WHEN TRUST MATTERS

Sjødeponi

Vitneforklaring

Tor Jensen, Dr. scient - Vice president DNV

17 September 2023

Erfaring

- Marinbiolog og leder av Miljøavdelingen i DNV
- Konsulent i over 35 år, hovedområde: effekter på det marine miljøet (fra oljeindustrien og gruvedrift)
- Engasjert meg i sameksistens mellom samfunn og industri, og vært med i flere ressursgrupper/ faggrupper hvor fokus har vært å dele erfaringer mellom industri og brukerinteresser i fjorder

DNV har utført mange studier i forhold til effekter på det marine miljøet fra gruver med deponering i sjø

Temaer

- Tilleggsstudier for Nordic Mining
- Erfaringer fra andre fjorden med operasjonelt depone
- Generelt og spesifikt om målbare effekter
- Dynamisk overvåking – miljøovervåking Førdefjorden i dag

Tilleggsvurderinger – Reguleringsplan og utslippstillatelse

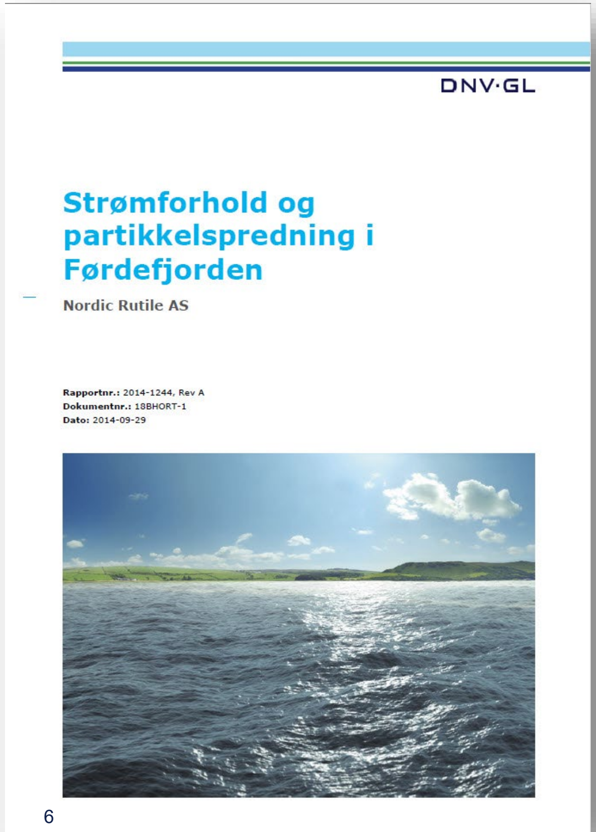
DNV ble engasjert av Nordic Mining i 2013 i forbindelse med tilleggsundersøkelser som det var gitt krav om.

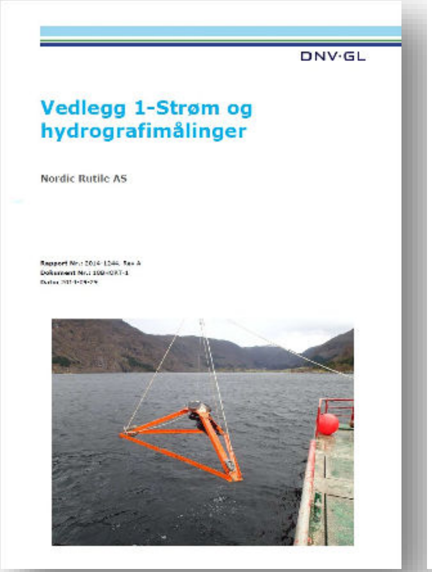
5 områder med tilleggsvurderinger

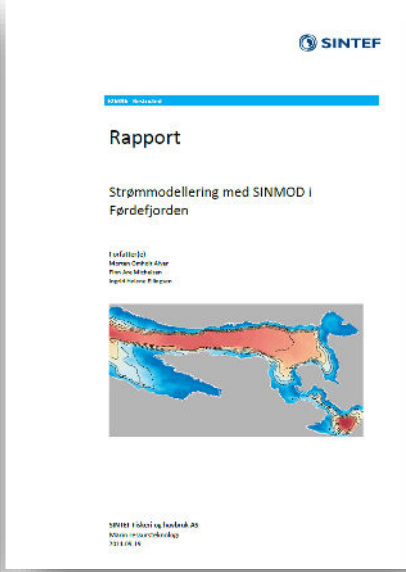
1. **Strømningsmønster i Førdefjorden, risiko for spredning av partikler (DNV + SINTEF)**
2. **Fiske, gyteområder, truede og verdifulle arter i deponiområdet (DNV)**
3. Plan for deponering av avgangsmasser (Nordic Mining)
4. Utgreiing av bore-sprenningsmønster, effekter for fisk, ål (Nordic Mining, DNV)
5. Informasjon om tilførsel av feskvann, vassdragsregulering, konsekvenser for naturmangfold og vanntilstand (Nordic Mining)

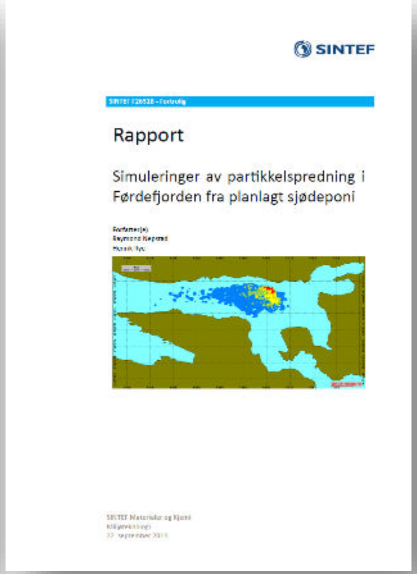
Rapport om partikkelspredning ble presentert høsten 2014

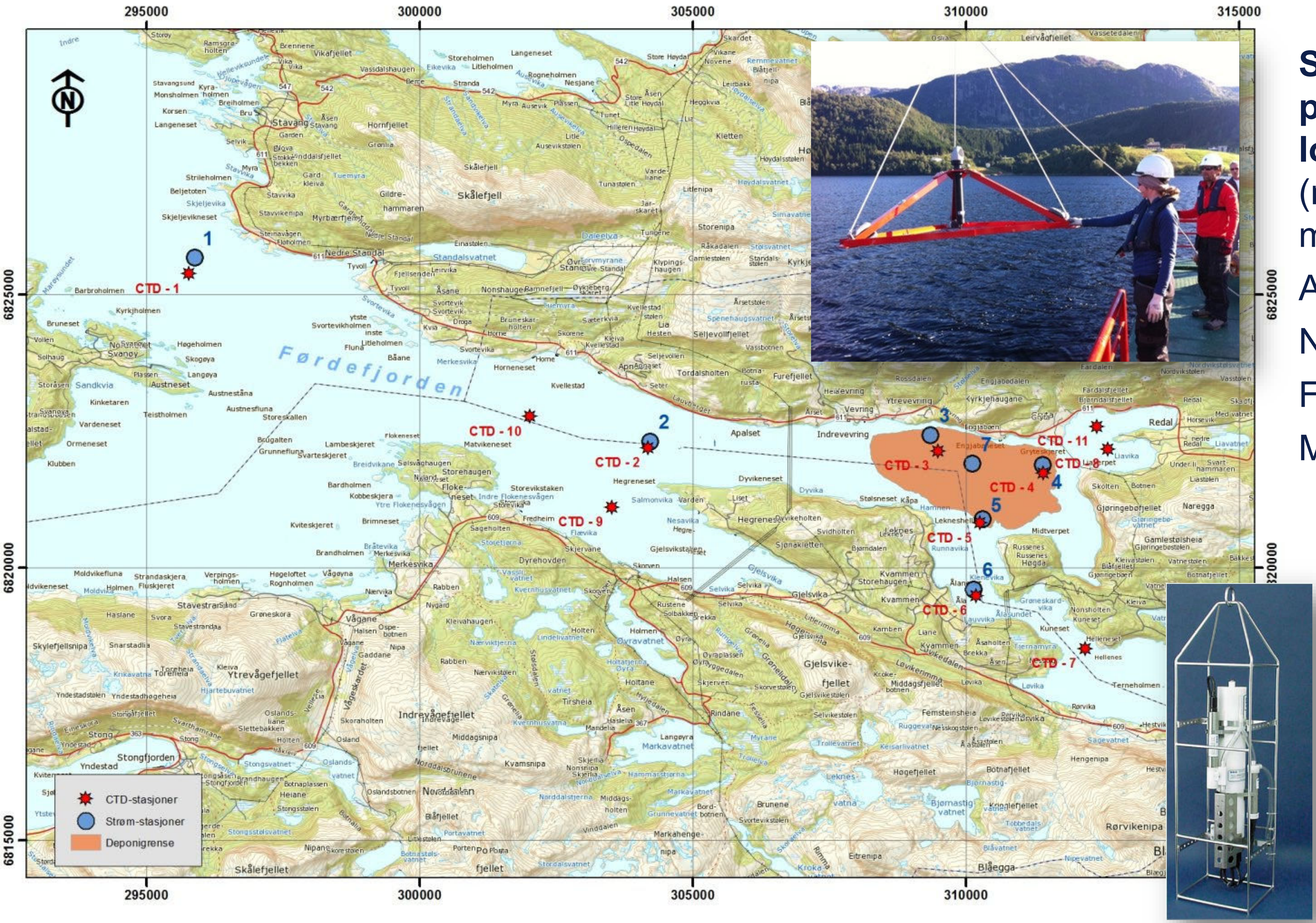
SINTEF: strømmodellering (SINMOD) og simulering av partikkel-spredning (DREAM)
DNV: Målinger og vurderinger av flokkulering











Stømmålinger i 4 perioder på 7 lokaliteter

(målinger hver 15. min)

Aug-nov. 2013

Nov.13 – febr 2014

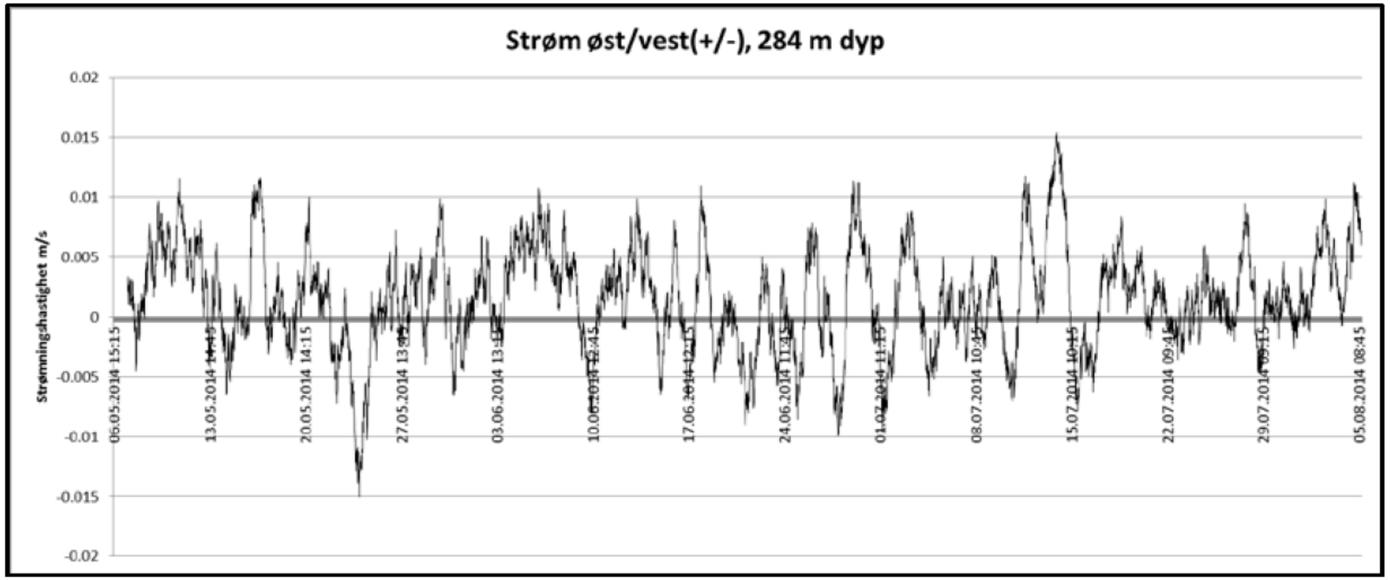
Febr – mai 2014

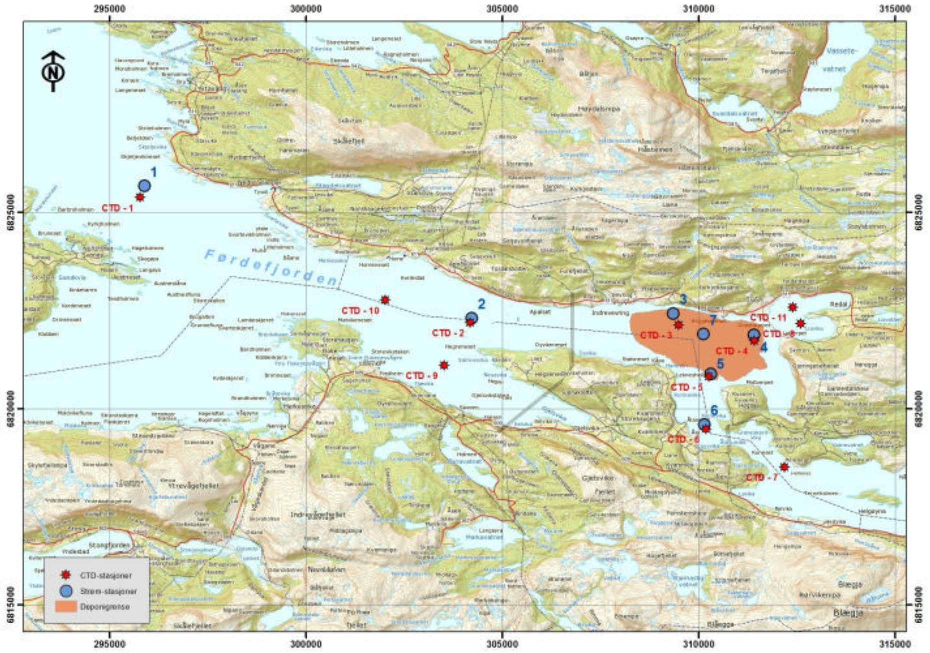
Mai – aug. 2014

CTD -11 st. 7

(målinger ca hvert sekund) ganger

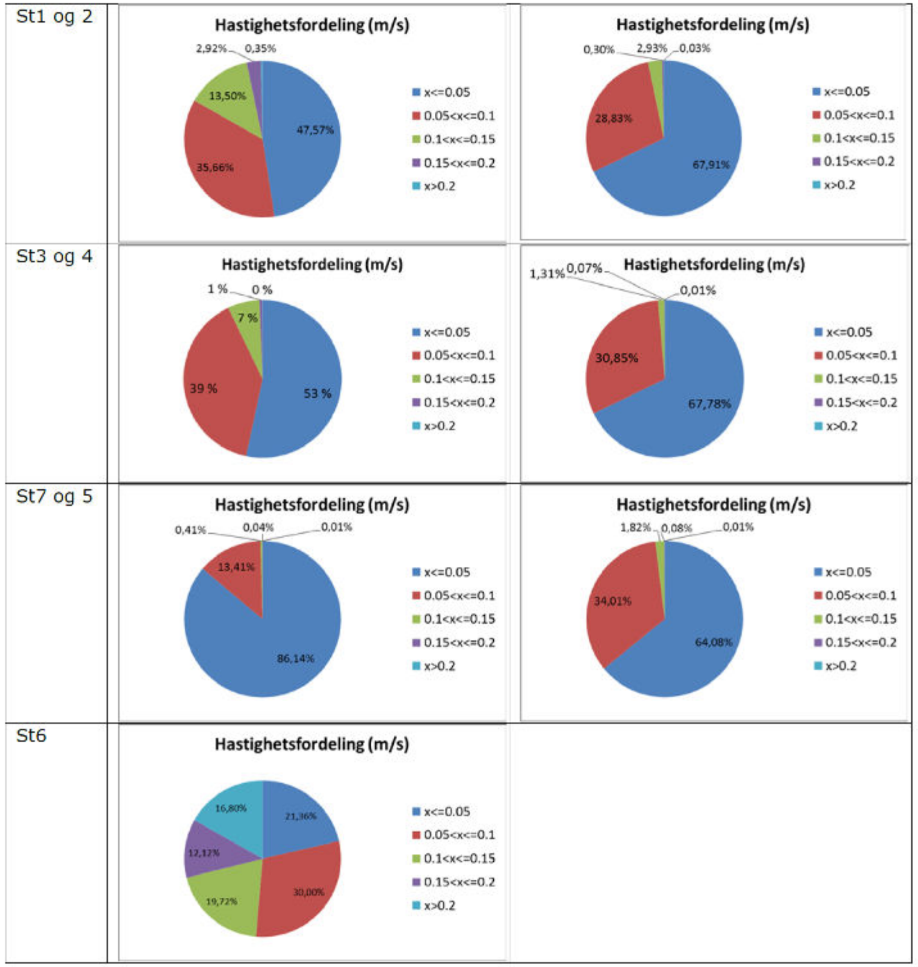
- Over hele måleperioden var mesteparten av målingene under 5 cm/s for stasjonene i deponiområdet.
- De høyeste strømhastighetene er målt for Stasjon 6 (7-24 cm/s), plassert ved Ålasundet, indre terskel.





SINMOD: 12 mnd data oppdatert hvert 20. min

Dataene presentert:



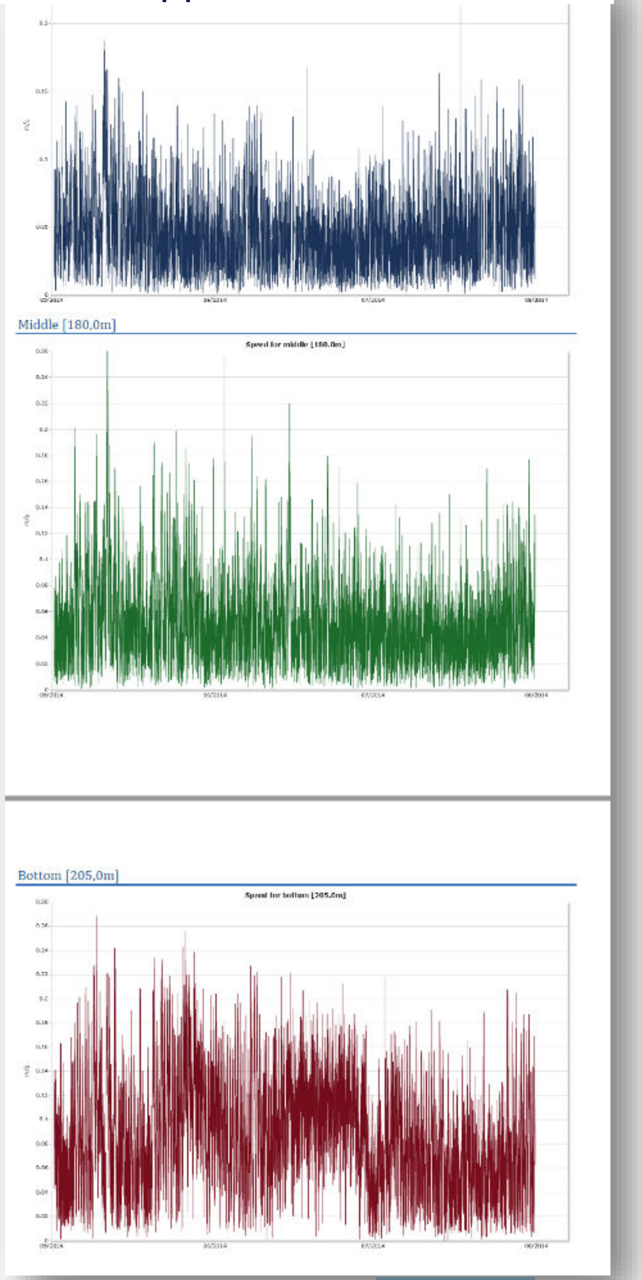
Figur 4: Strømmålinger stasjon 1-7, hastighetsfordeling, alle dybdeintervall for nedre målere, periode 4(se Appendiks 1). Førdefjorden 2014.

"Gjennomsnittsdata" (m/s)

Tabell 2: Sesongvariasjon i månedlig middelstrøm (cm/s) over måleperioden, utvalg av dybdelag i undersøkelsesområdet, Førdefjorden. Maksimum- og minimumsverdiene er basert på månedlige middelhastigheter. Stasjon 7 har bare målinger fra siste måleperiode. Flere detaljer, se Appendiks 1.

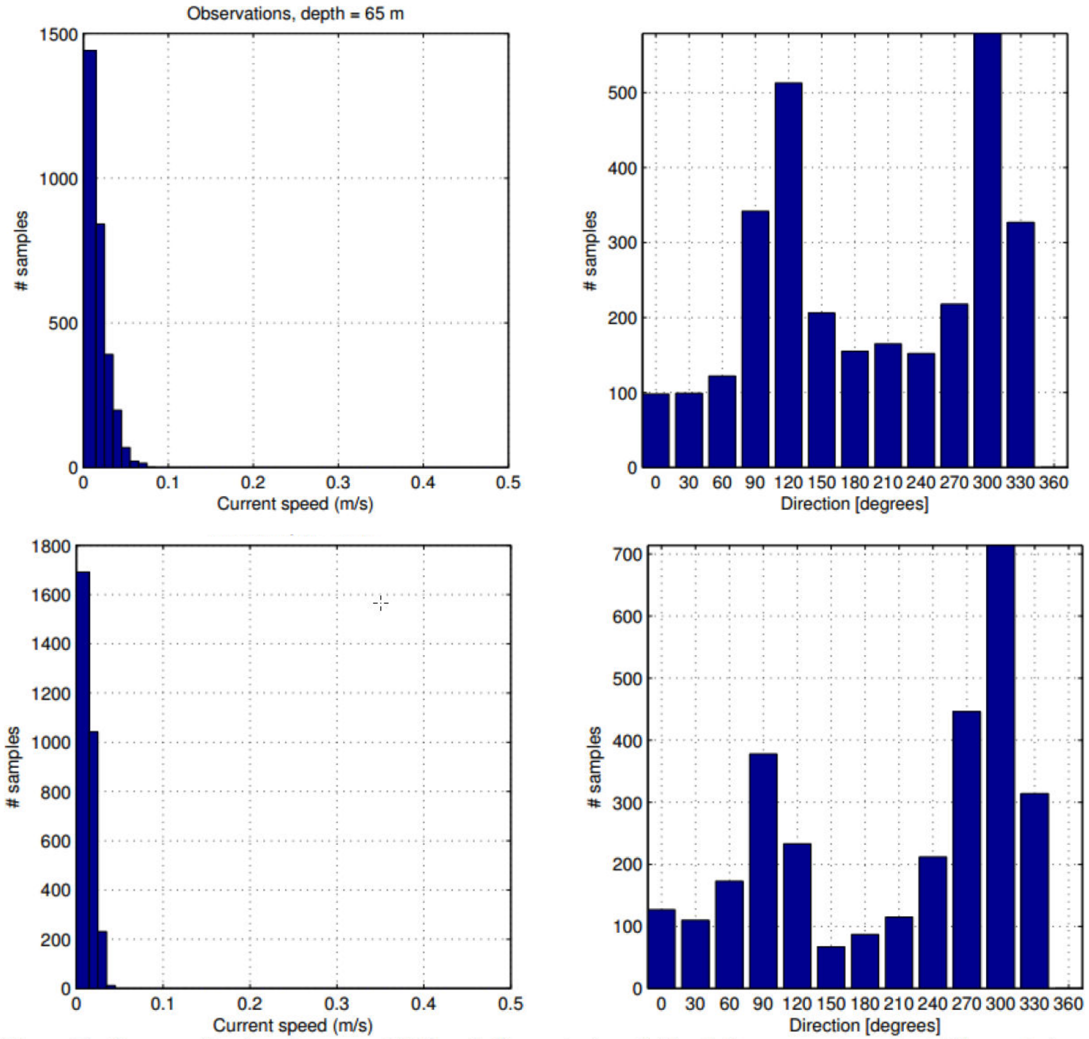
Område	Førdefjorden, ytre				Foreslått deponiområde								Indre terskel	
Stasjoner	St 1		St 2		St 3		St 4		St 5		St 7*		St 6	
Dyp (m)	Min	Maks	Min	Maks	Min	Maks	Min	Maks	Min	Maks	Min	Maks	Min	Maks
20													7,4	9,4
30													8,3	15,0
40													11,1	21,0
50							4,0	4,7	4,6	6,6			16,8	24,3
60			4,6	8,3			3,9	4,5	4,3	6,9				
70	4,6	7,5	4,4	7,9			3,7	4,8	4,2	6,6				
80	4,5	8,3	4,5	7,5			4,2	5,5	4,7	6,7				
90	4,6	10,8	4,5	8,0										
100	5,1	8,3	5,0	8,2										
130									4,5	5,9				
140									4,3	5,7				
150									2,8	5,3				
160							4,0	4,8	2,8	5,0				
170			3,6	5,4			3,8	4,4	2,7	4,7				
180	4,1	13,2	3,5	5,2			3,8	4,3	2,6	4,6				
190	4,7	12,8	3,7	5,1			3,7	4,2	2,6	4,6				
200	5,5	11,7	3,6	5,3			3,7	4,2	2,6	4,6				
210	6,0	12,9	3,7	5,6			3,7	4,1	2,6	4,6				
220			3,7	5,7			3,8	4,1	2,8	4,5				
230			3,8	5,7			3,9	4,3	3,1	4,5				
240			3,9	5,8			3,8	4,4	3,4	4,6				
250			4,0	6,4			3,8	4,6	3,8	4,8				
260			4,3	6,9			3,9	5,2	4,8	5,4				
270			4,3	7,3			4,1	6,1	5,0	6,0	2,7	3,0		
280			4,8	7,7			5,0	7,6			2,8	3,0		
290			5,0	7,8							3,0	3,1		
300			5,2	7,9	4,0	5,1					3,3	3,4		
310					4,0	5,6								
320					4,0	7,5								
Stasjons-dyp	215m		310m		325		290m		281m		316m		57m	

"Minimum/maksimum" (cm/s)

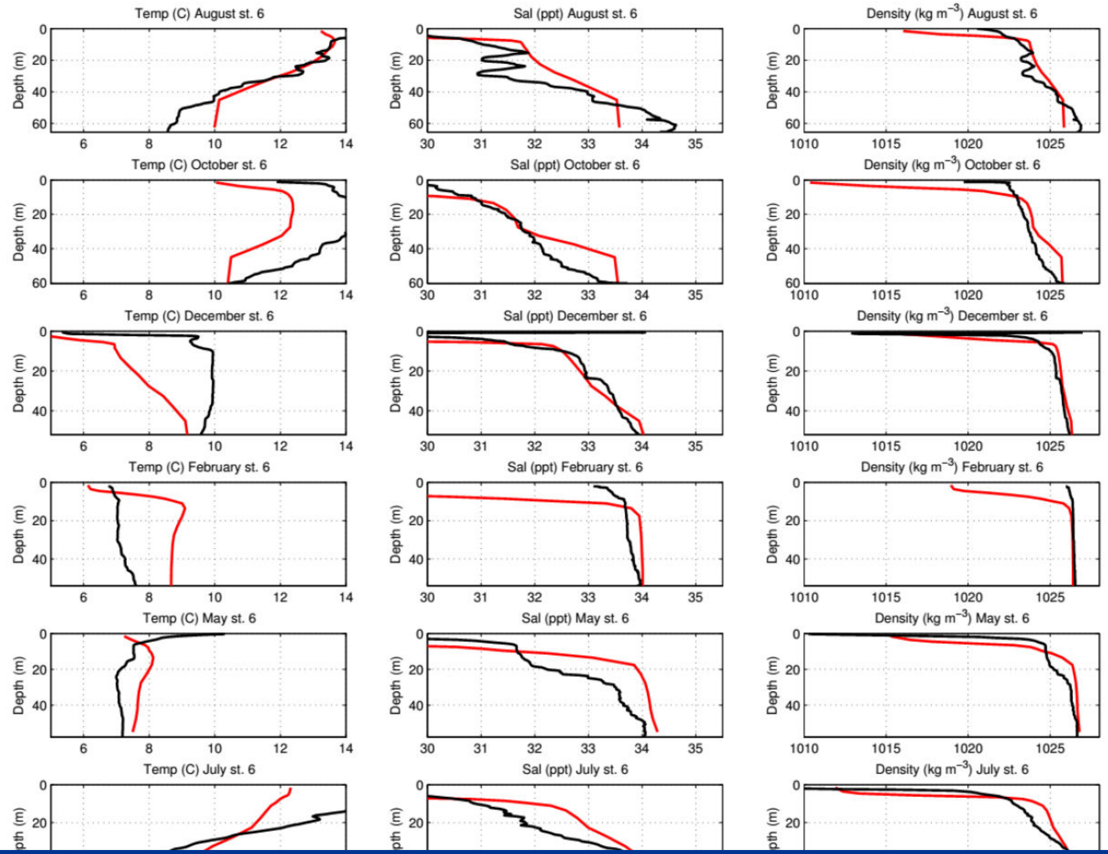


"Enkeltmålinger" (DNV 2014-1116)

Bruker måledata til å validere resultater fra strømmodellen til SINTEF (SINMOD)



Figur 31: Sammenligning for mars 2014 ved 65 m, stasjon 4. Fordelinger av strømfart (til venstre) og retninger (til høyre), sammenlignet mellom målinger (øverst) og modell (nederst).



Noe data viste stort samsvar – andre mindre samsvar (hyppigst når det var lav strøm)

SINMOD: 12 mnd data oppdatert hvert 20. min

SINTEF sin konklusjon mht validering av strømmodell (SINMOD)

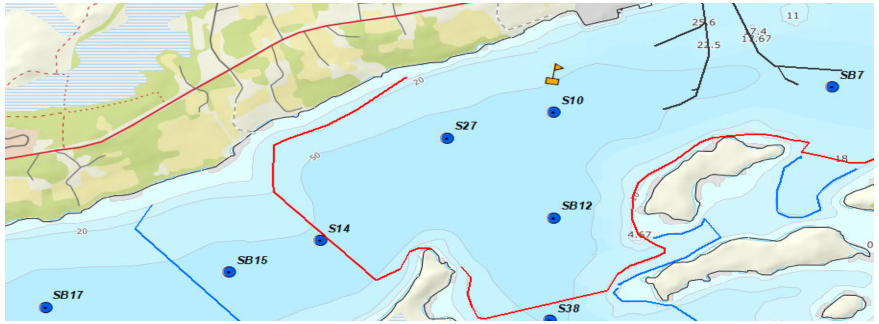
- *Vi konkludere med at modellen gir en god beskrivelse av strøm i Førdefjorden.*

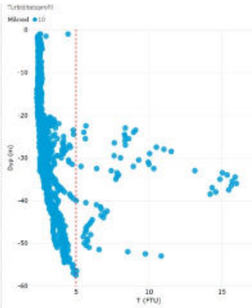
- *Modellresultatene er konsistente med rådende kunnskap om fjordsirkulasjon, og med tidligere modellresultater og observasjoner i fjorden.*

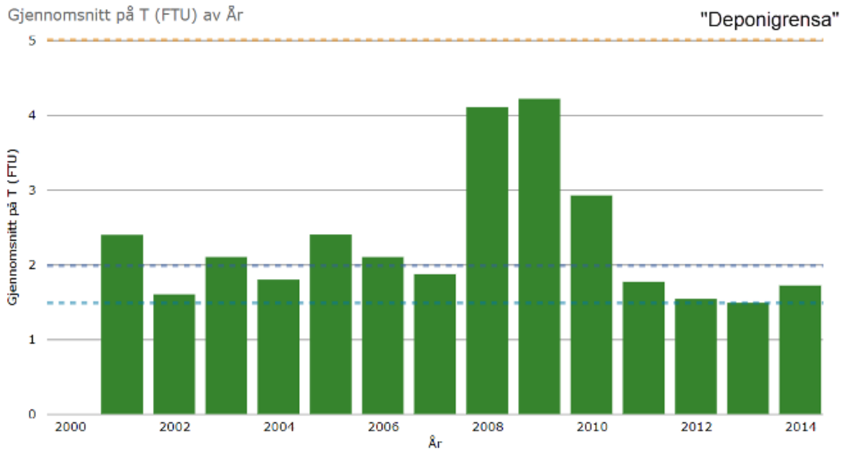
- *Det er betydelig grad av sammenfall mellom modellerte og målte resultater, og i de tilfellene der vi ser klare avvik handler dette om svakheter i å reprodusere dynamikken i punkter med utfordrende lokal topografi, eller dynamikken i spesifikke tidsperioder.*

I samme periode som vi gjorde tilleggsstudier i Førdefjorden gjorde vi studier i Frænfjorden for et annet gruveselskap, men som var operativt… og vi kunne teste ut bruk av modeller i en “real case”

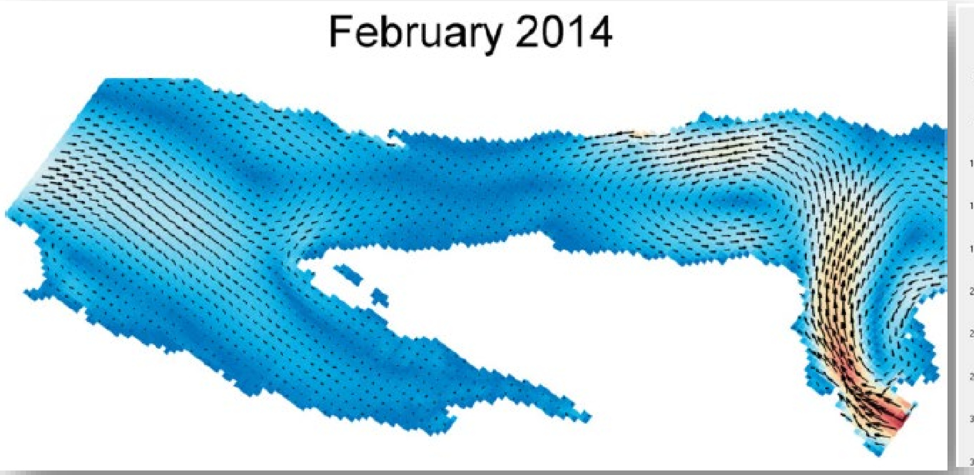
1 Samler inn data om partikkelspredning med målinger (tid – sted)

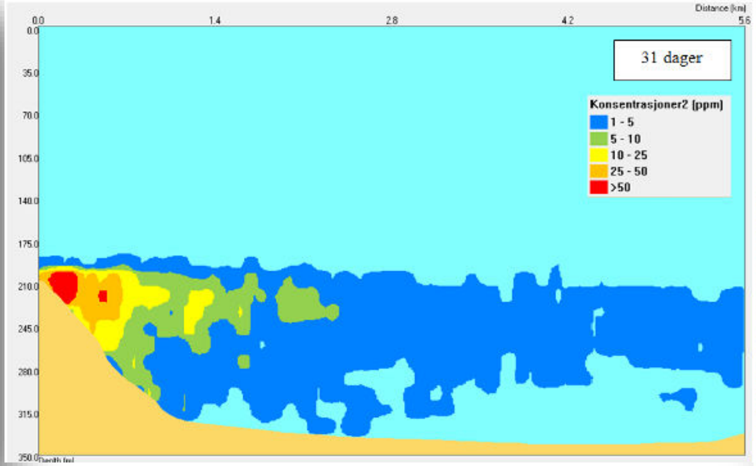


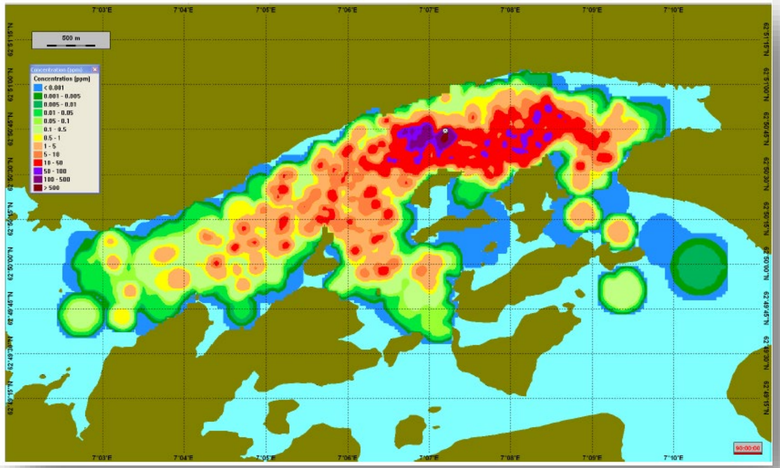




2 Utnytte modeller for å gi en prognose for hva som vil skje (simulere spredning) – eller for å kunne fylle hull i målte data





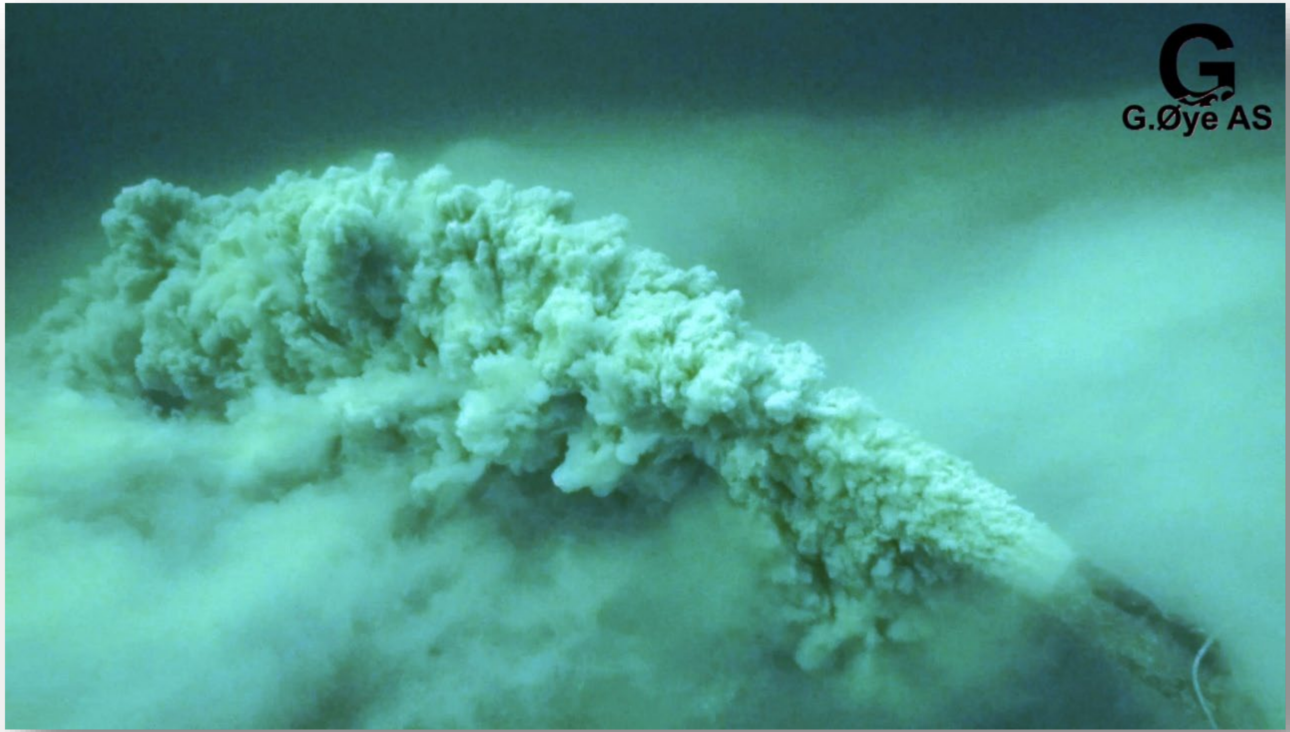


Spredning av partikler

Partikkelfordeling i avgangen

Particulate-Size Distribution

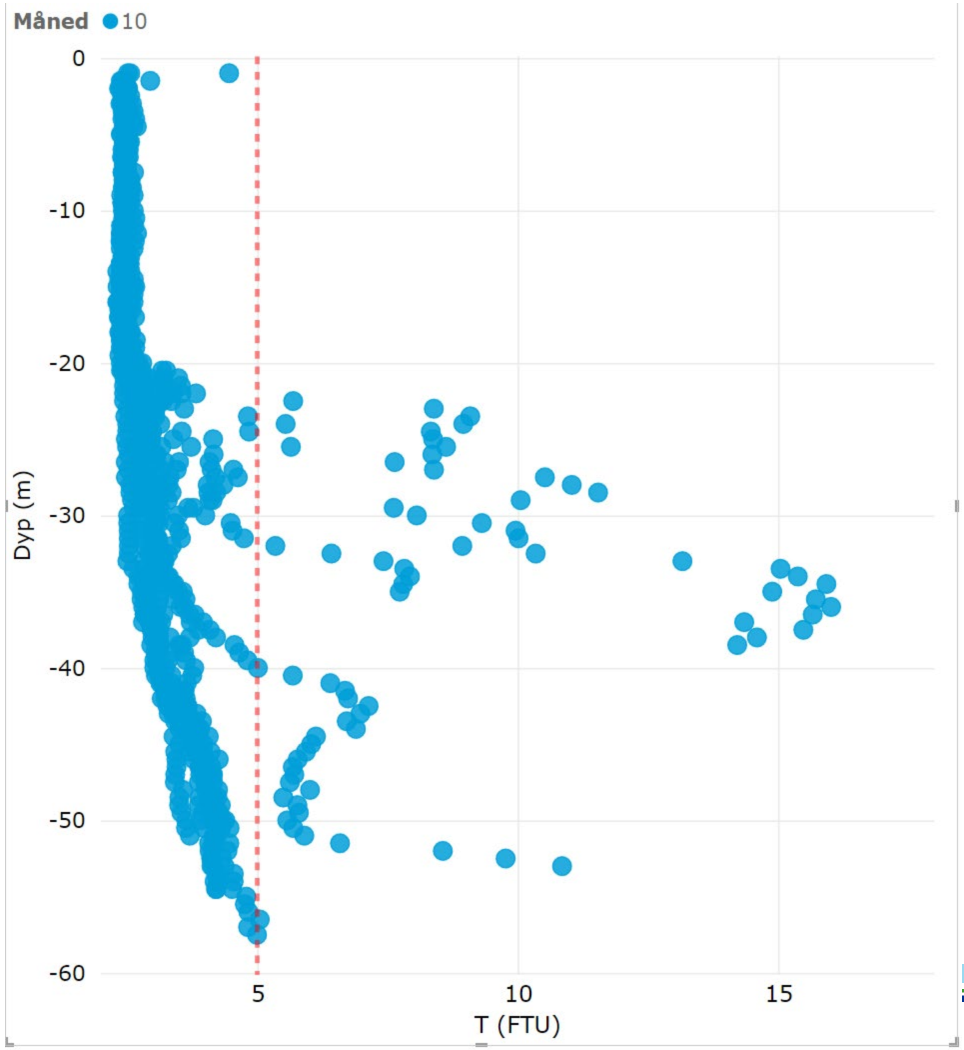
Size Interval (µm)	Fraction (%)	Cum.Fraction
1<>2	31.00	31.00
2<>20	40.00	71.00
20<>63	11.00	82.00
63<>250	14.50	96.50
250<>400	2.50	99.00
400<>800	1.00	100.00



Avgangsrør - Frænfjorden

DNV

Den vanligste måten å måle partikler på er å bruke sensorer som måler “turbiditet” - hvor klart vannet er…



Norsk Standard for overvåking av tiltak i vannforekomster, NS 9433

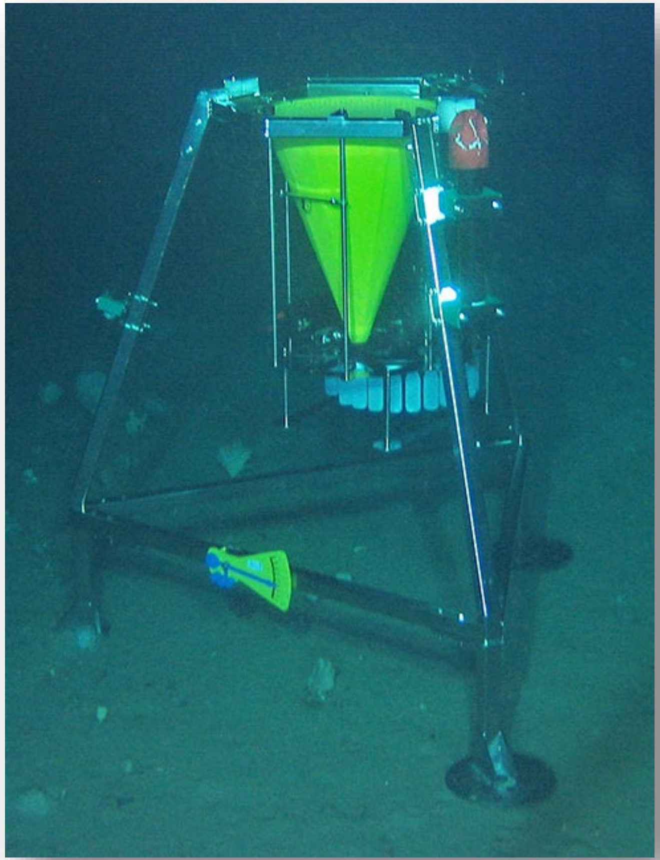
Arbeid og tiltak i vann medfører gjerne visse mengder forurensning. NS 9433 Turbiditetsovervåking av tiltak i vannforekomster, er et viktig verktøy for arbeidet med overvåking av partikkelkonsentrasjon eller turbiditet i vann hvor det er gjort inngrep.

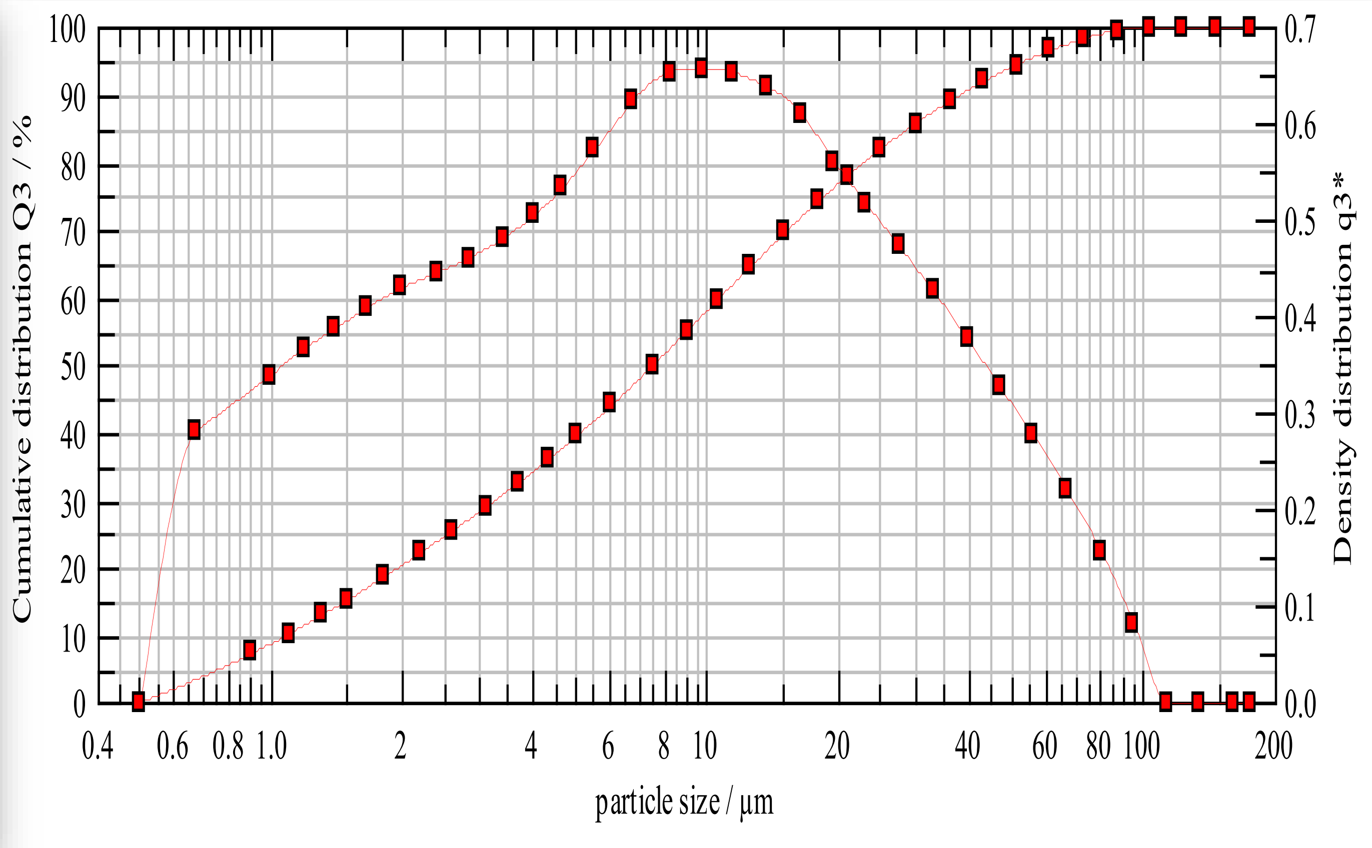
NV

Sedimentasjonsrater og kornfordeling

Particulate-Size Distribution

Size Interval (µm)	Fraction (%)	Cum.Fraction
1<>2	31.00	31.00
2<>20	40.00	71.00
20<>63	11.00	82.00
63<>250	14.50	96.50
250<>400	2.50	99.00
400<>800	1.00	100.00

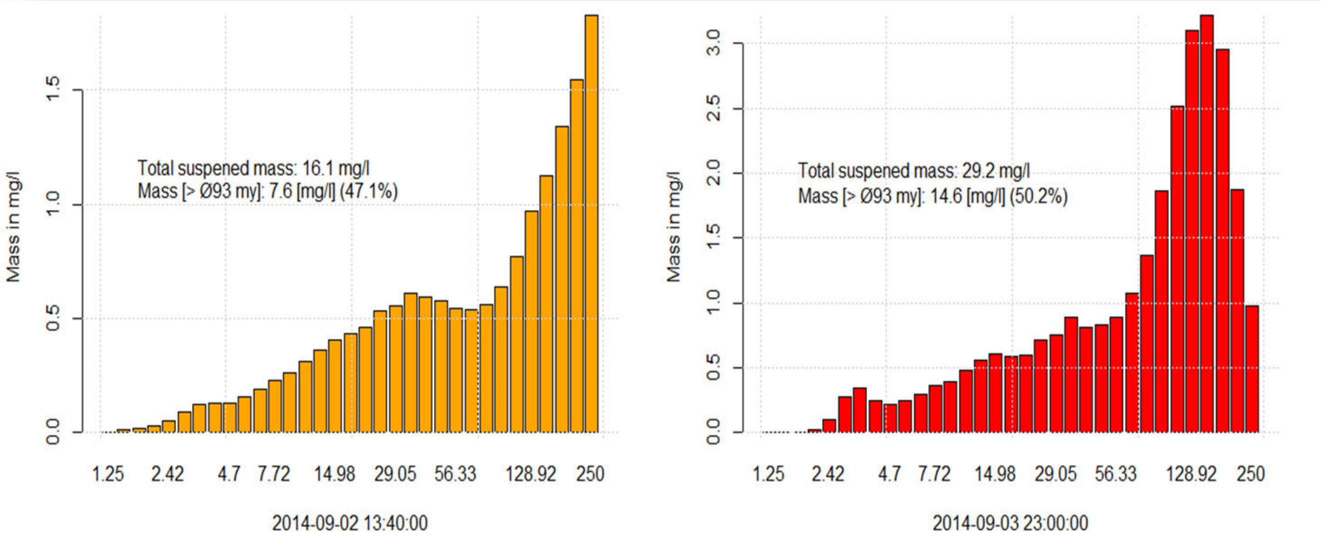




Måler partikkelfordeling på det som faller ned i fellene.

DNV

Kornfordeling slik det er i sjøen…



Målinger med et LISST instrument (som måler partikkelfordelingen slik den faktisk er i sjøen) viser ofte stor andel større partikler – fnokker.

Resultatene fra Frænfjorden viste at små partikler aggregerer til større partikler som synker raskere mot bunnen.

Denne flokkulering er godt kjent og mye studert i naturen

Pergamon

Deep-Sea Research II, Vol. 42, No. 1, pp. 223–256, 1995
0967-0645(95)00013-5

In-situ characteristics of particles settling within a deep-water estuary

JAMES P. M. SYVITSKI,* K. W. ASPREY* and K. W. G. LEBLANC*

(Received 20 June 1994; in revised form 5 December 1994; accepted 16 December 1994)

Abstract—A Floc Camera Assembly is used to obtain the in-situ size, shape, concentration and settling velocity of marine particles, providing insight into the in-situ excess-density, porosity and mass of flocs, their population characteristics, and aggregation and sedimentation rate. Data highlight the time dependent character of marine snow, including near instantaneous, daily and seasonal influences for a mid-latitude estuary, Halifax Inlet. Methods are developed for estimating the mean size of the constituent particles comprising flocs, for determining the number spectra of non-flocculated and flocculated particles, and for determining the mass concentration and mass flux spectra for suspended flocs.

The most active aggregation level is just below the estuarine surface layer. The largest aggregation rates involve the finest (<10 µm) suspended particles colliding by both differential settling and turbulent shear. During plankton blooms, large flocs become attached to the mucoid stringers. The settling velocity of stringers is, in turn, controlled by these large flocs attached to their base.

Floc settling velocity varies with floc size, and as a seasonally-variable power function. A floc's excess density also varies with floc size, but the relationship changes daily. Flocs account for between 35% and 102% of the total suspended mass within Halifax Inlet, and >90% of the mass below the surface layer. Floc concentrations may change by a factor of four in just a few minutes, affected by the flux of larger flocs. When river input of suspended load is high, floc concentration is also high, but the portion of total particulate matter composed of floc is low. Mean floc size varies considerably between seasons and sometimes between estuarine location. Small flocs form when primary production is low and river input is high. Large flocs form when river input is very low. Suspended stringers are highest during the spring freshet and associated plankton bloom.

INTRODUCTION

Four decades after the initial submersible observations of 'marine snow' by Suzuki and Kato (1953), many scientists have noted that particles suspended in oceans are mostly in the form of clustered primary particles of biogenic, terrigenous, anthropogenic and celestial sources (Syvitski et al., 1985; Aldredge and Silver, 1988). These clusters are referred to as floccules, pellets, agglomerates, aggregates, marine snow, streamers and stringers, and are herein referred to as flocs. They account for the accelerated transport of suspended material to the seafloor (Shanks and Trent, 1980). Particles form clusters due to their inherent stickiness, their ability to adsorb dissolved and colloidal material, and their interaction with microbes and plankton (Lewis and Syvitski, 1983). These interactions are

*Geological Survey of Canada, Bedford Institute of Oceanography, Dartmouth, NS, Canada, B2Y 4A2.

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Research paper

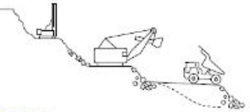
Natural flocculation of mineral particles in seawater – influence on mine tailings sea disposal and particle dispersal

Jens M. Skei[1,*] and James P.M. Syvitski[2]

[1] Skei Mining Consultant (SMC), Bassengveien 7A, 2006 Løvenstad, Norway.
[2] Community Surface Dynamics Modeling System (CSDMS), University of Colorado-Boulder, USA
* Corresponding author: jens@skeimining.com

ABSTRACT

Mineral particles introduced in the marine environment form aggregates held together by Van der Waals forces and their ability to stick to dissolved and colloidal organic material. The aggregates or flocs account for the accelerated transport of suspended material to the seafloor. In low stress environments the size of flocs are large, in high stress environments the floc size is smaller. High particle concentration increases the flocculation rates. In many coastal sea environments, floc settling velocity ranges from 1 to 200 m/d with most flocs settling in the 10 to 100 m/d range. Observations made in natural coastal systems and fjords are relevant for sea disposal of mine tailings. As mine tailings may enter the sea as a particle slurry already mixed with seawater, the particles in the slurry are in the early stages of flocculation. The flocculation process will reduce the dispersal of fine grained tailings.



I. INTRODUCTION

Mining of minerals and metals creates huge quantities of fine grained tailings particles which have to be disposed (Apte and Kwong, 2004). In countries like Norway (Klif, 2010), Canada (Pedersen et al.,1995), USA (Alaska) (Kline, 1998), Greenland (Johansen and Asmund, 1999), Turkey (Berkun, 2005), Phillipines (Dold, 2006) and Papua New Guinea (McKinnon, 2002), DSTP (Deep Sea Tailings Placement) has been practiced for more than 30-40 years. In other countries, like Chile, sea disposal is now seriously being considered as an alternative to land disposal of tailings (Neira, 2012).

Lack of suitable land disposal sites as well as the location of ore resources close to the coast has increased the interest of exploring the possibility of DSTP. However,

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ELSEVIER

In situ characterisation of complex suspended particulates surrounding an active submarine tailings placement site in a Norwegian fjord

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Particle size distributions
Sediment transport
Settling
Particle imaging

ABSTRACT

Suspended particle measurements over flood and ebb transects of a Norwegian fjord (Frænfjorden) with an active submarine mine tailings placement are presented. Measurements focused on characterisation of spatial variability in particle and floc size, and determination of suspended mine tailing concentrations. Such information is crucial for understanding transport and flocculation dynamics, which in turn can contribute to improvements of numerical models, and thus to more accurate predictions of settling fluxes and transport processes. Multiple instruments were used to ensure that all relevant particle sizes could be observed. These included a LISST-100x, a LISST-Holo and a bespoke particle imaging system, which were deployed together on a profiling frame at multiple stations transecting the fjord. Measurements were obtained close to the high-concentration plume from the tailings discharge and extended several kilometres horizontally. We observed a combination of few-micron fines, densely packaged flocs and large string-like flocs, several mm in length; a range which could not be captured by a single instrument. Such a range of floc sizes and complexities has significant implications for the transport and settling of the material suspended within the fjord.

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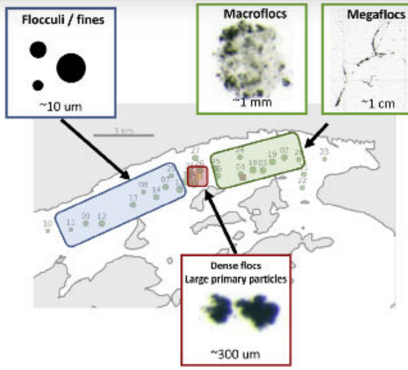


Fig. 11. Conceptual map showing the dominating particle/floc type in the three different areas discussed in the text.

time of measurement (June). Several studies have investigated aggregation and settling of particulate material relating to diatoms (e.g. Engel, 2000 and references therein). A similar flocculation process between inorganic material and diatom chains has been observed in other coastal sites (Cross et al., 2014). Flocculation between these diatom chains and the advected fine fraction of the mine tailings could therefore act to retain the tailings high in the water column. This type of phytoplankton–mineral flocculation implies that there is potential for significant seasonal variation in floc formation within the region, with a greater presence of the largest, string-like flocs coinciding with a spring diatom bloom. If this is the case, floc size and settling flux could have seasonally variability associated with diatom chain abundances. It is also worth noting that it is likely that such flocs would not be identifiable without particle imaging, as optical scattering measurements will be more sensitive to the smaller, dense components within these flocs, and be relatively insensitive to the diatom (or stringy feature) itself (Graham et al., 2012).

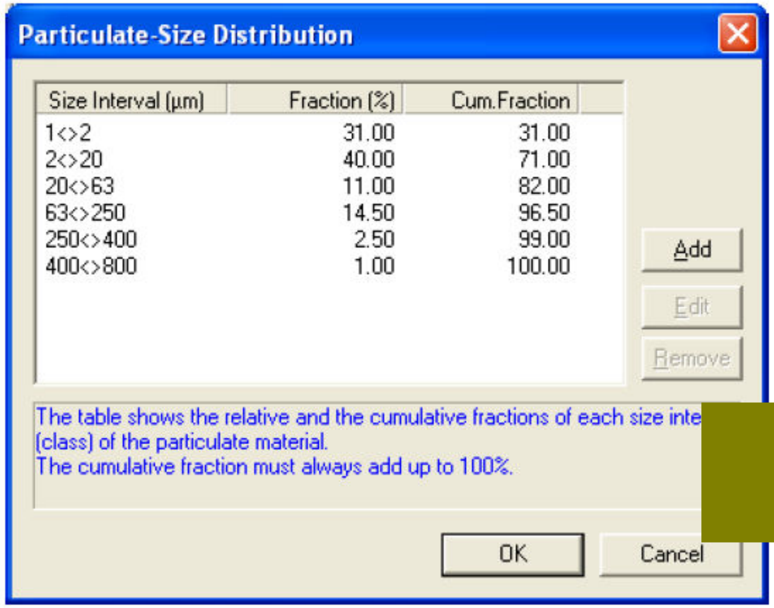
The question of particle orientation may also be of interest, especially in attempting to understand the implication of preferentially-oriented elongated particles in particle collision cross-sections and in optical measurements that are sensitive to

equal equivalent diameter. Further work in quantifying the bounds of this range of settling velocities could be usefully applied to modelling the fate and transport of flocculated material. Due to their length, such large, string-like flocs cannot be measured with standard instruments such as the LISST-100 or LISST-Holo, but could contribute significantly to the mass transport and environmental impact inland of the release point. These excessively large flocs appear to have been transported up to two kilometres horizontally from the release, or at least have formed from material that has been transported this far.

It is also not entirely clear why the fine tailings are transported west, but not the low-density large flocs, and why this feature remains persistent during the flood tide (Fig. 6E). This could be related to the time-scale for megafloc formation, where the material that exits the plume is transported west first and is then pumped east, by which time flocs have had opportunity to grow. There could also exist a region of converging flow to the East of the release point, where high diatom abundance converges with the fine mine tailings, stimulating the creation of a new type of aggregate unique to this region. Detailed hydrodynamic and transport modelling may help to test some of these hypothesis, and we plan to pursue

Partikkelspredningsanalyse (SINMOD -> DREAM)

Tabell 4.1 Partikkelfordeling for Hustadmarmor, fin fordeling.



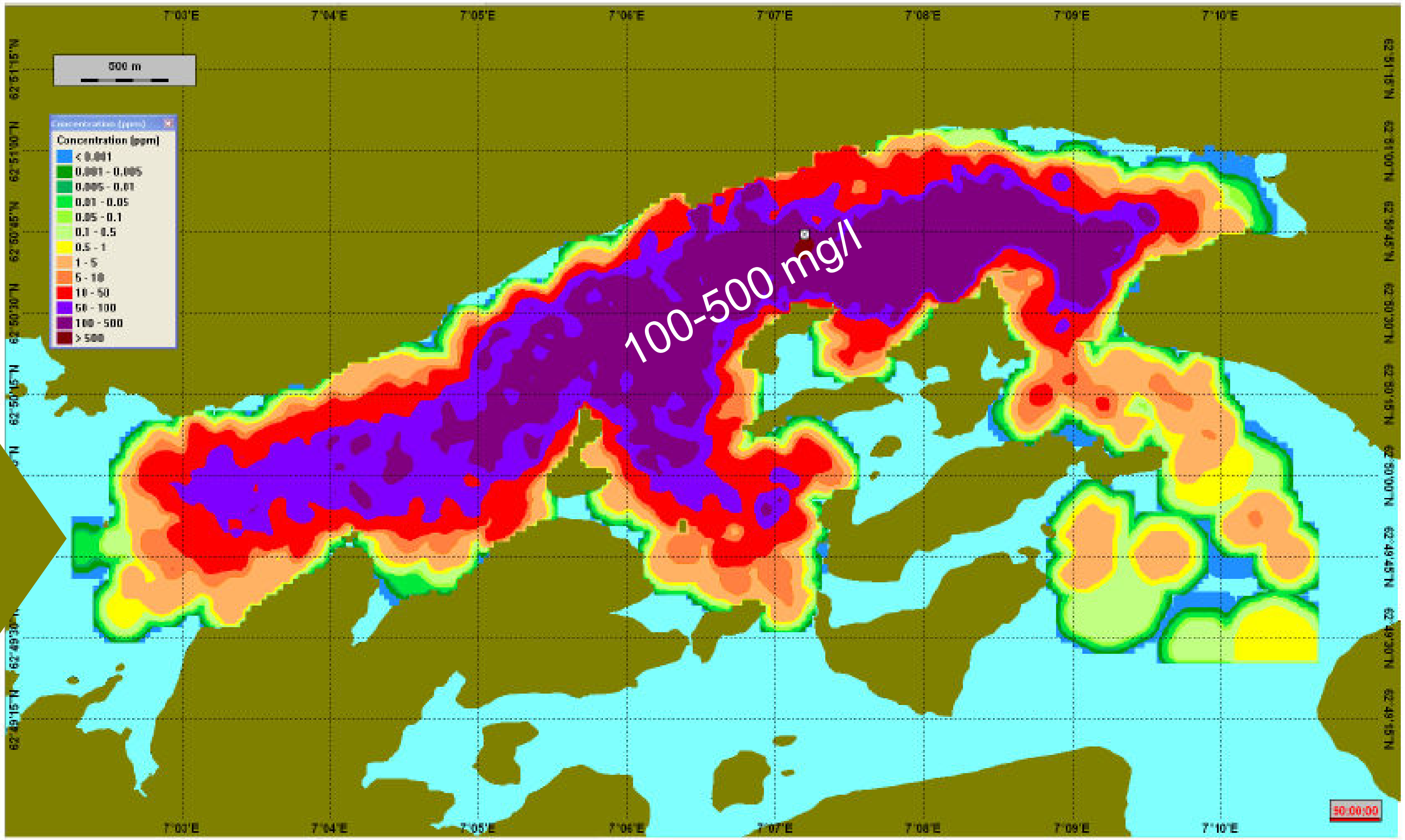
Particulate-Size Distribution

Size Interval (µm)	Fraction (%)	Cum.Fraction
1<>2	31.00	31.00
2<>20	40.00	71.00
20<>63	11.00	82.00
63<>250	14.50	96.50
250<>400	2.50	99.00
400<>800	1.00	100.00

Add
Edit
Remove

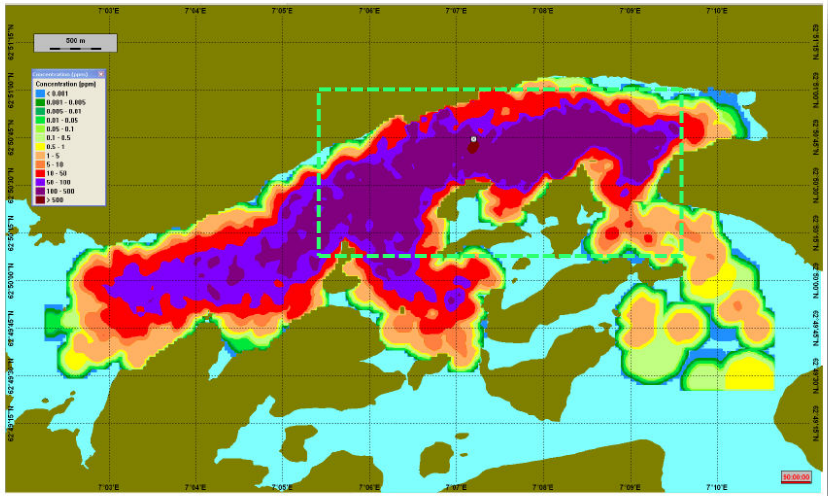
The table shows the relative and the cumulative fractions of each size inte
(class) of the particulate material.
The cumulative fraction must always add up to 100%.

OK
Cancel



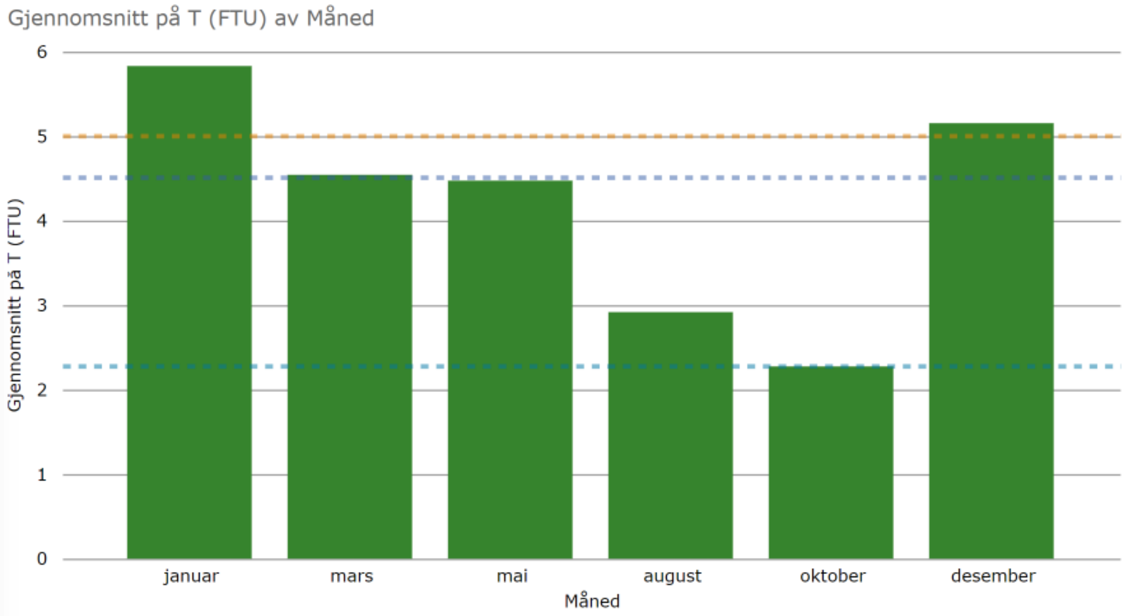
For å optimalisere utslippet (minst mulig spredning) er modellering et godt verktøy ved å kjøre ulike scenario for utslippspunktet (mengder, sammensetning, dyp, sted, tid)……..

Men modellen passet ikke med de målte verdiene



100-500 mg/l

De målte verdiene var mye lavere enn det som ble pressentert i modellen, selv om det ble registrert høye verdier nær utslippspunktet….

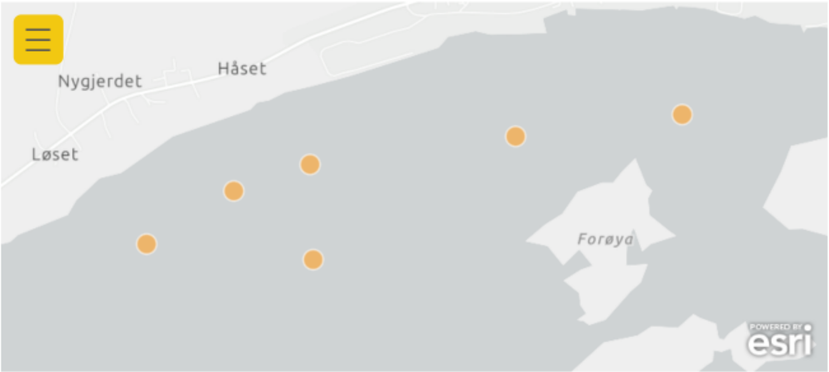


Stati...
- Velg alt
- S10
- S27
- S29
- SB12
- SB4
- SB7
- SB1

Stasjons...
- Velg alt
- (Tom)
- Border
- Deposit ar...
- Outside

1-10 mg/l

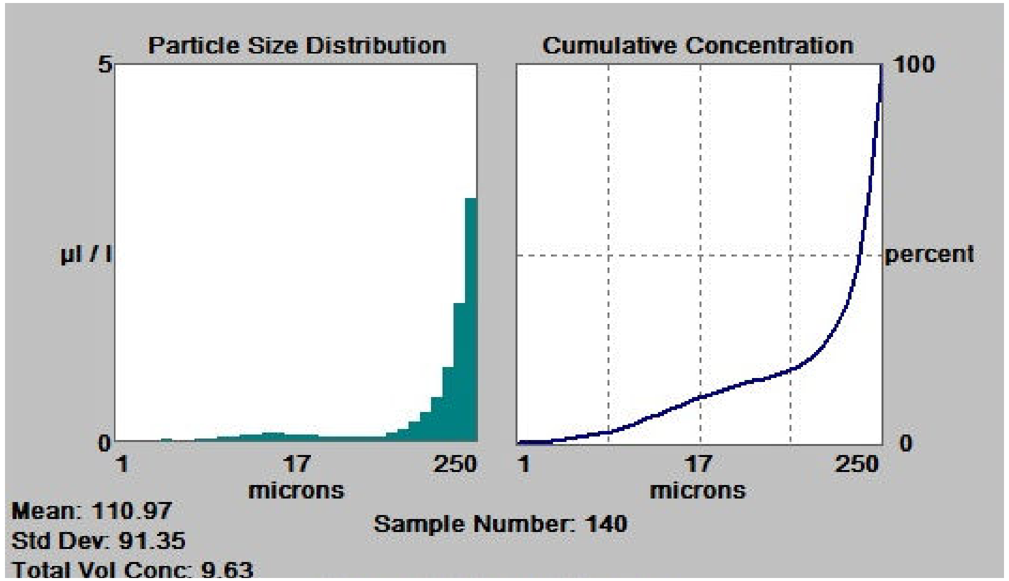
Antall Date av Station, latitude dec. Gr og longitude dec. Gr



Station	Stasjonsområde	Gjennomsnitt på T (FTU)	Standardavvik på T (FTU)	Maksimum T (FTU)
S27	Deposit area	3,21	1,57	9,13
S29	Deposit area	3,13	1,55	9,60
SB12	Deposit area	2,68	0,95	6,17
SB4	Deposit area	4,23	2,41	13,81
SB7	Deposit area	10,18	20,37	162,11
Totalt		**4,18**	**7,94**	**162,11**

DNV

“Flokkulering” var ikke inkludert i modellen (DREAM)



≠

Particulate-Size Distribution

Size Interval (µm)	Fraction (%)	Cum.Fraction
1<>2	31.00	31.00
2<>20	40.00	71.00
20<>63	11.00	82.00
63<>250	14.50	96.50
250<>400	2.50	99.00
400<>800	1.00	100.00

Particulate-Size Distribution

Size Interval (µm)	Fraction (%)	Cum.Fraction
10<>20	31.00	31.00
20<>45	40.00	71.00
45<>63	11.00	82.00
63<>250	14.50	96.50
250<>400	2.50	99.00
400<>800	1.00	100.00

Add
Edit
Remove

The table shows the relative and the cumulative fractions of each size interval (class) of the particulate material.
The cumulative fraction must always add up to 100%.

OK Cancel

Particulate-Size Distribution

Size Interval (µm)	Fraction (%)	Cum.Fraction
5<>10	31.00	31.00
10<>40	40.00	71.00
40<>63	11.00	82.00
63<>250	14.50	96.50
250<>400	2.50	99.00
400<>800	1.00	100.00

Add
Edit
Remove

The table shows the relative and the cumulative fractions of each size interval (class) of the particulate material.
The cumulative fraction must always add up to 100%.

OK Cancel

I og med at en flokkulering forekommer – de fineste partiklene slår seg sammen til grovere partikler ble DREAM modellen kjørt mange ganger hvor en gjorde “partikkelfordelingskurven” grovere. (flytter de fineste partiklene opp en klasse). I utgangspunktet var det 31% som var finere enn 2 µm

Hvilken partikkelfordelingskurve gir en modell som er mest mulig lik de målte resultatene…..?

Particulate-Size Distribution

Size Interval (µm)	Fraction (%)	Cum.Fraction
1<>2	31.00	31.00
2<>20	40.00	71.00
20<>63	11.00	82.00
63<>250	14.50	96.50
250<>400	2.50	99.00
400<>800	1.00	100.00

Particulate-Size Distribution

Size Interval (µm)	Fraction (%)	Cum.Fraction
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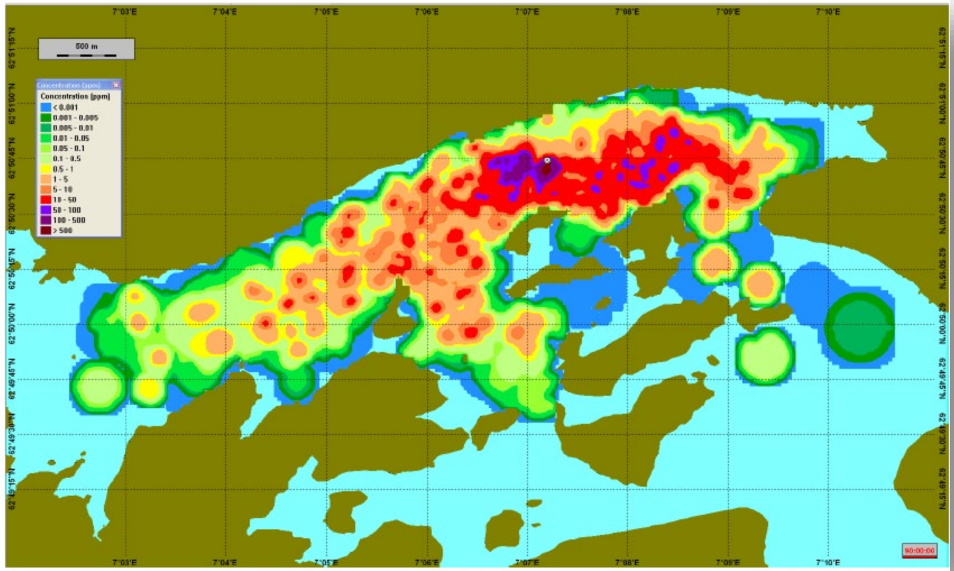
45<>63	11.00	82.00
63<>250	14.50	96.50
250<>400	2.50	99.00
400<>800	1.00	100.00



SINTEF konkluderte med at GROV 2 harmoniserte best

	St-3-30 m	St-3-49 m	St-1-53 m	Utenfor område %
Turbiditetsmålinger	**6.74**	**3.45**	**1.84**	
Bunndyp 30 m, opprinnelig partikkelfordeling, timestep 2 min	91.09	12.10	43.94	31.6
Bunndyp 30 m, Grov 1 partikkelfordeling, timestep 2 min	36.85	3.22	9.87	11.9
Bunndyp 30 m, Grov 2 partikkelfordeling, timestep 2 min	14.90	0.95	2.06	2.9
Bunndyp 30 m, Grov 3 partikkelfordeling, timestep 2 min	5.86	0.41	0.82	0.5

DNV

Engebø caset - tilpasset kornkurven ved å flytte andel < 15 µm til kornklasse 15-19 µm

10% < 15 µm

Kornstørrelse (µm)	Kumulativ (%)	Fraksjon (%)
0-5	4	4
5-15	10	6
15-30	19	9
30-57	33	14
57-84	45	12
84-146	69	24
146-195	81	12
195-235	88	7
235-340	100	12

"Opprinnelig kurve"

0,8% < 15 µm (NIVA test)

Kornstørrelse (µm)	Kumulativ (%)	Fraksjon (%)
0-1,1	0,009 %	0,009 %
1,1-2,2	0,013 %	0,004 %
2,2-3,8	0,320 %	0,028 %
3,8-5,3	0,063 %	0,035 %
5,3-7,6	0,18 %	0,145 %
7,6-11	0,45 %	0,305 %
11-19	0,80 %	0,495 %
19-27	1,60 %	1,105 %
27-34	3,00 %	1,895 %
34-42	4,50 %	2,605 %
42-60	10,0 %	7,395 %
60-85	18,0 %	10,605 %
85-132	40,0 %	29,395 %

"Basert på utsynknigsforsøk med Magnafloc"

Flyttet finstoffet under 15µm opp til kornklasse 15-19 µm

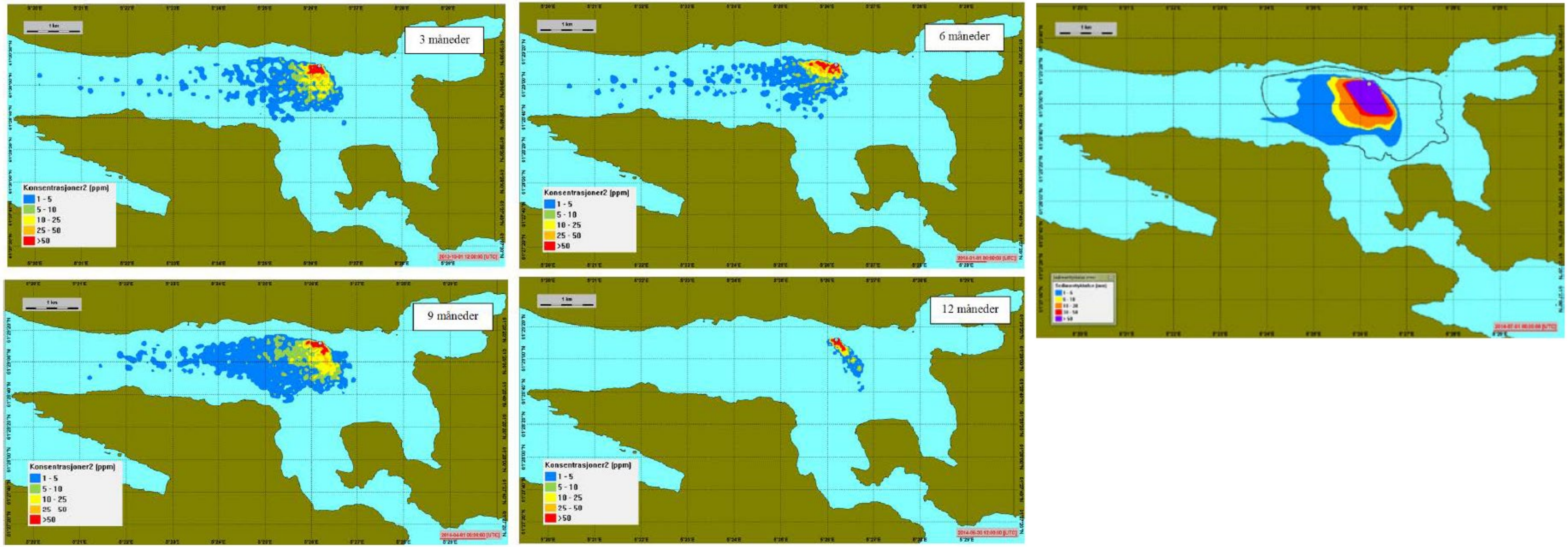
Kornstørrelse (µm)	Kumulativ (%)	Fraksjon (%)
15-19	0,8	0,8
19-27	1,6	0,8
27-34	3,0	1,4
34-42	4,5	1,5
42-60	10,0	5,5
60-85	18,0	8
85-132	40,0	22
132-195	81,0	41
195-235	88,0	7
235-340	100,0	12

"Kurve benyttet i DREAM modellering"

Fra Appendix 4 i rapporten: *De tilpasningene av kornkurven som er beskrevet ovenfor var nødvendig for å få representert flokkulering indirekte i DREAM.* ***Disse var av modellteknisk art, og betyr ikke at det ikke vil finnes partikler < 15** µm **i sjøen..***

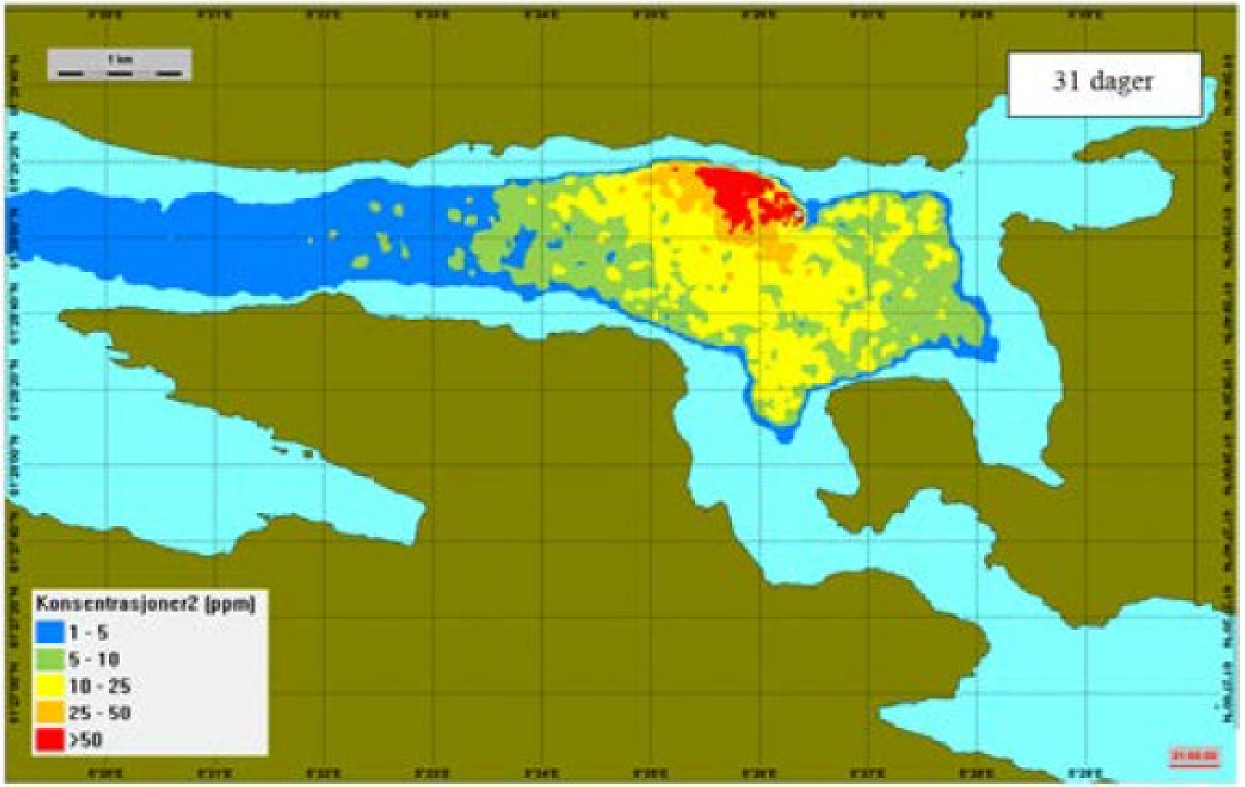
DNV

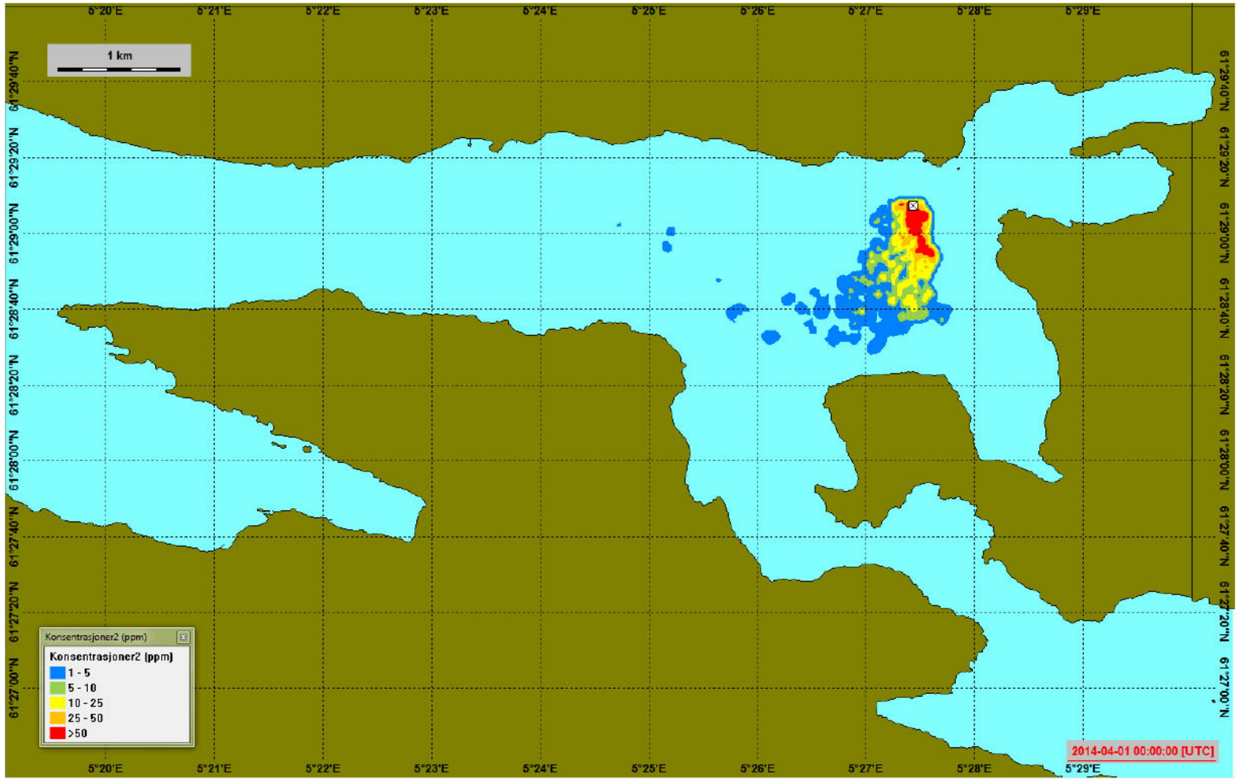
Spredningsmodell basert på DREAM



Figur 22: Resultat for scenario A: Spredningsbildet etter 3, 6, 9 og 12 måneder. Konsentrasjon av partikler, vertikalt maksimum. Siste del av simuleringsperioden sammenfaller med endringer i det underliggende strømbildet (april-juni), og et annet spredningsmønster kan observeres.

Fremtidssceanrio (25 år etter oppstart)





“annet utslippsted”

Usikkerheter i målingene og analysene

Utførte målinger:

- bl.a. fra selve instrumentet/sensorene, benyttet måleoppsett og rigg, ved utsetting, evt. ytre påvirkninger i måleperioden og datainnhenting/behandling.
- største usikkerheten knytter seg til strømmålinger ved hastigheter ned mot null.

Strømmodellering:

- De viktigste feilkildene til en modell som SINMOD ligger i inngangsverdiene som bunntopografi og atmosfæredata (vind, temperatur, skydekke, luftfuktighet og trykk),
- Grenseverdiene for hvert modelloppsett kan være en viktig feilkilde.

Partikkelspredningsmodell:

- De viktigste feilkildene til DREAM ligger i inngangsdataene. Sentral input til DREAM er bl.a. utslippskarakteristikk (eks. utslippsdyp, helning på rør, rater, kornstørrelsesfordeling), strømforhold og sjiktning. Det forventes noe usikkerhet knyttet til utslippskarakteristikk, inklusiv benyttet kornstørrelsesfordeling.

…når det er sagt så er flokkulering nå inkludet i ulike modeller som brukes til partikkelspredning

Flocculation model

17.1 Flocculation model for suspended sediment settling speed in DREAM

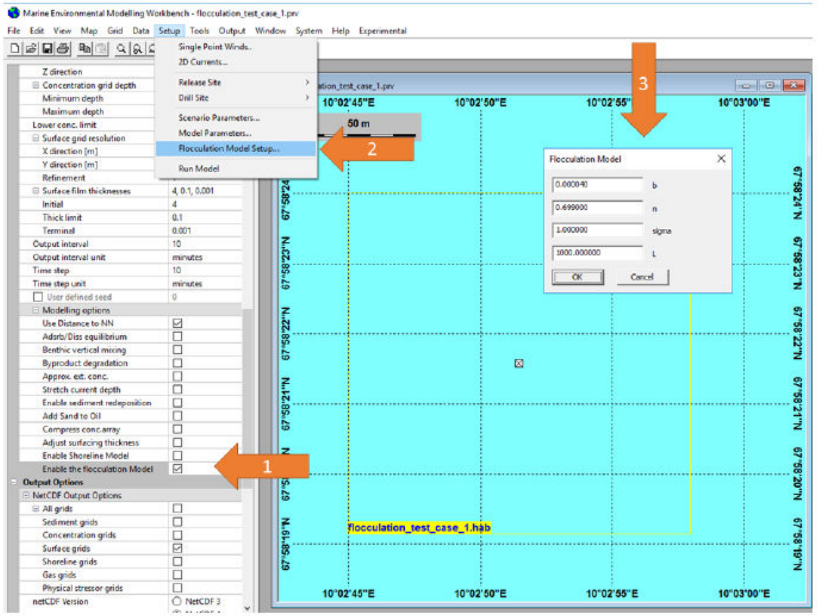


Figure 17.1: How to set up the flocculation model in DREAM.

DREAM (v13.0.0)

4.3 Settling Velocity and Flocculation

The settling velocity of the fine sediment depends on the particle/floc size, temperature, concentration of suspended matter and content of organic material.

Usually one distinguishes between a regime where the settling velocity increases with increasing concentration (flocculation) and a regime where the settling velocity decreases with increasing concentration. The latter is referred too as hindered settling. The first is the most common of the two in the estuary.

Following Burt (1986), the settling velocity in saline water (>5 ppt) can be expressed by:

$$w_s = kc^{\gamma} \quad for\ c \leq 10\,kg/m^3 \tag{4.3}$$

where

w_s	settling velocity of flocs (m/s)
c	volume concentration
k,γ	coefficients
γ	1 to 2

The relation for $c \leq 10$ kg/m³ describes the flocculation of particles based on particle collisions. The higher concentration the higher possibility for the particles to flocculate.

$c > 10$ kg/m³ corresponds to 'hindered' settling, where particles are in contact with each other and do not fall freely through the water.

Alternative settling formulations are also available:

The formulation of Richardson and Zaki (1954) is the classical equation for hindered settling:

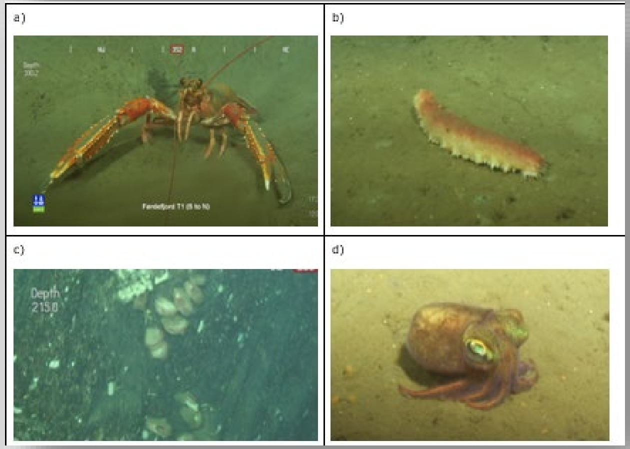
Utredningen av sjødeponiets effekter på livet i havet:

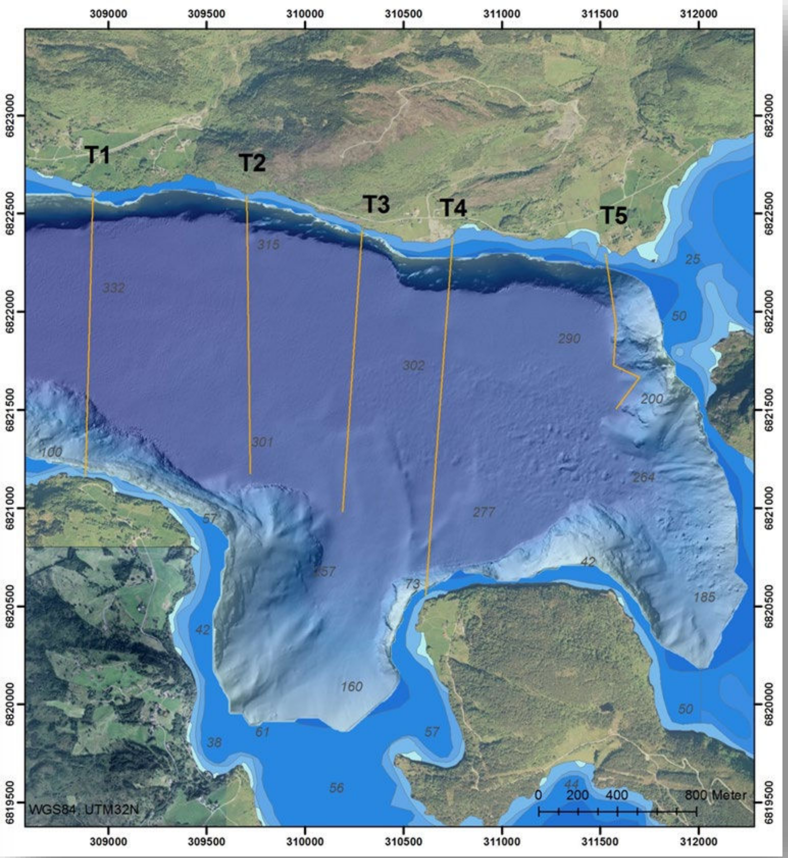
DNV·GL

Marinbiologisk tilleggsundersøkelse i Førdefjorden

Nordic Rutile AS

Rapport Nr.: 2014-1193, Rev 01
Dokument Nr.: 18BHORT-10
Dato: 2014-11-10





Utredningen av sjødeponiets effekter på livet i havet:


DNV·GL

Marinbiologisk tilleggsundersøkelse i Førdefjorden

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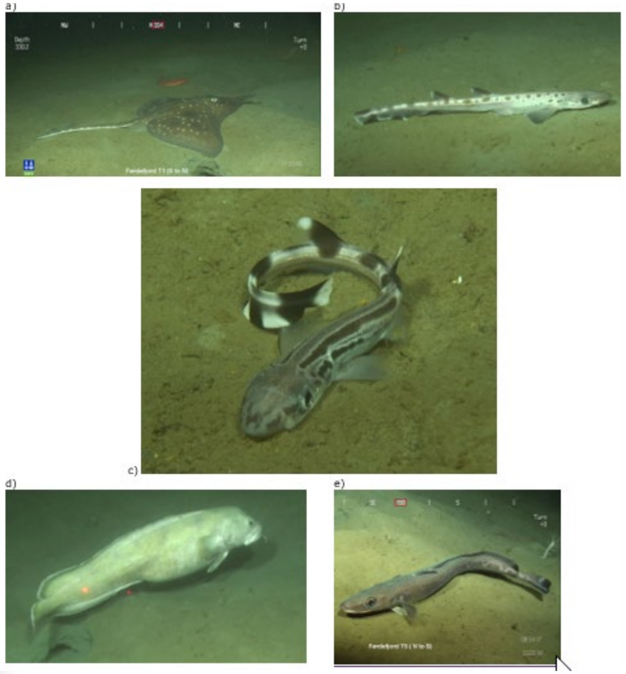
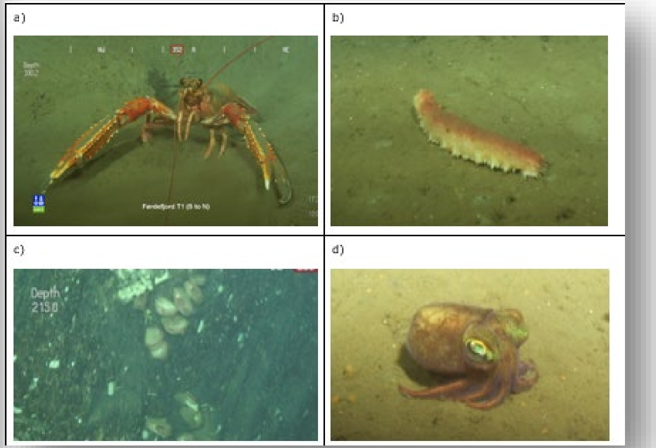


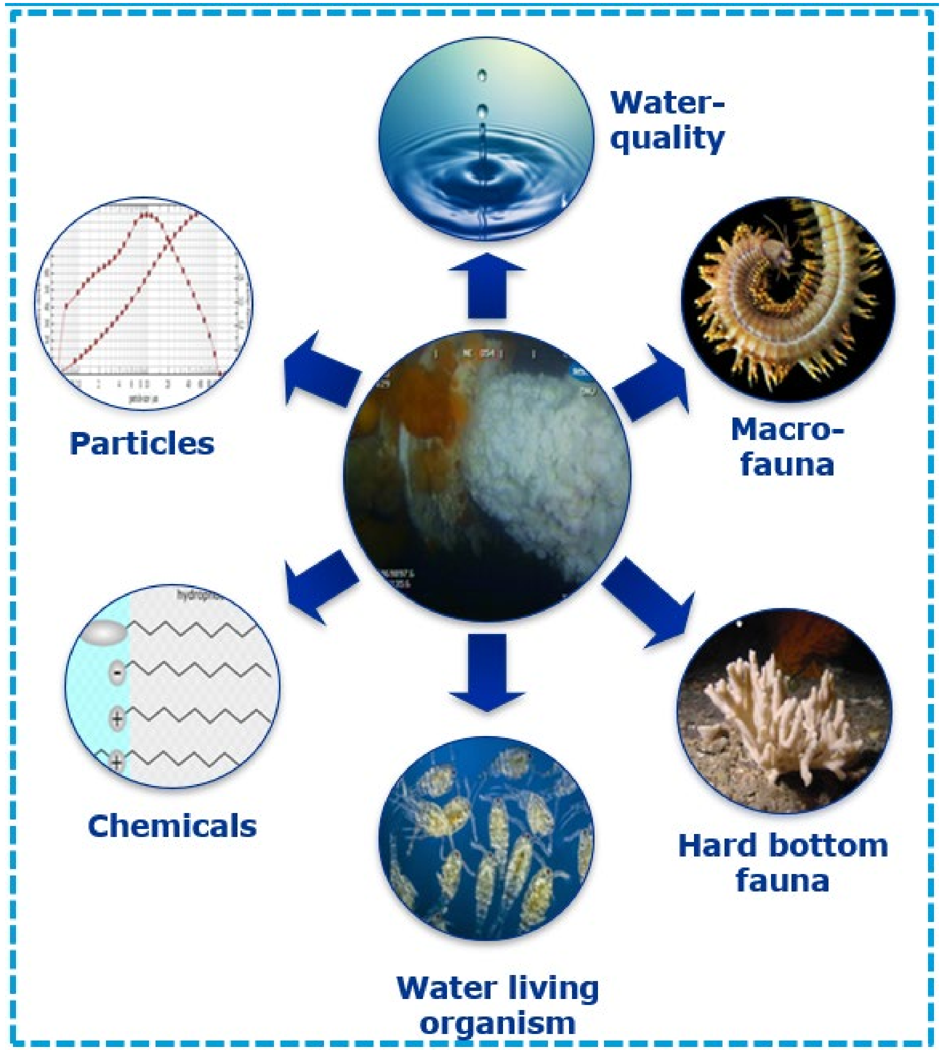


Tabell 3-6. *Oversikt over fiskeegg, Førdefjorden 2014.Stasjoner merket D fra bunn til overflate, alle andre fra 50m dyp til overflaten*

Stasjon	Laksesild	Brosme	Lange	Torsk/ hyse	Tang-brosme	Torskefisk	Sandflyndre	Rødspette	Skrubbe
HÅV 1-1	2			3		1			1
HÅV 1-2	9			1		1			
HÅV 2-1	3			4			2		
HÅV 2-2	7			1	2				1
HÅV 4-1D	21	2	298	5		8	1		
HÅV 4-2D	40	4	19	1		5	1		
HÅV 5-1	7	1	2	1			1	1	
HÅV 5-2	1			1	2	1			
HÅV 6-1	3			1			2		
HÅV 6-2	2	1		2		1			
HÅV 7-1D	21	1	1	3		2			1
HÅV 7-2D	30	2	2	6		9			

DNV

Generelt om effekter i det marine miljø



Marine Pollution Bulletin 174 (2022) 113150

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Review

New insights into submarine tailing disposal for a reduced environmental footprint: Lessons learnt from Norwegian fjords

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ARTICLE INFO

Keywords:
Submarine tailing disposal
Environment
Fjord
Best available techniques

ABSTRACT

Submarine tailing disposal (STD) in fjords from land-based mines is common practice in Norway and takes place in other regions worldwide. We synthesize the results of a multidisciplinary programme on environmental impacts of STDs in Norwegian fjords, providing new knowledge that can be applied to assess and mitigate impact of tailing disposal globally, both for submarine and deep-sea activities. Detailed geological seafloor mapping provided data on natural sedimentation to monitor depositional processes on the seafloor. Modelling and analytical techniques were used to assess the behaviour of tailing particles and process-chemicals in the environment, providing novel tools for monitoring. Toxicity tests showed biological impacts on test species due to particulate and chemical exposure. Hypersedimentation mesocosm and field experiments showed a varying response on the benthos, allowing to determine the transition zone in the STD impact area. Recolonisation studies indicate that full community recovery and normalization of metal leakage rates may take several decades due to bioturbation and slow burial of sulfidic tailings. The results are synthesised to provide guidelines for the development of best available techniques for STDs.

1. Introduction

Global demands for mineral resources are rapidly increasing, not only to sustain traditional uses but also for the development of new, green energy technology such as wind turbines or electric car batteries (Vogt, 2013; Dold, 2014a). Discussions based on robust scientific and engineering knowledge need to take place to find the necessary balance between exploration for and exploitation of known and new resources, the development of new technologies and recycling of existing resources. However, the United Nations Environment Programme (UNEP) has predicted that the amount of minerals, ores, fossil fuels and biomass consumed globally per year could triple between current day and 2050 (IRP, 2020). Mining activities produce large amounts of waste, and the environmentally sound management of such waste, at all stages of mining (production, closure and post-closure), is one of the major issues faced by the mining industry, and a major concern for civil society. Mining waste includes rocks from overburden and tailings representing the waste produced after the target mineral has been extracted from the ore, and may account for a high proportion of the extracted ore (e.g. up to 99% for copper and 99.99% for gold (MMSD, 2002)). Tailings usually

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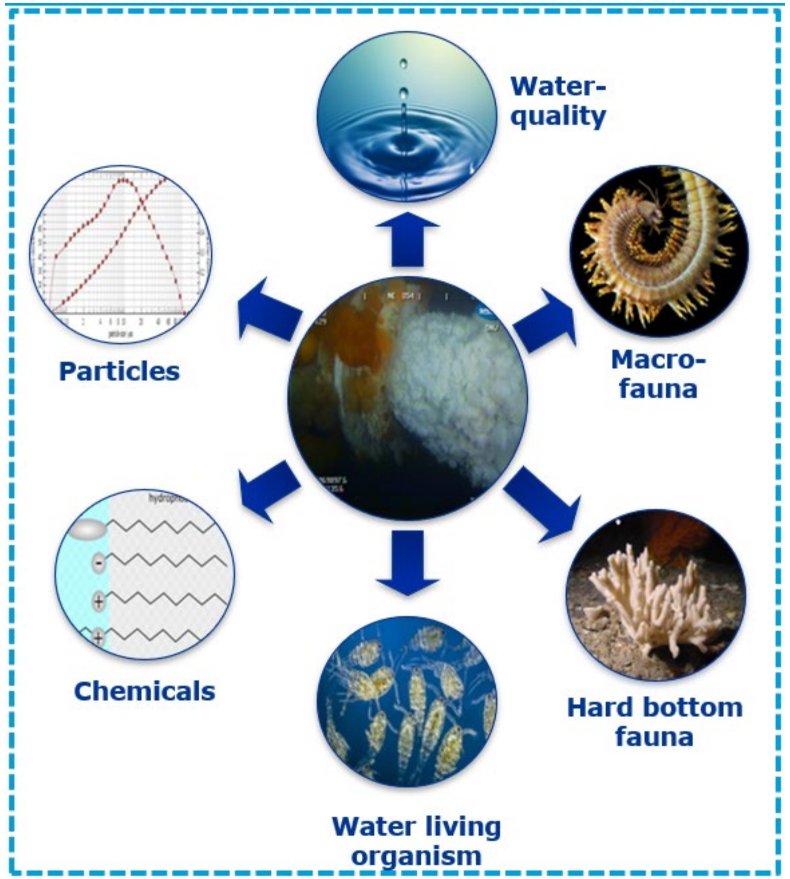
Via NYKOS-prosjektet har det blitt gjort mange forskningsprosjekter, oppsummert av Ramirez-Llodra (2022).

Generelt om effekter i det marine miljø



Environmental Research
Volume 200, September 2021, 111447
ELSEVIER

Effects of mine tailing exposure on early life stages of cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*)

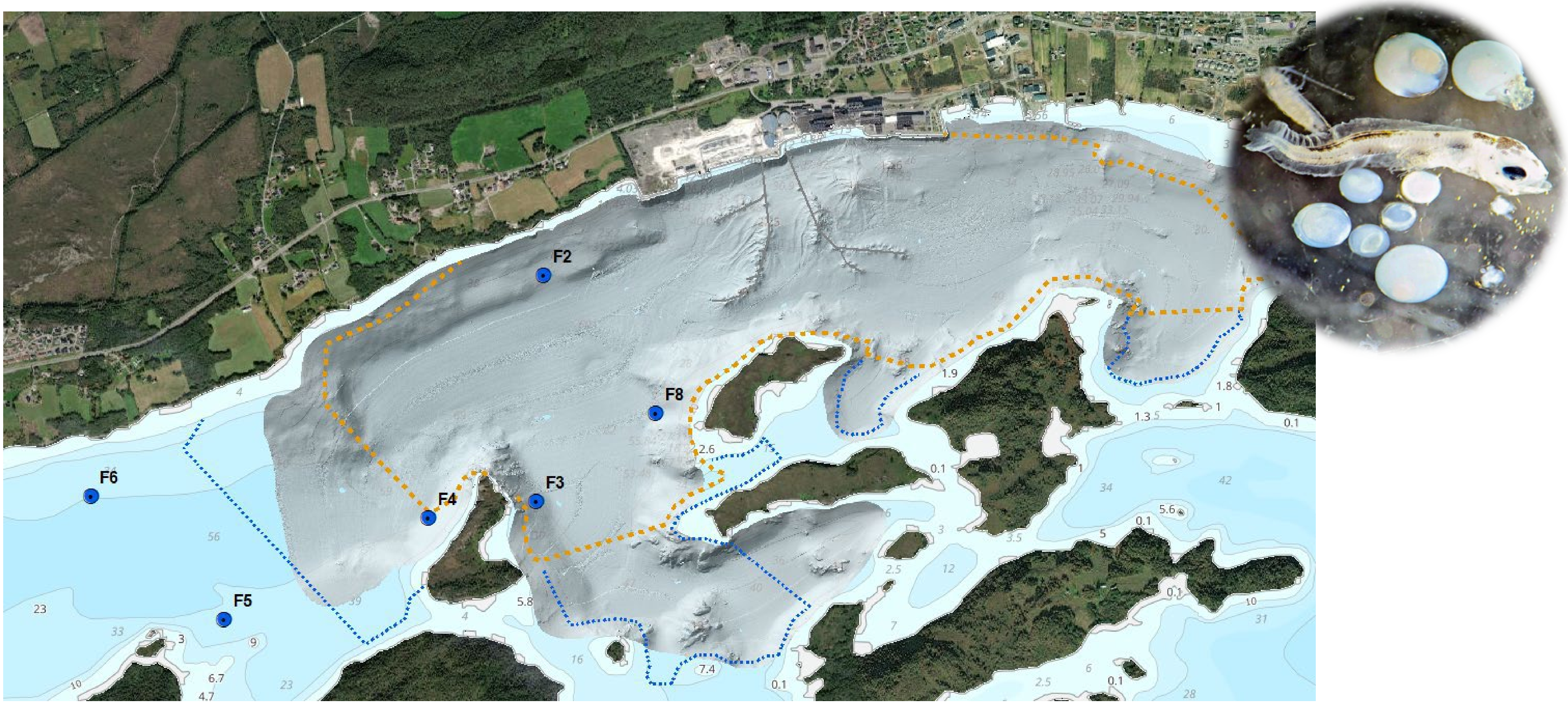
Julia Farkas [a], Trond Nordtug [a], Linn H. Svendheim [b], Elettra D. Amico [c], Emlyn J. Davies [a], Tomasz Ciesielski [c], Bjørn Munro Jenssen [c], Torstein Kristensen [b], Pål A. Olsvik [b], Bjørn Henrik Hansen [a]

Highlights

- Mine tailing particles attach to cod and haddock eggs during exposure.
- Tailings remained attached on egg surfaces after exposure.
- Exposure to tailings induced buoyancy loss and sinking at higher concentrations.

tailing release sites are not known to our knowledge. To predict risks related to positive buoyancy loss in real environmental scenarios, further research is needed to determine the likelihood and duration of particle-fish egg encounters at tailing placement sites.

…laboratorie-eksperimenter viser potensielt negative effekter på vannlevende organismer…. men hvordan måle disse i naturen?



En måte kan være å studere forekomst av fiskeegg og larver – Er det noen forskjell når det gjelder forekomst inne i deponiet vs utenfor?

Tabell 5-3. *Viser fangst for dag 2 med håvtrekk, tatt fra 0-20m og 20-40m.*

Dag 2	F2-2	F2-2	F3-2	F3-2	F4-2	F4-2	F5-2	F5-2	F6-2	F6-2	F7-2	F7-2	F8-2	F8-2
	0-20 m	20-40 m	0-20 m	20-40 m	0-20 m	20-40 m	0-20 m	20-40 m	0-20 m	20-40 m	0-20 m	20-40 m	0-20 m	20-40 m
Gapeflyndre			1			1					1			1
Rødspette	2							1		2		1		
Sandflyndre	15	6	6	3	5	1	9	6	5	6	8	5	5	8
Skrubbe (?)					1	1		1					1	
Brisling			11		1			1	3	1	2	1	9	2
Tangbrosme			1		2			1			1		1	
"Torskefisk"													1	
Brosme		1							1		1			
Torsk / hyse	2	1	12	2		10	6	13	8	10	7	13	11	2
Torsk larve					1									
Larve ubestemt														
Tobis larve														
Sum	19	8	31	5	10	13	15	23	17	19	20	20	28	13

“Utenfor deponi”

Hvor lik er fordelingen basert på arter og antall egg?

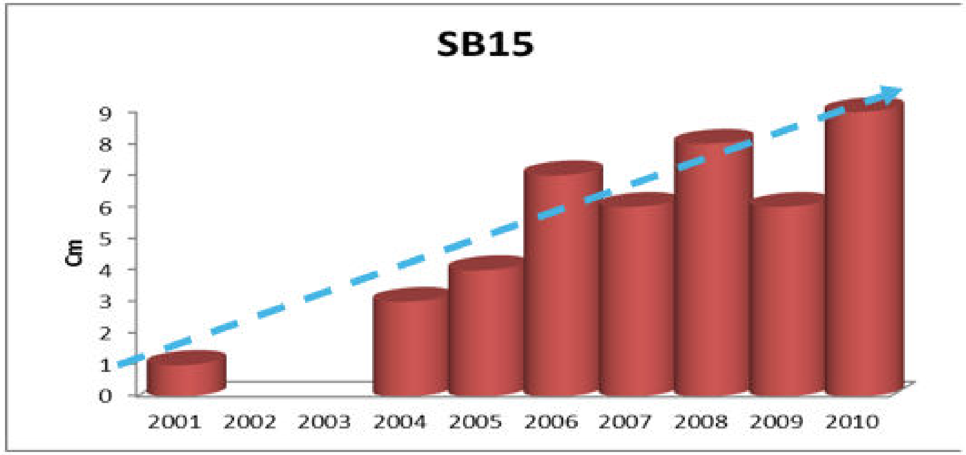
DNV (2022) 2022-0473

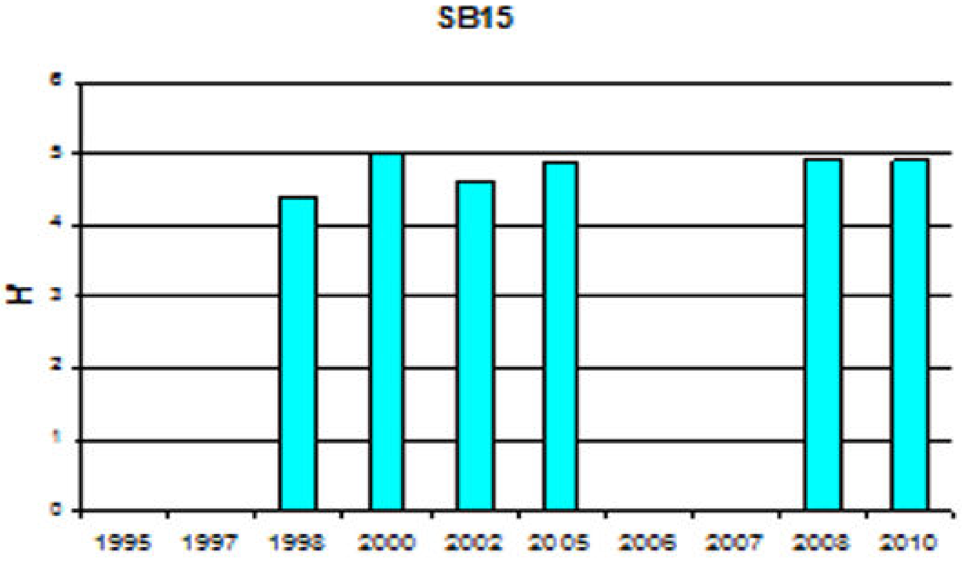
Forekomst av fiskeegg og larver – inne i deponiet vs utenfor 2016 – 2021: ingen signifikant forskjell

DNV

Grenseverdier

Macrofauna – effects when sedimentation is more than 6mm/year*

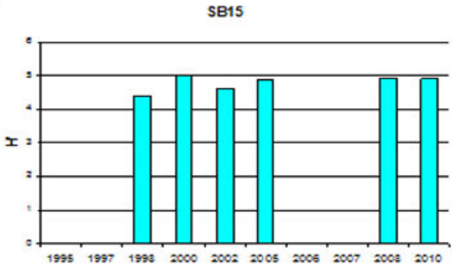


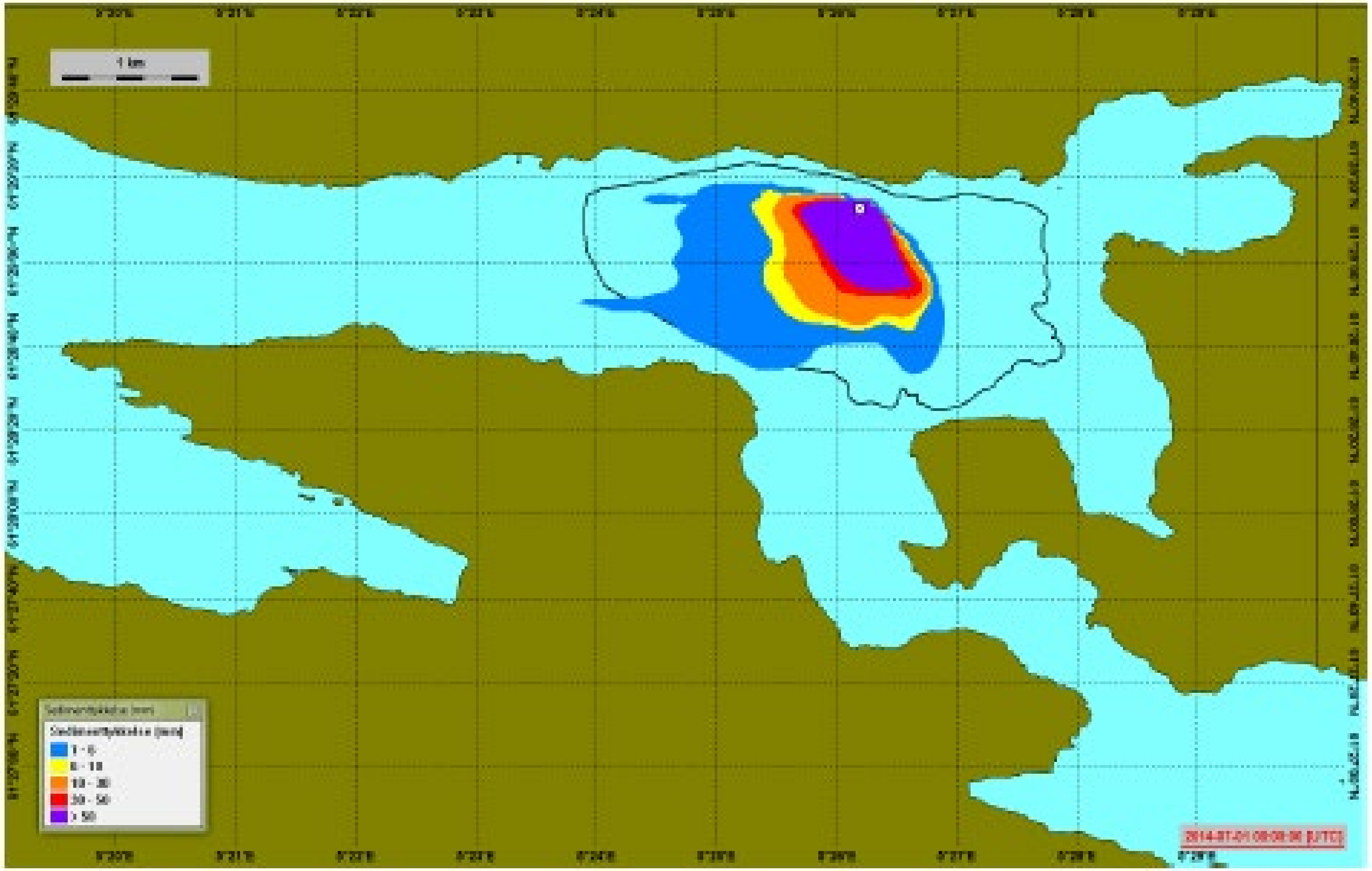


Smit MG, Holthaus KI, Trannum HC, Neff JM, Kjeilen-Eilertsen G, Jak RG, Singsaas I, Huijbregts MA, Hendriks AJ. 2008. **Species sensitivity distributions for suspended clays, sediment burial and grain size change in the marine environment**. *Environ Toxicol Chem* 27(4):1006–1012.

Grenseverdier

Macrofauna – effects when sedimentation is more than 6mm/year*





6mm/år er det som er angitt som gult og innenfor

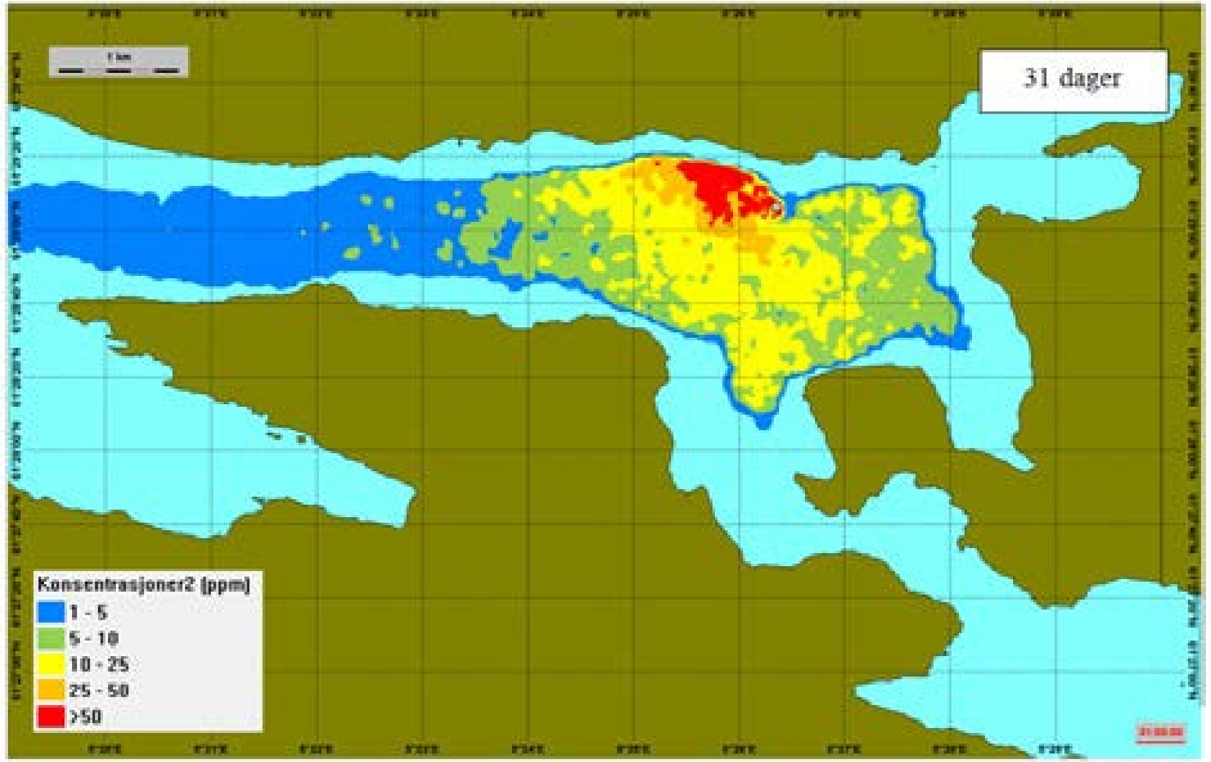
Smit MG, Holthaus KI, Trannum HC, Neff JM, Kjeilen-Eilertsen G, Jak RG, Singsaas I, Huijbregts MA, Hendriks AJ. 2008. Species sensitivity distributions for suspended clays, sediment burial and grain size change in the marine environment. *Environ Toxicol Chem* 27(4):1006–1012.

DNV

Grenseverdier

Litteraturstudie: effektgrenser for fisk av økt partikkelkonsentrasjon i vannsøylen

Lavest konsentrasjon for fiskeegg- og larver (basert på studier på torskegg og sildelarver) ble det foreslått en effektgrense på 5 mg/l

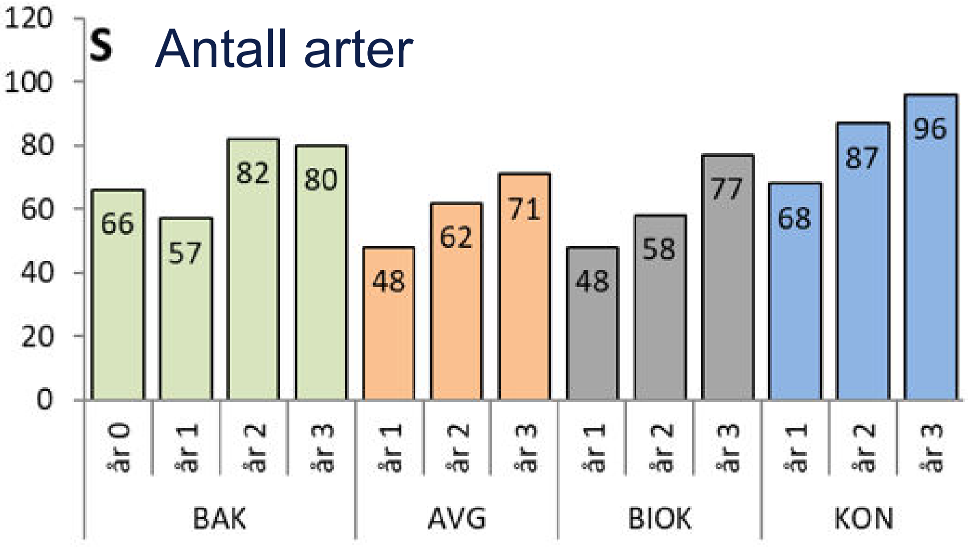


Smit MG, Holthaus KI, Trannum HC, Neff JM, Kjeilen-Eilertsen G, Jak RG, Singsaas I, Huijbregts MA, Hendriks AJ. 2008. Species sensitivity distributions for suspended clays, sediment burial and grain size change in the marine environment. *Environ Toxicol Chem* 27(4):1006–1012.

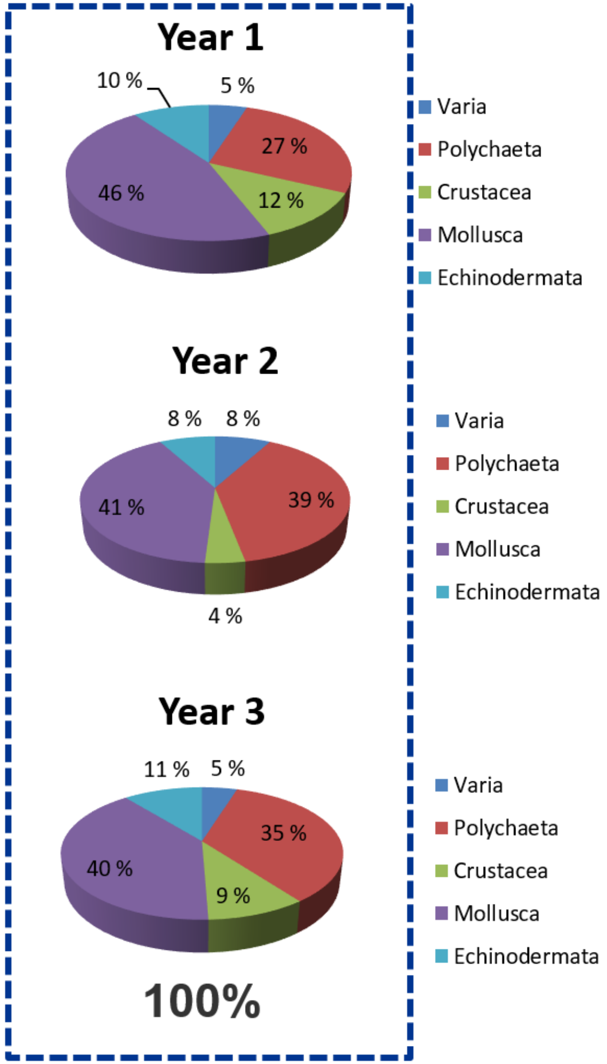
Hvor lang tid tar det før bunndyrsamfunnet kommer tilbake - rekolonisering?

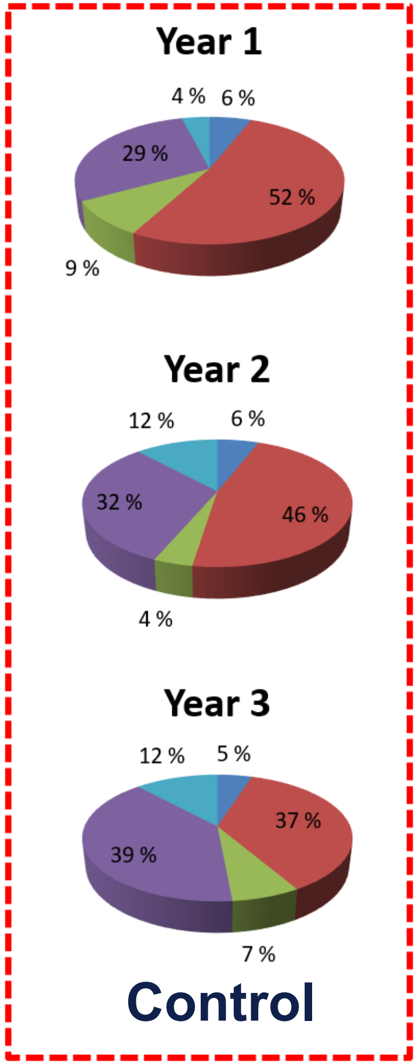
I **Frænfjorden** utført forsøk ved å sette ut kasser med avgang og se hvordan bløtbunnsfaunaen etablerer seg.

Gjennomført over 3 år (utført to ganger)



Rask etablering av arter – men også stor likhet i fordelingen av dyregrupper

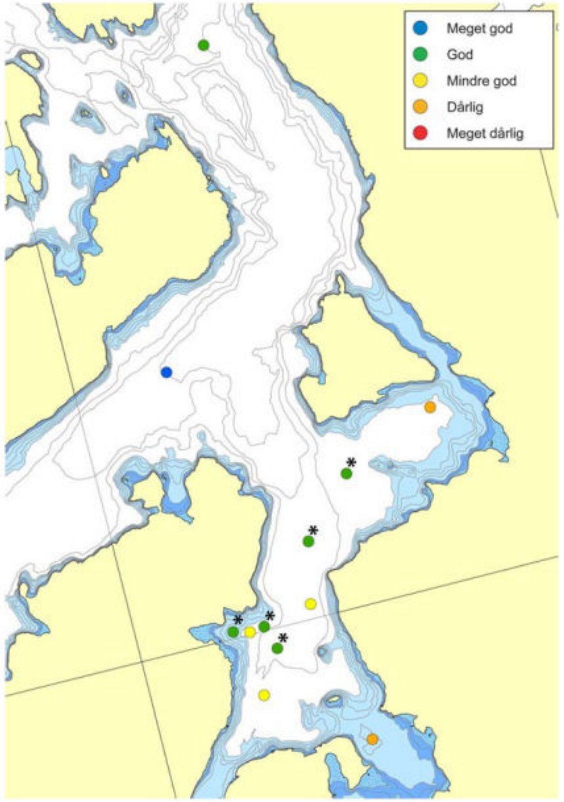




DNV

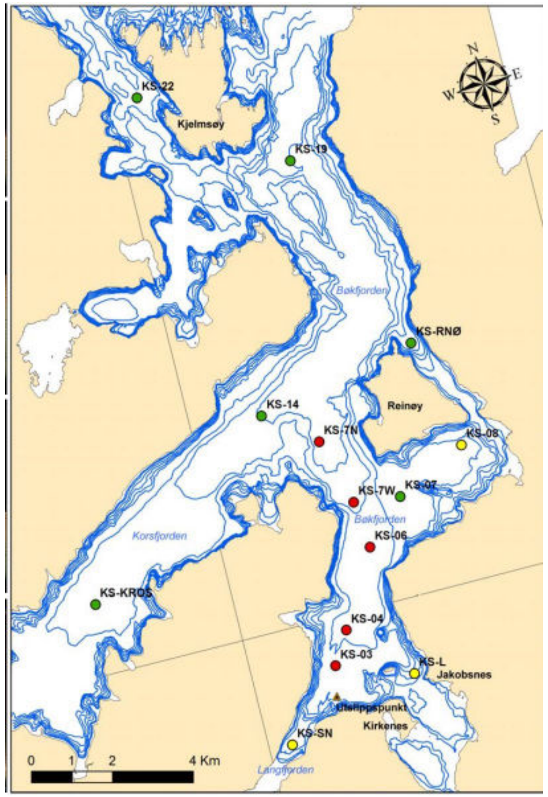
Hvor lang tid tar det før bunndyrsamfunnet kommer tilbake - rekolonisering? Eksempel fra Bøkfjorden

“god” “meget dårlig” “god”



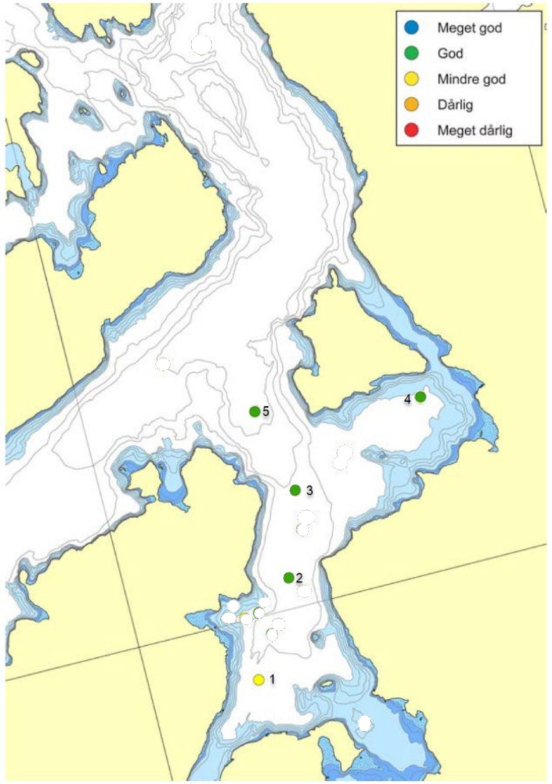
“Før oppstart”

NIVA 5472-2007



“2 år etter oppstart”

NIVA 6310-2012



“3 år etter avsluttet gruvedrift”

Modifisert etter Åkerblå MCR-M-18X094 (2018)

Stasjon/ Parameter	BØK-1	BØK-2	BØK-3	BØK-4	BØK-5	BØK-6	BØK-7	BØK-8
Antall arter	33	41	37	30	50	74	45	51
Antall individ	1156	569	526	387	497	2983	934	1219
H'	Moderat (2,187)	God (3,187)	God (3,260)	God (3,291)	God (4,073)	God (3,430)	God (3,446)	God (3,351)
nEQR	Moderat (0,595)	God (0,672)	God (0,697)	God (0,630)	God (0,724)	God (0,676)	God (0,694)	God (0,689)

“God” økologisk tilstand 3år etter avsluttet deponering basert på bløtbunnssamfunn

Basert på grabbprøver (EQR Environmental Quality Ratio=økologisk tilstand)

Basert på kamera (Benthic Habitat Quality index)


DNV

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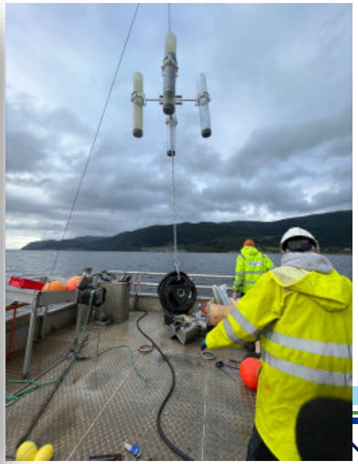
Miljøovervåkingsprogram

Nordic Rutile AS

Rapportnr.: 2022-1188, Rev. 2
Dokumentnr.: 1872674
Dato: 2023-03-21

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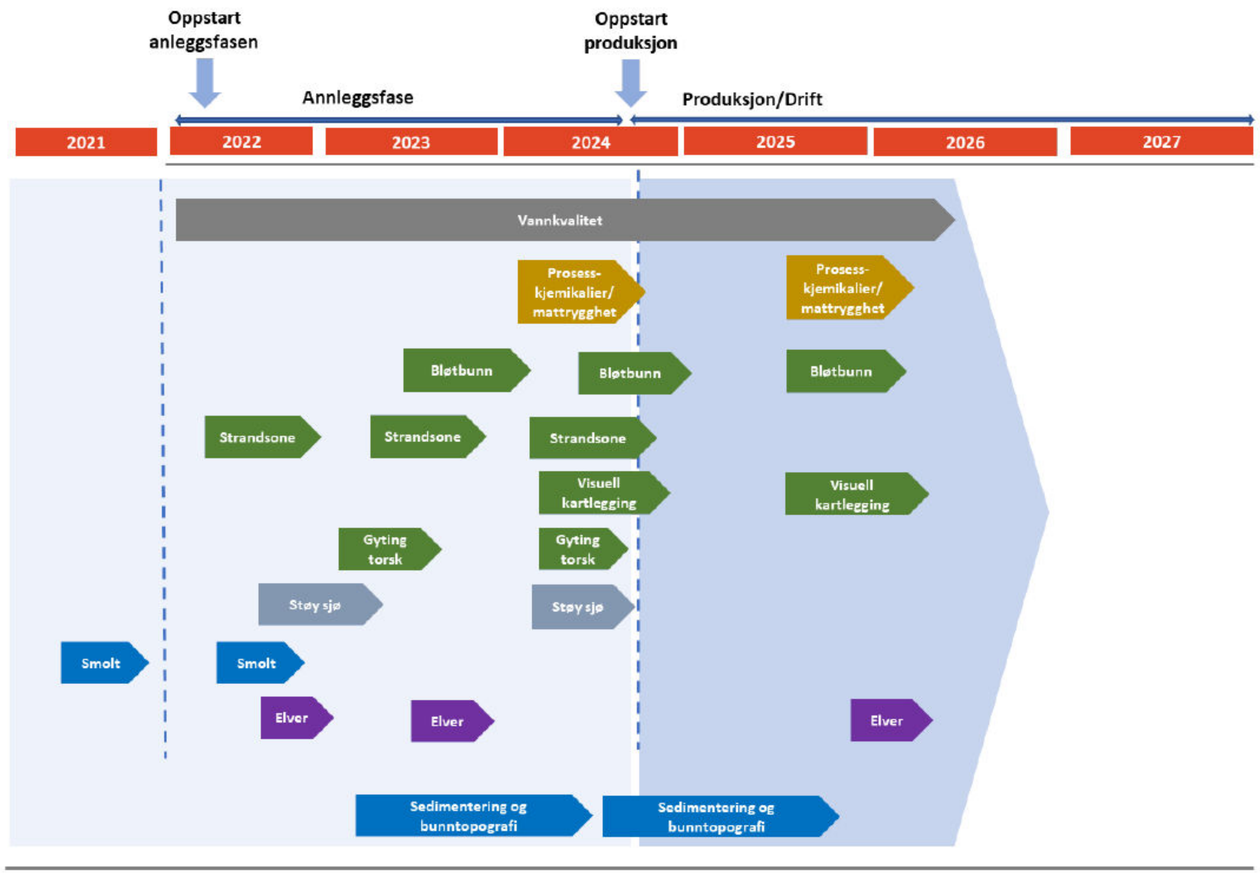

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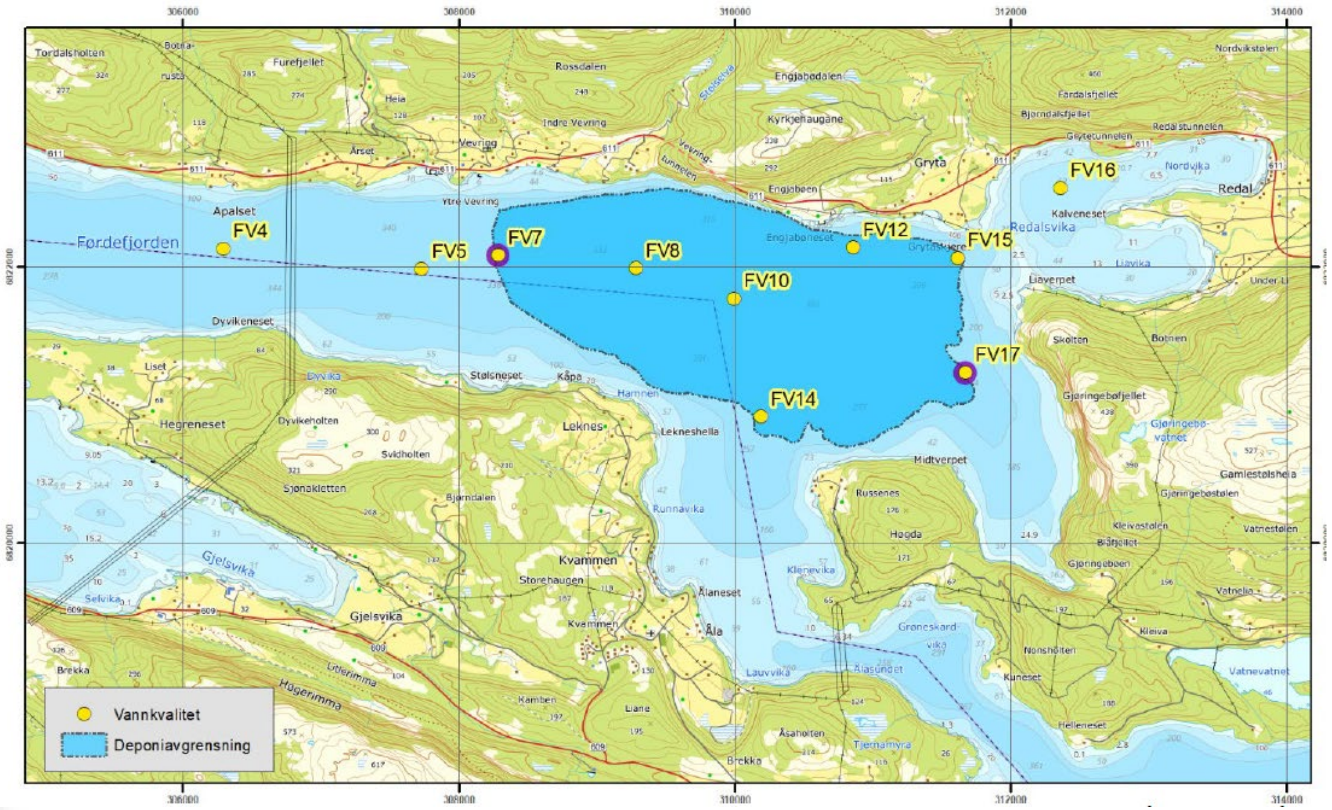

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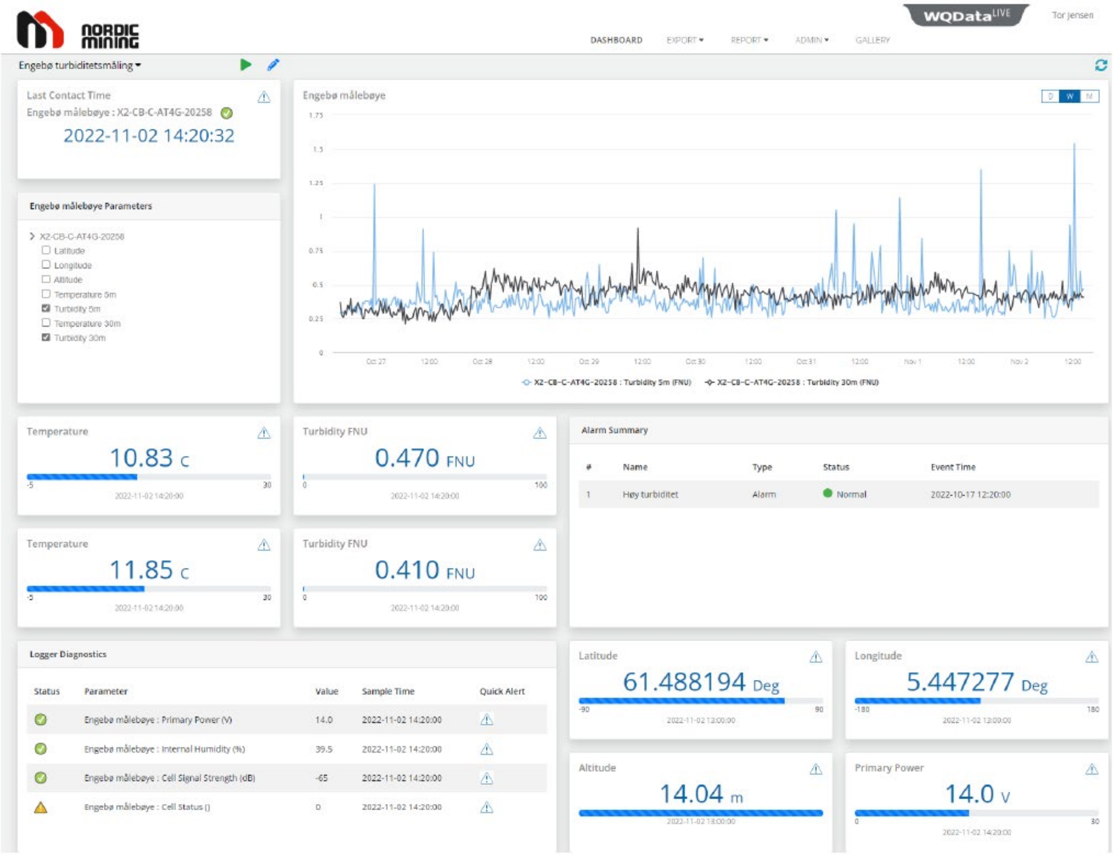

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