements in the environment that could cause trouble for a project
NbS or CBS	**Original SAT score**				
1. Societal challenges					
1.1 Pressing challenges prioritised					
Etc.					

2.3 Optimisation

After filling out the SAT and SWOT templates, the Demonstration Site Leads could start with drafting their optimisation plans. To keep the format of the site-specific optimisation plans similar, the Demonstration Site Leads were asked to synthesize the main points of their SWOT analysis into five categories, also aided by guiding questions (see below). Additionally, the Demonstration Site Leads were encouraged to include relevant findings from other FutureLakes deliverables and/or to take into account information supplied to them via their stakeholders in their plans. The goal in the end was to develop optimisation plans that were as relevant as possible, not to adhere too strictly to the templates.

The five categories and their guiding questions:

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- Multiple goal optimisation
    - *Each Demonstration Site tries to balance multiple goals. What would be ways to better align these goals? Could you think of additional goals that are currently not mentioned but that could be supported by the restoration efforts (e.g., looking at the Green Deal goals)?*
    - *Check SAT category 1, 2, and 5*
    - *Possibly add insights from FutureLakes Deliverable 4.1 (Kramer et al., 2026)*
- Societal optimisation
    - *Is everyone included who should be included? Are all partners included equitably? In which way could partners be included better?*
    - *Check SAT category 5 and 6*
    - *Possibly add insights from FutureLakes Deliverables 2.1 (Szulecka, 2025) and 2.2 (Johannessen and Kramer, 2026)*
- Technical optimisation
    - *Are there new techniques that could be used? Improvements to be made to the current techniques? Also think about if the technique would make the lake comply to WFD / water policy targets.*
    - *Check SAT category 3 and 7*
    - *Possibly add insights from FutureLakes Deliverable 1.1 (Härkönen et al., 2025a) or 1.2 (Thiemer et al., 2026)*
- Economic optimisation
    - *Are the ways to funding being found? (Possibly by including a new goal) Are there new financial resources to consider?*
    - *Check SAT category 4 and 6*
    - *Possibly add insights from Deliverable 3.1 (Albrecht et al., 2025)*
- Policy / regulatory optimisation
    - *Are all policies clear? Are regulations followed? Are there opportunities for policy implementation improvements that could help the restoration efforts?*
    - *Check SAT category 8*
    - *Possibly add insights from Deliverable 3.2 (Kamergi et al., 2026)*

To harmonize the plans even further, each category was subsequently structured to start with an introduction of the current approach of the category at the Demonstration Site, then explain the strengths, weaknesses, opportunities and threats, and lastly to discuss the optimisation. To guide the

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reader, these sections can still be identified by the following words in bold text: “Currently”, “Strengths”, “Weaknesses”, “Opportunities”, “Threats”, and “The way forward”.

After all plans were drafted, they were reviewed by the first author of this deliverable and further harmonized by both the first authors and the respective Demonstration Site Leads where required. Subsequently, the synthesis and conclusion sections were derived based on the information provided in the plans.

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3 Demonstration Site optimisation

3.1 Kartuzy Lakes

The Kartuzy Lakes complex consists of four post-glacial lakes: Lake Mielenko (area 0.079 km^2, max depth 1.9 m), Lake Karczemne (area 0.404 km^2, max depth 3.2 m), Lake Klasztorne Małe (area 0.137 km^2, max depth 20 m) and Lake Klasztorne Duże (area 0.575 km^2, max depth 8.5 m), located in the Kashubian Lake District (Northern Poland; Figure 2). The Kartuzy Lakes are connected by the Klasztorna Struga River (length 10.27 km), which originates at the outflow of Mielenko Lake (Grochowska, 2024).

All four lakes received untreated domestic, stormwater and industrial wastewater for several decades. Of the four, Lake Karczemne and Lake Klasztorne Małe received the largest volumes of untreated sewage, through six and five sewage inflows, respectively. Following the commissioning of a wastewater treatment plant in the 1980's, a substantial portion of the domestic wastewater was diverted for treatment. However, storm sewage was still discharged directly into the lakes. As the stormwater drainage system was also partially connected with the wastewater drainage system, wastewater could still enter the lakes during periods of heavy rainfall and snow melts. After decades of pollution, the Kartuzy lakes were transformed into hypertrophic and even saprotrophic lakes and lost most of their ecosystem services abilities. The only ecosystem service they retained was as an angling site (for a limited range of fish).

Considering the poor water quality of the Kartuzy Lakes and the high potential for internal nutrient loading, the main goal of the Kartuzy Lakes restoration programme was to improve the water quality of the lakes. In the longer term, the programme also aimed to improve the ecosystem services, including recreation, tourism, and biodiversity. The first step to improve the water quality of the lakes was the modernization of the stormwater and wastewater drainage system (Grochowska and Tandyrak, 2021). Following this modernization in the mid-2010s, lake-specific restoration plans were developed based on comprehensive ecosystem assessments. Phosphorus inactivation was selected as the most suitable restoration measure for all Kartuzy Lakes. However, for the most polluted lake, Karczemne, sediment dredging was used before the phosphorus inactivation as this lake had extremely high amounts of P stored in the sediment (Grochowska et al., 2021). The dredged sediment from this lake was subsequently treated at a local wastewater treatment plant and converted into a product ready for agricultural use as fertilizer (a Circular Blue-economy Solution). To support the restoration efforts, Nature-based Solutions were also applied in the Kartuzy Lakes. These took the form of biomanipulation of the fish community. In specific, predatory fish species were introduced to the lakes: pike and zander in Mielenko Lake and pike, zander, and asp in Karczemne Lake and the Klasztorne Lakes. Additionally, a proportion of undesirable benthivorous and zooplanktivorous cyprinid species was removed.

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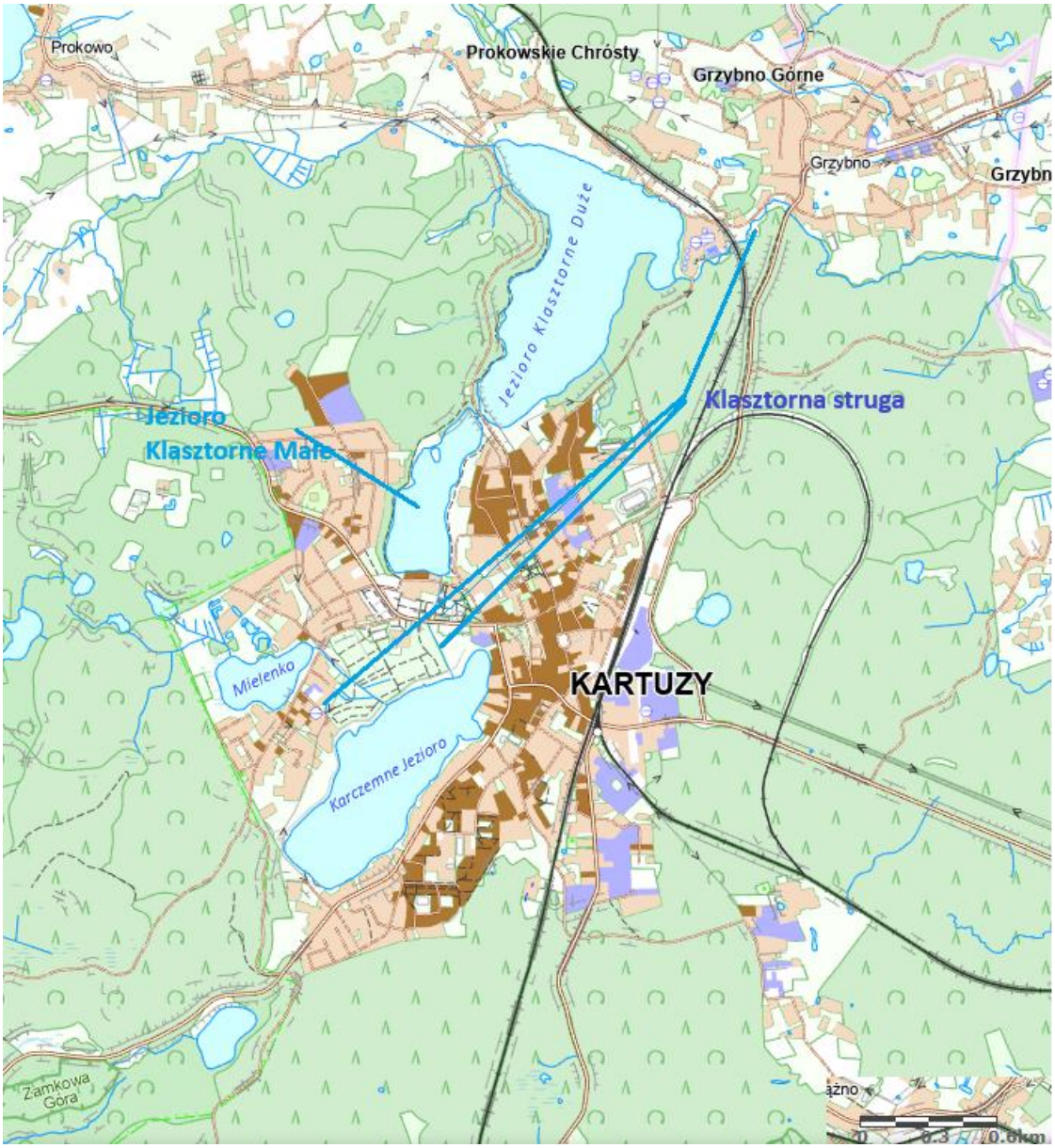


Figure 2. The Kartuzy Lakes complex (source: www.geoportal.gov.pl, modified).

The restoration programmes for the Kartuzy Lakes were implemented between 2020 and 2023 (Grochowska et al., 2023, Grochowska, 2024, Kramer et al., 2026) and their objectives were aligned with United Nations Sustainable Development Goals 6 (Clean water and sanitation), 11 (Sustainable cities and communities), 13 (Climate action), and 14 (Life below water).

3.1.1 Self-Assessment Tool (SAT) results

To provide an integrated assessment of the restoration programme, the Self-Assessment Tool (SAT) was applied across eight criteria covering ecological, social, governance, and economic dimensions. The overall score of 0.9 indicates that the restoration programme performs strongly in all areas, particularly inclusive governance, balancing trade-offs and adaptive management (

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Table 4). The following optimisation assessment explores these results in greater detail.

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Table 4. Self-Assessment Tool (SAT) results for Kartuzy Lakes.

Criterion	Your Criterion Score	Maximum Criterion Score	Normalised criterion	FINAL OUTPUT Your Criterion %age
1. Societal challenges	9	9	1.00	1.0
2. Design at scale	8	9	0.89	0.9
3. Biodiversity net-gain	10	12	0.83	0.8
4. Economic feasibility	9	12	0.75	0.8
5. Inclusive governance	15	15	1.00	1.0
6. Balance trade-offs	9	9	1.00	1.0
7. Adaptive management	9	9	1.00	1.0
8. Sustainability and mainstreaming	7	9	0.78	0.8
Total			7.25	0.9

Key		
	≥75	Strong
	≥50 & <75	Adequate
	≥25 & <50	Partial
	<25%	Insufficient

3.1.2 Multiple goal optimisation

Currently, the main goal of restoration efforts in the Kartuzy Lakes was the improvement of their hydrochemical and biological conditions. However, these improvements were also expected to generate wider societal and environmental benefits. Given their location within an urban area, the lakes represent an important recreational resource for local residents. Restoring water quality was therefore closely linked to improving opportunities for recreation and leisure activities. In addition, the restoration measures supported the recovery of biological communities within the lake ecosystem.

A key **strength** of the multiple goals of the Kartuzy Lakes restoration was that the foundation of these goals was built on scientific knowledge and that the goals were supported by the local community who has seen the lake degrade over the last decades. For the local community the Kartuzy Lakes are a valuable part of the city and the technical restoration (aimed to improve water quality) helped to rebuild the recreational aspects (e.g., contact with nature, safe angling, swimming, rowing etc.) which were missed for decades.

A **weakness** of the restoration efforts from a multiple goal perspective was the lack of data from the lakes. Three lakes were too small to fulfil the criteria for inclusion in the national monitoring and only partial data from Lake Klasztorne Duże were present in the national WFD monitoring. This lack of data delayed drafting the restoration programme. Furthermore, economic factors, although included, were not weighed heavily into the initial set up of the restoration plan.

The implementation of the restoration programme creates further **opportunities** to renovate ecosystem services benefitting local communities and tourists, particularly angling, swimming, and recreational activities.

Because of the heavy pollution of the Kartuzy Lakes, the restoration methods that had to be implemented were rather expensive. These high costs may be seen as a **threat** to implementation of the full restoration programme, if for example, further measures are needed and part of the funding could be denied.

The way forward for multiple goal optimisation should lie in the prevention of lake pollution, taking into account the possible impacts of the local community and climate change. Local ruling boards should be (made) aware of the fact that prevention and protection is always cheaper than a full technical restoration, while also keeping in mind that healthy lake ecosystem provides a range of benefits to the local community and nature (e.g., higher potential biodiversity, lower GHG-emissions, increased well-being of people)

3.1.3 Societal optimisation

The preparation of the Kartuzy Lakes restoration programme required cooperation among multiple stakeholders, including the Municipality of Kartuzy, the University of Warmia and Mazury in Olsztyn (scientific partner and author of the restoration concept), the Kartuzy Water and Sewerage Company (KPWiK), the National Water Holding “Polish Waters” (owner of three Kartuzy Lakes), the private owner of Lake Karczemne, the Polish Angling Association (responsible for fisheries management), as well as other local NGOs and citizens (Szulecka, 2025).

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Cooperation and trust among stakeholders were crucial to the success of the **current** restoration effort. The Municipality of Kartuzy played a leading role in coordinating the restoration plans, facilitating discussions and helping to achieve compromise where needed. Providing information to and engaging with the public also played a vital role in the process. In fact, it was local citizens who initially contacted the Municipality about the bad state of the Kartuzy Lakes and thus provided the initial demand for the restoration of the lakes. As a result, informing the public about the restoration efforts became a priority. Progress on the restoration programme was communicated through press and online publications, while informational events were organised for local citizens and organisations.

A key **strength** of the societal aspects of the Kartuzy Lakes restoration efforts was that all decisions about the restoration measures were discussed and approved by relevant stakeholders, ensuring that decisions were based on mutual trust and acceptance. For example, the decision to implement biomanipulation in the lakes was discussed with the Polish Angling Association, the National Water Holding "Polish Waters" and the private owner of Lake Karczemne. In addition, all decisions were thoroughly documented, with stakeholder consultations included as annexes, and were incorporated into the official Fishery Planning Legal Documents for the Kartuzy Lakes. All restoration actions were described and published on the project website, making this information publicly accessible, and the need for the restoration efforts was clear to the local citizens.

A **weakness** of the societal aspect was that the multitude of stakeholders included in the process made it sometimes challenging to obtain suitable compromises.

The variety in stakeholders involved in the restoration efforts also provided an **opportunity**: it paved the way for further upscaling of the chosen (NbS) restoration measures. The plans of biomanipulation were adopted for every Kartuzy lake after consultation with Polish Angling Association (fishery user of three Kartuzy Lakes) and privater owner of Karczemne Lake. Engaging adequate stakeholders in the decision making process and development of NbS is good practice for upscaling particular method.

A **threat** to the using NbS solution for the lake restoration is lack of mutual trust between stakeholders, and forcing options unfavourable for obtaining good final effect of restoration. For example, a fishery user could opt for introduction of phytophagous fish (such as *Ctenopahryngodon idella*, which is a non-native fish species) for fighting with excessive macrophytes growing, as this is in practice for artificial pond management. Therefore, the representation of scientists with experience in limnology and fisheries among stakeholders is necessary, and reaching a compromise is demanded.

The way forward for societal optimisation would lie in good cooperation between stakeholders by establishing an official working group directed to lake management. Kartuzy Lakes restoration example showed that a model with a leading stakeholder (Kartuzy Municipality) which coordinates actions in lakes' management and creates platform for stakeholders' engagement. It is worth of noting, that despite Kartuzy Municipality is not the owner of Kartuzy Lakes, it plays the role of "owner", and initiates lakes' management in the Kartuzy City in agreement with the actual owners. Also keeping a local community informed should be normal practice in lake restoration and management.

3.1.4 Technical optimisation

The **current technical approach** in the Kartuzy restoration programme was based on sound limnological knowledge and supported by extensive hydrochemical and biological monitoring before, during, and after implementation. Environmental conditions, particularly hydrochemical characteristics, formed the basis for assessing biological components and selecting appropriate restoration measures. Monitoring data were used to guide the design of the restoration plan, evaluate the effectiveness of interventions, and analyse the responses of biological communities to restoration-induced environmental changes. In addition, a risk assessment was conducted when selecting fish species for biomanipulation. Long-term monitoring datasets have shown improvements in water quality and biological communities, demonstrating the importance of monitoring as a foundation for adaptive lake restoration.

During project preparation, the initial dredging concept involved storing extracted sediments in specially constructed shoreline reservoirs and transporting the material to the wastewater treatment plant (WWTP) using slurry tankers. During technical consultations with dredging companies, an alternative approach involving direct hydrotransport of sediments to the WWTP via pipeline was proposed. This concept was subsequently developed into a dedicated pipeline and a sediment treatment facility at the Kartuzy WWTP (Kramer et al., 2026: DS-Annex b). Following sediment removal and P inactivation a nature-based solution in the form of biomanipulation was implemented. This measure contributed to a decrease in the abundance of invasive gibel carp and changes in the proportion of predatory fish relative to cyprinids (Figure 3). Furthermore, due to the improvement in water quality the presence of new plant species was noted in Lake Mielenko: *Chara delicatula* was spotted near the southern lake shore (Kramer et al., 2026: DS-Annex b).

As the Kartuzy Lakes had not been subject to systematic biological monitoring in the past, with the exception of Lake Klasztorne Duże, baseline biodiversity data were largely unavailable prior to the restoration programme. Historical and current monitoring provide valuable information on biodiversity changes over time (Kramer et al., 2026: DS-Annex b). Monitoring results indicate gradual improvements in biological components following restoration, although macrozoobenthos in Lake Karczemne may require a longer recovery period due to the intensive sediment removal intervention (Kramer et al., 2026: DS-Annex b).

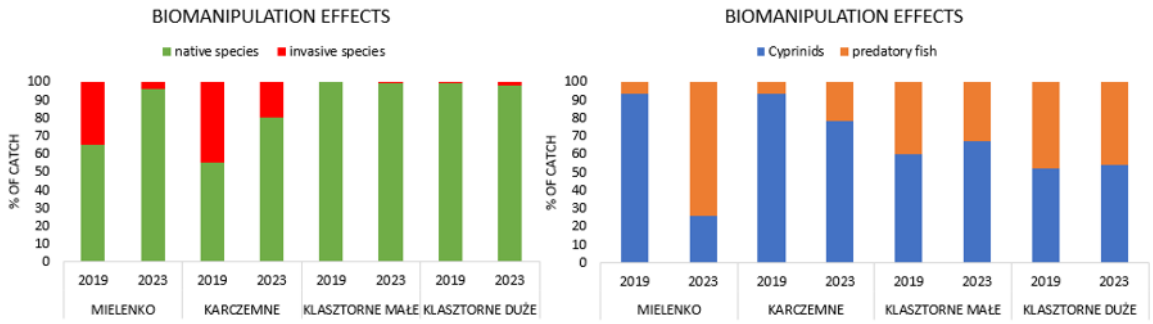


Figure 3. Changes in the percentage of invasive gibel carp species in the ichthyofauna of Kartuzy lakes, and in the percentage of predatory fish in the ichthyofauna of Kartuzy lakes (after Kramer et al., 2026: DS-Annex b).

The lessons learned from the restoration process, monitoring programme and observed ecological responses were synthesised in a SWOT analysis to identify areas where the current technical approach performs well and where further optimisation may be beneficial.

A key **strength** of the restoration programme was its flexibility during both planning and implementation, allowing measures and management approaches to be adapted in response to changing conditions, new knowledge, and emerging challenges. A thorough system diagnosis, including hydrochemical and biological data collected before the intervention and a systematic literature review, provided the basis for the development of the restoration plans.

Major **weakness** of the Kartuzy Lakes restoration efforts was the lack of historical monitoring data. This created the need to collect hydrochemical and biological information before restoration planning could start. Also, some technical restoration aspects, i.e., dredging and sediment hydrotransport, generated noise and thereby caused a disadvantage for local citizens.

Opportunities for further restoration efforts may lie in utilising funding resources to adopt cheaper and more effective solutions. For example, in the case of Kartuzy Lakes a pipeline turned out to be a cheaper way to transport polluted sediments, in comparison to the initially proposed use of slurry tankers, and this solution could be adopted for other lakes, restored with sediment dredging. Also using NbS solutions for minimizing the influence of excessive rainfall events on lake could be good

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strategy for Karczemne Lake protection. The Kartuzy Municipality together with UWM will develop such solutions in the next step of maintaing restoration effects.

A potential **threat** to the long-term success of the programme could be the lack of securing funding for post-intervention monitoring, especially in the case of biological restoration methods, where ecological responses may occur gradually and may require longer time periods before becoming visible. Lake restoration is not a one-time undertaking; it often requires a series of follow-up steps to sustain positive results. Hence, the financing for further actions helping to maintain the obtained restoration effects, if they will be necessary is very important.

The way forward for technical optimisation at the catchment scale could be to systematically include the impact of human pressures on the ecosystem states of lakes while working on spatial planning in the catchment scale. Additionally, funds for post-intervention monitoring and the incorporation of post-intervention monitoring costs into lake management programmes.

3.1.5 Economic optimisation

The funding of a lake restoration program is probably one of the most challenging aspects of the lake restoration process in Poland. As the majority of lakes are managed by the National Water Holding "Polish Waters" (NWHPW), Poland's national water authority, it is generally expected that lake restoration initiatives will be financed through public funds. However, NWHPW is responsible for thousands of lakes, making it unrealistic to expect systematic funding for restoration measures for all lakes. Every entity generating pollution pays for this to the NWHPW, including fines for excessive pollution. But money is directed for other aims eg. rivers conservation for flood prevention, not for lake restoration. This is despite the organisations obligation to fulfil the expectations of the WFD, which requires a good ecological status of all surface waters by 2027. Consequently, the need for lake restoration is often identified and championed by local communities and supported by local governance institutions, such as municipalities and communes.

The **current approach** of the Kartuzy Lakes restoration programme provides a prominent example of a successful restoration initiative driven by a local community and supported by a local government, in this case the Municipality of Kartuzy. The first stage of the programme focused on the modernisation of the stormwater and sanitary wastewater infrastructure within the Kartuzy Lakes catchment (Grochowska and Tandyrak, 2021). Funding for these measures was obtained from a European Union programme, with an additional contribution provided by the municipality. Subsequently, a comprehensive ecosystem assessment was conducted by the University of Warmia and Mazury (UWM) in Olsztyn to evaluate the ecological status of the Kartuzy Lakes, which was funded by the Municipality of Kartuzy. Based on the findings of this assessment the municipality, with substantial aid from UWM, was able to develop a restoration programme that successfully secured financial support from the EU Infrastructure and Environment Programme and the National Fund for Environment Protection and Water Management. This funding enabled the implementation of a range of in-lake restoration measures, including dredging and biomanipulation (see section 3.1.4 Technical optimisation). Of these measures dredging and treating the sediment of Lake Karczemne was the most expensive and logistically difficult (consuming ca. 50% of total restoration costs), while the biomanipulation of the fish structure was the cheapest measure.

One of the **strengths** of the availability of public funding for lake restoration programs in Poland is the possibility to gain substantial resources for ambitious lake restoration programs. Another strength, in the case of the Kartuzy Lakes restoration, was the fact that the appropriate restoration methods were chosen firstly based on science and only secondly based on costs.

However, smaller communes or local associations with smaller budgets can have difficulties in gaining funds from grant programs, which is perceived as a **weakness**. Successfully applying to grant programmes often requires preliminary research and the development of a restoration plan, which can be a relatively costly burden. Local communities focus their efforts on obtaining funding from

public sources, rather than from private sources. Funding sources other than public for lake restoration are rather marginal in Poland.

Opportunities could occur by developing other forms of lake restoration program financing (e.g., private funding, or blended funding) that could help smaller communes gain financing for lake restoration plans. Moreover, choosing cheaper lake restoration solutions, amongst which NbS, could also help in the realization of restoration plans. Biological methods could be effective, but in the case of heavily polluted lakes, NbS role is rather to support stronger working lake restoration methods, as they alone are too weak for obtaining good efficiency in relatively short time

A **threat** to the continuation of a restoration program is the failure to achieve its goals, by which public money will be wasted and which might also cause a loss of faith in how well restoration measures work.

The way forward for economic optimisation lies in ensuring that every lake restoration program has a solid scientific foundation. This will maximise the impact of the restoration efforts and prevent ill-fitting measures from being taken. Furthermore, it would be beneficial to further explore and develop financing mechanisms – other than public funding – in Poland, as the smaller communes and local associations have problems with financing ecosystem assessments and/or lake restoration initiatives.

3.1.6 Policy / regulatory optimisation

Policy and regulatory frameworks are a vital part in the preparation of effective lake restoration plans. At the same time, existing legal regulations may function as a slowing factor and/or a barrier during the preparation phase of a lake restoration project. The **current** distribution of legal competences over various institutions requires additional effort in planning and preparation of restoration programs. In some cases, procedures within different institutions are not well-aligned with each other and/or in regard to certain parts of plans, which brings difficulties in preparing these documents. It requires strong cooperation and mutual trust among the stakeholders to overcome these challenges.

The preparation of the Kartuzy Lakes restoration project was coordinated by the Municipality of Kartuzy, with the participation of experienced officers specializing in environmental protection law, the Water Act, and other legal acts. Cooperation with UWM in Olsztyn and other stakeholders facilitated the preparation of a strong funding application and a well-developed implementation programme. In 2013, following the initial research on the Kartuzy Lakes complex conducted to develop a long-term protection and restoration strategy, the Municipality of Kartuzy undertook efforts to incorporate the restoration plan into the water management planning framework of the Pomorskie Voivodeship and the Gdańsk Regional Board of Water Management.

A key **strength** of the policy and regulatory elements regarding the restoration of the Kartuzy Lakes was a close cooperation between the main stakeholders with expertise in legal, scientific and engineering matters while the restoration plans were drafted. Without this strong partnership the lake restoration program would likely not have been realized.

The complicated legal procedures and fragmentation of competences between different institutions lengthened the time required for project preparation, thus proving a **weakness** to the restoration efforts.

The publicly available information generated through the Kartuzy Lakes restoration programme provides an **opportunity** to help other entities in preparation of full-scale lake restoration projects.

Complicated and inconsistent policies dispersed between different institutions create barriers for inexperienced applicants in the development of lake restoration projects and therefore represent a **threat** to restoration efforts. Additionally, long-lasting legal procedures could be critical for the schedule of the whole restoration process. Hence, in the case of EU-funded projects (such as the Kartuzy Lakes restoration plan) this poses time-pressure for fulfilling all planned actions.

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The way forward for policy and regulatory aspects would be the continued cooperation between UWM and the Kartuzy Municipality, thus ensuring that the monitoring efforts are continued and that further challenges to the ecosystem state of the Kartuzy Lakes are being recognized and solved. For example, due to the continued cooperation and monitoring the possible negative impact of the thick ice cover on the lakes in the winter of 2025, with possibly oxygen depletion and consequent fish kills, was prevented in Lake Klasztorne Małe. Additionally, continued sharing of the knowledge that the Municipality of Kartuzy gains through the research on the Kartuzy Lakes with other municipalities would also be recommended. Especially seeing that their current efforts receive very positive feedback.

3.1.7 Stakeholder evaluation

During the Kartuzy Lakes restoration project, the main stakeholder, the Municipality of Kartuzy, was responsible for overseeing and implementing the entire restoration programme. Throughout the project, the Municipality demonstrated a high level of trust in the scientific experts involved. This mutual trust proved valuable in addressing challenges and overcoming difficulties encountered during the restoration process. An important lesson learned by all stakeholders was the need for flexibility in decision-making and implementation. The ability to adapt to changing conditions and unforeseen circumstances was essential to the project's success.

Cooperation among stakeholders continues today within the framework of the FutureLakes project through the organisation of Critical Friends Meetings, which provide an ongoing platform for knowledge exchange, reflection, and collaborative learning. Establishing such platform for lake management allows to answer very quickly for emerging problems, as well as to plan and to create future actions. Critical Friends group for Kartuzy Lakes, as it will be demonstrated in planned D 2.3 deliverable is task-oriented, active group of stakeholders.

3.2 Lake IJssel complex

The current shape of the Lake IJssel complex (Figure 4) was created by a sequence of measures: 1) the closure of the former Zuiderzee to the Wadden Sea through the construction of a large dike (Afsluitdijk) in 1932, 2) the reclamation of the Lake IJssel polders finalised in 1968 and 3) the construction of another large dike (Houtribdijk) in 1976. After the closure of the Afsluitdijk, the water in Lake IJssel became freshwater within a few months, effectively removing the former brackish transition zone to the sea. The salt and brackish organisms that originally inhabited the ecosystem were replaced by a freshwater species over the span of five years. The Lake IJssel complex is the largest lake complex in the Netherlands, consisting of two large lakes and a series of smaller “border lakes” that are situated around some of the reclaimed areas (Figure 4). Within FutureLakes we only study Lake IJssel and Lake Marken (with the latter including Lake IJ) and refer to these two lakes as the Lake IJssel complex.

Although the main reason for constructing the Afsluitdijk, and thereby the creation of the Lake IJssel complex, was flood risk reduction, the complex has become a crucial part of water management in the Netherlands. The lakes supply drinking water, water for irrigation, and are used to flush salt or highly eutrophic water out of canals and drainage ditches in other parts of the Netherlands. As such, the Lake IJssel complex has been nicknamed “the rain barrel of the Netherlands”. On top of that, the lakes provide a habitat for a plethora of birds, fish species and water plants, are used to mine sand, and are used for inland waterway transport and recreation. The water level and water quality of the Lake IJssel complex is carefully managed by Rijkswaterstaat, a governmental body that is part of the Ministry of Infrastructure and Water Management and that is dedicated to enhancing safety, mobility and quality of life in the Netherlands.

The Lake IJssel complex is labelled as (heavily modified) WFD water bodies and is a designated Natura 2000 area. Especially Lake Marken is an important national and international area for birds.

The main pressures experiences by the ecosystems are water level management, lack of shallow land-water transitions and their impacts on the ecosystem (e.g., less biodiversity and/or biomass), and (the after-effects of) eutrophication.

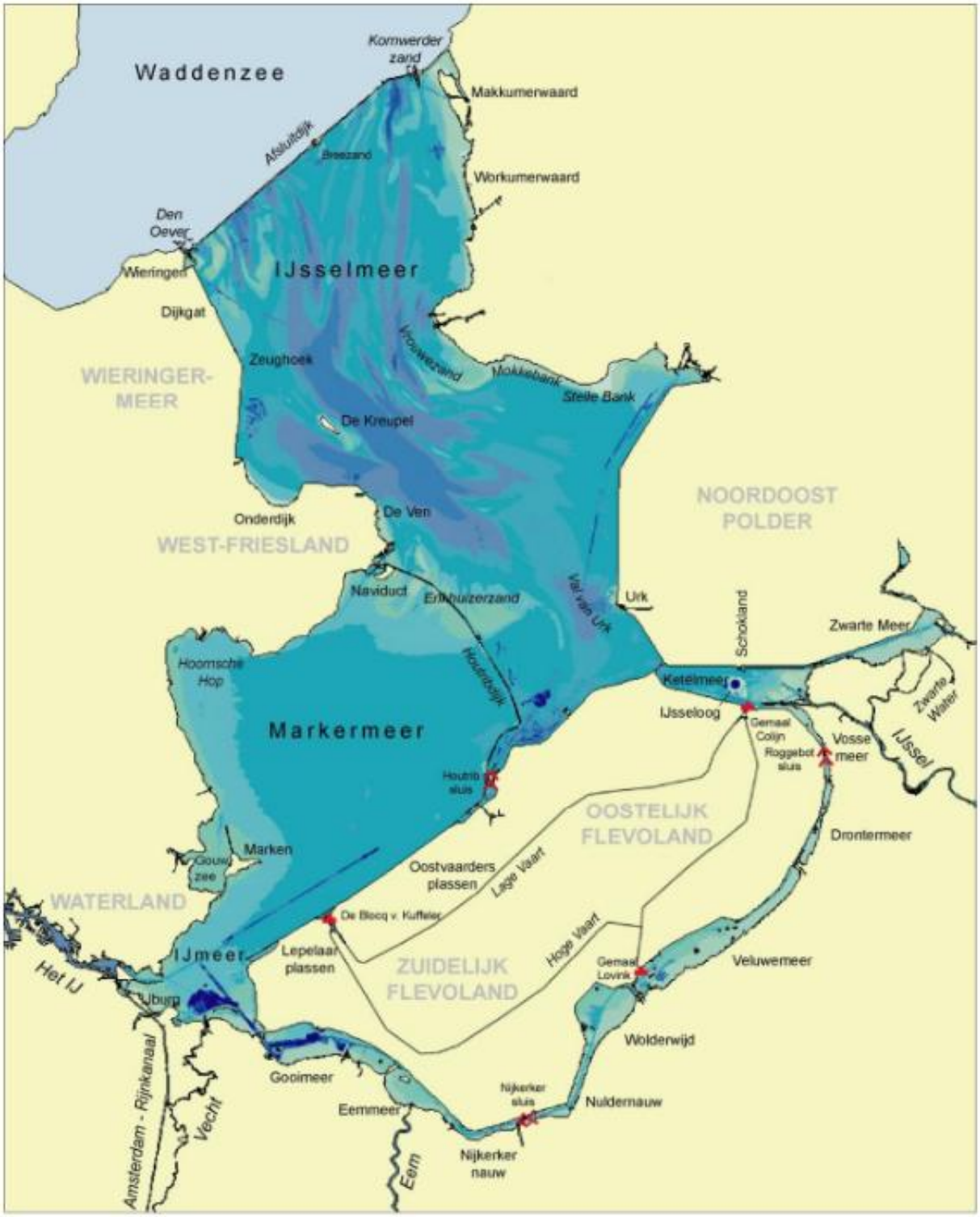


Figure 4. Map of the Lake IJssel complex and its surrounding area. Markermeer = Lake Marken, IJsselmeer = Lake IJssel, Waddenzee = Wadden Sea. Source: Noordhuis et al. (2014).

Darker blue colours indicate a greater depth.

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3.2.1 SAT Self-Assessment Tool results

The SAT assessment (Table 5) indicates that the Lake IJssel complex performs at an overall adequate level (overall score: 0.60), reflecting a well-developed management framework with several strong elements, while also highlighting opportunities for further integration of ecological and economic objectives.

The highest scores were achieved for societal challenges (0.80) and design at scale (0.80), demonstrating that management of the lake complex effectively addresses regional needs and is implemented at a system-wide scale. Biodiversity net gain also scored relatively highly (0.70), reflecting the goals and positive ecological outcomes associated with restoration initiatives such as Marker Wadden, shoreline restoration projects, and other nature-based solutions.

Moderate scores were obtained for inclusive governance (0.60), balance of trade-offs (0.60), adaptive management (0.60), and sustainability and mainstreaming (0.60), indicating that mechanisms for stakeholder engagement, learning, and long-term integration of restoration objectives are in place, but could be strengthened further. The lowest score was recorded for economic feasibility (0.40), reflecting the limited collection and availability of information on the economic costs and benefits of restoration measures and the continued reliance on public funding sources.

Overall, the SAT results suggest that the Lake IJssel complex provides a strong foundation for integrated lake management, while future optimisation efforts could focus on improving the quantification of economic benefits, strengthening adaptive management, and further balancing ecological restoration objectives with the many societal functions of the lake system.

Table 5. Self-Assessment Tool (SAT) results for Lake IJssel complex.

Criterion	Your Criterion Score	Maximum Criterion Score	Normalised criterion	FINAL OUTPUT Your Criterion %age
1. Societal challenges	7	9	0.78	0.8
2. Design at scale	7	9	0.78	0.8
3. Biodiversity net-gain	8	12	0.67	0.7
4. Economic feasibility	5	12	0.42	0.4
5. Inclusive governance	9	15	0.60	0.6
6. Balance trade-offs	5	9	0.56	0.6
7. Adaptive management	5	9	0.56	0.6
8. Sustainability and mainstreaming	5	9	0.56	0.6
Total			4.91	0.6

Key	
≥75	Strong
≥50 & <75	Adequate
≥25 & <50	Partial
<25%	Insufficien

3.2.2 Multiple goal optimisation

Due to its central location in the Netherlands, its large size, and its historical development, the Lake IJssel complex fulfils a wide range of functions. It provides habitat for numerous species, including migratory birds and fish, and supports freshwater supply for irrigation, drinking water, industrial cooling, and the mitigation of salt intrusion. During winter, the lake also serves as a buffer, storing water from the surrounding catchment. In addition, its sandy sediments are extracted for commercial use, while both commercial and recreational navigation take place on the lake. Reflecting these diverse functions and interests, the **current approach** of the coordination platform (also see 3.2.3) for the lake complex is organised around five overarching themes: freshwater availability, flood risk reduction, a future-proof ecosystem, a world-class landscape, and economic vitality. Together, these themes provide a framework for balancing the needs of the many stakeholders that depend on the lake system.

Many ongoing initiatives in the Lake IJssel complex are already designed to achieve multiple objectives simultaneously. A well-known example of this is Marker Wadden, a group of artificial islands in Lake Marken created between 2016 and 2020. Marker Wadden is an NbS that combined nature development, the use of local lake sediments, and recreational opportunities (Thiemer et al., 2026). The recently proposed MarkenWadden+ expansion would try to continue this approach by combining

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nature development with sand extraction while also creating deeper areas in the lake that may benefit fish. Other examples of the combination of multiple objectives include the implementation of flexible water levels (Thiemer et al., 2026), which represented a first step of integrating ecological considerations into a measures programme that primarily aimed at drought prevention and flood-risk mitigation, and ongoing dike reinforcement projects that seek to combine flood protection with nature development. Similarly, the climate buffer project that is being developed by a local drinking water company aims to secure future drinking water supplies while enhancing water purification through reed marshes and supporting biodiversity (PWN, 2026). Together, these initiatives demonstrate a growing focus on combining objectives and maximising co-benefits across the Lake IJssel complex.

A key **strength** in the Lake IJssel complex is the fact that considering multiple goals is already being implemented and has been shown to be beneficial as well. For example, the NbS Marker Wadden was designed with both nature and recreation in mind, and the outcome has been quite successful in both these endeavours. Additionally, the Lake IJssel complex, and in particular Lake Marken, benefits from a long history of monitoring efforts. Nutrient concentrations, birds, macrobenthos, plants, water balances have all been monitored for decades. Process-based computer models of both ecosystems are also available. The availability of the monitoring data and computer models make it easier to estimate possible impacts of measures in the near (and far) future.

A **weakness** of taking multiple goals into account in the Lake IJssel complex is the lack of monitoring of the impact of NbS and other nature restoration efforts on human well-being and on the economic benefits these measures might have. Additionally, even though a lot is known about the ecosystem, this does not translate into certainties in regard to the impacts of measures, also due to the complexity of the system (e.g., for the flexible water level innovation the impact of climate change was substantially underestimated even though thorough research was done and modelling efforts were applied). Moreover, transfer of the knowledge that is gleaned from implementing innovative measures (e.g., the implementation of Marker Wadden) to other nature restoration projects is not guaranteed, potentially hindering the optimisation of multiple goals.

The further development of foreshores in the 'Programmatische Aanpak Grote Wateren' (PAGW, roughly translated into Programmatic Approach for Large Bodies of Water) would be a good **opportunity** to continue designing flood prevention measures together with nature and recreation. Such designs are already being implemented in several areas in the lake complex. Additionally, sand mining companies that are active in the lakes are unable to use the top layers of sediment in their regular activities and thus need to find a good alternative location for this 'unusable' sediment. A cheap(er) solution for these companies would be to use this unusable sand and sediment for creating additional islands around Marker Wadden (e.g., MarkerWadden+).

A key **threat** to the Lake IJssel complex is posed by climate change. The river IJssel supplies on average 70% of the water to Lake IJssel and is largely dependent on precipitation in the Rhine basin. A lack of rainfall and/or snowmelt in the catchment in combination with prolonged periods of drought means that the freshwater supply to Lake IJssel dwindles which in turn can create substantial water shortages with severe consequences for water supply, transport and nature (NOS Nieuws, 2026a). Additionally, even though the creation of new islands can be beneficial to bird and fish populations and to the ecosystem, it remains important to control how and where these islands are built to ensure they fit into the larger vision of the lakes. Building artificial islands also takes away from (i.e., threatens) the open water nature the lakes provide and thus should be considered carefully. Furthermore, opening up restored nature areas for recreation requires careful monitoring to prevent undesired impacts, especially during the breeding season of birds or fish. Lastly, there is an increasing trend in both chronic and acute toxic pressure when considering (almost) all the substances that are being monitored (van Eck and Pit, 2025). When focusing solely on substances regulated under the WFD, this trend is less pronounced and relatively stable (van Eck and Pit, 2025). However, if this rise in toxic pressure would remain unaddressed it could lead to a decline in species richness and ecological quality, disrupt food webs, and increase ecosystem vulnerability.

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The way forward for optimisation of multiple goals in the Lake IJssel complex could be by working on a renewed integrated vision for the Lake IJssel complex, combining ecological (carrying) capacity with desires for energy use, shipping routes, recreational efforts and other elements. Developing such a plan might aid in making the best possible trade-offs and in improving the speed by which decisions are made. The previous vision appears to have been made in 2002, when, for example, the substantial impacts of climate change were much less apparent. The recently created "IJsselmeerkompas" (Arcadis, One Architecture, SMARTLAND, 2023), could aid in this endeavour. When designing the vision for the Lake IJssel complex the impact its catchment may have on the lakes should not be neglected. For example, decreasing the dependency of the hinterland on the freshwater lake supply by improving the sponge-capacity of the soils in the catchment could lessen the impact of climate change (i.e., drought) on the lakes. Also, according to the findings in Kramer et al. 2026 (D4.1), less eutrophication could lead to less CH_4-emissions. Hence, continuing to improve the water quality and stimulating the growth of submerged water plants could potentially address both WFD and climate goals.

The expansion of Marker Wadden via MarkerWadden+ could be beneficial to the ecosystem and to the stability of the current islands. However, its implementation should be carefully considered, also in the larger whole of the lake ecosystem, as the creation of 'dry islands' runs counter to the open water character of the lake and the creation of deep pits might pose problems for birds that forage in shallower waters or might become less productive areas due to them becoming anoxic. Moreover, if MarkerWadden+ is realized it would be good to incorporate this project into the continuation of the KIMA program (KIMA = Kennis- en Innovatieprogramma Marker Wadden; Knowledge and Innovation Program Marker Wadden) to ensure learning from this effort – this time also including the impacts of the restoration efforts on human well-being and the economy. Continuing with including foreshores in dike restoration projects, similar as to what is already being done at the North-Holland shoreline of Lake Marken would appear to be beneficial both as a flood protection measure (reducing wave height) and for habitat creation for submerged macrophytes and fish. Lastly, starting a citizen science campaign right after the opening of a new NbS might offer a relatively cost-effective way to monitor the development of the site while incorporating learning about the site by (local) citizens at the same time.

3.2.3 Societal optimisation

Currently, Lake IJssel complex wide goal setting is coordinated through the Bestuurlijk Platform IJsselmeergebied (BPIJ), a programmatic, multi-stakeholder governance platform that brings together ministries, provinces, water boards, municipalities, NGOs and user groups, including a drinking water company. The platform meets annually for a summit meeting, three times per year for themed platform days, and through additional committee meetings as well.

Although the BPIJ was established to coordinate agenda's, negotiate trade-offs, and develop a shared vision for the lake complex, it is not a regulatory authority. Decisions-making responsibilities remain distributed across multiple organisations. Rijkwaterstaat manages the lake water levels, the major hydraulic infrastructures, and compliance with national water policy; provinces are responsible for regional spatial planning; regional water authorities manage water quantity and quality in the direct catchment of the lake complex; and municipalities oversee local initiatives (Johannessen and Kramer, 2026). Consequently, decision making depends on topic and the geographical area under consideration.

A key **strength** of the societal aspects of the Lake IJssel complex is the existence of the BPIJ. This platform helps prevent fragmented policymaking and provides a mechanism for resolving disputes that previously stalled ecological action. It has been successful in aligning stakeholders, facilitating consensus, and launching high-impact projects like Marker Wadden. The platform also exemplifies the Dutch "polder model", in which consensus-based and collaborative water management is institutionalised across multiple levels of government (Johannessen and Kramer, 2026).

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The large number of stakeholders involved, combined with their sometimes-competing interests, can slow decision-making processes and thus form a **weakness** to the restoration efforts of the Lake IJssel complex. The BPIJ cannot prevent this, as it has no binding authority. Furthermore, even though agreements are reached within the BPIJ, implementation may be delayed due to multi-tiered administrative processes and complex funding arrangements (Johannessen and Kramer, 2026).

Recent periods of severe drought have increased awareness of water availability and water management challenges (NOS Nieuws, 2026). This may create **opportunities** to strengthen support among water authorities, organisations, and local residents for the implementation of more ambitious drought mitigation and flood protection measures within the catchment. The collaborative structure of the BPIJ also provides opportunities to further strengthen shared understanding of complex challenges and to build support for integrated solutions that address multiple functions of the lake system simultaneously.

Competing stakeholder interests create inherent tensions within the governance process. Without effective coordination, sectoral interests could dominate decision-making and result in suboptimal outcomes for the lake system as a whole. This may be perceived as a **threat** for a societal perspective to the restoration efforts of the lake complex. In addition, ecological objectives may be more difficult to define and communicate than objectives related to flood protection or freshwater supply, as their benefits are often less immediately visible. This can make it more challenging to secure consensus and support for restoration and conservation measures.

The way forward for societal optimisation lies with strengthening the knowledge base of the BPIJ platform participants further and ensuring the growth and maturity of this platform. This will help in making the best possible trade-offs for the Lake IJssel complex. In addition, maintaining an adaptive and inclusive governance approach is important to ensure that all relevant stakeholders, including smaller or less visible groups, are adequately represented in decision-making processes. Moreover, continuing with the improved integrated communication, reflecting for example the perspectives of both conservation and water management stakeholders, could further reduce public confusion and strengthen public engagement with the lake system.

Overall, long-term resilience will require sustained facilitation, political commitment, and continued investment in joint fact-finding and nature-based adaptation measures (Johannessen and Kramer, 2026).

3.2.4 Technical optimisation

The **current technical approach** of the Lake IJssel complex is generally effective in maintaining key functions such as flood protection and drinking water provisioning. Water levels are managed and monitored carefully, reflecting the Netherlands' long-standing expertise in water management and flood-risk reduction. Institutional coordination within the system is well established, contributing to the effective achievement of water management objectives. Furthermore, especially in the case of larger and potentially more impactful measures, their implementation can be supported with a scenario-analysis based on process-based models (Hanssen et al., 2022). Despite these achievements, several challenges remain. For example, maintaining the desired water level can be challenging due to evaporation and a limited river water supply in summer and a limit to the speed by which water can be transported out of the system in winter. Furthermore, ecological objectives are often constrained by competing demands on the lake system and may not always receive the same priority as other functions. Consequently, opportunities to enhance ecosystem dynamics and biodiversity can be limited. In particular, further progress is needed in aligning flood-risk and drought-risk management measures with ecological objectives, as well as in strengthening efforts related to water quality and ecosystem restoration. For example, due to the large amount of waterworks, the connectivity of the lake with its catchments and the downstream positioned Wadden Sea is limited; making it harder for fish populations to migrate and/or find suitable habitat to forage.

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A key **strength** of the technical aspects in the Lake IJssel complex is that measures that are implemented are usually well-researched beforehand and that a range of impacts of these measures are considered, including their impact on nature and society. For example, the latest dike renovations around Lake Marken, although originally designed for flood protection, now also include a foreshore that is intended to improve land-water transitions, and the flexible water level innovation is not only a measure that is designed to address water shortages but also includes environmental aspects and investigated its societal aspects (Thiemer et al., 2026). Furthermore, in the case of Marker Wadden, where a lot could be learned from an innovative measure, research programs KIMA and KIMA 2.0 were implemented and have contributed substantially to the knowledge of the ecosystem of Lake Marken and the artificial islands themselves.

A **weakness** of the technical aspects is that certain types of information that are essential to, for example, updating hydrodynamic and ecological models of the region, are spread out over multiple water authorities and can therefore be a challenge to obtain (e.g., data from a large amount of pumping stations spread across the region is required in order to create a water balance of the lake complex). Additionally, the amount of continuous monitoring stations around the lake has decreased over the years making it harder to research spatial impacts. Lastly, not all water quality monitoring locations are used in the assessment and reporting of the WFD ecological status for the lakes, thereby raising the question if these values are representative of the whole lake.

New **opportunities** for implementation of new measures, maintenance of existing measures or monitoring may be found in technical innovations such as slow dredging (SWECO, 2021) and eDNA-based monitoring (van den Berg, 2026). Additionally, research has shown that in some cases a Nature-based Solution may be cheaper than a 'conventional solution', paving the way for further implementation of these solutions around the Lake IJssel complex. For example, a foreshore in front of a dike can lessen wave height and therefore reduce the effort to heighten the dike while at the same time improve biodiversity (Redactie Waterforum, 2022). Moreover, AI models could be used to explore relationships between different environmental variables, e.g., wind and water height, in order to see if gaps in timeseries can thus be filled reliably.

A substantial **threat** to the Lake IJssel complex is posed by climate change. Prolonged periods of droughts have been shown to already pose limits on the freshwater supply of the lake complex, with severe consequences for water supply, transport and nature (NOS Nieuws, 2026). It is highly likely that, to address these challenges, the Netherlands will need to invest substantially into further technical and nature-based solutions, and it remains to be seen if these measures will be sufficient to tackle these challenges.

The **way forward at the catchment scale** is to continue strengthening ecological connectivity between the surrounding catchment and the lake system. This includes restoring land-water transition zones, removing barriers to fish migration to improve connectivity between Wadden Sea, the hinterland and the lakes, and creating conditions that allow water and sediment to move more freely through the system. These measures can contribute to improving the ecological functioning of the lake complex while supporting ongoing restoration ambitions. Continued integration of ecological objectives into broader catchment management and spatial planning will be important to maximise the benefits of existing and future restoration efforts. Moreover, further measures, such as the restoration of the capacity of the land to retain water in the catchment, such as already under research in the EU project SpongeWorks, will be required to counter the impacts of climate change (i.e., severe drought).

The **way forward at the in-lake scale** is to build on recent ecological restoration measures while strengthening monitoring, learning, and adaptive management. The introduction of flexible water levels in 2019 represented an important step towards incorporating ecological considerations into water level management. However, further research is needed to evaluate ecological impacts of measures, including potential effects on protected bird species (WSP, 2025; Thiemer et al., 2026). Additionally, opportunities for ecologically favourable water level management in smaller compartments within and around the lake system should be explored (PAGW, 2026).

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A re-consideration of the monitoring network used for WFD assessments could improve the representativeness of ecological status assessments. Currently only the centre-most monitoring locations are taken into account (one for each lake). The size of the lakes and the pressure gradients that occur within them should warrant multiple, spatially-distributed monitoring locations for sub-basins with different pressure contexts. Monitoring results and locations should be more systematically incorporated into management and restoration planning to strengthen adaptive management.

Further research into the ecological impacts of existing restoration measures, including the nature islands created within the lake system, would support learning from these efforts and could improve future decision-making (also already mentioned in Lauwaars and Platteeuw, 2003). In addition, innovative approaches such as eDNA-based monitoring, technical innovations such as slow dredging (particularly interesting for maintaining NbS Marker Wadden) and the use of AI models could enhance the efficiency and sustainability of monitoring and maintenance activities. Lastly, collecting the input data required for the hydrodynamic and ecological models of the Lake IJssel complex into one data management system would aid future modelling efforts.

Overall, continued investment in ecological restoration, monitoring, research, and adaptive management can further strengthen the ecological functioning of the Lake IJssel complex.

3.2.5 Economic optimisation

The **current approach** for funding nature restoration measures in the Lake IJssel complex and its catchment is primarily financed through public funds from European (e.g., CAP), national (e.g., WFD) and regional (e.g., a province adding to the budget to support recreational benefits) sources. In rare instances funding comes from a private source, such as the Lottery financing contribution to Marker Wadden, or a charity funding PhD research or part of a NbS measure.

While funding sources for the Lake IJssel complex are relatively well known, information on the economic costs and benefits of restoration measures is rather limited (Kramer et al., 2026). Data on restoration benefits are largely unavailable due to a lack of dedicated research and the fragmented nature of information held by the many organisations involved in managing the lake system. Restoration costs are generally known at the project level during implementation. However, retrieving cost information for measures implemented in the more distant past is often difficult because reports are not readily accessible. In some cases, financial information may remain confidential to protect commercial interests. Improved insight into both the costs and benefits of restoration measures would support more effective evaluation, facilitate learning, and help inform future restoration decisions

The **strengths** of the Lake IJssel complex case study can be found in the fact that government funding programmes are well established and in that alternative ways of funding have been proven successful (i.e., Marker Wadden). Also, the ability of management to combine functions (e.g., flood protection with habitat restoration in the case of dike renovation along the shorelines of Lake Marken and Lake IJssel) are providing an efficient way to implement and fund nature restoration measures.

A **weakness** of this case study is that there is still a lack of knowledge on the benefits of Dutch nature restoration efforts, such as Marker Wadden, regarding societal and economic benefits and/or CO_2-sequestration. People recreate in the newly made nature areas; however, it remains unclear how this benefits them and/or the wider area. This lack of data has likely already caused a lack of involvement of financial institutions due to the uncertainty around their return of investment.

Knowledge about the benefits of NbS (e.g., as reported in Kramer et al., 2026 for Lake Vesijärvi and Lake Vansjø) show that they have a substantial capacity to provide benefits to lakes (biodiversity, societal and economic) and thus provide an **opportunity** to promote such measures. Additionally, increasing knowledge on alternative ways of funding measures can create more opportunities for the implementation of NbS and similar innovations. Moreover, sand mining companies showing an

interest in using 'unusable sediment' for building with nature creates opportunities for additional measures taken in the Lake IJssel complex.

The large scale and the variety of goals and objectives for the Lake IJssel complex and its catchment form a **threat** to the implementation of certain measures. For example, the sheer size that certain measures need to obtain to reach impact cause substantial costs. More specifically, earlier plans to create islands similar to Marker Wadden were postponed due to high predicted costs. Moreover, although funds for flood protection and climate resilience are often well guarded, the funding for nature restoration efforts is more liable to changes according to the political climate.

The way forward for economic optimisations in the Lake IJssel complex would be to start disseminating knowledge of alternative financial arrangements for nature restoration measures to the Bestuurlijk Platform IJsselmeergebied (the governance body in which government authorities and key stakeholders in the Lake IJssel complex coordinate policies and strategic decisions). This could be a way to promote and aid the further implementation these types of measures. Additionally, monitoring the economic status of (recreational) establishments and/or human well-being impacts before and after nature restoration measures are taken, would help bring insights into their economic benefits to the Lake IJssel complex. One way to secure the data collection and to learn from such measures would be to set aside a percentage of the budget for a nature restoration measure funded by the government (e.g., PAGW) for research, similar to the KIMA programme upon the creation of Marker Wadden.

3.2.6 Policy / regulatory optimisation

In general, the policies for water quality and nature, including the WFD, Natura2000, and NRR, are in place and aligned in the Netherlands. Moreover, **current** national programmes (e.g., PAGW) aim to accelerate nature-based and climate-resilience measures. However, in some cases the practical implementation proves difficult (e.g., moving towards sustainable agriculture, protecting habitats) due to conflicting stakes for land and water use. For example, Lake IJssel does not yet reach a good WFD status for nitrogen but moving forward is complex as nitrogen-reductions are currently part of a complex political debate in the Netherlands, involving not only water quality, but also agriculture, housing, and the climate (Rijksoverheid, 2026).

Furthermore, although there are several funding sources that allow consortia to get involved with and share knowledge with each other about nature restoration efforts (amongst others), partnerships between universities, knowledge institutes and consultants are often difficult to achieve due to restrictions in funding schemes such as those provided by the Dutch Research Council or those provided by the Dutch government via the Top consortium for Knowledge and Innovation. Funding schemes are often designed for one or two organisation types only (e.g., universities + knowledge institutes, consultants + knowledge institutes).

A key **strength** of the policies and regulations currently implemented is the fact that these are well-established and come with well-developed policy goals.

A **weakness** to the implementation of specific catchment measures, i.e., measures related to nitrogen reductions, is the fact that the location and amount of impact they should have are driven by an ongoing complex political debate. Implementing nitrogen reduction measures can require substantial investments and effort from farmers. The uncertainty created by the continued debate inhibits farmers from taking action. Additionally, the fact that there are no regulations present to aid local water authorities to collect data relevant to modelling the Lake IJssel complex into one data system can be seen as a weakness (also see 3.2.4).

An **opportunity** for further nutrient reductions by farmers in the Lake IJssel complex catchment may be found in examples of nature inclusive agriculture (Staatbosbeheer, 2026). An opportunity for implementing additional NbS in the Lake IJssel complex could be the NL2120 project. NL2120 is a government funded program that is working on collecting and upscaling knowledge about Nature-

based Solutions in the Netherlands. This program will last until 2034 and connects theory with practise and tries to draw up feasible future perspectives.

One of the biggest **threats** to the implementation of nutrient reduction measures in the catchment is the continued political debate on the amount and location of nutrient reductions in the Netherlands (also mentioned as a weakness) causing further delays in taking action. At the same time the continued debate has caused a complete lack of trust between the government and specific groups of farmers (see for example the headlines from NOS from 13 August and 14 August 2026: “Minister: do whatever it takes to save permits for Brabant poultry farmers” and “Protest and interrupted holidays for politicians over revocation of farmers' permits”).

The way forward for policy and regulatory optimisation lies in settling the political debate surrounding the nitrogen reductions in the Netherlands. The latest plans and proposed legal actions will be presented to the Dutch government coming October (Rijksoverheid, 2026). This debate will have to be settled at the highest level first, before further optimisations regarding nutrient reduction efforts can be made. Additionally, the pathways of cooperation between different organisations, e.g., universities and knowledge institutes or consultants and knowledge institutes, could be smoothed by adjusting the current restrictions in the funding schemes. Lastly, implementing a new regulatory framework on data collection, including discharge data from pumps, from the local water authorities surrounding Lake IJssel complex would pave the way for further analysis of the water balance and nutrient balance of this (eco)system. One possible location for the data to be collected would be through “Informatiehuis Water” (www.ihw.nl). Informatiehuis Water is a platform that already facilitates the exchange of water quality and water quantity data between Rijkswaterstaat (the national water authority), the regional water authorities and the provinces.

3.2.7 Stakeholder evaluation

A draft version of this optimisation plan was shared with stakeholders involved in the FutureLakes project. The views of two stakeholders who provided feedback are summarised here. Both recognised the importance of ecological restoration but differed in their emphasis.

The stakeholder from Rijkswaterstaat acknowledged that projects such as the Marker Wadden are likely to generate economic benefits through recreation and tourism. At the same time, he questioned whether nature restoration should primarily be valued in terms of its economic returns. From his perspective, greater consideration should be given to the needs of the ecosystem itself, including species that depend on open-water habitats. Consequently, caution is warranted when implementing measures such as the Marker Wadden.

The stakeholder representing the Coalitie Het Blauwe Hart Natuurlijk (CBHN), a coalition of NGOs committed to protecting the natural values of the Lake IJssel complex, adopted a broader systems perspective. While acknowledging the region's highly visible engineering achievements and their political appeal, this stakeholder argued that they should not be equated with long-term ecological recovery. Instead, they emphasised the need to restore natural processes and environmental gradients, to move towards more adaptive and system-based governance rather than the current more sector-based approach, and to address the water quality pressures at the catchment scale as this is where the real nutrient problem originates. This stakeholder highlighted that sustainable recovery depends on tackling underlying drivers of degradation, such as altered hydrodynamics and nutrient inputs, and that more strategic use of existing water management infrastructure should be aimed at supporting ecological dynamics rather than maintaining the water levels. Finally, they mentioned that the scale of interventions should match the scale of the system, as fragmented projects are insufficient to reverse system-wide degradation.

The proposed optimisations will be discussed further during the next Lake IJssel complex stakeholder meeting to explore which elements could be adopted in future management and restoration efforts.

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3.3 Lake Karla

Lake Karla is a restored shallow lake (area 35 km^2, max depth <5 m, Figure 5) located in Thessaly Region, Greece. Historically, it was the largest natural Greek lake, but it was drained in 1962 for land reclamation and to increase the available agricultural land. Following decades of ecological challenges and growing awareness of the consequences of the drainage, including biodiversity loss and ground water deterioration, the lake was partially restored between 2000 and 2018 through the construction of a reservoir and associated technical/hydrological infrastructure (Panagopoulos and Dimitriou, 2020). Even though it was designed as a reservoir to store and provide agricultural water and to alleviate the adjacent area from flood impacts, the restoration has delivered multiple direct and indirect benefits for ecosystem services, including measurable ecological gains. Records now document 201 bird species and 16 fish species (Sidiropoulos et al., 2017, NECCA Management Unit data, Hellenic Ornithological Society data), amongst which are 50 bird species and 4 fish species that are listed as priorities under EU Birds and Habitats Directives. Additionally, the lake is designated a Natura 2000 site under both the Habitats and Birds Directives (Natura2000Viewer Database). However, the lake faces advanced eutrophication issues with high chlorophyll-a values and phytoplankton communities dominated by cyanobacteria (Gkelis et al., 2017, Latinopoulos et al., 2020a). The lake's ecological potential is assessed as "less than good" in the most recent River Basin Management Plan (2nd RBMP Amendment). Multiple pressures such as water scarcity/drought, extensive irrigation, climate change, pollution (fertilizers) occurring together with fragmented water governance lead to difficulties in management (Sidiropoulos et al., 2019). The suggested optimisation plan outlined below addresses these challenges across technical, societal, economic and policy dimensions.

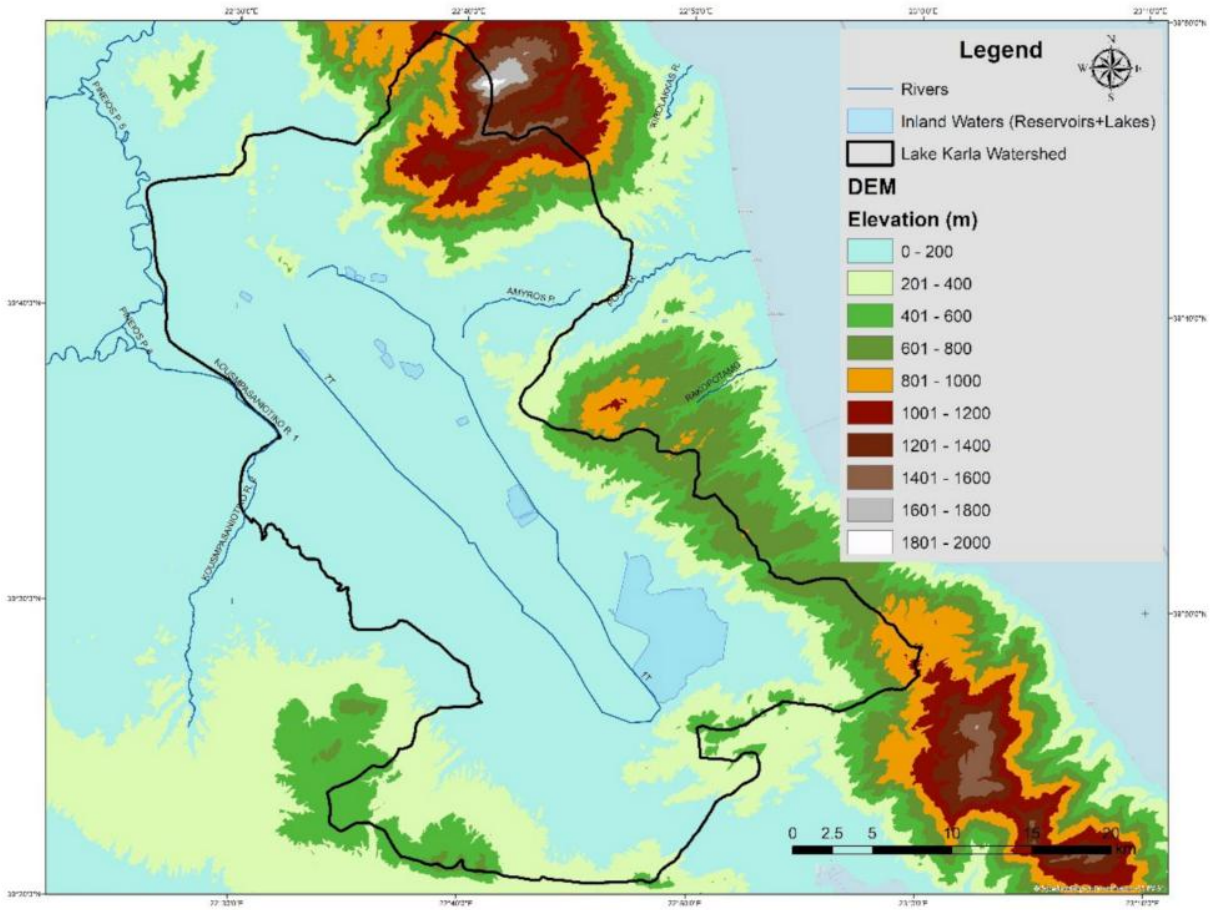


Figure 5. Complete hydrographic network of Lake Karla watershed upon a Digital Elevation Model (DEM) (Latinopoulos et al., 2020b).

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3.3.1 Self-Assessment Tool (SAT) results

The SAT assessment indicates that the Lake Karla restoration programme (Table 6) performs at an overall adequate level (overall score: 0.30), revealing several areas that require further optimisation.

The highest score was achieved for inclusive governance (0.50), reflecting strong stakeholder interest and local support for the lake's restoration and future management, albeit not always represented in official, institutional consultation procedures. Biodiversity net gain also scored relatively well (0.40), consistent with the aim of the recovery of open water habitat and species following the re-establishment of the lake.

Moderate scores were obtained for societal challenges, design at scale, and sustainability and mainstreaming (all 0.30), indicating that key restoration elements are in place but not yet fully integrated into long-term management. Lower scores for balance of trade-offs (0.20), economic feasibility (0.10), and adaptive management (0.10) highlight important challenges related to the integration of competing water-use objectives, the lack of comprehensive economic assessments, limited diversification of funding sources, and insufficient monitoring and feedback mechanisms to support adaptive decision-making.

Overall, the SAT expert assessment suggests that future optimisation efforts should prioritise strengthening adaptive management, improving economic sustainability, and better integrating ecological, agricultural, and societal objectives within a climate-resilient management framework.

Table 6. Self-Assessment Tool (SAT) results for Lake Karla.

Criterion	Your Criterion Score	Maximum Criterion Score	Normalised criterion	FINAL OUTPUT Your Criterion %age
1. Societal challenges	3	9	0.33	0.3
2. Design at scale	3	9	0.33	0.3
3. Biodiversity net-gain	5	12	0.42	0.4
4. Economic feasibility	1	12	0.08	0.1
5. Inclusive governance	7	15	0.47	0.5
6. Balance trade-offs	2	9	0.22	0.2
7. Adaptive management	1	9	0.11	0.1
8. Sustainability and mainstreaming	3	9	0.33	0.3
Total			2.30	0.3

Key		
	≥75	Strong
	≥50 & <75	Adequate
	≥25 & <50	Partial
	<25%	Insufficient

3.3.2 Multiple goal optimisation

The Lake Karla restoration project was originally planned as a water resource management initiative. Yet, **currently**, the restored lake offers a broader set of ecosystem services, including water supply for agriculture, flood risk mitigation, local biodiversity recovery and recreational uses (even though fishing and water-related activities are currently restricted). Multiple-goal optimisation will address the friction points between this broader set of services by treating ecological health, climate resilience, and agricultural stability not as trade-offs, but as interconnected targets. Moreover, the multiple-goal approach ensures that every engineering and administrative intervention simultaneously advances the lake's ecological status, climate adaptation, and resource utility (Spiliotis et al., 2022).

A key **strength** of the restoration efforts at Lake Karla is that the lake has already achieved delivery of multiple goals and that there is strong local willingness to support the lake’s presence and long-term future. This provides a good foundation for reframing and developing the restoration design at scale, including agricultural, societal and ecosystem services (Latinopoulos et al., 2020b).

A **weakness** in the restoration efforts at Lake Karla is that the interactions mapped are only partially integrated. Trade-offs are not formally recorded or modelled and knowledge gaps persist on the long-term effects. Moreover, there are no official data on risk assessment beyond the site scale. Administration and governance are restricted and fragmented and there is no guide available yet for restoration design under changing climate conditions and drought (Alamanos et al., 2019, Pavlis, 2025). Documentation, bottom-up consultation and formal processes, including taking into account

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the vulnerable voices, remain insufficient, as the governance model is centralised top-down (Kramer et al., 2026).

Opportunities for the restoration efforts include an alignment with the EU Green Deal, Nature Restoration Regulation and Water Resilience Strategy, which serve as policy instruments and possible funding pathways. Evidence-based climate projections and integrated landscape planning also provide opportunities to support the development of formal risk assessment and interaction maps in the site management plan (Tzabiras et al., 2016, Spiliotis et al., 2022, Kagalou and Latinopoulos, 2026).

Administrative complexity and overlapping roles slow down decision-making processes and reduce institutional responsiveness, thereby providing a **threat** to the restoration efforts. Without a multiple goal framework that formally maps interactions, assesses risks and documents trade-offs, management can only be reactive in responding to crises rather than steering toward coherent, negotiated outcomes and being proactive. Furthermore, climate change substantially amplifies this risk, as demonstrated by the impacts and the management of Storm Daniel in 2023 (Kagalou et al., 2025b).

The way forward for multiple goal optimisation would be strongly supported by the development of a decision-support dashboard, coupling a real-time hydrological water-budget model (e.g., SWAT or HBV) with ecological threshold indicators (EQR, TSI, cyanobacteria biomass) and formally mapping interactions and trade-offs across agricultural, ecological, and flood-management objectives, taking into account both catchment and in-lake attributes (Figure 6). Climate change scenarios including future projections (inflow reduction, evaporation etc.), resilience "building" towards the expected droughts, as well as completion of planned restoration measures and specified working plans for water distribution should be integrated within the dashboard to ensure that this multiple goal framework would remain operational under future regimes. Risk assessment protocols should be embedded in an updated site Management Plan, drawing on EU Green Deal alignment, Nature Restoration Regulation and Water Resilience Strategy obligations and initiatives provide both the policy mandate and the funding pathways to support multiple goals within the Karla basin. The MERLIN upscaling workflow (Baattrup-Pedersen et al., 2025) and the FutureLakes co-design methodology provide ready-made frameworks for formalising this multiple-goal integration with stakeholder validation.

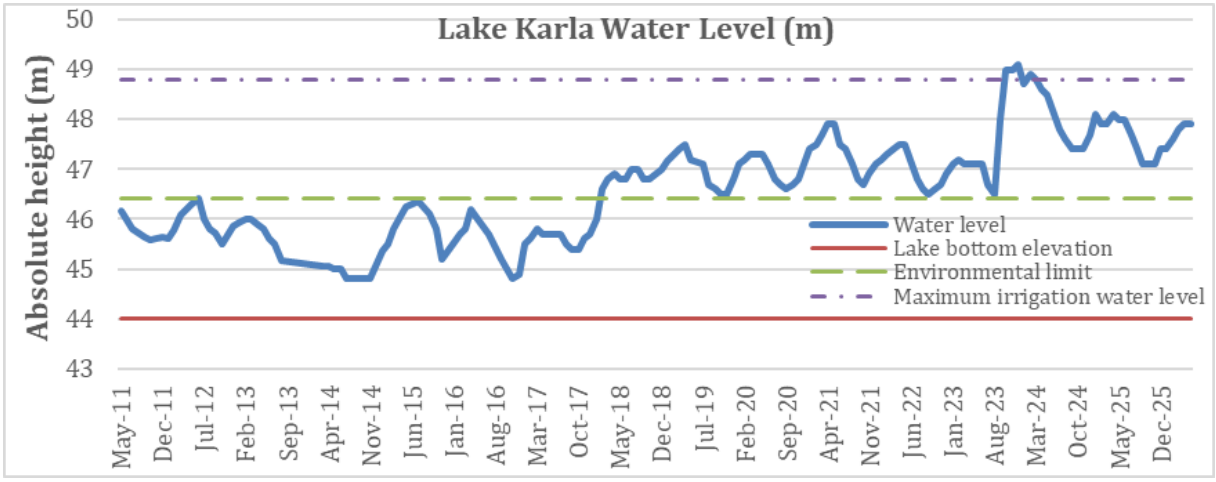


Figure 6. Inter-annual water-level fluctuation of Lake Karla based on Management Unit and HCMR records.

Blue line depicts monthly values of water level (fluctuation), green line depicts the environmental limit above which the use of water for irrigation becomes allowed (this water level was first reached in 2018 by works augmenting Pinios river inflows) and the purple line designates the maximum water level above which lake Karla overflows through a spillway, in line with multiple goals setting for Lake Karla.

3.3.3 Societal optimisation

The societal dimension of Karla's restoration reflects a pattern in which strong local support is present, but adequate institutional structures remain insufficiently developed. Yet, both are required in order to establish inclusive and evidence-based governance. The local support can be easily recognized within the positive public perception about the lake's return and the growing interest in the ecotourism development of the Lake Karla area. In parallel, the hyper-centralised top-down decision-making, the in-name-only formal participatory mechanisms and the lack of structured communication channels among water-related authorities, interrupt the connectivity between local needs and management, highlighting the urgency of building inclusive early-warning systems that could reach all affected groups.



Figure 7. Picture from a citizen science event hosted in May 2026 by DUTH and FutureLakes.

A key **strength** of the restoration efforts at Lake Karla is the strong local willingness to support lake presence and restoration. Moreover, human well-being needs of local communities have been identified and acknowledged and there are some periodic records of social benefits through national surveys from the Hellenic Statistical Authority. The availability of risk management plans for floods and the ongoing technical studies for accompanying works is a good aspect to mitigate societal challenges such as flood risk, water supply and limited recreational use.

A **weakness** of the societal aspects surrounding the restoration efforts at Lake Karla is the fact that the governance remains centralised and that it is not sufficiently inclusive, with overlapping roles and no formal grievance mechanism for all authorities and stakeholders. Participation in consultation has not been developed with equal weight among all actors, and not all affected groups are involved in decision-making (Kagalou et al. 2025a; Kagalou et al. 2026). Moreover, quantifying data on social indicators remain insufficient and therefore it is hard to demonstrate progress and to balance societal trade-offs.

The newly established Organisation for Thessaly Region Water Management (ODYTH) provides an **opportunity** for improving the societal aspects of the restoration efforts at Lake Karla. This organisation can hold an overarching role and act as a mediator for conflicts that arise among different societal parties. Other opportunities include the possibility for digital participation platforms, enforcement actions to prevent pollution events, participatory governance models and citizen science campaigns (Figure 7) that could engage further the local community and harder-to-reach groups, while

obtaining data for the area (Latinopoulos et al., 2025a). Additionally, EU legislation recognizes more and more the connection between well-being and green/blue spaces, providing an equitable policy entry point. Exchange programmes allowing local stakeholders to visit other restored areas across Europe could build trust and broaden perspectives. National efforts would maximise documentation results at lower cost.

The main **threat** is the loss of community trust and the lack of political will, if authorities do not support the associated local needs and if public engagement does not yield further results. Citizens usually choose to support short-term convenient solutions, rather than more long-term sustainable solutions. Furthermore, the administration complexity makes the processes slower and difficult to demonstrate progress.

The way forward for societal optimisation lies in establishing an open digital platform — integrated with existing citizen science tools (iNaturalist, Aquality, Bloomin' Algae) — that would allow access to real-time data upload by citizens, researchers, and authorities, and help create a shared evidence base. This would foster a greater sense of ownership among local communities. Early-warning reporting protocols and mapping of vulnerable zones by integrating climate change scenarios should be embedded in this open-platform to improve the proactive communication of stakeholders and people likely to be affected by physical disasters. Introducing this platform would expand inclusivity in water governance and further cultivate a sense of ownership in locals regarding lake management along with risk management. This societal optimisation aims to transform Lake Karla from a functional irrigation (and biodiversity enhancement) reservoir, which sometimes has health risks caused by (toxic) cyanobacterial blooms (Gkelis et al., 2017), into a local asset connected to community well-being and economy. An additional optimisation could introduce periodic indicator-based surveys to monitor societal benefits (tracking agricultural income, recreational use, well-being, and ecotourism uptake). The monitoring should feed into inclusive governance structures, with ODYTH acting as the overarching mediatory body ensuring that all affected groups (including harder-to-reach communities) are formally represented in decision-making. Furthermore, societal optimisation could involve the establishment of citizen science campaigns (Latinopoulos et al., 2025a) with multiple target audiences and open lessons, empowering local fishermen, farmers, and schools to participate in environmental monitoring (e.g., observations with iNaturalist, Aquality, Bloomin' algae), paving the way for sustainable agrotourism and ecotourism initiatives that would be beneficial to the local economy (Karanikola et al., 2017), while raising awareness (Trakala et al., 2023a, 2023b). Exchange visits to comparable restored European lake sites, combined with targeted communication campaigns for non-specialist audiences, would build the cross-community trust needed to shift local preference from short-term convenience toward long-term sustainability.

3.3.4 Technical optimisation

Lake Karla's restoration project relied mainly on hard engineering interventions (reservoir construction, pumping stations, collector channels, embankments) to re-wet the basin and regulate water inflows from the Pinios River. However, even though it was designed in the early 90's, it also applied measures for the restoration of the area that could be deemed as NbS (Kagalou and Latinopoulos, 2026). Others consider the lake itself an NbS (Panagopoulos and Dimitriou, 2020) that addresses the ecological restoration of the catchment. Although engineering and hydrological objectives have been fulfilled, ecological and water quality objectives have not yet. The root cause for this lack of fulfilment lies in the hierarchy of restoration priorities that placed irrigation and flood management above water quality and biodiversity (Kagalou and Latinopoulos, 2026). At the lake scale, water regulation has been the core operational tool and at the catchment-scale mainly ensuring the drainage ditch networks, that collect agricultural runoff via pumping stations before re-entrance to the reservoir, work as intended. The artificial wetlands and riparian buffer zones that were also implemented in the catchment do not function as intended. Therefore, the lake still receives a high

nutrient load from the catchment area, which is leading to advanced eutrophication. The **current approach** has resulted in only moderate progress in biodiversity recovery and critical gaps in the adaptive management infrastructure needed to sustain and build on those gains. BoPrimarily catchment-scale measures (e.g. buffer zones, sponge measures and agricultural land management interventions, biodiversity corridors) and in-lake measures (e.g. water-level regulation, banks/shores revegetation, biomanipulation / cyprinid removal) that remain to be implemented are substantial and will need to be designed in order to interact in a complementary way (Kagalou and Latinopoulos, 2026). At the same time there remains a need for a specified conservation plan and ecohydrological monitoring under the prism of climate change.

Key **strengths** of the restoration efforts at Lake Karla are the fact that rewetting has restored the open water habitats and that the biodiversity is increasing, especially documented for fish and birds. There is a strong connectivity between the wetland and agricultural activity that can work as win-win scenario given proper agroecological features are held. Restoring the lake has positively affected the recharge of groundwater and surface water storage (Panagopoulos and Dimitriou, 2020, Sidiropoulos et al., 2019).

A major **weakness** that was identified is that monitoring is inconsistent, data are sparse, reporting is delayed and not always openly accessible, and that there is no NbS strategy formally stating intended outcomes, actions and assumptions across ecological, social and economic dimensions. Adaptive management is tricky and demanding as monitoring results should feed systematically into decisions, but there is no formal protocol for detecting, recording and reporting unintended consequences. Another major weakness is that an emission limit protocol for external loads that also would take into account drought/flood events has not been established. Furthermore, habitat and species-specific conservation plans are absent, and a landscape-scale connectivity strategy is missing. In general, support of uptake of innovative solutions in national policy is variable (Kamergi et al., 2026).

Opportunities to further the restoration efforts lie in cost-effective monitoring tools such as eDNA techniques, remote sensing, acoustic monitoring and citizen science platforms. These tools could fill data gaps without requiring large institutional investments. Digital platforms with geo-references and open-access ecological recordings (such as iNaturalist, Aquality, Bloomin' algae) would support both biodiversity net-gain assessment and early warning functions (see the citizen science pilots in Latinopoulos et al., 2025a). Furthermore, IUCN NbS Standards provide ready-made templates for developing a comprehensive adaptive management strategy, while buffer zones, sponge measures, agri-environmental schemes and CAP-aligned measures offer practical pathways for integrating ecological connectivity into the surrounding agricultural landscape. Anticipation of plausible climate change scenarios for water level and biodiversity can be included in the technical planning with consideration of a whole basin plan for sponge measures considered.

A key **threat,** given the changing (climate) conditions, is the lack of adaptation cycles. The grey infrastructure cannot be easily adjusted to cope with the increasing severity of climate extremes and thus new investments will be needed for further develop restoration efforts. Climate-driven changes, such as drought frequency and intensity, increase water cycle irregularities and extreme events can challenge parameters like water availability and thus the solutions' effectiveness (i.e. functionality, nutrient absorbance ratio, etc.).

The **way forward at the catchment scale** would be to move from planning towards implementation of already approved restoration measures, particularly those included in the WFD Programmes of Measures. Priority should be given to the re-establishment of functional riparian buffer strips and retrofit of the constructed wetland. These measures should be implemented using IUCN NbS Standards as the adaptive management framework, including the formal definition of intended outcomes, underlying assumptions, and procedures for identifying and responding to unintended consequences. Catchment-scale interventions should include water use reduction and shift towards less demanding crops and circular wastewater reuse for agriculture (Sidiropoulos et al., 2017; Panagopoulos and

Dimitriou, 2020). In this context, the tailor-made zone planning approach proposed by Kagalou and Latinopoulos (2026), combining both catchment and in-lake interventions, could support the management of point and diffuse pollution sources once these pressures have been adequately quantified through an improved monitoring programme (Figure 8). In parallel, climate change considerations should be systematically integrated into the planning cycle by anticipating plausible future drought scenarios for water level and biodiversity. This would help ensure that infrastructure renewal and restoration investments are climate-resilient and proactive rather than reactive including NbS and circular (blue) solutions to enhance the resilience against the intensifying pressures.

The **way forward at the in-lake scale** would be to strengthen the monitoring infrastructure and improve the understanding of lake ecosystem functioning. Direct in-lake restoration efforts could prioritise the reduction of water retention time while sustaining (optimizing) the ecological water level, and mitigate nutrient accumulation and the frequency of algal blooms. In parallel, food-web manipulation for invasive cyprinids population control should be introduced, at first at a pilot scale and then at larger scales, in order to control phytoplankton and fish communities while promoting macrophyte growth (Kagalou and Latinopoulos, 2026). However, in order to achieve this, it is essential to develop habitat and species conservation plans with qualitative and quantitative data and standardised protocols for reporting, multi-approach methods, and modelling tools that integrate climate-change scenarios. This would include transitioning from periodic institutional surveys towards continuous, real-time monitoring through the deployment of low-cost water quality sensors, remote sensing applications (e.g., Sentinel-2 for chlorophyll-a and turbidity), eDNA techniques for biodiversity assessment, and acoustic monitoring. Data from these monitoring approaches should be integrated into an openly accessible georeferenced platform to support improved knowledge of system dynamics, including inflows, internal nutrient loading, and ecohydrological relationships. Enhanced monitoring would also provide the basis for more targeted and adaptive management.

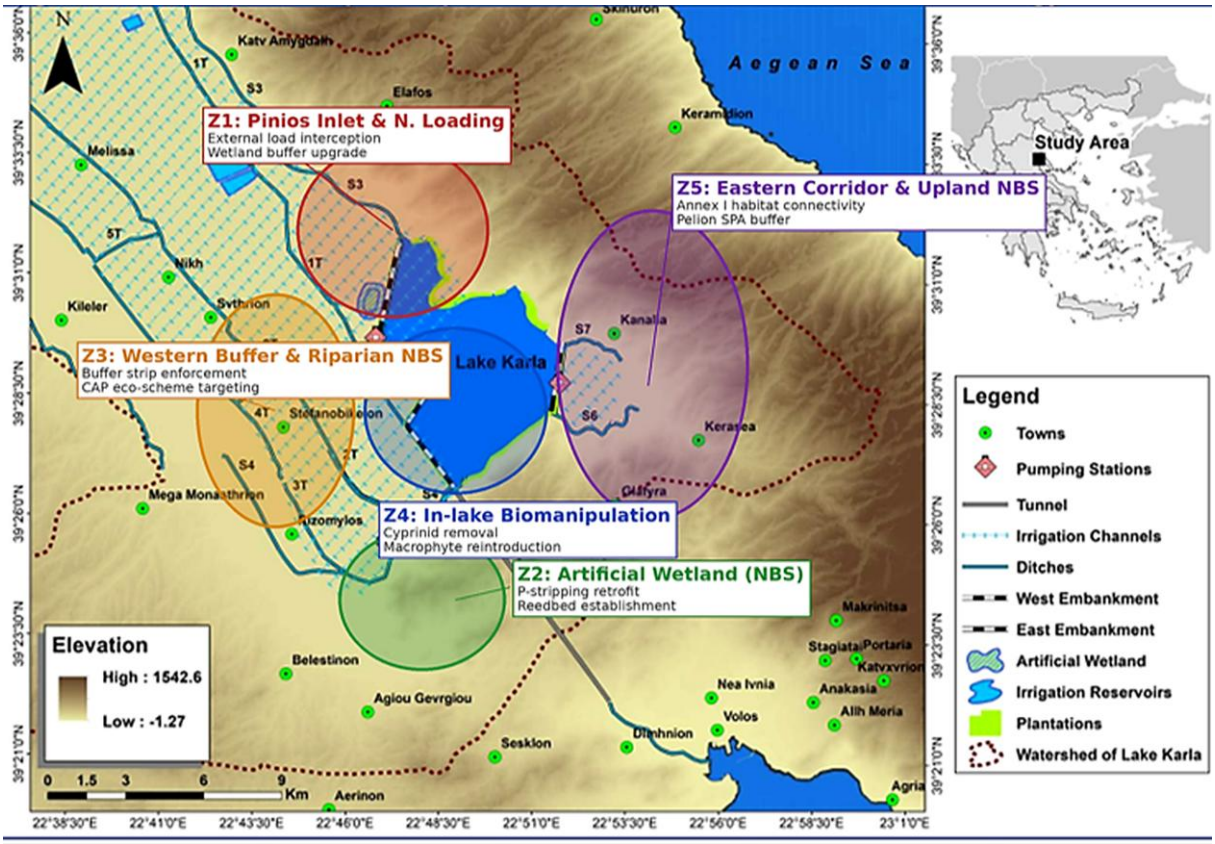


Figure 8. Proposed spatial intervention zones for the Lake Karla restoration strategy, overlaid on the infrastructure and elevation map (Kagalou and Latinopoulos, 2026).

3.3.5 Economic optimisation

Restoration efforts have been repeatedly funded by European Regional Development Fund (ERDF) programmes across different periods, complemented by CAP Rural Development Funds. Smaller-scale interventions have been funded though the Greek Green Fund and project-based EU co-financing. Up to date, no private sector funding has been mobilised for restoration purposes.

Currently, the economic dimension of Karla's restoration process is the least documented element of the restoration, including a lack of formal analysis of economic value. This knowledge gap leads to unquantified and unrecognised economic contributions (other than irrigation ecosystem services), with the respective infrastructure absorbing the lion's share of the available funding. Even though the lake's contribution to local economy for ecosystem services like flood protection is well-recognized, the recreation potential remains almost invisible to policy and budget processes, with the role of the lake being reduced practically only to irrigation. Recreation and tourism services are currently limited by very few places for overnight stay, ruined birdwatching areas and few organised activities, such as birdwatching tours, or infrastructure to support recreation and tourism. This lack of knowledge causes difficulties in finding additional funding sources for measures, as without a well-demonstrated benefit-cost ratio it is difficult to obtain further funding. Furthermore, the absence of continuous funding mechanisms and the resulting funding gaps between programming periods, have led to delayed Infrastructure completion and undermined the long-term operation and maintenance of the built assets. As a result, the financing gaps remain and the restoration process cycle cannot be successfully completed.

One of the **strengths** of the Lake Karla Demonstration Site is that there is a growing awareness for trade-offs and synergies among different water uses (agricultural and ecological) that create the potential for multiple economic benefits, although this is only marginally supported by sparse data at the national level. Furthermore, policy instruments for water-use pricing exist (but are not enforced) and there is a tendency to exploit EU-grant funds (rather than mobilizing national or private funds).

Among the major **weaknesses** are the non-obligatory reporting of various economic activities and the lack of a formal repository for this kind of data. No formal cost-benefit analysis has been conducted for Lake Karla, nor has an ecosystem services assessment been carried out. This lack of documentation makes it difficult to demonstrate the value of restoration efforts, weakening the case for continued public investment and reducing the potential for attracting future political support or alternative funding sources. The lake was not included in any economic cycle other than water provisioning for irrigation and agriculture. Furthermore, there is disbelief in NbS and a lack of awareness of more nature-friendly solutions that provide co-benefits in Greece in general, while support for such measures could be fundamental in countering the strong lobbying of the grey infrastructure sector, which remains largely uncontested. Meanwhile, there are no diverse or stable funding streams, there is no analysis of potential future revenue streams, and no preliminary assessment of complementary resourcing options. The business sector in the catchment is dominated by primary sector activities, which are disproportionally larger than the secondary and tertiary sectors. Consequently, thus the costs for transportation, manufacturing and processing of agricultural produce remain high, reducing the attractiveness of the area for further private investments. More broadly, private-sector engagement in lake restoration is non-existent and public-private investments are currently only just being developed as a practice across Greece. Therefore, the operational and maintenance costs of restoration measures need to be covered by public funds. This obvious reluctance of private investors is mainly attributed to the complicated administrative system and lack of governance structures to administer payments for ecosystem services. Nonetheless, the fact that regional public authorities, often, participate as partners in European projects is very promising, although their role is limited in dissemination activities.

Ecosystem service valuation/ accounting tools, periodic citizen science surveys or modelled quantification of flood regulation capacity and groundwater recharge volumes, and local knowledge

could be a prime **opportunity** to support a full direct and indirect cost-benefit analysis of NbS and their alternatives under different scenarios. Green investment programmes serve as a good opportunity but require NbS cost-effectiveness data. Ecotourism and agrotourism offer accessible revenue streams that could diversify local income while creating economic incentives aligned with conservation. Extra financial instruments, e.g., LIFE Programme, EU Restoration Fund, Cohesion Fund, CAP-related schemes and Public-Private Partnerships (especially insurance sector) could be activated to stimulate local development. Inclusive management could incorporate the modelling of water-related ecosystem services to valuate benefits (Latinopoulos et al., 2020b) and support restoration efforts in this direction.

The principal **threat** is related to the broader socio-economic trajectory of the (rural) area surrounding Lake Karla, as the lack of economic growth and job creation pushes local communities towards urbanization, leading to abandonment.

The way forward for economic optimisation lies in starting a full direct and indirect cost–benefit analysis of NbS interventions and their alternatives under multiple scenarios, quantifying the economic value of currently unpriced ecosystem services (such as flood mitigation, groundwater recharge, carbon/methane regulation, and ecotourism potential) to generate a robust Benefit-Cost Ratio (BCR) for national and EU funders. Ecosystem services modelling tools alongside local knowledge surveys should be used to populate this analysis (Latinopoulos et al., 2020b). The results should feed directly into a standardised, transparent framework which would ensure that long-term maintenance of restoration infrastructure is financially sustainable and also that investments yield high returns in ecosystem services. Another important step is to formalise water pricing implementation as the economic signal that aligns agricultural incentives with ecological recovery and creates a transparent framework for distributional fairness between those who pay for upkeep and those who benefit from water provisioning. This will allow policymakers to design fair water-pricing mechanisms, agricultural incentives, and public-private partnerships for agri-tourism (Trakala et al., 2023a, 2023b) that secure the lake's financial future. Finally, Public-Private Partnership mechanisms (blended finance) should be activated to develop ecotourism and agri-tourism infrastructure as diversified, conservation-aligned revenue streams. This would enable the integration of the lake's restoration into a local green economy network, not exclusively dependent on public funding.

3.3.6 Policy / regulatory optimisation

At Lake Karla, the restoration process operates within the established EU regulatory frameworks of the Habitats Directive and Birds Directive (including the designation of Natura 2000 site), the WFD, the Nitrates Directive, the Nature Restoration Regulation and the Biodiversity Strategy 2030. The **current** administrative cycle involves multiple actors, among which the Greek Ministry of Environment and Energy, the Region of Thessaly, the Management Unit of Protected Areas of Thessaly, local municipalities and ODYTH, an organisation responsible for water management in Thessaly. These actors have overlapping roles, fragmented responsibilities, and limited coordination across different levels of governance. For an overview of all parties involved in the administrative cycle see Figure 9. Although Greece follows the EU regulatory frameworks, the current infringement procedures from the EU against Greece indicate that the opinion of the EU is that Greece did not ensure full transposition of this water-related directive and that Greece has failed to report their third River Basin Management Plans (required by the WFD) and second Flood Risk Management Plans (required by the Flood Risk Directive). Moreover, the Habitats and Birds Directives along with Natura 2000 designated areas fall short in recent special environmental studies (approved by ministries) against land planning and green energy (wind mostly) structures, as demonstrated by environmental organisations sending such cases to the Counsil of State courts. In practice, the current governance network ineffectively feeds into decision-making in a timely or systematic way. Therefore, even though legislation and regulatory frameworks exist, there remains a substantial delay between the identification of the appropriate actions needed and the materialization of the corresponding measures.

A key **strength** of the current policies that have been implemented at this Demonstration Site is the fact that the policy for restoration commitment is well-linked to the Natura 2000 sites network and adopts EU Directives' obligations on habitats and species, as well as the new EU Nature Restoration Regulation, the Biodiversity Strategy 2030 and the Green Deal. The regulatory and policy framework covers a range of restrictions, obligations, incentives and tools.

A **weakness** can be found in the fact that knowledge gaps persist and that it is not clear how the restoration experience should be a part of an adaptive management approach and broader legislation (including the Water Resilience Stratgey). Empirical data (reporting platforms) and local knowledge are not endorsed in regulatory frameworks. Enforcement to follow regulations in protected lake areas is limited. Furthermore, policy frameworks do not prioritise recommendations for green, NbS and mild eco-friendly solutions for the better implementation of the EU Water Policy and there is a substantial delay in the application and materialization of measures.

Collaboration with private companies operating in the catchment could extend the reach of sustainability commitments into sectors not currently engaged. **Opportunities** to join international platforms and to adopt best practices can empower the uptake of regulatory frameworks. A targeted communication strategy, besides an enforcing strategy, that would reach both specialist and non-specialist audience through social media and citizen science efforts, could also strengthen policy uptake.

Threats to the existing regulatory framework implementation are the fragmented responsibilities and a lack of continuity in regional leadership (Johannessen and Kramer, 2025). Without tools for policy enforcement and a complete communication strategy, the lessons learned from the restoration of Lake Karla will not reach decision-makers or be replicated to scale.

The way forward for policy and regulatory optimisation is lying in the improvement of the administrative cycle by which environmental monitoring data is collected and used to actively shape policy decisions in a timely manner (for an overview of all parties involved in the administrative cycle see Figure 9). The monitoring–action loop must be closed by establishing a formal adaptive management protocol that bridges the gap between observation and executive action/legislation. Under this protocol, ecological monitoring data (including citizen science contributions) must feed into scheduled regulatory review cycles, with clear triggers and timelines for executive action — moving the site from reactive crisis management to proactive, evidence-led governance (Latinopoulos et al., 2025b; Kagalou et al., 2025b). Furthermore, targeted enforcement capacity should be strengthened around the protected area perimeter (e.g., Natura 2000 compliance, Nitrate Vulnerable Zone obligations, buffer zone restrictions), supported by a dedicated communication strategy reaching both specialist regulators and the general public via social media and open platforms to build the societal mandate that makes enforcement politically sustainable. International collaboration platforms, best-practice experience exchange and constant training of staff among EU restored sites may provide a regulatory learning pathway, while the Nature Restoration Regulation national plan creates the binding framework within which Lake Karla-specific measures can be formally embedded and resourced. It is also worth mentioning that as legislative tools are available, albeit their enforcement is limited and quite optional, a core element for optimisation would be the consistent and effective enforcement to reduce application delays and yield the best possible restoration outcomes.

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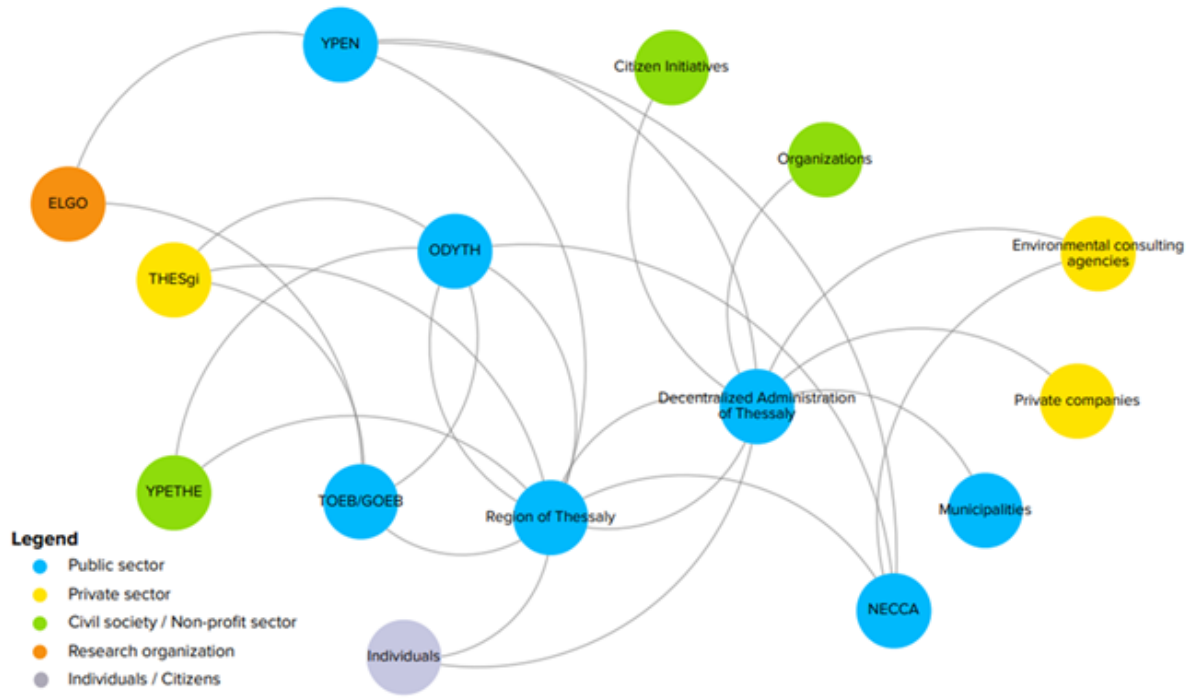


Figure 9. Map Network of collaboration among stakeholders as formatted based on local stakeholders' feedback (created on https://kumu.io/).

Connecting lines illustrate the interaction and collaboration among the various entities, not the specific direction of influence or reporting hierarchy (adopted from Kagalou et al., 2025b).

3.3.7 Stakeholder evaluation

The optimisation plan was discussed with critical friends involved as actors or final users in Lake Karla's management, including representatives from regional and local authorities, farming communities, research institutions and citizen organisations. The overall reception was positive, and the participants recognised the broken cycle of monitoring and regular reporting–implementing–evaluating–adapting in management.

Stakeholders expressed a strong interest in the economic opportunities linked to Lake Karla's restoration, such as ecotourism, watersports activities, water quality improvement and the fisheries exploitation. These were seen as potential revenue streams and initiatives for community investment in ecological improvement of the lake. With regard to the governance of the lake, it was clear that a bottom-up approach is needed to be established along with arranged and accountable management roles. ODYTH is willing to play the overarching and mediatory role it is attributed to it. A digital data dashboard platform would offer the opportunity to every citizen to contribute with real-time data and/or knowledge on this bottom-up governance model and enhance the sense of ownership. This optimisation plan will serve as a reference document for forthcoming funding applications targeting adaptive management infrastructure and NbS upscaling in the Karla catchment.

The immediate next step is to urge the regional authorities for ODYTH to formalise a coordination mandate and convene a structured multi-stakeholder working group with agreed roles, meeting cycles, and conflict resolution protocols. The optimisation plan could be used as a reference document for forthcoming funding applications (LIFE Programme, Nature Restoration Fund, CAP eco-schemes), with the economic analysis and multi-goal interaction map as the core evidence package.

3.4 Lake Vesijärvi

Lake Vesijärvi is a 107-km^2 seepage lake located in Southern Finland (Figure 10). It is surrounded by the City of Lahti and municipalities of Hollola and Asikkala. Lake Vesijärvi began to experience severe water quality deterioration in the 20th century due to population growth, industrialization, mechanization of agriculture, intensive drainage and utilization of artificial fertilizers. The lake became highly eutrophic with annual cyanobacterial blooms hampering the recreational and provisional use of the lake and its water sources.

Restoration of Lake Vesijärvi began in 1976 with the establishment of sewage treatment to restore lost recreational and provisional amenities. Since then, an extensive number of NbS water protection measures have been established to reduce external loading, including sedimentation ponds, buffer zones, wetlands, a two-stage channel, green infrastructure and other stormwater management measures. Additionally, annual biomanipulation by removal of planktivorous fish and stocking of predatory has been conducted since 1989 to tackle internal loading and to prevent proliferation of HABs. (e.g. Salonen et al., 2020, Härkönen et al., 2026a with references therein)

3.4.1 Self-Assessment Tool (SAT) results

Lake Vesijärvi restoration programme was evaluated in terms of following key measures: constructed wetlands, two-stage channels, wintertime vegetation cover, continuous cover forestry, biomanipulation, and macrophyte removal. The SAT assessment indicates that the Lake Vesijärvi restoration and management approach (Table 7) is performing at a relatively strong level overall (overall score: 0.70), demonstrating a well-developed and integrated restoration framework.

High scores were achieved for societal challenges (0.8) and biodiversity net gain (0.7), reflecting the project's goals and successes in addressing environmental pressures while delivering measurable ecological improvements. Design at scale (0.7), sustainability and mainstreaming (0.7), and inclusive governance (0.7) also performed strongly, suggesting a catchment-wide perspective of restoration, strong stakeholder engagement and well-established integration of ecological, societal, and management objectives.

Moderate scores, in turn, were obtained for economic feasibility (0.6), balance of trade-offs (0.6) and adaptive management (0.6), indicating that while effective monitoring and learning processes and funding mechanisms and economic considerations are present, additional work may be needed to better quantify restoration benefits, strengthen long-term financing, and improve the economic evidence base for future investments.

Overall, the SAT results suggest that Lake Vesijärvi provides a strong example of an integrated lake restoration programme, with future optimisation efforts focusing primarily on strengthening the economic dimension and maintaining the adaptive governance structures that have contributed to its success.

Table 7. Self-Assessment Tool (SAT) results for Lake Vesijärvi.

Criterion	Your Criterion Score	Maximum Criterion Score	Normalised criterion	FINAL OUTPUT Your Criterion %age
1. Societal challenges	8	9	0,83	0,8
2. Design at scale	6	9	0,69	0,7
3. Biodiversity net-gain	8	12	0,67	0,7
4. Economic feasibility	8	12	0,64	0,6
5. Inclusive governance	11	15	0,71	0,7
6. Balance trade-offs	6	9	0,65	0,6
7. Adaptive management	5	9	0,57	0,6
8. Sustainability and mainstreaming	6	9	0,69	0,7
Total			5,44	0,7

Key		
	≥75	Strong
	≥50 & <75	Adequate
	≥25 & <50	Partial
	<25%	nsufficient

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3.4.2 Multiple goal optimisation

Lake Vesijärvi restoration programme is characterised as a long-term, integrated approach consisting of broad catchment and in-lake measures, supported by extensive monitoring over decades and robust scientific evidence (e.g. Salonen et al., 2020 with references therein). Restoration attempts initially started with a goal to recover lost recreational amenities. Since the enactment of the WFD in 2000 and **currently**, the restoration programme aims to achieve good ecological status while safeguarding the lake's cultural and provisional ecosystem services. Safeguarding and restoring biodiversity are also key objectives, as Lake Vesijärvi and its surroundings have both international and national importance to waterfowl. Several bays of the lake are designated Natura 2000 sites (FI0306006). The lake and its catchment are also located on several groundwater areas. Safeguarding both their quality and quantity are to be considered in planning and implementing restoration and water protection measures.

Although substantial ecological improvements have occurred in terms of e.g., reductions in nutrient concentrations, these improvements are not yet reflected in the WFD status assessment, partly due to the one-out-all-out principle (Kramer et al., 2026). Achieving a good ecological status still requires addressing complex issues, such as internal loading (Jilbert et al., 2020) and diffuse pollution which both delay the complete recovery of the lake. The catchment area of Lake Vesijärvi is characterised by a mixture of forested, agricultural, and urban landscapes, resulting in diverse diffuse pollution pressures. Although agriculture occupies 18% of the catchment area, it is the largest external nutrient source, generating 42% and 37 % of the total phosphorus and total nitrogen load to the lake, respectively (Härkönen et al., 2026a). Additionally, with the expansion of residential areas and the increase in road traffic (Kuoppamäki et al. 2014) stormwater management in the catchment has become another important factor influencing the water quality of the lake. A national lake load response model (Kotamäki et al., 2015) suggests that substantial reductions of phosphorus and nitrogen would still be required to bring external loading within a sustainable range (Kramer et al., 2026). At the same time, water protection efforts must be aligned with the needs of landowners, business and industry.

A key **strength** of the Lake Vesijärvi restoration efforts regarding multiple goals is that there is strong empirical evidence showing long-term improvement of the lake from past nutrient loading and that the impacts are evaluated on multiple scales. Multiple goals, including also biodiversity, navigation and land use needs of humans are taken into account.

However, as a **weakness**, the diffuse and internal loading have not been satisfactorily and sustainably solved, with one of the hindrances being the insufficient policy backing to support catchment-wide water management solutions and practices. A further weakness is the misalignment between local water protection and broader land-use policies. For example, national agricultural subsidies can incentivize high production and do not consider the ecological status or restoration programme of the lake, counteracting local efforts to reduce nutrient runoff (Johannessen and Kramer, 2026; Kamergi et al., 2026).

Restoration efforts provide an **opportunity** for securing the value of multiple aquatic ecosystem services, at the same time benefitting biodiversity and reducing GHG emissions. Integrating and highlighting the direct and indirect benefits to humans may be an opportunity for enhancing the available funding for activities supporting restoration.

Climate change poses a **threat** to the efficacy of restoration impacts and catchment water management. Increasing temperatures have already affected lake surface water temperatures (Härkönen et al., 2026a) potentially increasing the risk of cyanobacterial blooms (e.g., Richardson et al., 2018) even when nutrient levels are decreasing. Warmer conditions have also resulted in shorter ice cover periods (Härkönen et al., 2026a) with potential implications for lake oxygen dynamics (Jansen et al., 2024; Jansen et al., 2025). Methane ebullition has been observed during recent acoustic fish surveys (KVVY Tutkimus Oy, 2026), highlighting the need for determining and managing lake GHG emissions. In addition, climate change is expected to alter both the frequency and duration of floods

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and droughts, challenging current drainage and flood management systems and maintenance practices regarding both agricultural productivity and urban stormwaters.

The way forward for multiple goal optimisation is in addressing the triple planetary crisis (biodiversity loss, climate change, pollution) even more holistically, while considering the needs and potential of agriculture, forestry and urbanisation in the Lake Vesijärvi restoration programme. Implementing climate-resilient water management measures that address both high-flow and low-flow conditions will be essential for reducing erosion risk, limiting external loading, and maintaining adequate water levels in the lake and surrounding groundwater systems. Where feasible, nature-based and nature-positive solutions should be prioritised for enhancing biodiversity, sustainability and adaptability. Ensuring the good status of groundwater areas around the lake is a further key priority to consider in water protection and restoration of Lake Vesijärvi.

3.4.3 Societal optimisation

Restoration and water protection of Lake Vesijärvi was initiated by the City of Lahti in 1971. In 2007, a dedicated Lake Vesijärvi Foundation for the protection and restoration of the lake, which **currently** engages a broad spectrum of stakeholders in planning and implementation of restoration. The foundation was established by the city, the two neighbouring municipalities (Asikkala, Hollola), and three private sector bodies (Kemppi Ltd, a society of industrial enterprises in Lahti and the press company Hämeen Media Oy) to coordinate the management of Lake Vesijärvi (Szulecka, 2025).

A key **strength** of the involvement of society in the restoration efforts of Lake Vesijärvi is the strong and broad stakeholder engagement coordinated and supported by the Vesijärvi Foundation. This strong stakeholder and expert engagement also provide a strong basis for planning and implementing further restoration activities. Since the 1970s, a total of c. 100 stakeholder organisations, including university researchers, governmental, regional authorities, and municipal authorities, non-profit and non-governmental organisations, private companies, consultants, landowners, farmers, water area owners, fishery owners, fishing communities, local media, artists from different fields, and general public have participated in improving the ecological status of the lake (Szulecka, 2025). The wide participation, cooperation and engagement of citizens, stakeholders and authorities were considered to secure the comprehensive management approach of Lake Vesijärvi by Suoraniemi et al. (2000) already before the establishment of Lake Vesijärvi Foundation.

Nevertheless, there are two identified **weaknesses;** 1) it is insufficiently known how well the catchment water management activities are aligned between the different sectors (agriculture, forestry) and 2) that young adults are not adequately reached by existing efforts.

Wide, multisectoral engagement and involvement of stakeholders provide **opportunities** to strengthen the acceptance and commitment to restoration programme and possibilities for mobilising both funding and voluntary work. In addition to broadening the funding opportunities through business investments (see section 3.4.5 Economic optimisation), there is an existing pool of volunteers offering in-kind contributions to restoration-related activities through voluntary events and campaigns. Building on this excellent stakeholder basis is expected to help in implementing new types of measures that have not been previously implemented in the Vesijärvi catchment. Broad inclusion of stakeholders ensures that decisions are science-informed and reflect the interests of those who use the lake for drinking water, cooling, and recreation (Johannessen and Kramer, 2026). Stakeholders openly discuss challenges, and citizens are actively engaged through events (Johannessen and Kramer, 2026), which is expected to ease the introduction and acceptance of activities.

The younger generation might take the current state of the lake for granted and does not sufficiently appreciate or recognise the need to maintain the restoration and management work that has been done. This lack of knowledge may be perceived as a **threat** to the future of the restoration efforts in the lake.

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The way forward for societal optimisation of restoration efforts for Lake Vesijärvi requires finding ways to include and engage young adults. Lake Vesijärvi is included in environmental education programme in Lahti City for 7th grade pupils to increase the awareness and interest of children to freshwater related issues. One option could thus be targeted communication and participatory activities to young adults through high or vocational schools, based on the good experiences with the secondary school programmes. This should be focused on ensuring that young people are familiar with the pollution history of the lake and do not take its present, less eutrophic state for granted, consequently improving commitment to protection and restoration needs. Second societal aspect to optimize is the alignment between catchment water management and water protection measures of different sectors. Recently available national tools and methods for this can be tested at Vesijärvi, such as catchment-scale water management plans involving agricultural, forestry and urban areas and actors (Malmström et al., 2026), or development of a shared "Vesijärvi watershed vision" (Haapasaari et al., 2024), already piloted by the Municipality of Hollola.

3.4.4 Technical optimisation

Several catchment- and in-lake-focused solutions have been implemented at Lake Vesijärvi since the 1970s (Härkönen et al., 2026a) forming the **current approach**. Here, we summarize the strengths, weaknesses, opportunities and threats (SWOT) of selected key measures (i.e., constructed wetlands, two-stage channels as agricultural water management measures, wintertime vegetation cover, continuous cover forestry, biomanipulation, and macrophyte removal). Some of these measures have already been implemented for a long time (Härkönen et al., 2026a) while others are innovative approaches potentially considered suitable for the Lake Vesijärvi context. A detailed evaluation of each measure can be found in Annex 0.

A key **strength** of the Lake Vesijärvi restoration programme is the extensive range of catchment- and lake-based measures used to control eutrophication and protect aquatic ecosystem services. Biomanipulation and constructed wetlands (CWs) are routinely implemented, well optimized, and recommended for continued use. Extensive practical experience and monitoring support their further optimisation and maintenance. Lake Vesijärvi also provides a strong example of successful biomanipulation in a large lake, while its combination with commercial operation enhances the potential for scaling these approaches to other lakes.

Identified **weaknesses** of the Lake Vesijärvi restoration programme include potential trade-offs between restoration goals. For example, poorly functioning CWs may increase nutrient loading while still benefiting local biodiversity. The scale of catchment measures, including two-stage channels (TSCs), winter-time vegetation covers (WVCs), and continuous cover forestry (CCF), is often limited by land availability and insufficient incentives for landowners and farmers. Furthermore, the extent of CCF implementation at the Vesijärvi scale is unclear. Although the Vesijärvi Foundation coordinates public and private funding and research, it has limited influence over these catchment incentives and land-use decisions. Sustainable land-use practices, including agricultural water management and CCF, are also not included in the current 2024–2027 restoration programme. Despite extensive WFD-compliant monitoring, knowledge gaps remain regarding the effects of several measures on biodiversity, flood and drought management, and lacustrine and terrestrial GHG emissions. Finally, internal loading remains a major challenge, with no straightforward solution suited to the lake's specific conditions.

As an **opportunity**, the restoration programme could strengthen its focus on multi-benefit catchment measures, including agricultural practices at plot, farm, and landscape scales, sustainable forestry, and mitigation of urban impacts. New measures (TSCs, CCF, WVC) would benefit from stakeholder co-creation and facilitation, with the Vesijärvi Foundation well positioned to promote their acceptance and uptake. Existing spatial models can already help target WVC and CWs to hotspots with suitable soil and catchment conditions (Figure 10). CCF and TSCs have yet to be integrated into these tools. Comprehensive, long-term monitoring also provides a strong basis for evaluating the cost-

effectiveness of restoration measures and alternatives. Communicating their multiple benefits, including improved water and soil quality, flood and drought resilience, reduced GHG emissions, and enhanced recreational value, could further encourage landowner adoption.

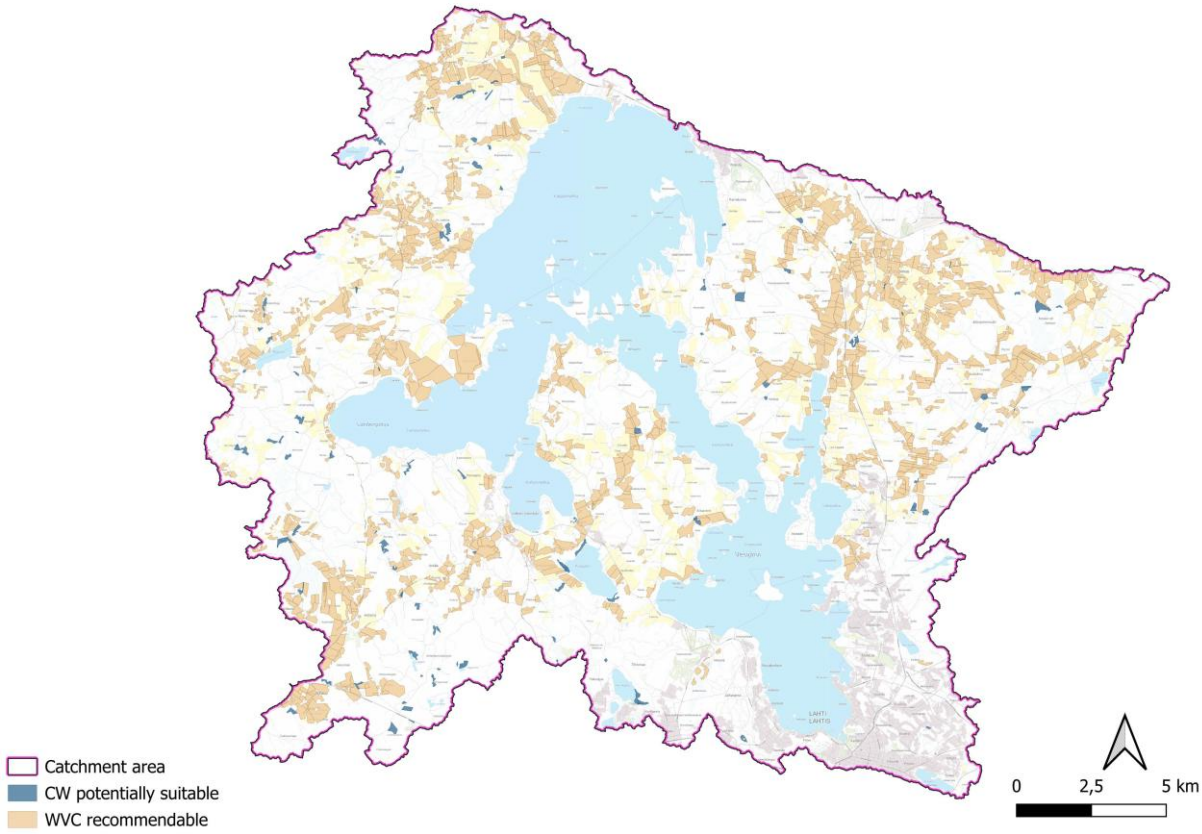


Figure 10. Potential sites suitable for constructed wetlands (CWs) and wintertime vegetation cover (WVC) around L. Vesijärvi catchment area.

Figure based on Spatial dataset for the targeting of water protection measures in agriculture and forestry (KOTOMA), Syke 2026. https://metadata.ymparisto.fi/dataset/{DF5FC7B1-9EB2-43DF-A090-22B8BB902C33}. Contains data from the National Land Survey of Finland Topographic Database 6/2026, License CC BY 4.0.

Climate change is a **threat** potentially compromising the efficiency of current water protection, restoration and water management measures (Härkönen et al., 2026a). Another threat is the legacy phosphorus stored in lake sediments and agricultural soils, for which no cheap, rapid, and readily scalable control measures currently exist. Consequently, reductions in stream and lake phosphorus concentrations are likely to be gradual and may be perceived by the public as a lack of progress unless expectations and timescales are clearly communicated.

The way forward at the catchment scale should increasingly consider multiple objectives, including climate-change and consequent flood and drought resilience. This can be achieved by prioritizing combinations of multi-benefit catchment-based measures (Härkönen et al., 2026b), while continuing established water-protection and in-lake measures. Greater emphasis should be placed on agricultural, forestry, and urban areas, and on measures that prevent pollution at source. Agricultural water management (WVC) and climate-smart forestry (CCF), complemented by targeted end-of-pipe measures such as TSCs, CWs and other nature-based solutions, should be integrated into future restoration programmes. Their importance should be emphasized in programme revisions to support wider uptake and scaling. Implementation of these approaches and measures could be facilitated through advisory services and practical plans for individual landowners or drainage collectives, Demonstration Sites for WVC and CCF, and analyses of soil structure and quality before and after

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implementation. Stakeholder engagement could be strengthened by highlighting benefits for production, water quality, biodiversity, and climate resilience.

The way forward at the in-lake scale may be found in biomanipulation. Biomanipulation has demonstrated positive effects in L. Vesijärvi (e.g., Salonen et al., 2020), consistent with its effectiveness widely recognized in the scientific literature (e.g., Triest et al., 2016). However, biomanipulation requires repetition, and complementary interventions are often needed to better tackle internal loading. Hypolimnetic withdrawal and treatment systems (HWTS), targeted phosphorus inactivation, and sediment removal have all been of interest and offer potential to address internal phosphorus loading in Lake Vesijärvi. However, their applicability is constrained by the lake's large and heterogeneous morphology, groundwater connectivity, ecological risks, and high implementation costs. The feasibility and long-term effectiveness of these measures therefore require site-specific assessment, including phosphorus sources and fluxes, groundwater interactions, spatial targeting, ecological impacts, technical requirements, and cost-effectiveness, before large-scale implementation. While the internal loading continues to slow the recovery of Lake Vesijärvi, surface sediment phosphorus concentrations still indicate a long-term recovery trend (Jilbert et al., 2020). Declining surface-water total phosphorus concentrations and signs of recovery in grazing crustacean zooplankton (KVVY Tutkimus Oy, 2026) further suggest that the lake may be gradually approaching a new, more oligotrophic dynamic equilibrium (Hanson et al., 2023). Until alternative in-lake measures have been thoroughly assessed for their feasibility, effectiveness, ecological risks, and cost-effectiveness, it remains to be recommended to continue biomanipulation alongside strengthened diffuse-load reduction to support further recovery.

3.4.5 Economic optimisation

In its **current form**, the Vesijärvi Foundation receives 60–70% of its budget from the municipalities, with the City of Lahti providing the largest contribution, followed by Hollola and Asikkala. Lahti Aqua and Lahti Energia are also key funders, in addition to which the Foundation has several major corporate and institutional supporters. The Foundation's fundraising activities also include product sales, events and collections and campaigns aimed primarily at individuals such as "Lake Godparent" donation scheme. Project funding also represents an important but variable component of the funding base, with several national and international projects contributing annually. Additional national and EU-level CAP-Agri-Environmental Schemes (CAP-AES) funding sources to agricultural landowners and farmers are also used to support implementing certain agri-environmental measures.

This diverse funding base is a key **strength** sustaining restoration efforts for decades. Thus, the foundation is not vulnerable to changes in one funding source, which better secures its long-term restoration activities. In addition, the restoration programme demonstrates a low cost-benefit ratio (Kramer et al., 2026).

A key **weakness** is the lack of compensation mechanisms for landowners who incur income losses or surrender land for restoration purposes, which may suppress the adoption of more sustainable forestry and agricultural practices. Incentives for sustainable forestry are insufficient (Miettinen et al., 2025; Härkönen et al., 2026b), while the CAP-AES inadequately compensates farmers for land losses associated with two-stage channels (Västilä et al., 2021). These funding and incentive gaps can hinder local nutrient-reduction efforts and limit the ability of local actors, such as the Vesijärvi Foundation, to address them (Johannessen and Kramer, 2026).

Opportunities may arise through the mobilization of under-utilized EU incentive schemes, such as CAP-AES, to strengthen the diversified funding base supporting restoration programmes. Other opportunities include further developing water-management-related ecological compensation mechanisms and exploring how the emerging Finnish nature-value markets could channel private funding towards restoration. Since 2023, Finland has a voluntary ecological compensation framework, while a broader nature-credits market is currently being developed. Its potential to finance restoration and compensate restoration costs should therefore be assessed as the market evolves.

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A potential **threat** is a reduction in national public funding for lake restoration and water management as government priorities shift towards defence and security. Reduced public funding could limit support for restoration projects, monitoring, and innovation, while increasing competition for available environmental funding. This could be particularly challenging for measures that require long-term investment.

The way forward for economic optimisation for Lake Vesijärvi lies in integrating agricultural measures at plot and landscape scales into the restoration programme and facilitating their spatially targeted implementation to maximise cost-effectiveness. An immediate opportunity is to make better use of available national CAP funding. For example, the currently underutilized "joint drainage investments" could cover 40% of the costs of landscape-scale nature-based agricultural water-management measures, such as TSCs, with the remaining costs covered by landowners (Keränen, 2024).

Further opportunities exist through collaboration with private-sector actors. A major grain-processing company operating in the catchment already offers higher grain prices to farms applying sustainable farming practices, including winter vegetation cover on at least half of their fields and reduced tillage (Fazer Mills, 2026). Such partnerships could be expanded to include scientific assessment and optimisation of measures and communication of their multiple benefits to farmers.

Emerging mechanisms for water-management compensation and nature and water credits, including those explored nationally through the VEHOKOMP project, may provide additional financing opportunities. This is increasingly important as national public funding for ecosystem restoration and water protection may decline due to increased spending on defence and preparedness. Greater reliance on EU funding, municipalities, private-sector partnerships, and emerging nature-financing mechanisms could partly compensate, although these sources may be less predictable in the long term.

Several of these opportunities depend on national and, in some cases, EU-level policies and incentives. Local restoration actors should therefore also engage in policy development to promote funding mechanisms that better support cost-effective, multi-benefit water management.

3.4.6 Policy / regulatory optimisation

After the establishment of WWTP in 1976, Lake Vesijärvi started to experience declining phosphorus trends even before the UWWTD (1991) and WFD (2000) were introduced, indicating stimulation of stakeholder cooperation and public pressure for initial restoration needs. Enactment of WFD has further promoted the implementation of water protection and restoration measures at the lake, which largely remains in moderate ecological status (Kramer et al., 2026). The newly established NRR is likely to further support the implementation of protective and restorative actions at the area.

In general, the **current approach** of Finnish policies has a positive impact on promoting implementation of protective measures and ensuring continuous financing for restoration (Kamergi et al., 2026). The national policies also somewhat support the integrated, participatory and inclusive lake basin management as well as foster climate adaptation and resilience. However, some national regulations display conflicting interactions with the afore-mentioned goals. For instance, national policies and regulations do not provide strong support for sustainable forestry practices (Ministry of Agriculture and Forestry of Finland, 2023), such as CCF (Annex 0. This conflicts with the national strategy for agricultural and forestry water management stating that carbon retention should be advanced by developing forestry practices and that new measures should be found to reduce loads from forestry considering predicted increases in rainfall outside growing season (Häggblom et al., 2020).

While the Finnish agricultural and forestry regulations show a great degree of uncertainty in alignment, the water-focused national regulations are perceived to be better aligned (Kamergi et al., 2026). The new CAP in 2028-2034 with proposed less binding measures at the EU level and stronger autonomy at

the country level may cause a risk for decreasing the level of national-level ambition, which would be reflected also at Vesijärvi.

Additionally, the strictness of the one-out-all-out principle in WFD obscures improvement in ecological status (Kramer et al., 2026). Despite the fact that, e.g. the nutrient concentrations keep declining at Lake Vesijärvi, its ecological status is deteriorating in the upcoming assessment due to the failure of one biological quality element. The naturally abundant fish stock of the lake continues to indicate worse than good ecological status, even though the consistent biomanipulation has successfully rebalanced the structure of fish communities and the abundance of piscivorous fish stock is high (Ruuhijärvi et al., 2023, Härkönen et al., 2026a).

As a main institutional actor, the Vesijärvi Foundation (est. 2007) coordinates and is committed to the restoration of L. Vesijärvi. The surrounding municipalities Asikkala and Hollola in addition to the City of Lahti have a pronounced, supportive impact on lake protection and restoration in terms of developing local and regional programmes, provision of funding and implementing concrete restoration measures. For instance, the stormwater management programme (City of Lahti, 2010) provides advanced local policies for treatment and diversion of urban rainwaters.

A key **strength** of the restoration efforts at Lake Vesijärvi is the fact that there is a coordinated restoration programme that has a strong support from surrounding municipalities. Furthermore, this programme is also backed by EU and national level policies and regulations.

A **weakness** of the restoration efforts is the insufficient coherence of certain policies (Kamergi et al., 2026). Additionally, potential changes in the key persons in lake basin management may influence the scope and direct financing of the Foundation. Thus, the restoration activities of the Foundation are subordinate e.g. to the views and political circumstances of the catchment municipalities.

EU level regulation, together with national, regional and local strategies provide **opportunities** to foster protective and restorative measures together with promoting the alignment of policies and regulations. Moreover, biomanipulation in Lake Vesijärvi has been combined with formerly under-utilized cyprinid catches by the local food industry (Tammeorg et al., 2024). Such sustainability visions developed by food processing companies can be considered as an opportunity to foster lake restoration by circular uses of catch of biomanipulation.

There is a risk of increasing miss-alignment between future agricultural and forestry policies on the one hand and the ambitious water, biodiversity and climate regulations on the other hand, which can be perceived as a **threat**.

The way forward for regulatory optimisation at Lake Vesijärvi lies in further optimisations to the stormwater management programme by targeting the renovation measures to most risky and effective locations based on a recent GIS-based tool (Municipality of Hollola et al., 2025). Additionally, an optimisation opportunity for mainstreaming continuous cover forestry is the new AEFC Global Forest Standard, developed in Nordic and Baltic collaboration, requiring the adoption of continuous cover forestry (The Association for Ecological Forestry Certification, 2026). This standard could be piloted and its benefits disseminated to foresters in future forestry-oriented projects at Vesijärvi. Also, visions of relevant food processing companies operating in the catchment area could be analysed, and where applicable, improvements could be proposed from the perspective of lake restoration.

3.4.7 Stakeholder evaluation

The draft optimisation plan was shared and discussed with Vesijärvi Foundation, which is the coordinating body of the restoration programme and is well familiar with the insights of key stakeholders through regular discussions. Current aim of the restoration is to achieve limnological and ecological boundary conditions that support the transition to an oligotrophic state. As concluded by Kramer et al. (2026), the WFD's "one-out-all-out" rule may mask the successes of lake restoration programmes. This is also seen in Lake Vesijärvi, where an overabundant fish population prevents an

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ecological status improvement even though nutrient concentrations have decreased and the structure of the food web has improved. About the current biomanipulation method, the Foundation notes that the methods used in fishing must be changed, as the current equipment and techniques do not yield a sufficient catch. Also, additional measures to address the internal nutrient flux must be considered. While the HWTS might have the potential for permanently removing the excess nutrients from the lake, building the necessary infrastructure might only be possible if a regional wastewater treatment plant were to be established. However, no such plan currently exists and funding is not available. A municipal water utility company, on the other hand, has facilities to treat abstracted groundwater but no capacity to integrate activities in lake restoration and HWTS. Nonetheless, the company is aware of the Foundation's interest in using chemical treatment to address internal nutrient loading and has concerns about the potential risks to the quality of groundwater.

External loading to the most polluted Enonselkä basin has decreased substantially after the diversion of sewage (1976) and stormwaters in the 21st century. However, managing external loading is becoming increasingly difficult, as the simpler measures addressing point-source and more easily identified diffuse pollution have already been implemented, while the more complex challenges, such as diffuse agricultural runoff, remain to be tackled (Kramer et al., 2026). The fact that monitoring has shown no clear retention of loading by the constructed wetlands is somewhat discouraging. On the other hand, measures to combat diffuse loading closer to the load sources depend on the acceptance of each individual agricultural and forestry landowner. Especially large-scale projects to enhance water management are challenging as they need to be jointly agreed and largely financed by the drainage collectives representing all private landowners. A further challenge in the agricultural sector is the national and EU policy that does not steer towards optimizing the crop yields and thus efficient usage of the nutrient inputs, but rather towards maximizing the agriculturally used area. Collaboration with forestry sector needs further strengthening, although it is being partly addressed in a joint information-sharing project by the Vesijärvi Foundation and the Finnish Forest Centre. The project aims at improving the forest owners' ability to manage and anticipate climate-driven changes in everyday forest management and water protection.

The optimisation plan will be further discussed with relevant stakeholders, evaluated in detail and, where appropriate, incorporated in the upcoming restoration programmes. The major economic issue preventing optimisation of restoration is the scarcity of funding, which prevents uptake of measures. This affects the entire chain of restoration from the actual construction of measures to plans being prepared and landowners' willingness to act.

3.5 Lake Vansjø

Lake Vansjø is situated in southeastern Norway and is a large lake consisting of several fjords and basins, which have separate catchments and different environmental pressures. For analytical purposes, the lake is often divided into two main parts/basins: Storefjorden being the eastern, largest and deepest part, and Vanemfjorden being the western part (Figure 10). Vanemfjorden has experienced rapid eutrophication and reoccurring toxic cyanobacterial blooms, especially between 2001 and 2007, but Storefjorden, which supplies water to Vanemfjorden, has also been enriched. The lake is the primary drinking water source for almost 80 000 people. It is also used for hydropower generation, agricultural irrigation, and recreational activities, including boating, bathing, ice skating, and fishing. Furthermore, the lake contains three nature reserves: two water-based and one terrestrial. The main sources of phosphorus are agricultural activities, wastewater treatment plants and scattered dwellings, but also natural runoff from forest areas. Mitigation plans for all relevant pressures and sectors have been developed, and individual measures for each source have been implemented throughout the extended catchment (the Morsa catchment).

The restoration measures aim to reduce nutrient loads, particularly phosphorus, throughout the catchment in order to stop eutrophication and to reduce and prevent toxic cyanobacterial blooms. These efforts support the main overall goals to safeguard the lake as a drinking water source, to

improve the ecological condition of the lake, and to provide a safe recreational space for residents. The Morsa river basin organisation coordinates the planning and organisation of mitigation measures across municipalities and sectors through the Morsa project. The organisation also includes thematic working groups on e.g. agriculture and wastewater control. Despite significant improvements in water quality and reduction of cyanobacterial blooms due to nutrient reduction, Vansjø is still not reaching the environmental target of good status according to the WFD.

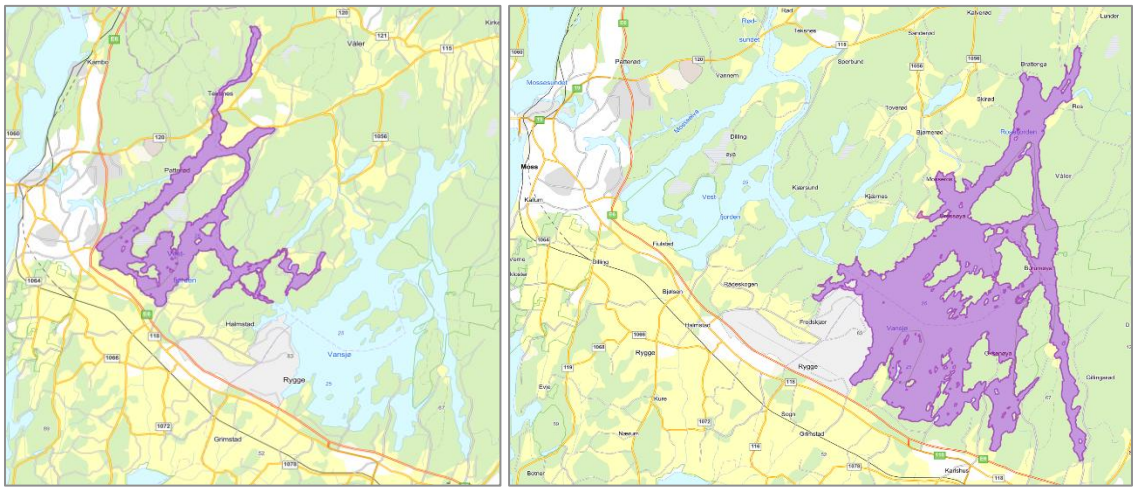


Figure 11. Lake Map of Vansjø with the two basins highlighted. Left: Vanemfjorden, the western basin. Right: Storefjorden, the eastern basin. Source: Vann-nett.no.

3.5.1 Self-Assessment Tool (SAT) results

The SAT assessment (Table 8) indicates that the Lake Vansjø restoration and management approach performs at an overall adequate to strong level (overall score: 0.70), reflecting a mature restoration programme with well-developed governance and long-term sustainability considerations.

The highest scores were achieved for societal challenges (1.00) and sustainability and mainstreaming (1.00), demonstrating that restoration measures are strongly embedded within catchment management and effectively address societal needs. High scores were also obtained for economic feasibility (0.80), inclusive governance (0.80), and adaptive management (0.80), indicating robust stakeholder involvement, effective monitoring, and a strong capacity to adjust management actions based on new knowledge and changing conditions.

Design at scale (0.60) and balance of trade-offs (0.60) achieved moderate scores, suggesting that restoration actions successfully integrate multiple objectives, although opportunities remain to further strengthen catchment-scale coordination and the management of competing interests. The lowest score was recorded for biodiversity net gain (0.10), indicating that biodiversity improvements have been less central to the programme and not well monitored.

Overall, the SAT results highlight Lake Vansjø as a strong example of integrated lake restoration and catchment management, with future optimisation efforts potentially focusing on strengthening and better demonstrating biodiversity outcomes while maintaining the successful governance and adaptive management structures already in place.

Table 8. Self-Assessment Tool (SAT) results for Lake Vansjø.

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Criterion	Your Criterion Score	Maximum Criterion Score	Normalised criterion	FINAL OUTPUT Your Criterion %age
1. Societal challenges	9	9	1.00	1.0
2. Design at scale	5	9	0.56	0.6
3. Biodiversity net-gain	1	12	0.08	0.1
4. Economic feasibility	9	12	0.75	0.8
5. Inclusive governance	12	15	0.80	0.8
6. Balance trade-offs	5	9	0.56	0.6
7. Adaptive management	7	9	0.78	0.8
8. Sustainability and mainstreaming	9	9	1.00	1.0
Total			5.52	0.7

Key		
	≥75	Strong
	≥50 & <75	Adequate
	≥25 & <50	Partial
	<25%	nsufficient

3.5.2 Multiple goal optimisation

Vansjø is an important drinking water source, it is used for hydropower and agricultural irrigation, as well as providing a valuable recreational habitat. There are several private and public harbours around the lake, as well as canoe rentals and organized camping trips, hiking trips, etc. The spatial diversity of the lake and the numerous basins and small islands provide great opportunities for privacy and sheltered recreation for many people. **Currently**, residents, cabin owners and tourists visit Vansjø for several reasons, including its biodiversity (fish and birds especially). Vansjø, with its large catchment, also provides the water purification service of being a nutrient retention system, as the lake drains into the polluted Oslofjord. The increasing focus on the Oslofjord in recent years, especially the role of nitrogen pollution in the loss of its fish populations, has led to more intensive regulations on public water treatment systems and on other measures to reduce the nitrogen loadings to the fjord. The recent fishing ban in the inner fjord is even creating a loss of workplaces and income. Good water quality and reduced nutrient loads are, therefore, still important and the main goal of the Morsa project. Both the close and the extended catchment area of Vansjø consists largely of high-quality agricultural land (17 %) which is of national importance to preserve for food production. Continuous work is being done in balancing and targeting these needs.

The **strengths** of the restoration efforts, in light of multiple goals, are the clear set of challenges that are identified, with an early mitigation analysis identifying pressures, challenges and drivers, leading to a knowledge-based mitigation plan. Measures in several sectors were implemented at the same time, and the management board is in continuous development, gaining new knowledge and adapting to emerging challenges.

A **weakness** in Vansjø is finding a balance between implementing measures with pressure on farmers and landowners and the need for food production. The current mitigation plan is limited in terms of focus on improving water quality and not considering the broader effects on the economy or biodiversity. Moreover, this plan has not sufficiently considered future climate change and extreme events.

An **opportunity** for Vansjø and its catchment is the increased focus on the downstream Oslofjord. The local and national willingness to prioritise the fjord restoration is substantial, and this creates more opportunities for funding and cooperation to reduce nutrient loads to, and from, Vansjø.

The **threat** for this catchment is the fact that climate change and reduced acidification impact phosphorus-transport and runoff, and that this creates increasing difficulties in achieving the water quality goals. NbS designs implemented are not sufficiently robust to withstand climate-related changes, especially in extreme run-off events. Furthermore, regulations on the use of agricultural land for other purposes than food production limits the possibilities for measures such as tree planting and buffer strips. Climate change may also impact the lake quality directly with warmer temperatures leading to increased internal loading from the sediments and more optimal summer growth conditions for cyanobacteria. Another threat for Vansjø is the recent years' discovery of PFAS pollution in certain areas of the lake, causing the authorities to advise against eating any fish from the lake due to high levels of PFAS. The main source of PFAS in the lake is from the use of fire extinguishers at the nearby military airport, however certain compounds also come from rivers in other areas of the lake.

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The way forward for multiple goal optimisation for Vansjø would be to have a greater focus on PFAS pollution to ensure the lake remains suitable for drinking water abstraction and that the fish becomes suitable for eating. There is a need for more knowledge on the occurrence of PFAS in Vansjø, and also the effects on and accumulation through the food chain. In addition to an increased focus on PFAS in the lake, an increased focus on nitrogen reductions in the catchment by the Morsa working group for agriculture is required due to the severe downstream issues in the Oslofjord. Future measures in Vansjø and its catchment should focus even more on preventing biodiversity loss, robustness for climate change and prevention and removal of (phosphorus) pollution. The shift in emphasis towards preventing biodiversity loss could start by assessing biodiversity in the lake, not just a focus on water quality monitoring, and by evaluating the impacts of existing plans on biodiversity. Followed by, if necessary, adjustments of these plans so nature conservation is included as a goal. Consideration of the climate resilience of plans is needed. Climate adaptation and mitigation options should be considered when planning NbS and agricultural measures. Finally, there is potential to evaluate alternative water level and outflow management regimes that balance hydropower production with ecological objectives. This has a potential to improve lake health by reducing low-flushing conditions at critical times of the year to minimise cyanobacterial blooms.

3.5.3 Societal optimisation

Currently, the Morsa organisation includes different levels of authorities, farmers associations and water and sewage companies, focusing on water quality. The coordinator of Morsa holds both professional and administrative leadership responsibilities in the river basin organisation. Strong communication and collaboration at all levels within Morsa, as well as with external partners, are essential for achieving good results. In this context, the coordinator serves as an important connector and driving force.

In terms of the existing mitigation plan and ongoing work in Vansjø/Morsa, the organisation is well built, with extended working groups that are dynamic, continuously including more people and/or organisations and turning their focus towards new challenges, such as PFAS pollution and nitrogen removal, upon demand and when needed. For instance, through the Critical Friends group, facilitated through FutureLakes, a consortium of research institutes, university, NGOs, water areas and farmers associations have created a space for working together on new measures for reducing nitrogen loads in catchments draining to the Oslofjord, including Vansjø and the Morsa catchment. Formation of this group has resulted in a successful 0,5-million-euro project which aims to improve nitrogen management in agriculture by developing and testing effective agronomic practices and documenting their impact on both nitrogen runoff and farm productivity.

The **strength** of the Morsa organisation is the transboundary cooperation between several levels of authorities (the water board) and local stakeholders (observers of the board; Farmer's associations, landowners, drinking water associations e.g.), who have regular meetings and close dialogue, and make scientifically based decisions in close collaboration. The intervention plan – which is long-term and from the beginning – is created in close collaboration with stakeholders through information campaigns and meetings, and in that way ensuring stakeholders' rights and interests.

The **weakness** is that the implemented measures are reducing farmer's crops and yields and are, therefore, based on voluntary involvement or economic compensation, through grants and subsidies. The farmers themselves do not benefit from the outcomes of the NbS. The Morsa organisation also consists mainly of members focused on water quality, with not enough focus on biodiversity, including no wildlife organisations. Increasing knowledge of PFAS impacts on public health and biodiversity is a new challenge for the military and industries to address.

The **opportunities** of this organisation are to be more inclusive of biodiversity issues at Vansjø, for instance by collaborating with wildlife organisations. The lake health and value would benefit from more knowledge on national and European species of interest, and monitoring of a wider range of

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organism groups, other than algae, supporting further conservation measures and providing evidence of the biodiversity response to the long-term lake restoration programme.

Threats are the continuous balance of trade-offs especially between necessary measures for improvement of water quality, and the need for food production. For example, climate events (wet/dry/extremely warm seasons) may prevent the successful implementation of certain measures when secure food production is prioritised. Climate changes happening now means that catchment NbS measures need to be adapted and strengthened, and further measures need to be considered to be more resilient to future climate change or to tackle new pressures.

The way forward for societal optimisation for the Vansjø Demonstration Site would be to add one or more employees working in the Morsa river basin district as assistants to the coordinator of Morsa. The coordinator of Morsa is an important connector and driving force behind the activities in the river basin and these assistants could work specifically on projects and help relieve the coordinator. An additional staff member would also provide institutional resilience in governance, so it was not reliant on a single person's knowledge and expertise.

Another opportunity for societal optimisation would be to extend the working groups to include biodiversity organisations, such as BirdLife Norge, the Norwegian Botanical Society and Entomology Association, anglers' associations etc., to gain knowledge on the current biodiversity condition in and around the lake (and develop plans for protection and prevention of biodiversity loss in Vansjø). The potential positive impacts of the implemented measures on species richness and ecosystem resilience in Vansjø is largely unknown (also see 3.5.4). There is need for habitat and species conservation plans with qualitative and quantitative data and protocols for reporting, multi-approach methods, modelling, and climate-change scenarios.

3.5.4 Technical optimisation

A wide range of measures has been implemented in the catchment area of Lake Vansjø since the 1970s (Hagman et al., 2026). From the beginning, the goal of the Vansjø/Morsa mitigation plan and implemented measures have been to improve water quality and secure the lake as a drinking water source, by reducing nutrient concentrations and preventing cyanobacterial blooms in Vansjø. The focus was largely on phosphorus pollution. Moreover, Vansjø is **currently** one of the most frequently monitored lakes in Norway, including many parameters covering water chemistry, physical properties and phytoplankton, and has a long time series of high-quality data.

The main current challenge for Lake Vansjø is climate change, with more intense rainfall events and warmer, longer summers. This leads to higher runoff, increased erosion along stream- and riverbanks, more nutrients entering the watercourses, increased internal nutrient loading and a greater risk of algal blooms. Ideally, from a water-quality perspective, there should be far more riparian buffer zones along watercourses in agricultural areas in the catchment, as well as meandering stream and river channels. This, however, conflicts with the need for agricultural land. We are seeing an increase in erosion issues and landslides along streams and rivers where vegetation is lacking. Changes in agricultural management practices could help counteract these increased erosion threats. We are also in a high-pressure development area, which will result in more impermeable surfaces. Combined with climate change, this will place an even greater burden on run-off to water courses.

The **strength** of Vansjø is that there is a substantial information basis on lake status, including relevant ecosystem elements (pelagic water quality and indicators). Additionally, there is substantial information available on the current and long-term status of all extended catchment waterbodies (rivers, streams and lakes), including water quality, biological indicators and biodiversity (both invasive and prioritised species).

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A **weakness** of the restoration efforts for Lake Vansjø in relation to its technical aspects can be found in the lack of identified outcomes related to biodiversity conservation in the lake itself in connection to the implemented measures, which has mainly been focused on reducing nutrients (phosphorus) and preventing cyanobacterial blooms. Additionally, measures are limited by the need to maintain agricultural areas and food production.

Opportunities in Vansjø include new possibilities for funding by focussing on reducing nitrogen to the Oslofjord, the fjord located downstream of Vansjø. Focus on measures that will be multi-beneficial and reduce nitrogen, phosphorus, and erosion of banks can be beneficial and release grants from new sources, as well as additional contributors and motivations for conducting measures. In terms of biodiversity gain, there are several local interested parties (NGOs) that regularly perform surveys (birds, fish), and there could be great benefits for the Morsa organisation to work more closely with these organisations to see broader effects (and challenges) of the mitigation measures.

A **threat** to the impacts of measures taken in the Vansjø catchment is climate change, as climate change is already known to counteract implemented measures in the Vansjø catchment. Other threats include a precarious balance between improved biodiversity and positive outcomes for society (e.g., increasing recreation affecting wildlife negatively) and the need to maintain land for food production (e.g., buffer strips encroaching on arable land).

The way forward at the in-lake scale: Future measures should not focus solely on lake water quality and the reduction of cyanobacterial blooms but should also consider measures aimed at reducing nitrogen loads to downstream Oslofjord and enhancing biodiversity in the lake and its catchment, such as sedimentation pond creation and shoreline habitat enhancement. Both in-field measures (e.g. reduced fertiliser application, catch crops, no-till) and edge-of-field measures, such as riparian buffer strips and sedimentation ponds, need to be further considered to deliver both nitrogen and phosphorus reductions, their climate resilience and their contribution to biodiversity protection and restoration. Lake management should also be strengthened through improved monitoring of the cost and effectiveness of measures. This includes more routine monitoring needed of biodiversity impacts. In the future, in-lake measures for sediment removal may also need to be considered to address PFAS pollution.

The way forward at the catchment scale would be to continue to encourage no tilling in autumn to reduce nitrogen and phosphorus loadings and soil erosion, supported by increased subsidies where needed. Balanced fertilisation practices should be promoted to better match nitrogen and phosphorus inputs with soil needs, together with the implementation of effective measures to reduce nitrogen losses from agricultural areas, including improved fertiliser use and nitrogen-binding crops. In addition, riparian zones should be restored through the planting of trees and a variety of vegetation to reduce erosion and increase biodiversity. Further efforts should focus on developing action plans to improve ecological conditions in streams and rivers and on implementing measures such as removing fish migration barriers, enhancing habitats for fish and other organisms, and planting trees. Action plans and mitigation strategies should also be developed to reduce PFAS contamination.

3.5.5 Economic optimisation

The **current approach** for implementing mitigation measures around Vansjø is coordinated, executed and funded by the Morsa River Basin District Organisation, whom in turn is funded by public sources. Implemented measures are mainly funded by the Ministry of Agriculture, the Ministry of Environment, and the affected municipalities. Funding is granted in 4-year intervals.

A key **strength** of the Morsa restoration programme is the well-documented cost of the measures implemented in the Morsa catchment. The measures that are taken are considered the best solutions for maximum nutrient retention within the current boundaries set by agricultural efforts.

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A **weakness** is the lack of focus on measuring the economic gains from implemented measures, creating a gap in the cost-benefit evaluation. The focus on largely public grant financing of measures is a weakness.

Opportunities exist to secure additional funding from the County Governor and additional Environmental agency funded projects, for the Morsa organisation alone and in cooperation with other catchment organisations. The recent focus on pollution reduction for the downstream Oslofjord creates opportunities for additional activities and funding for the Morsa catchment. Beyond public grants, other financing approaches could be explored for implementing measures, including new approaches to Payments for Ecosystem Services through Local Enterprise Networks (such as Leven LENs) or private financing (such as promoted by Vesijärvi Foundation).

A potential **threat** to the funding of restoration in the Morsa catchment is the reliance on national regulation and budgets, which are re-evaluated every 4 years and which could be de-prioritised. This stresses the need to consider other opportunities for financing.

The way forward for economic optimisation for Vansjø and Morsa may be to secure future funding for continuing existing measures, to find new funding sources and to not rely so heavily only on the baseline of government funding. For instance, the increased focus on the Oslofjord crisis may create new funding opportunities through local or county funding programmes focused on the fjord that might fund measures that reduce nitrogen loss from land to freshwater and thereby also benefit Vansjø. These measures are also likely to reduce phosphorus loads further and reduce erosion. The Morsa organisation and Critical Friends group has already been successful with one such proposal (as described in section 3.5.2), and more opportunities are foreseen.

3.5.6 Policy / regulatory optimisation

In 1999 the “Morsa-Vansjø Water District” was appointed as a pilot area in Norway for the implementation of the WFD, leading to initiation of a coordinated restoration programme from 2002 onwards and making Vansjø one of the best monitored lakes in Norway following WFD guidelines.

Currently, the Morsa river basin organisation is a best-practice example of the collaborative water management system in Norway. The entire catchment draining to Vansjø is included in the restoration efforts, including all relevant municipalities. Also, local, regional and national authorities are involved, securing transboundary cooperation. Coordination between municipalities, agricultural offices, environmental authorities, and local stakeholders has been central to its success. Long-standing thematic groups, particularly those focused on agriculture and wastewater, have built shared understanding and effective cooperation since 1999. These groups meet regularly, exchange knowledge, and jointly apply for project funding, creating a stable arena for dialogue and mutual learning. This approach of dialogue, trust, and informal networks also help compensate for limited resources, particularly in smaller municipalities. Shared projects, broader networks, and increased national visibility have strengthened access to higher-level decision-makers and improved policy influence. Challenges persist, including balancing environmental goals with agricultural land use, navigating political cycles, and ensuring long-term commitment. The role of a neutral coordinator, neither activist nor regulator, has proven effective in building trust and driving action.

A key **strength** of the governance model is its flexibility and responsiveness. Co-creation, local ownership and voluntary participation are also core strengths. There is a well-established collaboration between municipalities, regional and national authorities and common understanding of policies and environmental goals.

Most stakeholders are involved, however, NGOs working on biodiversity are not strongly involved, which may be perceived as a **weakness**. Additionally, some of the mitigation measures are voluntary.

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An **opportunity** for the Morsa river basin organisation to further their lake restoration efforts is the strong government interest in the WFD and adaptation to new environmental challenges (such as downstream Oslofjord and national biodiversity and climate adaptation plans).

Changes in government decision-making and funding programmes are perceived as a **threat**.

The way forward for regulatory optimisation for Vansjø and Morsa may be to establish a cooperative body who can develop and administer new financing mechanisms for agricultural measures. For example, establishing a Landscape Enterprise Network, as established at Loch Leven and other catchments in Europe[1], to co-fund regenerative agriculture and nature-based solutions to drive landscape resilience to climate change.

3.5.7 Stakeholder evaluation

The optimisation plan has been discussed with the leader of the Morsa river basin organisation, whom is the key stakeholder of the Vansjø Demonstration Site.

The overarching focus of the restoration efforts is to reach the environmental goals for Vansjø set by the WFD. The lake is still in moderate status based largely on indicators of eutrophication (TP, Phytoplankton Trophic Index), despite a long-term focus on measures to reduce nutrient loading from the catchment area. Although the water quality has improved and cyanobacterial blooms have decreased, the need remains to reduce external nutrient loading further, especially in light of the impacts of the changing climate.

Another important goal for the Morsa river basin organisation is to reduce nutrient loading to downstream Oslofjord where an ecological crisis has developed with massive algal growth, declines in fish populations and several other serious changes in ecology and water quality as a result of decades of eutrophication and overfishing. Nitrogen-loading from the catchment area, including Vansjø, is regarded as a main driver and the Morsa river basin organisation is currently working with municipalities and farmers to better understand how the nitrogen-loading from the catchment can be reduced. The Vansjø Demonstration Site coordinators, therefore, initiated a critical friend's group with a specific focus on identifying common interests and plans to work together on nitrogen runoff to the Oslofjord, especially from agriculture land. A think tank session was arranged for this critical friends group, during which several municipalities participating in two river basin organisations, researchers and stakeholders met and discussed strategic initiatives to reduce nitrogen inputs from agricultural land to the Oslofjord while maintaining food production (Figure 12). The purpose of this session was to develop and refine a focused strategic initiative that will serve as the basis for an application for funding under Akershus County's Oslofjord Initiative. An application was submitted in April and was successfully funded in June 2026.

The suggestions provided within this Vansjø optimisation plan will be further evaluated in the Morsa river basin organisation working groups and will be incorporated into further plans and future work on measures to restore Lake Vansjø and the extended catchment area.

[1] https://landscapeenterprisenetworks.com/

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Figure 12. Group work at the think tank session with our critical friends' group.

3.6 Loch Leven

Loch Leven is a shallow lake in south-eastern Scotland, UK, with a surface area of 13.7 km² and a mean depth of 3.9 m (Figure 13). The loch receives runoff from a predominantly agricultural catchment of 159 km² via four major inflows and eight small drainage channels. Nutrient concentrations in the inflows are elevated, particularly phosphorus and nitrogen, largely because of agricultural runoff. Two wastewater treatment works within the catchment also discharge nutrients into the loch.

Loch Leven is one of the best-studied lakes in Europe and benefits from one of the longest and most comprehensive lake-monitoring records available. Water quality has been monitored at fortnightly intervals since 1968, with regulatory monitoring under the WFD commencing in 2007 (Figure 13; right). Together, these datasets provide an almost continuous 58-year record of the loch's physical, chemical, biological and hydrological characteristics, creating a robust evidence base for understanding ecosystem change and informing management decisions.





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Figure 13. Location of main sampling sites at Loch Leven, Scotland, UK; the routine monitoring sites are indicated in red.

Loch Leven is also designated as a National Nature Reserve and a Ramsar Wetland of International importance, reflecting its significant ecological and nature conservation value. It is also an internationally-recognised wild brown trout fishery, a very popular site for recreation and a site of historical cultural importance (Loch Leven castle). Future restoration efforts will, therefore, need to balance water quality improvements, biodiversity conservation, climate change adaptation, flood risk management and the socio-economic needs of the surrounding community. The extensive long-term monitoring record, combined with a strong scientific understanding of the loch's functioning, provides the foundation for developing evidence-based and adaptive restoration strategies.

3.6.1 Self-Assessment Tool (SAT) results

The SAT assessment indicates (Table 9) indicates that the Loch Leven restoration case currently performs at an overall adequate level (overall score: 0.70), reflecting several strong elements of the restoration programme while also highlighting some areas that would benefit from further development and optimisation.

The highest score was achieved for societal challenges (1.0), demonstrating that the catchment scale restoration programme, underpinned by strong scientific evidence, effectively addressed regional needs for improving water quality to reduce algal blooms and sustain water use. High score for design at scale (0.8) reflects the catchment-wide approach to restoration, albeit with more extensive control of point sources of pollution than diffuse sources. An equally high score for inclusive governance (0.8) highlights the engagement of a wide range of stakeholders, which was critical to the success of the restoration programme. Biodiversity net gain also scored relatively high (0.7), reflecting documented ecological improvements and positive outcomes for biodiversity.

More moderate scores for economic feasibility (0.6), balance trade-offs (0.6), adaptive management (0.6), and sustainability and mainstreaming (0.6) indicate the need for greater diversification of funding mechanisms to support complementary interventions and long-term restoration efforts. They also highlight opportunities to develop a more comprehensive framework for evaluating the full range of restoration benefits and associated trade-offs.

Overall, the SAT results indicate that the restoration measures implemented at Loch Leven have established a strong foundation for future optimisation efforts. These should prioritise strengthening economic sustainability and adopting an integrated, catchment-scale and climate-resilient framework that delivers multiple benefits while balancing environmental, social and economic objectives.

Table 9. Self-Assessment Tool (SAT) results for Loch Leven

Criterion	Your Criterion Score	Maximum Criterion Score	Normalised criterion	FINAL OUTPUT Your Criterion %age
1. Societal challenges	9	9	1.00	1.0
2. Design at scale	7	9	0.78	0.8
3. Biodiversity net-gain	8	12	0.67	0.7
4. Economic feasibility	7	12	0.58	0.6
5. Inclusive governance	12	15	0.80	0.8
6. Balance trade-offs	5	9	0.56	0.6
7. Adaptive management	5	9	0.56	0.6
8. Sustainability and mainstreaming	5	9	0.56	0.6
Total			5.49	0.7

Key		
	≥75	Strong
	≥50 & <75	Adequate
	≥25 & <50	Partial
	<25%	Insufficient

3.6.2 Multiple goal optimisation

The primary goal of the original restoration programme was to reduce cyanobacterial blooms and improve water quality within Loch Leven (LLCMP, 1999). Achieving this objective was expected to deliver a range of wider benefits, including improved water clarity, increased aquatic plant coverage, enhanced habitat for wildlife, and a healthier functioning ecosystem. The programme also sought to

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maintain water supplies for downstream industry, provide flood protection, and support economic, recreational, and health and wellbeing objectives associated with the loch. While many of these goals have been achieved, the **current** overarching goal to attain and maintain Good Ecological Status under the WFD has not been achieved yet.

A major **strength** of the original restoration programme is that it successfully delivered many of its intended outcomes. The programme was underpinned by strong scientific evidence and was driven by multiple objectives that recognised the wider social, economic and environmental importance of the loch. In addition, there was broad support amongst many stakeholders who had witnessed the deterioration of the lake and recognised the need for action.

Several **weaknesses** were also identified. Many of the restoration measures required substantial investment, with costs borne mainly by water utilities and industry. The trade-offs associated with management decisions were not formally documented or evaluated, making it difficult to assess the relative contribution of different measures and the multiple benefits they generated. There was also no formal risk assessment framework in place to consider future pressures and uncertainties. In addition, while external nutrient inputs were successfully reduced, internal phosphorus loading from the loch sediments was not fully addressed and continues to influence ecosystem recovery.

There are several **opportunities** to build on the achievements of the original restoration programme. The extensive monitoring record and strong scientific understanding of the loch provide an exceptional foundation for adaptive, evidence-based management. Recent recognition of climate change as a key driver of ecological change creates opportunities to integrate water quality improvement, biodiversity conservation, natural flood management and climate adaptation within a single restoration framework. Further opportunities exist through catchment-scale initiatives such as regenerative agriculture, expansion of nature-based solutions and collaborative approaches such as Landscape Enterprise Networks (LENs), which can deliver multiple benefits for water quality, carbon storage, biodiversity and farm resilience. The potential re-optimisation of sluice gate management also provides an opportunity to simultaneously improve fish migration, reduce cyanobacterial blooms, enhance habitat quality and contribute to flood-risk management. There is also an opportunity to adopt more formal approaches to ecosystem-service assessment, natural-capital accounting and trade-off analysis. These tools could help quantify the broader benefits of restoration and support decision-making across competing environmental, social and economic objectives.

Several **threats** could undermine the achievement of multiple restoration objectives at Loch Leven. Climate change is likely to increase the frequency of extreme weather events, including droughts, heatwaves and intense rainfall, potentially exacerbating internal phosphorus loading, increasing cyanobacterial bloom risk and reducing the effectiveness of existing restoration measures. Growing demands on land for food production, housing and economic development may create conflicts with water quality and biodiversity objectives. In addition, management decisions designed to achieve one objective may generate unintended consequences for another. For example, changes to sluice gate operation intended to improve fish migration and ecological status could affect flood protection or downstream water users. Without clear mechanisms for identifying and managing such trade-offs, future restoration efforts may struggle to maintain support across all stakeholder groups.

The way forward for multiple goal optimisation at Loch Leven lies in the potential for a fully integrated catchment-scale restoration strategy. Future management should move beyond a primary focus on nutrient reduction and incorporate biodiversity recovery, climate adaptation, ecosystem resilience, natural flood management, recreation, public health and community wellbeing within a single decision-making framework. Currently, some of these objectives are considered separately, or not at all. Future restoration planning should include formal assessment of risks, uncertainties and ecosystem service benefits, ensuring that decisions maximise co-benefits wherever possible.

Additionally, to achieve the current overarching goal to attain and maintain Good Ecological Status under the WFD future restoration efforts will need to align environmental objectives with the needs

and priorities of landowners, businesses, industry and local communities to ensure long-term support and a sustainable future.

3.6.3 Societal optimisation

The development and implementation of the original Loch Leven restoration programme required cooperation between a wide range of stakeholders, including the Loch Leven Catchment Management Group (LLCMG), Scottish Water, Woollen Mill, Scottish Environment Protection Agency (SEPA), local authorities, conservation organisations (NatureScot, Royal Society for the Protection of Birds), land managers (including golf courses), farmers, fisheries interests (Loch Leven Fisheries) and the scientific community. Securing commitment from major nutrient contributors, particularly Scottish Water and the Woolen Mill, was critical to the success of the restoration programme. While the original restoration programme has come to its conclusion and there is currently no equivalent restoration plan in place, the success of any future strategy will also depend on cooperation, trust and shared ownership among a broad range of stakeholders.

The LLCMG is well placed to provide leadership and coordination of restoration efforts at Loch Leven, building on its historic role, but future governance arrangements should be broader and more inclusive, bringing together local communities, businesses, land managers, conservation groups and public bodies. Public information, engagement and transparency will be essential to maintaining support for future actions. Progress should be communicated regularly through local channels, including social media, local press outlets such as the Kinross Newsletter, public meetings and online publications. Smaller, topic-focused working groups could help develop specific actions and maintain momentum. However, there is currently no strong local support structure in place to facilitate this level of engagement and participation.

A major **strength** of the restoration programme was the extent of cooperation achieved between business, regulatory, research and conservation stakeholders. This collaborative approach enabled significant improvements to be made in water quality and provided a strong foundation for future restoration efforts that had strong support across sectors. Citizen science has been an important mechanism for increasing public involvement, expanding monitoring capacity and strengthening local stewardship of the loch.

Despite these successes, several **weaknesses** remain. Public awareness of the restoration programme and its achievements is generally low, and many local residents have limited understanding of how they can contribute to future restoration efforts. Although progress and lessons learned are documented in the Loch Leven Catchment Management Plan (LLCMP, 1999) and a substantial body of scientific literature (May and Spears, 2012), much of this information is not readily available to the wider public. Historically, governance structures have been relatively centralised, and social and behavioural evidence has not been documented as systematically as environmental data. Greater efforts need to be made to empower local people and foster a sense of shared responsibility for the loch.

There are **opportunities** to build on the collaborative foundations established during the original restoration programme. While the involvement of numerous stakeholders has sometimes slowed decision-making and, in some cases, required regulatory enforcement to achieve progress, these partnerships ultimately enabled substantial improvements and created a platform for larger-scale interventions. There is now an opportunity to broaden participation further, strengthen community ownership and leverage restoration successes to attract additional investment and support. There is also an opportunity to strengthen intergenerational engagement by building on programmes such as Growing up with Loch Leven and integrating youth voices more formally within future governance arrangements. This would help ensure that future restoration planning reflects both current and future community priorities.

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Several **threats** could undermine future progress. The most significant is the risk of failing to establish governance arrangements that are representative, inclusive and trusted by all stakeholders. Maintaining community support and political commitment over the long term will be crucial. Difficult trade-offs may also constrain restoration options. For example, modifications to the sluice gates operation could improve fish migration but may conflict with their role in water level management and flood risk reduction. Climate change and competing stakeholder priorities may further complicate decision-making. There is also a risk that short-term convenience and economic considerations could outweigh support for longer-term and more sustainable solutions.



Figure 14. Stakeholder engagement meeting held at Loch Leven in June 2025 as part of the Loch Leven Matters initiative.

The **way forward** for societal optimisation at Loch Leven lies in strengthening long-term stakeholder engagement through a more inclusive and transparent governance framework. Future restoration efforts should build on the collaborative foundations of the Loch Leven Catchment Management Group while expanding participation to include local residents, land managers, businesses and recreational users. Recent initiatives such as the Loch Leven Matters platform (Figure 14), the UKCEH Loch Leven data portal and FutureLakes engagement activities have demonstrated the value of making scientific information more accessible and creating opportunities for dialogue between stakeholders. These initiatives should be further developed building on innovations from other initiatives. For example, a major opportunity for future engagement would be the development of a Loch Leven Digital Twin and Community Dashboard, combining real-time monitoring, citizen science observations and predictive modelling in an accessible online platform. Such a system would allow stakeholders to visualise current environmental conditions, explore the consequences of different management options and better understand trade-offs between water quality, biodiversity, flood management and recreation. A second opportunity would be to establish a Loch Leven Citizens' Assembly or Community

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Forum, including youth groups from both upstream and downstream communities to discuss restoration priorities and provide community input into management decisions. This would help ensure that local knowledge, values and concerns are incorporated into future restoration planning while building trust and strengthening long-term support for restoration activities.

3.6.4 Technical optimisation

The **current** restoration approach has been underpinned by robust scientific evidence and comprehensive monitoring before, during and after implementation. This has enabled restoration actions to be informed by data and adapted in response to observed outcomes and provides clear evidence of effectiveness throughout the programme.

The restoration programme began in the 1990 and Loch Leven was restored by 2007. However, the impacts of climate change have partially reversed this process since 2018, and further restoration measures are now required. For example, there is substantial uncertainty around how climate change will alter nutrient cycling or the functioning and effectiveness of existing restoration measures in the future. This makes it difficult to confidently predict the level of intervention required to achieve and sustain Good Ecological Status.

Historically, restoration focused primarily on reducing external phosphorus inputs. Measures targeting wastewater and industrial sources reduced phosphorus inputs by approximately 60%, while additional catchment-scale interventions included buffer strips, sedimentation ponds, rain gardens and constructed wetlands. No in-lake restoration measures have been implemented. However, modelling studies suggest that modified operation of the sluice gates controlling water levels and outflow could reduce cyanobacterial peaks by around 40% while also improving fish migration, habitat quality and flood management.

Despite substantial reductions in external phosphorus loading and significant improvements in water quality, Loch Leven remains classified as having 'Poor Ecological Status' under the WFD. In 2024, this classification was driven primarily by elevated total phosphorus concentrations and the condition of the fish community, with the sluice gates recognised as a barrier to fish migration. Following improvements that achieved 'Moderate Ecological Status' between 2012 and 2017, conditions deteriorated again from 2018 onwards. This decline is thought to be linked to increased internal phosphorus loading from lake sediments, potentially exacerbated by climate change and warmer environmental conditions.

A key **strength** of the technical aspects of the restoration approach is the wealth of lessons learned from the initial restoration of Loch Leven and the availability of long-term historical datasets, as well as building capacity to conduct lake monitoring and assessment programmes in the context of restoration. These data have enabled a thorough systems diagnosis, providing a strong basis for identifying the most appropriate restoration measures and assessing their effectiveness over time. The extensive monitoring record has also provided confidence in decision-making and helped demonstrate the benefits of management interventions internationally.

However, the approach also has **weaknesses**. Although Loch Leven benefits from one of the most extensive long-term monitoring programmes in Europe, important knowledge gaps remain. Long-term monitoring has focused primarily on water quality, hydrology and regulatory ecological status indicators, while several aspects relevant to future restoration are less well understood. Routine monitoring of key ecological components, including fish, macrophytes and macroinvertebrates, is currently insufficient to fully understand ecological interactions, recovery trajectories and ecosystem responses to restoration measures. For example, there is limited information on greenhouse gas emissions from the loch and how restoration measures may influence carbon dioxide and methane dynamics. Similarly, uncertainty remains regarding the long-term effectiveness of many nature-based solutions and diffuse pollution control measures implemented within the catchment, as their individual contributions to nutrient reduction and ecological recovery have not been quantified. While

substantial effort has been invested in catchment restoration measures, including wetland creation at Vane Farm, the establishment of buffer strips on agricultural land, and controls on private sewage discharges through the Loch Leven "125% rule", there has been limited long-term evaluation of how these measures influence nutrient loading, biodiversity and ecological condition within the loch itself. Knowledge gaps also exist regarding the feasibility, effectiveness and potential risks of in-lake restoration measures aimed at reducing internal phosphorus loading, including sediment phosphorus management approaches or algal harvesting. There is also limited integration between catchment-scale monitoring programmes and assessments of ecological change within the loch, making it difficult to determine which interventions are producing the greatest environmental benefits.

There are significant **opportunities** to build on the current success through the adoption of cost-effective restoration measures with lower long-term maintenance requirements, including nature-based solutions such as buffer strips, constructed wetlands and raingardens. Greater engagement with emerging green finance mechanisms could help diversify funding sources and support larger-scale restoration efforts. Initiatives such as the Leven LENs project demonstrate how working with farmers and other land managers can help address environmental pressures at catchment scale. Continued investment in innovative and consistent monitoring technologies could further improve understanding of environmental pressures and ecosystem responses, strengthening the evidence base for future interventions. An additional opportunity lies in revisiting the operation of the Loch Leven sluice gates as a multi-benefit restoration measure. Previous modelling studies have suggested that modified operation could reduce cyanobacterial blooms by approximately 40%, while also improving fish migration, habitat connectivity and flood management. As climate change places increasing pressure on ecosystem functioning and water resources, revisiting these studies using current datasets could help identify management approaches that deliver multiple ecological and societal benefits simultaneously. A further opportunity is the development of integrated monitoring systems that combine conventional water quality monitoring with remote sensing, automated sensors, eDNA approaches and citizen science observations. Loch Leven's exceptional long-term datasets provide an ideal foundation for implementing and testing these approaches, potentially establishing the catchment as a Demonstration Site for adaptive lake restoration and climate resilience.

The principal **threats** relate to the long-term sustainability of the restoration programme. Securing funding for additional technical measures and the ongoing monitoring programme remains a substantial challenge, yet without continued monitoring it becomes difficult to demonstrate progress towards restoration targets and maintain stakeholder confidence. Climate change presents an additional threat; it is increasing environmental variability at the loch, with extreme events, particularly floods and droughts, becoming more frequent. Furthermore, legacy phosphorus stored in the loch sediments continues to pose a long-term challenge, delaying recovery and undermining restoration gains even though external nutrient inputs have been reduced. A further threat is the implementation of restoration measures at landscape scales before their effectiveness has been adequately quantified or verified under Loch Leven conditions. This is particularly relevant for some nature-based solutions, diffuse pollution mitigation measures, and emerging restoration approaches, where evidence of ecological effectiveness, longevity, and climate resilience remains incomplete. Without robust evaluation, there is a risk that substantial investment could be directed towards measures that deliver smaller environmental benefits than anticipated or whose effectiveness declines under future climate conditions.

The way forward at the catchment scale should ensure that sufficient evidence is collected to support an adaptive management approach with decisions being guided by robust scientific evidence. Monitoring of catchment hydrology would be an important development.

Nature-based measures should continue to play a central role in catchment restoration programmes. In particular, the re-establishment of riparian buffer strips can help reduce soil erosion and limit the transfer of sediment and associated pollutants into watercourses. Future optimisation should also strengthen the links between catchment interventions and ecological responses within the loch.

Monitoring programmes should be designed to evaluate how measures such as constructed wetlands, riparian buffers and septic tank improvements influence nutrient loads, biodiversity and ecological status. This would improve understanding of where losses are highest and which interventions provide the greatest environmental returns and help guide future investment. Importantly, integrated NbS planning tools are required and these should be validated using data from controlled pilot trials of NbS to inform efficacy, design and implementation, maintenance and scalability planning.

The way forward at the in-lake scale will require greater emphasis on restoring ecological connectivity. This should include a careful assessment of any future proposals for the removal of barriers to fish migration given the risk of non-native species ingress. Particular attention should be given to evaluating whether interventions are required to address internal phosphorus loading, which has become a major constraint on ecological recovery despite substantial reductions in external nutrient inputs. Future work should assess the feasibility, effectiveness and potential risks of in-lake interventions, including sluice gate management, alongside catchment measures, recognising that climate change may increasingly favour phosphorus release from sediments. Model-based scenario testing could help identify combinations of catchment and in-lake measures most likely to achieve and sustain Good Ecological Status.

There is also a need to re-evaluate WFD Programmes of Measures and assessment approaches to ensure they remain effective in delivering ecological improvements. Opportunities to optimise sluice-gate operation should be revisited in light of emerging evidence, particularly where benefits may be realised for water quality, fish migration, habitat condition and flood regulation simultaneously.

At the same time, advances in monitoring technologies offer significant opportunities to strengthen environmental assessment and management. Techniques such as eDNA-based biodiversity monitoring, acoustic surveys, low-cost water-quality sensors and monitoring buoys can provide more comprehensive, timely and cost-effective information on ecosystem condition and drivers of change. Greater attention should also be given to developing long-term monitoring programmes for fish, macrophytes, macroinvertebrates and greenhouse gas emissions, thereby improving understanding of ecosystem responses to restoration and climate change.

3.6.5 Economic optimisation

The original Loch Leven restoration programme was funded primarily through public and regulatory investment, particularly by Scottish Water and industrial stakeholders responding to increasingly stringent environmental requirements. Significant resources were directed towards reducing phosphorus discharges from wastewater treatment works and industrial sources, leading to substantial reductions in nutrient inputs to the loch. More **current** catchment-scale restoration activities have been delivered through a combination of public funding, environmental stewardship schemes, research projects and partnership-based initiatives. Emerging approaches such as the Leven LENs programme seek to attract private-sector investment into catchment restoration through payments for ecosystem services and nature-based solutions.

A key **strength** of the original Loch Leven restoration programme was its focus on addressing major point sources of phosphorus pollution through investment in wastewater infrastructure and tighter regulation of industrial discharges. This delivered substantial reductions in phosphorus inputs to the loch and demonstrated that targeted investment in pollution control could lead to measurable environmental improvements. The total cost of the wastewater interventions alone was estimated to be approximately €11.8 million (2025 values; UK Inflation Calculator). The programme also demonstrated that substantial environmental improvements can be achieved when regulatory, scientific and financial resources are aligned around clearly defined restoration goals.

A notable **weakness** is the heavy reliance on significant capital investment and public-sector funding to achieve restoration outcomes. While the benefits of improved water quality have been demonstrated, the economic costs, distribution of those costs across different sectors and the long-

term maintenance requirements associated with restoration activities have not always been fully quantified or communicated. There has also been limited assessment of the economic value of the broader ecosystem services generated by restoration, including biodiversity enhancement, flood mitigation, recreational benefits and climate regulation. Furthermore, limited information is available regarding the cost-effectiveness of many catchment-based interventions, making it difficult to determine which measures provide the greatest environmental return on investment.

There are significant **opportunities** to improve the economic sustainability of future restoration efforts. Greater use of relatively low-cost nature-based solutions, such as rain gardens, buffer strips, wetlands and other natural water management measures, could deliver water quality, biodiversity and flood mitigation benefits while reducing long-term maintenance costs. Initiatives such as the Leven LENs project demonstrate the potential for collaborative approaches with farmers and land managers to address catchment pressures in a cost-effective manner. There is also growing potential to access green finance and environmental investment mechanisms, particularly where restoration activities deliver multiple benefits such as biodiversity enhancement, climate adaptation, carbon sequestration and natural flood management. The development of biodiversity credits, natural capital markets and payments for ecosystem services may provide additional mechanisms for attracting private investment into catchment restoration. Linking biodiversity gains with wider societal benefits, such as flood alleviation, public wellbeing and climate resilience, may strengthen the case for investment and attract a broader range of funding sources. Growing evidence of the economic importance of Loch Leven for recreation, wildlife tourism, cycling, angling and outdoor education presents further funding opportunities. Loch Leven National Nature Reserve attracts visitors throughout the year because of its internationally important wildlife, recreational opportunities and heritage assets, generating economic benefits for local businesses and the surrounding community. However, these visitor benefits are not currently linked directly to restoration funding. Future opportunities may therefore include voluntary visitor contributions, conservation donations, biodiversity sponsorship schemes or tourism-based payment-for-ecosystem-service models. Such approaches could create additional revenue streams while strengthening the connection between visitors, local communities and long-term restoration objectives. There is also growing interest in the application of natural-capital accounting and social-return-on-investment approaches to environmental restoration.

The principal **threat** is the difficulty of securing long-term funding to support both restoration activities and the monitoring required to demonstrate progress towards restoration targets. Economic pressures and changing political priorities may reduce investment in environmental programmes. Conflicts of interest between different sectors and business interests may also hinder implementation where the costs and benefits of restoration are not perceived to be distributed fairly. A further threat is the large-scale implementation of restoration measures whose economic and environmental performance has not been adequately quantified. Many nature-based solutions and diffuse pollution mitigation measures are assumed to provide cost-effective outcomes, but robust evidence of their long-term effectiveness under Loch Leven conditions remains limited. Without rigorous economic and environmental evaluation, there is a risk that scarce restoration funding could be directed towards interventions that deliver lower-than-expected benefits or whose effectiveness declines under future climate conditions.

The **way forward** for future restoration programmes at Loch Leven should seek to diversify funding mechanisms and reduce dependence on a small number of traditional funding sources. Particular attention should be given to supporting community-led restoration activities and identifying opportunities to leverage green finance, biodiversity funding, natural flood management schemes and other innovative funding approaches.

Economic feasibility and long-term sustainability should be integral components of restoration planning, with clear consideration given to the trade-offs associated with different management options. Future decision-making should be supported by comprehensive cost-benefit analyses that consider both direct and indirect costs and benefits. These assessments should include the valuation

of ecosystem services that are often overlooked or unpriced, such as flood mitigation, groundwater recharge, carbon and methane regulation, biodiversity enhancement, recreational opportunities and ecotourism potential. Where possible, these assessments should incorporate natural-capital accounting and social-return-on-investment approaches to provide a more comprehensive understanding of the environmental, social and economic value generated by restoration activities.

Long-term monitoring should extend beyond environmental indicators to include assessment of the social and economic benefits generated by restoration activities. This would provide a stronger evidence base for future investment decisions and help demonstrate the return on investment delivered by restoration programmes. Greater emphasis should also be placed on evaluating the cost-effectiveness of individual catchment and in-lake restoration measures, enabling future investment to be directed towards interventions that provide the greatest environmental and societal benefits.

Initiatives like the Leven LENs approach provide a promising model for linking private-sector investment with catchment restoration outcomes and should be further developed and evaluated as a mechanism for delivering landscape-scale restoration. Similarly, the economic benefits generated by visitors to Loch Leven should be quantified more fully and opportunities explored for linking tourism and recreation directly to restoration funding. Ultimately, successful restoration will require balancing environmental, social and economic objectives while ensuring that the benefits delivered to people and nature are clearly understood, quantified and valued.

3.6.6 Policy/regulatory optimisation

Policy and regulatory frameworks have been fundamental to the restoration of Loch Leven, providing the legal drivers, targets and governance structures needed to support restoration actions. **Current** key frameworks include the WFD, the Habitats and Birds Directives, National Nature Reserve designation, Ramsar designation, the Nitrates Directive and associated River Basin Management Planning processes. Together, these frameworks have established clear environmental objectives and supported coordinated action to improve water quality, ecosystem function and biodiversity.

More recently, the policy landscape has expanded beyond water quality and species conservation to include climate adaptation, biodiversity recovery and natural capital investment. Scotland's Biodiversity Strategy aims to halt biodiversity loss by 2030 and achieve significant ecosystem recovery by 2045, supported by the Natural Environment Act and associated delivery plans. River catchments are increasingly recognised as the appropriate scale for delivering biodiversity recovery, climate resilience and ecosystem restoration. Scottish climate adaptation and net-zero policies are also placing increasing emphasis on nature-based solutions that deliver multiple benefits, including water-quality improvements, biodiversity enhancement, carbon sequestration and flood resilience.

Loch Leven has also benefitted from a number of innovative policy-driven initiatives. These include the Loch Leven phosphorus mitigation planning policy (the "125% rule"), which seeks to ensure that new developments do not increase phosphorus inputs to the catchment, the installation of rain gardens and other sustainable drainage measures, and ongoing investment in river and catchment restoration projects such as the River Leven restoration programme. Scotland's emerging Nature Markets framework and ecosystem restoration finance initiatives may further support catchment restoration by attracting private investment alongside traditional public funding sources.

A major **strength** of the policy landscape is the close cooperation it has fostered between environmental regulators, government agencies, conservation organisations and the scientific community. The key policy frameworks are well established, supported by clear environmental objectives and underpinned by strong evidence bases. These frameworks have provided continuity of purpose over several decades and have played an important role in driving improvements in water quality and ecological condition. Furthermore, Loch Leven has benefitted from several innovative policy mechanisms. The 125% phosphorus mitigation rule represents a precautionary approach to controlling additional nutrient inputs from development, while investments in rain gardens, river

restoration and catchment-scale nature-based solutions demonstrate increasing policy support for integrated management approaches that deliver multiple benefits for water quality, biodiversity and climate resilience.

However, there are several **weaknesses**. Historically, policy development and implementation have focused primarily on environmental stakeholders, with comparatively limited involvement from businesses, landowners and local communities. Many catchment management measures rely on the voluntary adoption of best management practices rather than mandatory requirements, creating challenges where incentives and environmental objectives are not fully aligned. This can lead to tensions with farmers and other land managers, despite initiatives such as LENs that seek to promote more collaborative approaches. Additionally, in some cases, policy objectives are not fully aligned, requiring trade-offs between water quality improvement, biodiversity conservation, agricultural production, food security and flood management. For example, measures such as riparian buffer strips, wetland creation and other nature-based solutions can reduce nutrient losses and improve biodiversity but may also remove productive agricultural land from use. Similarly, modifications to sluice-gate operation could improve fish migration and ecological status while potentially affecting water-level management, flood protection and downstream water users. As climate change increases pressure on water resources and ecosystem functioning, navigating these competing objectives is likely to become increasingly challenging. Furthermore, uncertainty remains regarding the effectiveness of some policy interventions, including the extent to which measures such as the 125% rule, buffer strips, wetlands and other diffuse pollution controls have delivered measurable ecological improvements within the loch itself. This highlights the need for stronger links between policy implementation, monitoring and ecological assessment.

There are significant **opportunities** to strengthen restoration outcomes through greater integration of policy objectives. Advances in precision agriculture, soil testing and targeted nutrient management provide opportunities to optimise fertiliser applications, reducing nutrient losses while maintaining agricultural productivity. Moreover, Scotland's Biodiversity Strategy, Natural Environment Act, National Adaptation Plan and emerging Nature Markets programme provide new opportunities to align biodiversity recovery, water-quality improvement and climate adaptation objectives. By linking biodiversity recovery, climate adaptation, water-quality improvement and sustainable land management within a single catchment framework, Loch Leven could help inform future development of policy cohesion across Scotland.

Several **threats** may constrain future progress. The policy landscape is often complex, with multiple overlapping regulations and governance frameworks that can be difficult for practitioners, stakeholders and less experienced applicants to navigate. This complexity can create barriers to implementation and increase administrative burdens. Ambitious environmental targets must also be achieved within challenging timescales, placing pressure on institutions and stakeholders alike. Climate change presents an additional threat by increasing uncertainty around future environmental conditions and the effectiveness of existing management measures. There is also a risk that policy development, funding mechanisms and regulatory approaches may fail to keep pace with the scale of intervention required to restore ecosystems and deliver climate resilience. Without regular review and adaptation, current policy mechanisms may prove insufficient to address emerging challenges such as internal phosphorus loading, biodiversity loss and increasingly frequent extreme weather events.

The way forward for future policy and governance arrangements should place a stronger emphasis on adaptive management, sustainability and inclusive decision-making, including the mainstreaming of wider social considerations within restoration planning and delivery. Regular review cycles should be built into restoration programmes and River Basin Management Planning processes to ensure that objectives, measures and priorities remain relevant and responsive to changing environmental, social and economic conditions.

The substantial monitoring datasets available for Loch Leven provide a unique opportunity to implement evidence-based adaptive regulation, whereby policies and restoration measures are

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periodically reviewed and adjusted in response to emerging scientific evidence. Particular attention should be given to evaluating the effectiveness of existing policy instruments, including the 125% phosphorus mitigation rule, diffuse pollution controls and nature-based solutions, ensuring that investments are delivering measurable environmental benefits.

There is also a need for stronger integration between water-quality objectives, biodiversity recovery, climate adaptation, natural flood management and emerging nature-finance initiatives. Future policy should seek to align agricultural support schemes, biodiversity targets and catchment restoration efforts, reducing conflicts between environmental protection, food production and economic development. Scotland's emerging Nature Markets framework provides an opportunity to develop new funding mechanisms that complement traditional regulation and public investment while supporting landscape-scale restoration.

Beyond supporting local restoration objectives, Loch Leven should be recognised as a strategic national asset for freshwater policy development and evaluation. The combination of extensive environmental monitoring, long-term scientific understanding and a history of restoration innovation creates a rare opportunity to trial, evaluate and refine integrated policy approaches before wider implementation across Scotland. This would enable Loch Leven to continue its historic role as a pioneering freshwater restoration catchment while providing valuable evidence to support future policy development relating to biodiversity recovery, climate adaptation, water quality improvement, sustainable land management and nature-based investment.

3.6.7 Stakeholder evaluation

The optimisation plan, discussed with Forth Rivers Trust, Perth and Kinross Council and members of the Loch Leven Catchment Management Group, successfully identifies many opportunities for future restoration, but the plan remains framed largely around phosphorus management and WFD compliance. A stronger vision would present Loch Leven as a catchment-wide socio-ecological system, building on existing governance structures such as the Leven Catchment Collective, integrating Nature Networks and regenerative agriculture, developing a diversified funding strategy, and pursuing multiple outcomes including biodiversity recovery, climate resilience, natural capital enhancement and community wellbeing alongside water-quality objectives. The document currently frames Loch Leven largely as a water-quality restoration project, whereas the emerging evidence and practice suggest it should be presented as a whole-catchment, multi-benefit, adaptive governance challenge.

Although internal phosphorus loading has been investigated extensively and is recognised as a significant factor influencing recovery, uncertainties remain in relation to its current level of contribution compared with catchment inputs. There is a key knowledge gap around how climate change is influencing sediment phosphorus release, and whether in-lake interventions could accelerate recovery. Stakeholders would like to understand this problem better.

Although nature-based solutions are mentioned, they feel disconnected from current Scottish policy. There is a clear opportunity to connect with initiatives such as:

- Nature Networks
- National Planning Framework 4 biodiversity enhancement requirements
- Agri-environment reform
- Natural flood management
- Emerging Nature Markets

This would strengthen the policy relevance of the proposed plan considerably.

Rather than simply calling for an ecosystem service assessment, the document should explicitly seek a quantified understanding of nutrient sources, pathways, retention and export, coupled with

assessment of the ecological, social and economic costs and benefits of the residual nutrient loading. This would move the discussion from accounting to decision support. A catchment-scale nutrient budget for all wastewater contributions would help compare all sources of nutrients in terms of their source apportionment.

The proposed integrated restoration strategy should be aligned better with, and potentially be delivered through, existing catchment governance initiatives such as the Leven Catchment Collective. This would avoid duplication of management structures and capitalise on established partnerships and networks. If the report is advocating a fully integrated catchment-scale restoration strategy, it needs to acknowledge that the Leven Programme, and now the Leven Catchment Collective, were designed to operate at a broader catchment scale rather than focusing on the loch in isolation. Existing representative organisations and community networks should form the foundation of future stakeholder engagement structures to avoid "committee proliferation", because there is already an emerging governance system around Kinross and the Leven catchment that includes the following initiatives:

- Leven Catchment Collective
- Greener Kinross-shire
- Kinross-shire Civic Trust
- TRACKS
- Guardian Rivers activities
- Portmoak Community Woodland Group
- Climate Café
- CATCH
- local community action groups

While WFD Good Ecological Status remains an important regulatory objective, future management may benefit from adopting a broader ecosystem-based framework incorporating biodiversity recovery, climate adaptation, natural capital enhancement, community wellbeing and sustainable land use alongside ecological status targets.

Climate change is not only an additional threat, but also likely to be a major driver of future ecological change in Loch Leven. Climate related drivers of change will include rising water temperatures, increased frequency of extreme rainfall events, enhanced nutrient mobilisation and greater sediment delivery from the catchment.

Development of an integrated catchment investment strategy should include public funding, agri-environment support, LENs, biodiversity markets, natural flood management funding, private investment and community-led initiatives.

Overall, the report provides a comprehensive assessment of Loch Leven restoration and identifies many relevant opportunities for future action. However, it remains heavily framed around phosphorus management and compliance with WFD objectives. The review suggests that a stronger and more forward-looking vision would be to position Loch Leven as a whole-catchment socio-ecological system requiring integrated, adaptive management that delivers multiple benefits across water quality, biodiversity, climate resilience, natural capital and community wellbeing.

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4 Synthesis

This synthesis compares the six FutureLakes Demonstration Sites across five optimisation aspects: multiple-goal, societal, technical, economic, and policy/regulatory optimisation. Each component combines a continuous comparative discussion with a keyword-based SWOT table. The assessment is deliberately constructive and critical: it identifies where each site is convincing, where claims or causal links need clearer evidence, and where the proposed way forward could be made more operational. The comparison also recognises that the sites differ markedly in physical scale, restoration history, institutional maturity, and the number and diversity of stakeholders. Consequently, differences should not be read as a simple ranking, but as contrasting strengths and transferable lessons.

4.1 Multiple goal optimisation

Across the six sites, multiple-goal optimisation ranges from a relatively focused extension of water-quality restoration to a fully multifunctional approach in which water supply, flood safety, biodiversity, recreation, agriculture and regional development must be managed together. Each site is discussed individually below.

Lake IJssel is the clearest example of a system where multiple goals are already embedded in management. Its five overarching themes and projects such as Marker Wadden, foreshores and climate buffers show a mature capacity to combine ecological restoration with water safety, freshwater supply, landscape quality and economic use. This breadth is a major strength, but it also creates the most complex trade-offs. Future opportunities could lie in a renewed integrated vision based on ecological carrying capacity. A future basin management plan needs to be clearer about decision criteria: which goals are non-negotiable, how trade-offs will be weighted, and how open-water habitat will be protected when new islands or shallow zones are proposed.

Lake Karla also has an inherently multifunctional role, combining irrigation, flood mitigation, biodiversity recovery and potential recreation. Its optimisation plan excels in recognising that these functions must be treated as interconnected rather than as competing afterthoughts. The proposal to optimise multiple goals in the future involves linking hydrological models, ecological thresholds and climate scenarios in one decision-support framework. Yet Karla's current practice is currently dominated by irrigation and flood-management priorities, while trade-offs are not formally documented and governance is fragmented. This is a threat to realising a more multi-goal basin plan. A future basin plan is also reliant on increasing monitoring data to include biodiversity and potentially other policy indicators (such as greenhouse gas emissions) Further weaknesses that need addressing are the limitations of the current operational models and the infrastructure and mandates required to turn the proposed data dashboard into a routine decision-making tool.

Kartuzy represents the other end of the spectrum. It began with a clear hydro-chemical and biological restoration goal, with recreation, biodiversity and ecosystem services expected as wider benefits. This focus supported decisive implementation and helped avoid goal dilution. Scientific diagnosis, visible local demand and the combination of wastewater-system modernisation, sediment management, phosphorus inactivation and fish-community measures give the site a coherent intervention logic. However, economic and climate objectives were not weighted strongly at the outset, and the lakes lack national monitoring coverage under the WFD because of their individual size. Optimisation of the Kartuzy plan needs to ensure its wider benefits are more explicit and measurable, including recreational use, greenhouse-gas emissions, biodiversity recovery and that the avoided future restoration and treatment costs are estimated. The justification that the expensive remediation is cost-effective in the long-term is persuasive but needs indicators and evidence to back-up this justification.

Vesijärvi and Vansjø are similar in that they are both strong long-term, catchment-based restoration programmes, that show how a dominant water-quality objective can constrain a broader framing for

restoration goals. Whilst water quality improvements in Lake Vesijärvi are supported by empirical evidence and decades of intervention, the co-benefits for biodiversity, provisional ecosystem services and climate resilience remain less comprehensively monitored and documented – although the current restoration programme explicitly addresses these targets. The strongest optimisation opportunity for Vesijärvi is to connect pollution control to the use of multi-benefit agricultural, forestry and urban measures, and to frame the upcoming restoration programmes around the triple planetary crisis. However, national land use incentives can counteract lake restoration aims and internal nutrient loading from legacy pollution remains unresolved. Vansjø combines drinking-water protection, ecological status goals, recreation, hydropower and food production, and its Morsa river basin organisation is continuously adapting to emerging pressures. The work for Vansjø should be optimised to broaden beyond phosphorus and cyanobacterial goals to emphasise biodiversity goals more, and the benefits of reduced nitrogen export to the downstream Oslofjord. Climate-resilient land management measures and emerging threats, such as PFAS, also require greater emphasis. In both sites, the optimisation would benefit from explicit outcome goals and trade-off safeguards, especially in terms of agricultural production.

Loch Leven has a strong historical record of monitoring providing exceptional scientific evidence of restoration impacts. The basin plan could be optimised so that future management moves beyond nutrient reduction, algal bloom reduction and WFD compliance as primary goals, towards a more integrated socio-ecological strategy including biodiversity, flood management, climate resilience and community recreation and wellbeing. The internal phosphorus legacy still remains unresolved by the current plan and the climate-driven reversal of gains seen in recent years make this re-framing urgent to stimulate support for broader action. The proposed list of benefits is very broad and risks being seen as aspirational unless a renewed governance mandate can be achieved and a prioritised programme of measures and more formal trade-off assessment carried out. The proposal for measures to manage the sluice-gate illustrates both an opportunity and the difficulties in implementing this: altered operation could potentially support improved water quality but may be limited by demands for water supply to downstream users. Water level management also needs to consider the needs of breeding wetland birds and their young.

Comparatively, Lake IJssel and Karla provide the strongest demands for integrated goal-setting, while Kartuzy demonstrates the value of a tighter focused restoration logic and Vesijärvi, Vansjø and Loch Leven show the importance of persistence needed to achieve restoration goals over decades. Optimisation at all sites needs to clarify the logic chain from goals to indicators, indicator thresholds, trade-off rules and monitoring to underpin adaptive decision-making.

Climate change is a new challenge for all lake basins. It is exposing where current plans are insufficient and where past assumptions are no longer adequate. Programmes of measures need to address ecological restoration and climate resilience combined, ideally supporting biodiversity restoration and flood and drought management (Table 10). Basin plans need to establish a limited set of headline goals with measurable outcomes, an explicit understanding of synergies and conflicts, scenario testing, monitoring and periodic stakeholder review. This would protect the clarity of specific goals at individual sites, while establishing the broader multifunctionality goals needed, especially at the larger and more contested sites. The comparison of goal-setting also highlighted that physical scale matters: the compact Karla system can organise goals around a bounded set of interventions, whereas Lake Ijssel, Vesijärvi and Vansjø must account for relationships extending across large catchments and multiple jurisdictions. Goal frameworks should therefore be designed to be proportionate. Larger systems need spatial differentiation, explicit allocation of scarce water and land, and rules for assessing whether local projects contribute meaningfully to system-wide recovery.

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Table 10. Comparative SWOT by Demonstration Site for multiple goal optimisation

Demonstration Site	Strengths	Weaknesses	Opportunities	Threats
Kartuzy	Science-led restoration; recreation co-benefits	Economic/climate goals weakly specified	Prevention; ecosystem-service indicators	High remediation costs; renewed pollution
Lake IJssel	Mature multifunctional projects; models	Trade-off criteria unclear; wellbeing data gaps	Integrated vision; foreshores; sediment reuse	Climate scarcity; open-water loss; toxic pressure
Lake Karla	Multiple services; strong local support	Goals poorly integrated; reactive governance	Decision dashboard; climate scenarios	Administrative delay; drought/flood shocks
Vesijärvi	Long-term evidence; broad goals	Diffuse/internal loads; policy misalignment	Triple-crisis framing; groundwater protection	Warming; floods/droughts; legacy phosphorus
Vansjø	Clear pressures; adaptive basin organisation	Water-quality bias; limited biodiversity/economy	Oslofjord alignment; PFAS and N focus	Climate runoff; food-land conflict; PFAS
Loch Leven	Historic multi-objective success; evidence	Trade-offs and future risks not formalised	Integrated catchment strategy; sluice review	Climate reversal; internal P; land competition

4.2 Societal optimisation

All six plans recognise that restoration depends on communication, trust and cooperation, but they differ substantially in institutional maturity. Vesijärvi and Vansjø stand out for durable, recognisable coordinating structures. The Vesijärvi Foundation connects municipalities, companies, researchers, landowners and citizens, while the Morsa river basin organisation links multiple levels of government with farmers, utilities and specific working groups for farming and water supply. These arrangements provide continuity beyond individual projects and create practical channels for learning and funding. Their weakness is not absence of participation but uneven representation. Vesijärvi struggles to reach young adults and to align agricultural, forestry and urban water management. Vansjø remains strongly water-quality oriented and lacks key biodiversity organisations. Both sites should use their existing platforms to close these gaps rather than create parallel structures.

Lake IJssel also benefits from an established coordination platform, the BPIJ, which helps align agendas and negotiate trade-offs across a very large and multifunctional system. Its strength lies in providing a forum where scientific and sectoral disagreements can be addressed. Its limitation is equally clear: it has no binding authority, while implementation responsibilities and funding remain distributed. Optimisation should emphasise more inclusive representation and joint fact-finding. This could be developed by examining which groups are currently underrepresented, how they should be selected, and how agreements reached in the platform would be translated into accountable decisions by competent authorities. Without such a bridge, consensus risks becoming slow consultation rather than effective governance.

Kartuzy shows the benefits of clear local leadership. The municipality coordinated parties, responded to citizen concerns, communicated progress and helped establish trust between owners, water managers, scientists and fisheries interests. The site excels in showing that formal ownership is not the only basis for stewardship. However, the process is dependent on municipal initiative and interpersonal trust. The proposed official lake-management working group is, therefore, a logical next

step. It should include transparent terms of reference, recurring meetings, a clear relationship to statutory owners and a mechanism for resolving disputes. A revised management plan should be clear about how conflicting preferences, such as fishery objectives that may undermine ecological restoration, will be assessed against scientific evidence and agreed ecological safeguards.

Karla has strong local support for the lake's restoration, but with a governance deficit. Decision-making is centralised, participation is uneven, no comprehensive grievance mechanism exist and vulnerable, or harder-to-reach, groups are insufficiently represented. The new regional water-management organisation offers a major opportunity to mediate conflicts and create clearer accountability. Citizen-science and data platforms to increase transparency and provide early-warning communications are positive opportunities. Yet creating a digital platform with governance functions would require significant investment. Digital participation is a complementary tool and does not replace formal representation, agreed mandates, conflict-resolution procedures and obligations from authorities.

Loch Leven has a history of collaboration among regulators, utilities, industry, conservation bodies and scientists, but has lacked a strong governance structure and clear restoration plan in recent years. Public awareness of past achievements and current pressures is limited, even though the scientific record is exceptional. Their optimisation plan, therefore, emphasises accessible data, community forums and youth participation. Stakeholder feedback warns against creating additional committees where catchment organisations and community networks already exist. The clearest way forward is to connect future restoration to the Leven Catchment Collective and related local networks, define their roles more explicitly, and use the data portal and proposed dashboard as a shared evidence infrastructure.

Across the sites, societal optimisation should shift from evaluating societal engagement by the numbers and type of participants but enhancing the quality and consequences of participation (Table 11). This would involve documenting who influences decisions, whose costs and benefits are considered, how disagreements are resolved, and whether stakeholder input changes priorities or measures. The strongest transferable lessons come from Kartuzy's visible local leadership, Vesijärvi's foundation model, Vansjø's thematic working groups, Lake IJssel's joint fact-finding, Karla's ambition for open data and Loch Leven's emphasis on catchment-wide community networks. Each basin needs to also guard against a characteristic risk: dependence on individuals, consultation fatigue, dominance by well-resourced sectors, digital exclusion, weak accountability or duplication of structures. A minimum standard for optimising societal engagement across the demonstrations includes following up on the stakeholder mapping exercise already completed, updating this periodically, creating a transparent place for publishing decisions and reasons for management actions, accessible channels for feedback and grievance, and initiating monitoring of social and economic indicators alongside ecological indicators. This is particularly important where restoration transfers land, income or access costs to farmers, fisheries interests or local residents. Participation is most credible when affected groups can see how evidence and lived experience alter decisions in the basin management programme, not merely when they are invited to meetings. Comparable indicators across the six Demonstration Sites would also make continued cross-site learning more possible and credible.

Table 11. Comparative SWOT by Demonstration Site for societal optimisation

Demonstration Site	Strengths	Weaknesses	Opportunities	Threats
Kartuzy	Municipal leadership; trust; transparency	Compromise burden; person-dependent	Formal lake working group	Conflict; unsuitable fisheries preferences
Lake IJssel	BPIJ platform; joint fact-finding	Non-binding; slow multi-tier delivery	Broader representation; shared vision	Sector dominance; ecological goals less visible

Lake Karla	Strong local attachment	Top-down; weak grievance and inclusion	ODYTH mediation; citizen science	Trust loss; political discontinuity
Vesijärvi	Foundation-based coordination; broad engagement; volunteers	Partial youth gap; sector alignment unclear	Watershed vision; targeted youth work	Complacency; leadership/funding shifts
Vansjø	Working groups; neutral coordinator	Biodiversity groups absent; workload of individual coordinator	Additional staff; biodiversity NGO participation	Climate/food trade-offs; participation fatigue
Loch Leven	Strong historic collaboration; new partnerships formed	Low public awareness; no current management plan	Use existing catchment networks; dashboard	Committee duplication; weak long-term mandate

4.3 Technical optimisation

Technical capacity is strongest where long-term monitoring, scientific diagnosis and adaptive implementation reinforce each other. Kartuzy excelled in intervention design and flexibility. It combined pre-restoration diagnosis with dredging, sediment transport and treatment, phosphorus inactivation and biomanipulation, and adjusted the engineering approach after consultation with contractors. The direct pipeline to the wastewater treatment plant illustrates practical innovation, while sediment reuse adds circular value. The weakness is the limited historical baseline and uncertain financing for long-term post-intervention monitoring and further measures. The technical way forward should consider the need for further corrective measures and management actions at both lake and catchment scales supported by more formalised monitoring.

Lake IJssel has the most advanced modelling and system-management context. Extensive monitoring and process-based models support scenario analysis, and major infrastructure projects increasingly integrate ecological features. The SWOT identified technical weaknesses: inadequate connectivity for fish and sediment, fragmented data ownership, reduced continuous monitoring and limited spatial representation of this large basin in WFD assessment. Opportunities for slow dredging, eDNA monitoring, AI-supported gap filling and a shared data environment need prioritisation and validation. The clearest optimisation proposal is to rebuild a coherent spatial monitoring network, standardise data exchange, and connect catchment hydrology, lake ecology and infrastructure operations more closely within an adaptive management cycle.

Karla presents the largest technical implementation gap. Rewetting and hydrological infrastructure have restored the open water habitats, groundwater recharge and water storage capacity, but constructed wetlands and buffers have been assessed as not functioning as intended as nutrient loads remain high. Further technical measures to achieve water quality goals need implementing at scale within the catchment. Monitoring needs strengthening and broadening to cover biodiversity and social and economic impacts. The optimisation plan is strong in proposing more tailored intervention zones, real-time sensors, remote sensing, eDNA and open data. Establishing conservation plans and operationalising adaptive management are important. Advanced dashboards and sensor systems add value if institutions are obliged and resourced to act on their results.

Vesijärvi demonstrates the broadest portfolio of catchment and in-lake measures and has substantial practical experience with biomanipulation. Spatial models to target measures and long-term monitoring provide a strong basis for optimisation. Their critical self-assessment is honest and a strength: constructed wetlands may offer biodiversity gains without clear nutrient retention benefits, land availability and incentives constrain two-stage channels and continuous-cover forestry, and

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internal loading have no simple solutions. The optimisation plan is appropriately cautious about some technical measures (closed-circuit hypolimnetic withdrawal, phosphorus inactivation and sediment removal) because of the lake morphology, groundwater connectivity, ecological risks and cost. Technical clarity could be improved further if each measure was linked to decision thresholds, expected effect size and maintenance responsibility.

Vansjø is distinguished by frequent monitoring and a catchment-wide mitigation history. It has a strong evidence base for water quality of the lake basins and the main tributaries to understand the main sources of nutrients, and this has helped prioritise the measures to reduce phosphorus inputs and cyanobacterial blooms. However, biodiversity outcomes, PFAS pollution and climate resilience are insufficiently integrated into the basin plan. The proposed expansion of measures in land management to reduce nitrogen loadings is a clear and constructive way forward. Sediment removal for PFAS requires much stronger fate, risk and feasibility evidence before being presented as an option for adoption. Development of a more inclusive management plan should establish a PFAS action strategy and broaden ecological monitoring beyond traditional eutrophication indicators to evaluate biodiversity status and trends in relation to the restoration programme and increasing or emerging pressures, including climate change.

Loch Leven's exceptional monitoring record and restoration history make it a showcase for evidence-based adaptive management. Yet its status deterioration since 2018, attributed to climate change, incomplete biodiversity monitoring in recent years, and unresolved issue of legacy phosphorus pollution in the sediments highlights that an updated basin management plan is urgently needed. Proposals to evaluate sluice-gate operation, integrated monitoring technologies and more targeted evaluation of catchment NbS are clear ways forward. Optimisation plans should distinguish clearly between well-supported options and hypotheses requiring trials.

Across all six sites, the shared priorities are sustained core monitoring, stronger biodiversity coverage, building in climate resilience to measures, integration of measures across catchment and in-lake, quantifying measures effectiveness and adopting more formalised learning cycles (Table 12). Innovation in monitoring should be judged by whether it will help improve decision-making, not by unsupported data collection alone. A common technical reporting framework for measures would improve cross-site learning (following approaches outlined in Deliverables 1.2 and 4.1) and wider learning needed by Member States for developing their National Restoration Plans. This consistent monitoring and evaluation framework would make it easier to measure the success of replication, provide evidence for establishing decision thresholds, and could expose where apparent underperformance reflects an unsuitable design, inadequate implementation at scale, climate conditions, weak maintenance or unrealistic ecological response times. Such disciplined reporting is especially important for NbS, which are often presented as multi-functional, but whose local effectiveness and technical limits still require verification.

Table 12. Comparative SWOT by Demonstration Site for technical optimisation

Demonstration Site	Strengths	Weaknesses	Opportunities	Threats
Kartuzy	Integrated measures; flexible engineering	Weak baseline; monitoring finance gaps	Catchment planning; funded post-monitoring	Delayed ecological response
Lake IJssel	Models; long monitoring; engineered-NbS integration	Fragmented data; reduced spatial monitoring	eDNA; slow dredging; shared data	Climate extremes; insufficient capacity

Lake Karla	Rewetting success; zoned strategy	Non-functional NbS; sparse/delayed data	Buffers; wetland retrofit; real-time monitoring	Rigid grey infrastructure; climate stress
Vesijärvi	Large, long-term portfolio; practical experience	Land/incentive limits; internal loading	Spatial targeting; source-control measures	Legacy P; climate-lowered efficiency
Vansjø	Frequent monitoring; catchment coverage	Biodiversity and PFAS evidence gaps	Measures for reducing N; broader biota monitoring	Increased runoff and erosion; land competition
Loch Leven	58-year record; strong diagnosis	Insufficient biodiversity and GHG data	Sluice scenarios; catchment NbS; integrated monitoring	Internal P; unvalidated NbS; funding loss

4.4 Economic optimisation

Public funding dominates across the six sites, but the institutional pathways and resilience of funding differ.

Vesijärvi has the most diversified established funding base, combining municipal support, companies, donations, projects and agricultural schemes. This reduces dependence on a single source and supports continuity. The remaining economic constraints are related to both managing internal and diffuse external loading. The costs and benefits of alternative in-lake measures over their life cycles should be weighed to establish evidence-based decision thresholds. However, limited financial resources constrain the implementation of measures designed to effectively reduce internal loading. At the same time, compensation for land loss or lower-income practices is often insufficient, and potentially useful CAP instruments are underused to better account for source control measures. The optimisation plan identifies targeted agricultural measures, private supply-chain incentives and emerging nature-credit mechanisms as areas to explore further. These new options need to be clear about additionality, transaction costs, permanence and who carries monitoring obligations in new markets. Diversification of financing should not obscure the need for stable core public finance for coordination and long-term monitoring.

Kartuzy demonstrates that a municipality can assemble EU, national and local resources around a scientifically credible restoration design. This enabled an ambitious programme in which ecological suitability preceded cost considerations. The model is effective but difficult for smaller municipalities because preliminary assessments and pilot applications that fail are costly. Economic optimisation should retain the scientific screening that prevented unsuitable measures being adopted while widening access to preparatory finance, blended funding and shared expertise. Optimisation should also address polluter-pays principles more directly and evaluate if cheaper NbS effectively address the dominant pollution pressures and how climate resilient and cost-effective they are over their life cycle.

Lake IJssel benefits from established public programmes and experience with multifunctional investments, including combinations of financing for flood protection, habitat creation, sand use and recreation. Marker Wadden shows that non-governmental contributions can supplement public funding. Yet the economic benefits of restoration, especially effects on wellbeing, recreation and carbon, remain undocumented and historical project costs are fragmented or confidential. This weakens comparison and future private investment. The proposed allocation of a research share within major project budgets is a practical opportunity. It should be accompanied by common appraisal and reporting standards so that costs, maintenance and benefits can be compared across projects without compromising legitimate commercial confidentiality.

Karla has the weakest economic evidence base and perhaps the greatest unrealised economic potential. Large engineering infrastructure has absorbed most funding, while ecosystem services,

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ecotourism, groundwater recharge, flood mitigation and other benefits remain unvalued. Public funding is episodic and private engagement is minimal. A full cost-benefit and ecosystem-services assessment is therefore a sensible way forward as an evidence base to support future financing. Fair water-pricing mechanisms and exploration of blended finance also should be investigated. An economic optimisation plan should separate public-good benefits that require public finance from revenue-generating activities suited to private financing. Safeguards to prevent tourism or water-pricing strategies from worsening social inequities or ecological pressure should also be considered in future basin management plans.

Vansjø has relatively well-documented costs of measures and a stable public coordination mechanism, but little evaluation of economic gains or co-benefits achieved by the restoration programme. Four-year funding cycles create vulnerability, while the Oslofjord crisis creates a new rationale for further investment in nitrogen and erosion reduction measures across the catchment. The successfully funded critical-friends initiative shows that new collaborative arrangements with downstream interests can unlock additional financing. The next step should not simply seek more public grants but aim to establish a financing portfolio that distinguishes core monitoring and coordination, which require predictable long-term finance, from innovation and demonstration projects, which may suit alternative financing mechanisms. Cost-effectiveness analysis of measures should include agricultural income effects and also the distribution of costs to farmers and landowners.

Loch Leven combines the clearest historical capital investment case with emerging financing opportunities in natural capital, tourism, Landscape Enterprise Networks (LENs), biodiversity finance and payments for ecosystem services. The optimisation highlights the need for comprehensive cost-benefit assessment and diversification. A weakness is that several proposed markets are highlighted as promising before their local performance and governance are demonstrated. Quantification of visitor benefits, NbS effectiveness and long-term maintenance is essential before revenue models can be established and scaled.

Across all sites, economic optimisation should follow five principles: protect stable public finance for core functions (coordination and monitoring); compare life-cycle costs and ecological effectiveness; value but do not commodify all benefits; distribute costs and benefits transparently; and use private or blended finance where accountability, additionality and ecological safeguards are credible (Table 13). The six Demonstration Sites should all establish a more consistent distinction between financing restoration and financing the enabling system around it. Ecological diagnosis, facilitation, data management, permitting and long-term monitoring are essential infrastructure, yet they are often harder to fund than visible implementation of technical measures. Economic reviews should include who pays, who receives benefits, which benefits remain public and non-market, and whether compensation is sufficient for actors expected to change land or water use. This would make claims of cost-effectiveness more transparent and socially defensible. It would also reveal unfunded long-term liabilities.

Table 13. Comparative SWOT by Demonstration Site for economic optimisation.

Demonstration Site	Strengths	Weaknesses	Opportunities	Threats
Kartuzy	Successful public funding; science first	High entry costs; public dependence	Blended finance; shared preparation support	Failure erodes trust and future finance
IJssel	Established programmes; multifunctional investment	Benefits and historic costs poorly recorded	Budgeted evaluation; alternative finance	Large scale; political funding shifts

Karla	EU funding experience; recognised services	No valuation; episodic funding; no private role	BCR; water pricing; ecotourism; PPP	Rural decline; undocumented benefits
Vesijärvi	Diverse funding base; continuity	Weak landowner compensation	CAP; supply-chain incentives; nature credits	Public budget contraction; volatility
Vansjø	Documented costs; coordinated public finance	Economic gains not measured; four-year funding cycles	Oslofjord funds; portfolio funding	De-prioritisation; farmer cost burden
Leven	Demonstrated capital impact; tourism value	Public reliance; NbS cost-effectiveness gaps	LENs; natural capital; visitor contributions	Unproven markets; long-term monitoring costs

4.5 Policy / regulatory optimisation

All sites operate within established water and nature policy frameworks, but regulation was most effective where responsibilities, incentives and evidence are aligned. The opportunities raised by the EU NRR and Water Resilience Strategy (WRS) were not raised by Demonstration Sites, probably because implementation of these is in an early development stage at European and national level and knowledge of potential opportunities from these policies has not yet tricked down to local level basin management and restoration planning which are driven mainly by the WFD. Nevertheless, it is expected that these new policies will support policy cohesion and provide additional incentives for implementing restoration measures that support water, nature and climate policy goals. The WRS strategy identifies NbS as a key mechanism for achieving resilience to both floods and droughts and specifically sponge landscapes and sponge measures that allow landscapes to absorb, store, and slowly release water. The WRS has specific actions to progress EU financial instruments, CAP funding and cohesion and regional development funds to support scaling up of NbS. Similarly, the NRR creates opportunities for policy cohesion through the requirement for national restoration plans to optimise the ecological, economic and social functions of ecosystems, as well as their contribution to the sustainable development of regions and communities (Art. 14(16)) and estimate the co-benefits of nature restoration measures for climate change (Art. 15(3r)).

Kartuzy demonstrates how experienced municipal staff, scientists and engineers can navigate fragmented policy requirements and secure implementation even when the municipality is not the formal lake owner. Close cooperation is a clear strength, while dispersed responsibilities and lengthy procedures remain weaknesses. Kartuzy could contribute to wider learning by sharing their experience and documenting how they used policies and regulatory needs, other than the WFD, to implement their programme. Continued bilateral cooperation between the municipality and the university environmental science team, albeit effective, is not a governance solution. Clarification of statutory responsibilities and monitoring duties would make the policy optimisation more durable.

Lake IJssel has well-developed WFD, Natura 2000 and national programme frameworks, but implementation is constrained by political conflict over nitrogen, fragmented data mandates and funding rules that inhibit collaboration among universities, institutes and consultants. The optimisation plan is honest that some barriers can only be resolved nationally. The proposals for a data-collection framework and broader cooperation are concrete ways forward. Policy optimisation needs to clarify legal requirements from policy choices, identify the authority responsible for goals, and consider how ecological objectives will be protected while national nitrogen decisions remain unsettled. Reliance on a future political settlement does not need to delay implementation of no-regret measures or improved monitoring.

Karla illustrates the largest gap between formal obligations and implementation. EU directives, Natura 2000 and restoration legislation provide a substantial framework, yet responsibilities are fragmented,

enforcement is limited, reporting and planning are delayed, and monitoring does not trigger action. The optimisation plan focuses on a need for a formal adaptive basin management process that bridges monitoring with action to deliver evidence-led governance. It highlights the need to better implement the WFD basin management process through monitoring, scheduled regulatory review cycles and stricter timelines and responsibilities for management actions. This optimisation of WFD implementation is a common need across Europe, indicating that better implementation of existing policy is just as important as new policies. Citizen science is proposed as an opportunity to enrich evidence, but official monitoring for water and biodiversity policies should be the cornerstone of basin planning and enforcement responsibilities must remain clear.

Vesijärvi benefits from well-coordinated basin planning, municipal support and water-focused regulation, but their SWOT highlights policy incoherence between water, agriculture and forestry. Subsidies may favour production or land use that conflicts with nutrient reduction, while WFD's one-out-all-out assessment has obscured successes with restoration goals. The policy optimisation plan identifies useful levers for reducing stormwater pollution, forestry standards, food-sector sustainability and CAP reform. It should further develop which changes can be made locally, which require national advocacy and which depend on EU reform. The critique of the WFD one-out-all-out rule should not weaken the WFD ambition at the site of good ecological and chemical status; component indicators can communicate progress with specific pressures whilst the over-arching classification rule, addressing multiple pressures and ecological outcomes, remains intact.

Vansjø is a strong example of collaborative WFD implementation across a whole catchment. Long-standing thematic groups, a neutral coordinator and transboundary cooperation support policy learning and local ownership. Policy weaknesses have included a reliance on voluntary measures and a dependence on political and budget cycles. The limited representation of biodiversity organisations and biodiversity policy goals, in part, is because Norway is not legally obliged to transpose EU biodiversity policy and no statutory national monitoring requirements for biodiversity exist. Despite this, Norway's new biodiversity action plan provides new policy incentive to strengthen biodiversity assessment and progress positive biodiversity outcomes. The optimisation plan should consider how voluntary measures, incentives and minimum statutory requirements fit together, and what needs to happen when voluntary participation is insufficient to meet statutory objectives.

Loch Leven has a rich and increasingly broad policy landscape, including water, nature, planning, climate adaptation and emerging nature-market mechanisms. Its 125% phosphorus rule in planning policy is a highly innovative and successful precautionary instrument to reduce P loadings to the lake. The major weakness identified was uncertain evidence about the ecological effectiveness of some of the policy instruments and limited inclusion of businesses, landowners and communities in past policy development. The optimisation plan proposes adaptive regulation evidenced by the site's long datasets and regular review of existing measures. Their stakeholder feedback outlines an important caution: future basin management plans should use existing catchment governance structures rather than create duplicate committees.

Across the six sites, policy optimisation requires a clear pathway from mapping obligations of responsible authorities, funded implementation of measures, monitoring, review and enforcement. Where this path is broken, new policy opportunities will not compensate for weak coordination and delivery. The comparison across the sites further indicates that policy coherence should be tested against concrete restoration pathways rather than assessed only at the level of specific objectives (Table 14). For example, a water-quality target may coexist with agricultural incentives that increase diffuse loading, or a biodiversity designation may coexist with infrastructure operation that restricts connectivity. Each site should map these policy implementation conflicts, identify the competent level of government, and specify whether reform requires enforcement, changed incentives, delegated authority, better data or legislative amendment. This would help turn their common calls for greater policy alignment into an actionable agenda. It would also clarify when better policy implementation at local level is possible and when national or European policy reform is indispensable, helping

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stakeholders' direct advocacy and resources to the policy level where change can actually be authorised.

Table 14. Comparative SWOT by Demonstration Site for policy or regulatory optimisation.

Demonstration Site	Strengths	Weaknesses	Opportunities	Threats
Kartuzy	Legal, scientific and engineering cooperation	Fragmented competences; slow procedures	Standard templates; learning transfer	Schedule pressure; inexperienced applicants
Lake IJssel	Established WFD / Natura frameworks	Nitrogen conflict; data/funding silos	Data mandate; nature-inclusive agriculture	Political stalemate; trust decline
Lake Karla	Strong EU legal framework	Weak enforcement; overlapping roles	Trigger-based adaptive protocol	Reporting delays; leadership discontinuity
Vesijärvi	Municipal programme; water-policy alignment	Incoherence of agriculture / forestry vs. ecological aims	GIS targeting; forestry standards; food-sector links	Lower CAP ambition; local political shifts
Vansjø	Whole-catchment WFD cooperation	Voluntary measures; biodiversity gap	Cooperative finance; incentive reform	Government/budget changes
Loch Leven	Multiple designations; 125% rule	Complexity; voluntary uptake; evidence gaps	Adaptive regulation; integrated policy	Climate impacts outpace policy; admin burden

4.6 Stakeholder involvement

The stakeholder evaluations broadly endorsed the direction of the optimisation plans, but they also reveal uneven depth and maturity across sites.

At Kartuzy, feedback emphasised mutual trust between the municipality and scientific experts, flexibility during implementation, and the continuing value of *Critical Friends* meetings. This supports the plan's collaborative model, although the evaluation gives limited evidence of disagreement or of how stakeholder input changed specific proposals.

Lake IJssel provides a sharper critical test. Stakeholders agree on the importance of restoration but caution against equating engineering visibility or economic return with ecological recovery. They call for protection of open-water habitats, restoration of gradients and natural processes, catchment-scale nutrient action and interventions proportionate to the system. This reinforces the need for a renewed integrated vision and prevents multifunctionality from becoming a justification for further engineering alone.

At Karla, stakeholders recognised the broken cycle between monitoring, reporting, implementation, evaluation and adaptation. Their support for ODYTH as a coordinating and mediating body, a structured working group and digital participation constructively links governance reform to practical next steps and future funding. However, willingness must be converted into a formal mandate, roles and conflict-resolution procedures.

Vesijärvi's evaluation is technically specific: biomanipulation needs improved fishing methods, internal loading still requires action, and groundwater risks constrain treatment options. It also stresses that diffuse-load reduction increasingly depends on individual landowners and collective drainage

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decisions. This usefully grounds the optimisation plan in feasibility, but broader stakeholder perspectives beyond the coordinating Foundation would strengthen legitimacy.

Vansjø's evaluation illustrates productive follow-through: a critical-friends process focused on nitrogen runoff to the Oslofjord led to a funded initiative while retaining concern for food production. Its weakness is that evaluation of the optimisation plan was only considered by the river basin organisation's leadership; future consultation is needed to receive feedback on proposals from farmers, biodiversity groups and affected communities.

Loch Leven stakeholders provided the strongest critique, arguing that the optimisation plan remains too centred on phosphorus and WFD compliance and should instead frame the loch as a whole-catchment socio-ecological system. Stakeholders favour existing catchment bodies over committee proliferation, a quantified nutrient budget, sluice management assessment and integrated public, private and community finance.

Across all sites, the strongest stakeholder evaluations did more than approve proposals: they identified omissions, challenged framing and connected recommendations to existing delivery routes. Future evaluations should document who participated, points of disagreement, resulting revisions, responsible organisations and how future progress will be reviewed.

5 Lessons learnt and Recommendations

5.1 Lessons Learnt

The synthesis of the SAT and SWOT analyses of the restoration programmes at the six Demonstration Sites provides a number of lessons learnt to support optimisation of lake basin management plans. These are considered below in relation to the five optimisation themes.

Multiple-goal optimisation

- Lake restoration is a long-term and adaptive process rather than a one-off intervention; long-term governance, monitoring and adjustment of basin management plans are needed to evaluate how ecosystems respond to changing pressures and restoration actions.
- Restoration programmes benefit from addressing multiple objectives simultaneously rather than focusing on one or few environmental targets. Goals in all basins have expanded from single water quality issues to multiple goals including ecological health (WFD), biodiversity, climate adaptation and resilience, societal benefits and economic growth.
- Multiple objectives also create unavoidable trade-offs; agricultural production, flood protection, water supply, urban development, recreation and tourism can all interact with water quality and biodiversity goals. Explicit consideration of trade-offs between societal and policy goals is essential and may require careful management or compensation.

Technical optimisation

- Successful restoration requires action at both catchment and in-lake scales; reducing external pressures remains fundamental to lake basin protection and restoration. Internal processes and legacy pollution often delay and limit ecological recovery, even after external pressures have been removed or reduced.
- Nature-based and biodiversity-focused measures have the potential to deliver multiple benefits, but their suitability and effectiveness remain context dependent; measures require appropriate design, targeting, monitoring and evaluation rather than an assumption that they will work in all geographical and societal contexts.

- A strong scientific evidence base, through long-term and targeted monitoring, is fundamental to evaluate and adapt basin management plans. Monitoring needs to go beyond regulatory reporting to support learning on effectiveness of restoration measures and adaptive management. Monitoring gaps, fragmented datasets and insufficient coverage of biodiversity, societal outcomes and economic benefits constrain evaluation and optimisation of basin management plans.
- Climate change challenges the effectiveness and durability of existing restoration approaches; drought, floods, warming and altered runoff can reinforce existing pressures and require restoration strategies, technical and management measures and restoration targets to remain flexible under changing conditions (shifting baselines).

Societal optimisation

- Ecological recovery can take considerably longer than implementation of restoration measures; legacy nutrient stores and slow biological recovery responses mean that visible improvements to restoration measures may emerge gradually and require sustained intervention and long-term stakeholder support.
- Strong stakeholder cooperation and trust are critical enabling conditions; restoration is more likely to progress when authorities, scientists, landowners, businesses, NGOs and communities jointly discuss objectives, evidence and necessary compromises.
- Formal and sustained coordination mechanisms strengthen continuity; platforms, foundations, working groups or coordinating bodies can maintain dialogue and collective learning beyond individuals, projects or funding cycles.
- Broad participation does not automatically mean inclusive participation; stakeholder processes can still overlook particular interests, younger generations, vulnerable groups need to be involved, and biodiversity interests should be explicitly represented. Conversely, large numbers of competing interests can also slow decision-making.

Economic optimisation

- Long-term financing remains a central vulnerability of lake restoration programmes; dependence on public financing programmes and individual funding cycles constrains implementation at scale, maintenance of measures over the long-term and post-intervention monitoring. Blended financing models need active development and policy incentives.
- The wider economic and societal benefits of restoration are often insufficiently quantified; incomplete information on ecosystem services, economic returns and distribution of costs and benefits weaken the evidence base for investment decisions and alternative financing models.

Policy Optimisation

- Policy frameworks can strongly support restoration, but implementation is often constrained by fragmentation, conflicting objectives or administrative complexity; having regulations and environmental targets in place does not by itself guarantee timely and effective restoration action.
- Restoration success ultimately depends on connecting ecological knowledge, governance, societal acceptance, policy and financing; technical knowledge alone is insufficient when implementation capacity, stakeholder ownership, regulatory coordination or long-term resources are lacking.

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5.2 Recommendations

Based on these lessons learnt we identify 12 recommendations to support optimisation of lake basin management plans:

1. Develop integrated restoration strategies that address water quality, biodiversity, climate resilience and societal goals together, while explicitly identifying synergies and trade-offs between objectives.
2. Prioritise measures that have been well evidenced to deliver multiple ecological and societal benefits. Continue to test their effectiveness in new contexts to evaluate their potential for replication in the catchment.
3. Plan restoration at the scale of the whole lake catchment, combining pollution source-control, catchment measures (especially in-field and field edge measures in agricultural areas) and in-lake measures, rather than treating these as isolated interventions.
4. Establish long-term monitoring as an integral and well-funded component of lake restoration programmes, covering water quality and biodiversity responses, as well as societal and economic benefits and trade-offs with key sectors (agriculture, energy, water supply).
5. Use monitoring results within explicit adaptive-management cycles so that measures, objectives and management practices can be adjusted when WFD and biodiversity policy goals are not achieved or in response to climate change or newly emerging pressures.
6. Strengthen the connection between scientific evidence and decision-making by making monitoring information accessible to all stakeholders with interests in the lake and use data systematically to inform management and review of basin management plans.
7. Integrate extreme-event risk management and future climate-change scenarios into the design and periodic review of restoration programmes rather than treating flood and drought management, or climate change more broadly, as a separate issue.
8. Maintain inclusive, transparent and continuous stakeholder engagement with clear coordinating roles essential for basin authorities and actively address gaps in representation, especially of impacted vulnerable groups.
9. Quantify the direct and indirect costs and benefits of restoration, including currently under-valued ecosystem services and societal benefits, including recreation and well-being, to strengthen investment decisions and demonstrate restoration value.
10. Diversify restoration financing beyond reliance on public funding streams by exploring complementary public, private, blended and emerging market finance mechanisms (carbon and nature credits) where appropriate.
11. Improve alignment between water, biodiversity, agriculture, land-planning and climate policies by reducing administrative fragmentation that delays or constrains implementation of measures. Exploit NRR national restoration plan requirements to support this integration.
12. Treat restoration as a continuing learning process by documenting outcomes, sharing lessons and incorporating new evidence, technologies and stakeholder knowledge into subsequent planning and implementation. Support the development of Communities of Practice in basin management at regional, national or international scales.

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Annex: Lake Vesijärvi measure-specific technical evaluation

7.1.1.1 Catchment-scale optimisation

Constructed wetlands (CWs) have been established at 16 locations around the lake, most of which after 2007. CWs mainly aim at decreasing the external loading of nutrients to the lake (Härkönen et al., 2026a).

Visual evidence of suspended sediment deposition has been observed, suggesting decreased SS loads. However, water quality analyses show practically no influence of the wetlands on water quality except for PO4-P (Päijät-Hämeen Vesijärvisäätiö, 2024). In general, the performance of CWs in other sites with comparable soil and climate conditions is often better (Kill et al., 2022). The area of most Vesijärvi wetlands is small in relation to the upstream catchment area (typically 0.1-0.2%). In such conditions, the performance of wetlands can be optimized by design and maintenance aiming at dense vegetation cover, supported by rather shallow water depths (Kill et al.,, 2022). Further optimisation opportunities include evaluating the load retentions based on long-term automatic monitoring at selected wetlands to overcome the limitations of manual water sampling and thus decrease the uncertainty in performance. Further, the impacts of wetlands on nutrient loads should be studied from the viewpoint of how they enhance catchment-scale water retention, which aspect is not covered by the current evaluations. Opportunities include designing further wetlands using recent knowledge on the properties controlling treatment efficiency and more targeted spatial optimisation to hot-spot locations with suitable soil and catchment conditions. The challenge is that the final decision on the locations of the wetlands is based on the willingness of landowners. Wetlands could be also boosted with additional smaller-scale structures with specific functions to optimize performance, such as the multi-structure wetland established in the Vesijärvi catchment (Thiemer et al., 2026).

Agricultural water management measures haven't been in the focus of the L. Vesijärvi restoration programme thus far. Nevertheless, agricultural loading and flooding of fields likely increase in the future due to climate change, with floods generating high nutrient and suspended sediment loads (Härkönen et al., 2026a). Thus, the technical optimisation includes improving water management in those parts of ditch and stream networks where fields are frequently flooded. The SWOT analysis was conducted for the nature-based **two-stage channel** (TSC) design which involves excavating man-made, vegetated floodplains along ditches and streams as an alternative to environmentally harmful conventional dredging for ensuring flood management and drainage (see also Västilä et al., 2021, Härkönen et al., 2026b). TSCs can reduce flooding and maintain functionality by up to 50 years with very limited maintenance as well as enhance local and catchment-scale aquatic and riparian biodiversity (Huttunen et al., 2024). Thus, TSCs likely decrease the decadal-scale nutrient loads compared to typical conventional channels requiring frequent maintenance. In the short term, however, the establishment of TSCs can cause negative water quality impact due to extensive areas of excavated soil surfaces and enhanced self-cleansing of channel beds (Västilä and Jilbert, 2025). To optimize the impacts, two-stage channels are best implemented at areas upstream of constructed wetlands where flood management requires improvement, but the existing streams have important natural values, in which case conventional dredging is practically forbidden. A short TSC has been implemented at one stream at Vesijärvi, which is an opportunity for a close-by demonstration site to other farmers. However, based on a few experiences of the Foundation, the threat is that landowners commonly object TSCs either in principle or because they take up arable land. Since most landowners are financially tight, the 40% subsidy level for the construction costs of TSCs (see Section 3.4.4) appears not sufficient, which is likely the main bottleneck as also indicated by Västilä et al. (2021).

Winter-time vegetation cover (WVC) is primarily a source control measure for reducing agricultural soil erosion and loading and included in CAP. Although the Foundation has typically not been involved with farming practices, winter-time vegetation cover (including fallow land) is already applied by farmers at 53% of agricultural area in the Häme region, but the true share on the sown fields excluding

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fallow land is notably lower. WVC's strengths include likely decreases in external loads of most parameters, i.e., total phosphorus, nitrogen, total organic carbon, and suspended sediment. The need for fertilization decreases and the soil quality is maintained and thus water retention improved. WVC likely improves carbon retention into the soil and potentially also benefits biodiversity of soil, farmland birds and wild game (Hyvönen et al., 2020a). In 2023, ~32% of the field area was ploughed, indicating substantial optimisation potential. These benefits can be optimized by advocating "true vegetation cover", i.e. planting catch and cover crops or winter crops in autumn, instead of stubble or autumn tillage, to priority areas at L. Vesijärvi. However, increases in dissolved P load can occur, which can be counteracted by communicating the importance of ploughing ~every 5 years to farmers. National CAP financing is not incentivizing the priority locations for WVC nor true vegetation cover instead of stubble. This NbS is generally the most cost-effective agri-environmental measure considering the key benefits to water quality, soil quality, and climate, while its implementation costs are low, according to Finnish study (Hyvönen et al., 2020b). Thus, the optimisation includes communicating the impacts of WVC on enhanced soil status and water retention, and thus on increased crop productivity, agricultural profitability and resilience, to farmers to increase willingness to implement particularly "true vegetation cover". Further, farmers should be informed that the CAP subsidy for WVC is incentive-based, i.e. the monetary support to farmers is slightly larger than the estimated implementation and lost earnings costs (see also 3.4.4). Potential increased need of pesticides due to WVC while the recommended mitigation based on increasing the requirements for crop rotation is not in place nationally. The existing extensive monitoring at Vesijärvi catchment could be used and amended to investigate the impacts of WVC on changes in pests, pesticide usage and loads.

Continuous cover forestry (CCF) is one of the approaches preventing pollution loss at source (e.g., Härkönen et al., 2023, Sarkkola et al., 2025, Härkönen et al., 2026b). Potential contribution of CCF to reduced external loading has been identified in national studies (Nieminen et al., 2018; Palviainen et al., 2022; Sarkkola et al., 2025), although the impacts of CCF on lake water quality may be hard to distinguish from other water protection efforts. CCF also has potential for reducing peatland forest GHG emissions if ditch network maintenance can be avoided (Nieminen et al., 2018), increase the recreational value and forest biodiversity (Mason et al., 2021; Sarkkola et al., 2025), and provide potential co-benefits to water abstraction, but the impacts remain unquantified. Nevertheless, conventional rotation forest management weakens the quality of groundwater (Palviainen et al., 2022) and L. Vesijärvi catchment is important for groundwater abstraction (Härkönen et al., 2026a). CCF can also safeguard small waterbodies by avoiding clear-cuts and ditch network maintenance. Despite these benefits, CCF has not yet been identified as a potential measure in L. Vesijärvi restoration programme, although it is promoted in regional forest programme for 2026-2030. Additionally, the extent of its implementation at L. Vesijärvi catchment-scale remains unknown, while the adoption of CCF on regional scales is being monitored as part of the programme. The method has a high scalability potential with low effort and should thus be marketed, communicated and justified to stakeholders to increase interest and engagement. The downside of CCF is that it requires high engagement and long-term commitment from landowners. Additionally, it provides lower net revenue compared to conventional rotation management (Miettinen et al. 2025) and there are currently insufficient compensations in current forestry policies to account for the lost income (Härkönen et al., 2026b). The economics of CCF have been evaluated on national scale (Miettinen et al., 2025) but no information at L. Vesijärvi scales is thus far available. This calls for analysing the costs, benefits and risks of CCF and its alternates over the measures' life cycles. Although Vesijärvi Foundation coordinates the portfolio of public and private financing and acts as a partner in research funded projects, the implementation of CCF is highly dependent on landowners and backed by incentives, which Vesijärvi Foundation has no impact on. In general, it has been identified that forestry culture and education, industrial networks and timber markets promoting rotation forest management are identified as barriers preventing CCF from becoming mainstream on international level (Hertog et al., 2022), but no information on local scales is available. There are also potential risks related to spreading of root pathogens and stem damage during harvesting, although little experimental research is yet available about possible damage and methods to prevent them (Ahtikoski et al., 2025). Despite these knowledge gaps,

however, we highlight that CCF is a promising forest management approach diminishing the negative water quality impacts of forestry and recommend increasing communication on the importance of CCF to stakeholders.

7.1.1.2 In-lake optimisation

Biomanipulation by removal of planktivorous fish and introduction of predatory species has been implemented at L. Vesijärvi since 1989 with positive impacts on water quality and structure of food web (e.g., Salonen et al., 2020). The efficiency of this method has been widely recognised scientifically (e.g., Triest et al., 2016), and the fact that it does not require an environmental permit in Finland further increases its scalability potential. Nevertheless, biomanipulation requires water area owners' consent and potential jurisdictional boundaries for biomanipulation are identified (water areas). A general downside of this method is that it requires annual repetition, and complementary interventions are often needed to tackle external and internal loading. The costs of L. Vesijärvi biomanipulation are annually recorded with c. M€2,2 (value of 2025) spent for biomanipulation since 2007 (Härkönen et al., 2026a). Cost-benefits of the lake's biomanipulation have not been evaluated, nor are those of the alternates. However, as an innovation, biomanipulation at L. Vesijärvi has been combined with commercial operation of formerly under-utilized cyprinid catches by the local food industry (Tammeorg et al., 2024, Härkönen et al., 2026a). Professional fishermen can get additional income from selling the catch to food/feed production, but the compensation remains unknown. Biomanipulation also has potential for benefitting waterfowl due to reducing food competition between fish and certain waterfowl guilds (Fox et al., 2019), but the impacts at L. Vesijärvi remain unquantified. Similarly, reduction of primary production due to biomanipulation has potential for reducing lake GHG emissions, but evidence is still lacking. Biomanipulation is being conducted by the City of Lahti using tendered contractor, and the planning and decision making of biomanipulation is conducted in close collaboration with researchers. Regular monitoring of the impacts (fish community, water quality, phytoplankton, zooplankton) is in place to ensure environmental sustainability allowing for adjustments in the intensity in case of deviations from the expected outcomes. Despite improved fish community structure due to biomanipulation, however, the fish stock remains abundant and, on its part, prevents the improvement of lake ecological status (Kramer et al., 2026). Commercial biomanipulation also poses some potential risks as it may threaten the target species (e.g., Tammeorg et al., 2024) and some trade-offs to piscivorous birds have been suggested at L. Vesijärvi due to their declined food sources (Lammi and Kolunen, 2010).

Macrophyte removal (mainly common reed (*Phragmites australis*), but also the invasive reed sweet-grass (*Glyseria maxima*) has been implemented at L. Vesijärvi since 2015 to prevent macrophyte overgrowth for both preserving the habitat value in Natura 2000-areas and securing the recreational amenities elsewhere. Vesijärvi Foundation coordinates the removal while involving and informing water area and landowners. Environmental permission is needed from regional environment authorities for mechanical removal, and in 2026 a temporary Government Decree on the Finnish Supervisory Agency's fees [1177/2025] may limit opportunities for mowing, as processing the mandatory mowing notification now incurs a fee, unlike before. The timing of implementation must consider bird nesting but also recreational use of the lake. Consequently, when applicable, mechanical removal of stems is often conducted on ice during the winter but frequently also during the summer. Small-scale, mosaic macrophyte removal can support habitat creation for fish, invertebrates and waterfowl (e.g., Lehikoinen et al., 2017). However, vegetation also promotes sedimentation and binding of carbon in the littoral sediments (Lindroth Dauner et al., 2026), due to which macrophyte removal poses threats to water quality (Thiemer et al., 2023) and carbon sequestration (Harpenslager et al., 2022). The equipment and vessels used for macrophyte harvesting also pose risks of introducing invasive species from other lakes, such as *Elodea* sp. (Zehnsdorf et al., 2015). During the permit process, regional authorities make suggestions for monitoring and evaluation of impacts, and in general the WFD indicators (water quality & biological quality metrics) are frequently monitored to indicate and assess eutrophication status. However, no strategy for impact monitoring throughout the intervention is available and indicators to monitor direct impacts of local harvesting not available.

Incorporating local biodiversity indicators to monitoring would be recommended to support justification of mowing. Additionally, impacts of harvesting of helophytes on GHG emission reduction should be evaluated. A survey for the lake end-users has estimated values of overall management activities, incl. also recreational aspects (swimming, boating, summer cottages) that are also linked to the local reed removals (Lehtoranta, 2013). However, the cost-benefits of harvesting alone have not been evaluated, nor are the potential financial biodiversity co-benefits. Some of the reeds removed can be used for green roofs, but only the stems harvested during winter are applicable and the compensational value of removed reeds used for in green roof structures is not estimated. While the removal of reeds opens habitats for nesting birds, the general re-oligotrophication of the lake and increased harvesting of macrophytes may have negatively affected some of the locally breeding waterfowl populations (Lammi and Kolunen, 2010). However, it must be noted that the declining trend in L. Vesijärvi waterfowl populations is in line with their national plight (e.g., Lehikoinen et al. 2016).

As the internal loading remains an issue to be tackled at L. Vesijärvi (Jilbert et al., 2020). From the innovative solutions reviewed by Härkönen et al. (2026b), the applicability of closed-circuit **hypolimnetic withdrawal and treatment systems** (HWTS) has also been evaluated for L. Vesijärvi, Enonselkä basin (Silvonen et al., 2024). Albeit the method has potential for reducing the internal phosphorus reserves and support long-term recovery when combined with catchment-level measures, its success depends heavily on design choices, such as withdrawal rate, spatial coverage, and whether shallow areas are also addressed (Silvonen et al., 2024). Due to the relatively large size of the basin, accommodation of multiple pipes and extended perforation would probably be needed to reach expected P reduction targets. Unless operated in technically advanced facilities in collaboration with e.g., the water treatment sector (see Nürnberg, 2020), establishment of large enough HWTS infrastructure at L. Vesijärvi context would probably be unrealistic given the limited financial resources. Recently, some interest among stakeholders has also emerged towards **P inactivation** of limited hypolimnetic areas to tackle the highest internal nutrient fluxes during anoxia, but its feasibility to L. Vesijärvi context has not yet been evaluated. While more environmentally friendly materials and application procedures for P inactivation have been recently developed (Härkönen et al., 2026b and references therein), there are several aspects to consider while assessing the feasibility of the method to L. Vesijärvi context. Lake Vesijärvi is a seepage lake with its surrounding groundwater areas used for water abstraction (Härkönen et al., 2026a). Many seepage lakes are dynamic, acting as both gaining and losing environments of groundwater. The bottom of L. Vesijärvi and the shoreline areas consist of clay and silt but there are also layers of gravel and sand extending into the lake offering conditions for lake water to infiltrate and become groundwater (Suunnittelukeskus Oy, 1981). In general, the hydrochemical composition of groundwater can be affected by transferred surface water (Zhao et al., 2021). Hence, potential leakage of binding chemicals into the aquifers must be prevented to protect groundwater quality. Nutrient-rich groundwater seepage can also continuously deliver new external P to seepage lakes (e.g., Lisboa et al., 2024) but the impacts of groundwater on Vesijärvi P budget remain unquantified. If groundwater P loads are high, in-lake inactivation may have limited long-term effectiveness. Moreover, P inactivating agents can potentially harm zooplankton (Sarvala et al., 2020; Van Oosterhout and Lürling, 2011) and extreme caution would be needed not to break down the observed positive response trajectory of grazing crustacean zooplankton to current restoration efforts (KVVY Tutkimus Oy, 2026). While the internal loading of deep areas during stratification and anoxia is high, the shallower, oxygenated depths also have a substantial impact to the release of sedimentary P in L. Vesijärvi (Tammeorg et al., 2013). Neither HWTS nor targeted P inactivation to hypolimnion would directly solve the problem of internal loading from these shallow areas above the thermocline. Hence, alternative solutions are also needed. **Sediment removal** is one of the promising strategies addressing internal nutrient loading in shallow lakes (e.g. Härkönen et al., 2025b), and its feasibility to one of the shallow basins of L. Vesijärvi is being evaluated as part of the MissionLakes FERRO project. The high operational costs of the method currently hinder the viability of the measure nationally (Härkönen et al., 2025b) but the experiences from FutureLakes' innovation site Ormstup in improving the cost-efficiency of the implementation (Thiemer et al., 2026) are anticipated to transfer internationally and support its uptake.

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