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Some Characteristics of the Vansjø-Hobøl (Morsa) Catchment

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Sammendrag:

Denne rapporten gir en oversikt over Vansjø-Hobølvassdragets nedbørfeltkarakteristika. Vassdraget kalles også for Morsavassdraget og er et av vassdragene i Norge som er best undersøkt mht. vannkjemi, både fordi det har vært et pilotvassdrag for gjennomføringen av Vanndirektivet i Norge, og fordi det har hatt betydelige eutrofiproblemer med oppblomstring av giftalger. Det har hittil ikke vært utgitt en samlet rapport om nedbørfeltets karakteristika på engelsk.

Summary:

This report gives an overview of some characteristics of the Vansjø-Hobøl (Morsa) catchment in Southern Norway. The catchment is one of the most studied catchments in Norway in terms of water quality, partly because it has been a pilot project for the implementation of the EU Water Framework Directive (WFD), partly because eutrophication and harmful algal blooms have been a problem in the latter years. Information from the catchment has until now been scattered in several different papers and reports, and most of these have been written in Norwegian.

Country/County:	Norway / Counties of Østfold and Akershus
Case:	Vansjø-Hobøl (Morsa)

Approved

Per Stålnacke
Head of Research

Project leader

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Preface

This report originated as a delivery to the EU FP7 ‘Refresh Project’ (the project’s full project title is ‘Adaptive strategies to mitigate the impacts of climate change on European ecosystems’). The Refresh Project is lead by the University College London, and comprises altogether seven work packages (WPs). For one of these work packages, WP 6, a catchment description was required. During the work of assembling the necessary information it became clear that the general information on the catchment was scattered in several reports and papers, and little of this was written in English. The authors therefore decided to expand the report made for the Refresh Project in order to arrive at an English report with updated information on the catchment.

Eva Skarbøvik has had the overall responsibility for the report and its content, whereas Marianne Bechmann has been responsible for the text on mitigation measures.

The Vansjø-Hobøl (Morsa) Catchment has been and is presently a case study for several research projects, including the EU funded projects EuroHarp (finalised in 2007) and Refresh (2010-2013), and research projects funded by the Research Council of Norway such as SeaLink (lead by NIVA) and Eutropia (lead by the University of Oslo). Several other projects are also on-going in the area, mainly funded by the Norwegian Climate and Pollution Agency and organised through the Morsa River Basin District Organisation. These include monitoring of lakes and tributaries, assessments of environmental state, evaluation of abatement measures, as well as projects involving contracts with farmers in order to ensure more environmental farming practices. These projects are usually reported in Norwegian through the reports of the research institutions or consultancy companies that perform the investigations.

Our hope is that this report may serve as a common reference for on-going and future research projects on the catchment.

Per Stålnacke, Bioforsk, has been responsible for the quality assurance of the report according to Bioforsk’s QA procedures. Helga Gunnardsdottir, leader of the Morsa River Basin District Organisation, has ensured that the facts given in this report is correct according to current knowledge. Both are thanked for their efforts.

Ås, October 2010

Eva Skarbøvik
Project leader

Contents

Names and abbreviations

Bioforsk – the Norwegian Institute for Agricultural and Environmental Research.

DPSIR – a framework used to assess and manage environmental problems. DPSIR = Driving forces-Pressures-State-Impacts-Responses.

EuroHarp – EU FP5 Research project lead by NIVA, finalised in 2007. Full title: ‘Towards European Harmonised Procedures for Quantification of Nutrient Losses from Diffuse Sources’. Morsa was used as a case for modelling purposes.

Eutropia – Research project lead by the University of Oslo on eutrophication problems in catchments. Financed by the Research Council of Norway. (Norwegian original full title: ‘Nedbørfeltsorientert forvaltning av eutrofieringsproblemer’) Morsa is used as a case for modelling purposes.

GLB. Glommens and Laagens Brukseierforening. Performs the hydrological analyses used to operate the hydropower plant at Moss Dam.

Glomma River Basin Authority: River Basin Authority (in accordance with the WFD) for the entire Glomma Catchment, including the cacthment of Morsa.

Greppерødfjorden. A narrow lake basin in Lake Vansjø, that is located between the two main lake basins.

Hobølelva, **River**. Main river of the catchment. 333 km^2.

Hydrological stations. The most important include: Water discharge: Høgfoss in River Hobølelva (since 1976/77); Moss Dam in River Mosseelva; Guthus Creek. Water level: Rødsund Bridge in Lake Vansjø.

Høgfoss. Waterfall in River Hobølelva. Hydrological water gauge with data since 1976/77.

KLIF – the Norwegian Climate and Pollution Agency.

Kure. Waterfall in River Hobølelva where the main monitoring station for water quality is located. Water quality data since 1986.

Morsa. Used as a name for the River Basin District Organisation, and as a name to describe the entire catchment. The name ‘Morsa’ is derived from the old name of the catchment. See also ‘Vansjø-Hobøl’.

Morsa Project. 1999-2007. Initiative between the local counties, regional authorities and stakeholder interests; its main objective was to improve the water quality of the catchment. Re-organised into the Morsa River Basin District Organisation in 2007 (see this).

Morsa River Basin District Organisation. Re-organised from the Morsa Project (see this) in 2007, as a district organisation under the Glomma River Basin Authority. Organisation linked to the implementation of the WFD in Norway. The duration is set to 2012, with possible continuation.

Moss – the main city in the catchment, located at its outlet in the Oslo Fjord.

Mosseelva, River. The outlet river of the catchment. Drains into the Oslo Fjord at the city of Moss.

Mosseros. The delta of River Hobølelva in Lake Vansjø (eastern basin).

MOVAR. Inter-municipal water system company, Serves about 60,000 people. Observer status in the Morsa River Basin District Organisation.

NIVA – the Norwegian Institute for Water Research.

Norwegian Food Safety Authority. Member of the board of the Morsa River Basin District Organisation.

NVE - Norwegian Water Resources and Energy Directorate. Member of the board of the Morsa River Basin District Organisation.

Peterson Linerboards – cornerstone factory at Moss, producing paper.

Refresh. EU FP7 Project (full title: 'Adaptive strategies to mitigate the impacts of climate change on European ecosystems'). Lead by the University College London. Uses Morsa as a case, amongst others for stakeholder involvement activities.

Regine. Norwegian system for registering rivers. www.nve.no

SeaLink. Research project financed by the Research Council of Norway. Lead by NIVA. Uses Morsa as a case for modelling purposes.

Skuterud. Adjacent catchment to Morsa, and one of Bioforsk's small research catchments. Often used as a case together with Morsa in different research projects.

Smaller lakes. Smaller lakes in the catchment comprise lakes Sæbyvannet, Mjær, Våg, Langen, Bindingsvannet, and Sætertjern.

Storefjorden. Name of the eastern basin of Lake Vansjø.

Sundet. A strait between the eastern and western basins of Lake Vansjø.

Vansjø. Lake. Main water body of the Vansjø-Hobøl (Morsa) catchment. Surface area of 36 km^2; 25 m asl.

Vansjø-Hobøl. Used as a name to describe the entire catchment. Is derived from the main lake (Vansjø) and main river (Hobøl). See also 'Morsa'.

Vansjø landowner organisation. NGO. Observer status in the Morsa River Basin District Organisation.

Western Vansjø. Lake system that comprises Vanemfjorden (western basin) and River Mosseelva.

Western basin. Used in this report to denominate Vanemfjorden. See also 'Western Vansjø'.

WFD: EU Water Framework Directive.

Østfold Nature Conservation Society. NGO. Observer status in the Morsa River Basin District Organisation.

1. Introduction

The Vansjø-Hobøl or Morsa Catchment is an important catchment for many reasons. It is one of the catchments in Norway most affected by agricultural runoff and therefore also eutrophication and harmful algal blooms; it has been a pilot catchment in the implementation of the EU Water Framework Directive (WFD); and it has a number of different user interests (Figure 1).

The official name of the catchment is either Vansjø-Hobøl or Morsa. The first refers to the largest lake and river in the catchment, i.e. Lake Vansjø and River Hobølelva. The second name was used in former years, and is now used as a name for the River Basin District Organisation. Both names are used to describe the entire catchment.

Projects in this catchment have included several monitoring programmes, abatement analyses, trend analyses, as well as projects wherein farmers have been contracted to implement more environmentally-friendly farming practices. Due to the relatively extensive data coverage of this catchment, modellers have used it to test out different types of models. The EU FP5 Project EUROHARP published the results from different models in the Morsa catchment in several papers in the Journal of Environmental Monitoring (no. 11, 2009). A new model to assess the impacts of different abatement measures has also been applied (AGRICAT; Øygarden et al. 2010). This report will not give any overview of models used in the catchment,but will concentrate on giving English spoken readers an overview of the catchment characteristics. In spite of all the reports from the catchment, only a few international papers exist apart from the aforementioned special issue from the EuroHarp Project. These include Stokke 2006 and Øgaard and Bechmann 2010. The information on this catchment in the English language is, therefore, limited.

Figure 1. *Lake Vansjø has many user interests - the lake is amongst others used for boating and recreation. Harmful algal blooms the latter years have resulted in less attractive conditions, as in 2005 when this photo was taken from the River Mosseelva. Photo: Eva Skarbøvik.*

2. Biophysical features of the catchment

2.1 Catchment Size and Main Water Bodies

The Vansjø-Hobøl catchment (Figure 2) covers about 690 km^2. The catchment is located in South-Eastern Norway and drains into the Oslo Fjord, south of the capital Oslo. Rivers in Norway are numbered according to the so-called Regine River System (www.nve.no) and this river is the third to enter the sea from the Norwegian-Swedish border in the south, after the rivers of Haldenvassdraget and Glomma.

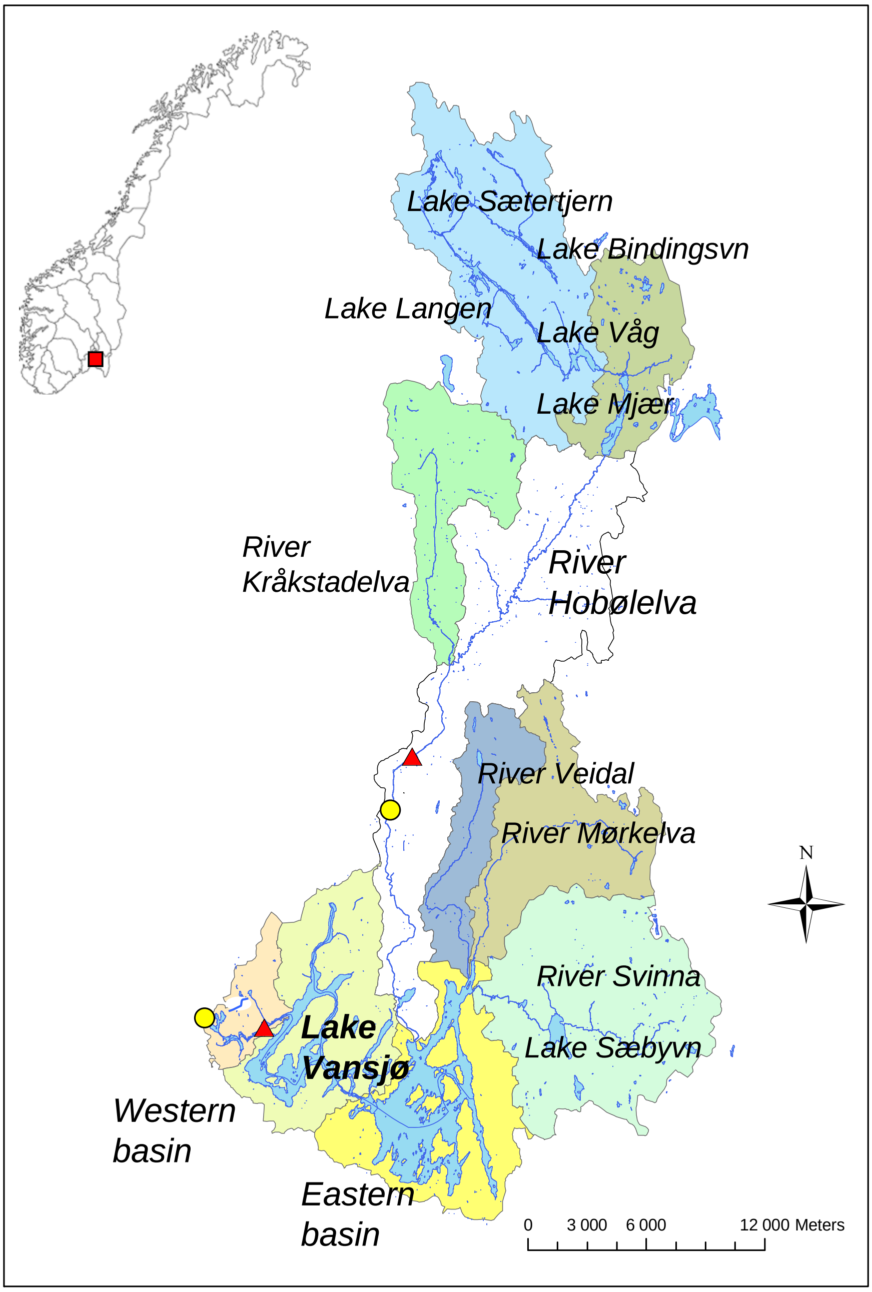


Figure 2. *The Vansjø-Hobøl Catchment with sub-catchments and lakes.*

The main lake system is Lake Vansjø (25 m asl; with a surface area of 36 km^2). The lake consists of several sub-basins; the two main basins are called Storefjorden (eastern basin) and Vanemfjorden (western basin). The outlet river is River Mosseelva. Due to a dam at Moss, there is at times no water discharge in River Mosseelva. The strait between the two main lake basins is usually referred to as Sundet. The area from Sundet to the outlet at Moss is often referred to as Western Vansjø; this area then comprises Vanemfjorden and Mosseelva. A narrow lake basin lies between the two main basins, this is called Grepperødfjorden.

Lake Vansjø is a relatively shallow lake for Norwegian conditions; its main morphometric features are given in Table 1 whereas a bathymetric map of the lake is shown in Figure 3.

Table 1. *Morphometric data for Lake Vansjø (from Skarbøvik et al. 2010).*

	Lake Vansjø	Vanemfjorden (Western basin)	Storefjorden (Eastern basin)
Mean depth (m)	7.0	3.8	8.7
Maximum depth (m)	41.0	19.0	41.0
Surface area (km^2) at 25.5 masl	35.8	12.0	23.8
Volume (10^6 m^3) at 25.5 masl	252.2	46.1	206.1
Water residence time (years)		0.21	0.85

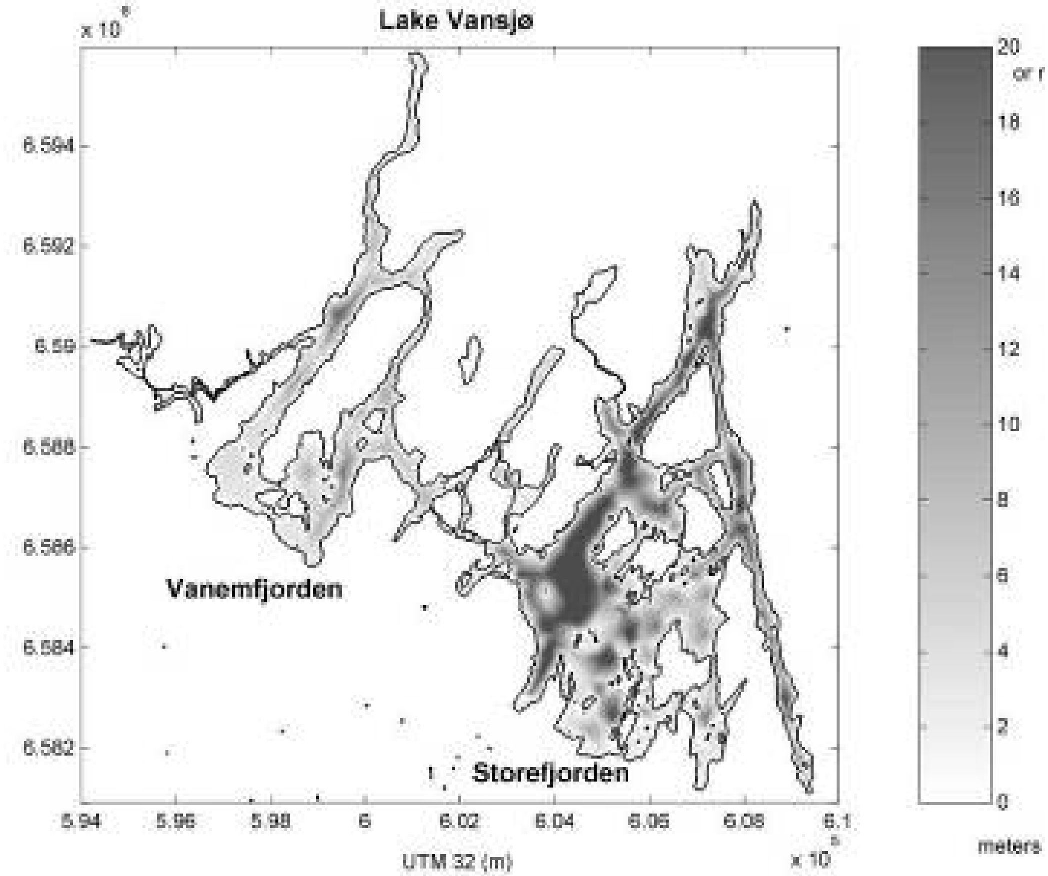


***Figure 3**. Bathymetric map of Lake Vansjø. Source: NIVA.*

There are also several smaller lakes in the catchment, such as Sæbyvannet, Mjær, Våg, Langen, Bindingsvannet, and Sætertjern. Characteristics of these lakes are given in Table 2.

Table 2. *Morphometric data for six smaller lakes in the catchment (from Skarbøvik et al. 2010).*

Lake	Surface area (km^2)	Mean depth (m)
Sætertjernet	0.1	7.2
Bindingsvannet	0.62	
Langen	1.49	6
Våg	0.92	
Mjær	1.67	6.5
Sæbyvannet	1.7	7.8

The main river in this catchment starts in the northern part of the drainage area and runs through forested areas. Downstream of Lake Mjær (Figure 4) the river is called the Hobølelva River. Downstream of Lake Mjær large parts of the catchment area is used for agriculture, and River Hobølelva is here meandering through clay-rich soils. In addition to agricultural runoff, the erosion of the river banks results in a marked increase in both suspended sediment and nutrient loads (the marine clay is rich in the phosphorus-rich mineral apatite). The tributary River Kråkstadelva joins the main river some 12 km downstream of Mjær. River Kråkstadelva is also draining agricultural fields and its waters carries sediments and nutrients that are added to the main river. River Hobølelva then runs through two waterfalls, one at Høgfoss where there is a mill and a hydrological water gauge, and one at Kure where there is a monitoring station for water quality. River Hobølelva drains into Lake Vansjø at a delta and wetland area called Mosseros.

The largest tributary to Lake Vansjø is, thus, River Hobølelva, with a catchment area of about 331 km^2. Smaller tributaries include Rivers Svinna, Veidalselva and Mørkelva; all of these drain into the eastern lake basin, Storefjorden. In addition, several smaller creeks drain directly into Lake Vansjø, both to the eastern basin and to western Vansjø.

The area distribution of the different sub-catchments in the Vansjø-Hobøl Catchment is given in Table 3. Due to many different estimates of sub-catchment areas in different reports, a major revision of the exact areas of the sub-catchments was done in 2009 (Blankenberg et al. 2008); Table 3 therefore reflects the latest calculated sub-catchment areas.

In total about 15 % of the entire catchment area is covered by agricultural land, about 7 % is covered by water bodies, and the remaining 78% is mainly covered by forest. There are only two larger settlements; Ski in the upstream parts and the city of Moss at the outlet of the catchment.

Table 3. Division of the catchment into sub-catchments (source: Blankenberg et al. 2008).

Sub-catchment	Total area km^2	Agricultural area km^2
Upstream of Tangenelva	105.4	2.6
From Tangenelva to the outlet of Lake Mjær	41.2	4.6
River Kråkstadelva	51.3	22
River Hobølelva (entire river catchment)	333.0	36
River Veidalselva	33.3	4.1
River Mørkelva	61.2	5.6
River Svinna	103.1	12
Catchment areas of smaller creeks draining to Storefjorden (eastern basin)	73.8	
Entire catchment upstream of 'Sundet' – the divide between the Eastern and Western basins of Lake Vansjø	604	4.3
Vanemfjorden (western basin)	67.6	11
River Mosseelva	16.3	0.5
The entire drainage area of the Vansjø-Hobøl	688	103

Figure 4. *Two of the upstream lakes, Lake Mjær (left; photo E. Skarbøvik) and Lake Våg (right, photo: NIVA).*

2.2 Hydrology and meteorology

The main hydrological stations at present include Høgfoss in River Hobølelva and Moss Dam in River Mosseelva for water discharges; and Rødsund Bridge in Vansjø for water levels. A hydrological station has also been installed in the Guthus Creek (Figure 5). The annual runoff at Høgfoss and Moss Dam are shown in Table 4, together with calculated runoff from the rest of the catchment area.

Table 4. *Annual runoff based on discharge data from 1961-1990 (30 years) and 1977-2002 (26 years) (from Skarbøvik et al. 2005).*

		1961-1990		**1977-2002**	
Catchment	**Area km^2**	**m^3/s**	**l/s*km^2**	**m^3/s**	**l/s*km^2**
Upstream of Moss Dam	688	11.4	16.6	11.2	16.2
Upstream of Høgfoss (River Hobøl)	300	5.4	18.0	4.5	14.8
Remaining local catchments	388	6.0	15.5	6.7	17.3

The discharge at River Hobølelva (at the Høgfoss station) comprises about 40 % of the total water discharge into Lake Vansjø. The total input of water to Lake Vansjø has also been calculated per month, based on data from 1977-2003, cf. Table 5.

Mean annual air temperature is 5.6^{o}C and the annual precipitation is about 829 mm, as measured at Rygge meteorological station (1961 – 1990). (Skarbøvik et al. 2007a)

Figure 5. *In addition to a hydrological station in River Hobølelva at Høgfoss, there is a water discharge station at Moss Dam (above) and a hydrological station has recently been installed in the Guthus Creek (left). There are also water level gauges in the lakes, in Lake Vansjø at Rødsund Bridge. Photos: E. Skarbøvik.*

Table 5. *Calculated monthly average, maximum and minimum water discharges into Lake Vansjø, based on the period 1977-2003, all values in m^3/s. From Skarbøvik et al. 2005.*

Period	**Mean** m^3/s	**Max** m^3/s	**Min** m^3/s
Jan	9.89	31.35	1.44
Feb	7.17	46.32	0.65
Mar	10.92	28.87	0.59
Apr	25.34	48.51	4.67
May	12.17	29.99	2.35
Jun	5.65	16.79	0.37
Jul	4.13	13.97	0.17
Aug	4.29	19.21	0.22
Sep	6.76	26.57	0.48
Oct	15.83	50.46	1.29
Nov	18.50	78.01	5.26
Dec	12.67	35.60	2.71
Total	11.12	18.83	5.92

2.3 Geology and relief

The highest point of the catchment area is about 346 m asl, whereas the lowest is at 0 m asl, since the river system drains into the Oslo Fjord. A topographic map is given in Figure 6.

The bedrock of the northern forested areas is mainly Pre-Cambrian bedrock with predominantly gneiss (Dons 1977). Relatively thin moraine layers give poor soil quality for agriculture, but further downstream in the catchment the soil becomes rich in silt and clay minerals. This is because this area was submerged under the sea during the Quaternary period. When the great inland glacier melted, the land rose from the sea and the marine clay deposits became the most fertile soils in Norway.

In the very south of the catchment, a huge end moraine is effectively damming the lake, and is the reason why the catchment drains to the west and not to the south. This end moraine runs along parts of the Norwegian coastline, and was caused by a colder period when the retreating ice front was stagnant for a long time. The Lake Vansjø basin therefore has a very characteristic form, with several basins and bays, which is rather unusual for Norwegian lakes.

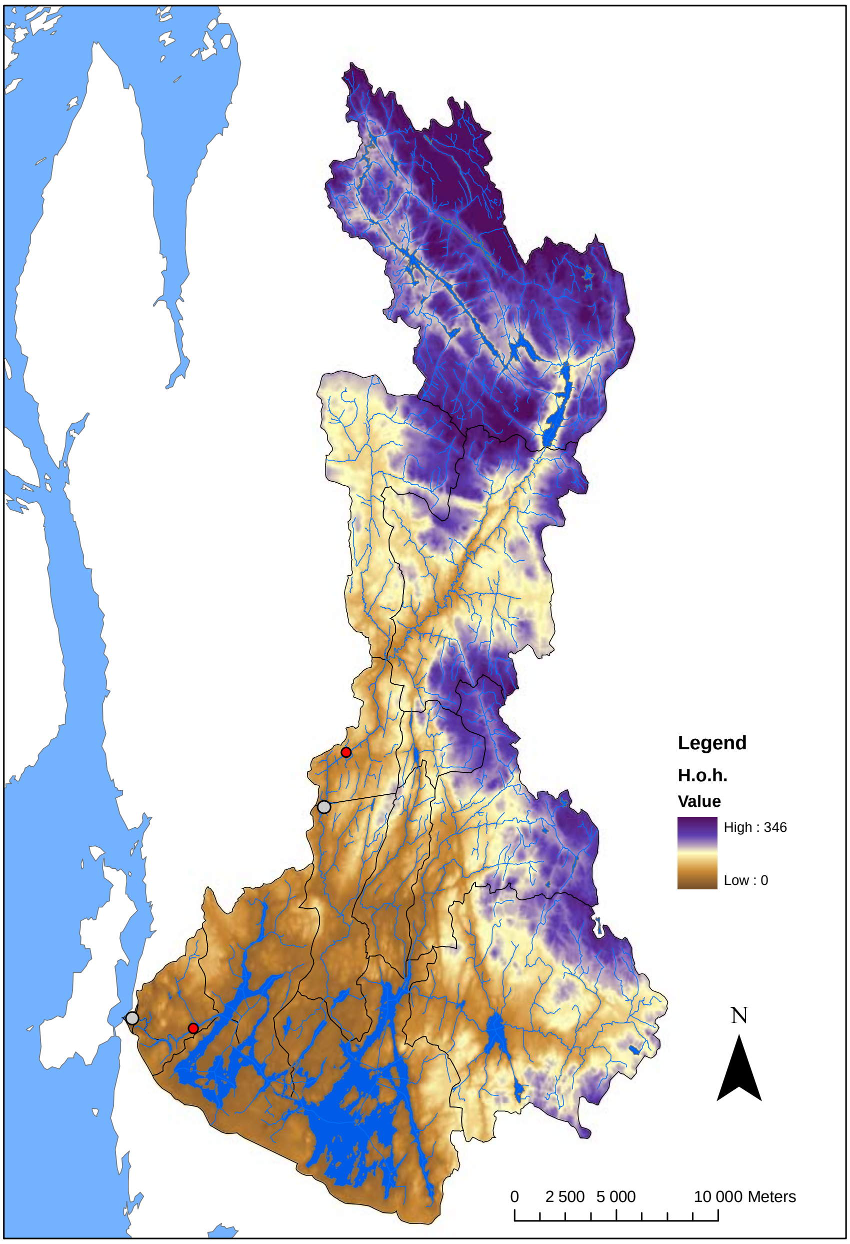


Figure 6. *The topography of the Vansjø-Hobøl Catchment (with height above sea level). (Source: Skarbøvik et al. 2007a)*

2.4 Soils

The soils in the catchment are closely linked to the geological history described above. Thus, in the forested areas the soils are predominantly coarse moraine whereas in the southern areas soils are dominated by marine deposits and are as such rich in clay. In the agricultural areas, therefore, the soils have up to 80 % clay, the rest silt and sand.

3. Land use in the catchment

3.1 History of human exploitation

The first people moved into the lower part of the catchment more than 4000 years ago (Martinsen 2007). In the uppermost part of the catchment there are artefacts from shortly after the end of the ice age. The early settlers sustained a living from hunting and fishing both in the stone- and bronze ages, and several burial mounds has been found from the bronze ages. In the early middle ages the number of farms increased, and several places are still today named from this period: Names ending in '-rød' mean 'forest clearance' i.e., an area where the forest was cleared in order to cultivate the soil. During the period 1000-1400 AD there seems to have been an increase in the number of inhabitants. When logging became a trade around 1400 AD, the population grew further. Since then, farming and forestry have been the main income sources in the major part of the catchment. Farmers produced coal from the forest and ice from the lake; this ice was said to be so pure that it was shipped to the royal courts in Europe (Martinsen 2007). In the latter years, the natural resources of the area have also sustained an increasing number of cottages around Lake Vansjø, with subsequent boating, fishing and hunting for recreation purposes; although this is local tourism and no major hotels or lodgings are located within the catchment.

At the outlet of the river to the sea (Moss), a major ironworks started in 1704, based on the rich timber resources, the waterfall at Moss and the coal produced by the farmers of the region. The works was the largest employer in the region for more than 150 years (Martinsen 2007). From 1801 onwards, a trading company flourished at Moss. In 1848 the company started in shipping, and in 1883 the company bought the ironworks. In 1898 the industry moved on to paper production, and today the company, presently named *Peterson Linerboard*, is the cornerstone factory of the township of Moss.

In the catchment of Lake Vansjø, agricultural practices have changed over time, which means that the choice of crops and the degree of intensified agriculture has changed. In the adjacent catchment, *Skuterud*, which is one of Bioforsk's small research catchments, detailed land use practices have been recorded since the early 90ies. These records include documentation of the use of fertilisers, of which crops have been cultivated each year, of the tilling practices, etc. To some extent these data can also give information on the changing practices in the Vansjø-Hobøl Catchment the two last decades.

3.2 Agricultural tenure and use

About 15 % of the catchment area is agricultural land (Figure 7). This is not much in a European context, but the catchment is one of the most cultivated areas in Norway. It should be borne in mind that for Norway as a whole, only 3% of the land is covered by agriculture.

For many years, Norwegian policy has been to enhance cereal production in this part of Norway, due to its good soils. There is therefore low livestock-production in the area. Some few farms have cattle, some chicken farms exist, and otherwise the main agricultural activities concentrate around the cereal production. In the southern parts around the western basin, potato and vegetable production covers a relatively large area. Table 6 shows the different types of agriculture in the rivers draining to the eastern basin of Lake Vansjø. Cereals and grass are the most important produce in this part of the basin.

Table 6. *Distribution of agricultural activities in the eastern parts of the catchment (from Skarbøvik et al. 2007a). Note that the area estimates here are based on the old calculations of the catchment area.*

Rivers	unit	Area	Water	Forest	Grass	Cereals	Potato	Vege-tables
Hobøl	km^2	337	16	265	4.08	50.6	0.007	0.58
	%	100	4.7	79	1.21	15.0	0.002	0.17
Veidal	km^2	32	0.9	27.9	0.48	3.3	0.000	0.00
	%	100	2.8	85.6	1.48	10.2	0.000	0.00
Svinna	km^2	104	4.2	87.7	1.65	10.6	0.001	0.07
	%	100	4.0	84.2	1.58	10.2	0.001	0.07
Mørkelva	km^2	59	2.6	52.5	0.19	3.7	0.000	0.05
	%	100	4.5	88.8	0.31	6.3	0.000	0.09

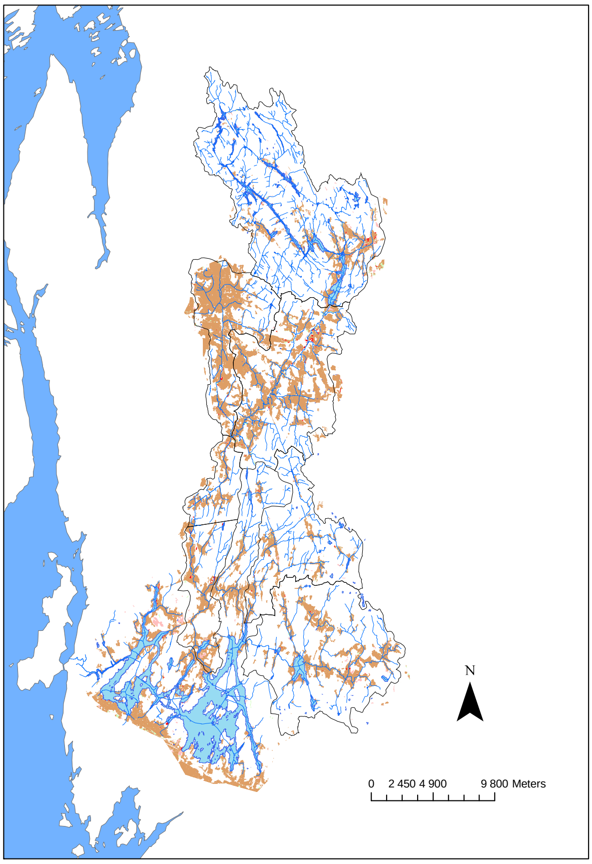


Figure 7. *Distribution of agricultural areas in the Vansjø-Hobøl Catchment (modified from Skarbøvik et al. 2007a).*

3.3 Forest tenure and use

Timber has been a major source of income in this area (Martinsen 2007). Before 1500 the Catholic Church owned large parts of the land and forest in this area. Around 1600-1700, the ownership was transferred to the richest farms (so-called ‘herregårder’). After 1814 their power diminished and the ownership of the forest was distributed to several farmers, including smaller livings.

Timber was transported through the rivers to Moss, where it was shipped out to different ports in Europe. Floating of timber ceased in the 1930ies.

There is presently little information on forestry in the catchment. The River Basin District Authority for Morsa has issued a brochure on forestry and water management. This is only meant as guidance on management of water, forestry and the environment, and does not give information on present practices in the watershed.

3.4 Settlement patterns, population, livelihoods and industrial activity

About 40.000 inhabitants live within the catchment area. The only townships are Ski in the upper part and Moss at the outlet; otherwise the settlements are mainly farms, some smaller communities and cottages. Industry is concentrated to the area around Moss. In the very south, the airport at Rygge is located at the catchment border.

3.5 Anthropogenic influences in the river system

River Hobølelva has several old dams; the largest are located at Høgfoss (where the hydrological water gauge is) and at Kure (where the main water quality station of the river is located). These dams have not lead to any upstream reservoirs, although the river just upstream flows more slowly due to the dams. Downstream of the dams are waterfalls that would have been present regardless of the dams. The dams are old and were made for the purpose of grain mills. A mill is still in operation at Høgfoss, whereas the mill at Kure has long been removed.

River Mosseelva is dammed before its outlet to the Oslo Fjord. The waterfall from the dam to the sea is presently utilised for hydropower.

Some erosion protection works are presently ongoing in Hobølelva downstream of Lake Mjær (Figure 8).

Figure 8. *The erosion in River Hobølelva is rather large (left) and erosion protection works have therefore been implemented in 2010 (right). Photos: E. Skarbøvik.*

3.6 Other land uses, including nature conservation, hunting etc.

Fishing and hunting for recreational use is common in the catchment.

Two nature reserves exist in Lake Vansjø (www.moss.kommune.no). One of them is located in the western basin (about 3300 daa) in the municipalities of Moss and Rygge; the other at Moaskjæra/Danskebukta (about 1000 daa) in the municipality of Råde. The objective of both reserves is to preserve important wetland areas.

The catchment was in 1973 protected against any further hydropower developments (St.prp. 1973; Fylkesmannen i Østfold 1999).

4. Factors affecting water quality and quantity

4.1 Factors affecting water quality

The main challenge in this catchment in terms of water quality is eutrophication caused by excess loading of nutrients.

Since the first river basin abatement analysis (Lyche Solheim et al. 2001), newer calculations have been done on the sources of total phosphorus in the catchment (Blankenberg et al. 2008, Øygarden et al. 2010). These now include natural runoff (5.1 tons TP/yr); agriculture (6.3 tons TP/yr); small sewage water treatment facilities (1.0 tons TP/yr); and municipal sewage water treatment plants (0.6 tons TP/yr). This would give a total phosphorus loading of about 13 tons of TP per year. It should be noted that this figure is based on theoretical figures and not measurement data. Figure 9 shows the relative distribution in percentages.

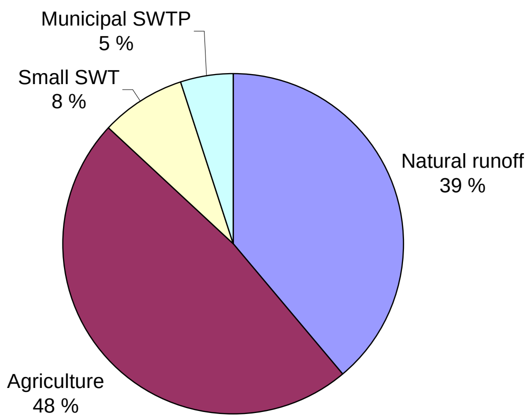


Figure 9. *Distribution of total phosphorus sources in the catchment (%). Based on data from Blankenberg et al. 2008.*

The main sources of diffuse nutrient runoff in the catchment include natural runoff, agricultural runoff from fields and sewage from scattered dwellings. About 2 300 sewage treatment plants for low density habitation has been said to exist (Stokke 2006). Forestry runoff may comprise a third source, but little is known on this.

Diffuse pollution usually increases in years with heavy rains and high water discharges. In the last years, clay avalanches have contributed significantly to increased suspended sediments and phosphorus in the river system (Figure 10).

Sewage treatment plants (4-5 larger) are believed to be the main point pollution sources in the catchment. During the flood in 2000, sewage pumps and pipes overflowed, this is believed to be one of the reasons for the subsequent years with toxic algal blooms, although it has not been scientifically proved.

__Figure 10.__ A clay avalanche in 2008 removed soil from a field and into River Hobølelva, not far from its outlet in Lake Vansjø's eastern basin. Photo: E. Skarbøvik.

4.2 Factors affecting water quantity

An overview of water use in the catchment is given in Table 7. The data are from 1998 but are still believed to be valid today. As shown, some water is used for irrigation during summer months. Other demands for water include drinking water (extracted from the eastern basin of Lake Vansjø); cooling water for the industry in Moss (Peterson Linerboard); and hydropower exploitation in Moss. The two latter activities will not extract water permanently from the system, but both activities put demands on water levels of the lake. The cooling water for the industry requires a minimum water level at the intake near Moss Dam, and it is therefore necessary that the operation of the hydropower plant takes this into account.

***Table 7.** Water extraction from the Vansjø system in 1998. From Skarbøvik et al. 2005.*

Water use	Extracted from	Amount
Drinking water supply (MOVAR)	Storefjorden	0.25 m^3/s
Peterson Linerboard AS (industrial water use)	Mosseelva	0.54 m^3/s
Hydropower (owned by the municipality of Moss)	Mosseelva	1 m^3/s
Irrigation (during 4 summer months)	Vansjø	0.35 m^3/s
Release of water in Lille Creek (minimum water flow according to concession)	Mosseelva	0.1 m^3/s

A certain water level is also required by the local boating clubs, since there are many submerged islands in the lake and the boats can capsize if the water level drops too low.

Floods may cause a problem in spring if agricultural fields are flooded, as farmers are inhibited from working on the land. Furthermore, floods both during spring and autumn/winter will lead to increased loadings of nutrients to the lake systems.

Environmental concerns in terms of algal blooms have lead to questions as to whether or not a change in the operation regulations of Moss dam could improve the water quality of the lake. Temporary permission to change the operation routines were given by NVE (the Norwegian Water Resources and Energy Directorate) in order to be able to carry out investigations. The results are presented in several reports (Skarbøvik et al. 2005, 2006, 2007b, Skarbøvik 2008, Skarbøvik and Rohrlack 2009); a final report will be produced in 2011. The two main options are to keep water levels as high as possible during summertime in order to dilute the nutrients as much as possible; or to maintain a stream of water through the dam at Moss. The latter seems to be beneficial for the water quality in the lower parts of the catchment, based on preliminary results from the investigations. Figure 11 shows Moss dam during a relatively substantial release of water from Lake Vansjø in 2005; the release was followed up with investigations on water quality before and after.

Figure 11. *The dam at Moss in 2005, during an experiment where water was released from the dam in order to assess impacts on lake water quality. Photo: E. Skarbøvik.*

4.3 Biodiversity issues

Lake Vansjø's many basins and bays, with both deep pelagic waters and shallow wetlands, provide a rich variety of habitats for both fish, birds and mammals. Also some of the meandering stretches of the rivers give suitable habitats for many different species. The lake is one of the most species-rich lakes in Norway in terms of fish, with 17 different species (Martinsen 2007). There are also several bird species and mammals in the catchment (moose, deer, beaver, fox, etc).

5. Water quality status

In the latter years, annual reports have been produced that show the nutrient and sediment loadings to the lake as well as lake nutrient and chlorophyll a levels (e.g. Bjørndalen et al. 2006, 2007, Hobæk et al. 2009, Skarbøvik et al. 2007a, 2008, 2009, 2010). In 2010, a classification of several water bodies within the catchment is being carried out by NIVA (Lyche Solheim et al. in prep).

5.1 Monitoring stations for water quality

The number of stations where water quality is monitored varies somewhat from year to year, but in Figure 12 the stations monitored in rivers in 2009 are shown; whereas the stations in Lake Vansjø in 2009 are given in Figure 13. In addition, lakes Bindingsvann, Sætertjern, Langen, Våg, Mjær and Sæbyvann were monitored that year.

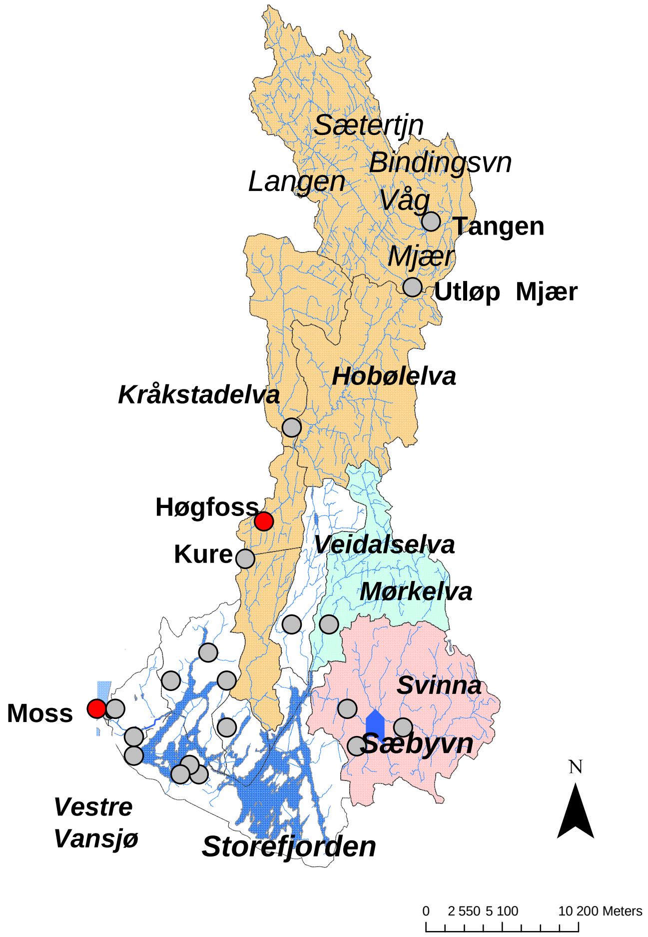


Figure 12. *Monitoring stations for water quality in rivers in the Vansjø-Hobøl catchment in 2009 (grey dots). Red dots show two of the water discharge stations, at Høgfoss and Moss dam.*

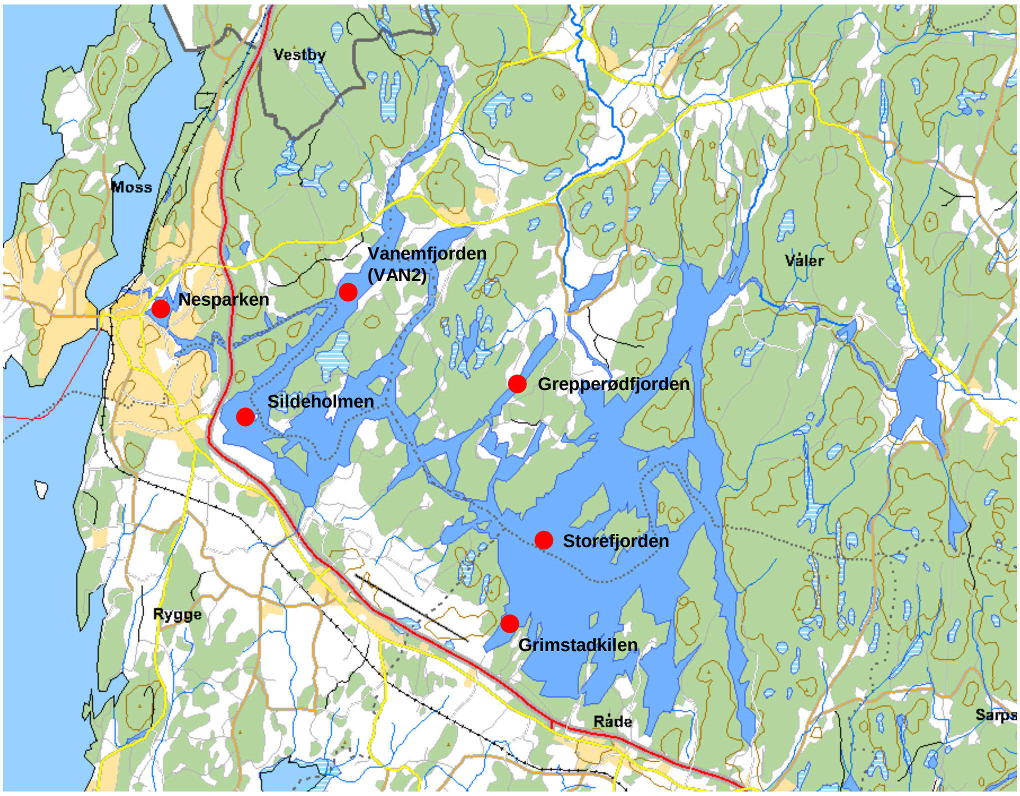


Figure 13. *Monitoring stations for water quality in Lake Vansjø in 2009. In addition to written reports, water quality data are also given online by NIVA. (From Skarbøvik et al. 2010).*

In addition, biological investigations in accordance with the WFD are undertaken in the catchment, but the authors have at present no thorough overview of these.

5.2 Concentrations of nutrients in rivers and creeks in 2008/2009

Average concentrations of sediments, nutrients and bacteria are shown in Table 8. The variations are relatively large from station to station. In the creeks, total phosphorus (TP) concentrations are especially high in the Støa and Huggenes Creeks; whereas the rivers with the highest TP levels are River Kråkstadelva and River Veidalselva. Total nitrogen levels are usually high at stations that also have high TP levels. Coliform bacteria are most abundant in River Hobølelva at Kure (Figure 14), in River Kråkstadelva, and in the creeks Ørejordet, Årvold and Guthus.

Table 8. *Average concentrations for tributaries to Lake Vansjø in the monitoring period 16 October 2008 – 15 October 2009. From Skarbøvik et al. 2010.*

Station	Q	STS	Tot-P	Tot-N	PO_4-P	E-coli 90%-percentile
	m^3/s	mg/l	µg/l	µg/l	µg/l	No/100ml
Upstream Lake Mjær	2.2	4	14	444	1	4
Outlet of Lake Mjær	2.8	4	18	763	3	52
River Kråkstadelva	0.91	38	86	3036	14	500
River Hobølelva	4.9	16	48	1325	9	700
River Veidalselva	0.59	35	72	1127	16	230
River Mørkelva	1.06	13	38	864	8	200
River Svinna	1.72	8	40	942	7	31
Boslangen Creek	-	1.4	14	398	2	23
Strait between eastern and western basin	10.1	5	23	974	4	5
River Mosseelva (outlet river)	11.1	5	29	957	5	78
Creeks draining to the western basin						
Guthus creek		22	85	2200	33	1200
Sperrebotn creek		22	73	2000	16	700
Augerød creek		29	78	1100	14	700
Ørejordet creek		15	47	2300	7	2400
Årvold creek		11	48	2200	14	1300
Støa creek		11	125	3000	43	74
Vaskeberget creek		19	87	4400	16	62
Huggenes creek		20	96	4300	23	400
Dalen creek		2	9	600	0.7	29

Figure 14. *Two of the tributaries to the eastern basin, or Storefjorden. To the left, River Hobølelva at the Kure waterfall during a flood in summer 2007, to the right River Svinna at the bridge of Klypen, during summer 2006. Photos: E. Skarbøvik.*

5.3 Nutrient and sediment loads in 2008/2009

In Table 9, the loads of total phosphorus, total nitrogen and suspended particulate matter are shown for the period 16 October 2008 – 15 October 2009 for 18 stations in the catchment. In the eastern part of the catchment, the highest loads derive from the tributary Kråkstadelva and River Hobølelva downstream of Lake Mjær. The creeks to the western part of the basin also show considerable variations in nutrient loads.

Table 9. *Loads of total phosphorus (TP), total nitrogen (TN) and suspended particulate matter (SPM) are shown for the period 16 October 2008 – 15 October 2009 for 18 stations. From Skarbøvik et al. 2010.*

Station	SPM	TP	TN
	Tons	Tons	Tons
Upstream of Lake Mjær	216	0.8	28
Outlet of Lake Mjær	294	1.4	60
River Kråkstadelva	1 871[#]	3.8[#]	69
River Hobølelva at Kure	3 945[#]	9.8[#]	191
River Svinna	502[#]	2.1[#]	57
River Mørkelva	604[#]	1.0[#]	24
River Veidalselva	784[#]	1.2[#]	19
Total loads to the eastern basin *	5788	14.1	285
Strait between eastern and western basin	1278	8.6	297
Creeks to the western basin:			
Guthus Creek	53	0.20	
Sperrebotn Creek	44	0.14	
Augerød Creek	110	0.30	
Ørejordet Creek	14	0.037	
Årvold Creek	4	0.015	
Støa Creek 1	2	0.018	
Vaskeberget Creek	2	0.010	
Huggenes Creek	15	0.068	
Dalen Creek	1	0.05	
Total local loads to the western basin **	957	4.5	-
Output from River Mosseelva	1793	9.9	330

* Smaller creeks to the eastern basin are not included here

** Unmonitored areas have been modelled, thus this figure includes both the nine monitored creeks and the unmonitored areas.

[#] The load calculation is based on the rating curve method. For all other load figures, linear interpolation has been used.

5.4 Developments in nutrient loads

In order to be able to compare nutrient loads in rivers and creeks from one year to another, so-called 'normalised' values have been calculated based on water discharge variations from year to year. A 'normal' water discharge year was calculated based on a long-term data series for representative hydrological stations. This normal year was then set as the standard and the 'normalised' loads in the five years (2005-2009) were calculated as

$$Gn = (G * Qn)/Q$$

Where
Gn is the normalised load
G is the load
Q is the water discharge
Qn is the average (normal) water discharge

Figure 15 shows discharge normalised loads per catchment area of total phosphorus in the rivers that drain to the eastern basin (upper panel) and the creeks draining to the western basin (lower panel). It should be noted that such normalisation may not necessarily be linear, but the method nevertheless allows a more equal comparison between different years with different water discharges.

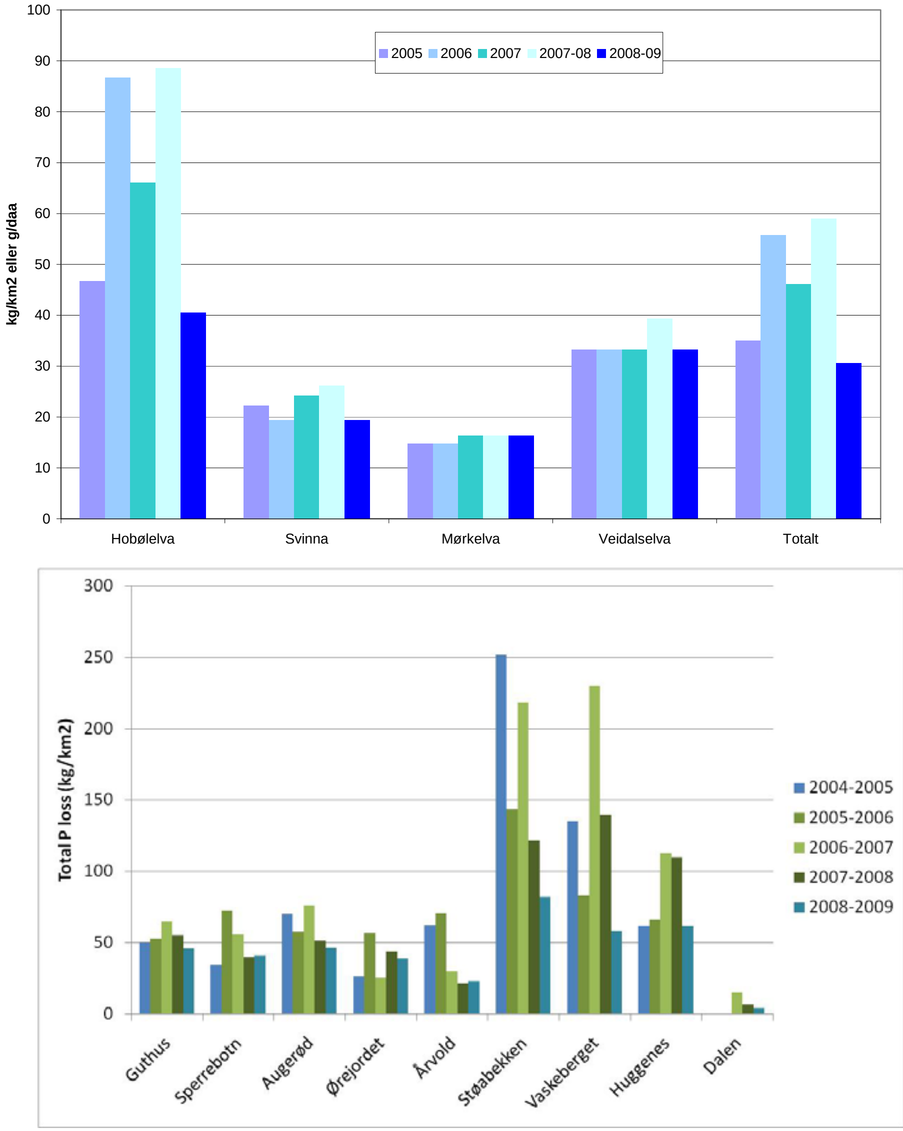


Figure 15. *Phosphorus loads (normalised in terms of water discharge) in kg/km^2 (upper panel) and g/daa (lower panel). From Skarbøvik et al. 2010.*

No clear developments can be deduced from these charts, but some conclusions can be drawn:

- In River Hobølelva (at Kure), variations in discharge related loads are much higher than in the three other tributaries to this lake basin. It is assumed that this is linked to the relief and erosion processes in rivers Hobølelva and Kråkstadelva, where active meandering and small ravination processes in its tributaries are believed to give high variations in loads with water discharges.
- In the creeks draining to the western basin, there are some indications of reduced loads the latter years, although this tendency is also present in the 'reference' creek, Dalen, where no agricultural activity is on-going. The latter may be linked to forest logging, but more years of monitoring are at any rate needed in order to assess the impacts of various applied mitigation measures.

However, it must also be noted that trend analyses for longer time series have been performed for total phosphorus (TP), total nitrogen (TN) and suspended sediments in River Hobølelva. The methodology and results are given in Skarbøvik et al. (2010). Basically, a downward trend was found for all three parameters from 1986 when the measurements started, and to 2009, but the trend was only statistically significant (i.e. p-value of less than 5%) for suspended sediments. For TP the p-value was between 6-9 % (depending on load calculation method), whereas for TN the p-value was 11%.

5.5 Lake environmental condition in 2009

The monitoring of the lakes in the catchment has been the responsibility of the Norwegian Institute for Water Research (NIVA) since 2004. Table 10 shows the conditions in both Lake Vansjø and six other lakes in the catchment during summer 2009. The concentrations of total phosphorus and chlorophyll a are related to the requirements in the EU Water Framework Directive for the respective lake types.

Based on the levels of chlorophyll a and total phosphorus, the lakes Sætertjern and Våg had good ecological condition. Lakes Bindingsvann, Langen and Mjær had moderate ecological conditions this year. In terms of Lake Vansjø, the eastern and western basins were this year both classified as being in moderate ecological conditions. However, a long and narrow lake basin located between the eastern and western basins of Lake Vansjø was classified as being in poor ecological condition (Grepperødfjorden).

Table 10. *Concentrations of chlorophyll a (Chl-a), nutrients (TP and TN), suspended particulate matter (SPM), as well as Secchi depths and biomass algae at nine lakes/lake basins in the catchment in 2009. The threshold for good ecological condition is given in parenthesis. Green: Good ecological condition; Yellow: moderate ecological condition; Orange: poor ecological condition. From Skarbøvik et al. 2010.*

Lake	Chl-a µg/L	TP µg/l	TN µg/l	SPM mg/l	Secchi depth m	Biomass algae mg/m^3
Sætertjernet	5.6 (7.5)	11.6 (16)	376	2.2	2.0	804
Bindingsvannet	10.2 (7.5)	12 (16)	336	2.8	2.1	1762
Langen	9.5 (7.5)	15 (16)	392	2.8	1.9	1757
Våg	6.9 (7.5)	14.1 (16)	485	3.1	1.7	482
Mjær	13.0 (7.5)	19.3 (16)	678	4.6	1.5	1081
Sæbyvannet	12.3 (7.5)	32.3 (16)	703	6.9	1.0	1829
Storefjorden	7.6 (7.5)	21 (16)	921	3.9	1.3	1356
Grepperødfj.	23.7 (10.5)	31 (19)	640	5.8	1.2	3195
Vanemfjorden	18.4 (10.5)	30 (19)	742	5.8	1.2	3609

5.6 Nutrient budgets

The methodology for the calculation of nutrient budgets in the catchment is given in Skarbøvik et al. 2008. Table 11 gives the actual load estimates (not normalised for water discharge differences) for total phosphorus, total nitrogen and suspended particulate matter at some stations. For the eastern basin, River Hobølelva is the largest contributor, whereas for the western basin, the input from the eastern basin through the strait between the two basins is the largest. However, there is reason to believe that the local inputs from creeks to Western Vansjø may play a major role in the eutrophication process, since the phosphorus may be more bio available when it arrives directly from the fields than when it has moved through the entire eastern lake system.

Table 11. *Nutrient budgets for the catchment. TP is total phosphorus; TN is total nitrogen and SPM is suspended particulate matter, all in tons/year. Q is water discharge in mill m^3. The budget for 2008 has not been calculated. From Skarbøvik et al. 2010.*

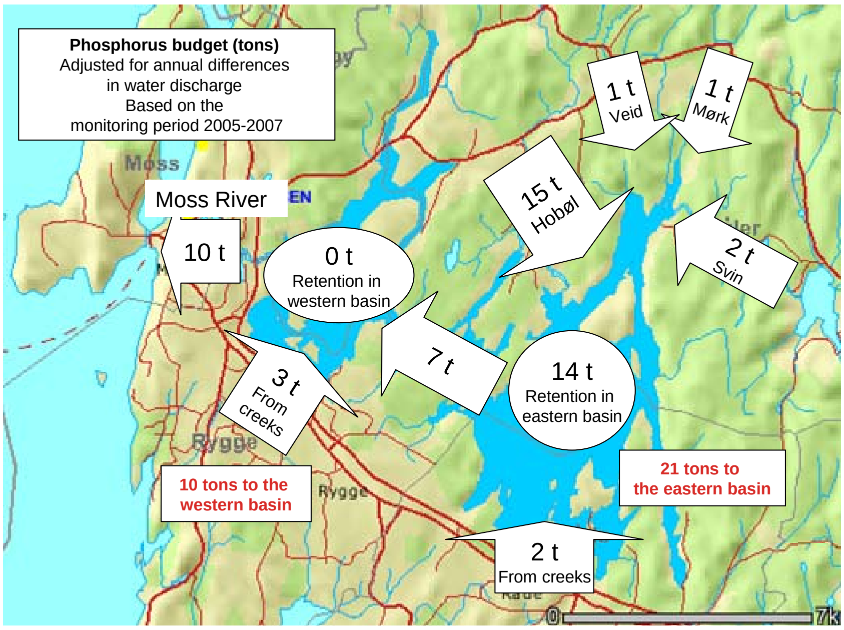
	2005				2006			
	TP	SPM	TN	Q	TP	SPM	TN	Q
River Hobølelva	7.8	3250	-	103.4	27	15150	-	192
River Svinna	1.7	-	-	36.2	2.8	709	-	67
River Mørkelva	0.7	-	-	20.5	1.2	682	-	38
River Veidalselva	0.8	-	-	11.3	1.5	890	-	21
Input to eastern basin*	11	3250	-		32	17431	-	
Strait between eastern and western basins	4.4	-	-	198	9.4	-	-	383
Creeks to western Vansjø**	1.4	-	-	-	4.5	-	-	-
Input to western Vansjø	5.8				13.9			
Output at Moss	7.05	1271	240	225.9	13.4	2301	569	437

	2007				Oct 2008 - Oct 2009			
	TP	SPM	TN	Q	TP	SPM	TN	Q*
River Hobølelva	15.3	5480	255.6	142.4	11.6	5884	184	151
River Svinna	2.5	465	61.1	49.8	2.1	528	57	49
River Mørkelva	1.05	375	17.9	28.3	1.1	835	26	31
River Veidalselva	1.15	456	15.2	15.6	1.3	1009	20	17
Input to eastern basin*	20	6776	350		16	8256	287	
Strait between eastern and western basins	9.7	1529	380	324	8.6	1278	297	306
Creeks to western Vansjø**	5.9	1143	36	-	4.1	957	-	-
Input to western Vansjø	15.6	2672	416	-	12.7	2235	-	-
Output at Moss	13.1	2642	447	369.5	9.9	1793	330	348

* Smaller creeks directly discharging to the eastern basin not included

** Includes inputs from the drainage area to the western basin (Vanemfjorden) and the River Mosseelva, but does not include the load that comes from the strait between the two basins.

The phosphorus budget has also been normalised in terms of water discharge, the result is shown in Figure 16 for an average of the three first years (2005, 2006 and 2007); and for the year October 2008-October 2009.



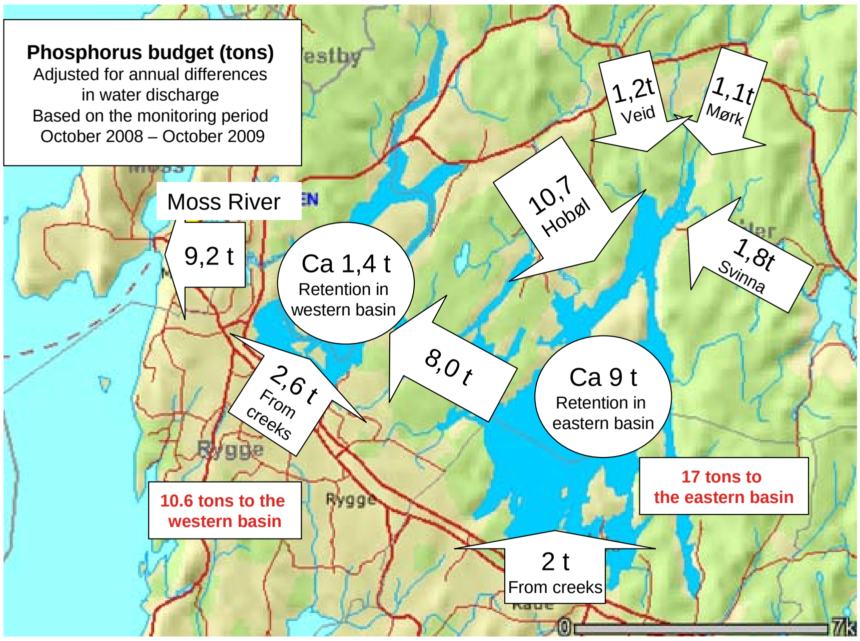


Figure 16. *Phosphorus budgets normalised for water discharges, in tons. Upper panel shows an average for the period 2005-2007, whereas the lower panel shows the budget for October 2008-October 2009. From Skarbøvik et al. 2010.*

There seems to have been a reduction in the normalised phosphorus loads from 2005/2007 and to 2008/09 but it is too early to draw any conclusions as yet.

6. Mitigation measures applied in the catchment

During the last decade a great effort has been made to improve water quality in Lake Vansjø by implementing various measures in all sectors contributing to the pollution of the lake. Several small-scale waste water treatment plants have been installed during the last years to reduce pollution from single households. Agriculture is one of the main contributors of nutrients to the lake and within this sector a comprehensive implementation of measures has been carried out.

6.1 Agricultural measures in the Vansjø-Hobøl catchment

During the latter decade, several mitigation measures have been applied within the agricultural sector in the entire catchment area. These include reduced tillage and reduced P fertiliser application, vegetated buffer zones and constructed wetlands. The relevant mitigation methods within the area have been described by Bechmann et al. (2006). Effects of these mitigation measures have been estimated both by modelling and from monitored data through studies by Bioforsk (Blankenberg et al. 2008, Øygarden et al. 2010).

6.1.1 Reduced soil tillage

The most effective change in tillage practice in Norway is to avoid ploughing of sloping fields in the autumn, so that the fields are covered with residue vegetation during the winter, and soil erosion is reduced. Blankenberg et al. (2008) calculated the effects of reduced soil tillage practices for the entire catchment from 2000 to 2006. Table 12 shows the reduction in soil loss from different sub-catchments due to this change in tillage practice. The reduction varied from 9 to 61%.

Table 12. *Changes in soil loss for different sub-catchments due to changed tilling practices from 2000 to 2006. From Blankenberg et al. 2008.*

Sub-catchment	Average soil loss 2000 kg/daa	Average soil loss 2006 kg/daa	Reduction %
Upstream Lake Langen	94	50	-47
Upstream Lake Mjær	49	45	-9
River Hobølelva between Lake Mjær and confluence River Kråkstadelva	169	68	-60
River Kråkstadelva	143	56	-61
River Hobølelva downstream of confluence with River Kråkstadelva	105	53	-50
Rivers Mørkelva and Veidalselva	100	49	-51
River Svinna (at Lake Sæbyvannet)	92	47	-49
Storefjorden (eastern basin)	56	41	-27
Vanemfjorden (western basin)	46	35	-25
River Mosseelva	72	66	-10

Similarly, the reductions in phosphorus losses were calculated. For areas with extensive cereal production, such as River Hobølelva and River Kråkstadelva, the reduction in total phosphorus losses amounted to 30-40 %.

6.1.2 High phosphorus levels in the soil

The phosphorus losses from the agricultural fields in this catchment are expected to be high for many years despite of reduced phosphorus fertilisation and changed tilling practices. This is because concentrations of available phosphorus in the soils are very high, and it will therefore take many years to reduce this to an environmentally sound level. Maps of phosphorus levels in the soils in this catchment exist.

6.1.3 Buffer zones and constructed wetlands

Since the effects of in-field mitigations (such as reduced tilling and less use of fertilisers) will probably only be detected in the long-term perspective, other mitigation efforts are necessary for more short term effects. Two such mitigation options are buffer zones and constructed wetlands.

Buffer zones have been established amongst others in the eastern part of the basin. Along e.g. River Hobølelva and Kråkstadelva, there is now commercial grass production in these zones, and only nitrogen is applied as fertiliser. The zones are intended to stop the surface runoff from the fields to the rivers, and may also protect against river bank erosion depending on vegetation used. The effect of buffer zones on nutrient and suspended sediment concentrations in surface water has been evaluated for Norwegian conditions by Syversen (2002). Figure 17 shows two examples of buffer zones in the eastern part of the catchment.

Figure 17. *Buffer zones in the catchment of Vansjø-Hobøl. Photos: E. Skarbøvik.*

Constructed wetlands are small artificial ponds where sediments and nutrients are retained through various sedimentation and filtering mechanisms. Norwegian experiments have shown that small constructed wetlands can remove between 21 to 44% of the total phosphorus in streams. However, only 5% of the orthophosphate was removed (Braskerud, 2002).

In the Morsa catchment, 60 constructed wetlands were built during the last decade. Figure 18 shows the location of constructed wetlands and buffer zones in the Vansjø-Hobøl catchment in 2007. Since then, several more constructed wetlands and buffer zones have been established, especially in the catchment areas that are bordering the western part of the lake.

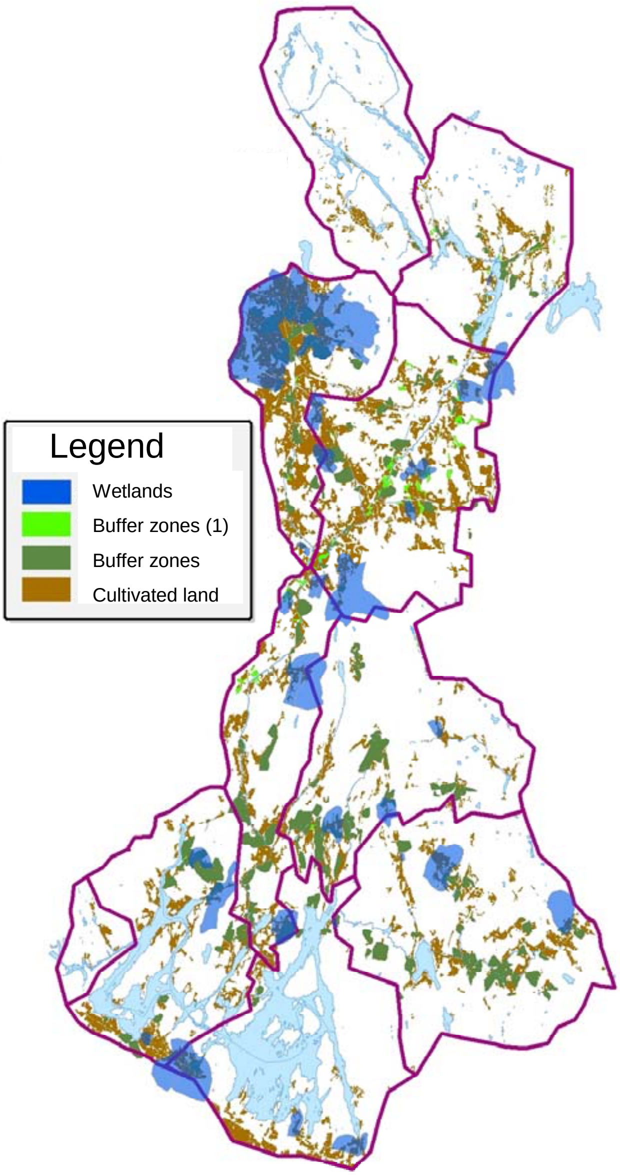


Figure 18. *Buffer zones and contructed wetlands by 2006 (shown as the drainage area of the wetlands). Buffer zones (1) in light green belong to the company Morsa Grass. From Blankenberg et al. (2008).*

6.2 Enhanced efforts on agricultural measures in Western Vansjø

Because of the huge problems of eutrophication in the western part of Lake Vansjø, a comprehensive integrated effort has been done to reduce diffuse pollution (especially phosphorus losses) from agricultural areas. The strategy has consisted of information campaigns, farmers' meetings, field trips, environmental planning on individual farms, farms visits, and - last but not least - legal contracts with the farmers combined with economic incentives.

An integrated project funded by the government was started in 2008 in order to carry out an action plan to improve the water quality of Lake Vansjø. In this project, the public agricultural management, agricultural advisers, farmers and the research institute Bioforsk collaborated.

The farmers were encouraged to sign a contract where they would receive a financial support for covering extra costs needed to implement a set of restrictions and mitigation options aiming at reduced phosphorus losses for a period of three years. The requirements in the contracts included:

- Use of less P fertiliser than the national recommended level
- No use of manure
- No soil cultivation during autumn
- No cultivation of potatoes or vegetables on fields that are frequently flooded
- Establishment of 10 meter buffer zones along open water
- Establishment of grassed waterways if large risk of erosion
- Establishment of constructed wetlands if this was recommended

In order to get more local knowledge about the effects of reduced phosphorus fertilisation, the farmers were also obligated to accept large scale experiments on their potato/vegetable fields.

An important part of this project was an agricultural adviser that had direct contact with each farmer, allowing discussions on specific challenges of each farm.

By the end of June 2008, 30 out of the 40 farmers in the catchment had signed the contract.

The effect of some of the implemented and other possible mitigation options on yields and phosphorus losses have been calculated. Implementation of measures was registered and reported for each farm at the field scale. The area of no-till in autumn increased, and for some sub-catchments covered 100% of the area. Vegetated buffer zones were established along most small streams, and 15 constructed wetlands were built during the period 2004-2010.

In connection with this project more light was shed on several issues, and therefore gave increased knowledge on the following issues;

- effects of reduced phosphorus fertilisation to potatoes, vegetables and cereals
- suitability of different plant species as cover crops
- effects of various filters in constructed wetlands in terms of adsorbing phosphorus
- phosphorus losses through tile drains
- documentation of the changes in use of phosphorus fertilisers in the catchment.

6.3 Lake specific measures

In addition, there have been mitigation measures specifically for the lake, such as fish catch of large pike (in order to increase the amount of plankton-eating fish) (e.g. Lien and Brabrand 2004, Brabrand 2006). As noted in section 4.2, there have also been investigations on the operation scheme of the dam at Mossefossen (e.g. Skarbøvik et al. 2005, 2006, 2007b, Skarbøvik 2008, Skarbøvik and Rohrlack 2009).

6.4 Improved sewage treatment from scattered dwellings

A major challenge in Norway is that settlements are often scattered, and connection to municipal sewage treatment plants is therefore in many places unrealistic. There are, however, a number of commercially available small-scale sewage treatment solutions. There is no official requirements as to which type of solution must be chosen, but there are requirements as to the effect of treatment for e.g. reduction of phosphorus and organic material. A huge effort has been done in this catchment the last years to reduce sewage from scattered dwellings and the number of such small-scale facilities has therefore increased. Figure 19 shows the results of a survey that was carried out in 2006 to investigate which small-scale sewage treatment facilities were acceptable and which were not in the municipalities within the Vansjø-Hobøl Catchment.

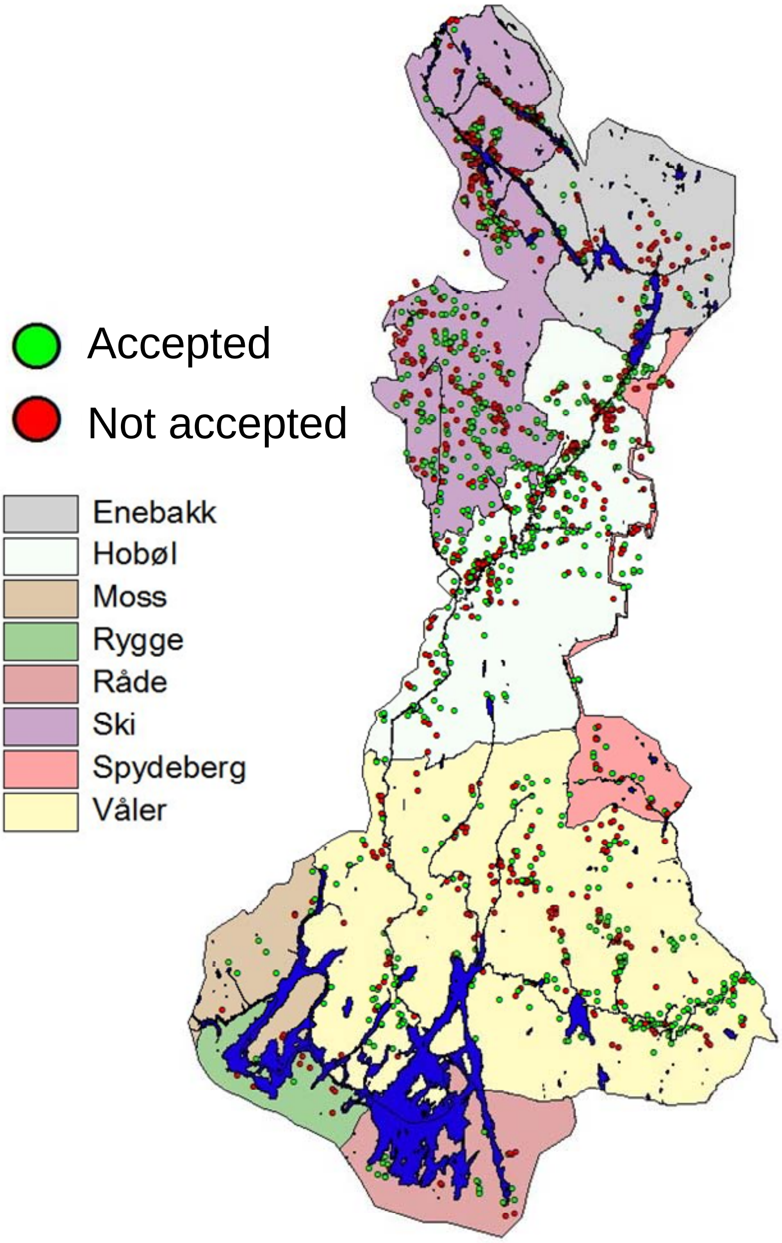


Figure 19. *Small scale sewage treatment facilities as of 31.12.2006. Green dots indicate facilities that are acceptable in terms of degree of treatment whereas the red dots indicate facilities with un-acceptably low treatment. From Blankenberg et al. (2008).*

6.5 Mitigation measures and climate change

Both researchers and managers are concerned that climate change may be masking the effects of the mitigation measures in the catchment. Flood frequency analyses and drought frequency analyses have been performed by Bioforsk in the largest tributary to the lake (River Hobølelva): No trends were found on the flood frequency analysis – but a downward trend in droughts was found, although not statistically significant (Skarbøvik et al. 2008). This means that there have been fewer drought episodes the latter years; which again may mean that the river banks become less stable. The many recent clay and soil avalanches in the catchment seem to confirm this hypothesis (cf. Figure 19).

Variations in weather conditions are also believed to cause increased erosion in the agricultural fields, especially if winters become less stabile, with several freezing and thawing episodes.

7. Local and national institutions and regulations

7.1 History of water management institutions in the area

The Morsa River Basin extends across two counties, Akershus and Østfold, and includes eight municipalities (Figure 20). As noted by Stokke (2006), there has in the past been a lack of a central management structure for the river basin. Responsibility for water quality used to be distributed on several government sectors, and responsibilities were often decentralised to local authorities that were more likely to promote local agendas than to take account of the river basin as a whole. In 1999, the Morsa Project started as a cooperation initiative between the local counties, regional authorities and stakeholder interests. The main objective was to improve the water quality of the catchment (www.morsa.org). Following the implementation of the Water Framework Directive, the Morsa Project was re-organised into a River Basin District Organisation in 2007, under the Glomma River Basin Authority. The duration is set to 2012, with possible continuation.

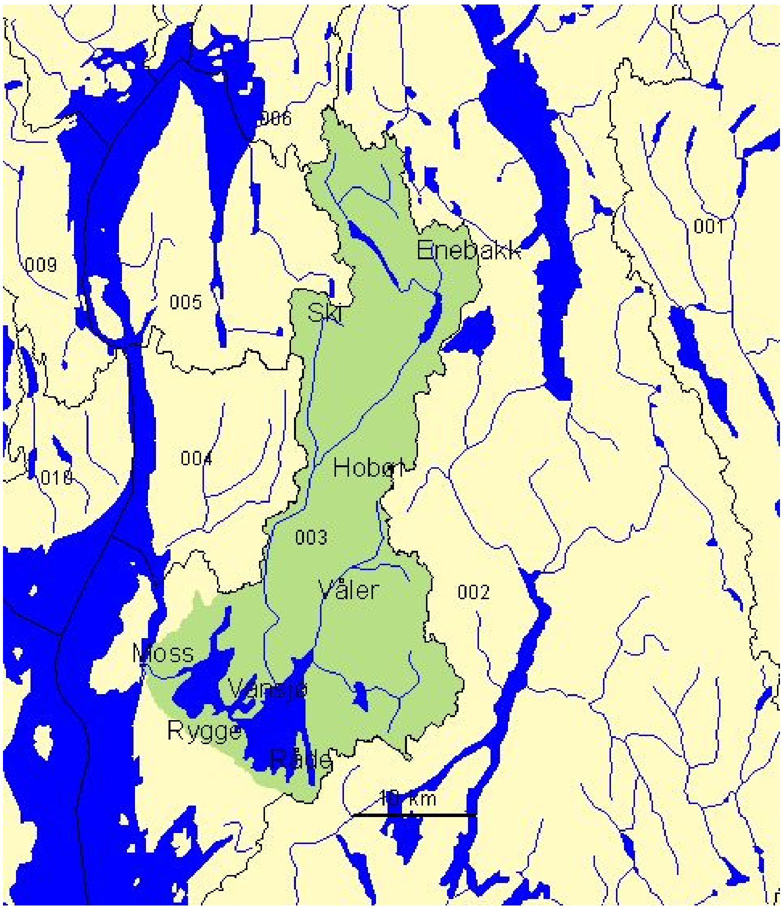


Figure 20. *Overview of the different local municipalities in the Vansjø-Hobøl Catchment. From http://www.iis.niva.no/php/euroharp/index.htm*

7.2 Current institutions

The main public institutions in the catchment include the Glomma River Basin Authority and the Morsa River Basin District Organisation. The catchment is located in two counties, Akershus and Østfold, but it is the Glomma River Basin Authority, located in the County Parliament of Østfold, that presently has the management authority.

The Morsa River Basin District Organisation has had a leader in a full time position since 1999. Three working groups have been appointed to oversee technical issues within sewage/drainage; agriculture; and forestry. These groups recommend steps to improve environmental standards within their areas of competence, promote inter-municipal collaboration and work to build competence and know-how. The working groups have civil servants as members (Stokke, 2006). The Organisation has a Governing Board which comprises the mayors of the eight municipalities and representatives from each of the county councils and county governor's offices together with representatives from the Norwegian Water Resources and Energy Directorate and the Norwegian Food Safety Authority.

Observer status was also granted to the farmers' organisations, the inter-municipal water system company MOVAR, Østfold Nature Conservation and the Vansjø landowner organisation (Helga Gunnarsdottir, Morsa River Basin District Organisation, pers. comm.).

The inter-municipal water system company MOVAR is running the drinking water plant that serves about 60,000 people. The water is extracted from the eastern basin (Storefjorden). The company is owned by the municipalities Moss (46%), Rygge (21%), Råde (9%), Vestby (20%) and Våler (4%).

The Glommens and Laagens Brukseierforening (GLB) performs the hydrological analyses used to operate the hydropower plant at Moss Dam. GLB is an organisation for all hydropower producers in the wider catchment area of the Glomma River System.

NVE – the Norwegian Water Resources and Energy Directorate – is the national regulation authority for hydropower. Any changes in the operation of the plant must be evaluated by NVE, and accepted by the King in Council. Presently, only temporary changes in the operation scheme have been authorised in order to carry out the investigations on the effects on the environment.

There are about 450 farms in the catchment (Stokke, 2006). The largest business is believed to be Peterson Linerboards, which is the cornerstone factory in Moss, producing paper.
To our knowledge, no analysis of market structures has been done.

There are farmer's organisations in both counties. Local groups of national hunting and fishing organisations also exist. An NGO with environmental interests is Østfold Nature Conservation Society.

7.3 The EU Water Framework Directive (WFD)

The Morsa Catchment has been a pilot catchment in the implementation of the WFD in Norway. The Morsa Project was transferred to the Morsa River Basin District Organisation in 2007 as a result of adhering to the Directive. Stokke (2006) stated that the work of this organisation has lead to increased cooperation between municipalities and across sectors in the catchment. Its organisation, including the board of the mayors of the eight municipalities, representatives from each county council and county governor's office has lead to more integration of the water management in the area.

Due to additional funding from KLIF (the Norwegian Climate and Pollution Agency), the Morsa catchment has undergone a series of different monitoring projects to identify sources of nutrients and evaluate the effect of abatement measures. Several river basin abatement analyses have also been made (Lyche Solheim et al. 2001, Blankenberg et al. 2008; Øygarden et al. 2010). River Basin Management Plans have also been made, cf. www.morsa.org.

Additionally, for the western basin of Lake Vansjø, available methods to reduce nutrient losses from agricultural areas have been evaluated (Bechmann et al., 2006) and a comprehensive effort has been done to implement these measures on agricultural areas within the catchment. Registration of implemented mitigation measures have been carried out (www.bioforsk.no/vestrevansjo).

8. A Preliminary DPSIR Analysis of Morsa

The DPSIR framework (Driving Forces-Pressures-State-Impacts-Responses) is often used to assess and manage environmental problems (e.g. http://www.unep.org/dewa/assessments/ecosystems/water). The driving forces include the socio-economic and socio-cultural forces that drive human activities, which can either increase or mitigate pressures on the environment. The pressures are the stresses that human activities place on the environment. The state is the current state of the environment, whereas the impacts are the effects of the present state. Finally, the responses are the responses by society to the environmental situation.

No thorough DPSIR-analysis has been carried out in the catchment, but based on current knowledge and the information in this report; a temporary analysis has been done:

8.1 Driving forces

In the Vansjø-Hobøl Catchment, the main socio-economic and socio-cultural forces that drive human activities include:

- food production, including the results of Norwegian policies regarding agriculture and remote settlements
- scattered dwellings (without satisfactory sewage treatment systems)
- economic drivers linked to the requirements for sufficient water flow at the outlet of the lake for purposes such as industry and hydropower
- requirements for drinking water extraction from the eastern basin
- requirements for water clean enough for swimming and other recreational use
- environmental concerns

8.2 Pressures

- Water quality pressures: High nutrient and particle loads to the lake from the tributaries, deriving mainly from wastewater and agricultural runoff
- Hydrological pressures: Water level fluctuations in Lake Vansjø that are at least partly due to the regulation of the lake. Flooding during spring/autumn (results in risk of overflowing sewage treatment plants, flooded fields with increased nutrient runoff; damage on infrastructure).
- Climate change pressures: May give increased frequency of flooding; increased erosion of river banks; more unstable winters with increased nutrient runoff.

8.3 State

High nutrient and particle concentrations in tributaries and lakes.

8.4 Impact

The main impact is eutrophication of the lakes, including

- Harmful algal blooms in Lake Vansjø. The most harmful algae is *Microcystis sp.* with the toxin microcystin.
- Swimming restrictions in Western Vansjø.

8.5 Responses to date

Establishment of the Morsa Project, which later became the Morsa River Basin District Organisation. The Organisation has managed to ensure funds to carry out monitoring and implement measures against pollution. Thus, the list of responses is long, cf. Chapter 6.

In the catchment of Lake Vansjø, a series of mitigation measures have been applied, and more are in the pipeline, they include

- reduced tillage in autumn,
- direct drilling,
- reduced P application rates,
- vegetated buffer zones,
- constructed wetlands,
- installing small-scale waste water treatment at single households.

Effects of the above mitigation measures have been estimated both by modelling and from monitored data through studies by Bioforsk (Blankenberg et al. 2008, Øygarden et al. 2010).

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