REPORT SNO 6108-2011

Askøy municipality. Environmental status and assessment of municipal waste water with regard to the requirement of secondary treatment in the EU Urban Waste Water Directive

Norwegian Institute for Water Research
– an institute in the Environmental Research Alliance of Norway

REPORT

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Abstract

Measurements of nutrients available for phytoplankton, chlorophyll-a and secchidepth and control of macroalgae close to municipal waste water discharges gave classification "High" or "Good" environmental conditions in the upper part of the watermasses around Askøy. Investigations of the soft bottom fauna and visual inspection with ROV at the pipe lines ends showed natural environmental conditions except at one station where technical problems had caused a clogged discharge pipe. Good water exchange and minimal effects of the municipal discharges justify the classification of the investigated area as a less sensitive area. Acceptable discharge depths for the planned municipal waste water flows in year 2030 were calculated. By following the recommendations the environmental conditions probably will be even better than today.

4 keywords, Norwegian	4 keywords, English
1. Askøy kommune	1. Askøy municipality
2. Kommunalt avløpsvann	2. Municipal waste water
3. Avløpsdirektivet	3. Urban Waste Water Directive
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Askøy municipality.

Environmental status and assessment of municipal waste water with regard to the requirement of secondary treatment in the EU Urban Waste Water Directive

Preface

In the period 2007-2010 the Norwegian Institute for Water Research (NIVA), Akvaplan-niva and UNI Research carried out studies of the environmental conditions in the fjord areas on the eastern, southern, and western side of the island Askøy northwest of Bergen. The main objective was to establish information about the environmental status of the fjord areas around Askøy, and to obtain sufficient information to Askøy municipality for decision whether or not to apply for a permit for less stringent treatment than secondary treatment of the waste water.

The present report is an abbreviated English version of three project reports written in Norwegian.

Bergen, 28.01.2011

Torbjørn M. Johnsen

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Summary

Background and objectives
In the EU Urban Waste Water Directive (UWWD) (1991/271/EØF and 1998/15/EF) there is a general requirement of secondary treatment for discharges of waste water to marine environment from agglomerations over 10 000 PE (person equivalents). However, according to Article 6 in UWWD less stringent treatment can be accepted if the recipient is a less sensitive area.

Askøy municipality is planning to restructure the waste water discharges from the 43 existing into 11 larger discharges. The restructured system is planned for 32 400 PE in 2030.

The objectives of the studies carried out have been to:

1. Obtain the requisite information so that Askøy municipality could decide whether or not to apply for a permit for less stringent than secondary treatment for the planned plants.
2. Obtain information about the environmental status of the fjord areas.
3. Create a basis for future monitoring of environmental conditions in the fjord areas.

The purpose of the recipient investigations has been to obtain important information concerning the environmental issues of combining the many existing discharges into fewer, but larger systems of waste water.

The recipients
The investigated areas consist of two main systems – Byfjorden and Hauglandsosen. Byfjorden is approximately 10 km long and the southern 6 km of this area has been included in the recipient investigations. The fjord has a maximum depth of about 350 meters in the southern part, but moving from east to west in the southern part of Byfjorden the depth is decreasing from 350 meters to about 150 meters just south of the southernmost point at Askøy. Byfjorden is a recipient for waste water from the eastern and southern side of Askøy and partly from the city of Bergen.

Hauglandsosen is an area about 9 km^2 with more or less open connection to the main fjord (Hjeltefjorden) west of Hauglandsosen. The seabed is rough with several minor deep basins. However, the sills are also deep.

Environmental status
Based on measurements of nutrients available for phytoplankton (phosphate, nitrate, ammonia) and chlorophyll-a (phytoplankton biomass) in the watermasses, oxygen in deep water, and investigation of macroalgae close to municipal waste water discharges, the watermasses have been classified as “Good” and “High” at all investigated areas. Analyzes based on benthic fauna also gave the classification “Good” or “High” for all stations except one, where technical problems had caused a clogged discharge pipe. Control by use of ROV at the end of all the pipe lines has shown very good bottom-conditions (except for the one with technical problems).

Impacts of municipal waste water discharges
According to EU Water Framework Directive focus should be put on how marine organisms respond on nutrient loads, organic load etc. The investigations carried out are all giving the classification “High” or “Good” for phytoplankton, macroalgae and benthic fauna, showing that the biota in the marine recipients around Askøy are not adversely affected by the municipal waste water discharges from Askøy or other nearby areas. High current speeds and the Norwegian Coastal Current leads to good water exchange in the fjords around Askøy. The results from the completed investigations support earlier classification of this area as a less sensitive area.

To make sure that the discharge trapping depths from the respective waste water discharges are acceptable, model calculations have been carried out for estimated water flows in 2030. The calculations show that discharge depths of 30 m are sufficient for all the 11 planned discharge pipelines if a diffusor is used.

1. Background and objectives

In the EU Urban Waste Water Directive (UWWD) (1991/271/EØF and 1998/15/EF) there is a general requirement of secondary treatment for discharges of waste water to the marine environment from agglomerations over 10000 PE (person equivalents). However, according to Article 6 in UWWD less stringent treatment can be accepted if the recipient is a less sensitive area.

Askøy municipality is planning to restructure the waste water discharges from the 43 existing into 11 larger discharges (**Figure 1**). The restructured system is planned for 32 400 PE in 2030 (**Table 1**).

The objectives of the studies carried out have been to:

4. Obtain the requisite information so that Askøy municipality could decide whether or not to apply for a permit for less stringent than secondary treatment for the planned plants.
5. Obtain information about the environmental status of the fjord areas.
6. Create a basis for future monitoring of environmental conditions in the fjord areas.

The purpose of the recipient investigations has been to obtain important information concerning the environmental issues of combining the many existing discharges into fewer, but larger systems of waste water.

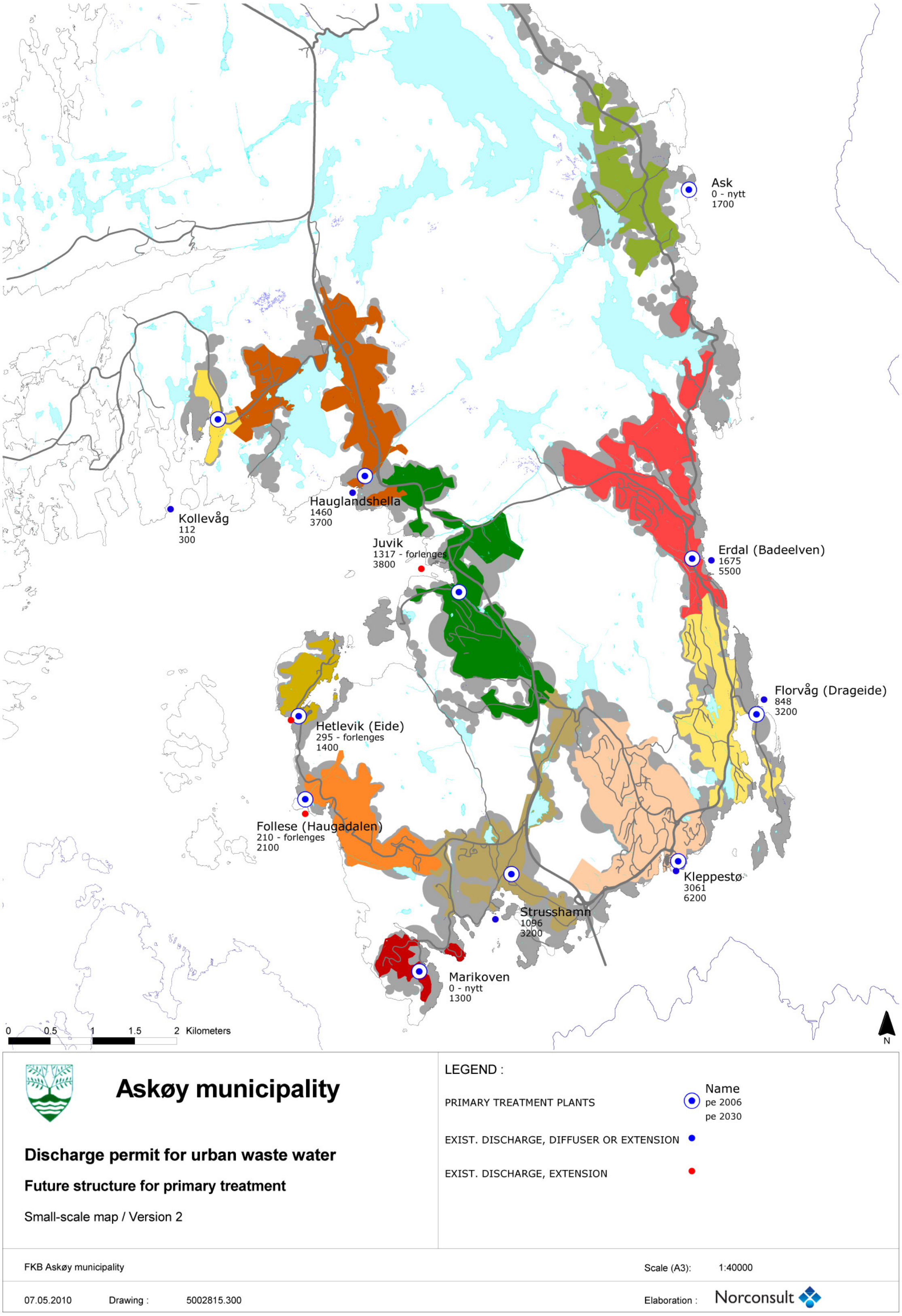


Figure 1. Future structure of waste water discharge from the southern part of Askøy.

Table 1. Waste disposal in 2006 and 2030 from the southern part of Askøy.

Sewerage system		Discharge > 50 PE			Total PE			Connected		
		Connected	To be transferred	Total	Population	Other	Total	%	%	pe
Name	**Discharge**	**2006**	**2006**	**2006**	**2006**	**2006**	**2006**	**2006**	**2030**	**2030**
Ask	New	0	583	583	1 125	40	1 165	48	83	1 700
Erdal	Existing	1 675	933	2 608	2 967	313	3 280	77	92	5 500
Florvåg	Existing	848	836	1 684	1 759	29	1 788	94	98	3 200
Kleppestø	Existing	3 061	155	3 216	3 246	304	3 550	90	97	6 200
Strusshamn	Existing	1 096	420	1 516	1 810	52	1 862	81	94	3 200
Marikoven	New	0	519	519	782	18	800	64	88	1 300
Follese	Existing, extended	210	754	963	1 206	53	1 259	76	92	2 100
Eide	Existing, extended	295	288	584	855	20	875	66	89	1 400
Juvik	Existing	1 317	543	1 859	2 131	83	2 214	83	94	3 800
Hauglands-hella	Existing	1 460	67	1 527	2 230	53	2 283	66	89	3 700
Kollevåg	Existing	112	0	112	215	4	219	50	83	300
Total		**10 074**	**5 098**	**15 172**	**18 326**	**969**	**19 295**	**78**	**93**	**32 400**

2. The recipients

The investigated area stretches from Ask in east to Kollevåg (Kolavåg) in west (**Figure 2**):

- East: From Erdal to Florvåg: – Byfjorden, east
- South: From Kleppestø to Strusshamn: – Byfjorden, south
- West: From Follese to Kollevåg: – Hauglandsosen

Byfjorden is an area with maximum depth of about 350 meters in the southern part (**Figure 3**), and the distance from Ask to Florvåg is about 6 km. Moving from east to west in the southern part of Byfjorden the depth is decreasing from 350 meters to about 150 meters just south of the southernmost point at Askøy. Byfjorden is a recipient for waste water from the eastern and southern side of Askøy and partly from the city of Bergen.

Hauglandsosen is an area about 9 km^2 with more or less open connection to the main fjord (Hjeltefjorden) west of Hauglandsosen (**Figure 4**). The seabed is rough with several minor deep basins with deep sills.

Figure 2. Map of the investigated area.

Figure 3. Map showing the depth contours in the Byfjorden area.

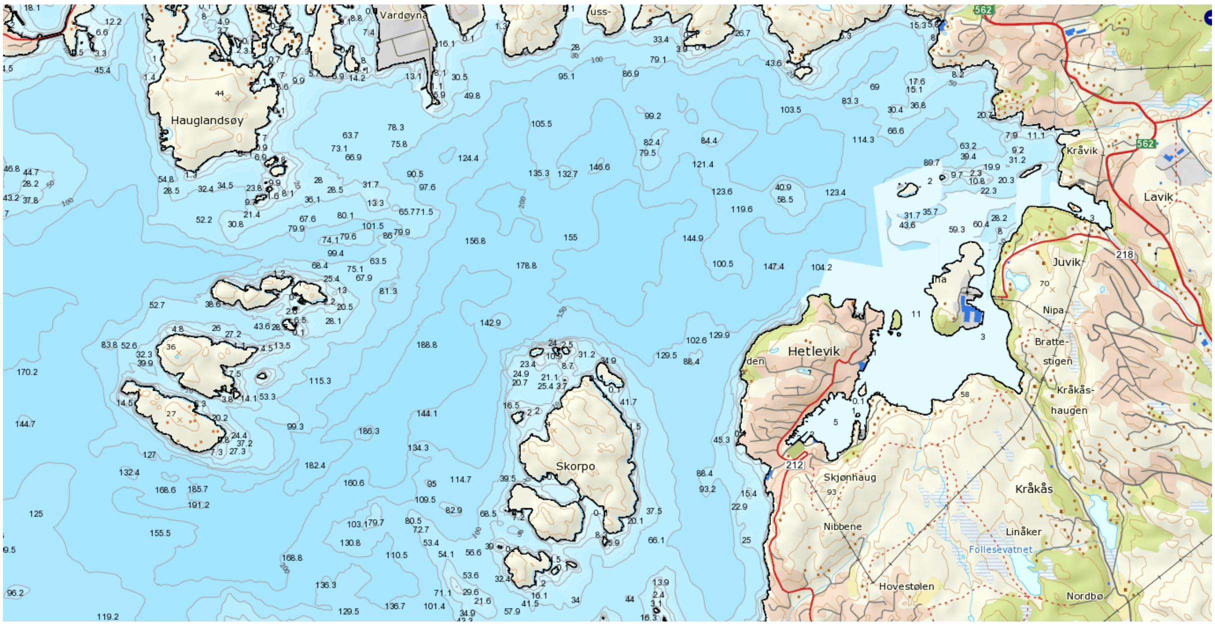


Figure 4. Map showing the depth contours in the Hauglandsosen area.

3. Environmental status

3.1 Investigations and methods

In order to investigate the marine recipients at the eastern, southern, and western side of Askøy, water quality has been examined in the upper part of the water masses by analysing nutrient concentrations, secchidepth and phytoplankton biomass (chlorophyll-a), and by measurements of oxygen in the deepwater. All analyses has been done according to Norwegian standards (phosphate – NS4724, total phosphorous – NS4725, nitrate+nitrite – NS4745, ammonium – NS4746, total nitrogen – NS4743, chlorophyll-a – NS4767, oxygen – NS-ISO 5813). The macroalgae have been investigated in shallow waters close to waste water discharges as an indicator of the environmental impact from the municipal discharges to the upper surface layer (0-20 m) following methods developed through the intercalibration work in NEA-GIG (North-East Atlantic Geographical Intercalibration Group). Soft-bottom fauna and organic content in the sediments have been analyzed to characterize the environmental conditions following ISO 16665:2005. In addition, the areas around the pipe ends have been checked by use of ROV (Remotely Operated underwater Vehicle). At the most influenced areas in east and west, samples have been taken for analyzes of heavy metal contents and organic contaminants and the samples have been analysed at the accredited laboratorium at NIVA. Moreover hydrographic measurements and measurements of current speed have been done as a basis for discharge water modelling by use of Visual PLUMES (developed by U.S. EPA) which is used in order to finding discharge depths giving acceptable trapping depths for waste water at estimated water flows in 2030.

3.2 Askøy east

3.2.1 Water quality

The water quality in Byfjorden at the eastern, southern, and western side of Askøy has been investigated through control of marine macroalgae close to municipal waste water discharges (**Figure 5**) (Johnsen et al. 2010). The investigations have been done with methods developed through the intercalibration work in NEA-GIG (North-East Atlantic Geographical Intercalibration Group). At Erdal the investigation gave "Good" conditions (**Table 2**, St.5). This is identical with earlier results both from investigations at the seashore and analyses of nutrients and chlorophyll-a in the water column done by UNI Research, University of Bergen (Heggøy et al. 2005).

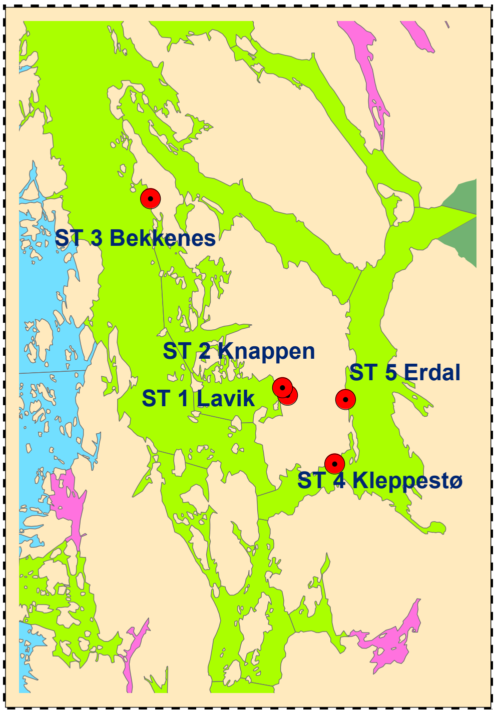


Figure 5. Stations for investigation of macro-algae.

Table 2. Water quality and EQR[1)]–values.

Stations	ST1 Lavik Askøy	St2 Knappen, Haugaland, Askøy	St3 Bekknes, Askøy	St 4 Kleppestøkaien, Askøy	St 5 Erdal, Askøy		ST1 Lavik Askøy	St3 Bekknes, Askøy	St 5 Erdal, Askøy
Watertype	NO3	NO3	NO3	NO3	NO3		NO4	NO26	NO4
Shore potential[2)]	1,14	1,14	0,93	0,93	1		1,14	0,93	1
EQR-value	0,809	0,805	0,807	0,813	0,730		0,889	0,790	0,791
Water quality - Status	High	High	High	High	Good		High	Good	Good

[1)] EQR - ecological quality ratio - is calculated by dividing the observed metric by the reference value for that metric. The range of EQRs is then divided into five classes giving the following ecological status: High – Good – Moderate – Poor – Bad.
[2)] Shore potensial – correction factor for the shore description. Adjustment for the potensial number of species on expects to fin at a specific type of shore.

3.2.2 Sediments

At Erdal and Florvåg (**Figure 6**) the sampling conditions were bad due to rocky bottom, resulting in chemical analyses of sediments only from Erdal. The sediments at Erdal (depth = 37 m) had relatively low contents of organic material (TOC) (**Table 3**) giving "Good" condition" according to the Norwegian Climate and Pollution Agency's (Klif) environmental quality classification system (Molvær et al. 2007) (cf. **Table A1**). Semi-quantitative analyses of benthic fauna from both stations showed natural species diversity and composition without unusual numbers of pollution-tolerant species. At Erdal, TBT was slightly elevated ("Good"), while the generally low contents of heavy metals and contaminants gave "High" condition (cf. **Table A2**). At Florvåg the sediments consisted of shell-sand with no visual organic loads at the surface, or smell of H_2S, indicating normal conditions with aerobic breakdown of organic material (Dahl-Hansen et al. 2007).

a) b)

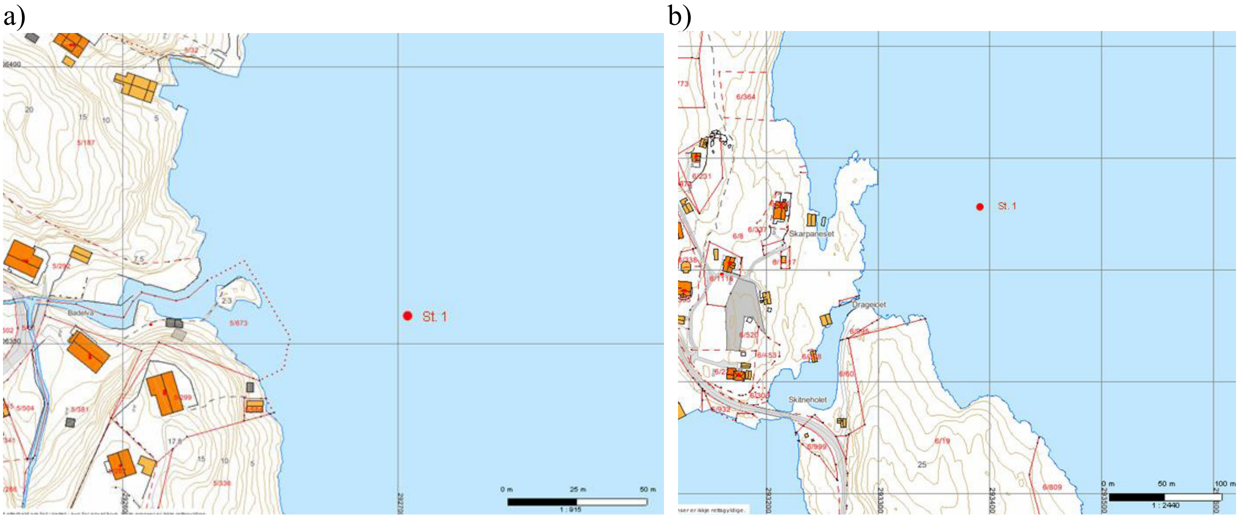


Figure 6. Sampling stations for sediments and benthic fauna at a) Erdal and b) Florvåg.

Table 3. Station parameters at Erdal. TOC = total organic carbon (mg/g); TOC_{63} = TOC normalised to grain size < 63µm.

Station	Depth	%<63µm	TOC	TOC_{63}
Erdal	37	3.5	5.5	22.9

Class II "Good"

Table 4. Heavy metals and organic contaminants in sediments at Erdal. TBT and organic contaminants are given in µg/kg, while all the metals are given in mg/kg. n.d = not detected

Station/Element	As	Cd	Co	Cr	Cu	Hg	Ni	Pb	V	Zn	TBT	B(a)P	PAH	PCB
Erdal	4.01	<0.01	0.747	7.45	4.54	0.0828	2.77	12.8	8.33	21.4	4.9	0.083	0.36	n.d

Class I "High"
Class II "Good"

3.2.3 Visual inspections with ROV

ROV (Remotely operated underwater vehicle) inspections around the pipe ends at Erdal and at Florvåg showed no visual debris or surface pollution (Molvær et al. 2007) (**Figure 7**, **Figure 8**). The positions and depths for the pipe end at Erdal and Florvåg is given in **Table 5**.

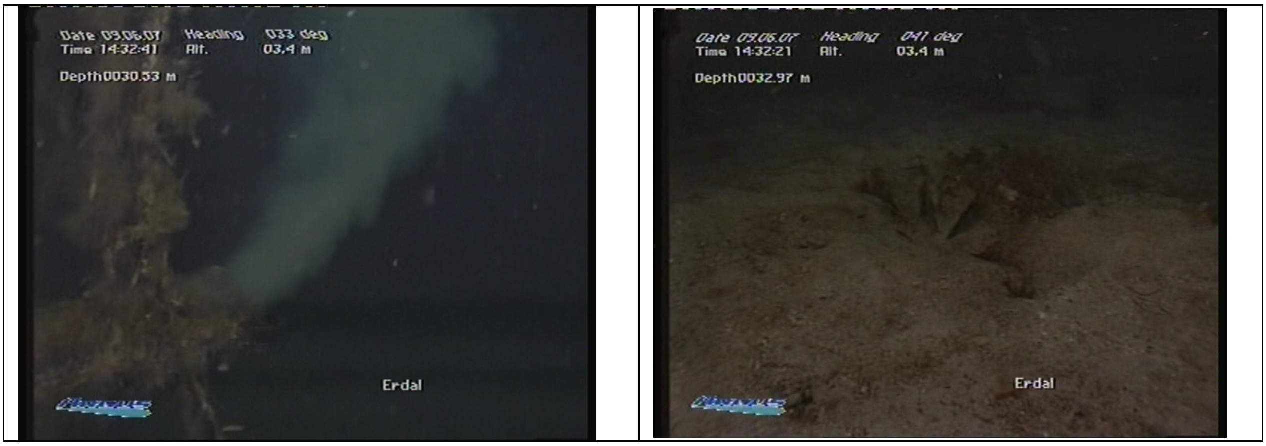


Figure 7. Plume and pipe end area at Erdal.

Figure 8. Plume and pipe end area at Florvåg.

Table 5. Position and depth for the pipe ends at station Erdal and Florvåg at Askøy east.

Area	Station	North	East	Depth (m)
Askøy east	Erdal	60° 26,327	5° 13,934	30
	Florvåg	60° 25,487	5° 14,797	39

3.2.4 Model calculations

Model calculation of discharge trapping depths relied on ambient current, discharge data for 2007 and 2030 (**Table 1**), and hydrographic conditions at Erdal showed that for most of the hydrografic conditions the discharge trapping depths were deeper than 4 m (discharge depth: 30 m). However, in cases with weak stratification and low current speed the discharge water may reach the surface. For the calculated discharge and water flow in 2030, the best results (trapping depths deeper than 10 m) were achieved if the discharge plume was positioned at 30 m depth and with use of a diffusor (**Figure 9**).

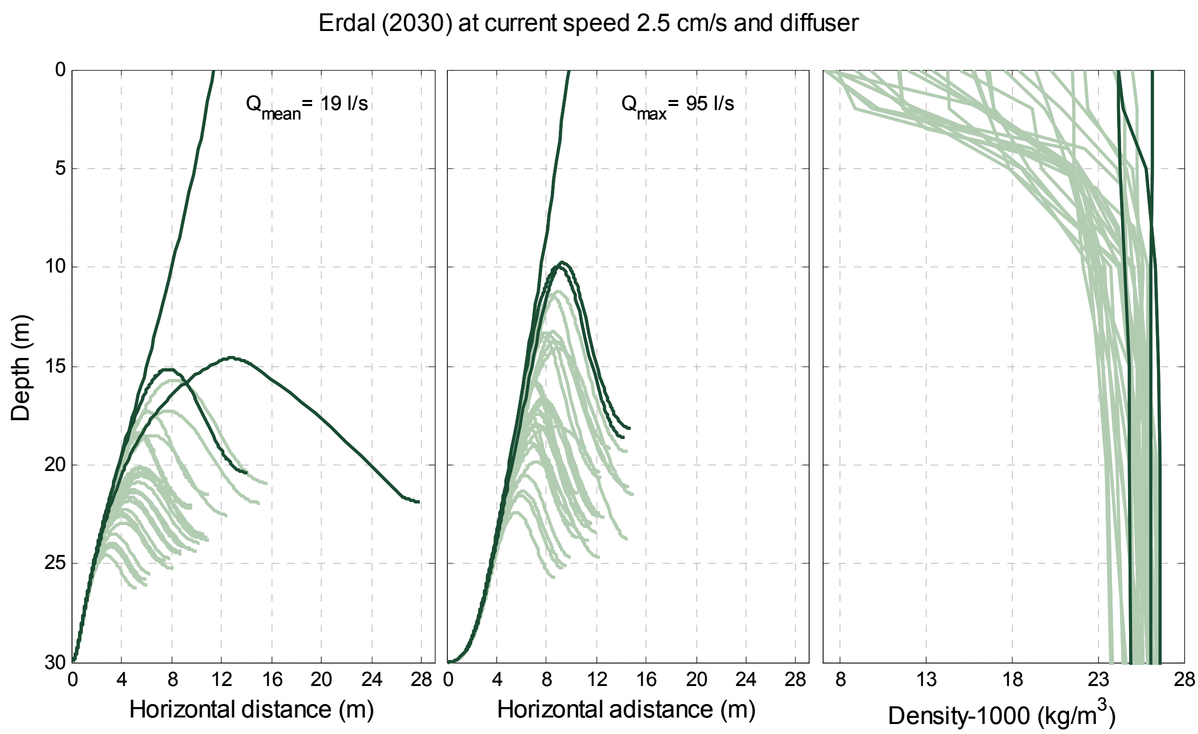


Figure 9. Discharge trapping depth at Erdal calculated for discharge water flows of 19 and 95 l/s in 2030, at 30 m depth, current speed 2.5 cm/s, and use of diffusor (15 holes, diameter = 8 cm, 3 m between holes). Right panel show the different stratification scenarios used. The three situations giving the worst cases are marked with darker colour.

At Florvåg the discharge depth is 39 m and model calculations by use of data for 2007 discharges showed that the discharge trapping depth is deeper than 12 m. The model calculations for discharge and water flow in 2030 showed that use of a diffusor and a position of the discharge plume at 40 m depth will be acceptable with discharge trapping depths always deeper than 12 m (**Figure 10**).

Table 6. Description of discharges.

Location	Current speed (cm/s)		Direction (°)		Interior pipe diameter (mm)	Water flow Q (l/s)			
						2007		2030	
	Average	Strong 90 persentil	Current	Pipe		Average	Max	Average	Max
Juvik	2,9	5,6	250	30	355	11	44	22	88
Hauglandshella	2,4	4,6	20	270	355	9	35	21	86
Eide	2,4	6	0	270	222	2	7	8	32
Kollevåg	2,4	6	0	200	142	1	2	2	7
Haugadalen	2,4	4,6	315	225	279	1	5	12	40
Erdal	2,5	5,5	280	270	397	15	40	19	95
Florvåg	2,5	5,5	280	280	279	6	20	11	56
Kleppestø	3,0	6,5	290	200	441	15	71	22	108
Strusshamn	3,0	7,0	350	270	279	6	32	11	56

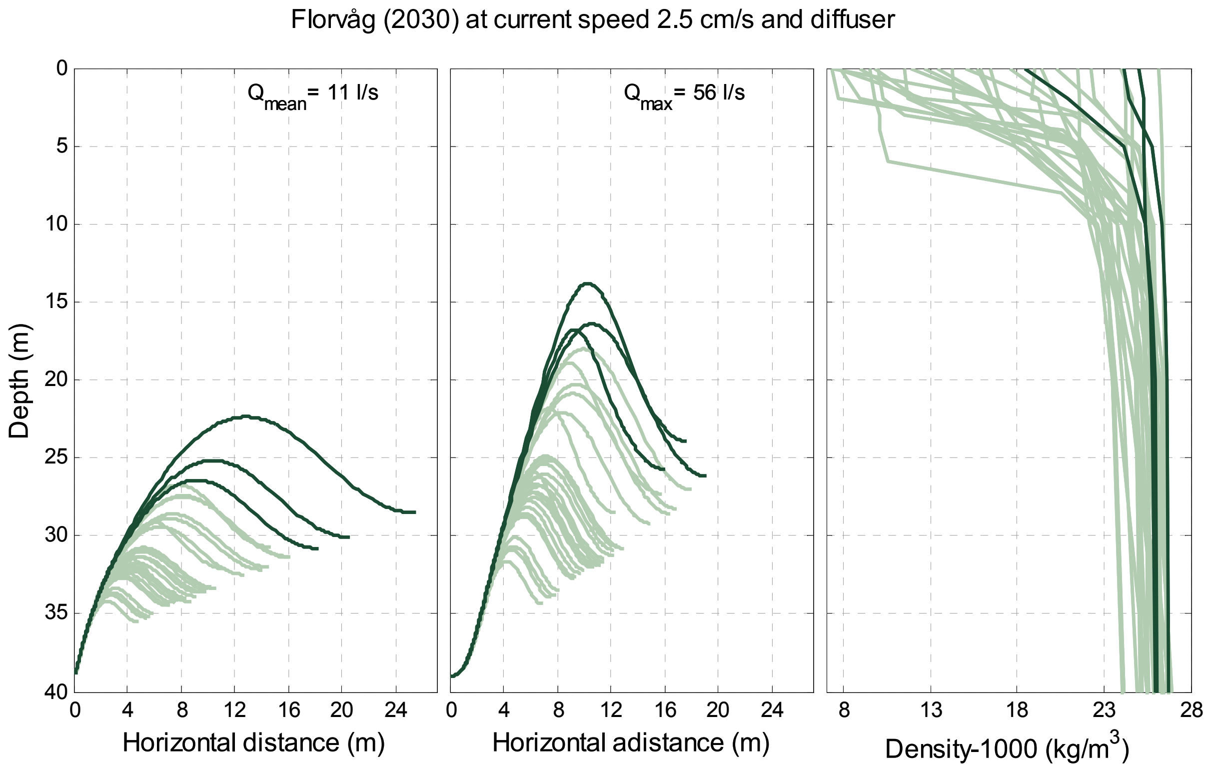


Figure 10. Discharge trapping depth at Florvåg calculated for discharge water flows of 11 and 56 l/s in 2030, at 39 m depth, current speed 2.5 cm/s, and use of diffusor (15 holes, diameter = 8 cm, 3 m between holes). Right panel show the different stratification scenarios used. The three situations giving the worst cases are marked with darker colour.

3.3 Askøy south

3.3.1 Water quality

At Kleppestø (**Figure 5**) investigations of macroalgae showed that the water quality was “Very Good” (**Table 2**, St.4), and confirms earlier results reported by UNI Research.

3.3.2 Sediments

Close to the outlet of waste water at Kleppestø (St.1) (**Figure 11a**), the TOC-content in the sediment was high (“Poor” condition), but the benthic fauna species diversity was high giving “High” classification (**Table 7**). The level of TBT was high (“Bad”, most likely due to antifouling paint used on vessels (ferry and fast-running boat traffic close to the sampling station)), and the sediments were also to some extent polluted with some heavy metals (Hg – “Poor, Cu – “Moderate”, Pb – “Good”) (**Table 8**).

Attempts to take sediment samples approximately 50 m outside the waste water discharge at Kleppestø (St.2) failed due to rocky bottom.

Sediments from three stations at Strusshamn (**Figure 11b**) showed varying contents of TOC (“Good”-“Poor”) (**Table 7**). Benthic fauna analyses showed “Good” conditions at all three stations. Station 2 and 3 had slightly elevated concentrations of lead (“Good”), and station 3 had elevated concentration of mercury (“Good”) (**Table 8**). TBT varied at the 3 stations between “Good” to “Poor”.

a) b)

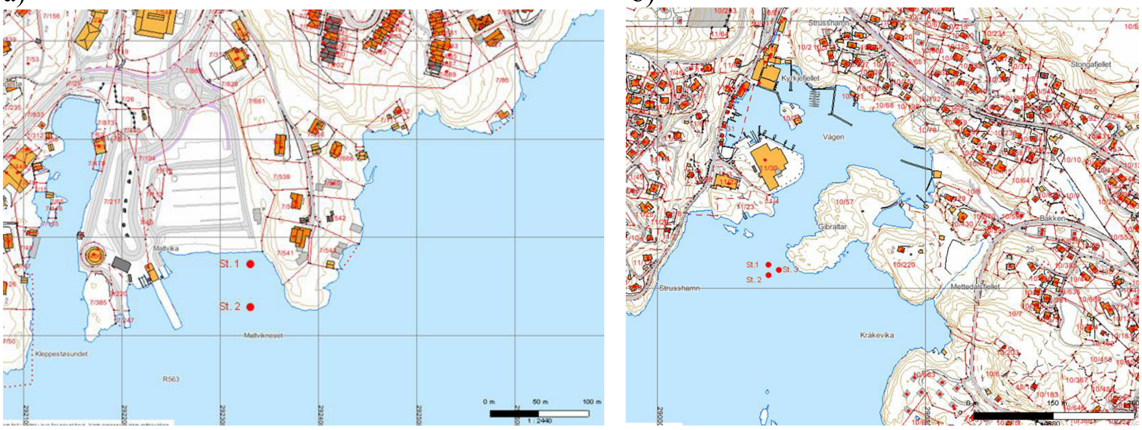


Figure 11. Sampling stations for sediments and benthic fauna at a) Kleppestø and b) Strusshamn.

Table 7. Station parameters at Kleppestø and Strusshamn. ES_{100} = Hurlberts index. H´ = Shannon-Wiener index. TOC = total organic carbon (mg/g); TOC_{63} = TOC normalised to grain size < 63µm.

Station	Depth	Sampled area (m^2)	Number of species	No. of individuals	%<63 µm	ES_{100}	H´	TOC	TOC_{63}
Kleppestø, St.1	14	0.4	121	2570	8.6	30	4.4	21.5	38.0
Strusshamn, St.1	26				3.6			5.9	23.3
Strusshamn, St.2	32				3.5			10.2	27.6
Strusshamn, St.3	33	0.4	159	1249	7.3	51	6.0	21.7	38.4

Class I “High”
Class II “Good”
Class III “Moderate
Class IV “Poor”

Table 8. Heavy metals and organic contaminants at Kleppestø and Strusshamn. TBT and organic contaminants are given in µg/kg, while the metals are given in mg/kg.

Station/Element	As	Cd	Co	Cr	Cu	Hg	Ni	Pb	V	Zn	TBT	B(a)P	PAH	PCB
Kleppestø	7.01	0.079	3.31	29.3	56.6	4.28	14.6	73.5	24.2	106	260	4.8	48.7	n.d
Strusshamn, St.1	8.57	<0.01	1.06	8.46	4.44	0.056	2.40	26.1	14.1	37.4	4.5	0.65	3.6	n.d
Strusshamn, St.2	15.9	<0.01	1.98	8.03	7.44	0.104	3.84	32.9	16.7	45.9	18	0.62	3.8	n.d
Strusshamn, St.3	18.4	0.085	3.84	21.0	21.4	0.217	9.35	70.8	40	113	21	3.3	15	n.d

Class I "High"
Class II "Good"
Class III "Moderate"
Class IV "Poor"
Class V "Bad"

3.3.3 Visual inspections with ROV

The end of the pipe at Kleppestø was found at 30 m depth (**Table 9**). No surface pollution or visual debris was observed at the pipe end (**Figure 12**). At Strusshamn several pipes were observed, but the end of the main pipe was found at 26 m depth (**Table 9**). At the main pipe end there was practically no debris and limited surface pollution (**Figure 13**).

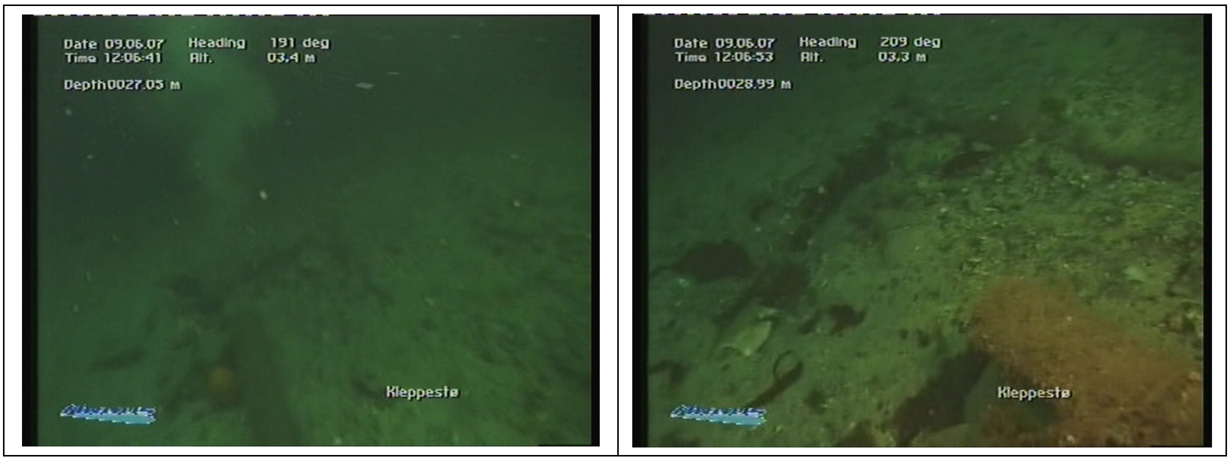


Figure 12. Plume and pipe end area at Kleppestø.

Figure 13. Plume and pipe end area at Strusshamn.

Table 9. Position and depth for the pipe ends at station Kleppestø and Strusshamn at Askøy south.

Area	Station	North	East	Depth (m)
Askøy south	Kleppestø	60° 24,320	5° 13,753	30
	Strusshamn	60° 23,808	5° 11,440	26

3.3.4 Model calculations

Figure 14 shows the results of model calculation of discharge trapping depths at Kleppestø based on description of discharges in 2030 at average current speeds and average and maximum water flows. The conclusion of these calculations is that a discharge depth of 30 m and use of a diffusor will in nearly all situations result in discharge trapping depths deeper than 7 m.

The calculations for Strusshamn by using a discharge depth of 30 m and use of a diffusor will also give very good results with trapping depths deeper than 9 m in nearly all situations (**Figure 15**).

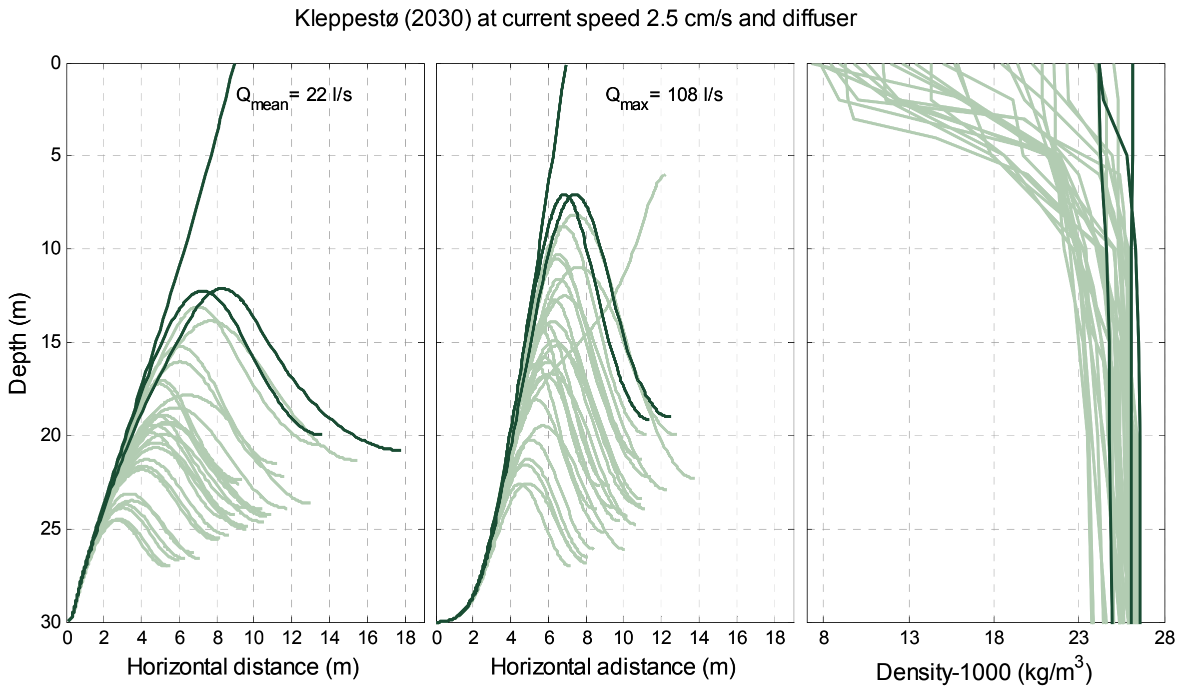


Figure 14. Discharge trapping depth at Kleppestø calculated for discharge water flows of 22 and 108 l/s in 2030, at 30 m depth, current speed 2.5 cm/s, and use of diffusor (15 holes, diameter = 8 cm, 3 m between holes). Right panel show the different stratification scenarios used. The three situations giving the worst cases are marked with darker colour.

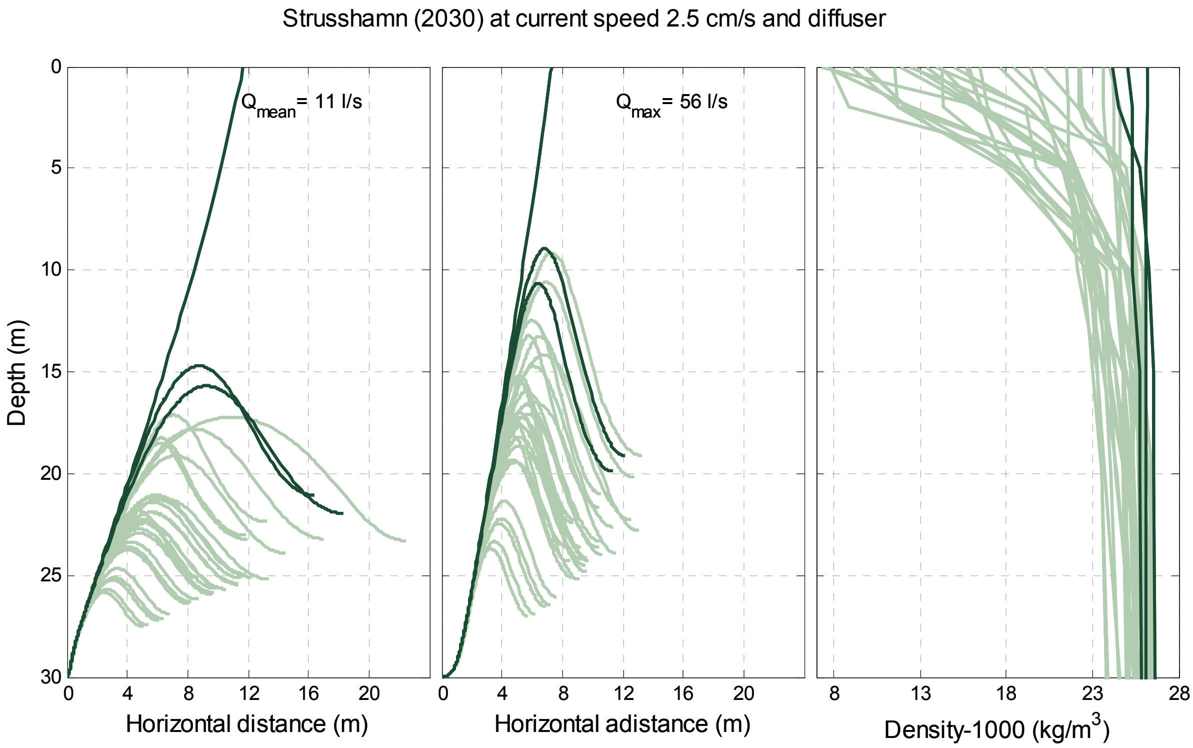


Figure 15. Discharge trapping depth at Strusshamn calculated for discharge water flows of 11 and 56 l/s in 2030, at 30 m depth, current speed 2.5 cm/s, and use of diffusor (15 holes, diameter = 8 cm, 3 m between holes). Right panel show the different stratification scenarios used. The three situations giving the worst cases are marked with darker colour.

3.4 Askøy west

3.4.1 Water quality

Water samples for classification of water quality (chlorophyll-a, total phosphorus, phosphate, total nitrogen, nitrate, ammonium and oxygen) and measurements of water transparencies (Secchi depth) were obtained in Hauglandsosen and at a reference location in Hjeltefjorden (**Figure 16**).

3.4.2 Nutrients, chlorophyll-a and benthic macro-algae

The nutrient analysis showed increased concentrations of total phosphorus and phosphate compared to unaffected areas at both locations. The total phosphorus was somewhat higher at Hauglandsosen (class III "Moderate") compared to the reference station (class II "Good") (cf. **Table A3**) (Molvær et al. 1997). However, the differences between the locations were small (**Table 10**). The amount of phosphate (class II "Good") was the same at both locations. The concentrations of total nitrogen, nitrate, and ammonium were low at both locations (Class I "High"). Classifications based on chlorophyll-a and Secchi depth resulted in class I "High" (**Table 11**,**Table 12**).

Investigations of macro-algae at two stations (Lavik and Knappen (**Figure 5**)) in the inner part of Hauglandsosen close to Juvik (**Figure 17**, st.3) showed good conditions and the surface water quality was classified as "High" (**Table 2**).

3.4.3 Oxygen in deep-water

Oxygen measurements in deep water gave "High" conditions (**Table A1**) and the classification at Hauglandsosen did not indicate any poorer conditions than at the reference station (**Table 13**).

Figure 16. Stations for hydrographic and hydrochemical analyses.

Table 10. Results of analyses of nutrients from Hauglandsosen and the Reference station. (Colour coding in accordance to the Norwegian Climate and Pollution Agency's (Klif) environmental quality classification system)

		12. June		22. June		12. July		1. August		7. August		26. August		Average (0-10 m)	
Para-meter	**Depth**	**St 1**	**Ref**	**St 1**	**Ref**	**St 1**	**Ref**	**St 1**	**Ref**	**St 1**	**Ref**	**St 1**	**Ref**	**St 1**	**Ref**
Tot. P (µg P/l)	1	18	16	20	22	11	11	11	10	13	11	16	14	17,1	15,1
	5	21	21	20	16	17	11	15	12	13	10	15	15		
	10	29	24	19	20	20	19	24	15	12	11	14	14		
PO_4-N (µg P/l)	1	4	3	4	4	2	5	2	1	4	4	4	7	4,4	4,4
	5	4	4	4	3	5	5	3	2	4	4	5	6		
	10	7	4	5	4	8	13	6	2	4	4	5	5		
Tot. N (µg N/l)	1	175	150	140	110	111	92	93	89	102	101	105	105	127	110
	5	133	150	112	98	132	80	180	92	102	117	113	107		
	10	180	165	110	122	146	104	120	101	108	104	116	92		
NH_4-N (µg N/l)	1	<5	<5	<5	<5	11	11	11	12	10	9	35	10	11,3	8,7
	5	<5	<5	<5	<5	26	16	14	10	10	9	10	11		
	10	<5	<5	<5	<5	15	8	11	13	9	9	11	8		
NO_3-N (µg N/l)	1	<1	<1	1	2	4	3	4	4	6	3	19	29	8,8	8,6
	5	<1	<1	1	2	3	3	5	3	2	3	24	26		
	10	33	<1	1	2	18	44	4	3	2	2	30	22		

Class I "High"
Class II "Good"
Class III "Moderate"

Table 11. Secchidepth (m) at Hauglandsosen (St 1) and the Reference station (Ref). (Colour coding in accordance to the Norwegian Climate and Pollution Agency's (Klif) environmental quality classification system)

	12. June		12. July		1. August		7. August		26. August		Average June-August	
Parameter	**St 1**	**Ref**	**St 1**	**Ref**	**St 1**	**Ref**	**St 1**	**Ref**	**St 1**	**Ref**	**St 1**	**Ref**
Secchidepth (m)	7.2	8.7	7.5	7.5	8.5	8.0	6.4	6.0	8.0	9.0	7.52	7.84

Class I "High"

Table 12. Chlorophyll-a concentrations at Hauglandsosen (St 1) and the Reference station (Ref). (Colour coding in accordance to the Norwegian Climate and Pollution Agency's (Klif) environmental quality classification system)

		12. June		22. June		12. July		1. August		7. August		26. August	
Parameter	**Depth**	**St 1**	**Ref**	**St 1**	**Ref**	**St 1**	**Ref**	**St 1**	**Ref**	**St 1**	**Ref**	**St 1**	**Ref**
Chlorophyll-a (µg /l)	1	0,9	2,3	0,9	1,0	<1,2	<1,2	<1,2	1,5	<1,2	<1,2	1,8	1,3
	5	2,5	2,5	1,7	1,2	<1,2	-	<1,2	1,7	1,6	<1,2	1,4	1,8
	10	9,2	2,2	3,0	3,5	2,1	2,1	2,2	1,8	1,9	1,7	1,3	1,9
	20	2,6	5,9	4,0	5,1	1,5	1,3	<1,2	<1,2	<1,2	<1,2	<1,2	<1,2

		15. September		5. October		18. October		11. November		Average 1-10 m June-August	
Parameter	**Depth**	**St 1**	**Ref**	**St 1**	**Ref**	**St 1**	**Ref**	**St 1**	**Ref**	**St 1**	**Ref**
Chlorophyll-a (µg /l)	1	3	2,8	<1,2	1,4	3,0	2,0	<1,2	<1,2	<2,0	<1,7
	5	2,3	3,7	<1,2	<1,2	1,7	1,5	<1,2	<1,2		
	10	<1,2	2,2	<1,2	<1,2	<1,2	<1,2	<1,2	<1,2		
	20	<1,2	<1,2	<1,2	<1,2	<1,2	<1,2	<1,2	<1,2		

Class I

Table 13. Oxygen in deepwater in Hauglandsosen and at the reference station.

Station	Date	Depth (m)	O_2 (ml/l)	Classification
Hauglandsosen	23.09.2009	100	4,85	Class I ("High")
		145	4,74	Class I ("High")
		155	4,86	Class I ("High")
		160	4,83	Class I ("High")
	11.11.2009	100	5,44	Class I ("High")
		145	4,88	Class I ("High")
		155	4,89	Class I ("High")
		160	4,93	Class I ("High")
Reference station	23.09.2009	100		
		150	4,83	Class I ("High")
		220	5,25	Class I ("High")
		230	5,08	Class I ("High")
		240	5,09	Class I ("High")
	11.11.2009	100	5,36	Class I ("High")
		150	4,90	Class I ("High")
		220	5,51	Class I ("High")
		230	5,62	Class I ("High")
		240	5,12	Class I ("High")

3.4.4 Sediments

At Askøy west sediments were only investigated for soft-bottom fauna and parameters necessary for classification (organic carbon, grain size). Soft-bottom investigations were performed following the Norwegian standard of investigation of soft-bottom fauna ISO 16665:2005 at all waste water discharges west of Askøy and at 2 references stations (**Figure 17**). The benthic fauna showed good environmental condition for the majority of the discharges. At Kollevåg, Hauglandshella, Eide (Hetlevik), and Haugadalen (Follese) the benthic conditions were excellent, corresponding to class I “High” in the Norwegian classification system (cf. **Table A1**). The benthic fauna at the reference stations showed, as earlier, good conditions and belongs to class I “High”. At Juvik (**Figure 17**, st.3) untreated waste water had been discharged during a period of 1-2 months, caused by a clogged discharge pipe. The discharges of untreated waste water lead to bad conditions corresponding to class V “Very poor” (**Table 14**). When discovered, the discharge of untreated waste water was immediately stopped.

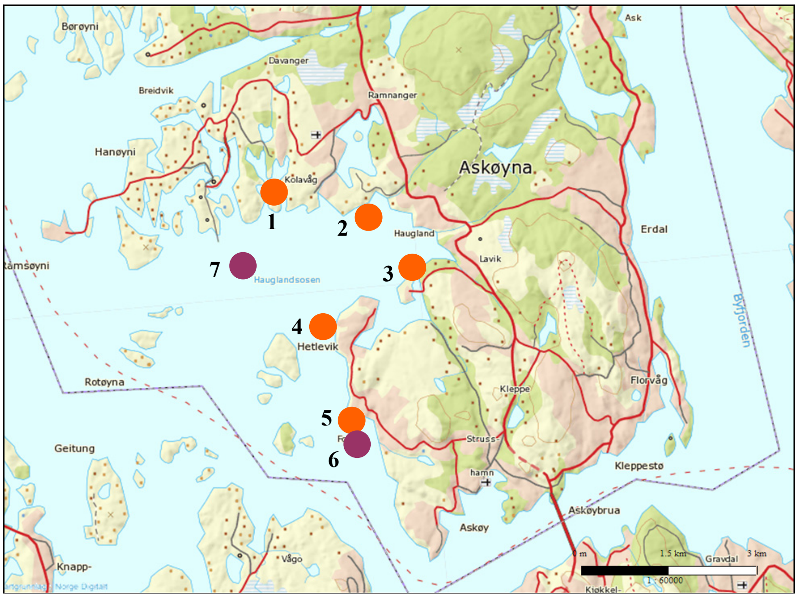


Figure 17. Map of soft-bottom sampling. 1 = Kollevåg, 2 = Hauglandshella, 3 = Juvik, 4 = Eide (Hetlevik), 5 = Haugadalen (Follese), 6 = reference station A24, 7 = reference station Ha10.

Table 14. Summary of station parameters at stations at Hauglandsosen. H´ = Shannon-Wiener index.

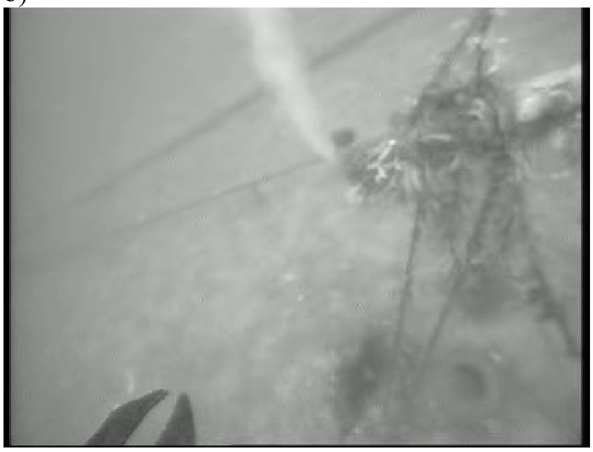
Station	Depth (m)	Area (m^2)	Number of species	Occur-rence	% <63µm	Ignition loss	H´
Kollevåg, St.1	45	0.4	64	70	11.8	4.9	4.70
Kollevåg, St.2	44	0.4	68	844	8.8	5.5	4.98
Hauglandshella, st.2	20	0.4	64	3416	6.2	2.9	4.18
Juvik, St.1	34	0.4	9	18420	41,3	32,4	0.48
Juvik, St.2	37	0.4	41	17353	3.5	10.2	0.52
Eide (Hetlevik), St.1	18	0.4	106	4306	3.5	4.6	4.70
Eide (Hetlevik), St.2	23	0.4	81	2550	1.5	3.5	4.36
Haugadalen (Follese), St.1	32	0.4	80	1251	2.3	4.2	4.42
Haugadalen (Follese), St.2	44	0.4	114	1181	17.9	8.3	5.79
A24 (reference station)	82	0.4	107	1337	24.6	11.6	5.05
Ha10 (reference station)	190	0.4	60	1009	97.3	14.7	4.46

3.4.5 Visual inspections with ROV

At all stations ROV was used to find position and depth for the pipe ends (**Table 15**). Videos were recorded to document the environmental condition at the pipe ends and for visual inspections of the pipeline. At all stations, except Juvik, there were no sign of debris or surface pollution at the pipe ends. At Juvik the ROV inspection revealed that untreated waste water was pumped out into the inner part of Juvik caused by a clogged discharge pipe. At the pipe end some debris were observed.

a)

b)



c)

d)

e)

f)

Figure 18. Plume and pipe end area at a) Kollevåg, b) and c) Hauglandshella, d) Juvik, e) Eide (Hetlevik), and f) Haugadalen (Follese).

Table 15. Positions and depth for the pipe ends at stations at Askøy west.

Area	Station	North	East	Depth (m)
Askøy west	Kollevåg	60° 26,486	5° 06,951	45
	Hauglandshella	60° 26,675	5° 09,291	27
	Juvik	60° 26,189	5° 10,256	33
	Eide (Hetlevik)	60° 25,181	5° 08,622	14
	Haugadalen (Follese)	60° 24,590	5° 08,908	32

3.4.6 Model calculations

The model calculations have given the following results in order to ensure acceptable discharge trapping depths in Hauglandsosen in 2030:

- Kollevåg – the discharge can remain as it is to-day (**Figure 19**).
- Hauglandshella – lowering the discharge depth to 40 m or a discharge depth at 30 m and use of a diffusor (**Figure 20**, **Figure 21**).
- Juvik – lowering the discharge depth to 40 m or a discharge depth at 30 m and use of a diffusor (**Figure 22**, **Figure 23**).
- Eide (Hetlevik) – lowering the discharge depth to 40 m or a discharge depth at 30 m and use of a diffusor (**Figure 24**, **Figure 25**).
- Haugadalen (Follese) – lowering the discharge depth to 40 m or a discharge depth at 30 m and use of a diffusor (**Figure 26**, **Figure 27**).

For Kollevåg the calculations are made for a discharge depth of 30 m, but the real discharge depth is 45 m. Despite this the discharge trapping depths at Kollevåg are deeper than 12 m.

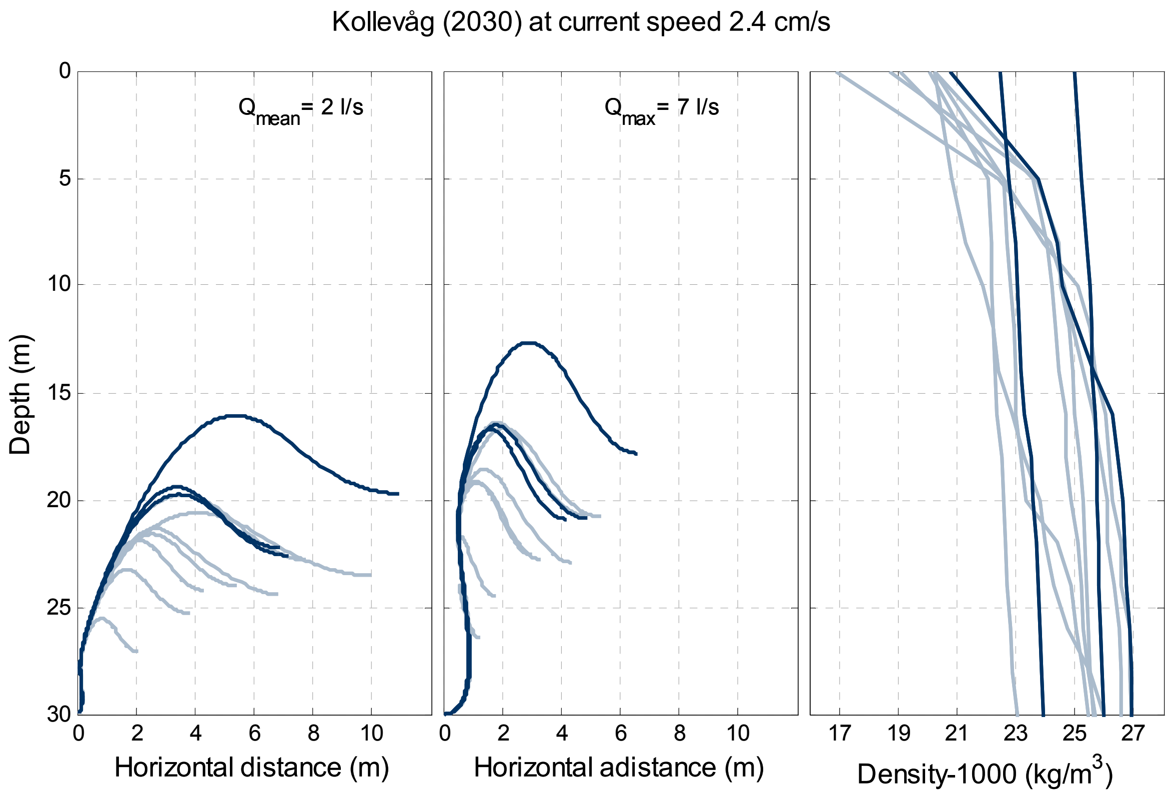


Figure 19. Discharge trapping depth at Kollevåg calculated for discharge water flows of 2 and 7 l/s in 2030, at 30 m depth, and current speed 2.5 cm/s. Right panel show the different stratification scenarios used. The three situations giving the worst cases are marked with darker colour.

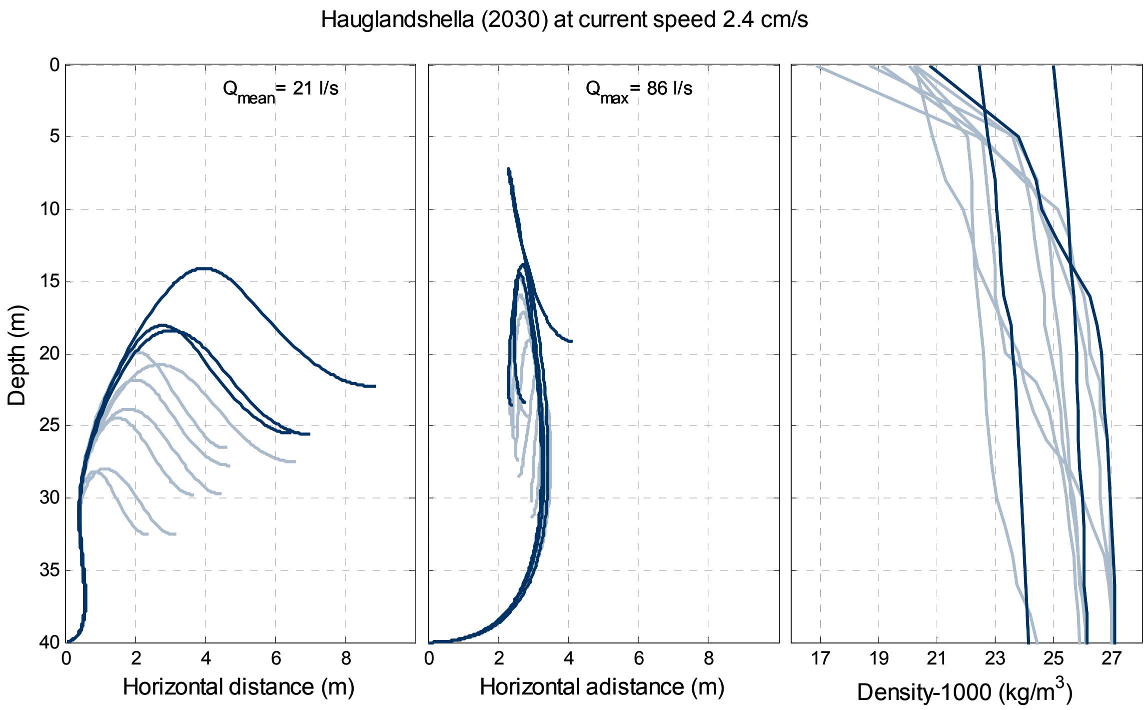


Figure 20. Discharge trapping depth at Hauglandshella calculated for discharge water flows of 21 and 86 l/s in 2030, discharge depth of 40 m, and current speed 2.4 cm/s. Right panel show the different stratification scenarios used. The three situations giving the worst cases are marked with darker colour.

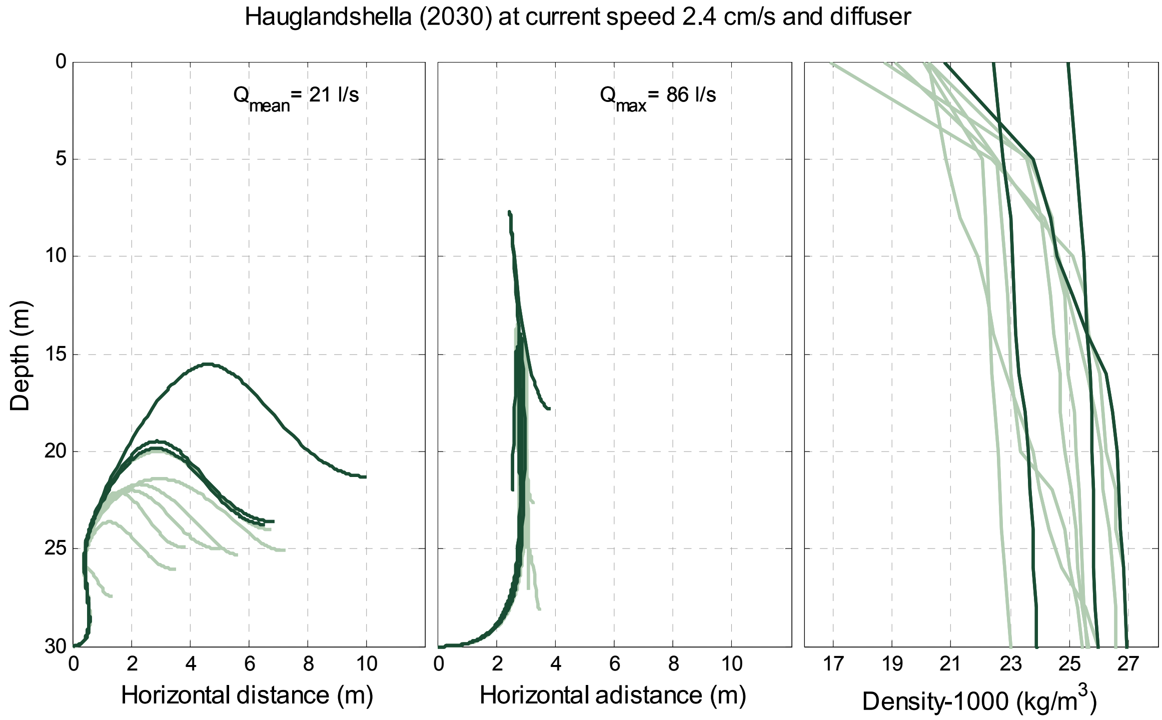


Figure 21. Discharge trapping depth at Hauglandshella calculated for discharge water flows of 21 and 86 l/s in 2030, discharge depth of 30 m, current speed 2.4 cm/s, and use of a diffusor (10 holes, diameter = 8 cm, 3 m between holes). Right panel show the different stratification scenarios used. The three situations giving the worst cases are marked with darker colour.

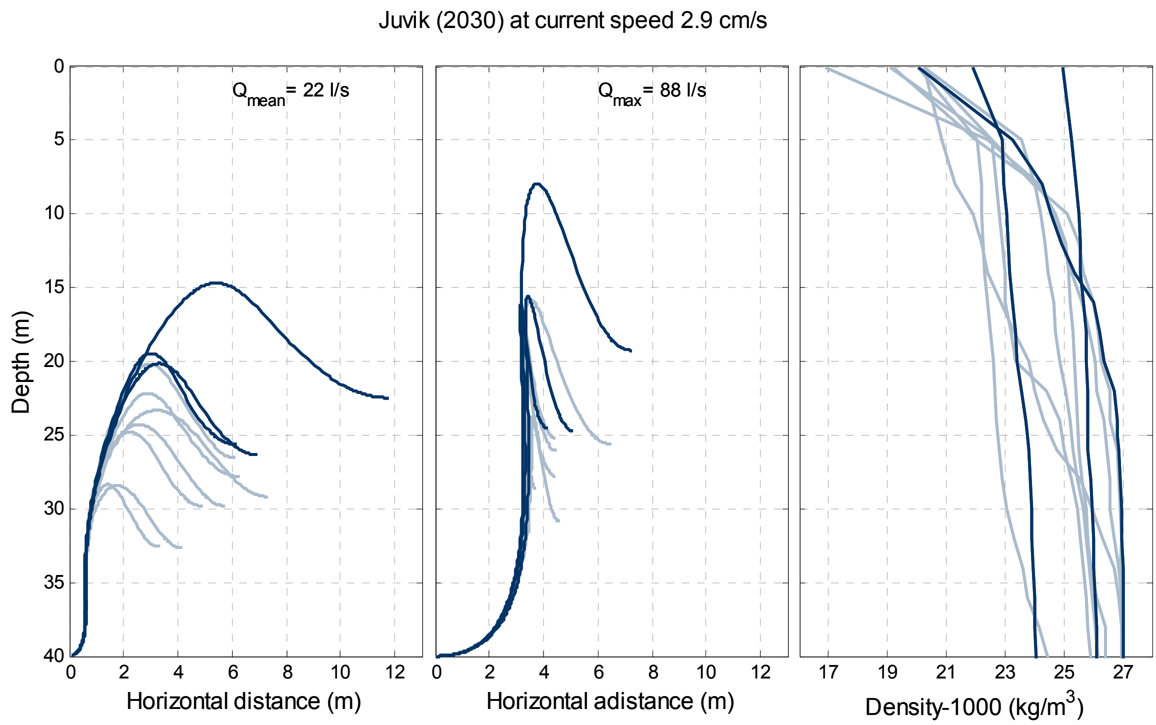


Figure 22. Discharge trapping depth at Juvik calculated for discharge water flows of 22 and 88 l/s in 2030, discharge depth of 40 m, and current speed 2.9 cm/s. Right panel show the different stratification scenarios used. The three situations giving the worst cases are marked with darker colour.

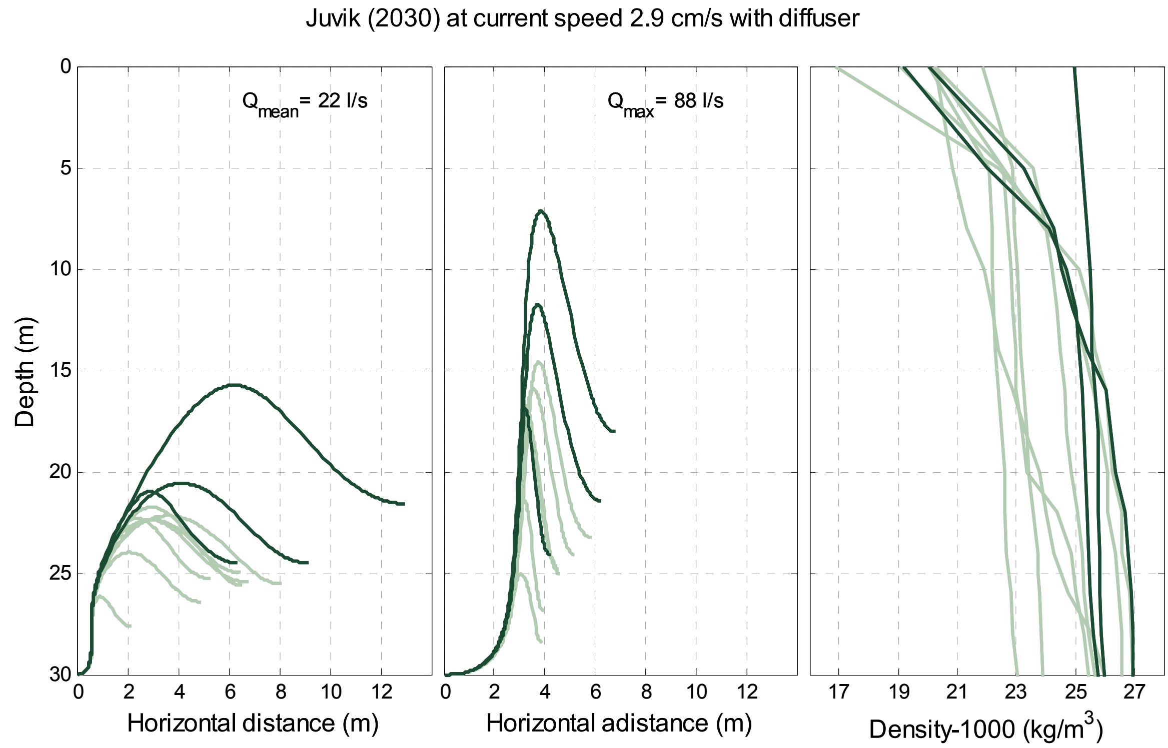


Figure 23. Discharge trapping depth at Juvik calculated for discharge water flows of 22 and 88 l/s in 2030, discharge depth of 30 m, current speed 2.9 cm/s, and use of a diffusor (10 holes, diameter = 8 cm, 3 m between holes). Right panel show the different stratification scenarios used. The three situations giving the worst cases are marked with darker colour.

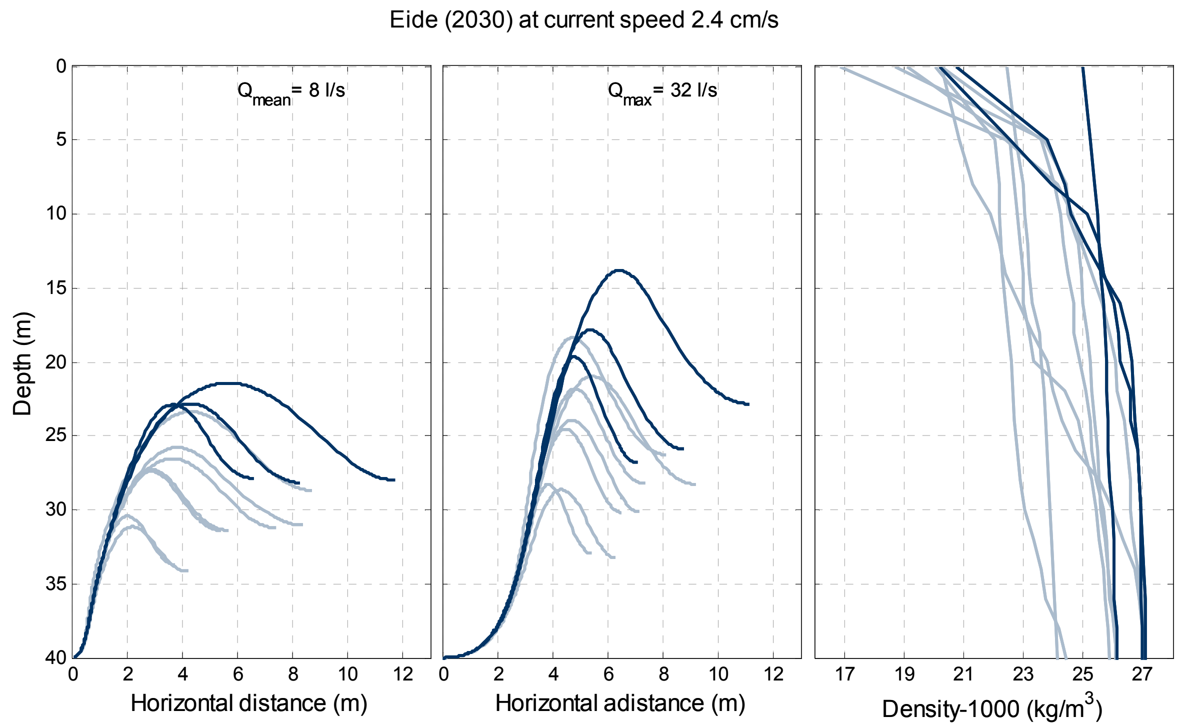


Figure 24. Discharge trapping depth at Eide calculated for discharge water flows of 8 and 32 l/s in 2030, discharge depth of 40 m, and current speed 2.4 cm/s. Right panel show the different stratification scenarios used. The three situations giving the worst cases are marked with darker colour.

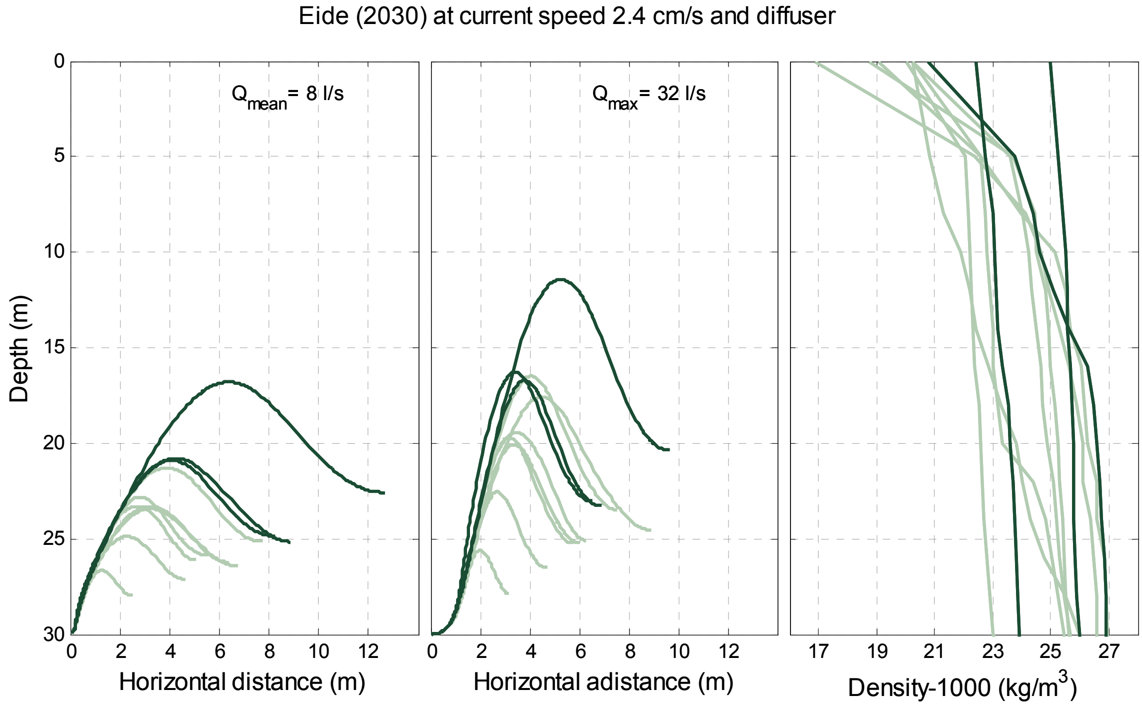


Figure 25. Discharge trapping depth at Juvik calculated for discharge water flows of 22 and 88 l/s in 2030, discharge depth of 30 m, current speed 2.4 cm/s, and use of a diffusor (10 holes, diameter = 8 cm, 3 m between holes). Right panel show the different stratification scenarios used. The three situations giving the worst cases are marked with darker colour.

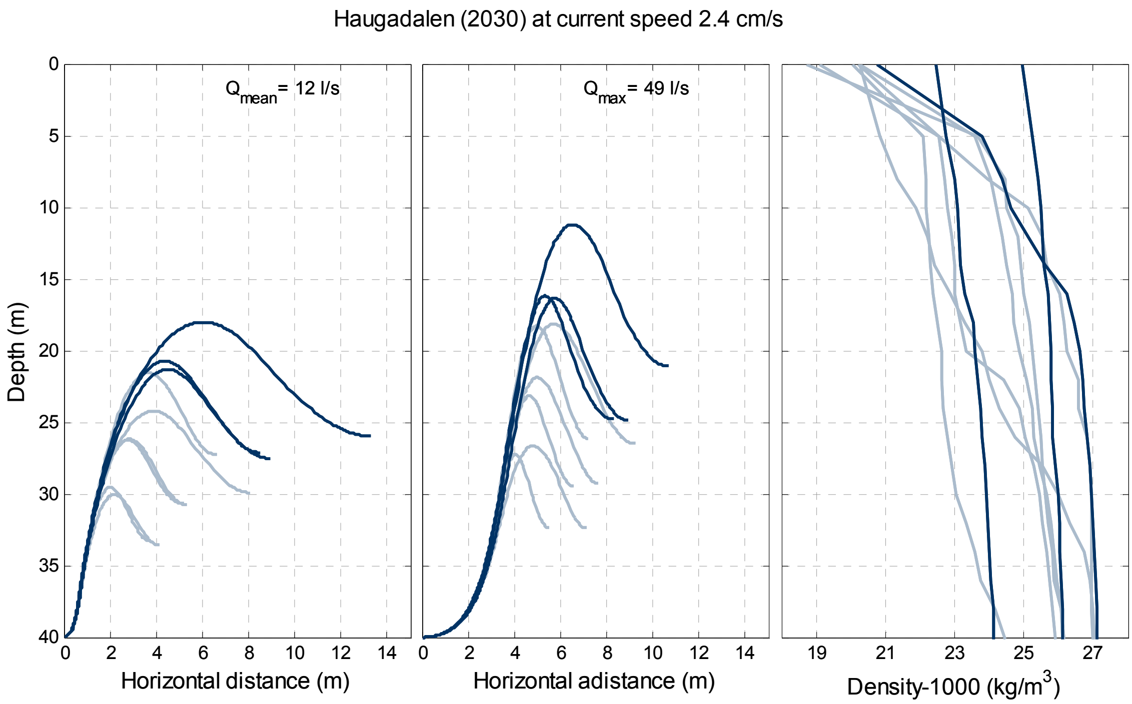


Figure 26. Discharge trapping depth at Haugadalen calculated for discharge water flows of 12 and 49 l/s in 2030, discharge depth of 40 m, and current speed 2.4 cm/s. Right panel show the different stratification scenarios used. The three situations giving the worst cases are marked with darker colour.

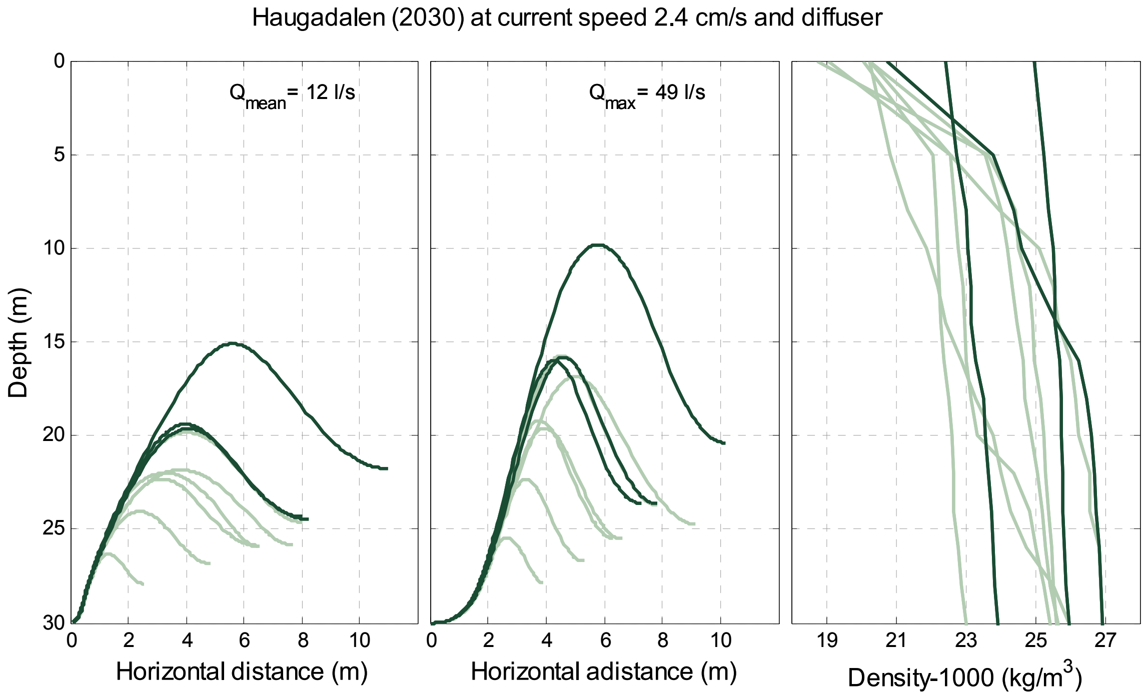


Figure 27. Discharge trapping depth at Haugadalen calculated for discharge water flows of 12 and 49 l/s in 2030, discharge depth of 30 m, current speed 2.9 cm/s, and use of a diffusor (10 holes, diameter = 8 cm, 3 m between holes). Right panel show the different stratification scenarios used. The three situations giving the worst cases are marked with darker colour.

4. Conclusions

4.1 Environmental conditions in the fjord areas and impacts of municipal waste water discharges

Based on measurements of nutrients available for phytoplankton (phosphate, nitrate, ammonia) and chlorophyll-a (phytoplankton biomass) in the watermasses, oxygen in deep water, and control of macroalgae close to municipal waste water discharges, the watermasses have been classified as “Good” and “High” at all investigated areas. Analyzes based on benthic fauna also gave the classification “Good” or “High” for all stations except one where technical problems had caused a clogged discharge pipe. Control by use of ROV at the end of all the pipe lines has shown very good conditions (except for the one with technical problems).

According to EU Water Framework Directive focus should be put on how marine organisms respond on nutrient loads, organic load etc. The control of chlorophyll-a, macroalgae, and benthic fauna all give the classification “High” or “Good”. This shows that biota in the marine recipients around Askøy are scarcely affected by the municipal waste water discharges from Askøy or other nearby areas. Current measurements have shown current speeds high enough to give good water exchange in all the investigated recipients around Askøy. At the west coast of Askøy the Norwegian Coastal Current causes powerful water transport to the northwest giving good water exchange in this area. This and the results from the completed investigations supports earlier classification of this area as a less sensitive area.

To make sure that the discharge trapping depths from the respective waste water discharges are acceptable, model calculations have been carried out for estimated water flows in 2030. The calculations have shown that discharge depths of 30 m are sufficient for all the 11 planned discharges pipelines if a diffusor is used. If the recommendations are followed, the environmental conditions in the recipients may be even better than today.

5. Literature

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Appendix A.

Table A1. Classification of soft-bottom fauna and sediment organic content (from Molvær et al. 1997 (TA-1467/1997)).

		Classes				
	Parameters	**I High**	**II Good**	**III Moderate**	**IV Poor**	**V Bad**
Biodiversity of soft bottom fauna	Hurlbert index ($ES_{n=100}$)	>26	26-18	18-11	11-6	<6
	Shannon-Wiener index (H)	>4	4-3	3-2	2-1	<1
Sediments	Organic carbon (mg/g)	<20	20-27	27-34	34-41	>41

Table A2. Classification of heavy metals and organic contaminants in sediment (from Molvær et al. 1997 (TA-1467/1997)).

Parameters	**Classification**				
	I High	**II Good**	**III Moderate**	**IV Poor**	**V Bad**
Arsenic (As) (mg/kg)	<20	20-52	52-190	190-580	>580
Cadmium (Cd) (mg/kg)	<0.25	0.25-2.60	2.5-17	17-160	>160
Copper (Cu) (mg/kg)	<35	35-51	51-120	120-220	>220
Chrome (Cr) (mg/kg)	<70	70-560	560-20000	20000-59000	>59000
Lead (Pb) (mg/kg)	<30	30-83	83-700	700-2200	>2200
Mercury (Hg) (mg/kg)	<0.15	0.15-0.6	0.6-3	3-5	>5
Nickel (Ni) (mg/kg)	<30	30-43	43-120	120-870	>870
Zink (Zn) (mg/kg)	>150	150-360	260-1800	1800-5100	<5100
Tributyltin (TBT) (mg/kg)	<1	1-5	5-20	20-100	>100
∑PAH (µg/kg)	<300	300-2000	2000-6000	6000-20000	>20000
B(a)P (µg/kg)	<10	10-50	50-200	200-500	>500
HCB (µg/kg)	<0.5	0.5-2.5	2.5-10	10-50	>50
∑PCB (µg/kg)	>5	5-25	25-100	100-300	<300

Table A3. Classification of nutrients, chlorophyll-*a*, Secchi depth and oxygen. Oxygen saturation refers to a water mass with temperature 6°C and salinity 33 (from Molvær et al. 1997 (TA-1467/1997)).

	Parameters	Classification				
		I High	II Good	III Moderate	IV Poor	V Bad
Surface layer Summer (June-August)	Total phosphorus (µg P/l)*	<12	12-16	16-29	29-60	>60
	Phosphate- phosphorus (µg P/l)*	<4	4-7	7-16	16-50	>50
	Total nitrogen (µg N/l)*	<250	250-330	330-500	500-800	>800
	Nitrate-nitrogen (µg N/l)*	<12	12-23	23-65	65-250	>250
	Ammonium-nitrogen (µg N/l)*	<19	19-50	50-200	200-325	>325
	Chlorophyll-*a* (µg/l)	<2	2-3.5	3.5-7	7-20	>20
	Secchi depth (m)	>7.5	7.5-6	6-4.5	4.5-2.5	<2.5
Surface layer Winter (December-February)	Total phosphorus (µg P/l)*	<21	21-25	25-42	42-60	>60
	Phosphate- phosphorus (µg P/l)*	<16	16-21	21-34	34-50	>50
	Total nitrogen (µg N/l)*	<295	295-380	380-560	560-800	>800
	Nitrate-nitrogen (µg N/l)*	<90	90-125	125-225	225-350	>350
	Ammonium-nitrogen (µg N/l)*	<33	33-75	75-155	155-325	>325
Deep water	Oxygen (ml O_2/l)**	>4.5	4.5-3.5	3.5-2.5	2.5-1.5	<1.5
	Oxygen saturation (%)	>65	65-50	50-35	35-20	<20

* Conversion factor from µg/l to µg-at/l is 1/31 for phosphorus and 1/14 for nitrogen.
** Conversion factor from mlO_2/l to mgO_2/l is 1.42

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