Demonstrating Successful Restoration

Lake Vansjø Demonstration Site

Deliverable D4.1 DS-Annex f

Publication Date: 31 May 2026

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Technical Details

Citation for deliverable: Hagman, C.H.C., Haande, S., Askedalen, B.K., Skjelbred, B. and Isdahl, C.R. (2026). Demonstrating successful restoration: Lake Vansjø Demonstration Site. Deliverable 4.1, DS-Annex f, FutureLakes. Available at: https://futurelakes.eu/knowledge-hub/deliverables

Project Acronym	FutureLakes
Project Title	Integrating Innovations for the Protection and Restoration of European Lakes
Project Duration	10.2024 – 09.2027

Deliverable No.	4.1
Dissemination level [1]	PU
Work Package	4
Task	4.1
Lead beneficiary	UWM
Contributing beneficiaries	Deltares, DUTH, NIVA, SYKE, UKCEH
Quality Assurance Reviewer	
Due date of deliverable	
Actual submission date	

1 PU = Public
PP = Restricted to other programme participants (including the Commission Services)
RE = Restricted to a group specified by the consortium (including the Commission Services)
CO = Confidential, only for members of the consortium (including the Commission Services)

Document history

V	Date	Beneficiary	Author
V0.1	28. February 2026	NIVA	Hagman et al.
V0.2			
V1.0			

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Summary

FutureLakes assessed how six major European lake restoration programmes perform – not only on water quality and biodiversity – but also on climate regulation and resilience, societal values and economic returns. The Demonstration Sites are Lake Vesijärvi (FI), Kartuzy Lakes (PL), Lake Ijssel complex (NL), Lake Karla (GR), Loch Leven (UK) and Lake Vansjø (NO). The results are documented in a synthesis report by Kramer et al. (2026).

This Annex report gives an overview of the restoration measures implemented in the extended catchment of Lake Vansjø, and documents their benefits and impacts.

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1 Lake details

Vansjø is a large and complex lake consisting of several fjords and basins with separate catchments and different influences, environmental conditions and characteristics. The lake is often divided into two main parts/basins, with Storefjorden being the eastern, largest and deepest part, and Vanemfjorden being the western part, as shown in **Figure 1** and **Figure 2**. Vanemfjorden, the western part, has experienced rapid eutrophication and reoccurring toxic cyanobacterial blooms, especially between 2001 and 2007. Therefore, this basin has been the main focus of the restoration program and mitigation measures. However, Storefjorden, which supplies water to Vanemfjorden, has also been eutrophicated and not reached environmental targets (Good status) over the past decades, and therefore, this basin and its' catchment is also subject to mitigation measures. Lake Vansjø is a popular and important lake for many purposes. It is the main drinking water source for almost 80 000 people around the lake, it is used for hydropower, agricultural irrigation as well as recreational activities (boating, bathing, ice skating, fishing), and it hosts three nature reserves, two water based and one terrestrial.

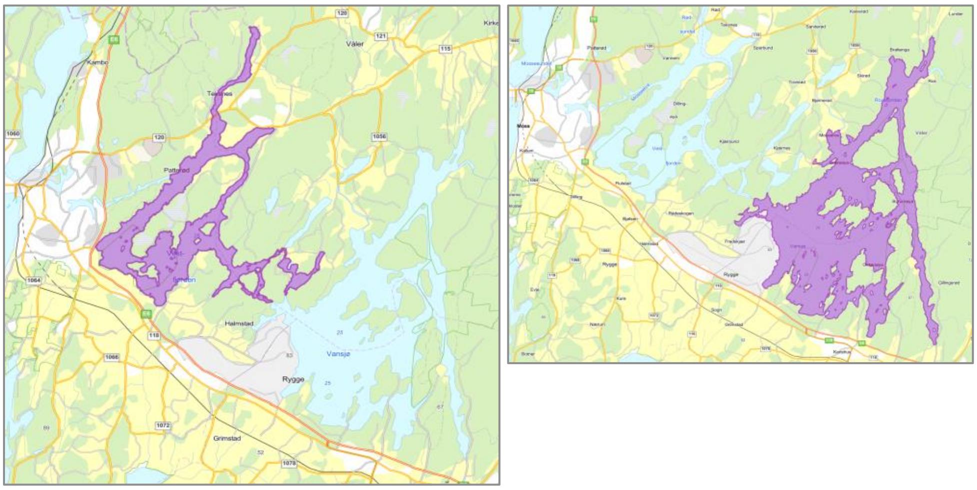

Figure 1. *Map of Vansjø with the two basins highlighted. Left: Vanemfjorden, the western basin. Right: Storefjorden, the eastern basin. Source: Vann-nett.no*

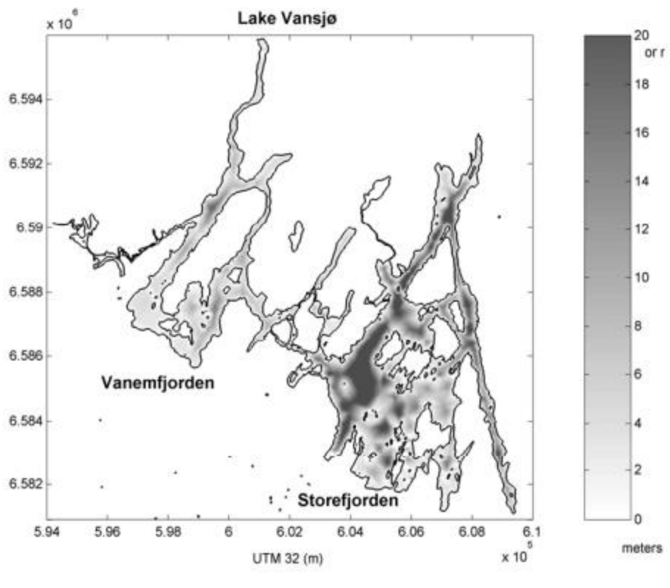

Figure 2. *Depth chart of Vansjø (Saloranta 2006).*

Lake name: VANSJØ			
Type of characteristics	**Characteristics**	**Store-fjorden**	**Vanem-fjorden**
Geographical characteristics	Geographical coordinators (EUREF89): Longitude Latitude Altitude (m a.s.l.)	 10.836507 59.393656 25 m.a.s.l.	 10.754305 59.443629 25 m.a.s.l.
Lake characteristics	Area [km^2]	23,8	12
	Maximum depth [m]	41	17
	Mean depth [m]	9,2	3,7
	Water volume [m^2]	73 000 000	
	Depth index (mean depth : maximum depth)	0,22	0,22
	Water residence time (τ) [years]	0,85 year	0,21 year
	Residence type (short < 1 year, moderate >1 year, long > 10 years)	Short (total 280 days)	
	Shoreline length	250 km	
	Mixing type	Meromictic	Polymictic/ meromictic
	Stratification	Storefjorden is stratified, other basins are mixed	
Catchment characteristics	Total catchment area [km^2]	679,91	
	Direct catchment area [km^2]	82	75
	Land-use (CORINE)	**% of total catchment area**	
	Agriculture	17	
	Urban	5	
	Forests	78	
	Wetlands	1,5	
	Schindler's index (sum of total catchment and lake areas to lake volume ratio)	9,8	

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<table>
<tr><td>Climate characteristics
(30 year average; 1991-2020)</td><td>Mean annual air temperature
Mean annual precipitation
Maximum summer air temperature
Days number > 15°C air temperature per year
Days with snow per year</td><td colspan="2">Temp: 7,03°C
Prec: 880,6 annual mean
Max. temp 33,9°C (27.7.18)
Days > 15°C average per year: 64,9
Snow: average 47,7 days per year</td></tr>
<tr><td rowspan="5">Hydrochemistry and trophic type (situation in 2025)</td><td rowspan="2">Alkalinity (meq/L), Alkalinity type (low - <0,2; medium 0,2-1,0; high - > 1,0)</td><td colspan="2">Medium</td></tr>
<tr><td>0,218 mekv/L</td><td>0,307 mekv/L</td></tr>
<tr><td>Colour type (colour in HAZEN units – clear < 30, humic 30-90, polyhumic >90)</td><td colspan="2">Humic</td></tr>
<tr><td>Trophic type (oligotrophic, mesotrophic, eutrophic, hypertrophic)</td><td colspan="2">Eutrophic</td></tr>
<tr><td>Calcium level (water hardness – softwater <25 mg Ca/L, hardwater ->25 mg Ca/L</td><td colspan="2">Softwater</td></tr>
</table>

2 Restoration Programme

2.1 History and background

Lake Vansjø has experienced high nutrient loading and eutrophication issues since the 1960s, mainly due to pressure from agriculture, sewage from municipalities and scattered dwellings, but also wastewater, urban runoff and floodings, landslides and erosion. Yearly monitoring was initiated in 1976-77, and several committees and action plans have been active since, in order to reduce the pressures on the lake.

The catchment of Vansjø is large, and is separated into several sub-basins with lakes, rivers and streams. The entire catchment and also rivers and streams draining from Vansjø to the Oslofjord are included in the larger catchment area called Morsa, and is shown in **Figure 3**. For the restoration of Vansjø, it has been necessary and crucial to have a holistic approach and include local, regional and national authorities. As a consequence of the declining conditions of several of the water bodies in the larger catchment, the Morsa project was started as a cooperation initiative in 1999. This allowed authorities to join forces with research organisations in order to develop a knowledge-based mitigation plan aiming to reduce nutrient loading to the lake. The Morsa Project was transferred to the Morsa River Basin District Organization in 2007, under the Glomma River Basin Authority.

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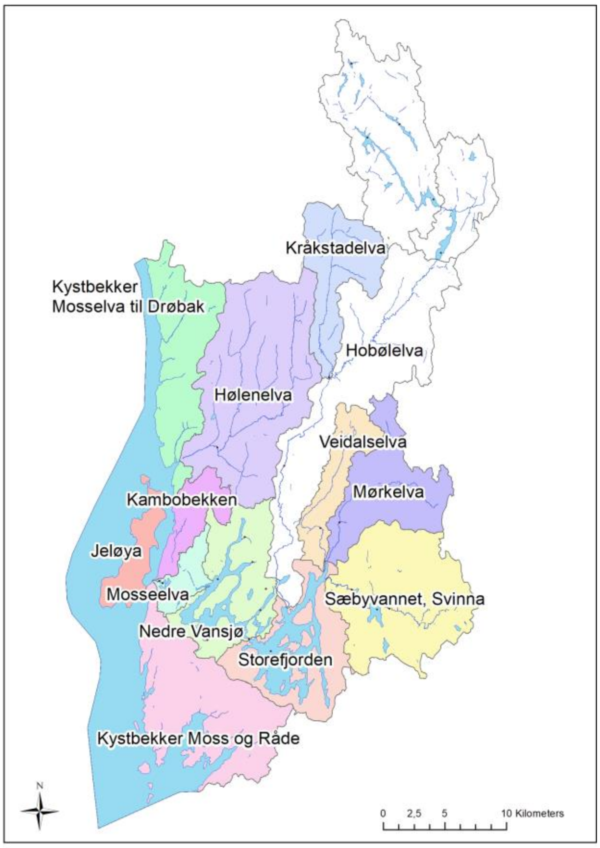

Figure 3. *Map of the entire catchment comprising the Morsa Water Basin Organization. The lake Vansjø consists in this context of "Nedre Vansjø" and "Storefjorden". Source: Skarbøvik et al. 2025.*

For the restoration of Vansjø, it has been necessary and crucial to have a holistic approach and include local, regional and national authorities. As a consequence of the declining conditions of several of the water bodies in the larger catchment, the Morsa project was started as a cooperation initiative in 1999. This allowed authorities to join forces with research organisations in order to develop a knowledge-based mitigation plan aiming to reduce nutrient loading to the lake. The Morsa Project was transferred to the Morsa River Basin District Organization in 2007, under the Glomma River Basin Authority.

In 2000, the area including the Vansjø catchment was exposed to a severe storm event with major flooding. After this, especially between 2001 and 2007, the lake, and especially the western part, experienced even more frequent and heavy blooms of toxin-producing cyanobacteria, leading to bathing bans and a local concern for the health of the lake.

The main environmental objectives of the restoration measures have therefore been to stop eutrophication by reducing nutrient loads, specifically phosphorous, in the entire catchment, and by that to reduce and prevent toxic cyanobacterial blooms. The main focus has been securing the lake as a drinking water source, but also to improve the general health and status of the lake.

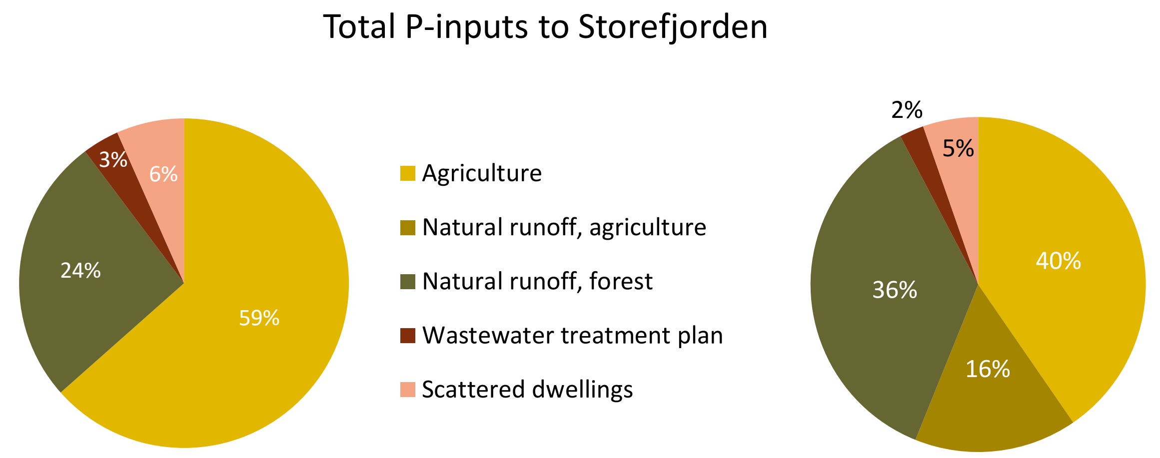

***Figure 4**. The origins of the total phosphorus inputs to Storefjorden, as estimated by an independent analysis in 2001 (left pie, Lyche-Solheim et al. 2001) laying the basis for the implementation of mitigation measures in the Morsa catchment. The calculations were later updated with data from 2006 (right pie, Øygarden et al. 2010).*

<u>History and timeline of major events in the restoration of Vansjø</u>

1976-77	Reportings of rapid eutrophication since before 1970. Yearly monitoring started
1979	A Vansjø committee is established
1984	The first action plan for Vansjø is implemented
1970-80s	Sewage control is established, but still there are high phosphorus and chlorophyll concentrations in the lake
1994-1997	A new action plan is implemented, and a collaboration is initiated between all municipalities in the catchment
1999	The Morsa project is onset
2000	Heavy flood in October leads to worsened conditions, lasting for years
2001	Mitigation analyses are performed, in order to determine the source of the excessive nutrient loadings and establish scientific background for he implementation of measures
2002-2007	Heavy cyanobacterial blooms occur (also toxic), especially n the Western basin (Vanemfjorden), swimming bans are implemented in several areas
2002-now	Intensive mitigation measures are applied in the catchment area of Lake Vansjø with main focus to decrease phosphorus loadings
2007	The Morsa River Basin Organization is established, in accordance with the EU WFD
2007-2023	Decreasing phosphorus concentrations are measured, and there is less cyanobacterial dominance in the lake and Western basin

2.2 Governance

Lake Vansjø has a long history, from the 1970s, of collaboration between municipalities, which has led to several action plans (1984, 1994-1997) addressing the lake's problems and solutions. The "Vansjø river basin organization" was appointed pilot area for the implementation of the Water Framework Directive in Norway, leading to initiation of the Morsa project in 1999, with local, regional and national authorities joining forces with research organizations to develop a knowledge-based mitigation plan to reduce nutrient loading to the lake. Nine municipalities cooperate to implement the necessary measures in order to improve the water quality in Vansjø.

The project is organized into a Water Board, consisting of representatives from the municipalities, county councils, county governors, and national directorates, with the intermunicipal drinking water association, Farmer's Organizations and other NGOs as observers. The organization is illustrated in **Figure 5**, and also shows the executive committee and the long-standing thematic groups—particularly on agriculture and wastewater—which have fostered a shared understanding and effective cooperation since 1999. These groups meet regularly, exchange knowledge, and jointly apply for project funding, enabling consistent dialogue and mutual learning.

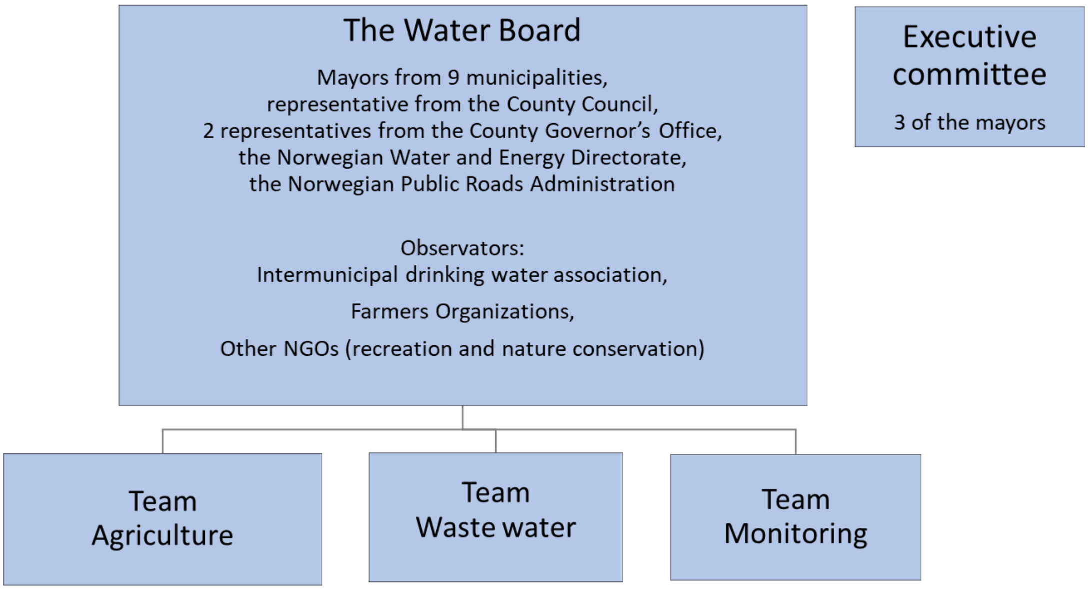

Figure 5*. The Morsa river basin organisation.*

A key strength of the governance model is its flexibility and responsiveness. New challenges, such as climate change, are addressed through adaptive measures, and efforts continue to engage farmers voluntarily, as Norwegian law does not mandate such actions. Knowledge-sharing and motivation are central to success.

Co-creation and ownership is important in the Morsa working group. For example, when developing a stormwater management guide, municipalities were involved throughout the process via workshops and consultations, ensuring relevance and uptake. Dialogue, trust, and informal networks help overcome resource limitations, especially in smaller municipalities. Collaboration across water areas—

covering 25 municipalities—has amplified impact, allowing for shared projects, broader networks, and stronger national visibility. This collective approach has facilitated access to higher-level decision-makers and improved policy influence.

The Morsa model demonstrates how locally anchored, knowledge-driven, and participatory governance can lead to meaningful environmental improvements.

Current challenges include balancing environmental goals with agricultural land use, navigating political cycles, and ensuring long-term commitment. The coordinator of the Morsa organization has a role as a neutral facilitator—neither activist nor regulator—something that has proven effective in building trust and driving action.

2.3 Implemented measures in each sector and cost of restoration

The mitigation measures around Vansjø are coordinated, executed and funded through the Morsa River Basin Organization, 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. Most measures were first implemented around or before 1999 and have continued ever since. The measures and costs are described in the following sections, and summarized in **Table 2**.

2.3.1 Agriculture

As agriculture was identified as one of the main contributors of nutrients to the lake, new mechanisms was developed to introduce agricultural measures. Starting with education, information campaigns, farmers' meetings, field trips, agricultural advisory for environmental planning on individual farms and farms visits, ending with a system of legal contracts signed with individual farmers combining incentive measures (Skarbøvik & Bechmann, 2010). Since 2005, legislative environmental claims have been in force in various degrees, resulting in various degrees of implementation of measures – the stronger claims the more measures have been implemented. In addition to this, subsidies are important in order to increase implementation of measures.

Overarching environmental contracts

In 2008, farmers in the catchment of the western part of Vansjø (around Vanemfjorden basin) were offered free consultancy on environmental planning and encouraged to sign committing and comprehensive environmental contracts, with financial support given to those who agreed. 75 % signed with the county government. The contracts included: no tilling in autumn, establishment of sedimentation ponds (if recommended), establishment of 10 m buffer zones along open water, establishment of gras-covered waterways where there's risk of erosion, and reduced P-fertilization. Farmers that did not sign this contract still contributed to the environmental measures. The costs of these contracts around Vansjø is estimated to € 106 per hectare, however the costs of the individual measures included in the contract is covered by the respective measure, as listed below.

No tilling in autumn

This is the single measure with greatest effect on reducing phosphorus inputs to Vansjø. It reduces soil erosion and protects the soil from rain and running water, increases organic matter content, increases the stability of the soil aggregates and increases biological activity and structure of the soil layers. In

2024, 90 % of the grain acre in the entire catchment was not tilled in the autumn, which was a large increase from ca 30 % in 1999 and 41 % in 2002. For the separate basins, the increase went from 51 to 96 % in the Storefjorden catchment and from 41 to 100 % in the western part. The cost of this measure is € 149 per hectare, which is funded by the Directorate of Agriculture. The estimated total costs for the Vansjø catchment is € 430 000 per year for implementing no autumn tilling.

Sedimentation ponds

This is another important measure implemented for reducing inputs of phosphorus and soil particles to the water bodies. The Morsa project created their own "sedimentation pond plan" with funding from the Ministry of the Environment and increased the number of ponds around the lake. 110 sedimentation ponds were established between 1994 and 2022 in the entire Morsa catchment. The costs are estimated to €18 064 for establishment of one pond with the size of 0,1 hectare. In addition, the ponds need maintenance (emptying) at appr. € 1063 per year for each pond.

Creating vegetated buffer zones

Wide strips of grass production have been established on agricultural areas (grain acres, fields, medows) adjacent to rivers and streams in order to reduce soil erosion. The costs are estimated to € 1775 per hectare, including establishment and maintenance and € 266 per hectare of lost earnings (lost production of vegetables or grain).

Grass covered water ways

This is a very important measure to reduce soil erosion on the fields. Low areas (small valleys) are sown with grass and thus reduce sediment losses from the land. The costs are estimated to € 3549 per hectare, including establishment, maintenance and € 266 per hectare of lost earnings (lost production of vegetables or grain).

Grass on flood-prone areas

This is another important measure to reduce soil erosion and floods. The costs are estimated to € 266 per hectare in lost earnings (lost production of grain).

Improved/reduced use of fertilisers

This was implemented nationally in 2007, however the western part of Vansjø has its own boundaries and recommendations for soil phosphorus content based on experiments conducted in cooperation with farmers. Between 1999 and 2012 the P-fertilization was reduced with 50 % in general, and 75 % around the western part of Vansjø. The cost of this measure has not been estimated.

Catch crops

This is a recent measure implemented to improve soil health, prevent erosion, and manage nutrients effectively. The cost of this measure is estimated to € 106 per hectare.

2.3.2 Sewage treatment

Improvements to municipal sewage treatment plants

This has been implemented to reduce nutrient discharges. Sewage measures in all municipalities in the catchment of € 23 220 000 have been implemented (Morsa 2003). The cost of upgrading municipal sewage treatment plants (e.g. including biological treatment steps) vary with the size and condition of the plants.

Improving local, separate sewage systems

This is implemented in order to separate wastewater from storm runoff and to ensure proper treatment of all sewage. Between 1999 and 2012 2040 residences were attached to public sewage systems, or have separate, modern treatment facilities. The estimated maximum cost per household for installing a mini-treatment or infiltration facility is € 14 876. The cost of connecting separate dwellings to the municipal system is estimated between € 12 220 and 23 377. The cost for the municipality of mapping their separate dwellings is estimated to appr. 132 823 for the municipality.

2.3.3 Solutions for erosion/flood management

Establishing and restoring riparian zones

Trees free of charge are provided by the Morsa organization to establish and restore riparian zones. More than 20 000 trees have been planted so far. In addition, bushes and other vegetation is planted. The work is performed by the land owners, farmers and schools, and is largely volunteer work. The costs, provided the use of 4 plants per 10 m, is € 4,13 per meter, or around € 11 per tree.

2.3.4 Other measures

Fish manipulation

Outfishing of large pike has been performed certain years, which has increased the number of plankton-eating fish, but also the number of other carnivorous fish.

Changes in water level regulation

Has been tested, especially during summer, and the Morsa organization has applied for permission to alter the regulation regime. The current regime has led to periods of standing water during the summers, which may facilitate the growth of cyanobacteria (Kaabbel 2014).

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Table 2. *Costs (2025 values, euros) of the different measures implemented in the Morsa catchment between 1999 and 2024. Sources: Morsa 2003, Kaabbel 2014, Direktoratsgruppen vannforskriften 2020.*

Sector, Measure	Source of finance	Cost for measure per hectare	Cost for lost earnings per year	Expected effect	Cost/ effect
Agriculture					
Environmental contracts	County government	€ 109 (in addition to costs listed below)		Large	High
No tilling in autumn	Directorate of agriculture	€ 152		Large	High
Sedimentation ponds/ wetlands establishment	Ministry of Environment	€ 18 485 for one pond of 0,1 hectare		Large	High
Sedimentation ponds/ wetlands maintenance	Ministry of Environment	€ 1087 / year for each pond (0,1 hectare)		Large	High
Vegetated buffer zones	Public	€ 1816	€ 272 (included in cost for measure)	Large	High
Grass covered waterways	Public	€ 3632	€ 272 (included in cost for measure)	Large	High
Grass on flood-prone areas	Public		€ 272 (for grain, less for veg.)	Large	High
Reduced use of fertilizers	Public	Not estimated			
Catch crops	Public	€ 109			
Erosion/flood management					
Establishing and restoring riparian zones	Public	€ 132		Medium-large	Medium-high
Sewage treatment					
Improvement of sewage treatment plants in 8 municipalities in 2002-08	Municipalities	Total costs € 21 692 021		Large	High
Improving local, separate systems (1999-2012)	Municipalities	Total costs € 14 132 898		Large	Medium
Installing treatment facilities	Residents	€ 14 876 (max. cost per household)			
Connecting separate systems to municipal systems	Residents	€ 12 220 - 23 377			

3 Evaluation of existing restoration programme

3.1 WFD

Vansjø has been monitored since the 1970s with various resolutions. Until 2004, data are mainly based on samples taken from June to September, and often every two weeks. Since 2005, the lake was monitored according to the WFD guidelines, with samples taken from April-October, also fortnightly.

For each figure, normalized ecological quality ratios (nEQR, total and phytoplankton parameters) or concentrations (Tot-P, Chl-a) are given, in addition to the corresponding ecological status classes, where Blue = High, Green = Good, Yellow = Moderate, Orange = Poor and Red = Bad. Storefjorden is evaluated as water type L106 (L-N3, low alkalinity, humic), while Vanemfjorden is evaluated as water type L108 (L-N8, moderately low alkalinity, humic).

3.1.1 Evaluation of ecological status class for eutrophication (nEQR)

NEQR values for eutrophication parameters from Storefjorden and Vanemfjorden are given in **Figure 6**, showing that both basins have mainly been in Moderate status since the 1980s. Earlier data showed that **Storefjorden** was in High status in the 1960s (data not shown). Some exceptional years have occurred, however, with Good status in Storefjorden in 1994 and 1996-97, and Poor status in 2007 and 2020. **Vanemfjorden** was in Poor status between 1994 and 2009 (Moderate in 2003).

The years with Poor status in Storefjorden was mainly due to the ecological status of phytoplankton parameters, especially PTI, but also Tot-P, as shown in the next sections. The period with Poor status in Vanemfjorden was the years where the western part of Vansjø experienced severe blooms of toxin-producing cyanobacteria, which was worsened by the year 2000-storm. Since 2010, the status has been Moderate, mainly determined (worsened) by PTI, while other phytoplankton parameters and Tot-P has improved, as shown in the following sections.

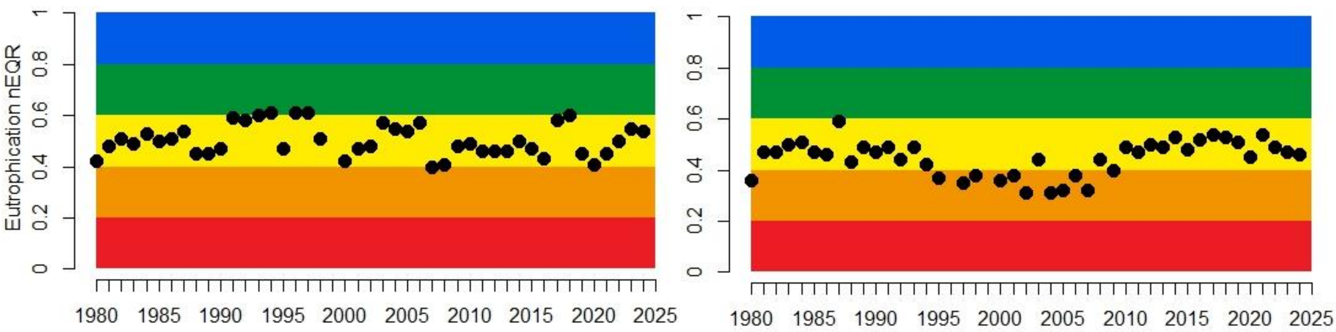

Figure 6. *total nEQR and corresponding ecological status class for Storefjorden (left) and Vanemfjorden (right) from 1980 to 2024.*

3.1.2 Total phosphorous

<u>**Storefjorden:**</u> Tot-P concentrations in the eastern part of Vansjø has been variable since the 1980s, mainly in Moderate ecological status, but some years of Good status occurred in the 1990s, around

2005, and in 2017-18 (**Figure 7**). The Tot-P concentration in the eastern part of Vansjø has not directly reflected the implemented measures as much as was expected. The concentration in this basin is partly determined by inputs of erosion particles from the catchment and thereby the amount of precipitation, number of flood events, magnitude of landslides and number of days with snow and cold degrees, and therefore not always directly related to activities in the catchment (Skarbøvik et al. 2025). All these factors are in turn influenced by climate change.

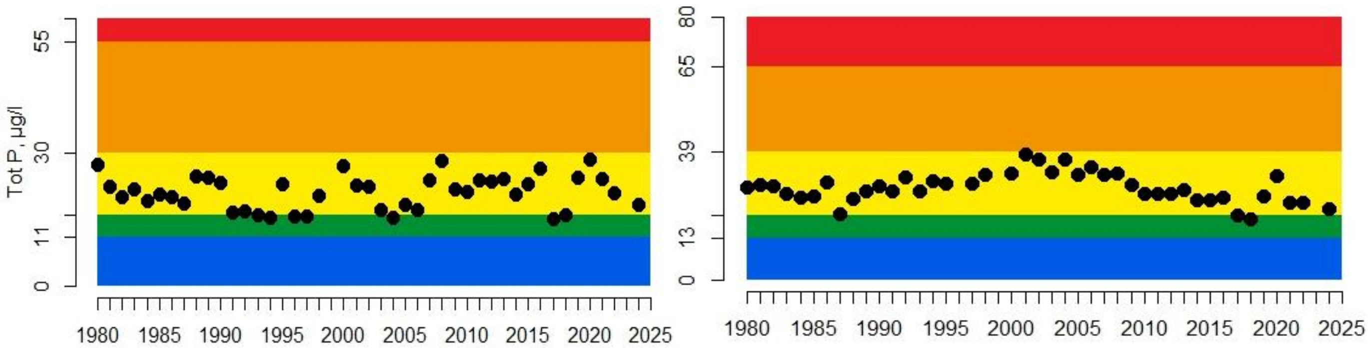

***Figure 7**. Tot-P concentrations in Storefjorden (left) and Vanemfjorden (right) from 1980-2024, with background colors corresponding to ecological status classes.*

<u>**Vanemfjorden:**</u> Tot-P concentrations have been higher in the western basin, Vanemfjorden, than in the eastern basin Storefjorden since the monitoring started in the 1980s and with less variation over the years (**Figure 7**). The concentrations correspond mostly to Moderate ecological status, with only a few years in Good status (1987, 2017-18), and with a peak in concentrations at the Moderate/Poor boundary between 2000 and 2005. The flood in 2000 lead to a large increase in Tot-P concentrations in the western basin. Together with the increased occurrence of toxic cyanobacterial blooms (2001-2006) this shows that flood events can have effects on eutrophication that influence the water quality for years after the event, and that counteracts the effect of costly mitigation measures. The P-concentration has declined since 2007, however in 2019-2021 there was a clear increase again as a result of years with much precipitation and high water flow in the catchment rivers (Skarbøvik et al. 2025).

The measures implemented for P-reduction in the Morsa catchment have been counteracted by other factors, such as climate change with increasing precipitation, storm events and warmer winters (more snow melt episodes), but also by reduction in acid precipitation. Less acidic soils and less sulfate has lead to increased humic inputs with following P-content, and a reduction in reactive aluminium, which normally would bind P and contribute to sedimentation of P (forskning.no). Studies have shown that the sediments in Vansjø are not as P-rich as expected, and are therefore not contributing to significant internal P-loading (Andersen et al. 2006). This means that the P-inputs to Vansjø is mainly coming from external sources.

The seasonality of nutrients in the two main basins of Vansjø for selected years are shown in **Figure 8**. Typically the western basin experiences dissolved inorganic nitrogen (DIN) under detection limit during summer months due to high algal growth. In the years with high cyanobacterial dominance, a change from non-N-fixing cyanobacteria like *Microcystis aeruginosa* to N-fixing cyanobacteria genera like *Dolichospermum* sp. and *Aphanizomenon* sp. were observed. This change in cyanobacterial dominance is no longer prominent in the summer phytoplankton community (Skarbøvik et al. 2025).

Figure 8. *Seasonal changes in Tot-N (TN), dissolved inorganic nitrogen (DIN), Tot-P (TP) and soluble reactive phosphorus (SRP) in the two basins Storefjorden and Vanemfjorden in Lake Vansjø, represented by years 2005 and 2022.*

3.1.3 Chlorophyll *a*

Chlorophyll *a* concentrations from both basins during the monitoring of 1980-2024 are shown in **Figure 9** with corresponding ecological status class.

In **Storefjorden**, chlorophyll *a* concentrations were variable (Good and High) from the 1980s, but increasing towards 2000, crossing the boundary to Moderate status several years between 1995 and 2003. Since 2004 the status has mainly been Good.

In **Vanemfjorden**, chlorophyll *a* concentrations are much higher than in Storefjorden, and have also been variable since the 1980s, but in Moderate status. The concentrations increased between 1990 and 2006, with mainly Poor status these years. From 2007 the concentrations declined and has been Moderate, with some years even Good status. The continued high levels of chlorophyll *a* can be explained to a certain degree by the presence and often high biomasses of *Gonyostomum semen*, a raphidophyte with high chlorophyll *a* content. This species is known to form extremely large biomass and chlorophyll *a* concentrations at lower phosphorous levels than e.g. cyanobacteria (Cronberg et al., 1988; Hongve et al., 1988).

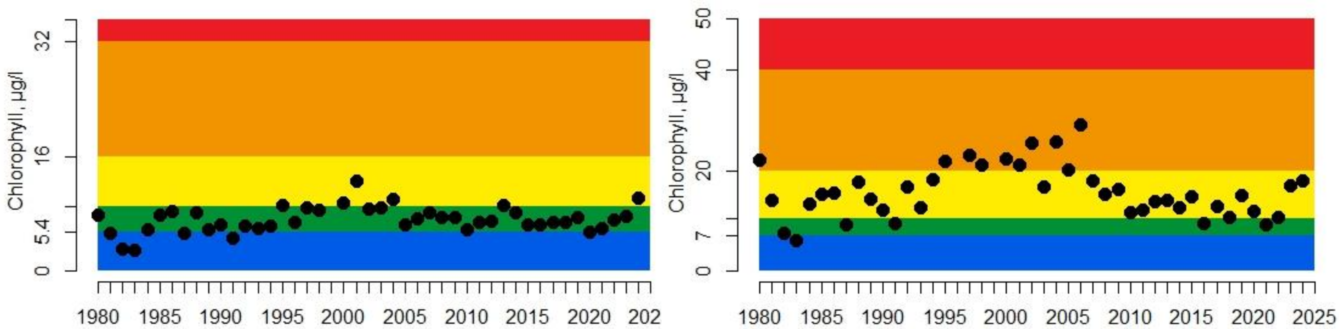

***Figure 9**. Chl-a concentrations in Storefjorden (left) and Vanemfjorden (right) from 1980 to 2024.*

3.1.4 Phytoplankton

Figure 10 shows the nEQR for phytoplankton parameters in **Storefjorden** from 2005-2024 and total phytoplankton classification from 1980 to 2024. Total phytoplankton status was mainly Good or High until the late 1990s, after when it has been mainly Moderate. The Moderate status is mainly caused by PTI and often biovolume, while chlorophyll a and cyanomax have been more or less Good or High status (**Figures 9** and **10**).

Figure 11 shows the nEQR for phytoplankton parameters in **Vanemfjorden** from 2005-2024 and total phytoplankton classification from 1980 to 2024. Total phytoplankton status was very variable from 1980 to 1990 (mainly Good-Moderate), and Poor since the mid-1990s until 2008 when it was back to Moderate status. In this basin, the total status is mainly caused by all parameters combined, including chlorophyll *a*, but from 2008 cyanomax was not causing the Moderate status. The data indicate no further problems with cyanobacteria in Vanemfjorden since 2010, however the low PTI nEQR reflects issues with other nuisance algal species such as *Gonyostomum semen*, which is not as closely correlated

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to Tot-P as cyanobacteria, and which is also increasing as Vansjø has become more humic (Lyche Solheim et al. 2023).

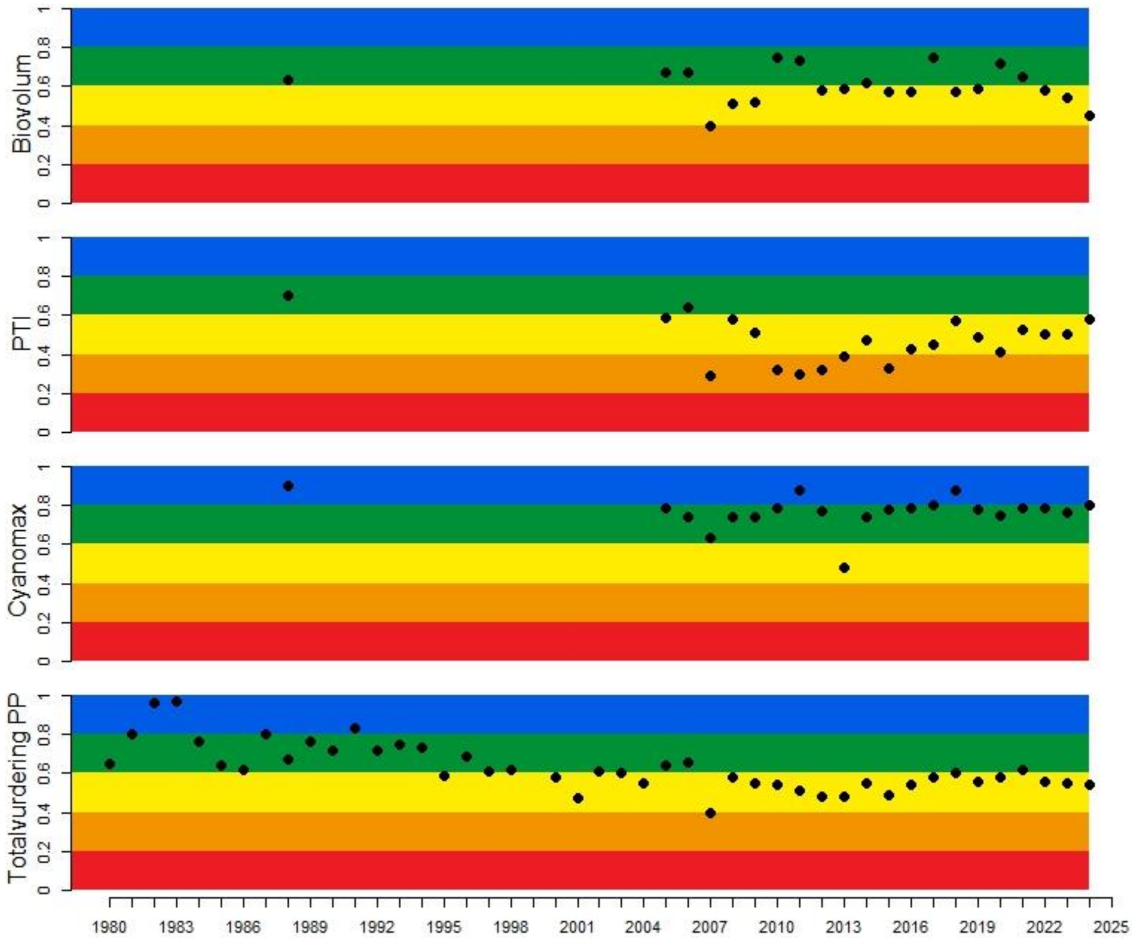

Figure 10. *nEQR for phytoplankton parameters in Storefjorden from 1980 to 2024.*

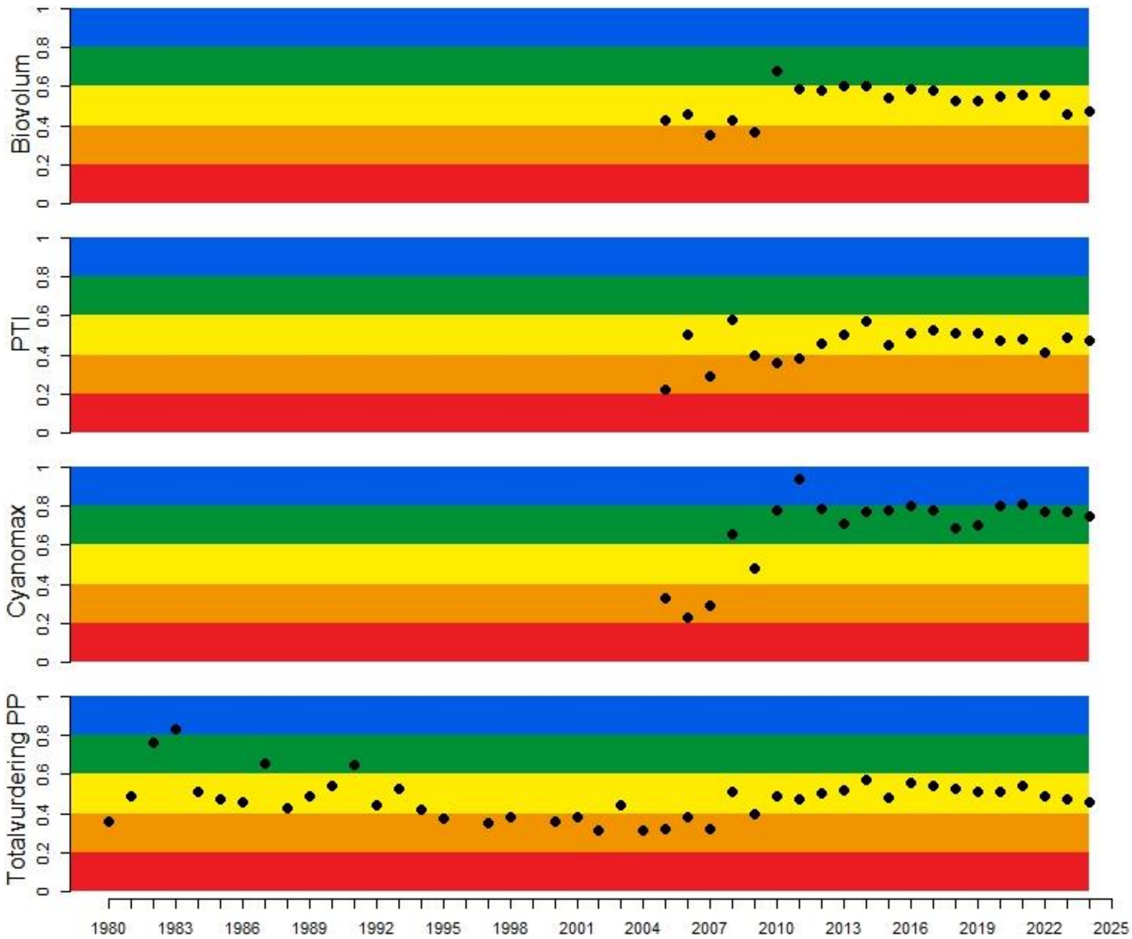

Figure 11. *nEQR for phytoplankton parameters in Vanemfjorden from 1980 to 2024.*

3.2 Biodiversity net gain

3.2.1 Macrophytes

A systematic waterplant survey was conducted in Vansjø in 2004 by NIVA (Mjelde et al. 2009). At that time, nymphaeids were the dominant growth form in the water's body, but a total of 29 other submerged and floating water plants were found. The protected shorelines were primarily colonized by helophytes such as *Phragmites australis* and *Schoenoplectus lacustris*. The results from this survey are presented in **Table 3**. The survey was done separately for the two major basins of the lake, Vanemfjorden (western part) and Storefjorden (eastern part).

None of the species found in Vansjø are priority species according to the EU Habitats Directive. However, six of the species found in 2004 are red listed according to the current Norwegian red list. Additionally, there are two other red listed species in the lake, both well documented and recorded after 2004. In 2004 the index for eutrophication level was still under devolvement, but the early calculation gave the lake a score indicating Moderate to Bad ecological condition, based on the water plant assembly (Mjelde et al. 2009).

***Table 3.** Aquatic plants recorded in Vansjø in 2004, with plant cover for the two basins and notes on red list category if worse than "least concern" by the latest red list in Norway . The scale indicates plant cover by the sizes: 0 = not present, 1 = rare, … up to 5 = dominant in the euphotic zone. "+" indicates drift material.*

Growth form	Plant cover		Norwegian redlist 2021
	Vanemfjorden	Storefjorden	
Submerged			
Elatine hexandra	0	1	EN
Elatine hydropiper	1	0	EN
Elatine orthosperma	0	1	EN
Elatine triandra	0	1	EN
Eleocharis acicularis	1-2	1	
Isoetes lacustris	0	1-2	
Lythrum portula	1	0	EN
Ranunculus reptans	1	1	
Callitriche palustris	1	0	
Ceratophyllum demersum	4	1	
Juncus bulbosus	2	1	
Myriophyllum alterniflorum	1	3	
Potamogeton crispus	0	+	NT
Potamogeton obtusifolius	2	1	
Potamogeton perfoliatus	2	0	
Ranunculus cf. peltatus	0	1	
Utricularia vulgaris	2-3	2	
Nymphaeids			
Nuphar lutea	4	4-5	
Nuphar pumila	3-4	1	
Nymphaea alba	3	2	
Persicaria amphibia	3	3	
Potamogeton natans	3	3	
Sparganium angustifolium	2	2	
Sparganium emersum	2-3	2	
Sparganium sp.	1	0	
Lemnids			
Lemna minor	1	2	
Spirodela polyrrhiza	1	1-2	
Charophytes			
Nitella opaca	1	1-2	
Bryophytes			
Fontinalis antipyretica	0	1	

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In addition to the 2004 survey, numerous volunteers and other professionals have recorded plant life in and around the lake before and after 2004. Below is an overview of other aquatic vascular plants found in and close to the lake as registered in the Norwegian Biodiversity Information Centre, Artsdatabanken (Artsobservasjoner.no).

Submerged to partly nymphaeids:

Callitriche cophocarpa, Callitriche hamulata, Callitriche stagnalis, Myriophyllum verticillatum, Nymphaea candida, Potamogeton alpinus, Potamogeton polygonifolius, Ranunculus aquatilis, Sparganium erectum, Sparganium glomeratum, Sparganium natans, Sparganium × splendens, Limosella aquatica, Littorella uniflora, Subularia aquatica, Lobelia dorthmana and *Utricularia australis* (VU), where the *Utricularia australis* have only been found at one locality, lastly in 2025.

Lemnids:

Hydrocharis morsus-ranae (NT), possibly introduced by people to the lake, first recorded in 2014.

Emergent to partly submerged species:

Alisma plantago-aquatica, Calamagrostis canescens, Calla palustris, Caltha palustris, Carex paleacea, Eleocharis mamillata, Eleocharis uniglumis, Glyceria fluitans, Glyceria maxima, Persicaria hydropiper, Ranunculus flammula, Ranunculus sceleratus, Rumex aquaticus, Schoenoplectus tabernaemontani, Sparganium erectum, Sparganium glomeratum, Typha latifolia.

3.2.2 Protected areas and birds

In 1992, two nature reserves with a total of 426,5 hectares were established in Vansjø, both with the aim of protecting important wetland areas with vegetation, bird species and other wildlife.

Vestre Vansjø nature reserve is 329,6 hectares and located in the western basin of the lake, Vanemfjorden (**Figure 12**). 59 wetland species were recorded before the establishment (e.g. Lågbu 1986, Miljødirektoratet Naturbase a).

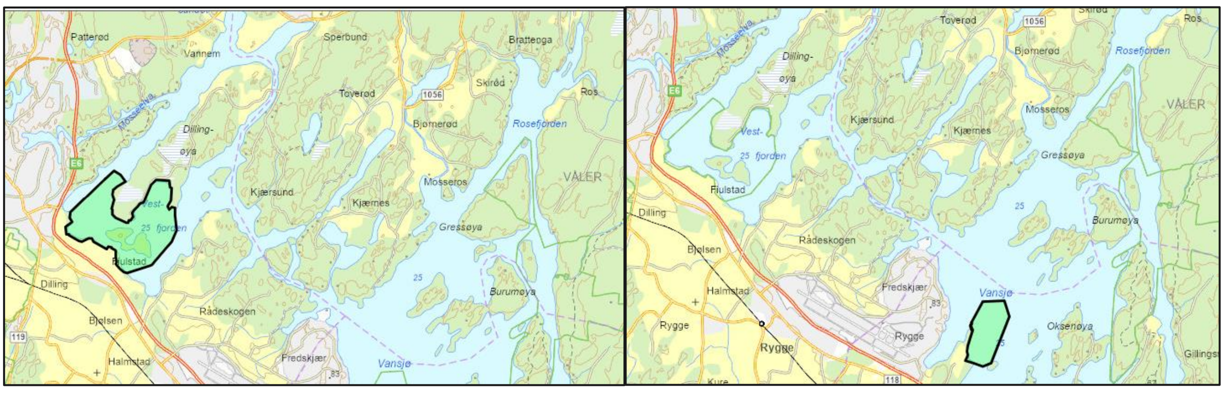

Figure 12. *Vestre Vansjø nature reserve (left) and Moskjæra nature reserve (right), established in 1992, protecting a total of 426,5 hectares of water, wetland and terrestrial grounds. Source: Miljødirektoratet Naturbase.*

Moskjæra nature reserve is 96,9 hectares and is located in the eastern part of the lake, Storefjorden (**Figure 12**, Miljødirektoratet Naturbase #2). The area is of great importance as nesting area for wetland birds, with observations of nesting *Podiceps cristatus* (Great Crested Grebe), *Cygnus olor* (Mute Swan), *Acrocephalus scirpaceus* (Common Reed Warbler) *Emberiza schoeniclus* (Common Reed Bunting), in addition to coastal species such as seagulls. Before establishment of the nature reserve (e.g. Lågbu 1986), 33 species of wetland birds were registered in the area, of which 16 were nesting (Miljødirektoratet Naturabase b).

Due to strict regulations on activities in the nature reserves, such as Vestre Vansjø and Moskjæra, scientists have not been able to enter the protected areas in order to make any evaluation of the breeding success for nesting of bird species, and the current productivity in the nature reserves are therefore more or less unknown. Some recent monitoring using drones have, however, indicated that Moskjæra is less attractive to birds than expected, with very few breeding pairs of some previously abundant species. This is likely related to the presence of the invasive Neovison vison (mink), but this is not verified. Also the nature reserve Vestre Vansjø have experienced breeding failures recent years, a reserve previously known for being susceptible to mink predation. Management targeting this invasive species is urgent in order to increase recruitment to populations of several species.

Numerous professional and non-professional volunteers have frequently recorded bird occurrences in and around Vansjø, and these observations are available from the Norwegian Biodiversity Information Centre (Artsdatabanken) and their database Artsobservasjoner.no. A total of 206 species was recorded between 2000 and 2025, of which 58 are red listed according to the Norwegian red list (CR, EN, VU and NT), and three are invasive species *Branta canadensis* (HI), *Phasianus colchicus* (LO) and *Columba livia* (NE).

Several species are found nesting in Vansjø, such as *Podiceps cristatus (Great Crested Grebe), Cygnus olor (Mute Swan), Gallinula chloropus (Common Moorhen), Fulica atra (Eurasian Coot), Acrocephalus scirpaceus (Common Reed Warbler), Pandion haliaetus (Osprey), Ardea cinerea (Grey Heron), Emberiza schoeniclus (Common Reed Bunting) and Pernis apivorus (European Honey Buzzard). Some coastal waterfowl is also found nesting, such as Seagulls, Terns and* Oystercatchers. Some populations are stable (e.g. *Larus marinus* (great black-backed gull)), and some also new to Vansjø (*Larus fuscus* (lesser black-backed gull) and *Larus argentatus* (European herring gull) and have been found nesting only in recent years (Ranke & Krokeide 2025b). However, for *Chroicocephalus ridibundus* (black-headed gull), *Larus canus* (common gull) and *Sterna hirunda* (mackerell tern), populations and nesting activities are believed to have declined the past decades (Ranke & Krokeide 2025b). Nesting of mackerell terns has also been disrupted by recreational activities outside the protected areas (Ranke & Krokeide 2025a).

3.2.3 Fish

Vansjø is one of the most species-rich lakes in Norway when it comes to fish, with 21 registered species, of which 11 are native; *Perca fluviatilis, Abramis brama, Lota lota, Esox lucius, Sander lucioperca, Lampetra fluviatilis, Coregonus lavaretus, Rutilus rutilus, Gasterosteus aculeatus, Salmo trutta* and *Anguilla anguilla*, and ten are invasive; *Blicca bjoerkna*, *Cyprinus carpio, Carassius carassius*, *Osmerus eperlanus, Alburnus alburnus, Tinca tinca, Scardinius erythrophthalmus, Lauciscus cephalus, Gymnocephalus cernuss* and *Cottus gobio* (Brabrand & Lien 2004, NJFF 2025). Vansjø is one of the few locations in Norway where *Sander lucioperca* (Pikeperch/Zander) are native.

3.2.4 Presence of invasive non-native species

According to the Norwegian Biodiversity Information Centre (Artsdatabanken) where volunteers can register observations, several species on the Norwegian red list were found in and around Vansjø from 2000 to 2025 (Artsobservasjoner.no). Most are terrestrial, but also *Rana arvalis* (moor frog) and *Astacus astacus* (European crayfish) are registered, in addition to the bird and fish species mentioned above.

Several invasive species are also registered in and around Vansjø, mainly terrestrial, but also *Neovison vison* (mink) in addition to the bird and fish species mentioned above.

3.3 Zero pollution

3.3.1 Chemical status of waterbody (WFD status class), and EQS of specific priority chemicals

The chemical status of Storefjorden is currently Not good due to high levels of mercury (Hg) and perfluorooctane sulfonic acid (PFOS) and its derivates. The PFOS originates from several sources, but the major source is fire extinguishers used at the military airport in Rygge, adjacent to the lake. The use has ceased now, and there are measures implemented to reduce the continued leakage into Vansjø, but these “forever chemicals” will still remain in the lake for years.

In 2014-2016 fish liver (*Perca fluviatilis*) was examined for pollutants and priority substances in **Storefjorden**, and the results were *Bad* for mercury (Hg) and PFOS, while other substances were *Good*. Environmental quality standard (EQS) for Hg in organisms is 20 µg/kg wet weight (w.w.), while the liver concentrations in Storefjorden were 385,8; 317 and 598,4 µg/kg w.w. respectively the three years, far above the EQS. Equally, concentrations of PFOS in Storefjorden was average 173 and 346,2 µg/kg w.w. in 2014 and 2015 respectively, also above the EQS for organisms of 9,1 µg/kg w.w. A larger survey of PFOS in 2020 and 2021 also measured concentrations above EQS in tissue from *Esox lucius*, *Perca fluviatilis*, and *Sander lucioperca* sampled at several locations in Storefjorden, and in liver from *Perca fluviatilis* (Helland 2023).

In 2006, sediments were sampled in the eastern basin, showing concentrations of PFOS averaged at 1,90349 µg/kg dry weight (d.w.), which is above AA-EQS (annual average threshold value) but under MAC-EQS (maximum annual concentration). At the same time and place, muscle tissue from three different species were examined (*Rutilus rutilus, Esox lucius* and *Perca fluviatilis*), all with high concentrations of PFOS; 7,49129; 24,77767 and 57,22508 µg/kg w.w. for the three species respectively, the two latter above EQS for organisms. It must, however, be noted that liver is the preferred matrix for PFOS and not muscle tissue.

In a narrow basin between Storefjorden and Vanemfjorden, sediments were sampled in 2006. Sediment concentrations of PFOS at 1,15268 µg/kg d.w. were above AA-EQS (0,23 µg/kg d.w.), but below MAC-EQS (72 µg/kg d.w.). At the same time, muscle tissue from *Esox lucius* was sampled, showing PFOS concentrations of 44,26 µg/kg w.w., which was also above the EQS, although this was not the preferred matrix.

West in Vanemfjorden, Hg concentrations in *Esox lucius* (muscle tissue) were 730 µg/kg w.w. in 1999. In 2000, Hg concentrations in *Sander lucioperca* were 220 µg/kg w.w., and in *Perca fluviatilis* (both muscle tissue) 440 µg/kg w.w. All were above EQS.

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3.3.2 Phosphorus emissions from separate dwellings

Due to several sewage measures implemented in the entire Morsa catchment area, the reduction in phosphorus emissions from separate dwellings were 87 and 90 % in the closest catchments of Storefjorden and Vanemfjorden respectively between 2001 and 2021, corresponding to a reduction from 550 to 75 kg P in Storefjorden and from 190 to 20 kg P in the western part of Vansjø (Bechmann et al. 2022).

3.3.3 Phosphate, PO_4-P (µg/L)

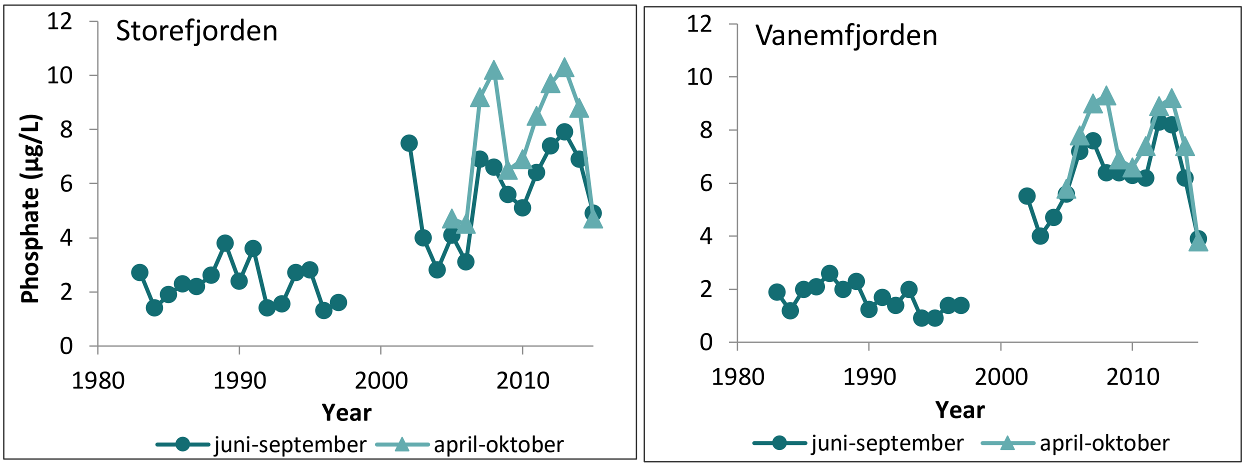

__Figure 13.__ Phosphate (PO_4, y-axis) measured in Storefjorden and Vanemfjorden from 1983-2015 (x-axis).

3.3.4 Total nitrogen, Tot-N (µg/L)

Inputs of total nitrogen (Tot-N) from the main river has not changed significantly since 1985, however the inputs of Tot-N to the main outlet river, draining to the Oslofjord, has had a week, but significant declining trend. This is not surprising, as the measures implemented around lake Vansjø has mainly been focusing on reducing phosphorus inputs to the lake, both from agriculture and sewage, and reduction in nitrogen inputs often requires different measures. As seen in **Figure 14**, Storefjorden – which is receiving water from the main river – had high concentrations of Tot-N since the 1970s, every year above the environmental target for the water type. Vanemfjorden on the other hand, which is the basin draining to the outlet, has lower concentrations of Tot-N since the 1970s, and several years with averages below the environmental target for the water type.

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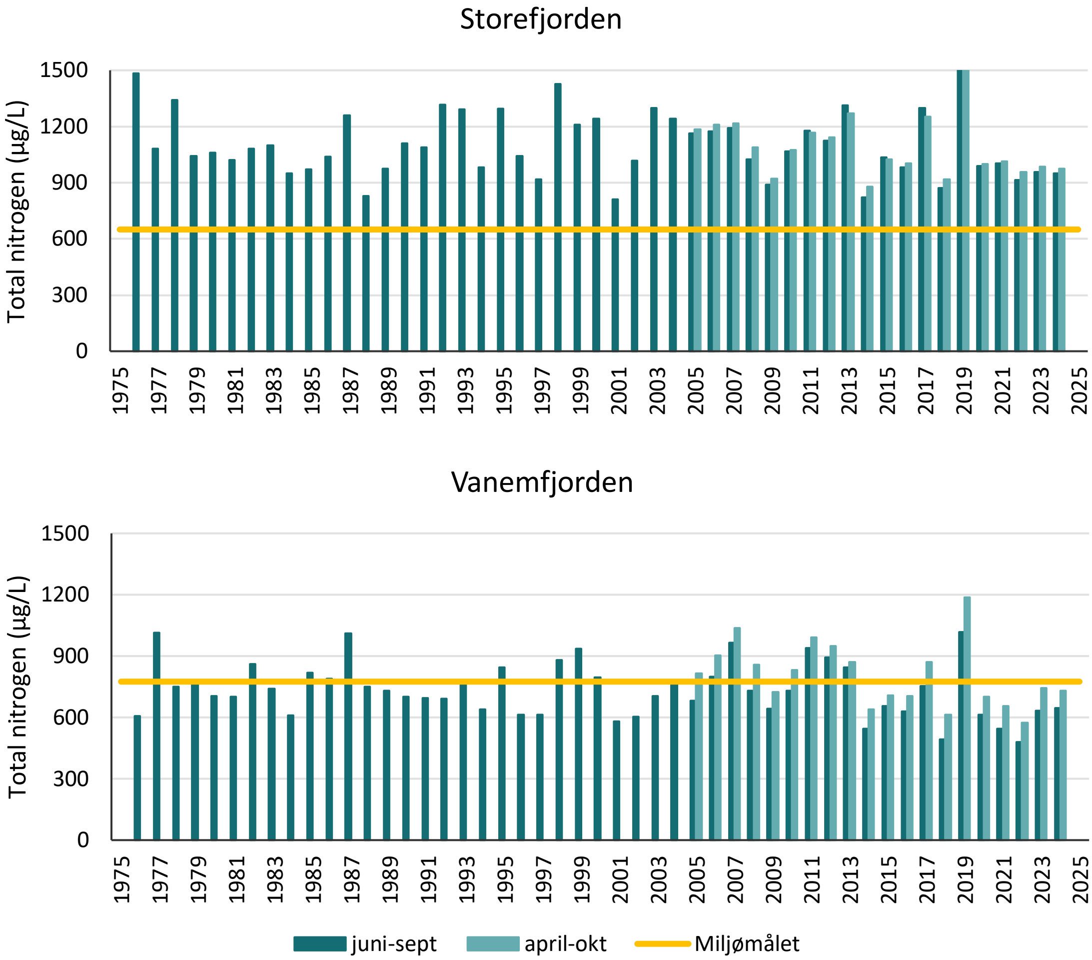

Figure 14. Total nitrogen (Tot-N, µg/L) in Storefjorden and Vanemfjorden from 1976-2024. The yellow lines mark the environmental targets (Good ecological status) for water types L106 (Storefjorden) and L108 (Vanemfjorden).

3.3.5 Nitrate NO_3-N (µg/L)

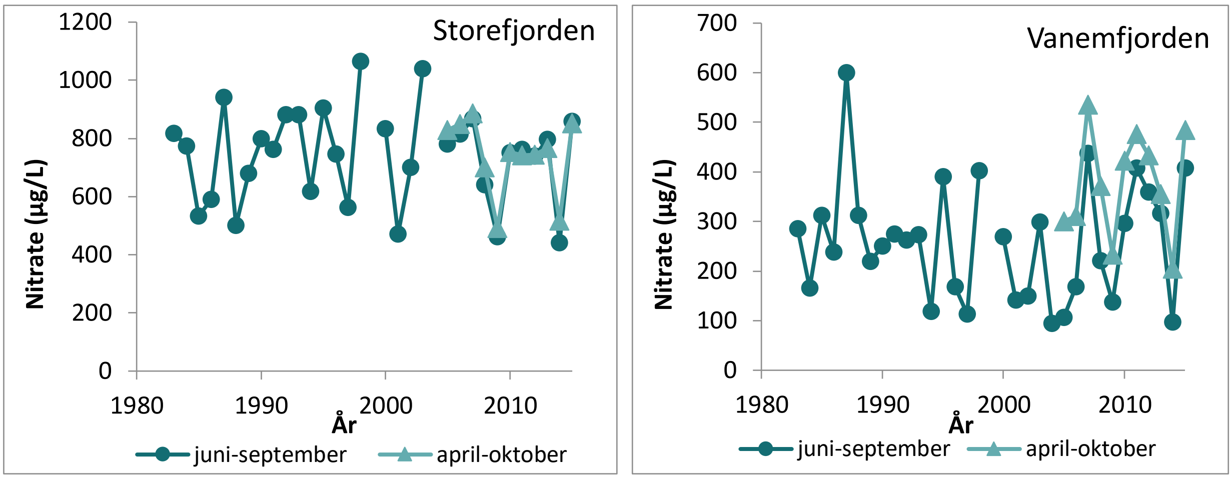

Figure 15. *Nitrate (NO_3, µg/L) measured in Storefjorden and Vanemfjorden from 1983-2015.*

3.3.6 Ammonium NH_4-N (µg/L)

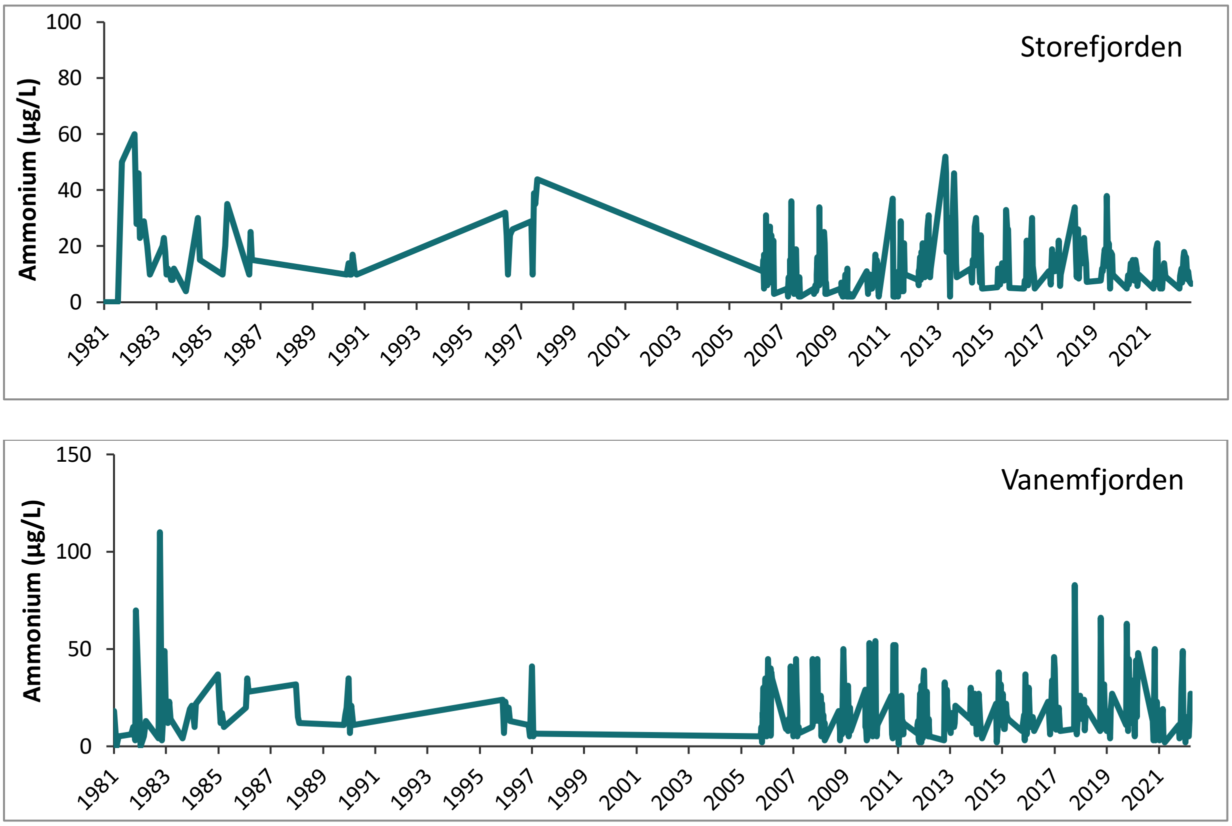

Figure 16. *Ammonium (NH_4, µg/L) measured in epilimnion of Storefjorden (top) and Vanemfjorden (bottom) from 1981-2022.*

3.3.7 DOC (mg/L) and water color

Vansjø has become increasingly more humic, as seen from both organic matter content (measured as total organic carbon, TOC) and water color, shown in **Figure 17** and **Figure 18**.

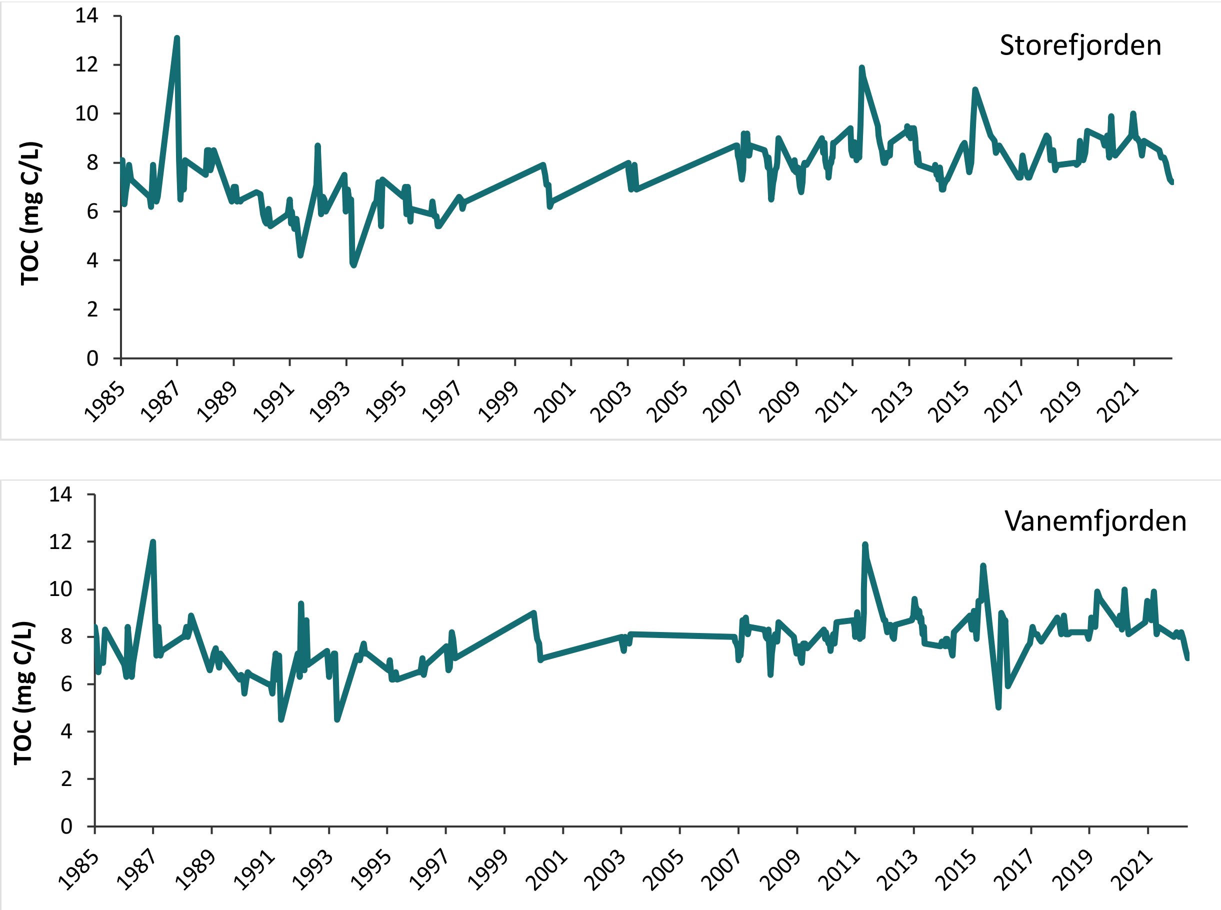

Figure 17. *TOC (mg C/L) in Storefjorden (top) and Vanemfjorden (bottom) from 1985 to 2022.*

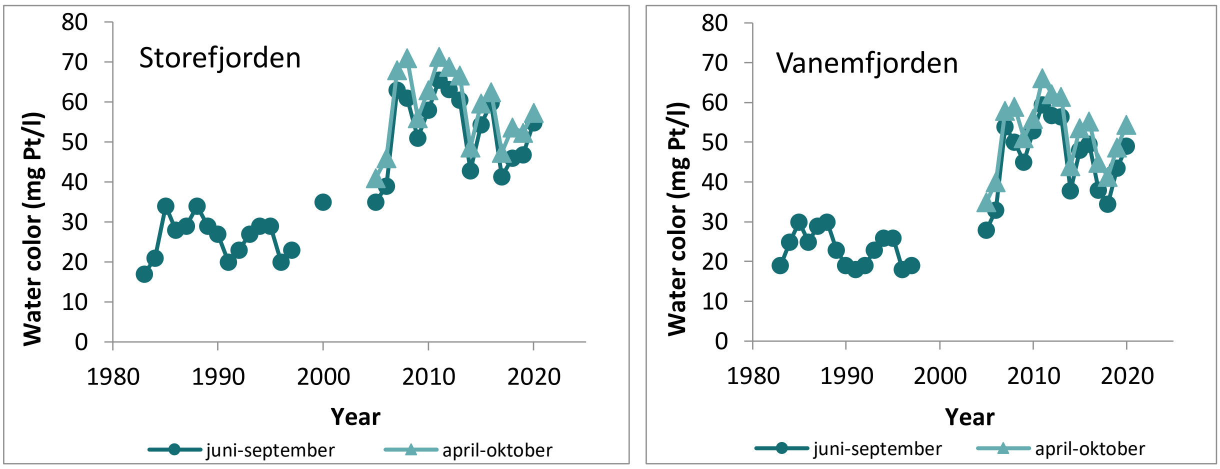

Figure 18. *Water color measured as mg Pt/L in Storefjorden and Vanemfjorden from 1983-2022.*

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3.3.8 *E. coli* (MPN/100 ml)

Cell numbers of *Escherichia coli (E. coli)* in three streams draining into Vansjø are shown in **Figure 19 and 20**. The stream in the eastern basin had low numbers of *E. coli* between 2008 and 2022. Contrary, the cell numbers were higher in the two streams draining into the western basin, however the numbers have declined significantly in both streams after 2011.

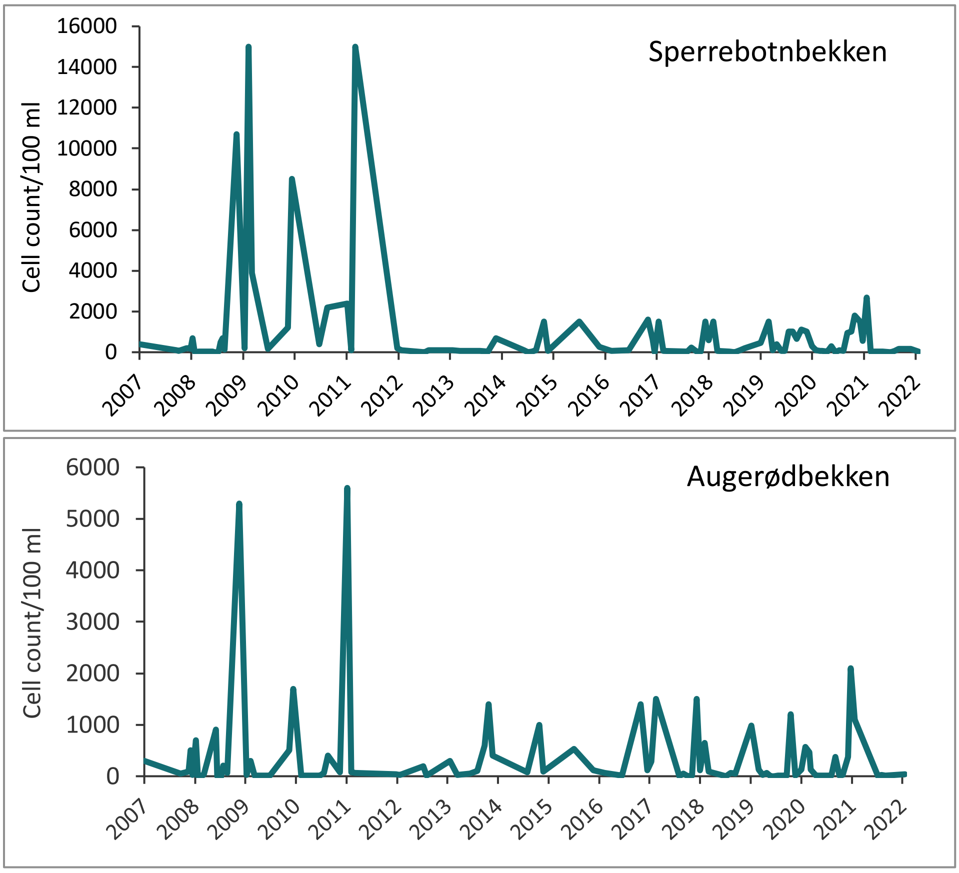

Figure 19. *E. coli concentrations in two streams draining to Vanemfjorden between 2007 and 2022.*

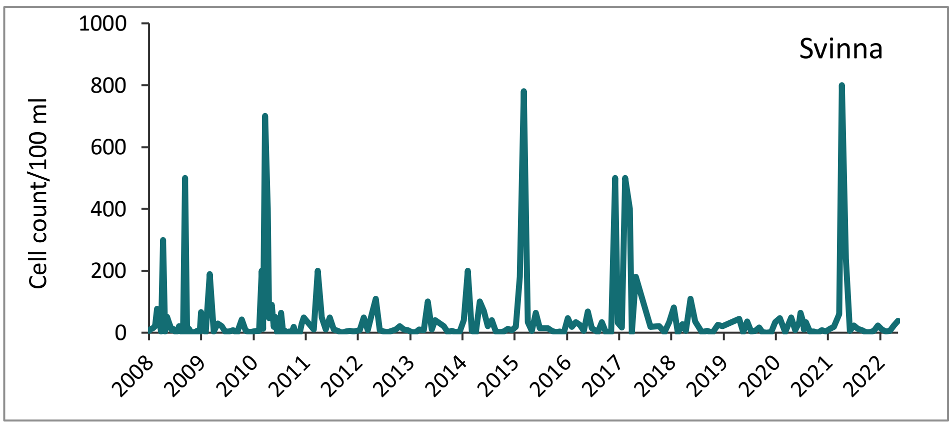

Figure 20. *E. coli concentrations in a stream draining to Storefjorden between 2008 and 2022.*

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3.3.9 Microplastics (< 5 mm)

In 2018, microplastics (< 5 mm) were investigated in the raw water at Vansjø Waterworks, and after treatment in the drinking water plant. The results showed average 2,3 particles per liter water in Vansjø (raw water), which is a low number and not considered to constitute an issue for the use of the lake as drinking water source.

3.4 Climate regulation

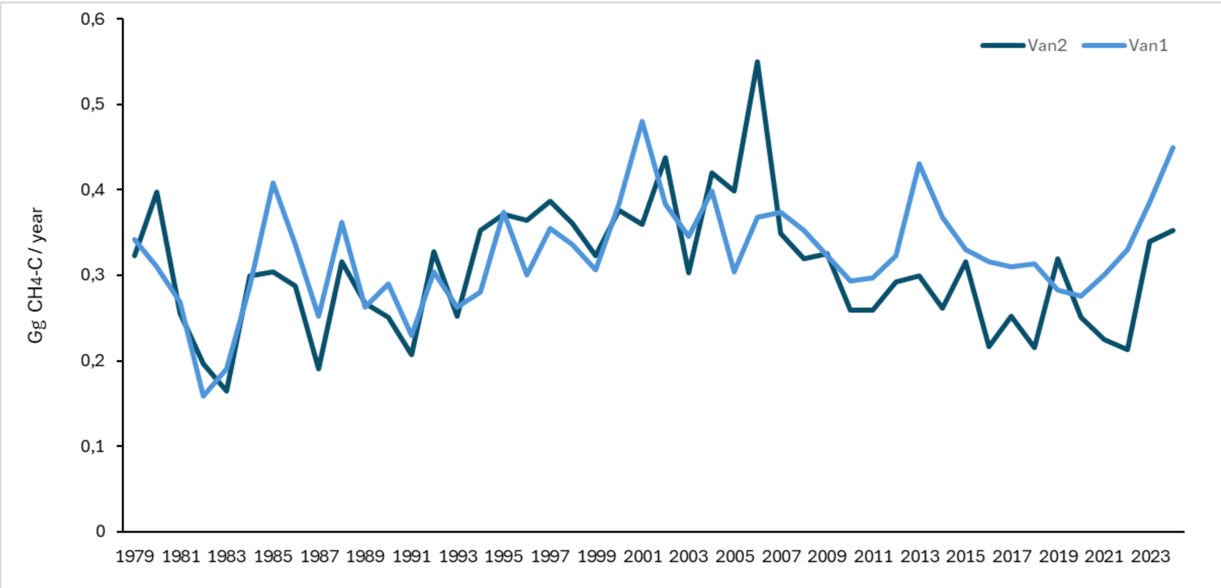


Figure 21. *Predicted sum of ebullative and diffusive methane (CH_4) emissions from the two main basins of Vansjø, based on average annual chlorophyll a concentrations (June-September). Predictions were made using a Bayesian model constructed from a global dataset of ground-based methane measurements and satellite-derived chlorophyl-a data. The data used to construct the Bayesian model is available as supplementary information in DelSontro et al. 2018.*

3.5 Climate resilience

Flooding is a frequent occurrence in Vansjø and its catchment. It has been documented that the implemented mitigation measures would have had an even more significant effect on nutrient loading and water quality if the flood in year 2000 had been prevented. However, still it is suggested that the only permanent measure to reduce flood problems in Vansjø is to increase the outlet capacity, e.g. by a flood tunnel. The estimated costs (per 2011) for this alternative was set to € 8,8 (by The Norwegian Energy Regulatory Authority, NVE) and has not yet been started (Morsa 2011). There is also a great need for securing rivers in the catchment for erosion and flooding, with a estimated cost of € 9.

3.6 Health & Well-being

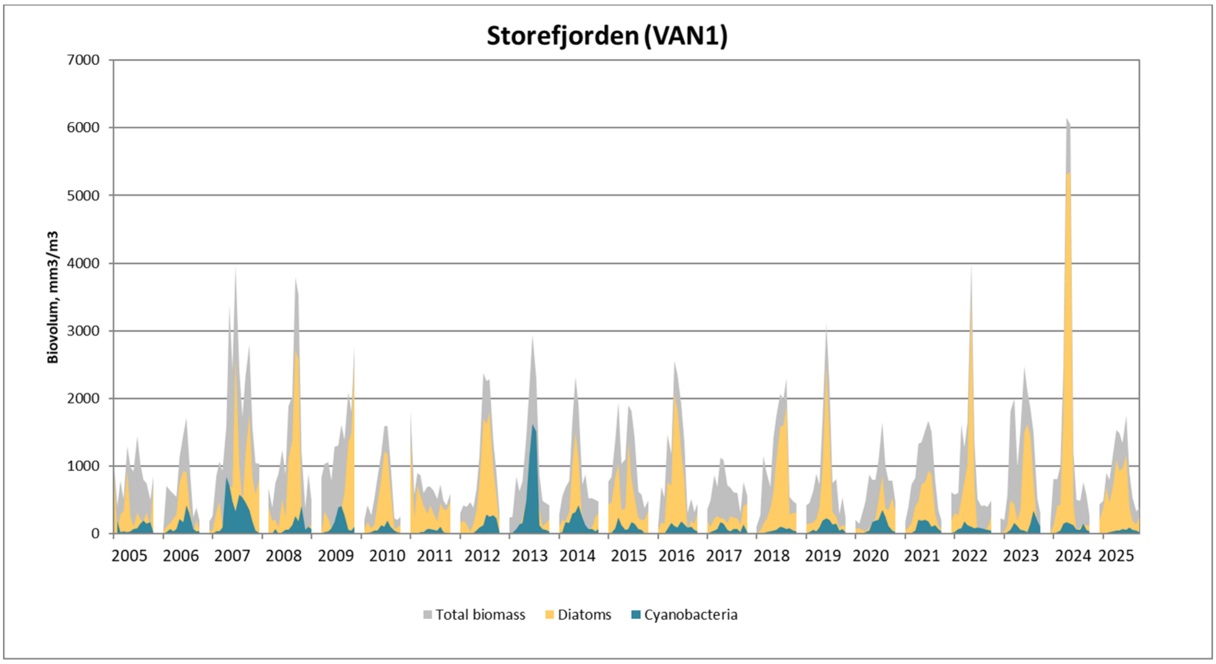
3.6.1 Bathing water quality

Vansjø has experienced several years of cyanobacterial blooms, with consequential bathing bans. The blooms were most frequent between 2000 and 2007, and since then the concentration of cyanobacteria in the western part of Vansjø (Vanemfjorden) has declined significantly. Still, visible blooms occur some years, and there were also recommendations not to swim in the western parts of the lake (Nesparken) in 2019 and 2020 (**Figure 22**).

Figure 22. *No swimming in Nesparken in 2019. Photo: Moss Avis, 12.08.2019.*

Cyanobacteria, biomass and toxins

Vansjø experienced heavy cyanobacterial blooms several years, with large, visible green mats occurring several places, especially in the western basin. The blooms were often toxic, but also unappealing to people in and around the lake, causing bathing bans and loss of recreational value. But the visible blooms also motivated stakeholders, farmers and land owners to engage in measures initiated to improve the water quality of the lake, e.g. environmental contracts, even if the costs were high. Since the implementation of mititation measures in the catchment of Vansjø, cyanobacterial biomass have significantly declined in both of the main basins (**Figure 23**), as have the concentrations of microcystin (**Figure 24**).



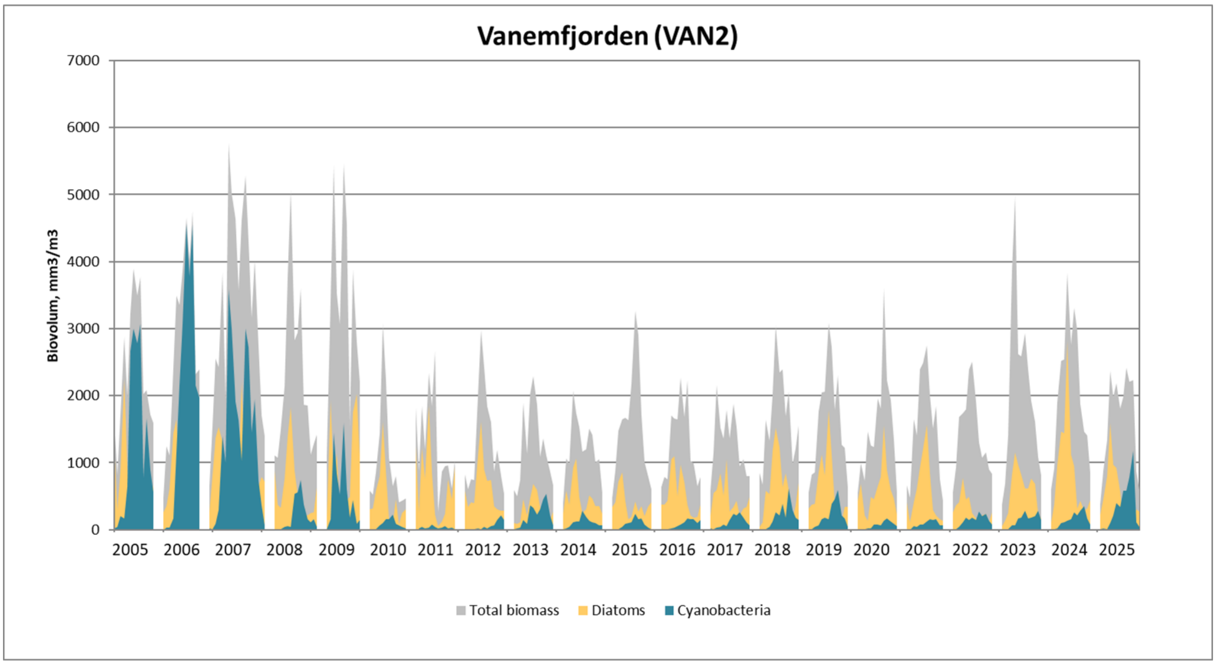
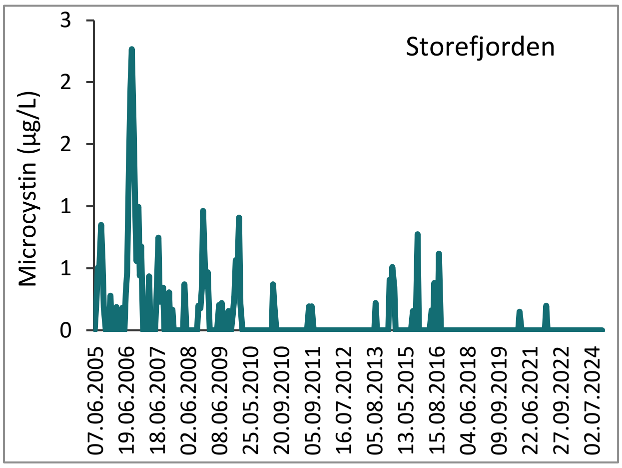
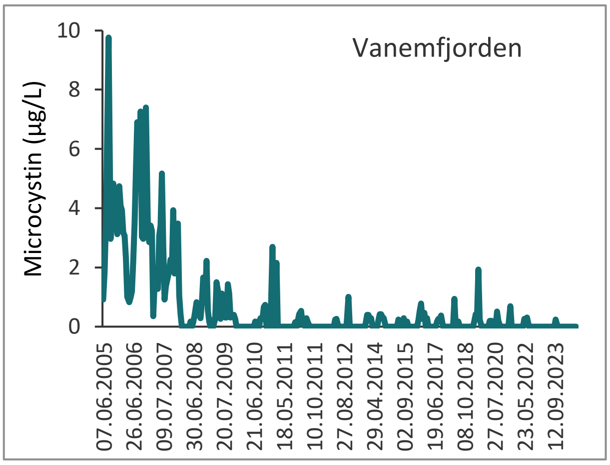


Figure 23. *Cyanobacterial biomass in Storefjorden (above, Van1) from 1988-2025 in relation to diatoms ("kiselalger"), which often are the most dominant group, and in Vanemfjorden (below) from 2005-2025, in relation to total phytoplankton biomass.*





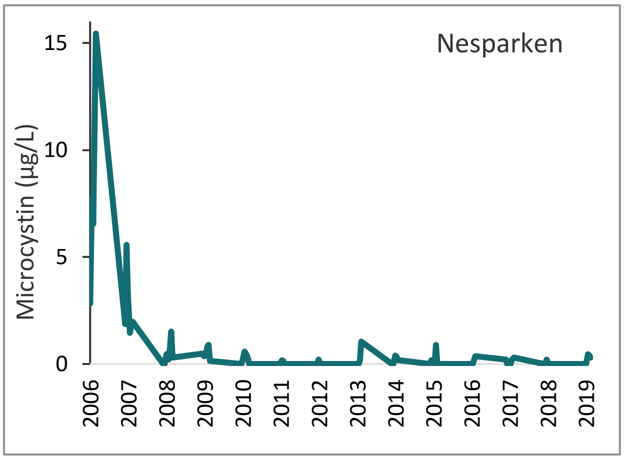


Figure 24. *Microcystin concentrations measured at three sites in Vansjø from 2005 to 2024; Storefjorden, Vanemfjorden, and the popular bathing site Nesparken.*

E. coli

E. coli numbers have been low between the main basins (station Van5) from 2008-2022, as seen in **Figure 25**. The numbers have been far beneath the threshold for Good bathing water quality of 1000 cells/100 ml.

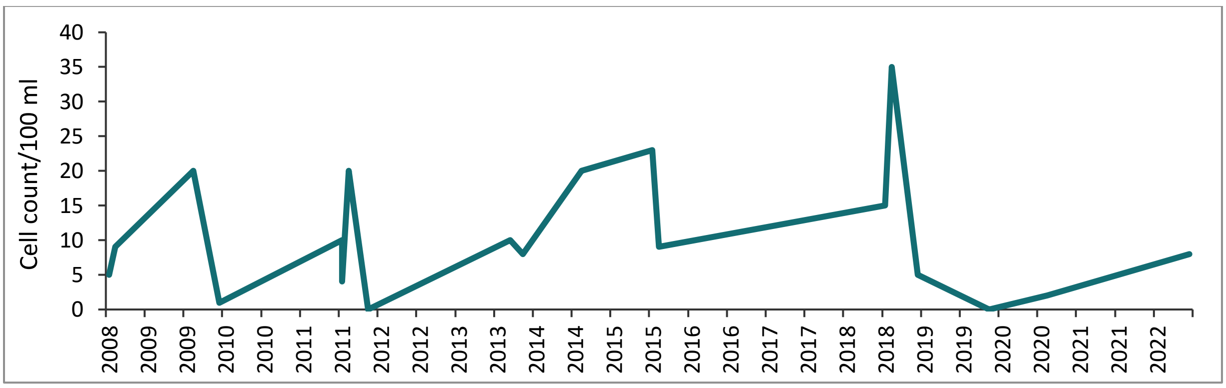


Figure 25. E. coli *numbers (count per 100 ml, y-axis) measured between Storefjorden and Vanemfjorden (station Van5) from 2008-2022.*

3.7 Inclusivity

The entire Morsa project is organized into a Water Board, consisting of representatives from the municipalities, county councils, county governors, and national directorates, with the intermunicipal drinking water association, Farmer's Organizations and other NGOs as observers. Thematic groups (agriculture, sewage, monitoring) meet regularly, exchange knowledge, and jointly apply for project funding, enabling consistent dialogue and mutual learning.

Nine municipalities cooperate to implement the necessary measures in order to improve the water quality and ecological status in Vansjø as well as the entire catchment. Co-creation and ownership is important in the Morsa working group. For example, when developing a stormwater management guide, municipalities were involved throughout the process via workshops and consultations, ensuring relevance and uptake.

Starting with education, information campaigns, farmers' meetings, field trips, agricultural advisory for environmental planning on individual farms, farms visits, ending with a system of legal contracts signed with individual farmers combing incentive measures (Skarbøvik & Bechmann, 2010). There are continuous efforts to engage farmers voluntarily, and they have been offered free consultancy on environmental planning since 2008. 75 % of farmers in the catchment draining to Vanemfjorden have signed comprehensive environmental contracts.

3.8 Recreation

The Norwegian Tourist Association (DNT) has its own local group covering the three municipalities around Vansjø, providing activities, maps, routes, cabins etc. in and around the lake (in addition to the rest of the area of these municipalities). The local (county) hunting- and fishing association (JFF) also provides licenses for hunting (ducks and geese) and fishing in Vansjø, and promotes activities connected to the lake. Together with municipalities, the two organizations arrange annual summer camps for kids (10-12 years) in the lake with financial support from the Morsa organization. The camps focus on nature and outdoor activities such as canoeing, fishing, camping etc, and attendance has been increasing each year.

As the lake has free access in all municipalities, the number of people involved in general recreation around the lake is difficult to estimate. The lake is very popular with summer camps, private cabins, beaches, marinas and hiking routes. Some of the hiking paths have been upgraded the past years, and are lit, and facilitated for wheelchairs and strollers. The lake is used all year round. In cold winters, the lake is popular for cross-country skiing and ice-skating, with its own ice-skating group arranging trips and providing information and training.

3.9 Sustainable Agriculture

The agricultural practices in the Morsa catchment are dominated by grain production, as seen in **Figure 26**. However, due to grants given to farmers and land owners, there was a large increase in grass covered areas between 1990 and 2020, including grass on flood-prone areas, grass covered buffer zones, and grass covered water ways. The increase was largest in the catchment of Vestre Vansjø (Vanemfjorden), and especially visible since 2008. In this area, there was also a reduction in areas with vegetable- and potato-crops, which in combination with increased grass covered areas reduces the risk of erosion and nutrient loss (Bechmann et al. 2022).

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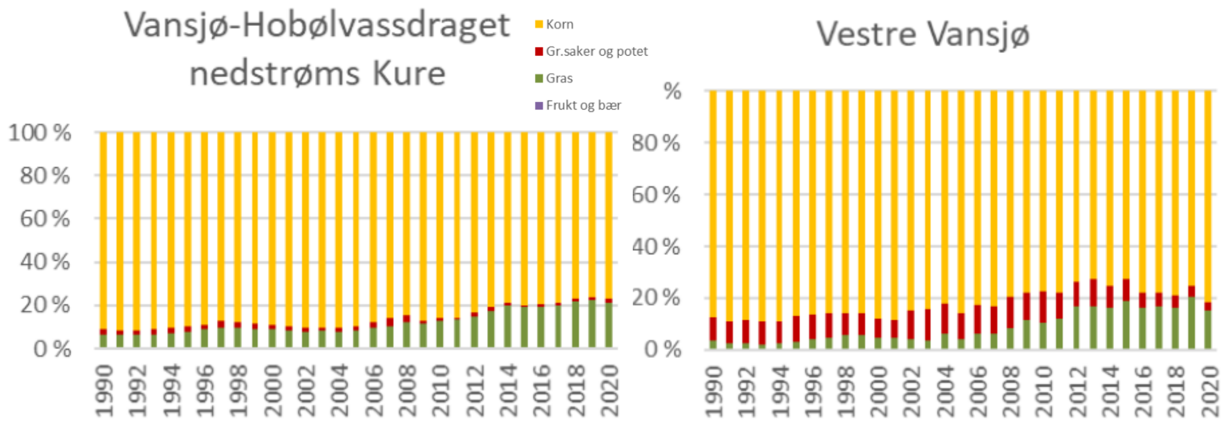

Figure 26. *Percentage of grain (yellow), vegetables and potato (red), grass (green) and fruits/berries (purple) in the catchments of Storefjorden (left) and Vanemfjorden (right) from 1990-2020 (Bechmann et al. 2022).*

The density of livestock in the Morsa catchment is very low, and not expected to have large influence on the water quality in Vansjø. There are some indications that the density of livestock has declined in the western part of Vansjø between 1999 and 2019, but not in any of the other areas around the lake (Bechmann et al. 2022).

As also described in section 2.3.1, there has been a large increase in the grain areas around Vansjø that are not tilled in the autumn, but instead overwintering with stubble. 80-90% of the grain areas around Van1 and Van2 had overwintering stubble around year 2010-11, which is an increase from 20-50 % in 2002. After 2013 the percentage declined again, but it has been stable at appr. 50-70 % since then (Bechmann et al. 2022). The large increase until 2013 was due to environmental agreements (as mentioned in 2.3.1) with requirements of 60 % overwintering stubble, a requirement which was removed in 2013.

There has been an increase in the use of catch crops in the Morsa catchment, with the largest increase occurring after 2013 and later. Catch crops reduces the nutrient losses outside the growth/production season, with especially nitrogen being stored in the crops. Loss of phosphorus is also reduced due to the soil not being tilled in the autumn, and because the catch crops covers the soil and protects against erosion. The use of catch crops has increased the recent years due to their positive effects on soil health and increased grants of subsidies (Bechmann et al. 2022).

3.10 Sustainable energy

The outlet from Vansjø into the Oslofjord goes through a small hydropower plant, utilizing a water fall of 22,4 m. The plant was established in 1986 and produces 13,00 GWh per year (with effect 3,1 MW, Hafslund 2025).

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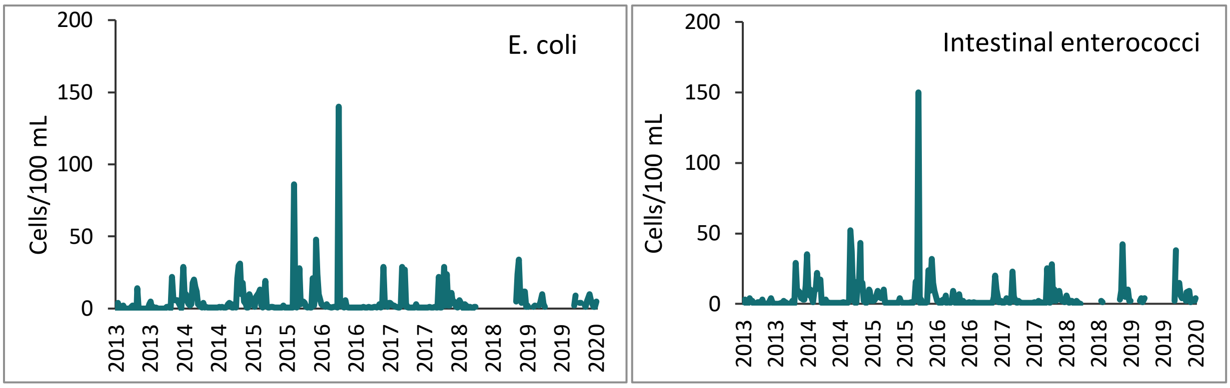
3.11 Sustainable Tourism

Vansjø is one of the most used freshwater localities in the county when it comes to sports- net- and commercial fishing. The lake is also used frequently for bathing, paddling and boating. Several venues are located close to the lake, offering accommodation, recreation and activities in and around the lake. The interest for commercial activities along the catchment and Vansjø is increasing (Kaabbel 2014).

3.12 Water supply & sanitation

Irrigation: Some of the catchments around Vansjø, and especially the lake itself are used for irrigation of e.g. vegetables.

Drinking water: Vansjø Waterworks is one of Norways most comprehensive treatment facilities, with several steps of treatment and disinfection of the raw water, supplying high quality drinking water. Despite the use of Vansjø as drinking water source, there is no restrictions on the use of the lake for protection of the source. The main intake is located in Storefjorden, at 12 and 25 m depth (25 m is mainly used), and is situated in the part of the lake which has the best water quality. Vansjø Waterworks sample weekly for microcystin analysis between from June through September. Microcystin has never been detected in the treated drinking water. Bacterial numbers in the raw water tested by the Waterwork has also been low during 2013-2020, as shown in **Figure 27**.



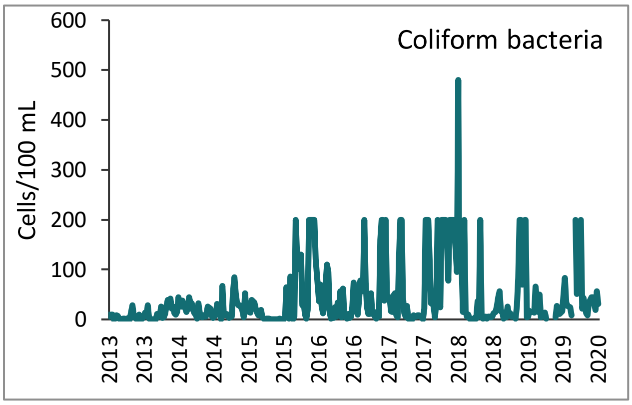


Figure 27. *Numbers of relevant bacteria analysed in the raw water of Vansjø Waterworks between 2013 and 2020 (movar.no).*

4 Summary of effectiveness of restoration programme

Knowledge-based management was put into practice early in the Morsa cooperation, hence the management and mitigation measures are based on both scientific and local knowledge based on experience. The first party-neutral mitigation analysis was conducted in 2001, and was the scientific foundation for political decision-making and plans of actions and mitigation measures. This analysis was decisive in order to gain accept and agreement on the mitigation measures that were implemented. An action-plan for restoration of Vansjø (western part) was approved by the municipal councils (2007) and therefore locally implemented.

A board (water basin team) was created, consisting of mayors from the catchment municipalities, representatives from the region, as well as professionals from municipalities and the county governor organized into thematic groups, which has been crucial for gaining trust and agreement on demanding and costly actions.

The municipalities have several of the necessary measures needed to e.g. reduce nutrient inputs, with local ownership and proximity to the residents, and are therefore the key actors for the implementation of mitigation measures. However, they do not possess all the necessary means, therefore it’s been crucial for the restoration of lake Vansjø that also the regional and national authorities actively participate. The Morsa group has good cooperation and dialogue with farmers and other users-interests.

The Morsa project has received funding from the Ministry of Agriculture to execute extra-ordinary agricultural environmental measures and to document the effects. Several fertilization experiments were conducted in cooperation with farmers.

Farmers have been offered free environmental consultancy, and they have been encouraged to voluntarily sign extensive and obligating environmental contracts, resulting in about 75 % of farmers in the Vanemfjorden catchment signing such contracts. Information campaigns and subsidies have increased farmers acceptance of legislative environmental claims, and the farmers’ willingness to change their practices, with or without economical gain, is important for the project’s success. Vansjø is also emotionally important for the people living close to the lake, and the fact that the farmers also use the lake and that recreational use (fishing, boating, bathing) had deteriorated due to the algal blooms, was an important driver for their involvement.

Yet, there are limitations in terms of conflicts of interest when it comes to balancing the environmental considerations with the farmers’ livelihood and national need for food production, e.g. with no tilling, which leads to reduced crops and harvest. Although dependent on the farmers’ willingness to participate, the implementation of measures are also been dependent on the establishment of regional or national legislation that promotes the necessary changes in practices.

For sewage treatment the upgrades of the sewerage system were paid for by the residents, either directly in case of private systems, or via their water- and sewage fees for public systems. This may also be creating conflict for the municipalities.

Following the implementation of many phosphorus reduction measures, the TP and chlorophyll-a concentrations declined towards WFD Good/Moderate boundary values and since 2009, the frequent, reoccurring blooms of cyanobacteria stopped. However, the lake has not yet reached Good ecological status after two decades of targeted mitigation measures to reduce nutrient loading, and cyanobacterial blooms still occur some years. Climate change seems to be one major factor counteracting the improvements achieved through mitigation measures. Increased precipitation is leading to even more floods and soil erosion, transporting soil and nutrients into the lake. In addition, Vansjø has become more humic, due to a combination of e.g. climate change, reduction of acid precipitation and changes in forestry. The reduction of sulfate is shown to reduce the concentration of aluminium in the catchment, which is then leading to less P being bound to Al, and also less P being deposited to the sediments and instead staying in the water column (forskning.no). Yet, studies show that without the implemented measures in the Vansjø catchment, the situation for the lake would be even worse than it is, with continued high inputs of nutrients (Vogt artikkel).

Also, reduced acid precipitation increases the pH of the soil, which leads to more leaking of organic (humic) matter containing nutrients into the rivers and lakes. The increase in water colour and organic carbon (browning) occurring in Vansjø over the past decades has led to a change in algal community composition and has also been a cause for the lower presence of cyanobacteria and increased presence of other algal groups and species, e.g. *Gonyostomum semen*. This species is rich in chlorophyll *a*, have large biovolume and often creates large biomasses that are not directly related to P-concentrations, which explains why the PTI values in Vansjø are not responding as positively to the reduction of P as hoped for.

Vansjø is also regulated in the outlet river for hydropower production. The current regulation regime involves high water levels during summer, which is creating stagnant conditions in parts of the lake for large parts of the summer season, increasing the risk for algal blooms (Kaabbel 2014)

The current key challenges in terms of eutrophication are therefore climate change, flooding, as well as nutrient loading. Climate change is expected to increase the eutrophication of Vansjø, however land use changes and management practices aimed at improving water quality, could still have an effect (Couture et al. 2013). The study of Couture et al. (2013) also showed that achieving the environmental goals for the western part of Vansjø, even without expected climate change, will be very difficult, but it is important to implement measures to reduce the effects of climate change (Kaabbel 2014).

A more recent development is the recognition that Lake Vansjø has been severely affected by pollution of certain per- and polyfluoroalkyl substances (PFAS). The main source of PFAS contamination has been identified as Rygge Airport, where PFOS (perfluorooctanesulfonic acid) was used in fire extinguisher foams. This led to substantial inflow of PFOS into the lake, resulting in concerning levels of the substance in sediments and biota. The Norwegian Food Safety Authority (Mattilsynet) has conducted assessments of PFAS content in fish from Lake Vansjø (2015, 2019) and now advises against consuming fish caught in the lake. The presence of PFAS in the lake ecosystem remains a long-term environmental issue of growing national and international concern that requires ongoing monitoring and management. The effect this has on recreation and fishing in Vansjø is not clear. However, a new working group is being formed to coordinate responses, emphasizing the strength of the organization to show flexibility and responsiveness, allowing the governance system to adapt to emerging challenges.

The way forward will be to develop even more targeted and innovative restoration measures to continue reducing nutrient loading to the lake, while also working on removing the PFOS pollutants.

5 Acknowledgements

We kindly acknowledge Peter Sjolte Ranke from BirdLife Norway for valuable input and feedback on this report.

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Funded by
the European Union