Planned submarine disposal of mining waste in the Førde Fjord of Norway

- underestimation and undercommunication

of

harmful effects

of

suspended industry-created particles

on fish

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«Absence of evidence

in reports

is not

evidence of absence»

Preface

The planned mining of the Engebø Mountain and submarine tailings disposal of millions of tonnes in the Førde Fjord is controversial despite granted by Norwegian Authorities. The environmental impact assessment (EIA) includes a number of issues, among these the effect of the industry-created particles in question on marine life.

The present report is a critical review of EIA reports made by the Norwegian Institute for Water Research (NIVA) and Det norske veritas (DNV) GL on behalf of the company Nordic Mining ASA, and on evaluations performed by the Norwegian Environment Agency. Especially is focused on effects of waste particles on fish, but a complete review of existing knowledge is beyond the scope of the present report. Importantly, the views expressed are my own and do not represent the university, to which I am affiliated.

This is not just about one particular discharge project but also generally about standards of Norwegian EIAs and environmental quality fulfilling the recommendations of e.g. the EC Water Framework Directive.

Most texts prepared during decision-making, i.e. reports, notes and public presentations, have been written in Norwegian. Therefore, selected texts have been translated into English by undersigned, for the purpose of the present report, and presented along with the Norwegian versions. Also selected texts in cited sources in other languages have been translated.

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Content

2 Summary

The Norwegian Government approved in 2015 the plans of the company Nordic Mining ASA to mine the Engebø Mountain in Western Norway for the titanium dioxide-containing mineral rutile, and to annually dispose of 4 million metric tonnes of waste from its operations to the adjacent Førde Fjord. The amount may increase to 6 million tonnes a year and up to 250 millon tonnes of discharge is permitted over a 50 year mining period.

The industrial process includes grinding of rock (eclogite) into fine inorganic (mineral) particles next kept in freshwater suspension, to which will be added process chemicals for the purposes to extract rutile and to flocculate (clump) the other particles into larger aggregates. These other single or aggregated particles with attached chemicals, i.e. industry-created particles, and also chemicals dissolved in the water phase, represent the waste (tailings). The permission is submarine tailings disposal, i.e. discharge at the fjord seabed. Flocculation is expected to increase the intended settling of particles at the bottom. This permitted discharge, and the environmental impact assessment (EIA) of undesired spread of particles in the water body and of harmful effects on marine life, are highly controversial. The present report critical reviews the EIA, emphasizing effects of particles on fish.

The EIA, conducted from 2007-2015, includes reports and other documents mainly from the Norwegian Institute for Water Research (NIVA) and Det norske veritas (DNV) GL prepared on behalf of the company, which forwarded these to the Norwegian Environment Agency (MDIR) and other official bodies. Additionally, NIVA commissioned to a report from MDIR.

The EIA was inadequately organized and based on a very simplified approach with no or weak reference to an overall assessment methodology. In concert action of industry-created particles and dissolved chemicals on marine life was not adressed. Nor that chemical compounds may harm ecosystems by other mechanisms than those traditionally considered toxic. Unexploited opportunities include use of knowledge in comparative medicine.

Knowledge about the industry-created particles, as product of the entire industrial process, is crucial for the evaluation of their spread in the water and for their effects on marine life. However, particles have been only partially characterized and it is unclear whether all studies were performed on material from the Engebø Mountain. Settling to the bottom of particles < 0.68 µm is non-documented. Moreover, the sizes of the 0.62 % of particles smaller than 15 µm were by DNV GL excluded from the modeling of spread. These particles, being most numerous and with the largest spread potential, may annually amount up to an order of magnitude 25,000 (37,000) tonnes including about 2,100 (3,000) tonnes of nanoparticles if 4 (6) million tonnes of waste are discharged. Therefore, the fate of these particles is non-documented and modeled particle concentrations may be too low.

Another important part of the EIA was to consider potential harmful effects on fish of industry-created particles suspended in the water. Although a lack of knowledge was early ascertained, and these particles have not been characterized, no experimental exposures of organisms to such particles were conducted. Instead, NIVA and DNV GL assumed or proposed effect limits for exposure of fish to industry-created particles based on knowledge as presented in scientific papers. But that approach failed for different reasons. Firstly, effects of «inorganic particles in general» were considered, although of non-documented relevance.

Secondly, they referred particularly to conditions in freshwater despite no documentation of that environment's relevance. Some references pertain to conditions in estuaries, which may be relevant, whereas few are about the marine environment. Thirdly, a somewhat narrow focus because NIVA in the first and basic report from 2008 considered effects on juvenile and adult fish and marine mussels only, whereas DNV GL also included fish eggs and larvae.

Fourthly, assessment methodology is lacking or inadequate. There is no reference to the EC water framework directive, which recommends use of *chronic NOECs (no-observed effect concentrations)*. NOECs are lower than NIVA's and DNV GL's effect limits, and must additionally be divided by a safety factor of 10, 50 or 100 for calculating what should be permitted, i.e. *environmental limit values (ELVs)*.

Fifthly, almost none of the scientific papers relevant for conditions in seawater were cited in the Norwegian reports. This applies especially to experiences from Norway's neighbor countries and pertains especially to Atlantic cod. The EIA of the Øresund Fixed Link included exposure of fish to sediments in question before construction commencement. Important results published in 1996 include pelagic (floating) cod eggs, which may sink if exposed to particle concentrations ≤ 5 mg/L. And adult cod avoided concentrations as low as 3 mg/L. These results imply NOECs < 5 and < 3 mg/L, and ELVs < 0.5 and < 0.3 mg/L if divided by the lowest safety factor 10. Similar results from the Fehmarnbelt Fixed Link construction published in 2012 included sinking of eggs at ≤ 4 mg/L, implying NOEC < 4 mg/L and ELV < 0.4 mg/L. In summary, the estimated ELVs for eggs and adult fish will be **< 0.4 and < 0.3 mg/L**, respectively. The uncertainty about properties of industry-created particles, including the nano-sized, should imply an additional safety factor. No data have been presented for salmonids in seawater, neither for direct nor indirect effects such as reduced abundance of their prey organisms.

The above-mentioned deficiencies were further compounded by NIVA's extensive reference to conditions in freshwater, including uncritical use of an incomplete and non-validated model and incorrect and/or incomplete reference to articles. Moreover, by uncritical and incorrect reference to one paper, about marine fish, with shortages in experimental design and interpretation. All these inadequacies caused underestimation of harmful effects, as further demonstrated when NIVA in 2009 assumed some kind of a general limit of **50 mg/L**. This is at least 17 times too high if compared with then available knowledge about avoidance at 3 mg/L, and at least 170 times too high if compared with the corresponding ELV (< 0.3 mg/L).

NIVA's Swedish daughter company, however, considered this non-cited but relevant literature in EIAs about construction of offshore wind farms. Therefore, standards of EIAs seem higher in Sweden than in Norway.

Next, in new assessments, which should be independent of previous work by NIVA, DNV GL did in a report from 2014 in part plagiarize the first report from NIVA, including significant mistakes. Based on NIVA's and self-produced errors, and in part on an old tertiary source, was proposed imprecisely-defined limits for lethal and sublethal effects. Those for sublethal effects are **20 mg/L** for eggs and larvae, and **50 mg/L** for juvenile and adult fish, all being too high if compared with existing knowledge, both the cited and even more the non-cited, and thereby not fullfilling their declared use the lowest-reported-effect concentration in evaluations. These limits are also at least 50 and 170 times too high, respectively, if compared with ELVs (< 0.4 mg/L and < 0.3 mg/L) estimated from the knowledge not cited in their report. All of DNV GL's inadequacies at critical points contribute to underestimation. Moreover, DNV GL knew about effects of nanoparticles at 0.1 mg/L, which may represent the lowest-reported-effect concentration, but did not take this knowledge into account when proposing effect limits, although including knowledge about numerous other particle types in freshwater.

The reports were presented by the company to the MDIR, which in transmitting letters to the Ministry of Climate and Environment evaluated the knowledge. MDIR accepted in 2015 the results of the modeling of spread, although the smallest sizes were ignored. In a letter from 2012 the MDIR apparently accepted NIVA's evaluations and assumed effect limit, and it was impossible to trace the content back to the primary sources cited by NIVA. Unawareness of MDIR to the non-cited knowledge about cod and other marine fish is indicated until late 2014. The Ministry set in 2015 limits of 2 and 3 mg/L for the **total** permitted concentration of inorganic plus organic particles at specific sites in the water body. These limits appear 2-8 times too high compared with the lowest ELV (< 0.3 mg/L) if inorganic particles should constitute the main fractions of these concentrations and the industry-created particles should amount 1 and 2 mg/L, respectively. A further evaluation of these limits is difficult due to insufficient characterization of the industry-created particles, including those of nano-size, and due to limited knowledge about effects of such on marine organisms.

NIVA has also presented and promoted the project, in particular submarine tailings disposal, to the public and representatives from official bodies. Underestimation and -communication were further amplified in these disseminations because of allegiations of «*Clean tailings*» and «*The concentration of particles upwards and aside for the disposal area are so low that there will be no effect on marine life*».

EIA with reports and public presentations disseminated current knowledge inadequately and constituted filters between knowledge and the public or decision-makers. Therefore, decisions were based on unrealistic high safety margins between the alleged effect limits for fish (too high) and the modeled particle concentrations in the water body (perhaps too low). One may ask how these inadequacies may affect the legal status of granting at different levels, including the decision by the local council of the Municipality of Naustdal, and also the quality of future Norwegian EIAs concerning particles in water. The EIA process would benefited from facilitating the scientific basis, and especially correct presentation of relevant knowledge, at the expense of project promotion. The modeling of spread is based on insufficiencies and levels of impacts on marine life have not been documented with reasonable certainty.

3 Summary in Norwegian

Den norske regjeringa godkjende i 2015 Nordic Mining sine planar for utvinning av det titandioksid-haldige mineralet rutil ved gruvedrift i Engebøfjellet i Vest-Norge. Medrekna er deponering av 4 millionar tonn avfall per år i Førdefjorden. Denne kan auke til 6 millionar tonn per år, og opp til 250 millionar tonn kan sleppast ut over ein periode på 50 år.

Industriprosessen omfattar oppmaling av fjell (eklogitt) til små uorganiske (mineral-) partiklar, som svevande i ferskvatn skal tilsetjast prosesskjemikaliar for utvinning av rutil og flokkulering (klumping) dei andre partiklane til større aggregat. Desse enkle eller aggregerte partiklane med fastsitjande kjemikaliar, dvs. industri-skapte partiklar, og i tillegg kjemikaliar løyste i vatn, utgjer avfallet (avgangen). Løyvet inneber avfallsdeponering på fjordbotnen. Flokkuleringa ventast å fremje den ønska søkkinga av partiklar til botnen. Utsleppsløyvet, og konsekvensutgreiinga (KU) av uønska partikkelspreiing i fjorden og skadelege effektar på livet der, er nokså omstridde. Denne rapporten er ein kritisk gjennomgang av KU-en og tilhøyrande rapportar, med vekt på partikkeleffektar (-skadar) på fisk.

KU-en vart gjennomførd frå 2007-2015. Den omfattar rapportar og andre dokument, hovudsakleg frå Norsk institutt for vassforsking (NIVA) og Det norske veritas (DNV) GL, på oppdrag frå gruveselskapet, som vidaresende desse til Miljødirektoratet (MDIR) og andre offentlege instansar. NIVA hadde i tillegg ansvaret for ein rapport, på oppdrag frå MDIR.

KU-en var utilfredsstillande organisert og basert på ei svært forenkla tilnærming med ingen eller svak referanse til overordna evalueringsmetodikk. Det er ikkje utgreidd korleis industri-skapte partiklar og løyste prosesskjemikalar i blanding kan påverke livet i sjøen. Heller ikkje at kjemikaliar kan skade økosystem på andre måtar enn det som tradisjonelt er rekna som giftverknad. Unytta moglegheiter omfattar bruk av kunnskap frå samanliknande medisin.

Kunnskap om industri-skapte partiklar, som produkt av heile industri-prosessen, er avgjerande for vurderinga av spreiinga i sjøen og for effektar på livet der. Men partiklane er berre delvis karakteriserte og det er uklart om alle desse undersøkingane er utførde på materiale frå Engebøfjellet. Det er ikkje dokumentert at partiklar mindre enn 0,68 µm vil søkke til sjøbotnen. Vidare, storleikane til dei 0,62 % av partiklane mindre enn 15 µm vart av DNV GL utelatne frå modelleringa av partikkelspreiing i sjøen. Desse partiklane, som er flest i tal og har størst even til spreiing, kan årleg vere av storleiksorden opp til 25.000 (37.000) tonn inkludert omlag 2,100 (3,000) tonn nanopartiklar ved utslepp av 4 (6) millionar tonn avfall. Difor er det udokumentert kva som vil skje med desse partiklane i fjorden, og modellerte konsentrasjonar kan vere for låge.

Ein annan viktig del av KU-en er vurdering av moglege skadelege effekar av industri-skapte partiklar på fisk i sjøen. Sjølv om manglande kunnskap tidleg vart fastslege, og desse partiklane ikkje er karakteriserte, vart det ikkje utførd forsøk der organsimar vart utsette for slike partiklar. I staden har NIVA og DNV GL tenkt seg eller føreslege effektgrenser for eksponering av fisk for industri-skapte partiklar basert på kunnskap henta frå vitskaplege publikasjonar. Denne tilnærminga mislukkast av fleire grunnar. For det første, effektar av «uorganiske partiklar generelt» vart vurderte, sjølv om relevansen var udokumentert. For det andre, dei synte særleg til tilhøve i ferskvatn, også her utan å dokumentere relevansen. Nokre referansar er til estuariar, som kan vere relevante, medan få gjeld tilhøve i sjø. For det tredje, NIVA hadde i den første og grunnleggande rapporten frå 2008 eit smalt fokus, dvs. på fisk og skjell i sjøen, medan DNV GL i tillegg vurderte effektar på fiske-egg og -larver.

For det fjerde, metodikk for vurderingane manglar eller er mangelfull. Det er ingen referanse til EU sitt vassråmedirektiv, som krev bruk av kroniske NOECs *(no-observed effect concentrations)*. NOECs er lågare enn NIVA og DNV GL sine effektgrenser, og må i tillegg delast med ein tryggingsfaktor på 10, 50 eller 100 for å rekne ut kva som skal vere tillate, dvs. miljøgrenseverdiar (*environmental limit values (ELVs))*.

For det femte, nesten ingen av dei vitskaplege artiklane relevante for tilhøve sjøvatn vart refererte i dei norske rapportane. Dette gjeld spesielt røynsler i Norge sine naboland, og spesielt torsk. KU-en for Øresundbrua omfatta eksponering av fisk for lokalt sediment (botnslam) før igangsetjing av byggearbeidet. Viktige resultat publiserte i 1996 omfattar torske-egg, som er pelagiske (flytande). Desse søkk dersom utsette for partikkelkonsentra-sjonar på 5 mg/L eller mindre. Vaksen torsk unngjekk konsentrasjonar ned til 3 mg/L. Dette tilseier NOEC < 5 og < 3 mg/L, og ELV < 0,5 og < 0,3 mg/L dersom dividert med den lågaste tryggingsfaktoren 10. Tilsvarande resultat frå Fehmarnbelt-sambandet vart publiserte i 2012, og då fann ein søkking av torskeegg også ved konsentrasjonar under 4 mg/L. Oppsummert har ein for egg og vaksen fisk ELV høvesvis **< 0,4 og < 0,3 mg/L**. Uvissa omkring eigenskapane til industri-skapte partiklar, inkludert nanopartiklar, tilseier ein tryggingsfaktor i tillegg. Ingen data er lagde fram for laksefisk i sjøvatn, korkje for direkte effektar eller indirekte effektar som redusert tilgang på deira bytedyr.

Ovanfor nemnde manglar vart forsterka av NIVA si omfattande referering til tilhøve i ferskvatn, inkludert ukritisk bruk av ein ufullstendig og ikkje-validert modell og feil og/eller ufullstendig referanse til fagartiklar. Vidare, ved ukritisk og feil attgjeving frå ein artikkel, om fisk i sjø, med manglar i forsøksoppsett og resultattolking. Alle desse manglane resulterte i undervurdering av skadelege effektar, som tydeleggjort då NIVA i 2009 antok ei form for generell grense ved 50 mg/L. Denne er minst 17 gonger for høg dersom samanlikna med då kjend men ubrukt kunnskap om unngåing av partiklar ved 3 mg/L, og minst 170 gonger for høg dersom samanlikna med tilsvarande ELV (< 0.3 mg/L).

NIVA sitt svenske dotterselskap har derimot, i samband med bygging av havvindmøller, brukt denne kunnskapen, som manglar i den norske KU-en. Standarden synest såleis høgare i Sverige enn i Norge.

Deretter, i nye utgreiingar, som venteleg skulle vere uavhengige av NIVA sitt tidlegare arbeid, har DNV GL i ein rapport plagiert den første NIVA-rapporten, inkluderte større mistak. Basert på NIVA sine og eigen-produserte feil, og delvis på ei gamal tredjehands kjelde, vart det føreslege upresist definerte grenser for letale (døyelege) og subletale (ikkje-døyelege) effektar hjå fisk. Grensene for subletale effektar er **20 mg/L** for egg og larver, og **50 mg/L** for ung og vaksen fisk. Alle desse er for høge samanlikna med eksisterande kunnskap, både den refererte og i endå større grad den ikkje-refererte, og samsvarar dermed ikkje med deira erklærte bruk av den lågast rapporterte effektkonsentrasjonen i vurderingane. Desse grensene er også minst høvesvis 50 og 170 gonger for høge dersom samanlikna med ELVs (< 0,4 mg/L og < 0,3 mg/L) baserte på kunnskap DNV GL ikkje brukte. Alle DNV GL sine manglar på kritiske punkt medverkar til undervurdering. Dessutan, DNV GL visste om effektar av nanopartiklar ved 0,1 mg/L, som kan vere den lågast rapporterte effektkonsentrasjonen, men tok ikkje denne kunnskapen med i vurderingane av effektgrenser, sjølv om anna kunnskap om fleire ulike partikkeltypar i ferskvatn vart brukt.

Gruveselskapet la rapportane fram for MDIR, som vurderte deira innhald i oversendingsbrev til Klima- og miljødepartementet. MDIR aksepterte i 2015 resultata frå modelleringa av partikkelspreiing, sjølv om dei minste partikkelstorleikane var utelatne. I eit brev frå 2012 vart tilsynelatande også NIVA sine vurderingar aksepterte, og det var umogleg å spore innhaldet attende til førstehandskjeldene brukte av NIVA. Direktoratet syntes vere ukjend med den ikkje-refererte kunnskapen fram til slutten av 2014. Departementet sette i 2015 grenser på 2 og 3 mg/L for den totalte tillatne konsentrasjonen av uorganiske pluss organiske partiklar på bestemte stader i fjorden. Desse grensene kan vere 2-8 gonger for høve dersom samanlikna med lågaste ELV (< 0,3 mg/L), uorganiske partiklar utgjer hovuddelen av dette og dei industri-skapte partiklane utgjer høvesvis 1 og 2 mg/L. Ei vidare vurdering av desse grensene er vanskeleg pga. utilstrekkeleg kunnskap om dei industri-skapte partiklane, inkludert dei av nanostorleik, og pga. avgrensa kunnskap om effekten av slike på organismar i sjøen.

NIVA har også presentert og fremja prosjektet, spesielt fjorddeponi, for ålmenta og representantar for offentlege institusjonar. Denne formidlinga hadde endå større grad av undervurdering og underkommunisering pga. påstandar som «*Ren avgang ….*» og «*Konsentrasjonen av partikler oppover i vannmassene og utover deponiområdet er så lave at det ikke har effekt på marint liv*».

KU med rapportar og presentasjonar formidla eksisterande kunnskap på ein utilfredsstillande måte og fungerte som filter mellom kunnskap og ålmenta eller avgjerdstakarar. Avgjerder vart difor baserte på urealistisk høge tryggingsmarginar mellom dei påståtte grensene for effektar på fisk (for høge) og dei modellerte partikkelkonsentrasjonane (moglegvis for låge). Ein kan spørje kva innverknad slike manglar har på legal status til avgjerder på ulike nivå, inkludert vedtak i Naustdal kommunestyre, og på kvaliteten til framtidige KU-ar vedrørande partiklar i vatn. Utgreiingane hadde tent på vektlegging av det vitskaplege grunnlaget, og spesielt korrekt framlegging av relevant kunnskap, på kostnad av prosjektfremjing. Modelleringa av spreiing er basert på manglar og grad av skade på livet i sjøen er ikkje dokumentert med rimeleg grad av visse.

4 Background

Official bodies, institutions and acronyms are presented in App. A.

4.1 A large project

The Ministry of Climate and Environment of Norway (KLD 2015) recently approved the plans (permit granted 19.04.2015 pursuant to the Pollution Control Act) of the company Nordic Mining ASA (Nordic Rutile AS) to mine the Engebø Mountain for the titanium dioxide (TiO_2)-containing mineral rutile and to annually dispose of 4 million metric tonnes of waste from its operations at the bottom of the adjacent Førde Fjord. There is a planned increase to 6 million tonnes per year later in the mining period (NIVA & Asplan Viak 2009). In total is permitted the discharge of 250 million tonnes over a 50 year period. The annual amount of 4 or 6 million tonnes of waste are significant if compared with the estimated total annual loads of about 800,000 tonnes to the Norwegian Coastal Zone (KLIF 2011).

The Engebø Mountaint is located in the Municipality of Naustdal, Western Norway. In this project the ore must be grinded into fine particles and different process chemicals will be added for the purposes to extract rutile by flotation and to flocculate the other particles suspended in freshwater into larger complexes (aggregates, flocs) (NIVA 2008a). Annually permitted discharges now include 4 million metric tonnes of inorganic particles and additionally process chemicals such as dextrin (120 tonnes), sulphuric acid (800 tonnes), sodium silicate (720 tonnes), Flotinor FS2 (120 tonnes), Flotol B (32 tonnes) and the flocculant Magnafloc 155 (polyacryl amide, 60 tonnes) (KLD 2015). It will be applied for the discharge of at least one additional compound.

The waste, or tailings, will thus consist mainly of inorganic particles but also substantial amounts of process chemicals. Magnafloc 155 (BASF 2015) and next seawater will be added for the purpose of flocculation of particles into larger aggregates. The flocculation is said to contribute to a faster settling of particles at the bottom of the fjord (NIVA 2009b; DNV GL 2014d). The term industry-created particles will be used in the present report for the purpose to discriminate between these and a number of other particle types dealt with in the reviewed scientific literature.

The fjord is about 300 meters deep and the seabed relatively flat at the planned disposal area. The maximum of 250 million tonnes of tailings is permitted disposed of at an area of maximum 4.4 km^2 (KLD 2015). The tailings will be transported through a pipeline and discharged above the bottom; initially at maximum 50 m above but elevated throughout the mining period. After about 50 years a cone- to fan-shaped deposit may have risen to about 150 meters above the bottom if one point of discharge is selected (Nordic Mining 2014). Maximum permitted concentrations of particles are 2 and 3 mg/L, depending on site in the water body, and also include the natural background of organic and inorganic particles (KLD 2015). Outside the permitted area the maximum allowed annual sedimentation rate is 3 mm.

There is general agreement that the waste will smother bottom-living organisms in the area in question. The main controversies apply to the degree of vertical and horizontal spread of particles due to currents in the water body as estimated by modeling (SINTEF 2014; DNV GL 2014d; HI 2014). This applies especially to the finest particles. Whatever is the risk of spread, it is required **emission limit values (ELVs)**, to which particle concentrations estimated by modeling can be compared.

Additionally, a land deposit of estimated 460 acres will contain waste rock amounting about 15 million m^3 after 50 years (NIVA & Asplan Viak 2009). Spread in the fjord of washed out particles from this depony has been modeleg (NIVA 2008d).

4.2 Legislation and EIA

4.2.1 Selected legislation

Legislation first of all include EC directives, and in special:

The water framework directive 2000/60/EC (EC 2000), in which the main purpose is «*to establish a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater*». It was implemented in Norwegian law from 01.01.2007 by Vannforskriften (2007), i.e. before the beginning of this EIA in 2007 (NIVA 2008d). The implementation was further detailed by Direktoratsgruppa (2009; 2013).

Directive 2006/21/EC (EC 2006) about wastes from extractive industries and further detailed in Commission Decisions 2009/360/EC and 2009/359/EC. According to its article 13.4 should the water framework directive as well as other specified directives prevail over the mineral waste directive if there are contradictions.

The EIA Directive 85/337/EEC as amended by the directives 97/11/EC and 2003/35/EC (EC 1985) recommends assessment of (1) «*the direct and indirect effects of a project*» on «*fauna and flora*», (2) «*water*» and (4) «*the interaction between the factors mentioned in the first, second and third indents*». «*This description should cover the direct effects and any indirect, secondary, cumulative, short, medium and long-term, permanent and temporary, positive and negative effects of the project*» (footnote 6 of the directive).

Additionally, the *London Convention and Protocol - Revised specific guidelines for the assessment of inert, inorganic geological material* from the International Maritime Organization (IMO 2008).

The EIA should lead to some kind of permitted limits which should not be exceeded in the water body. The water framwork directive (EC 2000), article 2, contains two terms related to limits.

35: «*‘**Environmental quality standard**’ means the concentration of a particular pollutant or group of pollutants in water, sediment or biota which should not be exceeded in order to protect human health and the environment*».

40: «*‘**Emission limit values [ELVs]**’ means the mass, expressed in terms of certain specific parameters, **concentration** and/or **level** of an emission, **which may not be exceeded during any one or more periods of time**. ELVs may also be laid down for certain groups, families or* *categories of substances, in particular for those identified under Article 16. The ELVs for substances shall* ***normally apply at the point where the emissions leave the installation****, dilution being disregarded when determining them».*

That ELVs should apply at the point of discharge does not make sense for submarine tailings disposal unless the disposal area of 4.4 km^2 is considered part of the installation. However, this demonstrates that this kind of disposal was out of question when the directive was developed.

4.2.2 From observations to ELVs

Observations of experimental or natural exposures of fish to particles form the basis for most, if not all, of present knowledge about effects. The steps from observations to ELVs include the use of terms describing different types of concentrations. Consistent use of clearly-defined terms should be mandatory in the EIA. The present report uses the IUPAC Glossary of terms for ecotoxicology (IUPAC 2009) as extended from the field of general toxicology (IUPAC 2007). See App. B for details. A number of these definitions also reflect methodology.

Two of the IUPAC-defined terms; **effect (effective) concentration (EC)**, of which LC_{50} is a special case, and **no-observed-effect concentration (NOEC)**, are central in the water framework directive EC (2000). They are defined by **type of effect** (response) and **magnitude of effect** (percentage of test population affected) as observed after a specified **time of exposure** under defined conditions (App. B). But the directive does not present detailed procedures for estimationg such concentrations. Although developed for chemical compounds I suppose these terms and associated approaches should be appropriate also for suspended particles as long as no other guidelines seem to exist for these.

Limit value (LV) is by IUPAC (2009) defined as: «*Limit concentration at or below which Member States of the European Community must set their environmental quality standard and emission standard for a particular substance according to Community Directives*». Thus, ELV is one type of limit value.

As particles of the present project are supposed or alleged to settle and not to accumulate in the water body, although not documented for the smallest particles, the **environmental quality standard** should approximately correspond to the **emission limit values [ELVs]**. Inferring ELVs from present knowledge requires an appropriate methodology including consistent use professional terminology. Therefore, and because procedures for setting «particle standards» apparently have not been developed from the directive, one should apply the procedures for the setting of chemical quality standards as expressed in Annex V 1.2.6 (page 52) of the directive (EC 2000).

This procedure involves at least two steps in assessing ELVs. **In more detail, the directive recommends the use of acute LC_{50} and chronic NOEC values, all for different trophic levels. Both are effect concentrations or estimated from observations. Further, it recommends acute LC_{50} values to be divided by a safety factor of 1,000 and chronic NOECs to be divided by factors of 10, 50 or 100, depending on the number of species**

and trophic levels investigated.

Finally, the directive also has one category of «*other cases*», in which there must be «*case-by-case*» assessment of the safety factor. Such assessment has apparently not been performed in the EIA of the present mining project.

The directive is about concentrations related to effects observed in the short (acute) or long (chronic) term but does not define these terms. But 0-4 days has been suggested acute (IUPAC 2009; App. B) and that definition will be used in the present report. The LC_{50} value decreases with increasing exposure duration. Examples are presented in Sherk et al. (1975, table 1), with 24 hr and 48 hr LC_{50}s being e.g. 88.0 and 1.9 mg/L in spot, and 9.9 and 3.0 mg/L in white perch. Divisions of all with the safety factor 1,000 may therefore produce somewhat different ELVs.

NOECs are by definition lower than corresponding threshold concentrations, which again frequently are lower than the directly observed effect concentrations. First observable effect concentration (FOEC) as used by Partridge & Michael (2010) is at the level of the threshold or higher. It should also be obvious that a lethal limit for direct effects on fish, unless divied by a high safety factor, makes no sense as long as concentrations for sublethal effects are lower. Therefore, an operational limit for lethal effects in a water body should be inexpedient.

A number of scientific papers report observations or effect concentrations without specifying all or the most important conditions, and there is also a variation in terminology. LC_{10} and LC_{50} values are frequently used in publications but it remains unclear whether they always are calculated according to the guideline of IUPAC (2009) (App. B). Additionally, papers also present data for chronic LCs and acute NOECs, both uncovered by the directive. This implies that division of chronic LC_{50}s with the safety factor 1,000 would be incorrect, whereas acute NOECs should be divided by a high factor. It is therefore a challenge to relate published data to one or more of the above-mentioned terms. However, this should not excuse confusing terminology in reports. Limits are further commented in other parts of the present report.

Norway is obliged to establish emission limit values (ELVs) in accordance with principles laid down in the water framework directive, based on e.g. acute LC_{50} values and/or chronic NOECs, all divided by appropriate safety factors (10-1,000).

The present report evaluates aspects of the EIA according to these principles and guidelines.

4.3 EIA and granting of the mining project

Nordic Mining, the Norwegian Institute for Water Research (NIVA), Det norske veritas (DNV) GL and different official bodies in Norway (App. A) have published many documents and reports during the planning and decision-making processes from 2007 – 2015 but the present report refers only to documents relevant for effects on fish (App. C). The reports and other publications from NIVA and DNV GL are on behalf of the company. The impact assessments have been performed mainly in two phases (App. C).

The first phase depended mainly on the NIVA reports but also on the note by NIVA & DNV GL (2009), which were all cited in a transmitting letter (KLIF 2012) sent from the Norwegian Environment Agency (MDIR) to what is now the Ministry of Climate and Environment (KLD). NIVA also commissioned a report from the MDIR (KLIF 2010). The zoning plan with EIA (NIVA & Asplan Viak 2009) was granted by the Municipality of Naustdal in 2011.

The second phase included supplemental investigations performed during 2013-2014 subsequent to recommendations from what is now the KLD. This phase, therefore, also includes reports from DNV GL and SINTEF, which were all cited in transmitting letters (MDIR 2014; 2015) to the KLD. Finally, the Ministry of Climate and Environment permitted the discharges and set limits for particle concentrations (KLD 2015).

One of these reports (NIVA 2008a) has been referred to in EIAs of at least two road construction projects (Norconsult 2012a; 2012b), in an evaluation of particles in seawater NIVA (2009e) and in a report being part of EIA for submarine tailings disposal in the Reppar Fjord (Akvaplan-NIVA 2011b). Also, therefore, it is important that reports intended to compile basic knowledge actually do so. The project in question may, therefore, also represent a test case of how Norwegian Authorities are going to further implement the water framework directive (EC 2000).

4.4 Debate

Undersigned has publicly criticized parts of the EIA in newspapers or at their websites (Kvellestad 2014a; 2014b; 2014c; 2014d; 2014e; 2015b). NIVA has answered once (NIVA 2014b), but without directly countering important objections. DNV GL has not answered at all. Additionally, a letter along with a report (Kvellestad A 2015a) was 22.01.2015 sent to the Norwegian Authorities.

4.5 The present report

The present report critically reviews a number of publications prepared by NIVA and DNV GL (App. C) on behalf of Nordic Mining ASA or MDIR. The above-mentioned publications are evaluated on (1) the basis of what should be expected from an environmental impact assessment (EIA), i.e. a knowledge-based and analytical approach supplemented with experiments if necessary, and (2) from intentions articulated by the reports themselves.

Key points relate to the industry-created particles in question; their largely unknown properties, preconditions for modeling their spread in the water body, and their effects on fish in the water. Sediments bedded at the bottom of the fjord and dissolved chemicals are not considered. The focus is especially on basic or primary reports, such as NIVA (2008a) and DNV GL (2014a) with an intention to lay down premises for subsequent parts of the EIA. Especially is focused on their argumentations for limits.

It is primarily focused on the fish species and life stages which, according to published research, appear to be most sensitive, especially if present in the Førde Fjord. Further, on exposures of long duration, and to particle concentrations most closely related to those modeled in the water body of the fjord.

In an overview of papers not cited by the Norwegian reports has been selected those in which the amounts of particles have been measured by concentration (mg/L), since all the Norwegian reports do so, and because the relationships between turbidity units and concentration are commonly non-documented. Importantly, it should be kept in mind that the published concentrations might have been obtained by different analytical methods. If primary sources contain poorly- or undefined terms, which is frequently the case, their results are in the present report preferently presented by the words of the authors in question. Parts 5 & 6 of the present report focus on deficiencies more or less common to reports from NIVA and DNV GL whereas whereas their specific evaluations of effects on fish are reviewed in separate chapters (7; 8). Finally, 9 is about government bodies.

Author names of reports from NIVA and DNV GL have been replaced by the acronyms of the institutions.

The present report critically evaluates parts of the EIA concerning the industry-created particles and their effects on sensitive fish.

5 Characterization of particles

This section is all about themes which are common to reports from NIVA and DNV GL.

5.1 Particles

Knowledge about suspended particels in terms of quality and quantity is absolutely essential for the assessment of their spread and biological effects. The title «*Sedimentological research as a basis for environmental management: The Øresund fixed link*» of a paper published by Valeur & Jensen (2001) is very informative, and the summary as well: «*Environmental planning and management when constructing the fixed link were heavily dependent on **extensive sedimentological and biological research prior to construction**. Base-line turbidity and seabed sediments were investigated, and sediment spill parameters were measured during test dredging and test reclamation, in addition to the environmental impact*». See also Gray (2006).

Suspended particles are «*organic and inorganic particles that are suspended in, are carried by, or accumulate in waterbodies*» and «*that remain in suspension in water for a considerable period of time without contact with the bottom. Such material remains in suspension due to the upward components of turbulence and currents and/or by colloidal suspension*» (US EPA 2006).

A number of characteristics of particles are important for their spread potentials in water bodies and for their biological effects. Particles can be characterized by e.g. quantity, size, shape, surface area, crystalline form, density, sinking velocity, chemical composition especially at the surface, electrical charge, degree of aggregation (flocculation) and ability to modify light transmittance in the medium. Probably none of these characteristics, or variables, except quantity, are independent of the others. Additionally, the ambient environment will modify the surface due to e.g. adsorption of dissolved substances to their surface, resulting in e.g. altered degree of aggregation. The importance of surface alterations increases with decreasing size of particles. **This implies that the same particles, and especially the smaller ones, may have quite different properties in freshwater and seawater.**

Table 1. Size classes of particles in sediments (NGU 2015).

Type	Diameter, mm	Diameter, µm	Diameter, nm
Clay (leire)	< 0.002	< 2	< 2,000
Silt (silt)	0.002 – 0.063	2 – 63	
Sand (sand)*)	0.063 – 2.0	63 – 2,000	
Gravel (grus)	2.0 - 64	2,000 – 64,000	

*) The range including sand is wide, and is further divided into very fine (63–125 µm), fine (125–250 µm), medium (250–500 µm), coarse (500–1,000 µm) and very coarse (1,000–2,000 µm) particles (wikipedia.no).

Size has been focused in the EIA. There is commonly a continuum of sizes, which are used to classify particles (table 1). Additionally, nanoparticles are those smaller than 100 nm (0.1 µm) (IUPAC 2007) and colloids range 1 nm – 1 µm (IUPAC 1971/2001).

The quantity of particles can be described by mass concentration (hereafter: concentration, mg/L), number concentration, volume per volume and turbidity (cloudiness) or light penetrance. Turbidity is the particles' ability to scatter light (unit NTU) and results from all types of particles present, including both inorganic and organic particles as well as plankton. Actual distributions for number and mass concentrations, as function of particle size, are commonly different. Therefore, whereas the fine fraction dominates by number the coarse fraction may dominate by mass.

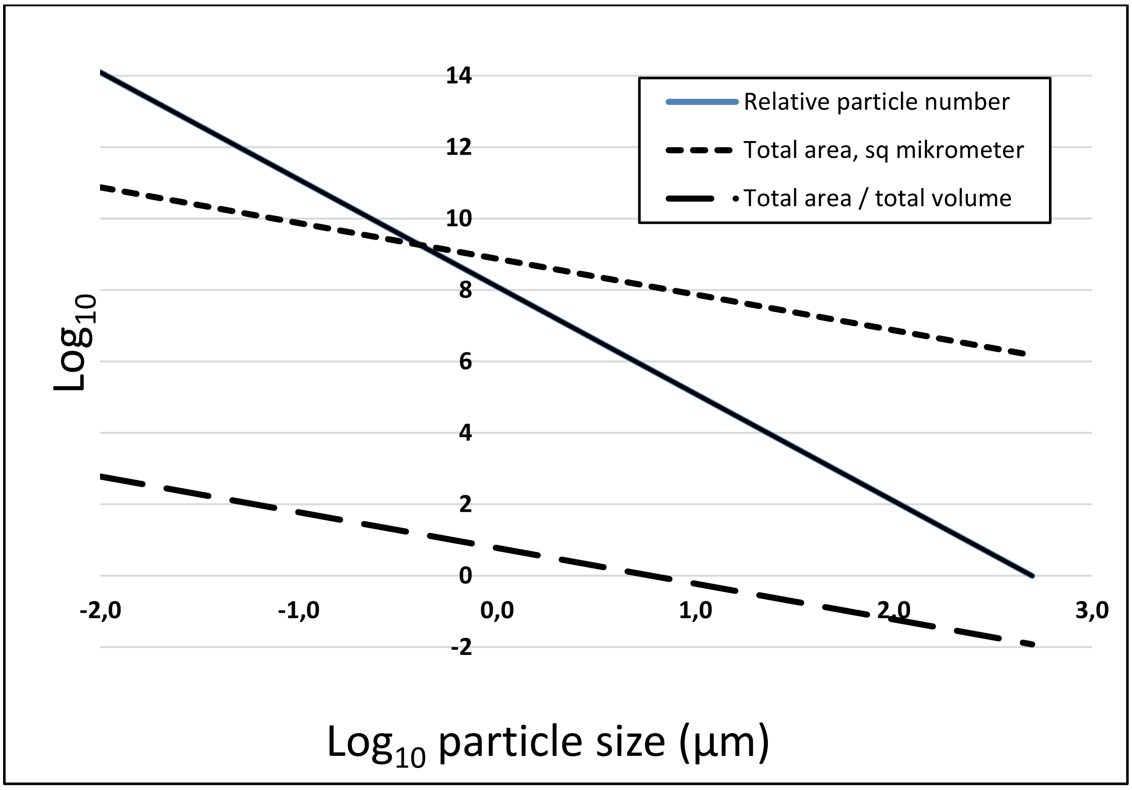

Figure 1. Relative numbers, total area and total area / total volume of particles as function of their size (0.01[left]-500[right] µm) given their total mass is constant and all particles at given sizes are of exactly the same size and cubic form. One 500 µm particle is represented by the relative number of 1 ($\log_{10}$=0), total area (µm^2, $\log_{10}$=6.2) and total area / total volume ($\log_{10}$=-1.9) at right in the diagram.

How particle numbers may increase with decreasing size are indicated by the theoretic curve in figure 1. Grinding of one cubic particle into new cubes being one tenth as large produces 1,000 new particles. If starting with one 500 µm particle, which is in the upper range of the size distribution of grinded eclogite (NIVA 2009b; NIVA 2014a), there will be 10^{14} new 0.01 µm particles. And importantly, most particles in that case will be smaller than 0.1 µm, i.e. nano-sized. Moreover, there is increase in the total area by a factor 5 x 10^4 (from 1.5 x 10^{-6} m^2 to 7.5 x 10^{-2} m^2) and an identical increase in the ratio between area and volume. If particles are plate- or needle-shaped, which they frequently are, the total area will be even greater. For to types of nanoparticles described in a study was estimated 51 and 205 m^2/g (Canesi et al. 2010).

In practical situations grain size distributions will be obtained. Integration of such data downwards a particle size interval may demonstrate even higher relative values for numbers of small particles than indicated in the figure.

5.2 The natural background of particles

Water was sampled from different depths at four sites in the Førde Fjord from 2007 October to 2008 June (NIVA 2008d). Salinity, temperature and density were all recorded at one site on five occasions during the period, and salinity and temperature in June from three other sites. Turbidity (as nephelometric turbidity units, NTU) was measured two times (October and March) at that site, and in June also at three other sites. Additionally, turbidity was during June continuously recorded at a depth of 3 m at two sites. Turbidity was mainly lower than 1 NTU but the continuous record revealed a rise to approximately 2.5 NTU in June. Additionally, was in late summer 2007, and late winther and spring 2008, measured about 0.1-0.3 NTU in profiles of the water column and 0.3-0.5 NTU at 305 and 335 m (NIVA 2008e). One cannot conclude on the total concentration (mg/L) of particles in genereal and inorganic particles in special from these results. The report makes this clear, but also assumes that 1 NTU frequently may correspond to 1 mg/L. Considering the size of the project one may ask why concentrations of inorganic particles were not recorded. The natural concentration of suspended fine particles of all types at deep water in the Førde Fjord is said to be about 1 mg/L (DNV GL 2014a 3.3 page 31). But that report does not provide any reference for this, and the fine particles' size range and types are unclear.

Knowledge about normal background of mineral particles seems insufficient although representing one prerequiste for estimating what increase should be permitted.

5.3 Industry-created particles

5.3.1 General

Characterization of the suspended industry-created particles to be disposed of is crucial for assessing their spread potential and their effects on marine organisms and ecosystems, as stated by Partridge & Michael (2010): «*It is critical that data be obtained using the appropriate sediment*». And for this reason, fish were experimentally exposed to Øresund or Fehmarnbelt sediments – as part of the EIAs - because resuspension was predicted during the construction periods (Westerberg et al. 1996; Petereit & Franke 2012). In accordance with the purpose of the present report will be focused on **industry-created particles (single particles and particle aggregates)** suspended in the water body, although dissolved chemicals and the bedded particles should be kept in mind. The properties of particles depend on a number of variables as mentioned above.

The industrial tailings (waste, slurry) will consist of different components; (1) industry-created particles, i.e. single or aggregated industry-grinded particles to which process chemicals are bound (adsorbed), and (2) chemicals dissolved in the process water. The proportions between dissolved and adsorbed chemicals can be described by equilibrium constants. Therefore, if adsorption is reversible, adsorbed chemicals can be released into the ambient water («the reaction is driven to the left») when the concentrations of dissolved chemicals in the process water are reduced due to the dilution of the plume following its discharge. However, there has in part been a one-by-one evaluation of tailings components; particles (NIVA 2008a; 2009b; 2014a; DNV GL 2014a) and chemicals (NIVA 2009c). It also remains unknown how properties of suspended particles diluted by spread may have altered properties, although the largest particles or aggregates are known to settle most rapidly.

An EIA must be based on knowledge about the particles in question and not primarily a number of particles of other types («inorganic particles in genereal»).

The following text focuses on particles without and with flocculant, but keeping in mind the absence of other process chemicals.

5.3.2 Grinded eclogite

The Engebø Mountain contains large amounts of eclogites, which are metamorphic rock (Kleppe 2013). These eclogite types contain a number of minerals, of which garnet may constitute up to 50% by weight and mineable rutile (with > 99.5% titanium dioxide) up to 5.5%.

A size distribution for grinded eclogite, with no chemicals added and not necessarily representative for the mineable parts, has been presented as a diagram denoted figure 2 in two reports (NIVA 2008a; 2014a). The reports do not clearly state that the tested eclogite originated from the Engebø Mountain. See also 5.3.3. The following approximate size distribution of particles was found (cumulative volume percentage of particles) by comparing the diagram with the table 1 above: 10% is medium sand, 30% is fine sand, 25% is very fine sand, 33% is silt and 2% is clay. One may ask about the relevance of this distribution as long as there seems to be no published evaluation of the extrability of rutile from a suspension with these particles sizes.

NIVA (2008a, see App. F §4), **quote**: «*Figure 2 depicts the grain size distribution of grinded material anticipated to represent tailings from Engebø. A small fraction of the material is very fine whereas the main bulk of particles range 100-250 µm, i.e. it is like sand*».
NIVA (2008a Summary, see App. F §3), **quote**: «*The material to be disposed has a grain size distribution which is comparable with that of sand, in which the main bulk of particles range 100-250 µm*».

Firstly, that the main bulk of particles should range 100-250 µm is incorrect. According to the published figure 2, only 37% are 100-250 µm whereas 53% are < 100 µm. Secondly, if we compare with the classification (table 1) 55% is fine to very fine sand, 33% is silt and 2% is clay, demonstrating that sand unspecified may be misleading. Thirdly, the statement in the report summary misleadingly communicates that this is sand, and it disregards the substantisal amounts of fine particles (see below).

The importance of small particles is supported by this conclusion about settling tests with grinded eclogite (without any process chemical added) from the Engebø Mountain: «*Based on the results it seems impossible to specify a specific sinking speed, which can be used to estimate how far the fine fraction of suspended particles can spread (Ut fra resultatene ser det ut til at det ikke er mulig å angi noen bestemt synkehastighet som kan brukes til å beregne en grense for hvor langt finfraksjonen av suspenderte partikler kan spre seg)*» (NIVA 2009b).

Attention is thus taken away from the smallest particles with the largest spread potential and, therefore, for harmful effects on marine organisms. The further use of this information will also be commented later (7.7.2).

Nanoparticles (ultrafine particles, < 100 nanometer [0.1 µm]) - if 4 (6) mill tonnes of tailings are disposed - will annually amount about 2,100 (3,000) metric tonnes including 70 (100) tonnes of titanium dioxide (Naturvernforbundet 2014). DNV GL (2014c) agrees on the amount of TiO_2 nanoparticles but argues that the concentrations in the water will be low. It would also be interesting with an evaluation of the 2,000 (2,900) tonnes of other types of industry-created nanoparticles.

Most particles of the tailings are said to be oval with a roundness about 0.6 (proportion between diameters along two axes perpendicular to each other) whereas a minor fraction are needle-shaped (NIVA 2008a; NIVA 2009b). One may ask if the degree of roundness is the same in all the size fractions of particles. This is important if the angularity should be higher in the fine fraction with the highest spread potential. Generally, small particles such as clay are by nature plate- or flake- formed. Chemically, silicates constitute the predominat portion of the particles (46% when calculated as SiO_2) (NIVA 2008a). One may also ask if the mineral composition is the same in all fractions.

The reports do not address numbers of particles. Number concentrations can be very approximately estimated by dividing the volume percentages with corresponding particle volumes (= 4/3 x 3.14 x [size/2]^3). The values of these two variables can most easily be read from the distribution curve for 0.1 – 500 µm sized particles as published in figure 2 in NIVA (2014a). In this approach the particle's volumes are over-estimated, because they are irregular, and therefore their numbers underestimated. However, if the relative number is 1 for 500 µm sized particles the other numbers (corresponding size) will be about 3.1 x 10^3 (100 µm), 4.2 x 10^5 (10 µm), 1.7 x 10^7 (2 µm), 8.3 x 10^7 (1 µm) and 1.0 x 10^{10} (0.1 µm). The last figure is the most uncertain, but the estimates indicate 1,000 times as many 0.1 as 1.0 µm particles. A full integration also including nano-sized particles would produce cumulative data that would further underline that most particles will be small. **A cautious conclusion is that most particles will be smaller than 2 µm, i.e. smaller than the silt fraction**.

A clear statement about the origin of the tested eclogite is lacking. The smallest particles' amounts are undercommunicated and their form (angularity) and mineral composition seem insufficiently documented. There is no information about number concentrations, to which the smallest particles contribute most significantly. Most particles will be smaller than the silt fraction.

5.3.3 Grinded eclogite with flocculants

Additionally, effects of artificial flocculants (e.g.Magnafloc 155) and seawater on settling of inorganic particles were tested in the laboratory (NIVA 2009b; NIVA 2014a).

NIVA (2009b) is unclear about the origin of the eclogite, from which particles were examined, as illustrated by the summary and introduction.

Summary: «*Physical/chemical examinations of **grinded eclogite from the Engebø Mountain** were performed. It was chosen to carry out the tests on eclogite or raw ore because insufficient quantities of representative tailings were available (Det er gjennomført fysisk/kjemiske undersøkelser av nedmalt eklogitt fra Engebøfjellet. Det ble valgt å gjennomføre testene på eklogitt eller råmalm fordi en ikke hadde tilstrekkelige mengder representativ avgang tilgjengelig)*».

*Introduction: «Tailings were not available. Therefore, the experiments were conducted with grinded raw ore **supplied by MinPro in Sweden**. **This ore has been used in previous assessments in Sweden**. Leaching experiments were performed with eclogite deposited in seawater. Moreover, the settling properties of the grinded eclogite were tested (Da det ikke fantes tilgjengelig avgang, ble forsøkene utført med nedmalt råmalm skaffet til veie av MinPro i Sverige og som var benyttet til tidligere utredninger der. Det ble gjennomført utlekkingsforsøk med eklogitt deponert i sjøvann. Videre ble sedimenteringsegenskapene til den nedmalte eklogitten testet)*».

One may ask whether (all) the tested eclogite originated from the Engebø Mountain. NIVA (2014a), on the other hand, states that grinded eclogite from the mining area was tested.

Common to these experiments (NIVA 2009b; NIVA 2014a) is the **absence** of the other process chemicals in the test suspensions, i.e. the surfaces of particles were «clean» prior to adding flocculant.

NIVA (2009b) reports several experiments, including one in which flocculation and settling of the fraction smaller than 10 µm was tested in beakers left undisturbed for half an hour. The result was monitored by measuring turbidity, which was 109 FNU in the control and reduced to 85.6 FNU in the suspension with Magnafloc 155. A turbidity of 85.6 FNU is still relatively high, and compared with 109 FNU it strongly indicates an inefficient settling. No sediment at the bottom is reported, and **settling of particles is non-documented**. However, the report concluded «*Dosage of Magnafloc seemed to produce good results (Dosering av Magnafloc 155 så ut til å gi gode resultater)*». NIVA's further use of this statement is commented in 7.7.2.

In the second experiment, flocculation and settling of a suspension was tested with all size fractions present (NIVA 2014a). The percentage of particles smaller than an equivalent diameter of 19 µm was reduced from more than 10% to 0.8%. However: «***Settling rates** of particle size fractions below 0.68 µm are **not possible to determine** from these tests, other than that they will be lower than the stated settling rate of the 0.68 µm size fraction*»), and «*It is indicated that a concentration-dependent flocculation might occur in the fjord after discharge*».

This means that it was impossible to document the settling rates of particles with the highest potential for spread and possibly most numerous. And the question about possible accumulation in the water body is left open. The absence of the other process chemicals in these experiments raises the question about how these – if present – might enhance or inhibit flocculation by competing with the flocculant in non-covalent binding to chemical groups present at the surface of particles.

Also the nano-sized particles (Naturvernforbundet 2014; DNV GL 2014c) should be expected to attract process chemicals. However, DNV GL does not take into account that the particles in question will be neither natural nor constructed but will be an unintentional result of an industrial process in which process chemicals are expected ti attach to their surface.

As the largest particles will settle most rapidly within the planned disposal area the finer particles will constitute a larger fraction of those dispersed in the water body. General knowledge and the above-presented results strongly indicate that the discharged particles will represent a mixture of single and aggregated particles, to which varying amounts of Magnafloc 155 and other chemicals will be bound. An important question is what can be expected – in terms of number, size, form, chemical composition and surface properties – at distance from the deposit site. One may ask how long a significant flocculation process may continue as spread inevitably increases the average distance between particles.

The smallest fraction of aggregates (< 15 µm) is of special interest in association with modeling of spread (5.3.5). Regression curves for cumulative aggregate fractions (y = $9x10^{-5}$-0,4) and equivalent diameters (D = 1.1-132 µm) as presented in table (NIVA 2014a) were established by undersigned (Excel). The equation best fitting with the data is y = 0,0038 x $D^{1,8806}$ (R^2 = 0,990) if particular emphasis is put on consistence with the values for sizes ≤ 11 and 19 µm. Estimated cumulative percentage for particles smaller than 15 µm is by this 0.62 % whereas another equation gave a higher value. This value **0.62 %** and will be used in a further estimation.

Also the relative number of aggregates < 15 µm is of interest. Their numbers can be very approximately estimated in the same manner as those above without flocculant added, although aggregates will be even more polymorphic than single particles.

Interval (0-1.1 µm, 1.1-2.2 µm, etc.) aggregate fractions were calculated and next divided with volume (= 4/3 x 3.14 x [median equivalent diameter of interval/2]^3) to produce relative interval number concentrations for aggregates. Estimated relative number concentrations for different intervals are e.g. 1 for 132-85 µm, 16 for 19-15 µm, 18 for 15-11 µm and 3,000 for 1.1-0 µm. Actually, most aggregates will be smaller than 1.1 µm. If summarized, 52 for 132-15 µm and 3,800 for 15-0 µm. Althoug very approximate t**hese figures indicate that most aggregates will be smaller than 15 µm**.

Industry-created particles, as the product of the entire industrial process, have not been characterized. Flocculation has been tested under unrealistic conditions because the other planned process chemicals were absent. Results of these tests were inconclusive for aggregates < 0.68 µm (corresponding to nano-sized particles and part of the clay fraction if compared with single particles) because their settling rates could not be

documented. Estimations based on these results also indicate the fraction smaller than 15 µm to amount about 0.62 % and to contain most aggregates.

5.3.4 Particles referred to by NIVA and DNV GL

NIVA and DNV GL have not adequatiely characterized the industry-created particles, but their assessments rest on studies about «inorganic particles in general».

Effects of a number of types of particles on a number of aquatic organisms in very different environments (freshwater, estuarine, marine) are presented in the scientific literature. Most types of particles appear to be natural, from e.g. sediments. NIVA and DNV GL refer to studies of different particle types in all the types of environments but do not consider the relevance of these in relation to the industry-created particles and do not document the relevance of results pertaining to extramarine environments. The well-known effect from salinity on fine particles alone should be sufficient to address this relevance.

NIVA and DNV GL have intended to report studies of effects from inorganic particles. Many papers poorly describe the particles' properties, such as the grain size distribution. A number of studies cited in the reports and in the present report exposed fish to natural sediments, which I suppose all contain organic matter. This is documented in publications (Johnston & Wildish 1981; 1982; Wildish & Power 1985) not cited in the reports, except one. On the one hand, this may mimic particles with flocculant. On the other hand, this question has not been addressed.

Studies of effects of particles of non-documented relevance, all in freshwater, also include wood fibre and coal-washery waste (Herbert & Richards 1963) and particles of ferric hydroxide (Sykora et al. 1972). These are referred by NIVA (2008a) and as plagiarism in DNV GL (2014a). EIA is thus in part based on particles for which the relevance is non-documented. Also particles composed of barite (barium sulphate) (Smit et al. 2008 cited by NIVA & DNV GL 2009) and calcium carbonate (DNV GL 2014d) differ chemically from the silicate-containing particles in question.

NIVA and DNV GL uncritically refer to studies involving effects of particles of non-documented relevance, also including organic particles, in environments of non-documented relevance.

5.3.5 Modeling of particle spread in the water body

The Dose Related Risks and Effects Assessment Model (DREAM) used to simulate particle spread in Førde Fjord has size distribution as an input parameter but cannot take the flocculation process into account (DNV GL 2014d).

First of all, results from NIVA (2014a) were referred as follows by DNV GL: «*The recommended experiments demonstrated a significant flocculation of the fine particles, in which the fraction smaller than 15 µm was reduced to 0.8% (De anbefalte forsøkene viste at det skjer en betydelig flokkulering av finstoffet, hvor andelen under 15 µm ble redusert til 0,8 %)*». According to the table in NIVA (2014a) the correct should be 0.8% were smaller than <u>19</u> µm. The estimations by undersigned indicate 0.62 % smaller than 15 µm (5.3.3).

DNV GL included all particles in modeling but decided to base it on the size range 15 – 340 µm. This means that those smaller than 15 µm were considered greater, i.e. 15 – 19 µm.

DNV GL's altered distribution was attempted justified by expected ongoing flocculation and *in situ* measurements of particles with a LISST instrument at a submarine disposal site of other types of mineral particles (mainly $CaCO_3$, in the Fræna Fjord). This adjustment of the distribution, based on those measurements, can be questioned. **(1)** It seems non-documented that flocculated fine particles of similar size but different chemical composition - mainly silicates (silicate minerals) versus mainly calcium carbonate (carbonate mineral) – should behave identical with regard to settling. **(2)** It also seems non-documented that these two types of particles are of identical size, shape and specific weight. **(3)** Measurements by LISST include not only mineral particles but also organic particles and plankton. **(4)** Flocculation and settling should be expected to be influenced also by biological and other conditions. Of interest are the high molecular-weight exosubstances liberated from microorganisms (6.1.3) and one may ask if the short-term conditions in the Fræna Fjord were representative for those long-term in the Førde Fjord. Notably, the flocs in the Fræna Fjord depicted in figure 1 lower picture in DNV GL (2014d) look similar to nanoparticles associated with biological material as depicted in figure 1 in Canesi et al. (2010).

The distribution altered by DNV GL (2014d, page 2-3) was used in DREAM to predict spread (SINTEF 2014, page 9), and results were summarized in DNV GL (2014e). The smallest fraction of aggregates (0.62 % < 15 µm) omitted from the modeling may, if annually discharged 4 (6) million tonnes of tailings and the specific weight is similar in all fractions, represent about **25,000 (37,000) tonnes**. Additionally, the above-described estimations (5.3.3) indicate that most aggregates (in term of number) will be smaller than 15 µm. Such aggregates may most easily escape the plume, but to seemingly unknown degree, and spread in the water body. These smallest aggregates therefore have the potential for accumulation to higher steady state concentrations than larger particles in water, depending on e.g. the rate of water exchange.

Including sizes smaller than 15 µm in modeling of particle spread might have predicted higher concentrations of suspended particles due to slower settling of such small particles.

Modeling was based on results of flocculation tests on other particles than those that will arise from the industrial process. Results of these tests could not document the fate of particle aggregates smaller than 0.68 µm. Moreover, aggregates smaller than 15 µm (corresponding to nano-sized particles, clay and part of the silt fraction if compared with single particles) and amounting about 0.62 % were in modeling considered to be of size 15 – 19 µm. Therefore, the modelling may not account for the fate (spread) of the finest and presumptively most numerous aggregates (< 15 µm), which may annually amount up to an order of magnitude of 25,000 (37,000) tonnes if 4 (6) million tonnes of tailings are discharged, and correspondingly may include up to about 2,100 (3,000) tonnes of nano-sized particles. The modeled concentrations may thus be too low. The finest particles may have potential for accumulation in the water body. Unknown amounts of flocculant and other process chemicals will also be bound to these smallest

particles and these may interact not only with biological surfaces but also with dissolved macromolecules.

5.4 Are the industry-created particles inert?

NIVA does not directly adressed this issue whereas DNV (GL 2014a) in chap. *3.1 Background* (App. G §1) «*considers modeled particles to be inert mineral particles without any specific content or form*». And DNV GL (2014c) states: *«Larger particles of rutile are basically considered inert,. (Større partikler av rutil er i utgangspunktet regnet som inert,.)»*.

An attempt to answer the question of the heading can be done by first considering the particles of industry-grinding, and next the industry-created particles as result of the entire industrial process also involving process chemicals.

5.4.1 Grinded eclogite

The London Convention (IMO 2008) states that geological material cannot be characterized as inert if «*altered from its original state by **physical** or chemical processing in a way that would result in different or additional impacts to the marine environment compared with those expected from the unaltered material*».

In this project rock will be crushed into substantial amounts fine particles, most smaller than the silt fraction by number (5.3.2), including nano-sized particles, with a potential for spread in the marine environment and for interactions with the physical, chemical and biological environments (6). It also sounds contradictory to claim inertness, as does DNV GL (2014a), and next document harmful effects on fish and other organisms from «inorganic particles in general».

The grinding into fine particles also result in a very large external surface relative to their volumes, being of importance for their properties such as binding or releasing of chemical substances. Therefore, an ultimate and undisputable evidence against **chemical** inertness is the binding of particles to Magnafloc 155, which is a high molecular weight anionic polyacrylamide flocculant (BASF 2015). By this, smaller particles aggregate into larger complexes (NIVA 2014a). Thus, the below-mentioned (6.1.4**)** accumulation of particles at the surface of fish may not be due to the physical stickiness of mucus only, but also to interactions with anionic chemical groups at the surfaces of fish. Also interactions between toxic compounds and particles, as discussed (NIVA 2008a), supports this kind of reactivity.

5.4.2 Grinded eclogite with process chemical compounds

Also this second question is answered by the London Convention guidelines for the assessment of inert, inorganic geological material (IMO 2008), which in the above-quoted sentence also includes «***chemical** processing*». It states that geological material can be considered inert

(1) only if uncontaminated. The flotation and flocculation chemicals, which will be added in this industry process, certainly represent more than «*incidental and trivial amounts of compounds with carbon chemically bound to hydrogen*», as formulated under the heading of

decision criteria on page 13 of that document.
(2) if «*the chemical constituents of the material **are unlikely to be released** into the marine environment*» (discussion on page 12). As said above (5.3.1), the dilution of the plume may promote release of particle-bound process chemicals into the water. As far as I can see, this eventuality has not been considered. The question about release of heavy metals from particles has also been raised, but is outside the scope of the present report.

Interestingly, the UK summarizes this in a comment (IMO 2000), quote: «*If the essential nature of the waste is different to that of the raw material as a result of manufacturing or processing operations, the impact of the waste on the marine environment could be significantly different to that of the raw material. Such material should therefore be categorised as industrial waste*». Moreover, US EPA (2006) considers sediments as contaminated even if no toxic effects are «*revealed by a whole sediment toxicity test or as predicted by equilibrium partitioning*» (App. B).

DNV GL's (2014a) claim may also be misleading if compared with the definition of «inert» in Directive 2006/21/EC (EC 2006) about wastes from extractive industries and further detailed in Commission Decisions 2009/360/EC and 2009/359/EC. According to 2006/21/EC article 3 «*Inert waste will not …. biodegrade **or adversely affect** other matter with which it comes into contact in a way likely to give rise to environmental pollution*».

Thus, this definition seems to apply especially to chemical compounds, which are also present in the tailings. However, submarine tailings disposal with subsequent spread of particles in water bodies was apparently out of question when this directive was developed. But in the context of its intention it should be obvious that the industry-created particles in question cannot be considered inert. Anywhy, because particles resulting from the entire industrial process have not been characterized, and because NIVA and DNV GL do not distinguish between effects from natural or «inorganic particels in general» and industry-created particles, the EIA is greatly hampered. The burden of proof of inerty lies with NIVA and DNV GL.

The final, and still unanswered question, is how such more or less aggregated industry-created particles may interact with biological surfaces. One may think that flocculated particles may have an increased, decreased or unaltered potential for harmful effects, depending on e.g. the saturation with the flocculant and other substances. Additionally, as flocculation may continue for an unknown period of time following discharge (NIVA 2014a), one may ask if also the flocculation process by itself may represent a mechanism of harm to biological surfaces. As far as I can see, these issues have not been addressed, neither by any of the primary sources referred nor by the reports from NIVA and DNV GL. Finally, the non-documented fate of thousands of tonnes of fine particles represents an uncertainty.

In summary, smaller particles – amounting thousands of tonnes - are certainly not inert in a chemical or biological context. The claim of inerty is non-documented and misleading.

Conditions pertaining to inerty are further detailed and discussed under the heading *Mechanisms of effects* (6.1).

6 Effects of particles on fish

In the absence of literature about effects of industry-created particles the reports from NIVA and DNV GL refer to a number of studies about effects following the exposure to a number of other types of particles («inorganic particles in general»). A number of these studies cited pertain to freshwater salmonids and to some extent to estuarine fishes, whereas few relate to marine fish.

6.1 Mechanisms of effects

6.1.1 General

Organisms and ecosystems are normally exposed to particles, which appear to be present almost everywhere in varying amounts and of different types. Changes in quantity or quality may affect biota. In the following text, which is not a review, is highlighted potential mechanisms for mediating effects on fish, and how knowledge about such mechanisms could have been used to a larger extent in the present EIA. Also references to conditions in freshwater and estuaries will be included for the purpose to highlight a diversity of mechanisms, although such results are not necessarily valid for conditions in seawater. Awareness of such mechanisms is also a necessary basis for interpreting the many scientific papers.

Quality and quantity of effects from submarine tailings disposal can be fruitfully considered within the causal triad model (Thrusfield 2005) by considering properties of (1) the particles by themselves and process chemicals added, (2) the environment in which the waste is disposed of, and (3) the organisms and ecosystems. Within each of these three main categories there are numerous factors, which vary temporally and spatially, and influence the outcome of exposure. The model deals with interactions, which may represent a more fruitful approach than «effects on», especially if dealing with organisms abundantly present. But for simplicity, the following texts deals withn particles, environment and fish separately.

6.1.2 Particles

Properties of particles have already been discussed, both generally and in connection with inerty, and are further detailed in the following text.

NIVA (2008a) states about conditions in freshwater that «*small particles seem to do less harm than large particles (Servizi & Martens 1987)*» (App. F §13). Servizi & Martens (1987) observed increasing mortality with increasing particle size in sockeye salmon underyearlings exposed to very high concentrations of particles (96 h LC_{50} = 17,560 mg/L for smallest particles [< 74 µm]).

However, results of studies in other environments provide an opposite result, demonstrating that no generalizations can be made about effects of size.

Sherk et al. (1975, table 1) reported 3-4 times higher 24 h LC_{10}, LC_{50} and LC_{90} values in estuarine fish (spot and striped killifish) exposed to Patuxent River silt («*0.78 µ med. size,* *72% < 2 µ*») than in those exposed to fuller's earth («*< 0.5 µ med. size, 82% < 2 µ*»). Differences between sizes of particles denoted silt and clay seem small but there was observed highest mortalities in fish exposed to the smallest particles.

Wildish et al. (1977) found an avoidance threshold at about 19 mg/L to a fine sediment (4.5 µm) and 35 mg/L for a coarser sediment in herring. Petereit & Franke (2012) exposed different species and life stages to fine (~ < 1 – 100 µm) and coarse (~ < 100 – 1000 µm) sediment particles. On the one hand, they observed e.g. accumulation of **fine but not coarse** sediment particles in the mouth of recently hatched larvae of cod following exposure for 24 h (App. E). On the other hand, the coarse particles were apparently the most detrimental to herring eggs during the fertilization process.

Some of the lowest concentrations reported to cause effects in fish (6.4); 3 mg/L threshold for avoidance in cod and herring, and 5 mg/L (lowest concentration tested) for sinking of cod eggs, were observed following exposure to glacial clay or grinded Copenhagen limestone (Westerberg et al. 1996). That clay by definition includes a main portion < 2 µm implies that these effects at low concentrations were associated with fine particles whereas a grain size distribution curve for limestone particles (< 38 µm) was unknown.

During recent years have been published studies of effects in fish and other taxa exposed to metal oxide nanoparticles at very different concentrations (e.g. 20 µg/L – 4 mg/L), as reviewed in Baker et al. (2014). Release of toxic metals from the particles may contribute to effects observed. Effects have been observed in rainbow trout juveniles in freshwater exposed to 0.1 mg/L of TiO_2 particles (Federici et al. 2007) and in a marine mussel exposed to 1 mg/L of TiO_2 or SiO_2 particles for 24 h, as detailed in 8.8.

Small sizes commonly imply high numbers of particles and large particle surfaces (5.1; Figure 1). It is therefore difficult to conclude separately on the importance of mass concentration, number concentration, area of particles and surface properties such as chemistry. High numbers imply more frequent collisions between particles and biological surfaces.

The total surface area (or ratio between surface area and mass or volume) of suspended fine particles may become very large, and the chemical groups exposed at the surface become of increasing importance. Occurrence of non-covalent chemical bonds between these groups and solutes (substances dissolved in water, e.g. flocculant and other process chemicals) or tissue-associated molecules then become of increasing importance.

Therefore, also the chemical composition of industry-created particles should become of increasing importance for their properties (such as ability to remain suspended) and potential to harm as their **size decreases**. A gradual transition from «mechanical» to «chemical» damage should be obvious. This is evident for nanoparticles, which may have quite different physicochemical properties compared with their larger counterparts. Other evidence supporting interactions of especially fine particles with fish are further detailed in 6.1.4.

NIVA (2008a) describes the expected shape of a predominant particle type (garnite) and refers to publications considering angular particles to be most harmful. This is supported by the picture observed in gills of fish exposed to blooms of angular diatoms (Yang & Albright 1992). However, the plate form of many clay mineral particles may indicate an association between size and form. Therefore, the relative importance of each of these two factors appear unknown.

The above-mentioned examples rise the question about what parameters best characterize the risks for effects on marine organisms. The very low effect concentration of nano-sized particles suggests that number, surface area or chemistry may be more adequate parameters, and may next indicate a need for ELVs differentiated with regard to e.g. particle size.

At least some types of fine particles may have significant effects on fish or other organisms at low concentrations. But the important factor may not be size *per se* but e.g. surface area. Given fine particles appear most numerous and have the largest potential for spread in the water body, and the uncertainties about flocculation and spread of such particles from the tailings, the suggestion that finer particles do less harm (based on one reference about conditions in freshwater) is unfortunate.

6.1.3 Environment

One striking difference between freshwater, estuarine and marine environments is the different levels of salinity, being crucial for the natural flocculation and settling of particles of sizes corresponding to clay. Therefore, single or aggregated particle distributions may be different in these environments, with aggregates dominating in seawater. And physical and chemical properties of nano-sized particles in seawater differ from those in freshwater (Baker et al. 2014).

Algal blooms are common (Hallegraeff 2010). Interestingly, algal and bacterial high molecular-weight exosubstances may be present in concentrations sufficient to increase viscoelasticity of water (Jenkinson & Biddanda 1995, Jenkinson & Sun 2010; Badel et al. 2011) and can potentially interact directly with particles. Seawater is thus more than H_2O with dissolved salts. Moreover, clay in high concentrations (100 mg/L) can experimentally aggregate particulate organic matter and bacteria (Attradamal et al. 2012). Although the experimental concentrations were very high compared with modeled concentrations in the fjord it demonstrates a potential for interactions with biological surfaces and organic material.

6.1.4 Fish

Avoidance (if possible), physiological changes, reduced feeding and growth rates, increased sensitivity to other agents, respiratory distress and coughing, pathological changes, and mortality have been reported in exposed fish (Newcombe & Jensen 1996, Kemp et al 2011). Such observations of effects may indicate the nature of the mechanisms behind.

There are at least two main types of mechanisms operating in fish, and probably also in species of other taxa. NIVA (2008a) briefly reviews this topic for salmonids in freshwater. The following text is based on effects of «inorganic particles in general».

Firstly, reduced visual clarity may alter e.g. predator-prey interactions (Newcombe 2003). Avoidance is thus only one type of behavioral effect (Wenger et al. 2011; 2012; 2013; Wenger & McCormick 2013).

Secondly, mechanisms include interactions of particles with external and internal biological surfaces and eventual uptake by organisms across these interfaces. The surfaces in fish includes those of gills, skin, digestive tract and sensory structures comprising the olfactory organ, the cornea of the eye, the lateral line canal system, free nerve endings in skin. Moreover, taste buds present in mouth, pharyngeal (throat) cavities and other places, such as the chin barbell in cod. Harmful effects on sensory structures can potentially alter the behavior of fish. Gametes and fertilized eggs as well as components of the immune system, such as the thymus, are also in direct contact with the ambient water.

Importantly, all the external surfaces of fish, such as gills and skin, as well as the internal surface of the digestive tract, are constituted by mucous membranes, which may contribute to a large area by different types of folds or projections. Such membranes in warm-blooded animals, humans, fish and a number of other taxa have a surface epithelium (outermost tissue layer) of cells, which may have surface projections further increasing the area. These epithelia bear a coat (glycocalyx) and an overlaying (outer) mucus layer. Such biological surfaces are polyanionic due to the presence of substantial amounts of carboxylate and sulphate groups as parts of the macromolecules (e.g. glycoproteins) present in the coat and the mucus (Alberts et al. 2008). The mucus layer is compared with a gel (Shephard 1994) and causes increased viscosity if dissolved in water.

A number of publications including NIVA (2008a) highlight effects on fish gills. This organ contains two sieves each with four gills (Hughes 1984; Evans et al 2005). Briefly, each gill is a highly branched structure of filaments (primary lamellae) and lamellae (secondary lamellae). The resultant large external surface (0.1-0.4 m^2/kg body weight) in combination with short distances (< 1 - > 10 µm) between ambient water and blood within vessels, makes the gills a vulnerable organ. The thin mucous membrane further contributes to vulnerability. During ventilation water flows through the interlamellar spaces (water channels). The widths (distance between lamellae) of these spaces range 20 – 100 µm (Piiper & Scheid 1984), depending on fish species and habitats, and ventilation of gills can be compared with filtration of water.

Particles have been detected in interlamellar spaces of gills of surviving sockeye salmon underyearlings exposed to fine (<74 µm) but not larger (75-149, 150-295 and 180-740 mg/L) particles (Servizi & Martens 1987), and in moribund and dead Japanese flounder following 96 h exposure to a clay mineral (Baba et al. 2006), indicating a clogging effect. There obviously must be a limit to how large particles can enter these spaces. The diameter of rounded particles or the thickness of needle-shaped or platelet-formed particles must probably be less than the range 20 – 100 µm. Entry of non-rounded particles thus seems to depend also on their orientation in relation to the flow direction of inspired water. This is nicely illustrated in fig. 4B in Baba et al. (2006).

Gills have a well-documented glycocalyx (Sardet et al. 1979) and a mucus layer in contact with ambient water (Fletcher et al. 1976; Shephard 1994; Speare & Ferguson 2006). Studies of the mucus layer in freshwater rainbow trout – subsequent to some kind of preservation - indicated a thickness of 0.6-1.0 µm at the gill surface (Powell et al. 1994; Lumsden et al. 1994) and 0.8-1.3 µm at the skin (Sanchez et al. 1997). The thickness should be expected to depend on the species and the environments they inhabit.

Particles may adhere to and embed in the surface mucus layer of skin and mucous membranes in the mouth and pharyngeal cavities of marine fish (Wilson & Connor 1976; Partridge & Michael 2010; Petereit & Franke 2012). There obviously must be a limit to how large particles can embed within or attach to a mucus layer, although this also depends on their form. This is supported by observed accumulation of fine (~ < 1 – 100 µm) but not coarse (~ < 100 – 1000 µm) particles in the mouth of recently hatched larvae of cod (Petereit & Franke (2012) (App. E). There was no information about size of accumulated particles, but they probably were in the lower part of the range ~ < 1 – 100 µm.

Binding between particles and biological material, or embedding in that material, is nicely illustrated in Canesi et al. (2010) fig. 1.

This embedding could be explained by «physical» and/or «chemical» mechanisms. Physically, mucus is sticky. And a physical requirement for entrapment within a mucus layer is probably met if its thickness is greater than the diameter of round particles or thickness of needle- or platelet-shaped particles. The «chemical» mechanism relates to the polyanionic nature of biological surfaces. That the polyanionic Magnafloc 155 binds to particles strongly indicates a similar binding between particles and the sulphate or carboxylate groups present at biological surfaces.

Mucus hypersecretion occurs following different kinds of irritation (Speare & Ferguson 2006) and may represent a metabolic cost. Then it is convenient to mention increased cortisol levels – indicating stress - in freshwater ayu (*Plecoglossus altivelis*) following a three hour exposure to 200 mg/L of kaolin (Awata et al. 2011).

Components of the immune system are abundantly present in gills (Koppang et al. 2015) and may significantly modulate the effects of particles. This may explain why particles entrapped in the mucus layer may next be taken up by the epithelial tissue (the outermost cell layer). Uptake of particles smaller than 2.5 and 5 µm has been demonstrated in cells present in epithelium and subepithelial tissue of freshwater salmonids (Goldes et al. 1986, Martens & Servizi 1993). Also nanoparticles can be taken up by cells of marine organisms (Baker et al. 2014). Comparatively, it has been demonstrated uptake of 22 nm titanium dioxide particles in lung tissues (Geiser et al. 2005), in which there is also an aquatic-to-tissue transition. A number of mineral particles are also associated with chronic lung diseases generally denoted pneumoconioses, including e.g. silicosis. Again, and because of limited cell sizes, there must be a limit to how large particles can be taken into cells.

The immune system also contributes to gill pathological changes, which may develop, and which may include – in freshwater and marine fish - vascular changes, mucus hypersecretion and epithelial cell death, hyperplasia of epithelial cells and inflammation as observed in marine or freshwater fish after long-term exposures (Herbert & Merkens 1961; Au et al. 2004; Baba et al. 2006; Humborstad et al. 2006; Sutherland & Meyer 2007), and mortality may occur (Au et al. 2004). Moreover, a subsequent transportation of particles by blood to internal organs has also been demonstrated in freshwater fish (Martens & Servizi 1993).

The drinking of water by marine teleost fish (Perrott et al. 1992), although of lower volume than that ventilated by the gills, brings particles into the digestive tract, which has a large internal surface with a lot of immune mechanisms operating also in fish (Salinas & Parra

2015). Interestingly, particles of titanium dioxide (anastase, 100-200 nm), aluminosilicates (<100-400 nm) and other silicates (100-700 nm) have been demonstrated within immune cells (macrophages) of the gut-associated lymphoid tissue in humans (Powell 1996). This uptake of different types of particles may indicate an uptake of mineral particles in general. Althoug the significance of such uptake appears uncertain it has caused concern about consequences for human health.

Importantly, it has been demonstrated adherence of particles to the surface of marine pelagic eggs, which may sink (Westerberg et al. 1996; Isono et al. 1998; Petereit & Franke 2012), as further detailed below. Knowledge about surface properties of eggs (Berois et al. 2011) may indicate mechanisms of interactions with particles.

This highlights the importance of extermal surface area, which is very high relative to volume or mass in a number of organisms. Therefore, one may also ask if other planktonic organisms may be affected by sinking. That issue has also been adressed for freshwater *Daphnia* sp. (crustacea, cladocera) in a NIVA report citing a number of papers (Hessen 1992). This report was cited by NIVA (2008b), which addressed other aspects than sinking.

Hathcing implies an increased external surface in contact with the ambient water. Therefore, different mechanisms may operate in larvae compared with eggs, and in at least some species the marine pelagic larvae appear more sensitive than the pelagic eggs if sinking is eliminated as a mechanism (Westerberg et al. 1996; Isono et al 1998) or benthic eggs are compared with larvae (Auld & Schubel 1978). Moreover, in at least one marine species has been reported higher sensitivity in open-mouthed larvae (with presumed exposure of the gills) than in closed-mouthed larvae (Partridge & Michael 2010).

It has also been claimed that disease of fish in the German Bright has been associated with dumping of titanium dioxide-containing waste (Vethaak & ap Rheinallt 1992, review). To prove an association is a challenge, but, on the other hand, it cannot be dismissed. At least one conclusion can be drawn: There is no evidence to support a claim that mineral particles of titantium dioxide or other compositions are completely harmless.

The large similarities in anatomy, physiology and immune system of fish, humans and e.g. mammals indicate that comparative approaches may be fruitful. It is therefore important to use available knowledge, and many papers concerning effects of nanoparticles and larger particles have been published during the recent years.

Only particles of sizes below certain limits can clog gills, embed in mucus or be taken up by cells. Therefore, the high number of particles implicated from small particles at a given concentration are potentially of greater importance than concentration as measured in mg/L. Additionally, small and coarse particles from a given rock type may also have different mineral and chemical composition, which may be of importance if small particles taken up by cells are next attempted dissolved in their phagolysosomes. One may therefore think that an organism A is most sensitive to particles around 10 µm whereas another organism B is most sensitive to those around 100 µm.

Predisposing to secondary diseases due to infections (Herbert & Merkens 1961; Servizi & Martens 1987) or toxicants (McLeay et al. 1987) have been reported in freshwater fish.

There are a number of unexploited opportunities for assessing effects of particles, including use of knowledge in comparative medicine. The present knowledge indicates a high relative importance of suspended fine particles.

6.1.5 Mechanisms of indirect effects

River Jølstra and River Nausta are the most important rivers with anadromous salmonids including Atlantic salmon, and smolts from these rivers migrate through the fjord segment with the planned depony area (Bremset et al. 2009). One minor river within the project area probably harbors sea trout. River Nausta and part of the Førde Fjord have the status of *National Salmon River* and *National Salmon Fjords*, respectively.

Post-smolts feed on crustaceans and marine pelagic fish larvae during their migration through fjords, although to lower extent in fjords in Southern Norway (Rikardsen et al. 2004). This migration represents a critical life history stage, and one may ask if the waste disposal may have effects on the availability of prey organisms for migrating salmon.

6.2 Simplified approach of EIA

An important and recurring question in reports and EIA is whether a discharged material is harmful or not for certain marine organisms. And when it comes to process chemical compounds one asks about toxicity. However, whether adverse effects are detected or not in organisms in question, there remains one more issue to be raised. This can be exemplified by a non-toxic substance like phosphate, which in increased concentration is beneficial for a number of organisms and therefore may profoundly and deleteriously alter entire aquatic ecosystems. This demonstrates limitations of an approach considering only toxicity of chemicals and only harmful effects of particles in certain organisms, and highlights the need for evaluation of effects also at the ecosystem level. Actually, both «wanted» and «unwanted» organisms may benefit or lose from altered environments. «Non-toxic» effects may therefore be important.

A consequence of overwhelming complexity already described is that most studies focus on only a few factors which may modulate the effects of particles. Apparently no experimental or field studies take into consideration the large number of factors presumptively being of importance for the effects observed. The path of least resistance leads to simplifications in e.g. metastudies such as Newcombe & Jensen (1996) as detailed in 7.1.1 and in reviews aimed at establishing limits. And therefore, particles are also considered «in general» and «general limits» are proposed, as prescribed in the water framework directive (EC 2000) Annex V 1.2.6. However, as already mentioned, effects of sediments in question have been studied prior construction projects (Westerberg et al. 1996; Valeur & Jensen 2001; Petereit & Franke 2012).

The reports present knowledge based on effects of exposure to a number of particle types, as published in scientific papers and other primary sources. But the reports do not at all document that these types of particles, i.e. “inorganic particles in general”, are comparable with the industry-created particles of the present project or otherwise relevant in this context. Relevance has not been addressed at all.

Experimental exposures of organisms to suspended solids under controlled and artificial conditions for a limited period of time dominates the literature. Effects (impacts, damages, harms) are denoted sublethal or lethal depending on whether the experimental animals survive or die, respectively, within the observational time period. The qualitattive and quantitative degrees of effect frequently increase with inceasing exposure duration. Sublethal effects preceede the lethal effect and small scale effects may add upto become significant, implying that exposure duration and other experimental condtions determine whether a sublethal or lethal effect will be observed.

Scientific papers and reports focuse on sublethal and lethal effects as observed during a defined time period of exposure whereas few papers describe effects persisting post exposure (Phillips & Shima 2006; Partridge & Michael 2010). The same applies to repeated exposures (Shaw & Richardson 2001; Wilber & Clarke 2001; Wenger et al. 2012). Effects should also be expected to emerge after termination of exposure, similar to numerous observations in human and veterinary medicine.

Although experiments represent a reductionistic approach, which do not characterize the complexity of associations present under natural conditions, they may nevertheless provide valuable knowledge (Westerberg et al. 1996; Petereit & Franke 2012). However, such results can at best indicate effects in wild populations and at the ecosystem level. Extrapolation of experimental results to the field is thus challenging but the reports do not take this complexity into account. On the one hand, whereas captive animals survive in a protected environment of an experiment their wild counterparts may die during a corresponding exposure. One reason for this may be sublethal effects predisposing to other diseases or predation. Sublethal effects may also cause recruitment failure of the population. On the other hand, experimental conditions may prevent adaptive behavior in exposed animals. Ecological consequences have been discussed in a review report by Hansson (1995).

The distinction between lethal and sublethal, as made from results of experimental exposures of different durations, thus appears artificial, arbitrary and meaningless when it comes to assessment of effects on wild populations and ecosystems. However, these terms will be used in the present report for the purpose of easily reference to the reports from NIVA and DNV GL or to other sources.

A more fruitful approach would be to evalutae what concentrations may allow the existense of viable and self-reproducing natural populations in the environment in question. Valuable contributions to this approach would be studies of key species, sensitive species and the most sensitive life stages or critical life-history stages such as spawning, and studies of effects on habitats and available food resources. **Therefore, long-term studies with exposure of sensitive stages to sublethal concentrations should be preferred**.

Finally, NIVA and DNV GL do essentially not document impact assessment methodology, as later detailed.

The reports express a reductionistic view which does not take into account the complexity of particle effects on ecosystems, and an overall assessment methodology is lacking.

6.3 Incorrect and confusing use of terms

DNV GL (2014a) writes «*acute (lethal)*» and «*chronic (sublethal)*» (App. G §2) but in human and veterinary medicine the terms acute and chronic are not synonymous with lethal and sublethal, respectively. A cold is frequently acute but rarely lethal, whereas cancer is commly chronic and frequently lethal. This has later been excused (DNV GL 2014b). Approximately the same is found in NIVA (2010a, page 2) writing «*acute or sublethal effects*» (7.4).

Further, chronic effects are associated with prolonged exposure to low concentrations (App. G § 2), but as mentioned above, short-term exposures may also cause chronic effects.

NIVA categorizes avoidance and other behavioral responses as sublethal effects (NIVA 2008a), wheres DNV GL is unclear whether avoidance should be considered an effect (8.1).

Except for LCs **a professional terminology is essentially lacking** in the reports and EIA. This will be further commented.

6.4 Important knowledge not referred in the EIA

6.4.1 General

Given «inorganic particles in general» in estuaries or seawater, and estuarine conditions, should be relevant, as apparently claimed but not documented by NIVA and DNV GL, there are a number of studies (App. E) which have not been referred to in the reports, although they obviously fullfill their inclusion criteria. This applies especially to early life stages, regarded as more sensitive than older fish (Sherk et al. 1975; Auld & Schubel 1978), although reviewed to some extent by DNV GL (2014a) but hardly by NIVA. And very importantly, dependence of pelagic eggs and larvae on buoyancy has not been addressed at all in any report.

The reports in question include NIVA (2008a; 2008b; 2008c; 2009; 2010), NIVA & DNV GL (2009), KLIF (2010) and DNV GL (2014a; 2014c). Most of the non-cited publications, including the most important, were available when the first reports were prepared in 2008, and all were available in 2014 with the possible exception for one paper published in April (Wenger et al. 2014). However, there is one exception as DNV GL (2014a) cited one of these papers, although incorrectly (8.6).

Although several of experiments cited in the following text included few fish and/or short exposure times, the results from all of these – taken together - point to deleterious effects from concentrations significantly lower than those referred to in the reports. When reading the following text it should be kept in mind that the fish species or different life stages referred to are adapted to a wide range of environments including particle levels. Additonally, all experiments deal with particles within a size range, as do all other investigations. Inclusion of papers has not been restricted due to particle size, of which the finest are most easily kept suspended whereas larger particles offer some challenges. Particle sizes were reported < 15 µm in most of these sources.

One of the studies to be cited included both clay and limestone (Westerberg et al. 1996). All the results of that study will be presented but it should be kept in mind that limestone may have other properties due to a chemical composition (calcium carbonate) different from that of the more common silicates.

Preferently is cited studies of effects at low concentrations, in accordance with the use of *lowest-reported-effect concentration (LREC)* (DNV GL (2014a). Additionally, it is suggested how inorganic particles may cause sinking of cod eggs at the Redal Bay.

NIVA, DNV GL and MDIR were apparently unaware of the important knowledge presented in the following text, including sinking of cod eggs, until 2014 when parts of it was presented in a hearing statement (IMR 2014). Given they had referred to the literature available during the preparation periods for the different reports, the knowledge presented in the following paragraphs was already published.

6.4.2 Effects on eggs

Mechanisms of deleterious effects from suspended solids appear different in pelagic and benthic eggs.

Atlantic cod eggs are pelagic and are positioned at a depth where their specific weight equals that of the surrounding water. Salinity is the most important factor deciding the specific weight of seawater, and therefore the eggs will position at a depth where salinity corresponds to their specific weight (salinity of neutral buoyancy). Westerberg et al. (1996) experimentally exposed eggs to suspended glacial clay and limestone, in a study being part of the EIA of the Øresund Fixed Link project. The eggs sank at the lowest concentration tested (**5 mg/L**) with a buoyancy loss estimated to 0.02 psu per hr per mg solid/L under conditions in question. The results also clearly indicated that even lower concentrations would cause sinking given the exposure duration was extended. Moreover, exposure to **4 mg/L** (the lowest concentration tested) sediment particles (size ~ < 1 – 100 µm) of the Fehmarnbelt caused sinking and indicated the effect at even lower concentrations (Petereit & Franke 2012).

Sinking to the bottom within four days was estimated for eggs exposed to 5 mg/L of Øresund sediment (Engell-Sørensen & Skyt (2000), thus indicating an acute LC value of ≤ 5 mg/L. Results pertaining to Fehmarnbelt sediment support a chronic NOEC well below 4 mg/L. Division by even the lowest safety factor of 10 recommended by the water framework directive yields an **ELV well below 0.4 mg/L for eggs of cod** under the conditions in question.

Sensitivity to sinking seems to vary considerably between species. Isono et al. (1998) exposed pelagic eggs from three marine species to different concentrations of the clay kaolinite. In two of these species was observed adhesion of kaolinite to the eggs and significant sinking following exposure to concentrations above 320 mg/L. Adhesion of particles and sinking was less in the third species, in which even higher concentrations were needed for these effects to occur. Finally, buoyancy and hatch rate of eggs of pink snapper were not affected following exposure to a concentration of 10,000 mg/L of calcareeous dredge material for 24 hours (Partridge & Michael 2010).

Westerberg et al. (1996) were, to the best of my knowledge, the first to demonstrate that inorganic particles may cause sinking of eggs. However, as mentioned above, the question has been addressed by e.g. Hessen (1992) in a report from NIVA.

Westerberg et al. (1996) and Petereit & Franke (2012) also demonstrated that **mortality in eggs (late phase), independent of sinking**, may occur at concentrations higher than the 4 mg/L causing sinking (35% mortality after 3 days at 200 mg/L limestone). However, these results were less clear-cut because of variability in mortality in the controls.

Increased mortality has also been observed in Atlantic herring eggs, which are benthic, following sedimentation onto eggs (Messieh et al. 1981) but the main determinant may not be the concentration *per se* as other factors also determine the thickness of deposited sediment. Moreover, no effects on hatching success were detected at concentrations above 7,000 mg/L in these experiments. Griffin et al. (2009) performed studies in Pacific herring but with an experimental design different from and more documented than the above-mentioned. Eggs were exposed at 0-2 h post fertilization to different concentrations. Briefly, increased self-aggregation of eggs and sublethal and lethal effects were indicated at 125 mg/L and statistical significant at 250 and 500 mg/L. If we take into account the short exposure time a chronic NOEC would possibly be well below 100 mg/L. No statistic significant mortality was observed in Atlantic herring eggs exposed for 14 days to Fehmarnbelt sediment up to 50 mg/L (Petereit & Franke 2012). Exposure of herring eggs during the fertilization process indicated that the coarse particles were most detrimental to that stage.

In summary, Atlantic cod eggs may lose buoyancy and sink at ≤ 4 mg/L whereas eggs from a number of other fish species may tolerate significantly higher concentrations. The lowest ELV supported is < 0.4 mg/L for eggs of Atlantic cod.

6.4.3 Cod eggs at Redal Bay in Førde Fjord

Field investigations in winter 2010 and 2011 revealed the Redal Bay, which is close to the planned disposal site, to be one of the most important spawning areas for coastal Atlantic cod in the Førde Fjord (van der Meeren & Otterå 2011).

In Atlantic cod eggs from the Norwegian coast has been detected specific weights corresponding to salinities above 30 ‰ but with some variation (Stenevik et al. 2008). If we, based on that study, assume a specific egg weight corresponding to 32-33 ‰ and relate this to salinity data from March 2010 and 2011 at Redal Bay (van der Meeren & Otterå 2011) the eggs will attain a vertical distribution at shallower depths than about 25 m.

If inorganic particles, which have a larger specific weight than the eggs, attach to their surface, and no significant upward current exists, the eggs will sink through water of increasing salinity. This increasing salinity will offer a resistance to further sinking, but if more particles attach the sinking will go on. As the salinity may be constant from about 45 m to 60 m depth (the bottom), there will be a «free fall» of eggs downwards from 45 m. More exact predictions require experimental exposure of eggs from this place to the industry-created particles in question. C.f. to studies associated with the Øresund and Fehmarnbelt fixed links (Westerberg et al. 1996; Petereit & Franke 2012).

Thorough modeling of surface spread of fine particles from accidental runoff from the land-based waste rock depony via the River Grytaelva to the fjord predicts concentrations at Redal Bay above those documented to cause sinking of eggs (NIVA 2008d).

6.4.4 Effects on larvae

The hatching of eggs implies a significant increase in the external surface area. Therefore, the pelagic yolk sac larvae of cod should be expected to lose buoyancy faster than the eggs. Loss of buoyancy was taken into account during Fehmarn Belt Fixed Link construction (FeBec 2013).

The results presented in the following text all pertain to mechanisms different from sinking. In exposures of coral reef damselfish larvae to bentonite was observed effects at the lowest concentrations tested, i.e. **prolonged larval development** (delayed metamorphosis) with increased variation at 15 mg/L (Wenger et al. 2014 April) and **impaired habitat choice** at 45 mg/L (Wenger et al. 2011).

Feeding on *Artemia* has been studied in larvae of herring. Introductory trials indicated a threshold concentration about 3 mg/L (Messieh et al. 1981). A significantly reduced feed uptake has been observed following exposure to sediment concentrations of 20 but not 4 and 8 mg/L (Johnston & Wildish 1982) but these results should be interpreted with caution as few fish were exposed for 3 hours only. Wenger et al. (2012) observed altered foraging and reduced growth in fish surviving daily short-term exposures to 45-180 mg/L of bentonite for six weeks. However, the exact magnitude of reduction is somewhat uncertain because of mortality especially at 180 mg/L. Larvae of herring **avoid** concentrations of 10 and 20 mg/L (it was tested 0, 10 and 20 mg/L) (Johnston & Wildish 1982).

Results indicate pelagic **larvae** to be more sensitive than the pelagic eggs when **mortality** is investigated independent of sinking (Westerberg et al. 1996; Isono et al 1998). Also in estuarine species, all or most with benthic eggs, the larvae seem more sensitive than eggs (Auld & Schubel 1978).

Yolk sac larvae of cod displayed increased **mortality** – independent of sinking - following exposure to limestone (≥ 10 mg/L for up to 6 days) (Westerberg et al. 1996). Isono et al. (1998) investigated effects on larvae of three species of marine fish, and in the most sensitive (presented in the table of appendix) was observed about 20 % mortality following exposure to 32 mg/L for 12 hours, and the LC_{50} was estimated to 170 mg/L.

For mortality in the most sensitive larval stage (open mouthed) of pink snapper exposed for 12 h to 0 mg/L, 32 mg/L, 100 mg/L and higher was observed about 24 % mortality at 32 mg/L (Partridge & Michael 2010). It was estimated a first observable effect concentration (FOEC) = 4 mg/L and 12 h LC_{50} = 157 mg/L. In a replicate experiment the corresponding values were 14 & 142 mg/L. Such variation between replicates should be expected, and the varying diffence between lethal FOEC and LC_{50} reflects different forms of the dose-response curves. On the one hand, there should be uncertainties when estimating a lethal effect at 4 mg/L when the lowest tested concentration was 32 mg/L, although mortality was high. On the other hand, this estimated lethal FOEC indicates sublethal effects at < 5 mg/L. They also exposed a less sensitive stage (closed mouthed) and found about 10 - 30 times as high concentrations for the effects, i.e. 150 and 2,020 mg/L, respectively. **The 12 h LC_{50}s of 157 and 142 mg/L are highly acute and division by the safety factor of 1,000 yields ELVs around 0.15 mg/L.**

Auld & Schubel (1978) observed a significant mortality in American shad exposed to 100 mg/L for 96 h. They observed 82 % survival in 100 mg/L, 93 % in 50 mg/L and 95 % in the control and concluded: «*Concentrations ≥ 100 mg l^{-1} significantly reduced the survival of shad larvae continuously exposed for 96 h*». This result strongly indicates that mortality would also occur at concentrations between 50 and 100 mg/L if tested. It was indicated a 96 h LC_{35} in the range 500-1,000 mg/L (table 8 in article). This result indicates an ELV of perhaps 1-2 mg/L if an acute LC_{50} was divided by the safety factor of 1,000.

Petereit & Franke (2012) observed **accumulation** of fine but **not** coarse sediment particles in the mouth of recently hatched larvae of herring following exposure to 25 mg/L or higher for 24 h. There was no statistically significant mortality but it would be interesting to see how mortality might have developed if the exposure lasted longer. Because also Partridge & Michael (2010) observed particles in the mouth of open mouthed larvae, which represented a most sensitive larval stage (12 h LC_{50} = 170 mg/L) as mentioned above. Comparatively, it has been observed attachment of particles within the mouth and gills in wild marine fish exposed to china clay (Wilson & Connor 1976).

In summary, concentrations < 5 mg/L may lead to effects in larvae of sensitive species. Effects have been documented at 10 mg/L in cod and herring but there are seemingly few studies with exposure to < 10 mg/L in these species. ELVs < 1 mg/L are supported.

6.4.5 Juvenile and adult fish

In juvenile herring has been observed **avoidance** thresholds between 9 and 12 mg/L (Johnston & Wildish 1981; Messieh et al. 1981) or about 19 and 35 mg/L for fine and coarse sediments, respectively (Wildish et al. 1977). From studies of **rainbow smelt** has been reported increased swimming activity at all concentrations tested (10-40 mg/L) (Chiasson 1993) and an avoidance threshold around 20 mg/L (Wildish & Power 1985). **Adult cod and herring** exposed under daylight conditions for 1 h to glacial clay or limestine displayed a threshold of about 3 mg/L (ca. 5 NTU) for avoidance of the particles, and cod exposed in the dark showed a similar behavior (Westerberg et al. 1996). **Horse mackerel** (*Trachiurus japonicus*) avoids concentrations above 5 mg/L while **parrot fish** (*Oplegnathus fasciatus*) does not respond to this and higher concentrations (Morinaga et al. 1988 cited in Westerberg et al. 1996).

In juveniles of species of coralf reef damselfish exposed once a day (during feeding) to bentonite was observed mortality (6 weeks cumulative < 10 % at 45 & 90 mg/L, 42 % at 180 mg/L) (Wenger et al. 2012), altered habitat choice at 30 but not 10 and 20 mg/L following 90 min exposure (Wenger & McCormick 2013), and significantly lower survival due to predation at 45 mg/L (Wenger et al. 2013). One may ask if this latter has more to do with the predator than the prey. Another damselfish exposed to kaolin at 0, 9 and 41 mg/L displayed altered antipredator behavior at 41 mg/L (Leahy et al. 2011).

In summary, avoidance thresholds detected in cod and herring vary between 3 and 12 mg/L, indicating NOEC < 3 mg/L and ELV < 0.3 mg/L.

6.4.6 Summary

The results for important marine species like cod and herring, can be summarized as follows: It has in experimental exposures been observed acute **(1)** sinking of cod eggs at ≤ 4 mg/L, **(2)** death of yolk sac larvae of cod at 10 mg/L if sinking is eliminiated as a mechanism of death, **(3)** reduced feed uptake in herring larvae at 3 - 20 mg/L, **(4)** avoidance in herring larvae at 10 mg/L, **(5)** avoidance in juvenile herring at 9 – 35 mg/L, **(6)** avoidance in adult cod and herring at 3 mg/L.

Taken together, acute lethal effect (sinking of eggs) and acute sublethal effect (avoidance) have been reported in cod and herring exposed to concentrations ≤ 4 and 3 mg/L, respectively. Chronic NOECs would be even lower, and ELVs < 0.4 and < 0.3 mg/L are supported.

6.4.7 Perception of this knowledge in other countries than Norway

This growing body of evidence has been repeatedly reviewed in reports or papers and the trend is reduced effect concentrations as the number of examined species or life stages increases. There appears to be a degree of consensus in how to interpret the research results, as evident in these second hand publications:

Hansson (1995): «*Messieh et al. (1981) and Johnston och Wildish (1981) reported juvenile herring (15-20 cm) to avoid water with a particle concentration of about 10 mg/l («Messieh et al. (1981) och Johnston och Wildish (1981) rapporterade at småsill (15-20 cm) undvek vatten med partikelkoncentrationeer på omkring 10 mg/l)*».
Westerberg et al. (1996) refer to Johnston & Wildish (1982) in their introduction and interpret the results as «*a threshold of approximately 10 mg/l*» for avoidance.
Engell-Sørensen & Skyt (2000): «*At suspended sediment concentrations of 5 mg/l, cod eggs in the Øresund would sink to the bottom within 4 days*».
Naturvårdsverket (2000) page 30: «*Westerberg et al. (1996) demonstrated that cod and herring avoided areas with particle concentrations above 3 mg/l in an experimental tank conducted before the Öresund Fixed Link construction (Westerberg et al. (1996) visade att torsk och strömming undvek områden med partikelkoncentration över 3 mg/l i ett bassängexperiment inför Öresundsförbindelsen)*».
Fiskeriverket (2007) page 15: «*Cod and herring belong to the most sensitive species and avoid waters with a sediment concentration above 6-8 mg/L (Westerberg m.fl. 1996) (Torsk och sill tillhör de mest känsliga arterna, och undviker vattenmassor där sedimentkoncentrationen överstiger 6-8 mg/L (Westerberg m.fl. 1996))*».
Didrikas & Wijkmark (2009 & 2011) page 7-8 & 5 and Enhus et al. (2012) about juvenile and adult fish: «*The avoidance limits have been assessed to 3 to 12 mg/l (Johnston och Wildish, 1981; Messieh m fl., 1981; Westerberg m fl. 1996) (Gränsen för de halter som undviks har uppmätts till 3 till 12 mg/l (Johnston och Wildish, 1981; Messieh m fl., 1981; Westerberg m fl. 1996))*».
FeBec (2013): The above-mentioned and a number of other studies are listed in table 4.9 at page 61.
Lagenfelt (2014) page 14: The knowledge was summarised approximately as described above.
Page (2014b) about effects of **total** suspended solids on estuarine and marine fish: «*Overseas studies show that avoidance generally occurs at concentrations of approximately 3−5 mg/L for pelagic and demersal species. This concentration range is similar to the Australia and*

New Zealand Environment Conservation Council (ANZECC) guideline trigger turbidity of 2−3 mg/L in marine and estuarine waters. The avoidance threshold for benthic species appears higher, at greater than 50 mg/L».

6.4.8 Different quality standards in Norway and Sweden

Literature (mainly primary sources in scientific journals) cited by NIVA, Akvaplan-NIVA, AquaBiota Water Research AB (ABWR AB) and DNV GL in reports dealing with the same issue (assessing effects of suspended particles on marine fish) is compared in App. D.

Firstly, a large variation is obvious and the use of sources seems somewhat arbitrary, with possible exception for DNV GL's plagiarsim. One must ask how such a variation may occur. ABWR AB has a very targeted use of sources, by including only important papers pertaining to conditions in estuaries and seawater. The others refer mainly to conditions in freshwater, and have largely not incuded the most important sources, such as Westerberg et al. (1996).

Secondly, two of NIVA's five reports about fish and particles refer to primary sources.

Interestingly, ABWR AB is NIVA's Swedish daughter company. The report by Didrikas & Wijkmark (2009) listed in the appendix and additionally reports by Didrikas & Wijkmark (2011) and Enhus et al. (2012) were published by ABWR AB. Additionally, the report of Enhus et al. (2012) was in cooperation with NIVA, which also performed the quality assurance. One topic of these reports is resuspension of sediments associated with the construction of offshore wind farms. One has to conclude that the EIAs for relatively small-scale and short-term projects in Swedish Waters were of substantially higher quality than that of NIVA's, Akvaplan-NIVA's and DNV GL's reports dealing with large-scale and long-term projects in Norway. That higher quality was also found in Enhus et al. (2012) dealing Norwegian offshore wind farms.

6.4.9 Foreign limits

The evaluations before construction of the Fehmarnbelt Fixed Link resulted in the following limits for Fehmarnbelt sediment resuspension during a limited period of time (FeBec 2013), page 62 and 63:

*«Considering the hatch times this indicates that 1 mg/l suspended sediment seldom will present a serious threat affecting **egg density** while there at times might be problems with respect to concentrations between 1 mg/l and 2 mg/l. **Therefore the threshold level for drifting eggs and yolk sac larvae towards suspended sediment has been set to 2 mg/l**, which is considered representing 100 % mortality».*

and

*«For **juveniles and adults** the selected thresholds values are **based upon avoidance behaviour**, since this is the reaction expected before other impacts set in. Avoidance is regarded as escape from a specific nursery area for juvenile fish or feeding area for adult fish, which according to the general assessment principle equalizes total loss in a worst case*

scenario. This principle is also applied with respect to migration where avoidance equalizes unsuccessfull mission, either this is a spawning or feeding migration. ***The thresholds has been set to 10 mg/l suspended sediment for pelagic fish species as whiting, herring, sprat and cod while 50 mg/l has been set for more benthic species as flatfish, snake blenny and shallow water species. The threshold value for migrating silver eel has been set to 50 mg/l, which definitely is worst case scenario for this species».***

Partridge & Michael (2010) also compared their results with Australia and New Zealand Environment Conservation Council (ANZECC)'s limit at 1-2 NTU (measure of turbidity) and found the limit corresponding to about 2-3 mg/L for the type of particles they used in their experiments. They concluded that ANZECC's limit is appropriate.

6.5 Unexploited opportunities

Suspensions of grinded stone were producede on at least two or three occasions. This included particles only (NIVA 2008a; NIVA 2009b), particles with Magnafloc added (NIVA 2009b; NIVA 2014a) or particles with Magnafloc or other process chemical added (NIVA 2009c).

NIVA therefore seemingly had the opportunity to make dilutions of suspensions and determine correlations between concentrations (mg/L) and turbidities (NTU) for particles only and for particles with Magnafloc or a number of process chemicals. This would allowed more extensive reference to papers presenting results as turbidity, e.g. Meager et al. (2006).

To prepare a tailing identical to that of a future industrial process seems at present impossible. However, with the steps already taken as mentioned, one may ask why marine organisms were not exposed to an experimental tailings (i.e. industry-created particles in suspensions also containing dissolved chemicals). This would probably given more information than considering «inorganic particles in general». Small volumes would be needed for investigating effect of e.g. buoyancy on small organisms.

7 Contributions from NIVA

A number of reports from NIVA (App. C) were important during the entire decision-making and especially in the earlier and important phase from 2008 – 2011 when the Municipality of Naustdal accepted the Zoning plan with EIA (NIVA & Asplan Viak 2009) but also in transmitting letters from the Norwegian Environment Agency (MDIR) to the Ministry of Climate and Environment (KLIF 2012; MDIR 2015). In addition to the central role in developing the Zoning plan with EIA, NIVA also commissioned a report from MDIR

7.1 An important report

NIVA (2008a) was the first report and according to the title and other text it is a risk assessment for fish and blue mussels. It is described as «*a thorough review of the literature for fish (primarily salmonids) and blue mussels (en grundig gjennomgang av litteraturen for fisk (primært laksefisk) og blåskjell)*» (NIVA 2009e).

The focus is narrow, i.e. fish and mussels, and, therefore, not fullfilling the requirements of the water framework directive (EC 2000) Annex V 1.2.6 page 52. Higher sensitivity in early life stages compared with older fish was briefly mentioned but otherwise eggs and larvae were given minor to no attention. However, in an impact assessment of submarine tailings disposal of mining waste in Repparfjord is included fish, zooplankton, littoral zone and sublittoral soft bottom (Akvaplan-NIVA 2011a; b). Limits for suspended particles were not clearly proposed but assumed in later reports.

Another reason to foucus on this report is its aforementioned citation in EIAs of other types of projects (Norconsult 2012a; 2012b; Akvaplan-NIVA 2011b). Additionally, text was copied from this report into another report (NIVA 2009e).

The report exists in two versions, which both have the same serial number and date of publication:
(1) The first published is available at NIVA's homepage and lacks a summary.
(2) The second was published later and is available together with the Zoning plan with EIA at the homepage of the Municipality of Naustdal, but with another cover picture and a revised description of the project. It also contains a summary of results. Apart from this the review of particle effects appears identical in both versions.

The report contains a part reviewing litterature concerning effects of inorganic suspended particles on adult fish and mussels (App. F), and claims that most of existing knowledge pertains especially salmonids in freshwater. The search was initially limited to literature published over the past decade, but important older publications were included. Because a limited amount of knowledge was found, especially about marine organisms, one may ask why NIVA did not include other taxonomic groups and early life stages of fish in the assessment. The most important should be knowledge acquired from exposures of marine organisms including especially eggs and larvae.

7.1.1 Salmonids in freshwater - models for exposure

Under the heading *4.1 Salmon* (*4.1 Laks*) there is a long review of effects of particles on fish in freshwater, mainly salmonids. Challenges of determining limits is discussed, apparently for conditions in freshwater.

I consider this part dealing with freshwater to be of lower relevance as long as there exists a number of publications concerning marine fish and as long as NIVA has not discussed and not at all documented the relevance of knowledge acquired about conditions in freshwater. Also Humborstad et al. (2006), in their introduction, were of the opinion that «*generalizations of results obtained for freshwater/estuarine species to marine species are therefore not necessarily valid*». Therefore, the text under 4.1 has not been critically evaluated except for three paragraphs quoted and commented below, in part because it also demonstrates the basis for criticism of important parts of the report from DNV GL (2014a).

The third and sixt paragraph of 4.1 (App. F §9,12), **quotes:**

«*Newcombe & Jensen (1996) conducted a metaanalysis of 80 "published and adequately documented reports" on effects of suspended sediment on fish in rivers and estuaries. Data from these investigations were used to establish models (mathematical equations) aimed at describing the association between biological response, particle concentration and exposure duration. In summary, the model provides the following thresholds*[1] *for **lethal** effects in adult salmonids: Exposure for 1-7 hours, lethal effects at >22,000 and >3,000 mg/L, respectively. Exposure for 1 to 6 days, lethal effects at >3,000 and > 400 mg/L, respectively.*
Exposure for 2-7 weeks, lethal effects at >400 and > 55 mg/L, respectively. Thresholds were approximately the same for juvenile salmonids».

«*The above-described models of Newcombe & Jensen (1996) also proposed thresholds*[2] *for direct **sublethal** effects. In summary, the model provides the following thresholds for adult salmonids: Exposure for 1-7 hours, effects at >403 and >55 mg/L, respectively. Exposure for 1 to 6 days, effects at >55 og > 7 mg/L, respectively. Exposure for 2-7 weeks , effects at >7 og > 3 mg/L, respectively. The thresholds were approximately the same in juvenile salmonids*».

These empirical models or dose-response equations (table 2) were established following analyses of data about direct (and partly indirect) effects of particles on fish in streams and estuaries from a number of publications (Newcombe & Jensen 1996). NIVA has used the second and third models for calculations concerning adult and juvenile salmonids, respectively, in freshwater. The equation for adult salmonids is $\underline{z = 1.6814 + 0.4769 (\log_e x) + 0.7565 (\log_e y)}$, where z = severity of ill effect (denoted biological response in quoted text), x = exposure duration, y = concentration of the predominant particle size (mg/L), 1.6814 = intercept with z axis, and the two other numerical valus are slope coeffisients.

[1] Newcombe & Jensen (1996) used the term "thresholds of ill effect (N: terskler for skadelig effect)" whereas NIVA translated this by "limit values (N: grenseverdier)". However, limit value as defined by EC directives has another meaning than threshold (IUPAC 2009). Therefore, in order to avoid confusion, it has been translated by threshold.

[2] See text to the first footnote.

These models contain a qualitative and in part quantitative scale 0-14 for the severity of ill effects (z). On this scale 1-3 are behavioral effects (3 is avoidance), 4-8 are other sublethal effects such as feeding reduction, 9 are paralethal effects such as reduced growth, and 10-14 are lethal effects (depending on percentage mortality). From the equations can be estimated «***thresholds of ill effect***», i.e. «*the **minimum** concentrations and durations that trigger sublethal and lethal effects*». Therefore, threshold is defined identically by the authors of the paper and by IUPAC (2009). Threshold is «terskel» or «terskelkonsentrasjon» in Norwegian. But NIVA har used the term «grenseverdi», which means limit value. This may be confusing because limit values as defined by IUPAC (2009) are associated with environmental quality standards and emission standards. And strictly speaking, it is incorrect by NIVA to put the symbol > in front of the estimated thresholds. In the present report the term *threshold* will be used wherever referring to values estimated by these models.

Table 2. Models proposed by Newcombe & Jensen (1996). M = model, N = number of studies included in the establishment of equations

M	Taxonomic groups and life stages	Environ-ment	Particle size range	N
1	Juvenile & adult salmonids	FW	0.5-250 µm	171
2	Adult salmonids	FW	0.5-250 µm	63
3	Juvenile salmonids	FW	0.5-75 µm	108
4	Eggs & larvae of salmonids and non-salmonids	FW	0.5-75 µm	43
5	Adult non-salmonids	Estuarine	0.5-75 µm	28
6	Adult non-salmonids	FW	0.5-75 µm	22

Thresholds calculated from models correspond to the common belief, i.e. the concentration, which is necessary to cause a particular effect in fish, decreases with increasing duration of exposure.

To clarify, the present report considers behavioral effects (1-3) as types of sublethal effects, in accordance with the view expressed by NIVA (2008a) and not as a separate type of effects as did Newcombe & Jensen (1996).

NIVA has used equations 2 and 3 to calculate thresholds for lethal and sublethal effects following exposure for 1 & 7 hours, 2 & 6 days, and 1 & 7 weeks. The results pertaining the second equation are presented in the NIVA report.

Important questions not asked or important themes not commented are:

(1) It is generally a challenge to establish mathematical equations well predicting biological effects. The equations in question depend on effects being deterministic, which seems unlikely. And therefore, the model cannot include stochastic variables such as secondary diseases.

(2) The models intend to predict threshold concentration and duration of exposure. These two are, of course, not the only variables, and Newcombe & Jensen (1996) therefore attempted to take other factors into account by proposing different models. But one important factor not included is species sensitivity. As can be seen in table 2 (Newcombe & Jensen 1996), the model 5 for adult non-salmonids in estuaries is based on results obtained in species classified as tolerant, sensitive or highly sensitive by Sherk et al. (1975). Therefore, at least model 5 lacks a dimension or axis for sensitivity. Another aspect of sensitivity is different mechanisms of damage or ill effects, such as sinking of pelagic eggs. Different sensitivities are expected to relate also to a number of environmental factors, which are also lacking in each model. The wide ranges of particle sizes may also confound the estimated outcomes.

(3) The amount of data have also been questioned, Berry et al. (2003): «*Although the visual presentations in Newcombe and Jensen (1996) of the models look complete, it is evident from the figures of the «empirical data» (Appendix A) that there are not enough data for the various groups of organisms (with the possible exception of the salmonids) to fill in the idealized model of fish response to increased suspended sediments shown in Figure 2. This is because there are not enough data, and because of the great variability in the data*». NIVA notes that the models in question may not describe well the relationship between effect, concentration and exposure duration but has no suggestions for the uncertainties of the calculated thresholds. In this context should especially have been considered the reliability of calculations involving exposures of long duration to concentrations in the range of e.g. 0-20 mg/L. The reliability has also been discussed by e.g. Sutherland & Meyer (2007).

(4) None of these models apply to the marine environment of the disposal area of the fjord but the closest is that (5) for adult non-salmonids in estuaries, including e.g. Atlantic herring but not Atlantic cod. This model, which was not used by NIVA, appears most relevant in this context but the formula is incorrect (Wilber & Clarke 2001) and it is based on fewer observations than most other models. The model has been corrected and the information is available upon request (Berry et al. 2003).

(5) The fact that Newcombe & Jensen (1996) proposed different models for different environments and different taxa of fish suggests caution when using models for salmonids in freshwater in this context. **Therefore, NIVA (and DNV GL) should at least discussed the relevance of freshwater models.**

(6) Although one model was established for eggs and larvae in freshwater, the models do not fully take into account the different life stages. And they do not consider different critical life-history stages, such as spawning, which may be affected in different ways (Berry et al. 2003).

(7) Newcombe & Jensen (1996) consequently used the term suspended sediment without further specification of particle types, and their presentation seems somewhat vague in terms of this. On the one hand, they classified particles as fine (clay, silt and very fine sand) or coarse (very fine – fine sand). On the other hand, they have included wood fibre, coal-washery waste and particles of ferric hydroxide (Herbert & Richards 1963; Sykora et al. 1972), as further detailed in 7.1.2. Interestingly, in this context of industry-created particles, the authors behind the models emphasize the need for research on how adsorption of chemicals onto particle surfaces may alter their properties or capabilities of causing damage.

(8) The particle size ranges included are relatively large, for adult salmonids spanning 0.5-250 µm, whereas size fractions in the lower part of this range are of particular importance in the planned project. Nano-sized particles were not addressed.
Berry et al. (2003) considered different models and stated: «*The principle is simple: if the SABS [suspended and beded sediment] problem in a stream is related to suspended sand and silt, a suspended sediment model should be used; if the problem in the stream relates to suspended clay particles, a water clarity model should be used; and if the problem relates to sediment deposition, a sediment quality model should be used. .... For suspended* ***sand and silt problems****, models like those in Newcombe and Jensen (1996) should be used*».
Therefore, the high spread potential for the finest particles in the fjord provides another reason for questioning the relevance of this model. NIVA has not explained why this suspended sediment model and not a water clarity model (e.g. Newcombe 2003) was selected.

(9) Their scale of severity mainly include direct effects on fish, but in the categories of sublethal and lethal effects are also included the indirect effects «*7 Moderate habitat degradation*» and «*10 Moderate to severe habitat degradation*», respectively. Habitat degradation does not relate to properties of the fish itself and may thus confound the models.

(10) Newcombe & Jensen (1996) presented no information about magnitudes of sublethal effects, i.e. what percentage of individuals in an exposed population should display signs or other evidence of a selected effect. But their formulations «***onset*** *of sublethal ... effects*», «*the minimum concentrations and durations that* ***trigger*** *sublethal and lethal effects*» and «*response of the* ***more sensitive individuals*** *within a species group*» may indicate effects in a low percentage of individuals. The importance of this is highlighted in the glossary of IUPAC (2009): «*Concentration of a substance that causes a defined magnitude of response in a given system after a specified exposure time, e.g., concentration that affects* ***x % of a test population*** *after a given time (ECx)*».

In addition to lacking information about magnitudes NIVA does not inform about type of sublethal effect studied. Such effects range 1 (alarm reaction) – 8 (major physiological stress), thus representing a wide range. A calculation I performed indicates the degree ≥ 5-6 (minor to moderate physiological stress) in the calculations of thresholds for a sublethal effect following different exposure times. If correct this represents significant effects on fish.

(11) Levels (z) of mortality are 10 (0-20%), 11 (>20-40%), 12 (>40-60%), 13 (>60-80%) and 14 (>80-100%) on the scale (Newcombe & Jensen 1996). Thus, if 12 is selected the threshold should be around a LC_{50} value. However, NIVA does not inform about magnitude of effect.

(12) The use of such models should be related to the water framework directive (EC 2000), which recommends the use of acute LC_{50} values and chronic NOECs, and associated safety factors. NOECs are lower than corresponding thresholds, and implies the use of lower concentrations in assessing ELVs.

(13) The quoted paragraphs do not tell whether the effects were observed under the exposure and/or afterwards (and neither does Newcombe & Jensen).

(14) At least some papers, from which the results have been used to establish the models, are also cited elsewhere in the report from NIVA (Sigler et al. 1984; Herbert & Richards 1963; Sykora et al. 1972; McLeay et al. 1987). Thus, some results have been used both directly and indirectly.

Incomplete models developed for salmonids exposed to particles of non-documented relevance in the freshwater environment, also of non-documented relevance, have been used uncritically and non-validated for estimating poorly-defined thresholds for effects of industry-created particles on fish in seawater.

7.1.2 Salmonids in freshwater – reduced growth rate

An important sentence (App. F §14), which has also been copied into the text of DNV GL (2014a), **quote:** «*Older studies on different species of trout demonstrates reduced growth at concentrations as low as 50 mg/L (Herbert & Richards 1963, Sykora et al. 1972)*».

This sentence, which refers to experimental studies of growth rates in freshwater salmonids exposed to particles of different types, contains two major deficiencies along with others of minor importance.

Water Research Pergamon Press 1972. Vol. 6, pp. 935–950. Printed in Great Britain

EFFECT OF LIME NEUTRALIZED IRON HYDROXIDE SUSPENSIONS ON JUVENILE BROOK TROUT (*SALVELINUS FONTINALIS*, MITCHILL)

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(*First received* 30 *July* 1971 *and in final form* 10 *February* 1972)

Abstract—The experimental dosing apparatus was a modified proportional diluter equipped with a neutralization device and with a series of detention and oxygenation tanks. Ferric hydroxide was obtained by neutralization of ferrous sulfate using calcium hydroxide. After neutralization, oxygenation, and detention, suspended iron was released automatically at regular intervals into the test aquaria. Four concentrations of iron were maintained, each containing 10 young brook trout (3 months old). The data on length of brook trout revealed a definite trend toward smaller size with increasing concentration of suspended ferric hydroxide, with the largest trout in 6 mg Fe l^{-1} and in the control. The average weight of brook trout was much lower in high iron concentrations than in the control and 6 mg Fe l^{-1}. The final mean weight of fish in 50 mg Fe l^{-1} represented only 16 per cent of the control, with gradually increasing percentage proportions occurring in lower iron concentrations. The final mean weights of the fish in 6 mg Fe l^{-1} and in the control were almost identical. The average growth rate computed for five different size groups of fish revealed a sudden decline in growth of brook trout exposed to 12, 25, and 50 mg Fe l^{-1}. The growth rate of brook trout in 6 mg Fe l^{-1} and in the control shows only a leveling trend as of the thirty-fifth week. It is assumed that impaired visibility due to high turbidity prevented the fish from feeding which in turn resulted in slow growth in high iron concentrations—12, 25 and 50 mg Fe l^{-1}.

Figure 2. Abstract in article of Sykora et al. (1972). The presented concentrations 0, 6, 12, 25 and 50 mg/L are "theoretical" and correspond to 0.2, 8, 13, 23 and 50 mg/L, respectively. With permission from Elsevier.

Firstly, Herbert & Richards (1963) concluded on reduced growth rate in fish experimentally exposed for 30 – 40 weeks to 49 mg/L of **wood fibre** or 41 mg/L of **coal-washery waste solids** (the lowest and actual concentrations tested). Sykora et al. (1972) observed reduced growth rates following exposures for several months to **50, 23 and 13** but not 8 or 0.2 mg/L of **ferric hydroxide**. The concentrations were presented as "theoretical" in the abstract (figure 2). The NIVA report neither mentions the effect of coal-washery waste at 41 mg/L nor effects of ferrich hydroxide at 13 and 23 mg/L. **The chronic NOEC in this experiment was between 8 and 13 mg/L**.

Secondly, t**he report does not inform about the natures of these three types of particles**, which are quite different from inorganic particles commonly present in water. Additionally, the wood fibre are organic although this part of the report should be about inorganic particles. Finally, at least two of these particle types may also cause toxic effects («non-mechanical» damage). When studies like this are referred in the context of the report NIVA should not only have informed about the unusual particle types, but also documented their relevance.

Reduced growth is 9 on the scale of the severity of ill effects (0-14) and is categorized as a **paralethal effect**. The results from these cited papers (App. F §14), all about freshwater fish (Sigler et al. 1984; Herbert & Richards 1963; Sykora et al. 1972; McLeay et al. 1987), are listed as 9 in table A.1 in Newcombe & Jensen (1996). Since NIVA has emphasized this model so much it does not harmonize well to refer results for a paralethal effect, which is potential lethal at the population level, under the heading of sublethal effects. Although NIVA is aware of this, the text as written may undercommunicate this type of effect.

Since NIVA decided to refer to conditions in freshwater, a logical consequence would be to include other relevant publications. Sutherland & Meyer (2007), who were also cited in table 3 in the report, documented reduced growth in a minnow (spotfin chub, *Erimonax monachus*) following exposure for three weeks to 25 mg/L (the lowest concentration tested) of particles («*primarily clay and mica-based silt*», < 45 µm). The growth inhibition concentration (IC_{25}) value in smallmouth bass (*Micropterus dolomieui*), for which exposure duration was not presented, was 11.4 mg/L of suspended bentonite (Sweeten & McCreedy 2002, cited in Berry et al. (2003). Finally, in rainbow trout exposed to nanosized TiO_2 particles was observed sublethal effects such as gill damage following exposure to 0.1 mg/L (Federici et al. 2007, 8.8).

NIVA has not cited all studies fullfilling their own inclusion criterium, has not informed about particle types and has undercommunicated effects by citing two studies incorrect.

7.1.3 Marine fish

The report deals with marine fish under the heading *4.2 Cod (4.2 Torsk)* on page 28 and 32 in the first and second versions, respectively.

7.1.3.1 Marine fish – lethal concentrations

Sherk et al. (1975) about LC_{10} concentrations (App. F §17) as **quoted** in the report: «*Species with 24 h LC 10 >10,000 mg/L were classified as tolerant, species with 24 h LC 10 from 1,000 to 10,000 mg/L as sensitive and species with 24 h LC 10 < 1,000 mg/L as very sensitive*».

The referred paper also presented LC_{50} values along with the LC_{10} values, with the former being up to five times as high as the latter. For Atlantic silverside, the most sensitive species, there is 24 h LC_{50} = 2,500 mg/L. Division of this acute LC_{50} with the safety factor of 1,000, as recommended in the water framework directive, yields an emission limit value (ELV) of 2.5 mg/L.

7.1.3.2 Marine fish – misrepresentation

Two sentences are highlighted. The first (App. F §17): «*Mortality was observed in Atlantic silverside (Menidia menidia) following exposure for 24 hours to a concentration as low as 580 mg/L, whereas mummichog (Fundulus heteroclitus) survives 300.000 mg/L for 24 hours (Newcombe & Jensen 1996)*».

and the second (App. F §18): «*In the above-mentioned comparison of six different species (Sherk et al. 1975) sublethal effects were not observed below 650 mg/L in any species*».

Both sentences are thus based on the same primary source:
The first sentence correctly refers to table A.1. on page 725-726 in Newcombe & Jensen (1996), in which the data in question are based on table 1 in Sherk et al. (1975). The value 580 mg/L for silverside is a 24 h LC_{10} concentration.
The second sentence, about sublethal effects in six species, incorrectly cites data from table 1 in Sherk et al. (1975). I suppose the six species in question are those represented by adults in that table, i.e. spot, white perch, striped killifish, common mummichog, Atlantic silversides and bay anchovy. Two other species are represented by juveniles and larvae only. For adults of all six species there are figures for 24 h LC_{10}s, LC_{50}s and LC_{90}s, and for two of these species also 48 h LCs. Although the table is about LCs it indirectly provides information about sublethal effects, which must occur at lower concentrations.
The second sentence has incorrect citation and is also in conflict with the first sentence because:

(1) For Atlantic silverside the table 1 in the article says 24 h LC_{10} = 580 mg/L, i.e. **silverside died at a concentration below a limit (650 mg/L) at which there – according to NIVA – should be no sublethal effects.** The same trial is correctly referred to in the first sentence and incorrectly in the second. **The 24 h LC_{10} = 580 mg/L indicates sublethal effects to occur at substantial lower concentrations.**

(2) For adult white perch exposed to fuller's earth was estimated 24 h LC_{10} = 3,050 mg/L and 48 h LC_{10} = 670 mg/L (table 1 in Sherk et al. 1975), consistent with effects taking longer to emerge at lower concentrations. In another experiment with the same species was observed increased hematocrit (table 3 in article) and histopathological changes in the gills following exposure to 650 mg/L of the same particles for five days (page 548-552). Taken together, all these results demonstrate that **sublethal effects must have been present below 650 mg/L within 48 h** also in white perch, as sublethal effects precede the lethal effects.

(3) Since the report includes data for juvenile salmonids it is also in its place to highlight results pertaining to that life stage. Table 2 on page 545 reports 100% mortality in juvenile bluefish following 18 h exposure to 800 mg/L and in juvenile white perch following 20 h exposure to 750 mg/L. Both were exposed to fuller's earth. These results **strongly indicate**

that sublethal effects occurred at concentrations below 650 mg/L also in these fish, which are characterized as highly sensitive.

That «*sublethal effects were not observed below 650 mg/L in any species*» is highly incorrect. Actually, such effects developed at concentrations below 650 mg/L in at least two species within 24-48 h, and in a third species within 18 h. The report thus undercommunicates the results of the paper.

7.1.3.3 Marine fish – Uncritical and incorrect reference to a paper with deficiencies

This part refers to a study of Au et al. (2004). Green grouper (*Epinephelus coioides*), a teleost species said to «*inhabit turbid coastal reefs and are often found in brackish water over mud and rubble*» (fishbase.org), was experimentally exposed for six weeks to different concentrations of suspended sediment «*from a clean site in Hong Kong*». It was in the study a special focus on the gills. This paper is relevant because of the concentration range tested and the long exposure time.

Weaknesses of the paper include:

(1) A more detailed characterization of the particles (resuspended sediment) is lacking.

(2) The paper in most places refers to so-called nominal concentrations (i.e. the intended concentrations of 0, 50, 100, 200, 1,000 and 2,000 mg/L) although those realized in the experiment were lower, as stated in the results section on page 268: «.. *the actual exposure concentrations were maintained at 60 to 70 % of nominal concentrations throughout the 6 wk exposure period*». **The presentation of nominal values may thus contribute to underestimation of effects.** The difficulty of keeping concentrations at planned levels may have applied especially to the larger particles, a well-known challenge in such experiments. Therefore, the fish might have been exposed particularly to the fine particles.

(3) Only cumulative mortalities during the experimental period are reported, but no information about when fish died. Mortality at different nominal concentrations were reported as follows: 0 mg/L (0%), 50 mg/L (30%), 100 mg/L (20%), 200 mg/L (30%), 1,000 mg/L (40%) and 2,000 mg/L (65%). Atlhouth relatively high at the lowest concentration tested, the trend is increasing mortality with increasing concentration. It appears uncertain whether the estimated LC_{50} concentrations of 1,400 mg/L is based on nominal or actual values. This LC_{50} concentrations also appear uncertain because the dose-response curve seems relatively flat in that concentration interval. If mortality occurred throughout the exposure period this is also a chronic LC_{50} value.

(4) It is a significant weakness of the experimental design that only fish surviving until the end of exposure were examined. Common practice is to randomly sample living fish at planned time intervals throughout an experimental period. Additionally, to evaluate if the dead fish actually died because of the exposure. The design of Au et al. (2004) corresponds to investigating effects of smoking by only examining very old people and disregarding all who died at younger ages. Therefore, **the results pertaining to surviving fish are not representative at all and they contribute to underestimation of effects**. The authors of the paper have not addressed this.

The mortality data in combination with the actual concentrations are of value in the EIA wheras reference to the results pertaining to surviving fish must include clear information about the experimental design.

Results from this article are presented in two places in the report (App. F §18-19). Firstly, in two rows of table 3 (1. row: «*> 20 % mortality. (LC50 was 1400 mg/L)*», and 6. row: summary of histopathology). Secondly, in the text by the two cited sentences, **quote:**

«Gill damages were observed in green grouper exposed to a concencentration as low as 50 mg/L but these were very limited. More extensive damages were first observed at concentrations above 200 mg/L».

NIVA refers to the nominal concentrations, which are incorrect. Instead of e.g. 50 mg/L there should be 30-35 mg/L. NIVA does not mention the weaknes of the experimewntal design including examination of surviving fish only, resulting in an non-representatively sampled material from fish. This is a significant deficiency of the report. NIVA also interpreted the gill damages as very limited («*svært begrenset*»). Based on my experience in gill pathology it is difficult to see how the paper provides a basis for that interpretation.

The NIVA report does not discuss if 30% cumulative mortality – following exposure to 30-35 mg/L - is consistent with «*very limited*» gill damages. Thus, the report is contradictory.

All of these noted deficiencies and mistakes pull in the same direction, i.e. towards underestimation of harmful effects.

Because sublethal effects occur at lower concentrations than lethal effects the chronic NOEC in this case, with fish adapted to turbid water, was significantly lower than 30-35 mg/L. Division by the lowest safety facor of 10 (the others are 50 and 100) provides an ELV significantly lower than 3-4 mg/L.

7.1.3.4 Marine fish – living space

There is one sentence about avoidance (App. F §18), **quote:** «*Humborstad et al. (2006) further highlighted that cod has great opportunity to avoid "clouds" of high turbidity water*».

Humborstad et al. (2006) did not design their study for observation of behavioral effects and is therefore, in this context, a second or higher order source, which should have been made clear by NIVA. Moreover, avoidance in seawater has been studied by e.g. Westerberg et al. (1996) as mentioned (6.4.5). And e.g. yolk sac larvae of cod do not have the ability to avoid (Hansson 1995).

Avoidance is level 3 on the scale of Newcombe & Jensen (1996) and the resulting restricted living space, i.e. habitat loss, is level 7 or 10 (also including 0-20% mortality and increased predation) on that scale. They apparently have taken into account that habitat loss has implications for e.g. food acquisition and survivorship. Additionally, the fish's planktonic prey organisms may not have the ability to move in parallell with their predators. This may next result in reduced populations of fish.

Wenger et al. (2013), published five years after this report, in their discussion suggest that rapidly fluctuating turbidities may alter predator-prey interactions by offering advantates to the predator. The observation of e.g. very pale dorsal pigmentation of wild fish subjected to china clay (Wilson & Connor 1976) **may indicate that avoidance is not always an option**. Species-specific reaction patterns have been suggested in a report (Naturvårdsverket 2000).

One may also ask how such clouds, if present in more shallow water, may influence or prevent seawater or freshwater migration of Atlantic salmon, for which no data seem to be available, or how it may influence migration of Atlantic cod, for which a threshold of 3 mg/L has been observed, to the important spawning area of Redal Bay.

The quoted sentence belittles consequences of avoidance.

7.1.4 Summary in the second version of the report

About mortality, cited sentences from summary (App. F §3), **quote:**

«*The literature shows possible effects of suspended particles on fish and blue mussels to depend on concentration, exposure time, particle size/shape as well as characteristics of the animal itself such as age/life stage. Generally, only very high particle concentrations may cause acute mortality in salmonids and blue mussels (> 1,000 mg/L). No data exist for Atlantic cod. However, after prolonged exposure (weeks to months) has been observed mortality at significantly lower concentrations (55-400 mg/L)*».

It should have been made clear that mortality in salmons refers to conditions in freshwater. The statement about no data for acute mortality in cod is possibly correct if adult fish is considered. However, this statement of no data is unfortunate given that «*age/life stage*» is mentioned in the first sentence but largely not considered in the report. And because other results (Westerberg et al. 1996) actually demonstrate potential lethality in cod eggs as presented elsewhere in the present report (6.4.2). The formulation of the last sentence is imprecise because Au et al. (2004), who were cited in the report, observed 30% cumulative mortality following exposure for six weeks to 30-35 mg/L.

The summary inaccurately reflects the content of the report.

7.2 Unclear reports

Two reports (NIVA 2008b; 2008c) consider effects of particles on wild and farmed fish and on mussels. Both refer to (NIVA 2008a).

The first report (NIVA 2008b), page 31:
«*In relation to the litterature about damage on fish these concentrations are far below these levels (NIVA 2008a) (I forhold til litteratur som omhandler skade på fisk er disse konsentrasjonene langt under disse nivåene (NIVA 2008a))*».

The second report (NIVA 2008c), page 8:
«*… then these values will be well below what has been referred to as the limit for influencing*

the growth and survival in seawater for the species in question (NIVA 2008a) (… så vil disse verdiene ligge godt under det man har omtalt som grenseverdi for påvirkning av vekst og overlevelse i sjøvann for de aktuelle artene (NIVA 2008a))».

It is not possible to know the exact meanings of «*damage*», «*these concentrations*», «*far below these levels*», «*these values*», «*limit for influencing the growth and survival in seawater*». Both reports cited (NIVA 2008a) but it is not possible to trace all such information back to the sources of that report. Otherwise there were no references to primary sources.

The designation «*the limit*» is surprising since NIVA (2008a) did not conclude clearly about limits and because NIVA in a newspaper claimed that one did not operate with a limit (NIVA 2014b). But see the next parts 7.3 and also 7.5.
Exact and traceable use of knowledge as published in primary sources is lacking.

7.3 Report with general limit of 50 mg/L

This report (NIVA 2009a) contains comments to hearing statements of the Institue of Marine Research.

Quote, page 13: *«Marine organisms tolerate particles very well and recent research indicates 50 mg/l as a level where damage may be initiated. Fine particles occasionally transported to the west of the Svanøy Sill will occur at a concnetration of maximum a few mg/l».*
«Marine organismer har ganske høy toleranse for partikler og nyere forskning angir 50 mg/l som et nivå der skader kan begynne å inntreffe. Finstoff som iblant blir transportert utenfor Svanøyterskelen vil være i konsentrasjon på høyst noen få mg/l».

Quote, page 19: *«Recent literature shows that it is only at particle concentrations > 50 mg/l that negative effects for some groups of organisms may occur».*
«Nyere litteratur viser at det er først ved partikkelkonsentrasjoner >50 mg/l at negative effekter for noen organismegrupper kan oppstå».

It is tempting to conclude that the limit of 50 mg/L represents the missing conclusions of the previous report NIVA (2008a) although this report (NIVA 2009a) totally lacks arguments and references to sources (no reference list present). In particular, NIVA should present a bibliography for *«recent research»*. In this report is also concluded for marine organisms although the first report was about fish, mainly in freshwater, and mussels.

The limit is poorly defined by type and is not at all related to terms defined by the water framework directive (EC 2000) or IUPAC (2007; 2009 – see App. B). «*Tolerate … very well*», «*damage*», «*negative effects*» and «*some groups of organisms*» are not defined. But from the context it is reasonable to assume that «*damage*» and «*negative effects*» relate to sublethal effects. The first sentence also illustrates how too high safety margins have been claimed.

The quoted sentences contain non-documented claims, including a generalization from a weak or missing basis, and some kind of a limit that is obviously too high in relation to research results described in cited (NIVA 2008a) and non-cited sources (6.4). The report contains an element of risk assessment, which appears somewhat independent of other

work by NIVA.

The underestimation and undercommunation of this report were further augmented in a public presentation by NIVA (2009d): «*The concentration of particles upwards and aside for the disposal area are so low that there will be no effect on marine life*» See 7.7.2.

7.4 Note about farmed fish

A note (NIVA 2010a) considers effects on fish cultured in netpens in the fjord.

Page 1-2: «*Firstly, one has to take into account salmon's high tolerance for particles. This can be observed annually when salmon migrate up the rivers during rain weather, high flow and flood. The risk of damaging fish by particles from the discharge has been evaluated in the assessment report # 19 (see App. B of the EIA, especially chap. 4.1). Limits, above which damage occur, vary a lot and 50 mg/L may be a starting point. For safety, in relation to the dense populations in fish netpens, the concentration for acute damage is discretionary reduced to 20 mg/L in this evalutation. Similtaneously, smallar particles do less harm than larger. This is very relevant because here it is about spread of very fine particles (size less than 15 µm = as silt and clay)*».

«*For det første må man ta i betraktning at laks har høy toleranse for partikler. Dette ser man årlig når laksen svømmer opp i elvene under regnvær, høy vannføring og flom. Risikoen for at partikler fra utslippet skal skade fisk er vurdert i utredningsrapport #19 (se Vedlegg B i KU, spesielt kap. 4.1). Skadegrensene varierer mye og 50 mg/l kan være et utgangspunkt, men for å være mer på den sikre siden – i forhold til tette bestander av fisk i mærer – vil vi i denne vurderingen skjønnsmessig redusere akutt skadekonsentrasjon til 20 mg/l. Men samtidig merke oss at små partikler gjør mindre skade enn store, noe som er svært relevant fordi her snakker vi om spredning av meget små partikler (størrelse mindre enn 15 µm = som silt og leire)*».

Page 2, conclusion: «*Numerous assumptions and choices are made along the way, but it has all the time been selected a high concentration. And, when finally arriving at 1-3 mg/L, i.e. about 1/10th of putative harmful concentration, is an uncertainty of 2-3 mg/L not very important. In conclusion, it is unlikely that particles from intermediate or deeper water - given a short-term upwelling from a deep of 10-30 m at all occurs - may pose a risk, in terms of acute or sublethal effects, for fish within neptens*.

Her er gjort mange antakelser og valg underveis, men hele tiden er det valgt en høy konsentrasjonen. Og når man så «lander på» 1-3 mg/l, dvs. ca. 1/10 av vår antatte skadelige konsentrasjon, er ikke lenger usikkerhet på 2-3 mg/l så viktig. Konklusjonen er at – hvis en slik kortvarig situasjon med oppstrømming helt til 10-30 m dyp i det hele tatt forekommer – så er det usannsynlig at partikler fra mellomlag eller dypvann utgjør noen risiko for fisken i mærene - i forhold til akutte eller subletale effekter».

The evaluation (quote page 1-2) is with reference to #19, i.e. NIVA (2008a), and the apparently low sensitivity of salmonids in freshwater is emphasized. This reference to salmonids in freshwater as a starting point is understandable as long as – to the best of my knowledge - effects of inorganic particles on salmon in seawater (wild or farmed) have not been adressed, and not to say industry-created particles. That smaller particles should do less harm has already been commented (6.1.2). A starting point of 50 mg/L agrees with my impression of above-commented reports (NIVA 2008a; 2009a), but in total, the selections of the values of 50 and 20 mg/L are presented without reference to any source, assessment methodology or safety factors. It is also unclear what is meant by acute and whether one talks about lethal or subletal effects.

Avoidance has been observed in Atlantic cod following exposure for 1 h to 3 mg/L (Westerberg et al. 1996), see also 6.4.5. This should be as relevant as information about salmonids in freshwater, and if seawater-reared salmon should be as sensitive as cod there is apparently no safety margin as suggested.

The note refers to knowledge of non-documented relevance but has no reference to very relevant knowledge.

7.5 Note by NIVA & DNV GL

The subject of the note (NIVA & DNV GL 2009) is effects on the ecosystem in the short and long term and the note is referenced in zoning plan with EIA (NIVA & Asplan Viak 2009) and seems important in transmitting letters (KLIF 2012; MDIR 2015a).

Chapter 4.2 The ecosystem in the water column, page 10:

«Når det gjelder partikkelkonsentrasjoner, viser litteraturen at det skal svært høye konsentrasjoner til for å forårsake direkte dødelighet. Påvirkning på vekst, fôropptak og adferd kan imidlertid skje ved langt lavere partikkelnivå. Smit et al (2008) har ut fra litteratur på en rekke aktuell dyrearter utledet toleransegrenser for suspenderte mineralpartikler av kornstørrelse som i leire. Ca 50 % av artene tolererer en TSM på opp til 3000 mg/l, mens 95 % vil tåle 18 mg/l eller mindre. NIVA (Bjerkeng og Sundfjord 2008) har beregnet at vann med TSM-konsentrasjon fra avgangen på ≥10 mg/l vil kunne spre seg langs bunnen inntil ca 1-2 km fra utslippet. Dette er et nivå langt under grenseverdi for påvirkning av vekst og overlevelse i sjøvann for alle de aktuelle fiskeartene (NIVA 2008a)».

These six sentences are quoted two by two in English in the following text.

1st & 2nd sentence:

«According to literature, only very high particle concentrations cause direct mortality. Influence on growth, feed intake and behavior, however, can occur at much lower particle levels».

It is unclear (1) whether these two sentences refer to marine organisms in general and also include all life stages, (2) what sources this builds on, (3) what is «*very high concentrations*» and «*much lower particle levels*». C.f. to Au et al. (2004) reporting 30 % mortality following exposure to 30-35 mg/L for six weeks.

3rd & 4th sentence:

«Smit et al (2008) have – based on literature dealing with a number of topical animal species – estimated tolerance limits for suspended mineral particles of size corresponding to clay. Approximately 50 % of the species tolerated a TSM [total suspended matter] up to 3,000 mg/l, while 95 % will tolerate 18 mg/l or less».

Smit et al. (2008) conducted a metastudy and estimated two sigmoid-shaped dose-response curves (Figure 3). These intend to predict how large percentages of the species in question (fish and other animal taxa, and algae) are influenced in one way or another following exposure to varying concentrations of bentonite (a type of clay) and barite (barium sulphate), all with particles of sizes corresponding to clay. **Concentrations (median values) that affect about 5% of the examined species were estimated to 7.6 mg/L for bentonite and 17.9 mg/L for barite**.

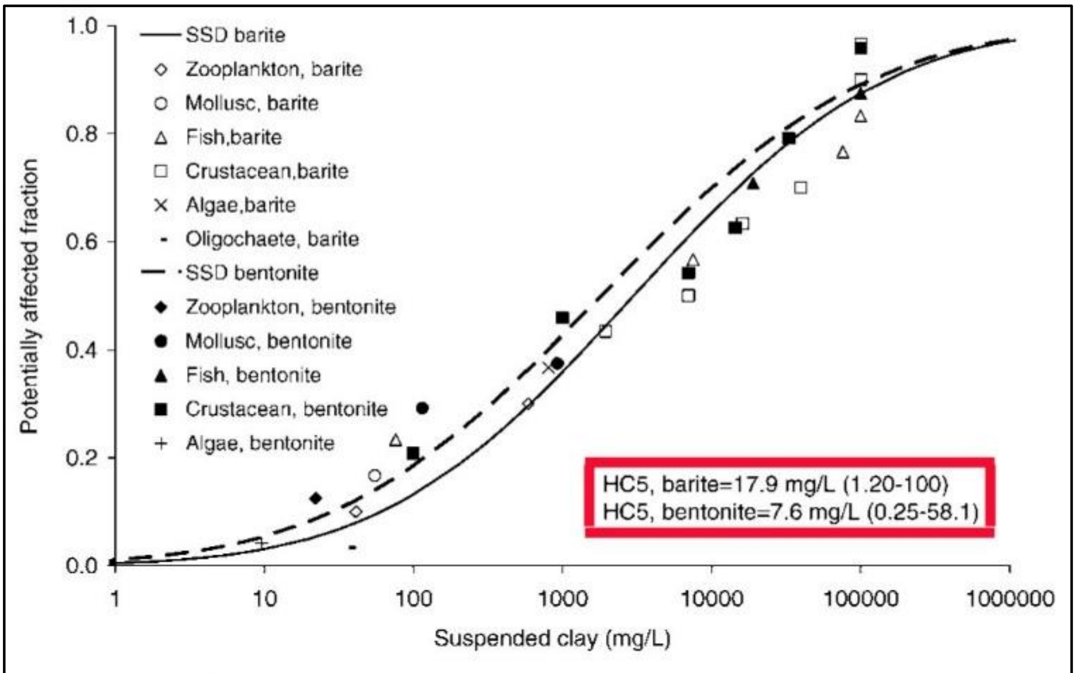


Fig. 2. Species sensitivity distributions (SSD) and the corresponding hazardous concentration for 5% of the species (HC5) (median values and 5–95% confidence intervals) based on 50% effect concentrations for barite (n = 15) and bentonite (n = 12).

Figure 3. From Smit et al. (2008), with red rectangle marking important information. With permission from John Wiley and Sons.

These results are misrepresented in the note:

(1) Another term, *tolerance limits*, is introduced although the cited paper deals with sensitivity.

(2) The paper does not specify types of effects on organisms. If both sublethal and lethal effects are included in the data collection, from which estimations were performed, it implies that limits for sublethal effects inferred from the estimated concentrations (median values) most probably will be too high. The note neither discusses this uncertainty nor the fact that different mechanisms of damage may operate in such a number of species and taxa over such a wide range of concentrations.

(3) The note does not mention that both bentonite and barite were considered.

(4) In the note has been used the value 17.9 mg/L estimated for barite for the purpose to conclude on «*tolerance limits for suspended mineral particles of size corresponding to clay*». The lower value 7.6 mg/L for bentonite, which I should think is a more typical clay, is **not**

mentioned. **Therefore, the note undercommunicates the potential damages from particles of sizes corresponding to clay**.

(5) The relevance of this knowledge to industry-created particles in question is non-documented.

5th & 6th sentence:

«*NIVA (Bjerkeng og Sundfjord 2008) has estimated that water with TSM concentrations of tailings at ≥10 mg/l could spread along the bottom until about 1-2 km from the discharge. This is a level far below the limit for influencing growth and survival in seawater for all the fish species in question (NIVA 2008a)*».

«*≥10 mg/l*» means 10 mg/L or more, and is in this context an unclear formulation. It is also unclear what is meant by «*all the fish species in question*». That ≥ 10 mg/L should be «*a level far below **the limit***» is another confirmation of NIVA's poorly worded limit.

Smit et al. (2008) estimated that a bentonite concentration (median value) of 7.6 mg/L would influence about 5% of the investigated species. Given the abundance of species in the fjord, 5 % corresponds to a high number. Detrimental effects on one or more of these may be harmful to ecosystems given they are key species. This could have been a starting point for evaluating effects at the level of ecosystems, in accordance with the title of the note. But instead it stops at det levels of species and individuals.

The estimated values of 7.6 and 17.9 mg/L do not – as far as I can see – correspond to defined terms of IUPAC or the water framework directive. The study is at level above that of species. But a NOEC below 7.6 mg/L should at least be indicated, and the use of the lowest safety of 10 implies an ELV < 1 mg/L.

NIVA & DNV GL (2009) have (1) an unclear presentation and (2) incomplete and incorrect referencing of Smit et al. (2008) by mentioning the highest value only. This results in underestimation and undercomunication of potential harmful effects from particles.

7.6 NIVA commissioned to a report from the Norwegian Environment Agency (MDIR)

The Norwegian Environment Agency commissioned NIVA to chair a committee who prepared a report (KLIF 2010) summarizing the state of knowledge regarding mining and environmental challenges, with a primary focus on sea disposal of waste and use of process chemicals. The committee contained representatives from governmental and non-governmental bodies. The editor of the report was a NIVA employee involved in reports and central in preaparing the zoning plan with EIA. This is certainly no consensus report, as clearly demonstrated when one of the committee members, from the Norwegian Society for the Conservation of Nature, at the publishing of the report 18.10.2010 stated: «*I completely disagree with what I perceive as a postive attitude to submarine tailings disposal and a* *belittling of toxic compounds as expressed in the report, especially in the summary (Eg vil markere usemje mot kva eg oppfattar som ei positiv haldning til sjødeponi og ei nedtoning av giftige kjemikalier som kjem til uttrykk i rapporten, spesielt i samandraget)*» (Løkeland 2010). It was published after Nordic Mining had submitted their application with zoning plan and EIA to the Municipality of Naustdal (Asplan Viak & NIVA 2009) and has been cited in one transmitting letter (MDIR 2015).

Effects of inorganic suspended solids are reviewed primarily in three different parts of the report. I.e. in **chapter 5.1.3** *Effects on natural resources (Effekter på naturressurser*, 1st & 2nd paragraph on page 59), **chapter 5.2.3** *Ecological effects (Økologiske effekter*, page 70-76), and **chapter 8.2** *Submarine tailings disposal – need for research (Deponering i sjø – forskningsbehov*, page 93-95).

The report claims that NIVA (2008a) summarizes present knowledge. None of the publications cited in 6.4 in the present report, except Hessen (1992) and Wilson & Connor (1976), are included. Grande (1987) is cited but not mentioned in the reference list. That list also contains at least one public unavailable NIVA report (Jacobsen et al. 1987).

Throughout sections 5.1.3 and 5.2.3 are generally scarce information about particle concentrations. References to Wilson & Connor (1976) and Humborstad et al. (2006) on page 75 are inaccurate. But in chapter 8.2 about research needs, is referred the metastudy of Smit et al. (2008), **quote:**

«*A substantial amount of new knowledge now exists about what concentrations of mineral particles in seawater which are acceptable in terms of negative effects on fish and plankton (Smit et al., 2009). This states that the lowest concentration of negative influence appears to be approximately 50 mg/l, whereas large negative manifestations first arise at a concentration that is at least 10 times this limit. It should be mentioned that negative effects depend not only on the concentration but also on duration of exposure*».

«*Det eksisterer nå en god del ny kunnskap om hvilke konsentrasjoner av mineralske partikler i sjøvann som er akseptable i forhold til negative effekter på fisk og plankton (Smit et al., 2009). Her fremgår at laveste konsentrasjon for negative påvirkning synes å være ca. 50 mg/l, mens store negative utslag først melder seg ved en konsentrasjon som er minst 10 ganger denne grensen. Det bør påpekes at negative effekter avhenger ikke bare av konsentrasjon, men også av eksponeringstid*».

The quoted text indicates that sublethal effects are considered. But it is unclear whether «*negative effects*» and «*negative influence*» should mean the same thing, and what should be the meaning of «*large negative manifestations*».

As already mentioned (7.5), the study of Smit et al. (2009) showed concenctrations of 7.6 mg/L (median value for bentonite) and 17.9 mg/L (median value for barite) to have some kind of effect on about 5% of the studied species. At 50 mg/L there are, according to figure 2 in that paper, marked effects (i.e. impact on about 10 % of the species). The methodology of deducing 50 mg/L is lacking. As already discussed a NOEC well below 7.6 mg/L should at least be indicated, and the use of a safety factor ≥ 10 would imply an ELV < 1 mg/L.

This study should have been cited in the first two sections of the report, in which few concentration valus were presented, and of course correctly. The value 50 mg/L mathches the non-documented allegiations of NIVA (2009a). NIVA has in the newspaper claimed that since the study of Smit et al. (2009) was cited under the heading of research need it should not be interpreted as being a proposed limit (NIVA 2014b).

The report claims some kind of a general limit of 50 mg/L, in conflict with results presented in the article, which indicates a «general» limit < 5 mg/L. It is disorderly to cite that paper under the heading of research need, and the interpretation should not - under any circumstances - depend on a heading in the report.

7.7 NIVA promoted mining and waste disposal in the Førde Fjord

NIVA was engaged by Nordic Mining, not only in producing reports, but also in presenting the project to public and politicians, and in preparing the zoning plan with EIA.

7.7.1 Reports from NIVA

Reports have also been used to promote the project. The first report, NIVA (2008a), in its first version, contains five pages, including three animated photographs, about land-based constructions. In the second version of the report the project presentation was revised and extended to about nine pages. Included are arguments for the benefits of mining the Engebø Mountain, photographs depicting e.g. an aircraft and a paintbrush, and five more animations of land-based constructions

That project presentation was exactly replicated in three subsequent reports from NIVA. These are NIVA (2008b) about aquaculture and fishing activity in the fjord, a report with a total of 33 pages, NIVA (2008c) about effects on wild fish and cultured species, a report with a total of 39 pages, and finally NIVA (2008d) about spread of particles in the upper part of the water column, a report with a total of 55 pages.

Finally, the presentation is part of the zoning plan with EIA (NIVA & Asplan Viak 2009), which I suppose should be the appropriate place for this information.

The exact replication of this information in four reports is excessive and largely out of contexts, and looks more like sales prospects.

7.7.2 Public presentations

NIVA has supported submarine tailings disposal in at least five public presentations (no 1-5).

<u>Absence of evidence is not evidence of absence</u>
No. 1) Presentation title: «*Submarine tailings disposal in the Førde Fjord – natural minerals without harmful compounds (Sjødeponi i Førdefjorden – naturlige mineraler uten skadelige stoffer)*» (NIVA 2009d).
Comment: The title is self-explanatory, and likewise the subtitle, **quote**: «*The concentration*

of particles upwards and aside for the disposal area are so low that there will be no effect on marine life (Konsentrasjonen av partikler oppover i vannmassene og utover deponiområdet er så lave at det ikke har effekt på marint liv)».
It is tempting to revise a known probverb: «Absence of evidence **in reports** is not evidence of absence»

Hiding the head in the sand – no clouds of particles recognized

The presentations no. 2-3 claim a high percentage of particles defined as sand.

No. 2) Presentation title**:** *«5. Key items. Environment, natural resources and society (5. Hovedmomenter. Miljø, naturressurser og samfunn)»* (NIVA year?)**:**
Slide 5, **quote**: «*About 60 % is sand and 4 % is in the size range of clay (Ca. 60 % er sand og 4% er i leirefraksjonen)*».

No. 3) Presentation title: «*Submarine tailings disposal in the Førde Fjord (Sjødeponering i Førdefjorden)*» NIVA (2010b).
Slide 7, curve for grain size distribution: About 65% sand, about 24% silt and about 10% finer particles.
Slide 9, **quote**: «*65% is sand or coarser and sinks immediately to the bottom (65% er sand eller grovere og synker umiddelbart til bunns)*».
Comment: In the first presentation was apparently omitted the silt fraction. If this should relate to particles without artificial flocculant added it is to say, as already stated (5.3.2), that 53% of particles will be smaller than 100 µm whereas 37% are in the range of sand as defined by NIVA (100-250 µm). Whatever definiton of sand, these messages obscure the presence of fine particles.
Secondly, NIVA has, in addition to the finer particles, documented very fine – medium sized sand. Thus, the allegiation of «*sand or coarser*», which implies gravel, is directly wrong.

These claims about sand in presentations and also in NIVA (2008a) have apparently impacted public opinion, as very well illustrated by the following statement by an eager debater and former politician and mayor of the Municipality of Naustdal in the local newspaper Firda 14.01.2015: «*It goes far beyond my ability to understand that **a heap of sand** at the bottom of the Vevring Fjord* [part of the Førde Fjord] *should destroy sales of all Norwegian farmed fish and fishery which are run on all the seven seas of the world (Det går langt over min forstand å forstå at ein sanddunge på botnen av Vevringsfjorden skal øydelegge for omsetninga av all Norsk oppdrettsfisk og fiskeri som vert drive på alle verdens sju hav*)».

Wishful thinking

No. 2) Additionally, from NIVA (year?):
Slide 10, **quote**: «*The finer fraction of the tailings is flocculated and will settle in the same area (Finfraksjonen i avgangen er flokkulert og vil avsette seg i samme området)*».
Comment: This undercommunicates the results of flocculation tests, one unsuccessful (NIVA 2009a) and another (NIVA 2014a), from which was concluded: «*Settling rates of particle size fractions below 0.68 µm are **not possible to determine** from these tests, other than that they will be lower than the stated settling rate of the 0.68 µm size fraction*», as already detailed (5.3.3).

Slide 12, **quote**: «*Estimated concentrations* [of «metals or chemicals»] *in the plume will be*

far below a concentration which will cause problems for marine organisms (Basert på konsentrasjonsberegninger i slamstrømmen vil nivået [av «metaller og kjemikalier»] *i utslippspunktet være langt unna en konsentrasjon som vil skape problemer for marine organismer)».*
Comment: This is not documented at all.

Ole Brumm?
No. 4) Presentation title: «*Submarine disposal of mine tailings in the fjords – yes please, both? (Gruvedeponier i fjordene - ja takk, begge deler?)*» (NIVA 2012)**:**
Slide 16, **quote**: «*Clean tailings sent via aerated pipeline to a deep fjord (Ren avgang sendt via luftet rør til en dyp fjord)*».
Comment: This corresponds to an allegiation in one of Nordic Mining's public presentations (Nordic Mining 2009, slide 16): «*The tailings is clean and contains low amounts of heavy metals (Avgangen er ren og har lite tungmetaller)*». This seems to be the key message although mentioned that harmful effects will be surveyed.

Pushing allegiated limits upwards
No. 5) Presentation title: «*Sea disposal – ecological sustainable solution? (Sjødeponi – økologisk levedyktig løsning?)*» (NIVA 2013):
Slide 11, **1st quote**: «*Clay particles: LC50: ~3,000 mg/l, PNEC: ~18 mg/l (Smit et al 2008) (Leirpartikler: LC50: ~3000 mg/l, PNEC: ~18 mg/l (Smit et al 2008))*».
Comment: Firstly, Smit et al. (2008) presented the ~3,000 mg/l as a concentration at which effects were observed in 50% of the species studied («*50% hazardous concentration*»). NIVA has not documented that this represents a LC_{50}. And what should a LC represent in such a study referring to a number of species? Secondly, and as already documented (7.5), NIVA & DNV GL (2009) cited Smit et al. (2008) incorrectly as it should not be 18 mg/L but 7.6 mg/L for bentonite. This is a median value for effects (not specified) in 5% of studied species. To denote this PNEC (predicted no-effect concentration) represents a significant error in addition to those already pointed out. Underestimation and undercommunication of effects was taken a step further in this presentation compared to the previous reports.
Slide 11, **2nd quote**: «*Lethal levels in adult and juvenile salmonids are >55 mg/l (Letale nivåer for voksen og juvenil laksefisk er >55 mg/l)*».
Comment: This has been commented (7.1.1) and for salmonids in seawater this text on slide 11 is a non-documented allegiation.
Slide 5, **3rd quote**: «*Most often clean masses, but not always (Som oftest rene masser, men ikke alltid)*».
Comment: The same allegiation as above-mentioned no. 4, slide 16 (NIVA 2012).

Politics
No. 2) And finally, from NIVA (year?):
Slide 36 has the heading: «*Consequences for society (Konsekvenser for samfunn)*», and the subsequent slides until 49 argue for benefits of the project.
Slide 40, **quote**: «*An EIA, if compared with the alternative of no mining (0 alternative), attains a negative focus in relation to environment and natural resources (En KU hvor sammenligningsalternativet er ikke gruvedrift (0-alternativet), får negativ fokus i forhold til miljø og naturressurser)*».

Sponsorship
(7) NIVA and MDIR (then SFT) were two of several sponsors for ***Marine and lake disposal of mine tailings and waste rock.*** *Criteria for acceptance – Case stories – Regulations. International Conference in* ***Egersund, Norway,*** *September 7-10, 2009*.
http://www.niva.no/www/niva/resource.nsf/files/wwww8msfrz-annex_5_second_annoncement/$FILE/annex_5_second_annoncement.pdf

7.7.3 Application for permit

The zoning plan with EIA (NIVA & Asplan Viak 2009) accompained the comany's application for mining. It was granted by the Municipality of Naustdal in 2011.

Salmonids are briefly mentioned, and cod in connection with aquaculture and/or sound pressure. The citation of NIVA (2009a) in the EIA further **supports that NIVA assumed some kind of a genereal limit of 50 mg/L for suspended solids**.

Results from the first flocculation and settling tests (NIVA 2009b), despite at best inconclusive, as detailed by e.g. «*seemed to produce good results*» (5.3.3), were cited in the zoning plan with EIA by this statement: «*Experimental adding of polymer demonstrated the possibility of obtaining effective flocculation of the fine particles. Dosage of Magnafloc 155 produced good results (Forsøk med polymertilsetning viste at det vil være mulig å gjennomføre en effektiv flokkulering av finfraksjonen. Dosering av Magnafloc 155 ga gode resultater)*».

«*seemed to produce good results*» were now «*produced good results*».

This clearly represents improper use of results from an unsuccessful experiment. The politicians of the Municipality of Naustdal, who granted the company's application for mining, probably understood this as «good» **settling** of particles in the fjord. To conclude, **good results were not documented at all**.

Submarine tailings disposal has been supported and promoted by underestimation and undercommunication of the lacking knowledge and uncertainties, and by misrepresentation of published knowledge. NIVA presents effects as smaller than those described in the sources cited and presentations look more or less like sales prospects.

7.8 Summary of NIVA's contribution

This summuary also includes topics dealt with in parts 5 & 6.

- EIA was disordely organized with e.g. additional and highly required flocculation tests 3 years after the Municipality of Naustdal granted the zoning plan with EIA
- The origin of eclogite for particle studies is not adequately documented
- The industry-created particles were not characterized. The EIA was in stead based on knowledge about «inorganic particles in general» and also organic particles, all of non-documented relevance

- Nano-sized particles were not addressed
- The claims that «*the main bulk of particles … is like sand*» and «*fine particles appear to do less harm than coarser particles*» are separately unfortunate and in concert misleading because attentions is drawn away from spread and effects of fine particles
- The EIA was based particularly on freshwater conditions, being of non-documented relevance, estuaries which should also be documented, and to lesser extent on those in seawater
- There was no clearly pronounced risk assessment methodology and ecological effects are hardly considered. Types of limits are not adequately defined, and ELVs recommended by the water framework directive are not mentioned.
- A lack of knowledge was ascertained in the focus on adult fish and shells but the literature search was not expanded, and no experimental exposures to particles in question were performed
- No knowledge obtained from exposure of salmonids in seawater is presented
- The most sensitive life stages and critical life-history stages were not adressed
- EIA was based on insufficient knowledge about marine organisms present, such as Atlantic cod at an adjacent spawning site
- Harmful effects were underestimated because a number of relevant and important publications about effects on marine fish – based on research activities also in Norway's neighbor countries, and known to NIVA's Swedish daughter company – were not considered despite available in 2008
- Uncritical use of incomplete and non-validated models pertaining to salmonids in freshwater
- Uncritical, incomplete and incorrect citing of scientific papers, which all contribute to underestimation of harmful effects
- Data obtained from exposures to particles of non-documented relevance in environments of non-documented relevance were used in an inadequate and disordered manner to assume a poorly-defined limit of 50 mg/L for exposure of marine organisms to industry-created particles.
- A limit of 50 mg/L is least 17 times too high if compared with then available knowledge about «mineral particles in general» and at least 170 times too high if compared with ELVs based on present knowledge
- EIA evaluated effects of concentrations in a range considerably higher than those predicted in the Førde Fjord by modeling
- NIVA promoted the project including submarine tailings disposal and undercommunicated risks in public presentation, pushed allegiated limit upwards and claimed «*Clean tailings*» and «*there will be no effect on marine life*» in the water body aside for the disposal area
- The EIA process would benefited from facilitating the scientific basis at the expense of project promotion

8 Contributions from Det norske veritas (DNV) GL

Some objections have already been mentioned (5; 6), and two reports (DNV GL 2014d; 2014e) were cited in part 5. Additionally, one report (DNV GL (2014a)[3] and two notes (DNV GL 2014b; 2014c) are cited in this part 8. These reports deal with effects of suspended particles on marine organisms and the first part of chapter 3 (page 25-28, translated in App. G) reviews literature about effects on fish and proposes limits.

8.1 Risk assessment methodology

I assume the following sentence is meant to summarize the methodology for the establishment of the effect limits proposed in the report:

«***The evaluation of effects is based on the lowest-reported-effect concentration for relevant resources and relevant components of the mine tailings from Engebø***» (App. G §2).

In the following text is the content of this sentence critically analysed in the light of statements in other text of the same chapter and in other sources from DNV GL.

(1) «*The evaluation of effects is based on the lowest-reported-effect concentration* ***for relevant resources*** *and relevant components of the mine tailings from Engebø*».

DNV GL has identified fish larvae, and juvenile and adult fish as relevant resources (see 3.2 Background (§2)). Further is specified that DNV GL has considered effects on «*the group of organisms mentioned above*». Taken together, this means larvae, juvenile and adult fish in general, with apparently no restrictions to marine fish. Neither eggs and critical life-history stages of fish nor other taxa (Direktoratsgruppa 2009; 2013) are included.

(2) «*The evaluation of effects is based on the lowest-reported-effect concentration for relevant resources and* ***relevant components of the mine tailings from Engebø***».

(§2): «*The literature study includes studies of effects of natural sediments from rivers and estuaries, and drilling muds from offshore operations*».

Effects of drilling muds were considered by Smit et al. (2008), who were cited in the context of smothering of benthic organsims but not in the evaluations of effects on fish. Therefore, what DNV GL actually says is that the evaluations about fish were based on natural sediments from rivers and estuaries. However, not all sediments were natural (Herbert & Richards 1963; Sykora et al. 1972), see 8.4.1.

I assume «*relevant components*» is defined by this formulation in 3.1 Introduction (§1): «*No distinction is made between different particle sizes. Total concentration of suspended particles, which is used in SINTEF's modeling, is considered biological relevant and is used as the basis for the effect evaluation. DNV GL considers modeled particles to be inert mineral particles without any specific content or form*».

[3] MDIR (2015) on page 38 states that they have considered a revised version of this report. I suppose that the version present at Nordic Mining's homepage (Date 2014-09-15 - Project no PP079572 - Report no 2014-1193 Rev A - Document no 18BHORT-10) has the same content as the one with these bibliographical data: (Date 2014-09-15 / date of issue 2014-09-23 – Project no PP098955 – Report no 2014-1193, Rev A / 2014-1136, Rev. 01 – Document no 18BHORT-10 / 18UAQWM-2).

It is very far from obvious that effect concentrations are independent of size. Therefore, the importance of sediments in question have been emphasized (Westerberg et al. 1996; Partridge & Michael 2010; Petereit & Franke 2012) as already mentioned. And nanoparticles were not considered in this context.

The size distribution of aggregates (NIVA 2014a) was modified by DNV GL (2014d) to comprise the range 15 – 340 µm, thus ignoring the sizes < 15 µm of approximately 0.62 % of flocculated particles (5.3.55), and next used as basis for modeling by SINTEF (2014). The particles, from which effect on fish were studied, were < 15 µm in most primary sources cited by DNV GL (App. C) and also in most of the non-cited sources (App. E). The possible significance of this discrepancy between sizes in effect evaluations and modeling should be considered. Particle sizes reported in sources cited by DNV GL will be mentioned in the following text (8.4-8.7).

From (1) and (2) follows that DNV GL intended to consider **LRECs for larvae, juvenile and adult fish in general** exposed to what they consider artificially **flocculated but inert inorganic particles without any size restriction. Therefore, these should be the inclusion criteria for appropriate studies for citation in the report**. DNV GL has not presented any data about effects of such artificially flocculated particles. Instead, the references used by the report include everything else, especially «*inorganic particles in general*» but also organic particles (Herbert & Richards 1963). DNV GL has not documented the relevance of any of these particle types, of which most were present in freshwater.

(3) «*The evaluation of effects is based on **the lowest-reported-effect concentration** for relevant resources and relevant components of the mine tailings from Engebø*».

The lowest-reported-effect concentration (LREC) is not a term found in the IUPAC glossary but it should be similar to or identical with the lowest-observed-effect concentration (LOEC) (App. B). The use of **LREC** is very appropriate but requires extensive literature search to find that or those values pertaing to the particles studied by DNV GL, i.e. «inorganic particles in general». However, as already documented (6.4 & App. E), there has not been included a number of important publications reporting concentrations far below those presented in the report as LRECs. And these lower concentrations are more close to those modeled for the Førde Fjord. This will be detailed in 8.3-8.7.

The criteria for assessing a published result as a LREC is unclear. A LREC may be misleading if it corresponds to the lowest concentration tested (Herbert & Richards 1963; Johnston & Wildish 1982; Sigler et al. 1984) or if there are large intervals between tested concentrations in the interval of special interest (Auld & Schubel 1978-indirectly cited by DNV GL). The challenge is increased by the fact that sources cited by the reports, except e.g. Johnston & Wildish (1982), report concentrations more than 10 times as high as those modeled for the Førde Fjord.

Thus, the LRECs are by nature somewhat arbitrary and higher than the corresponding threshold concentrations or NOECs. In such cases it may be a challenge, if not impossible, to estimate or suggest a limit. In fact, the difference between the presented LRECs and the lower thresholds or NOECs are unknown. LRECs must be related to clearly-defined (-described) effects as well as other factors of importance. According to Newcombe & Jensen (1996), who are referred several times, is avoidance an effect and it is number 3 on the scale. It is therefore logical to select avoidance (or even a lower level type of effect) as the type of sublethal effect, to which limits should be related.

However, DNV GL is inconsistent when it comes to avoidance and other behavioral responses. On the one hand, DNV GL (2014a, §7) says that «*Another kind of indirect sublethal (chronic) effect is behavioral response*» (page 26, plagiarism from NIVA) and talks about «*The reported effect limit for escape response* ..» (§9). On the other hand, DNV GL (2014b) says in its second last paragraph: «*It should also be said that DNV GL has not considered avoidance as an effect*». Such inconsistencies contribute to a disorderly representation in the report and to more uncertainty about what their sublethal effect limits represent. DNV GL (2014b) is the first and only publication that I have ever seen disregarding avoidance as an effect.

Genereally, alleged LRECs have not been consequently related to magnitudes of effects, exposure time, types of particles, fish species etc. These inaccuracies apply especially to LRECs of sublethal effects, as detailed below (8.4).

(4) «*The evaluation of **effects** is based on the lowest-reported-effect concentration for relevant resources and relevant components of the mine tailings from Engebø*».

There has to be some association between evaluated effects and effects related to LRECs. Therefore, as long as LRECs are only partly related to defined lethal and sublethal effects – in terms of type and magnitude - it is impossible to know the exact meaning of the effects being evaluated. This applies especially to NIVA's and DNV GL's use of the model of Newcombe & Jensen (1996).

In addition to the above-mentioned «***effect concentrations*** *[effektkonsentrasjon]*» (§2,9,13), which are those presented in cited publications, DNV GL also talks about «***tolerance limits*** *(tålegrenser)*» (§1,4,5) and «*thresholds (grenseverdier)*»[4] as calculated from the equations (§5,8). In one paragraph (§5) thresholds and tolerance limits are used interchangeably although tolerance limit is defined different from threshold by IUPAC (App. B), but I suppose both means effect concentration in this context. Then follows «***effect limit***» for lethal and sublethal effects (§10,11), and finally «***effect concentrations*** *in fish larvae*» (§13). Firstly, all these terms, of which at least one is used incorrectly, is confusing but I suppose they all denote effect limits. Secondly, as we shall see later, DNV GL bases their argumentation for their effect limits on calculated thresholds copied from NIVA and/or alleged LRECs. These represent two different types of information.

Confusion about types of limits is also found in DNV GL (2014c): «*… a lower limit for negative effects on the environment. Decision of such a lower limit (threshold concentration; PNEC) must be based on … (… en nedre grense for negative effekter på miljøet. Fastsettelse av en slik nedre grense (terskelkonsentrasjon; PNEC) må baseres på …)*».

[4] NIVA and DNV GL has translated «thresholds» by «grenseverdier», which is incorrect.

(5) «*The* ***evaluation*** *of effects is based on the lowest-reported-effect concentration for relevant resources and relevant components of the mine tailings from Engebø*».

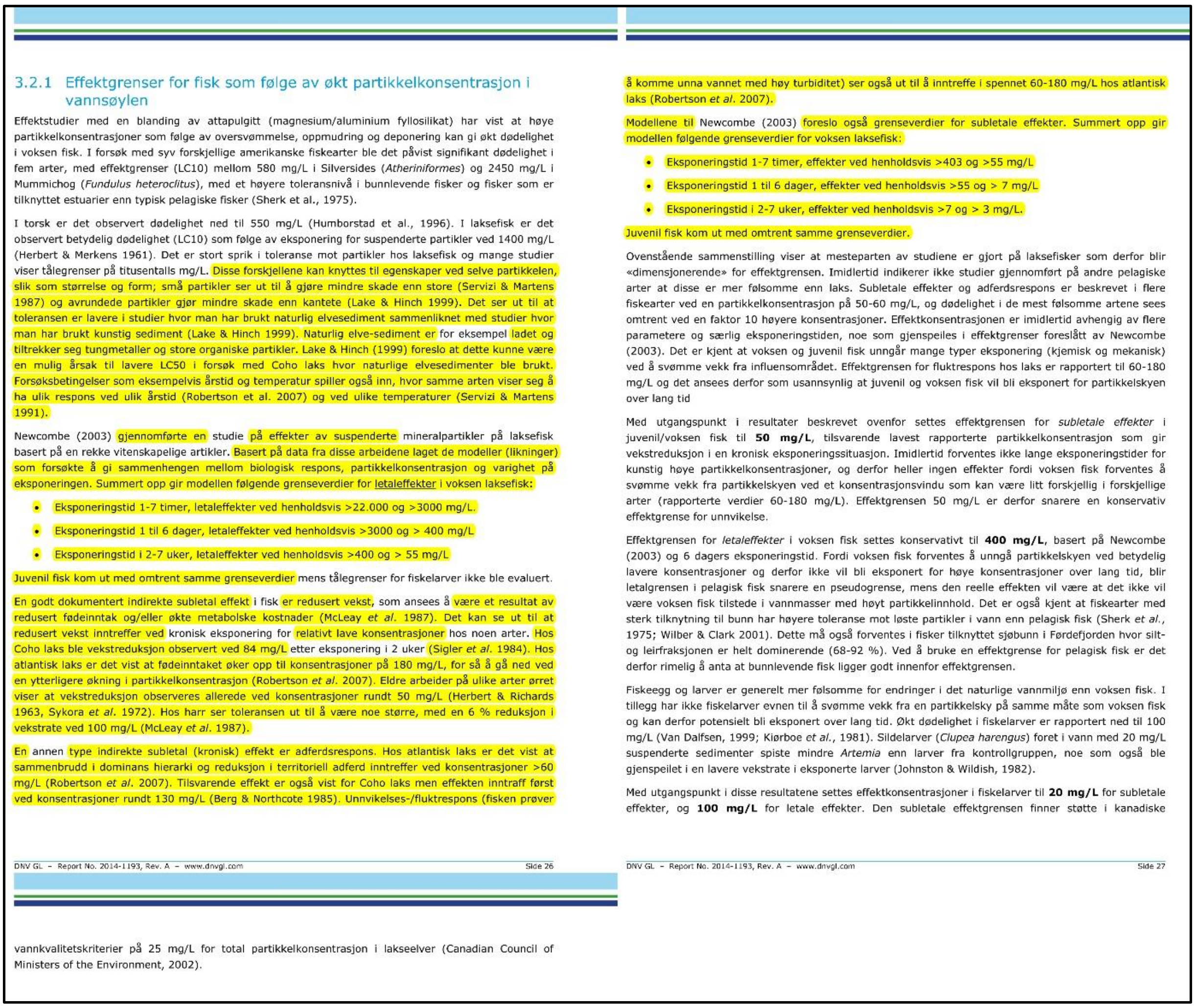
This should lead to conclusions. DNV GL argues against the use of PNECs (DNV GL 2014a), which are more close to the NOECs recommended by the water framework directive (EC 2000), **and their evaluation implies setting their proposed effect limits equal to their allegiated LRECs** (DNV GL 2014b, the second last paragraph). There is no reference to the directive, which recommends use of acute LC_{50}s and chronic NOECs with subsequent division with safety factors for establishing ELVS (4.2). **DNV GL's approach inevitably leads to underestimation of risks of damages** as long as LRECs by nature are higher than the thresholds, which again are higher than NOECs or PNECs. And this evaluation, as we shall see, went wrong also because LRECs alleged in the report are higher than those published.

Assessment methodology appears unclear and the requirements of the premise sentence have largely not been met. The used terminology is more or less inadequate and confusing. The inevitable result of the approach is the proposal of too high effect limits. The final step including estimation of ELVs is lacking.

8.2 Plagiarism from a previous NIVA report

The subchapter «*3.2.1 Effect limits for fish subsequent to increased particle concentration in the water column*» contains a lot of verbatim replication from NIVA (2008a). This is depicted in figure 4, and is documented by highlighting App. F, §9,12-15 the text copied from NIVA (2008a), and by highlighting in App. G, §4-8 the pasting into DNV GL (2014a). Copied text amounts to about half of the text in subchapter 3.2.1 on page 26 - 28. DNV GL has in few places either omitted single words, added a few new words (not marked) or replaced words with synonyms (not marked). The sequence of copied sentences in part differs from that of the original text. A few sentences have not been marked because they have been profoundly edited.

The report does not inform about the copied text and the source (NIVA 2008a) is absent from the bibliography. Other parts of the report have not been checked for copy. Plagiarism of two paragraphs was documented in October 2014 (IMR 2014) and the full extent of copying in 2015 January (Kvellestad 2015a). Additionally, all the primary sources cited clearly in the text by DNV GL (2014a), except one (Johnston & Wildish 1982), were also cited by NIVA (2008a) (App. D).



3.2.1 Effektgrenser for fisk som følge av økt partikkelkonsentrasjon i vannsøylen

Effektstudier med en blanding av attapulgitt (magnesium/aluminium fyllosilikat) har vist at høye partikkelkonsentrasjoner som følge av oversvømmelse, oppmudring og deponering kan gi økt dødelighet i voksen fisk. I forsøk med syv forskjellige amerikanske fiskearter ble det påvist signifikant dødelighet i fem arter, med effektgrenser (LC10) mellom 580 mg/L i Silversides (*Atheriniformes*) og 2450 mg/L i Mummichog (*Fundulus heteroclitus*), med et høyere toleransnivå i bunnlevende fisker og fisker som er tilknyttet estuarier enn typisk pelagiske fisker (Sherk et al., 1975).

I torsk er det observert dødelighet ned til 550 mg/L (Humborstad et al., 1996). I laksefisk er det observert betydelig dødelighet (LC10) som følge av eksponering for suspenderte partikler ved 1400 mg/L (Herbert & Merkens 1961). Det er stort sprik i toleranse mot partikler hos laksefisk og mange studier viser tålegrenser på titusentalls mg/L. Disse forskjellene kan knyttes til egenskaper ved selve partikkelen, slik som størrelse og form; små partikler ser ut til å gjøre mindre skade enn store (Servizi & Martens 1987) og avrundede partikler gjør mindre skade enn kantete (Lake & Hinch 1999). Det ser ut til at toleransen er lavere i studier hvor man har brukt naturlig elvesediment sammenliknet med studier hvor man har brukt kunstig sediment (Lake & Hinch 1999). Naturlig elve-sediment er for eksempel ladet og tiltrekker seg tungmetaller og store organiske partikler. Lake & Hinch (1999) foreslo at dette kunne være en mulig årsak til lavere LC50 i forsøk med Coho laks hvor naturlige elvesedimenter ble brukt. Forsøksbetingelser som eksempelvis årstid og temperatur spiller også inn, hvor samme arten viser seg å ha ulik respons ved ulik årstid (Robertson et al. 2007) og ved ulike temperaturer (Servizi & Martens 1991).

Newcombe (2003) gjennomførte en studie på effekter av suspenderte mineralpartikler på laksefisk basert på en rekke vitenskapelige artikler. Basert på data fra disse arbeidene laget de modeller (likninger) som forsøkte å gi sammenhengen mellom biologisk respons, partikkelkonsentrasjon og varighet på eksponeringen. Summert opp gir modellen følgende grenseverdier for letaleffekter i voksen laksefisk:

- Eksponeringstid 1-7 timer, letaleffekter ved henholdsvis >22.000 og >3000 mg/L.
- Eksponeringstid 1 til 6 dager, letaleffekter ved henholdsvis >3000 og > 400 mg/L
- Eksponeringstid i 2-7 uker, letaleffekter ved henholdsvis >400 og > 55 mg/L

Juvenil fisk kom ut med omtrent samme grenseverdier mens tålegrenser for fiskelarver ikke ble evaluert.

En godt dokumentert indirekte subletal effekt i fisk er redusert vekst, som ansees å være et resultat av redusert fødeinntak og/eller økte metabolske kostnader (McLeay *et al*. 1987). Det kan se ut til at redusert vekst inntreffer ved kronisk eksponering for relativt lave konsentrasjoner hos noen arter. Hos Coho laks ble vekstreduksjon observert ved 84 mg/L etter eksponering i 2 uker (Sigler *et al*. 1984). Hos atlantisk laks er det vist at fødeinntaket øker opp til konsentrasjoner på 180 mg/L, for så å gå ned ved en ytterligere økning i partikkelkonsentrasjon (Robertson *et al*. 2007). Eldre arbeider på ulike arter ørret viser at vekstreduksjon observeres allerede ved konsentrasjoner rundt 50 mg/L (Herbert & Richards 1963, Sykora *et al*. 1972). Hos harr ser toleransen ut til å være noe større, med en 6 % reduksjon i vekstrate ved 100 mg/L (McLeay *et al*. 1987).

En annen type indirekte subletal (kronisk) effekt er adferdsrespons. Hos atlantisk laks er det vist at sammenbrudd i dominans hierarki og reduksjon i territoriell adferd inntreffer ved konsentrasjoner >60 mg/L (Robertson *et al*. 2007). Tilsvarende effekt er også vist for Coho laks men effekten inntraff først ved konsentrasjoner rundt 130 mg/L (Berg & Northcote 1985). Unnvikelses-/fluktrespons (fisken prøver

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å komme unna vannet med høy turbiditet) ser også ut til å inntreffe i spennet 60-180 mg/L hos atlantisk laks (Robertson *et al*. 2007).

Modellene til Newcombe (2003) foreslo også grenseverdier for subletale effekter. Summert opp gir modellen følgende grenseverdier for voksen laksefisk:

- Eksponeringstid 1-7 timer, effekter ved henholdsvis >403 og >55 mg/L
- Eksponeringstid 1 til 6 dager, effekter ved henholdsvis >55 og > 7 mg/L
- Eksponeringstid i 2-7 uker, effekter ved henholdsvis >7 og > 3 mg/L.

Juvenil fisk kom ut med omtrent samme grenseverdier.

Ovenstående sammenstilling viser at mesteparten av studiene er gjort på laksefisker som derfor blir «dimensjonerende» for effektgrensen. Imidlertid indikerer ikke studier gjennomført på andre pelagiske arter at disse er mer følsomme enn laks. Subletale effekter og adferdsrespons er beskrevet i flere fiskearter ved en partikkelkonsentrasjon på 50-60 mg/L, og dødelighet i de mest følsomme artene sees omtrent ved en faktor 10 høyere konsentrasjoner. Effektkonsentrasjonen er imidlertid avhengig av flere parametere og særlig eksponeringstiden, noe som gjenspeiles i effektgrenser foreslått av Newcombe (2003). Det er kjent at voksen og juvenil fisk unngår mange typer eksponering (kjemisk og mekanisk) ved å svømme vekk fra influensområdet. Effektgrensen for fluktrespons hos laks er rapportert til 60-180 mg/L og det ansees derfor som usannsynlig at juvenil og voksen fisk vil bli eksponert for partikkelskyen over lang tid

Med utgangspunkt i resultater beskrevet ovenfor settes effektgrensen for *subletale effekter* i juvenil/voksen fisk til **50 mg/L**, tilsvarende lavest rapporterte partikkelkonsentrasjon som gir vekstreduksjon i en kronisk eksponeringssituasjon. Imidlertid forventes ikke lange eksponeringstider for kunstig høye partikkelkonsentrasjoner, og derfor heller ingen effekter fordi voksen fisk forventes å svømme vekk fra partikkelskyen ved et konsentrasjonsvindu som kan være litt forskjellig i forskjellige arter (rapporterte verdier 60-180 mg/L). Effektgrensen 50 mg/L er derfor snarere en konservativ effektgrense for unnvikelse.

Effektgrensen for *letaleffekter* i voksen fisk settes konservativt til **400 mg/L**, basert på Newcombe (2003) og 6 dagers eksponeringstid. Fordi voksen fisk forventes å unngå partikkelskyen ved betydelig lavere konsentrasjoner og derfor ikke vil bli eksponert for høye konsentrasjoner over lang tid, blir letalgrensen i pelagisk fisk snarere en pseudogrense, mens den reelle effekten vil være at det ikke vil være voksen fisk tilstede i vannmasser med høyt partikkelinnhold. Det er også kjent at fiskearter med sterk tilknytning til bunn har høyere toleranse mot løste partikler i vann enn pelagisk fisk (Sherk *et al.*, 1975; Wilber & Clark 2001). Dette må også forventes i fisker tilknyttet sjøbunn i Førdefjorden hvor silt- og leirfraksjonen er helt dominerende (68-92 %). Ved å bruke en effektgrense for pelagisk fisk er det derfor rimelig å anta at bunnlevende fisk ligger godt innenfor effektgrensen.

Fiskeegg og larver er generelt mer følsomme for endringer i det naturlige vannmiljø enn voksen fisk. I tillegg har ikke fiskelarver evnen til å svømme vekk fra en partikkelsky på samme måte som voksen fisk og kan derfor potensielt bli eksponert over lang tid. Økt dødelighet i fiskelarver er rapportert ned til 100 mg/L (Van Dalfsen, 1999; Kiørboe *et al.*, 1981). Sildelarver (*Clupea harengus*) foret i vann med 20 mg/L suspenderte sedimenter spiste mindre *Artemia* enn larver fra kontrollgruppen, noe som også ble gjenspeilet i en lavere vekstrate i eksponerte larver (Johnston & Wildish, 1982).

Med utgangspunkt i disse resultatene settes effektkonsentrasjoner i fiskelarver til **20 mg/L** for subletale effekter, og **100 mg/L** for letale effekter. Den subletale effektgrensen finner støtte i kanadiske

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vannkvalitetskriterier på 25 mg/L for total partikkelkonsentrasjon i lakseelver (Canadian Council of Ministers of the Environment, 2002).

Figure 4. Plagiarism in part 3.2.1 Effect limits for fish as a result of increased particle concentration in the water column, page 26-28.

8.3 Effect limit for lethality in adult fish

Three paragraphs (App. G §3-5,11), of which § 4-5 contain mainly copied text, deal with lethal concentrations and effects.

The second paragraph (§4) states a «*mortality down to 550 mg/L (Humborstad et al., 1996)*» in Atlantic cod. But the fish were exposed to 550 mg/L and the first sentence in the results section of that paper starts with «*All fish survived* ..». The year of publication was 2006. The paper is not listed in the bibliography. These errors, and the fact that NIVA (2008a) wrote both 1996 and 2006 for Humborstad et al., indicate that DNV GL has based this sentence on the NIVA report only. The result from this paper indicate a chronic lethal effect limit above 550 mg/L for the tested sediment, in 47% of particles by mass were smaller than 63 µm.

The second paragraph (§4) also refers to another study: «*In salmonids has been observed significant mortality (LC10) following exposure to 1,400 mg/L of suspended particles (Herbert & Merkens 1961)*». Herbert & Merkens (1961) conducted experimental exposures of a freshwater salmonid to kaolin (medin size 0.46 or 3 µm, depending on method for analysis) and diatomaceous earth (median 2.2 or 17.5 µm). However, the highest concentration tested was **780** mg/L (mean value). Most kaolin particles and probably also the diatomaceous earth particles were by weight smaller than 15 µm.

The first paragraph (§3), with referense to (Sherk et al. 1975), presents acute (24 h) LC_{10} values said to range 580 – 2,450 mg/L for seven (should be six?) species of adult estuarine fishes (App. G §3). However, the correct is up to 24,470 and not 2,450 mg/L, and the highest concentration presented is actually 97,200 mg/L for striped killifish. **The LC_{10} = 580 mg/L is the acute lethal LREC that I have found.** The fish were exposed to Patuxent River silt («*0.78 µ med. size, 72% < 2 µ*») and fuller's earth («*< 0.5 µ med. size, 82% < 2 µ*»), i.e. smaller than 15 – 340 µm.

Arguments for effect concentrations for lethal effects are built on the model of Newcombe & Jensen (1996) as copied from NIVA (§5), followed by a concluding paragraph (§11) starting with: «*The effect limit for lethal effects in adult fish is set conservatively at **400 mg/L**, based on Newcombe (2003) and exposure duration of 6 days*».

Data for acute or chronic mortality in adult marine fish are sparse, and the proposal of this effect limit is commented as follows:

(1) Whereas NIVA (2008a) correctly refers to Newcombe & Jensen (1996), DNV GL has in the copied text (§5) replaced them with Newcombe (2003), who focused on other aspects. DNV GL (2014b) has excused this.

(2) The threshold concentrations presented in the paragraph have been calculated by NIVA. NIVA's use of the model has already been commented (7.1.1).

(3) DNV GL does not emphasize that this model applies to **adult and juvenile salmonids** in **freshwater**, but uses it for the considerably broader term **fish** in **seawater** without any validation. Caution is highly justified by the fact that Newcombe & Jensen (1996) proposed different models for different environments and different taxa of fish (7.1.1).

(4) The thresholds calculated from the model are 3,000 mg/L for 24 h exposure, 400 mg/L for 6 days and 55 mg/L for 7 weeks. The levels (magnitudes) of mortality for these thresholds are not specified. DNV GL does not logically explain why the 6 days 400 mg/L was selected as the effect limit for lethal effects and does not explain how this would be conservatively (for safety sake). One should think that a 7 weeks 55 mg/L is more relevant in such a long-lasting project, although this is also a short period of time. Calculation based on a longer time would result in a threshold considerably lower than 55 mg/L.

(5) One may ask how such estimated thresholds from a model (dealing with salmonids in freshwater) can be in accordance with the introductory statement about «*the lowest-reported-effect concentration for relevant resources*».

(6) In summary, what we have for adults of one estuarine species (Atlantic silversides) are 24 h LC_{10} = 580 mg/L = **LREC** and 24 h LC_{50} = 2,500 mg/L. The latter can best be compared with the calculated 24 h threshold = 3,000 mg/L for freshwater salmonids, although the level of effect is unspecified. Data for estuarine fishes should presumptively be more relevant than those from freshwater salmonids, especially when the criteria for the latter are unclear.

Division of the 24 h (acute) LC_{50} value with the factor 1,000 yields an ELV of 2.5 mg/L. An additional safety factor may be required due to different environments and particles.

(7) Wenger et al. (2012) – in the study with repeated short term exposures of juvenile marine fish to bentonite (App. E) – observed mortality, which after 6 weeks was < 10 % at 45 & 90 mg/L and **42 % at 180 mg/L**. Although chronic effects one may ask what had been the mortality if these fish had been continuously exposed during the period. A significant mortality at concentrations well below 400 mg/L should be expected.

(8) In the study of Au et al. (2004) referred to in NIVA (2008a) was observed **30% cumulative mortality following a six weeks exposure to 30-35 mg/L** (7.1.3.3). This is a putative chronic LC value. However, it fulfills the recommendations laid down in DNV GL's premise sentence, which contains no restrictions to exposure times. Additionally, observations pertaining to a marine fish should prevail over thresholds (e.g. 400 or 55 mg/L) for unknown level of mortality predicted from a freshwater model. Moreover, if taken into account the high experimental mortality in this marine species normally living in turbid water this result would support an effect limit well below 30-35 mg/L in more sensitive species. Since this is a putative chronic LC (with estimated LC_{50} = 1,400 mg/L) it would be incorrect to divide it by the safety factor 1,000 recommende for acute LC_{50}s.

DNV GL's proposed effect limit of 400 mg/L for lethal effects in adult fish after 6 days is based mainly on knowledge about salmonids in freshwater. It comprises uncritical plagiarism of secondary texts including estimated thresholds for mortality (magnitude unknown) in an incomplete and non-validated model. The limit is non-documented. According to relevant but non-cited literature, the LREC for lethal effects, putative chronic (6 wk), is ≤ 30-35 mg/L. The lowest reported 24 h LC_{50} of 2,500 mg/L in an estuarine species yields an ELV of < 2.5 mg/L if divided by the safety factor 1,000.

8.4 Effect limit for sublethality in juvenile and adult fish

Sublethal effects and limits for juvenile and adult fish are considered in five paragraphs (App. G §6-10), of which three (§6-8) are plagiarism from NIVA (2008a), and the last contains a proposal of effect limit.

8.4.1 Reduced growth rate

Reduced growth rate as a sublethal effect is described (§6), among other this sentence: «*Older studies of different species of trout demonstrates reduced growth at concentrations as low as 50 mg/L (Herbert & Richards 1963, Sykora et al. 1972)*».

This sentence, which is plagiarism, has already been commented (7.1.2). It is about salmonids in freshwater exposed for several months, the particles (wood fibre, coal-washery solids or ferric hydroxide) are of totally non-documented relevance (perhaps the least relevant of all types referred to in these reports) and **the LREC of these studies is 13 mg/L** and not 50 mg/L (Sykora et al. 1972; figure 2). Moreover, most particles were smaller than 15 µm; 86% of coal-washery solids by weigth (Herbert & Richards 1963) and 65% of ferric hydroxide particles by number (Sykora et al. 1972). Additionally, as mentioned, was in another study (Sutherland & Meyer 2007) of freshwater fish observed reduced growth at 25 mg/L.

Results in the cited papers indicate a chronic NOEC between 8 and 13 mg/L for reduced growth. Divison of the NOEC with a safety factor (10, 50 or 100) from the water framework directive yields an **ELV < 1.3 mg/L**.

8.4.2 Model

The use of the model of Newcombe & Jensen (1996) by text copied from NIVA (§8) has been commented in general (7.1.1).

(1) DNV GL has especially emphased reduced growth. As previously mentioned, reduced growth is 9 and **a paralethal effect** on Newcombe's & Jensen's scale 0-14. The effects desribed in already cited papers (Herbert & Richards 1963; Sykora et al. 1972), which are important for DNV GL, are also listed as 9 in table A.1 on page 721 and 723 in Newcombe & Jensen (1996). Since the model is important in DNV GL's argumentation it sounds disharmonic to use data for a paralethal effect in arguing for what is the LREC in sublethality. And reduced growth, which can be observed as a sublethal effect in experiments, may be lethal for wild populations. Therefore, **reduced growth as observed in experiments should not be the first choice for type of effect** in wild marine fish, in order to find a LREC.

(2) As mentioned, NIVA has used the model without defining what type of sublethal effect is considered, and there is no information about magnitude of effect. But the exposure durations and thresholds calculated by NIVA indicate an effect of degree 5-6 (minor to moderate physiological stress). If this is correct, then DNV GL refers to an effect 5-6 when using the model and refers to an effect of 9 (reduced growth) when using the argumentation copied from NIVA. This appears disorderly.

(3) If we should accept results pertaining to freshwater, it is to say that thresholds for sublethal effect (type not specified) estimated by the model range from 403 mg/L after 1 h to 3 mg/L after 7 weeks. Since 50 years are considerably longer than the lifespan of most, if not all fish, one may ask why DNV GL apparently has selected the threshold of 55 mg/L associated with exposure for 1 day. The threshold of 3 mg/L for 7 weeks should be more relevant.

8.4.3 Avoidance

Avoidance or escape is dealt with in three paragraphs (§7,9-10) based on the same reference. The first (§7), **quote: «***Avoidance/escape response (the fish attempts to escape water with high turbidity) also seems to occur in the range 60-180 mg/L in Atlantic salmon* (Robertson et *al. 2007)*».

In the last paragraph (§10), **quote:** «*…… and thus no effects because adult fish is expected to swim away from the particle cloud at a concentration window that may be slightly different in different species (reported values are 60-180 mg/L)*».

Juvenile Atlantic salmon in freshwater were exposed to different concentrations of sediment (<75-250 µm) for 2.5 h in a stream tank (Robertson et al. 2007). The size range indicates that fine and very fine sand were dominating fractions, and a stream tank was apparently necessary for keeping the particles suspended. The settling of the coarsest 90% of particles in the Førde Fjord has not been disputed (MDIR 2015). This reference should therefore be of minor relevance. However, what DNV GL actually claims in the last sentence is that results pertaining to **juvenile salmon exposed to mainly sand in freshwater** should be valid for **adult fish exposed to finer particles in seawater**.

DNV GL also belittles by stating that **adult fish** are expected to swim away from the cloud of particles. See also 7.1.3.4 for comments. Robertson et al. (2007) also observed increased foraging activity at 20 mg/L. If not harmful to the fish itself in the short-term it may have long-term ecological consequences.

8.4.4 Pelagic species

The next paragraph (§9), among other this sentence, **quote:** «*However, studies conducted in other pelagic species do not indicate higher sensitivity than in salmon*».

I suppose other pelagic species refer to marine fish. Anywhy, the allegiation **lacks reference and has not been substantiated at all**. **All the references listed in App. E and detailed in 6.4.5 demonstrates that this s**tatement is in conflict with results of several studies dealing with conditions in seawater. Otherwise, the text in the paragraph is about concentrations and limits applying to conditions in freshwater, and is therefore of minor relevance as long as research data do exist for fish in seawater (as discussed further below).

8.4.5 DNV GL's proposed effect limit

The concluding paragraph (§10) starts with, **quote: «***Based on the above-described results is concluded an effect limit for sublethal effects at **50 mg/L** in juvenile/adult fish. This corresponds to the lowest reported particle concentration that results in reduced growth in chronically exposed fish*».

DNV GL (2014b) confirmed this proposal in a comment to HI (2014), the second last paragraph: «*It is claimed that 50 mg/L is an unreasonably high particle concentration **but it corresponds to lowest reported sublethal effect concentration in adult fish**, whereas most studies show significantly higher effect concentrations (Det fremstilles som om 50 mg/l er en urimelig høy partikkelkonsentrasjon men det tilsvarer altså lavest rapporterte, subletale effektkonsentrasjon i voksen fisk, mens de fleste studier viser betydelig høyere effektkonsentrasjoner)*».

Based on the quoted paragraphs it is obvious that the effect limit of 50 mg/L is based on an non-validated and incomplete model and on incorrectly cited results from two papers (Herbert & Richards 1963; Sykora et al. 1972) dealing with a salmonid in freshwater exposed to uncommon types of particles. Effects of nano-sized particles were not evaluated. This part of the report is certainly not a new and independent evaluation but apparently an attempt to substantiate NIVA's assumed limit of 50 mg/L by plagiarism of text from NIVA.

8.4.6 Relevant literature about marine fish not cited by DNV GL

(1) Relevant literature about marine fish (6.4.5) has not been referred to**.** All of these apply to marine fish, contrary to the above-mentioned. A number of these studies report behavioral effects at concentrations well below 60-180 mg/L, and the acute LREC is 3 mg/L for adult Atlanic cod and herring (Westerberg et al. 1996).

(2) Additionally, the afore-mentioned (7.5) metastudy by Smit et al. (2008) indicates a «general» effect limit at < 5 mg/L for bentonite and barite. The DNV GL report refers to this paper in association with burying of bottom-living organisms but not in this context of suspended particles.

(3) Finally, that green grouper died at 30-35 mg/L (Au et al. 2004) implies significant chronic sublethal effects at concentrations far below that level (7.1.3.3), i.e. NOEC < 30-35 mg/L and ELV < 3 mg/L.

(4) A paper documenting effects of 0.1 mg/L of nanoparticles (8.8) was not considered in this context.

DNV GL's proposed effect limit of 50 mg/L for sublethal effects in juvenile and adult fish is based entirely on knowledge about salmonids in freshwater, all of non-documented relevance. In detail, it includes uncritical plagiarism of secondary texts; (1) estimated thresholds for physiological stress (type and magnitude unknown) in an incomplete and non-validated model, and (2) incorrect citation of at least two scientific articles pertaining to reduced growth. According to non-cited but very relevant literature, the acute LREC for sublethal effects in marine fish is ≤ 3 mg/L and not 50 mg/L, which means that the limit of 50 mg/L is at least 17 times too high. The implied acute NOEC < 3 mg/L and a safety factor of at least 10 yields an ELV < 0.3 mg/L, indicating the effect limit to be at least 170 times too high. Moreover, if the effect concentration of 0.1 mg/L for nano-sized particles is taken into account, in accordance with DNV GL's declared preconditions, the resulting ELV would be < 0.01 mg/L.

8.5 Effect limits for lethality in larvae

Larve are dealt with in two paragraphs (App. G §12-13).

DNV GL refers to Kiørboe et al. (1981) and van Dalfsen (1999) in §12: «*Increased mortality in fish larvae has been reported down to 100 mg/L (Van Dalfsen, 1999; Kiørboe et al., 1981)*» And concludes in §13: «*Based on these results is effect concentrations in fish larvae set to …… **100 mg/L** for lethal effects*».

However, Kiørboe et al. (1981) reported effects on eggs (embryo development and hatching) and **not** larvae. The other reference, and the only one, van Dalfsen (1999), is a tertiary source. DNV GL's intended use of LRECs should be kept in mind when reading how the actual content of an article was communicated through the following sequence of citations:

Primary source, article, Auld & Schubel (1978) reported effects of different concentrations (±10%) of 1-4 µm particles on anadromous and estuarine fish larvae in Chesapeak Bay (App. E and 6.4.4). In American shad, the apparently most sensitive species, was observed 82 % survival in 100 mg/L, 93 % in 50 mg/L and 95 % in the control following exposure for 96 h. This result strongly indicates that mortality would also be observed at concentrations between 50 and 100 mg/L if tested. They concluded: «*Concentrations* $\geq$ *100 mg* l^{-1} *significantly reduced the survival of shad larvae continuously exposed for 96 h*».

Secondary source, a report by Baveco (1988), cited the above-mentioned source and concluded: «*The larvae of Alosa sapidissima showed reduced survival at levels higher than 0.1 g/L*». The reality of ≥ was thereby altered to > despite indications of increased mortality even at concentrations below 100 mg/L if tested. This report also cited another report (Messieh et al. 1981) about mortality in herring larvae, and a primary source dealing with effects of ferric hydroxide particles. But in the context of LREC it is the paper of Auld & Schubel (1978) that is relevant.

Tertiary source, the report by van Dalfsen (1999) very briefly deals with this topic in this quoted paragraph on page 23: «*Increased level of turbidity influences the feed uptake by filter feeders, the gills of fish, fish larvae and gas exchange of eggs (Baveco, 1988). Sublethal effects have been demonstrated at concentrations of 100-300 mg/l (Baveco, 1988). Larvae and eggs are more susceptible to an increased content of suspended solids. Concentrations above 100 mg/l may already lead to an increased mortality.*
Een verhoogd zwevende stofgehalte beïnvloedt de voedselopname van filterfeeders, de kieuwademhaling van vissen, vislarven en ongewervelden en de gasuitwisseling van viseieren (Baveco, 1988). Sublethale effecten zijn aangetoond bij concentraties van 100-300 mg/l (Baveco, 1988). Larven en eieren zijn gevoeliger voor een verhoogd zwevende stofgehalte. Concentraties boven de 100 mg/l kunnen al tot een verhoogde sterfte leiden».

This text as written is clearly insufficient for the purpose to find the LREC and to conclude about an effect limit. Additionally, this third level source was based entirely on Baveco (1988), despite availability of source such as Westerberg et al. (1996).

Finally, DNV GL neither relates «*the effect concentration*» to magnitude of mortality nor to exposure duration. But 96 h are indicated from the primary source. As already pointed out (6.4.4) the results of Auld & Schubel (1978) may indicat an ELV of perhaps 1-2 mg/L. Additionally, the size range 1-4 µm (Auld & Schubel 1978) was clearly outside the modeled size range 15-340 µm.

Interestingly, Sherk et al. (1975), which were cited in 8.3, also presented 24 and 48 h LC_{50} values of 3,730 and 1,550 mg/L, respectively, for white perch larvae, and 24 h and 48 h LC_{50} values of 4,850 and 2,800 mg/L for striped bass larvae. Although the relevance of data for estuarine fishes can be questioned in this context, it should be noticed that division by the safety factor 1,000 indicates ELVs well below 5 mg/L.

The apparently most relevant results are the 12 h LC_{50} replicates of 157 and 142 mg/L for open-mouthed larvae, and 2,020 mg/L for closed-mouthed larvae (Partridge & Michael 2010), and 12 h LC_{50} = 170 mg/L (Isono et al. 1998) (App. E and 6.4.4). Division of these highly acute LC_{50}s, which were obtained during very short exposures, with the safety factor of 1,000 yields **ELVs ≤ 2 mg/L** if close-mouthed larvae are included, and an **ELV ≤ 0.15** if the most sensitive stage (open-mouthed larvae) is considered.

These results are supported by those of Westerberg et al. (1996, figs. 8-10), i.e. about 30 % mortality (although not always conclusive) after 6 days at 10, 20 or 40 mg/L). And also about 20 % mortality after 12 h at 32 mg/L (Isono et al. 1998). The directive does not contain any safety factor to be applied to the estimated replicate FOECs of 4 and 14 mg/L (Partridge & Michael 2010), which as already pointed out should be interpreted with caution. But these values does not seem inconsistent with ELVs ≤ 2 or ≤ 0.15 mg/L.
Finally, the results of these papers can also be considered in a more simple way: Mortalities would occur at concentrations far below 100 mg/L in all studies if the exposures lasted for 6 days. As already suggested (6.4.4), concentrations that cause sinking of cod eggs should produce the same result in yolk sac larvae.

DNV GL has propoosed an effect limit of 100 mg/L for lethal effects - without specifying exposure duration and magnitude of effect - based on one single and 15 years old tertiary source being very brief, inexact and outdated at the publishing time. According to relevant literature not cited, the LREC for lethal effects in larvae is ≤ 10 mg/L, which means that DNV GL's proposed effect limit of 100 mg/L is at least 10 (perhaps 25) times too high. The lowest reported acute LC_{50}s are about 150 mg/L, which divided by the safety factor of 1,000 yields an ELV ≤ 0.15 mg/L, indicating the effect limit to be at least 670 times too high.

8.6 Effect limits for sublethality in larvae

Larve are dealt with in two paragraphs (App. G § 12-13).

The DNV GL report refers an article presenting two experiments carried out in herring larvae by Johnston & Wildish (1982) and concluded on an effect limit of 20 mg/L. In a **first** experiment with exposure to 4, 8 and 20 mg/L for 3 h was observed significantly reduced feeding on *Artemia* at 20 mg/L, as correctly referred by DNV GL. But the report incorrectly states that reduced growth was observed. What the authors actually did was to compare the feed uptake with length of larvae, and concluded that the reduction was largest in the shortest larvae. The short exposure time also means that an acute sublethal effect was observed. A **second** experiment described in that paper, with exposures to 0, 10 and 20 mg/L, was not mentioned in the report. It was observed **avoidance at 10 mg/L**. («*...significantly fewer (p < .05) larvae in the the bottom section of the tank in the suspended sediment treatments* ….)». As already mentioned, Westerberg et al. (1996) interpreted this result in their introduction by stating «*a threshold of approximately 10 mg/l*». Therefore, the LREC in literature cited by DNV GL themselves is **10 and not 20 mg/L**. Importantly, this result was obtained during the very short exposure duration of 3 h. The sediment particles were smaller than 15 µm.

The above-cited estimated FOEC lethal effect at **4 mg/L** (Partridge & Michael 2010) indicates sublethal effects at even lower concentrations because these precede the lethal ones. This equals the concentration (Petereit & Franke 2012) supposed to cause sinking of cod yolk sac larvae. Prolonged larval development was observed in larvae of a coral reef damselfish at the lowest tested concentration (15 mg/L) of bentonite (Wenger et al. 2014 April) (6.4.4). Finally, if it is possible to talk about sublethal effects in drifting cod larvae there will be a NOEC well below 4 mg/L.

Therefore, the LREC is certainly lower than 20 mg/L, and a NOEC will be ≤ 10 mg/L, probably ≤ 4 mg/L. Division with the safety factor 10 yields **ELVs < 1.0 or < 0.4 mg/L**.

DNV GL has not included relevant literature but based the sublethal effect limit at 20 mg/L in larvae on only one primary source, which is cited incorrectly. The LREC for sublethal effects in larvae is ≤ 10 mg/L (probably ≤ 4 mg/L), which means that DNV GL's proposed effect limit for sublethal effects is at least 2 (probably 5) times too high. A NOEC < 10 mg/L (probably < 4 mg/L) is indicated, and division by a safety factor 10 implies an ELV < 1.0 mg/L (probably < 0.4 mg/L), indicating the effect limit to be at least 20 (probably 50) times too high.

8.7 Effect limits for lethality and sublethality in eggs

DNV GL (2014a) mentioned eggs but contained neither argumentation nor conclusions for effect limits. Later (DNV GL 2014b) stated that *«the sensitivity of eggs is considered equal to that of larvae (følsomheten til egg ansees lik følsomheten i larver*)». This implies proposal of **100 mg/L** and **20 mg/L** effect limits for lethal and sublethal effects, respectively.

The report of van Dalfsen (1999) very briefly mentioned eggs as evidenced by the above-quoted text (8.5), with reference to Baveco (1988), who cited Auld & Schubel (1978), Kiørboe et al. (1981), Messieh et al. (1981) and other papers about effects on eggs, of which most or all are benthic. van Dalfsen (1999) seemed to suggest some level of lethality at 100 mg/L for eggs of unspecified type. As said above, the paper of Kiørboe et al (1981) is about herring eggs but DNV GL did not refer to its content in this context. According to that paper exposure of e.g. 10 days to a silt concentration about 300 mg/L did not result in any observable effect, which seems to be in accordance with results reviewed in the present report.

DNV GL has not documented the sensitivity of eggs to generally equal that of larvae. And results of at least some studies may support higher sensitivity for larvae compared with eggs (6.4.4). However, it is important to differentiate between pelagic and benthic eggs (6.4.2), and to focus on sensitive species. Finally, a distinction between lethal and sublethal effects possibly makes sense for benthic eggs but does not seem straightforward for pelagic eggs. Effects on pelagic eggs may occur at ≤ 4 mg/L (6.4.2). Interestingly, before construction of the Fehmarnbelt fixed link was set a permissible limit of 2 mg/L (FeBec 2013). The limit of

25 mg/L for Canadian rivers with salmon eggs buried in riverine gravel has no documented relevance for conditions in seawater in general and for pelagic marine eggs in special.

DNV GL has based the LREC for lethal and sublethal effects in eggs (100 and 20 mg/L) on only one source (van Dalfsen 1999), which is tertiary, 15 years old and incomplete. The LREC for effects in cod eggs is ≤ 4 mg/L, which implies DNV GL's proposed effect limits for lethal and sublethal effects to be at least 25 and 5 times, respectively, too high. Division of NOEC (< 4 mg/L) by the lowest safety factor 10 implies ELV < 0.4 mg/L, demonstrating the sublethal effect limit to be at least 50 times too high.

8.8 Nanoparticles

Nanoparticles are dealt with in one report (DNV GL 2014c), which is DNV GL's comments to a letter about such particles (Naturvernforbundet 2014). Selected text from the note is presented and translated:

«***Documented effects of titanium dioxide particles***
Most effect studies of titanium dioxide particles have been conducted with chemically produced particels (size-dependent fractions), and many have been conducted with a crystalline form (anastase) which is more reactive/toxic than the form which is discharged in the Førde Fjord (rutile). The differences in reactivity between size fractions and crystalline forms can be associated with surface properties of the particles (Yeo and Kang 2008; the Norwegian Board of Technology). The effect levels found in the literature are therefore *a conservative starting point for evaluation of effects in the Førde Fjord.*

Larger particles of rutile are basically considered inert, but they can cause a localized physical effect due to smothering of organisms.

………

Except one study in fish (Federici et al. 2007) have harmful effects of titanium dioxide particles been observed first at a level of mg/L. However, Federici et al. (2007) observed harmful effects in the gills of rainbow trout fry at concentrations as low as 0.1 mg/L. The authors of the study observed no accumulation of titanium dioxide in the fish and explained the effects by a physical adsorption of the particles at the gill surface, at which they exerted their effect.

………

Conclusion: Effects of titanium dioxide nanoparticles have been documented down to 0.1 mg/L. Several chronic studies have been conducted in algae and crustaceans (daphnia) as well as sublethal studies in fish.

The effect studes have been conducted with chemical prepared nanoparticles, which will be more reactive than rutile particles in the mining waste. To base an environmental risk assessment for mining waste in the Førde Fjord on results of such studies will be very conservatively

Expected effects in the Førde Fjord
Titanium dioxide accumulates in mussels and to some extent in other filtering organisms but ***not*** *in fish …..*

Dokumenterte effekter av titandioksidpartikler
De fleste effektstudier av titandioksidpartikler er gjennomført med kjemisk fremstilte partikler (størrelsesbestemte fraksjoner), og mange er gjennomført med en krystallform (anatase) som er mer reaktivt/giftig enn den formen som slippes ut i Førdefjorden (rutil). Forskjellen i reaktivitet mellom størrelsesfraksjoner og krystallformer kan knyttes til overflateegenskaper til partiklene (Yeo og Kang 2008; Teknologirådet). Effektnivåene som er funnet i litteraturen er derfor et konservativt utgangspunkt for vurdering av effekter i Førdefjorden.
…………………….
Større partikler av rutil er i utgangspunktet regnet som inert, men de kan gi en fysisk effekt ved nedslamming av organismer der de deponeres lokalt.

Med unntak for en studie på fisk (Federici et al., 2007), er skadelige effekter av titandioksidpartikler observert først på mg/L-nivå. Federici et al. (2007) observerte imidlertid skader på gjellene på yngel av regnbueørret ved konsentrasjoner helt ned til 0,1 mg/L. Forfatterne av fiskestudien observerte ingen akkumulering av titandioksid i fisken og forklarte effektene med en fysisk adsorpsjon av partiklene på gjelleoverflaten og at de utøvet sin virkning der.

Konklusjon: Det er dokumentert effekter av nanopartikler av titandioksid ned til 0,1 mg/L (100 µg/L). Det er utført flere kroniske studier med alger og krepsdyr (dafnier), samt sub-letale studier med fisk. Effektstudiene er gjort med kjemisk fremstilte nanopartikler, som vil være mer reaktive enn rutilpartikler i gruveavfallet. Å basere en miljørisikovurdering for gruveavfallet i Førdefjorden på resultater fra slike studier vil være svært konservativt.

Forventede effekter i Førdefjorden
Titandioksid akkumuleres i muslinger og til en viss grad i andre filtrerende organismer, men ikke i fisk. …».

The study of Yeo & Kang (2012) was conducted in zebrafish eggs exposed to TiO_2 nanoparticles, i.e. the crystalline forms anastase (size 7-8, 12-14, 17-23 nm) and rutile (size 80-100, 150-200 [500?] nm), at the same concentration (20 g/L).

Firstly, this study was not conducted in seawater but in freshwater. As already said, physical and chemical properties of nanoparticles in seawater differ from those in freshwater (Baker et al. 2014). Secondly, the rutile particles were about 10 times as large as the anastase particles, to which they were compared. Therefore, the authors of the paper suggested that «*the crystal type and **particle size** of TiO_2 nanoparticles determine their effects on cellular developmental processes*». This message is also clearly reflected in the title. The most serious effects were observed following exposure to 12-14 nm sized anastase particles wheras rutile of that size were not included in the study. Effects of the next size class of anastase, i.e. 17-23 nm, were similar to those of the larger rutile particles. Therefore, it is not possible from this study to conclude on relative effects of anastase and rutile. Thirdly, both types of particles were found inside cells of larvae subsequent to hatching.

In the other study, by Federici et al. (2007), also in freshwater, rainbow trout juveniles were exposed to 0, 0.1, 0.5 or 1.0 mg/L of TiO_2 nanosized particles (75% rutile & 25% anastase, 24.1 ± 2.8 nm) for 0, 7 or 14 days. Mortality did apparently not result from the exposures. Gill pathological changes were observed following 14 days of exposure to all TiO_2 concentrations. Exposure also affected tissue levels of Zn, Cu, NaK-ATPase activity, thiobarbituruc acid reactive substances and glutathione. This effect concentration of 0.1 mg/L is far below all those reported from freshwater and other environments by NIVA and DNV GL, and it's inclusion in assessments would have been a logical consequence of their emphasis on conditions in freshwater.

During recent years have been published studies of effects in fish and other taxa exposed to metal oxide nanoparticles at very different concentrations (e.g. 20 µg/L – 4 mg/L), as reviewed in Baker et al. (2014).

One of the studies of nanoparticles in seawater, by Canesi et al. (2010), involved exposure of a marine mussel for 24 h to four different types of commercial nanoparticles, such as Nanosized Titanium Dioxide P25 (n-TiO_2) and Nanosized Nanosilica Aerosil200 (n-SiO_2), at concentrations from 0.05 – 5 mg/L. All the types of NPs caused reduced lysosomal membrane stability of hemocytes and digestive gland following exposure to 5 mg/L, and additionally n-TiO_2 also provoked that effect at 1 mg/L. Additionally, and briefly, 1 and 5 mg/L of n-TiO_2 or n-SiO_2 cause some other types of effects.

The allegation «*Titanium dioxide accumulates in mussels and to some extent in other filtering organisms but **not** in fish*, with reference to Federici et al. (2007), lacks evidence. It is a major scientific challenge to prove «***not** in fish*», especially when analyzing only four organs as did the authors of that paper. Actually, the mentioned ventilation of large water volumes by fish gills is very much like filtering of water (6.1.4). And marine fish also drink seawater. From knowledge of comparative medicine can be concluded that fish will likely take up nanoparticles of titanium dioxide or other materials, which will subsequently be present in cells and tissues.

DNV GL's allegiations about harmful effects of nanoparticles lack a scientific basis. A logical consequence of DNV GL's (1) extensive use of knowledge about effects of larger particles of different types in freshwater and (2) use of LREC independent of particle size would be to include also knowledge about nanoparticles in freshwater and to set the LREC = 0.1 mg/L.

8.9 Literature survey and limit

In a later comment (DNV GL 2014b) is claimed that a new literature study was not promised in the first report (DNV GL 2014a). However, DNV GL in the first report clearly proposed effect limits, for the first time in the EIA of the project. To propose such limits requires a thorough literature review of primary sources. But DNV GL has partially based their review on copying from a secondary source published by NIVA. This plagiarism, which also appears uncritical, includes mistakes made by NIVA. If DNV GL intends to say that their literature study was limited, then their proposed limit values become more understandable but also even more blameworthy. For outsiders without a professional basis in this field the report may look academically solid work. As already mentioned, reports of this EIA may also be referred to in future EIAs.

8.10 Summary of report from DNV GL (2014a)

This summuary also includes topics dealt with in parts 5 & 6.

- The sizes of the fraction of aggregates particles smaller than 15 µm, presumptively the most numerous, were not included in the modeling of spread. Therefore, the fate of an annual amount of an order of magnitude up to 25,000 (37,000) tonnes may not be accounted for if annually discharged 4 (6) million tonnes of tailings

- Most of the primary sources cited by DNV GL report effects of particles smaller than 15 µm whereas the range 15 – 340 µm was used for modeling of spread. This discrepancy has not been addressed.
- Incorrect use of scientific terms
- The use of LRECs (lowest-reported-effect concentrations) and the proposal of effect limits urgently require a thorough literature review, which was apparently not conducted. Given knowledge about effects of particles of non-documented relevance should be considered - important knowledge about marine fish was not included.
- The assessment is not based on effects of industry-created particles but of particle types of non-documented relevance (i.e. “inorganic particles in general” and organic particles), and mainly in environments of non-documented relevance, i.e. freshwater. Alleged inerty of particles is non-documented.
- DNV GL knew about effects of nanoparticles at 0.1 mg/L, which may represent the lowest-reported-effect concentration, but did not take this knowledge into account when proposing effect limits, although including other knowledge about numerous particle types in freshwater.
- The use of LREC requires a subsequent risk assessment step, which is missing. This might have included assessments of acute LCs and chronic NOECs and next evaluating ELVs by using safety factors as described in the water framework directive.
- Uncritical plagiarism of a NIVA report with errors, although this should be a new and independent evaluation
- No knowledge obtained from exposure of salmonids in seawater is presented
- The most sensitive life-history stages were not adressed
- LRECs have not been used because important literature about marine fish remained non-cited, because of incorrect citations in plagiarized text and because of citation errors by DNV GL themselves
- The effect limits for lethal and sublethal effects are poorly defined
- The effect limit of 400 mg/L for lethal effects in adult fish is based on studies mainly in freshwater, is based on plagiarized text presenting an incomplete and non-validated model, and is of non-documented relevance. The lowest reported 24 h LC_{50} of 2,500 mg/L in an estuarine species yields an ELV < 2.5 mg/L if divided by the safety factor 1,000.
- The effect limit of 50 mg/L for sublethal effects in juvenile and aduld fish is based entirely on salmonids in freshwater, is based on plagiarized text with incorrect citation of studies of non-documented relevance, and is at least 17 times too high if compared with LREC and at least 170 times too high if compared with the ELV
- The effect limit of 100 mg/L for lethal effects in larvae is non-documented, is based on a 15 year old tertiary and incomplete source and is proposed independent of more recent and relevant literature, and is at least 10 (perhaps 25) times too high if compared with LREC.
- The effect limit of 20 mg/L for sublethal effects in larvae is non-documented, is proposed independent of relevant literature and is at least 2 (probably 5) times too

high if compared with LRECs and at least 20 (probably 50) times too high if compared with the ELVs

- Egg of Atlantic cod, perhaps the most sensitive of all, were not considered. The LREC is ≤ 4 mg/L and not 20 or 100 mg/L as proposed for eggs in general. DNV GL's sublethal effect limit for eggs is at least 50 times too high if compared with the ELV
- All the errors at critical points contribute to underestimation and undercommunication of effects
- References were used disordely and the bibliography is incomplete

9 Governmental agencies

The EIA and decision process included mainly two phases (4.3).

9.1 The first phase

The first letter (KLIF 2012) did not at all indicate any awareness of knowledge presented in 6.4, thus demonstrating a dependence on NIVA reports presented by Nordic Mining.

Chapter 6.8 has the title *Environmental assessments of submarine tailings disposal* (*Miljømessige vurderinger av sjødeponi*). A section under the subheading *6.8.3 Consequences for species and ecosystems (Konsekvenser for arter og økosystem)* contains on page 39 a reference list that reportedly demonstrates the knowledge base used. It includes e.g. NIVA (2008a; 2008b; 2008c [indirect cit.], 2009a [appendix to Jensen 2009]; 2010a). In addition also NIVA & DNV GL (2009), which is considered an important source under the heading *Summary of the knowledge base* (*Sammenfatning av kunnskapsgrunnlaget*).

Under the heading *Consequences for the life in the water body* (*Konsekvenser for livet i vannmassene*) is on pages 42 - 50 evaluated effects of inorganic suspended particles.

Page 42, the first paragraph, quote:
«*Turbulence at the discharge site and slides in unstable deponi buildup will lead to a high level of suspended particles along the bottom of the deponi (NIVA & DnV GL 2009). It should be very high concentrations needed to cause direct mortality. Impact on grwoth, feeding and behavior can, however, occur at far lower lower levels of particles. Clouds of turbidity will negatively affect e.g. the foraging activity in deepwater fish hunting with eyesight. They consider the risk for damage to such fish low as long as the clouds of turbidity stay deeper than 100 m above the bottom and has a limited distribution from the point of discharge. Estimates NIVA has conducted indicate that the concentrations along the bottom will be far below the limits for effects on growth and survival in seawater for all the fish species in question*».

«*I følge NIVA & DnV GL (2009) vil turbulens ved utslippsstedet og ras ved ustabil deponioppbygging føre til høyt nivå av suspenderte partikler langs bunnen i deponiet. Det skal svært høye konsentrasjoner til for å forårsake direkte dødelighet. Påvirkning på vekst, fôropptak og adferd kan imidlertid skje ved langt lavere partikkelnivå. Turbiditetsskyer vil for eksempel virke negativt på næringssøket til dypvannsfisk som jakter med synet. Så lenge turbiditetsskyene holder seg dypere enn 100 m over bunnen og er begrenset i utstrekning fra utslippet, vurderer de risikoen for skade på slik fisk som liten. Beregninger NIVA har gjennomført tilsier at konsentrasjonene langs bunnen 1-2 km fra utslippet vil være langt under grenseverdiene for påvirkning av vekst og overlevelse i sjøvann for alle aktuelle fiskeartene*».

The text contains phrases similar to those used in cited reports, such as «*It should be very high concentrations needed to cause direct mortality*», «*far lower lower levels of particles*» and «*far below the limit values for effects on growth and survival in seawater*».

And in following paragraphs, formulations like this: Page 42 «*high concentrations of particles*», page 43 «*harmful concentrations of particles*» and «*high concentrations of particles*», and page 49 «*particle concentrations of importance*».

The meaning of these formulations is unclear, and it is impossible to relate these to concentrations (mg/L).

It is impossible to trace the content of the letter back to concentrations described in the primary sources (scientific papers) used by NIVA and DNV GL.

9.2 The second phase

The next letters (MDIR 2014; 2015) were transmitted subsequent to the supplemental investigations performed during 2013-2014. Therefore, both have additionally reference to DNV GL (2014a), which on page 38 in MDIR (2015) is referred to as a revised version (footnote to 8). It is unclear what this revision entails. Finally, the Ministry of Climate and Environment permitted the discharges and set limits for particle concentrations (KLD 2015).

9.2.1 Particles

MDIR (2015) has apparently accepted

- inadequate characterization of industry-created particles (5.3.3),
- that the fate of aggregates (flocs) smaller than 0.68 µm is non-documented (5.3.3), and
- DNV GL's ignorance of sizes < 15 µm, due to the adjustments of grain size distribution to 15 – 340 µm prior to modeling of particle spread in the water body (5.3.5).

The objection that «*the fine fraction is removed from the data set before modeling of particle spred. This contributes to an underestimation of spread of particles* (*Finfraksjonen er fjernet fra datasettet før spredning av partikler er modellert. Dette bidrar til en underestimering av spredningen av partikler*)» is commented as follows by MDIR on page 35:

«Comment: For the modeling of particle spread is sinking velocity for tailings particles, and thereby also the flocculation effect, important. DNV GL has in the appendix to the report about current conditions and particle spread evaluated the flocculation effect and associated uncertainty. There is also uncertainty associated with the characterization of the discharge, including the used grain size distribution. For the models predicting spread has been made comparisons with three operating sea deponies in Norway. Based on comparisons between modeled and measured values (operative deponies) the model seems to properly represent this type of discharge. Obviously, there are larger uncertainties associated with the results pertaining to the future scenarios, compared with Scenario A (the 12 months simulation).

Kommentar: For modellering av partikkelspredning er synkehastighet for avgangspartiklene, og dermed også flokkuleringseffekten, vesentlig. I vedlegg til rapporten om strømforhold og partikkelspredning har DNV GL vurdert flokkuleringseffekten og usikkerhet knyttet til denne. Det er også usikkerhet knyttet til utslippskarakteristikk, inklusiv benyttet kornstørrelsesfordeling. For spredningsmodellene er det også gjort sammenligninger med tre aktive sjødeponier i Norge. Med basis i de utførte sammenligningene mellom modellert og målte verdier (operative deponier), virker det som om modellen på en god måte representerer denne type utslipp. Åpenbart er det størreusikkerheter knyttet til resultatene for framtidsscenarioene, sammenlignet med Scenario A (12måneders simuleringen)».

These general comments from the MDIR do not at all refute the objection by concrete arguments. And, of course, there are uncertaintiess (5.3.5). Therefore, spread of the smallest aggregates of particles (< 15 µm) amounting up to an annual order of magnitude 25,000

(37,000) metric tonnes, including 2,100 (3,000) tonnes of nano-sized particles, were not adequately included in modeling. Moreover, the fate of aggregates smaller than 0.68 µm is non-documented. The ignorance of these sizes, associated with the lowest sinking velocity, the largest spread potential and presumptively the most numerous aggregates, implies that modeled mass concentrations (and consequently the number concentrations in special) in the water body may be too low.

9.2.2 Effects of particles

MDIR (2014) considers concentrations ≤ 2 mg/L to represent a minor risk. MDIR (2015) discusses specific limits with reference to NIVA reports cited in the first letter (KLIF 2012) and additionally a few other NIVA reports (App. C), as well as (DNV GL 2014a). And NIVA & DNV GL (2009) is still considered an important source under the heading *Knowledge base (Kunnskapsgrunnlag).*

MDIR (2015) has apparently accepted

- reference to knowledge about effects of «inorganic particles in general», being of non-documented relevance (7; 8.1),
- minor focus on small particles, including nano-sized particles, and
- reference to environments of non-documented relevance, especially in freshwater, including an incomplete and non-validated model (7.1.1; 8.3; 8.4.2).

Under the heading *Consequences for life in the water body (Konsekvenser for livet i vannmassene)* on page 42, and with reference to (DNV GL 2014a), is written: «*Highest limit is assessed as 50 mg/L for sublethal effects in filtrating organisms. Lowest identified effect limit is assessed as 5 mg/L for eggs and larvae of cod and herring (Høyeste grense er vurdert til 50 mg/l for subletale effekter hos filtrerende organismer. Laveste identifiserte effektgrense er satt til 5 mg/l for egg og larver av torsk og sild)*».

I suppose the limit of 50 mg/L for sublethal effects also should pertain to adult fish, as proposed by DNV GL (2014a) (8.4). However, DNV GL proposed an effect limit of **20 and not 5 mg/L** for sublethal effects in larvae (8.6), and 20 mg/L was in DNV GL (2014b) said to apply also to eggs (8.7). The next paragraphs refer to IMR (2014) and Kvellestad (2015a).

Finally, the Ministry of Climate and Environment – in a document lacking the features of a formal letter (see note in the reference list) set limits of 2 and 3 mg/L for the **total** permitted concentration of total suspended particles, i.e. including those naturally present, at defined vertical and horizontal distances from the discharge point (KLD 2015):

«*Limit values for concentrations and sedimentation of particles in the approved depony area including the natural background level:*
- Maximum allowed particle concentrations in the water body are 2 mg/L at 40 meters above the point of discharge.
- Maximum allowed particle concentrations in the water body are 3 mg/L the outer borders of the approved depony area at the depth of discharge.

- Maximum allowed sedimentation rate for particles at the sea bed is 3 mm a year along the border of the approved depony area.

Grenseverdier for konsentrasjoner og sedirnentering av partikler i området regulert til sjødeponi, inkludert naturlig bakgrunnsnivå:
- Konsentrasjonen av partikler i vannmassene skal være maksimalt 2 mg/l høyere enn 40 meter over utslippspunkt for avgangsmassene.
- Konsentrasjonen av partikler i vannmassene skal være maksimalt 3 mg/l ved grensen for det regulerte deponiområdet, målt horisontalt fra utslippspunkt.
- Sedimentering av partikler på fjordbunnen skal utgjøre maksimalt 3 mm per år ved grensen for det regulerte deponiområdet».

These permitted limits can be considered from different perspectives:

A discussion of the permitted limits must be based on a few assumptions (table 3). Firstly, the present concentrations of total suspended particles are possibly 1 mg/L in the Førde Fjord, as allegiated but not documented (DNV GL 2014a, 5.2). This value, if representative, indicate concentrations of inorganic particles lower than 1 mg/L and ecosystems of the Førde Fjord adapted to low concentrations of such particles. In the following reasoning is assumed that the present concentration of 1.0 mg/L includes 0.5 mg/L of inorganic particels. Secondly, the limits of totally 2 and 3 mg/L may imply an allowed increase by 1 and 2 mg/L, respectively, in inorganic particle concentrations (i.e. industry-created particles) if present total concentration is 1 mg/L.

Table 3. Estimation of concentrations of mineral particles based on assumptions. Total PC (particle concentration) includes organic and inorganic particles.

Present		Discharge period		
Total PC (DNV GL 2014a, 5.2)	Assumed inorganic PC	Total permitted PC (KLD 2015)	Assumed permitted increase in inorganic PC *)	Assumed permitted total inorganic PC **)
1	0.5	2	1	1.5
1	0.5	3	2	2.5

*) Synonymous with industry-created particles.
**) Present assumed inorganic PC plus assumed permitted increase in inorganic PC (industry-created particles).

Based on these assumptions, a 3- and 5-fold increase, respectively, is permitted for the total concentrations of inorganic particles (present and industry-created) at the specified sites. Such an increase mismathches MDIR's own guidelines, which recommend the increase in the total particle concentration in fjords and coastal waters – due to discharges from anthropognic sources – be less than 100% of the natural state (SFT 1997, table page 16). Comparatively, guidelines recommend a maximum of 1.5-3.0 mg/L for good quality in freshwater (Direktoratsgruppa 2009).

The assumptions also imply final and total inorganic particle concentrations of 1.5 and 2.5 mg/L to be close to the concentration of 2 mg/L, which in the EIA of the Fehmarnbelt Fixed Link project was «*considered representing 100 % mortality*» in «*drifting eggs and yolk sac larvae*» (6.4.9).

Finally, the increases of 1-2 mg/L due to industry-created particles are in total 2-5 times as high as the ELVs (< 0.3 and < 0.4 mg/L) derived by the metholodogy of the water framework directive from present knowledge about effects of «inorganic particles in genereal» on marine fish (6.4.6). And assumed total permitted concentrations of 1.5 and 2.5 mg/L are in total 5-8 times as high.

If the initial discharge point will be at the maximum of 50 m above the bottom the vertical limit may apply to 90 m above the bottom. The limit 3 mg/L at the outer border of the approved area at the depth of discharge may imply close to 3 mg/L at the same level outside the area. The elevation of the discharge point during the mining period implies that even larger parts of the water body will be affected.

MDIRs methodology behind the evaluations seems unclear and one may ask why there is no reference to the water framework directive including the annex recommending use of NOECs, safety factors and ELVs. Use of the safety factors yields limits lower than 2-3 mg/L

These limits of 2-3 mg/L are more in line with present knowledge about effects of «inorganic particles in general» and with MDIR's own guidelines than with the limits of 20 - 50 mg/L (sublethal effects) assumed and proposed by NIVA and DNV GL, respectively. However, they are still at a level, which may harm fish, corresponding to a limit used in the Fehmarnbelt project, which in this context was a short-term project.

MDIR (2015, page 56-57) deals with nanoparticles and claims that «*Studies of effects of nanoparticles in aquatic systems have not provided unambiguous conclusions about effects. ….. Many of the papers cited in the letter from the Norwegian Society for the Conservation of Nature are about effects of constructed nanomaterials. It should be considered the relevance of these types of particles compared with those of grinded rock. It should also be considered the probability that nanoparticles from grinding still are of that size when discharged in seawater.*

Når det gjelder studier på effekter av partikler på nanostørrelse i akvatiske systemer er det ingen entydig konklusjoner. ……. Flere av de siterte artiklene i Naturvernforbundets brev omhandler studier på konstruerte nanomaterialer. Det må vurderes hvor relevante disse er i forhold til å vurdere effektene av nanopartikler som oppstår ved nedmaling av fjell. Det må også vurderes hvor sannsynlig det er at nanopartikler som dannes ved nedmaling fortsatt er på nanostørrelse når de slippes ut i sjøvann».

As regards the first statement must be said that a number of papers have reported effects, including lethality, of nanoparticles in marine organisms, as reviewed by e.g. Baker et al. (2014). The limits of 2 and 3 mg/L logically also include the nano-sized particles. And sublethal effects have been reported in freshwater rainbow trout exposed to 0.1 mg/L of such particles (8.8). A logical consequence of NIVA's and DNV GL's focuses on effects of larger particles of different types in freshwater, and of MDIR's acceptance of their reports, would be to accept also the mentioned primary source (Federici et al. 2007) about nanoparticles in freshwater. That source possibly present the lowest reported effect concentration. But at present it seems unknown how such particles at that concentration would behave in seawater and affect fish.

Moreover, as long as a number of particle sizes, including clay particles < 2 µm, have documented effects in fish, it seems unlikely that there suddenly should be no effects if the size is within the range of nanoparticles, i.e. smaller than 0.1 µm (100 nm).

I fully agree that «*It should be considered the relevance of these types of particles* [nanoparticles] *compared with those of grinded of rock*». However, by this sentence the MDIR contradict themselves because they have unconditionally accepted the extensive reference to knowledge about effects of larger "inorganic particles in general" in freshwater, despite of non-documented relevance. A main objection of the present report applies to this extensive and uncritical use of this knowledge of non-documented relevance.

To recall, the above-described reasoning is based on at least one quantitative assumption and that the properties of the industry-created particles, including the nano-sized, are non-documented. Exactly how 1-2 mg/L of these industry-created particles may affect e.g. cod at different life stages is unknown, and the EIA would benefited from adequate particle characterization and from experimental exposures of e.g. cod eggs from the Redal Bay. No knowledge obtained from exposure of salmonids in seawater is presented in the reports. And it has not been considered how effects on marine pelagic organisms may alter food availability for e.g. migrating postsmolt of Atlantic salmon (6.1.5). **A further evaluation of these limits of 2 and 3 mg/L is therefore difficult**.

9.2.3 Summary

MDIR and KLD have apparently accepted all of NIVA's and DNV GL's considerations, but possibly with exception of their assumed and proposed effect limits, respectively. The environmental limits of 2 and 3 mg/L set by KLD can be traced back to primary sources about types of particles being different from the industry-created particles in question, and there is no reference to assessment methodology including safety factors. It is unknown how estimated 1-2 mg/L of industry-created particles may directly or indirectly affect fish, such as migrating Atlantic salmon and cod at different life stages.

Most effect concentrations reported by DNV GL and undersigned, and perhaps also by NIVA, relate to particles smaller than 15 µm, i.e. a relevant size range despite particle types of non-documented relevance. The exclusion of such small sizes from the modeling of spread, which included 15 – 340 µm, means that estimated concentrations in the water may be too low, and it cannot be accounted for the fate of thousands of tonnes of fine particles, which may accumulate in the water body. Moreover, the significance of this discrepancy between sizes in effect evaluations and in modeling is unknown. The actual safety margins, if present at all, seem lesser than those indicated by the differences between the possibly too low modeled concentrations and the allegiated and too high effect or permitted limits.

10 Literature

10.1 Mining the Engebø Mountain

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10.3 Debate

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Kvellestad A (2014e): Det norske veritas GL about submarine disposal of mining waste (Det norske veritas GL om fjordeponering av gruveavfall). Feature article in the local newspaper Firda. Published at the home page 28.10.2014 and subsequently in the paper version. http://firda.origo.no/-/bulletin/show/843630_det-norske-veritas-gl-om-fjordeponering-av-gruveavfall

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Kvellestad A (2015c): Professional environments as fig leaves (Fagmiljø som fikenblad). Feature article in the national newspaper Klassekamp en, the paper version 01.06.2015.

NIVA (2014b): Questionable criticism of research reports (Tvilsom kritikk av forskningsrapporter). Feature article in the regional newspaper Bergens Tidende. Published at the home page 10.09.2014 and subsequently in the paper version. http://www.bt.no/meninger/debatt/Tvilsom-kritikk-av-forskningsrapporter-3193783.html

11 Appendix A. Institutions and acronyms

History of the Norwegian Environment Agency

SFT (Statens forurensingstilsyn, Norwegian Pollution Control Authority), which later was renamed to
KLIF (Klima- og forurensingsdirektoratet, Climate and Pollution Agency Norway). In 2013 KLIF and **DN** (Direktoratet for naturforvaltning, Norwegian Directorate for Nature Management) merged into the present
MDIR (Miljødirektoratet, Norwegian Environment Agency), being under the Ministry of Climate and Environment. http://www.miljodirektoratet.no/

Others

ABWR AB (AquaBiota Water Research AB, a Swedish daughter company of NIVA). http://www.aquabiota.se/

Akvaplan-NIVA (a Norwegian daughter company of NIVA). http://www.akvaplan.niva.no/no/

Direktoratsgruppa is chaired by the Environment Agency and consists of representatives of 12 sector authorities. http://www.vannportalen.no/organisering/

DNV GL (Det norske veritas GL, Bureau Veritas Norway), https://www.dnvgl.com/,

HI (Havforskingsinstitutet, , Bergen, Norway), http://www.imr.no/nb-no

IMO (International Maritime Organization), http://www.imo.org/About/Pages/Default.aspx

IUPAC (International Union of Pure and Applied Chemistry), http://www.iupac.org/

KLD (Klima- og miljødirektoratet, the Ministry of Climate and Environment), https://www.regjeringen.no/en/dep/kld/id668/

Naturvernforbundet (Norges Naturvernforbund, the Norwegian Society for the Conservation of Nature) http://naturvernforbundet.no/

NIVA (Norsk institutt for vannforskning, the Norwegian Institute for Water Research), http://www.niva.no/

SINTEF (Stiftelsen for industriell og teknisk forskning, the Foundation for Scientific and Industrial Research, Trondheim, Norway), http://www.sintef.no/

US EPA (United States Environmental Protection Agency) http://www3.epa.gov/

12 Appendix B. Definition of terms

Particles and sediments

Suspended sediment (US EPA 2006):
Very fine soil particles that remain in suspension in water for a considerable period of time without contact with the bottom. Such material remains in suspension due to the upward components of turbulence and currents and/or by colloidal suspension (US EPA 2006).

Clean sediments (US EPA 2006):
Suspended and bedded sediments that are not contaminated with toxicants.

Contaminated sediments (US EPA 2006):
Deposited or accumulated sediments, typically on the bottom of a waterbody, that contain contaminants. These may or may not be toxic as revealed by a whole sediment toxicity test or as predicted by equilibrium partitioning.

Colloid (IUPAC 1971/2001):
The term *colloidal* refers to a state of subdivision, implying that the molecules or polymolecular particles dispersed in a medium have at least in one direction a dimension roughly between 1 nm and 1µm, or that in a system discontinuities are found at distances of that order. It is not necessary for all three dimensions to be in the colloidal range: fibers in which only two dimensions are in this range, and thin films, in which one dimension is in this range, may also be classified as colloidal. Nor is it necessary for the units of a *colloidal system* to be discrete: continuous network structures, the basic units of which are of colloidal dimensions also fall in this class (e.g. porous solids, gels and foams).

Nanoparticle (IUPAC 2007):
Microscopic particle whose size is measured in nanometers, often restricted to so-called nanosized particles (NSPs; <100 nm in aerodynamic diameter), also called *ultrafine particles*.

Effects on organisms

Effective (effect) consentration (EC), is defined by IUPAC (2009):
«*Concentration* of a substance that causes a defined magnitude of *response* in a given system after a specified *exposure* time, e.g., concentration that affects *x* % of a test *population* after a given time (EC*x*). *Note*: EC50 is the median concentration that causes 50 % of maximal response».
One type of EC is **lethal concentration** (LC): «Concentration of a substance in an environmental medium that causes death following a certain period of *exposure*. *Note*: LC50 is the median concentration that causes death in 50 % of the test *population*».

Lethal & sublethal
Lethal means «deadly; fatal; causing death» and sublethal is the opposite of lethal.

Lowest-observed-effect concentration (LOEC) (IUPAC 2009):
«Lowest concentration of a material used in an aquatic *toxicity* test that has a statistically significant adverse effect on the exposed *population* of test organisms compared with controls. *Note*: When derived from a life cycle or partial life cycle test, it is numerically the same as the upper limit of the *maximum acceptable toxicant concentration* (MATC). Also called *lowest-observed-adverse-effect level* (LOAEL)».

No-observed-effect concentration (NOEC) (IUPAC 2009):
«Special case of the *no-observed-effect level* (NOEL), commonly used in aquatic toxicology. *Note*: When derived from a life-cycle or partial life-cycle test, it is numerically the same as the lower limit of the *maximum acceptable toxicant concentration* (MATC)».
No-observed-effect level (NOEL):
«Greatest concentration or amount of a substance, found by experiment or observation, that causes no statistically significant alterations of morphology, functional capacity, growth, development, or life span of target organisms distinguishable from those observed in normal (control) organisms of the same *species* and strain under the same defined conditions of *exposure*».

PNEC (predicted no-effect concentration), which is mentioned by DNV GL (2014a), is by IUPAC (2009) defined as «Concentration that is expected to cause no adverse effect to any naturally occurring *population* in an environment at risk from *exposure* to a given substance».

Threshold (threshold concentration, threshold dose) as defined by IUPAC (2007):
"Dose or *exposure concentration* below which a defined effect will not occur".

Tolerance is by IUPAC (2009) defined as:
«1. Adaptive state characterized by diminished effects of a particular dose of a substance: the process leading to tolerance is called "adaptation".
See *genetic adaptation*, *physiological adaptation*.
2. In food toxicology, *dose* that an individual can tolerate without showing an effect.
3. Ability to experience *exposure* to potentially harmful amounts of a substance without showing an adverse effect.
4. Ability of an organism to survive in the presence of a *toxic* substance: increased tolerance may be acquired by adaptation to constant exposure.
5. In immunology, state of specific immunological unresponsiveness».

Exposure duration

Acute and chronic, as defined by IUPAC (2009), denote duration:

acute
1. Of short duration, in relation to *exposure* or effect; the effect usually shows a rapid onset.
Note 1: In regulatory *toxicology*, "acute" refers to studies where dosing is either single or limited to one day although the total study duration may extend to two weeks to permit appearance of *toxicity* in susceptible organ systems.
Note 2: In aquatic *ecotoxicology*, exposure of the test organisms is typically continuous and of

four days or less.
2. In clinical medicine, sudden and severe, having a rapid onset.

chronic effect (long-term effect, antonym: *acute effect*)
Consequence that develops slowly and (or) has a long-lasting course: may be applied to an effect which develops rapidly and is long lasting.

13 Appendix C. Citation of reports in important documents

# denotes number in the bibliography of the zoning plan with EIA.

	Cited in zoning plan with EIA (NIVA & Asplan Viak 2009)	Cited by MDIR in transmitting letter (KLIF 2012) p. 38-39	Cited by MDIR in transmitting letter (MDIR 2015) p. 30-31, 38-39
NIVA 2008a	#19	x	x
NIVA 2008b	#21	x	x
NIVA 2008c	#22	x[6]	x[7]
NIVA 2008d	#20	x	x
NIVA 2008e	#3	x	x
NIVA 2009a	#36[8]	x[9]	x[10]
NIVA 2009b	#1	x	x
NIVA 2009c	0	x	x
KLIF 2010[11]	0	0	x
NIVA 2010a	#39	x	x
NIVA 2014a	-	-	0
NIVA & DNV GL 2009	#31	x	x
DNV GL 2014a	-	-	x
DNV GL 2014b	-	-	0
DNV GL 2014c	-	-	0
DNV GL 2014d	-	-	x
DNV GL 2014e	-	-	x
SINTEF 2014	-	-	x
Kvellestad (2015a)	-	-	x

[6] Referred in NIVA (2008b), which is cited by MDIR
[7] Referred in NIVA (2008b), which is cited by MDIR
[8] Referred to as DNV GL in the reference list.
[9] Referred to as Jensen, Tor (DNV) 18.11.2009
[10] Referred to as Jensen, Tor (DNV) 18.11.2009
[11] Report commissioned by NIVA.

14 Appendix D. Different use of sources about effects of inorganic particles on fish

Comparison of references used in reports reviewing effects in freshwater, estuarine and marine fish exposed to suspended particles. Included are only sources dealing with fish and suspended particles. Only primary sources are included except a few reports and important reviews or metastudies. Those marked in blue are listed in the bibliography of the present report. F = freshwater, E = estuary, S = seawater, A= article, Met = metastudy, Rep = report, Rew = review paper, book or book chapter.

NIVA (2008a; 2008b; 2008c; 2009a; 2010a), NIVA & DNV GL (2009), Akvaplan-NIVA (2011a), ABWR AB (Didrikas & Wijkmark 2009) and DNV GL (2014a; 2014c) were checked for references. Citations relating to the topic in question were found in those underlined. ABWR AB is NIVA's Swedish daughter company.

			NIVA	Akvaplan-NIVA	ABWR AB	DNV GL
F	Alabaster & Lloyd 1982	Rew	2008b			
F	Berg & Northcote 1985	A	2008a			2014a
	Billotta & Brazier 2008	Rew	2008a			
F	Bisson & Bilby 1982	A	2008a	x		
F	Bunt et al. 2004	A	2008a			
F	Federici et al. 2007	A				2014c
F	Goldes et al. 1988	A	2008a			
F	Gregory & Northcote 1993	A	2008a			
F	Gregory 1994.	Rew	2008a			
F	Greig et al. 2005	A	2008a	x		
F	Herbert & Merkens 1961	A	2008a			2014a
F	Herbert & Richards 1963	A	2008a			2014a
F	Hessen 1992	Rep	2008b			
F	Lake & Hinch 1999	A	2008a			2014a
F	Lehtiniemia et al. 2005	A		x		
F	McLeay et al. 1987	A	2008a			2014a
F	Newcombe & Flagg 1983	A	2008a			
F	Newcombe & MacDonald 1991	A	2008a			
F	Newcombe 2003	Met				2014a [12]
F	Redding et al. 1987	A	2008a			
F	Robertson et al. 2007	A	2008a	x		2014a
F	Rowe *et al.* 2003			x		
F	Servizi & Martens 1987	A	2008a			2014a
F	Servizi, & Gordon 1990	A	2008a			
F	Servizi & Martens 1991	A	2008a			2014a

[12] Present in bibliography by mistake.

F	Servizi & Martens 1992	A	2008a			
F	Shaw & Richardson 2001	A	2008a	x		
F	Sigler et al. 1984	A	2008a			2014a
F	Sutherland & Meyer 2007.	A	2008a			
F	Sykora et al. 1972	A	2008a			2014a
F	Walling et al. 2003	A	2008a	x		
F	Whitman et al. 1982	A	2008a	x		
F	Yeo et al. 2012					2014c
F,E	Newcombe & Jensen 1996	Met	2008a			2014a [13]
F,E	Wilber & Clarke 2001	Met	2008a	x		2014a
E	Auld & Schubel 1978	A			x	
E	Messieh et al. 1981	Rep			x	
E	Sherk et al. 1975	Rew	2008a			2014a
S	Au et al. 2004	A	2008a			
S	Humborstad *et al.* 2006	A	2008a	x		2014a [14]
S	Johnston & Wildish 1981	A			x	
S	Johnston & Wildish 1982	A				2014a
S	Johnson et al. 1998	A		x		
S	Kiörboe et al. 1981	A			x	2014a [15]
S	Meager et al. 2005	A		x		
S	Smit et al. 2008	Met	NIVA & DNV GL 2009			2014a [16]
S	Utne 1997	A		x		
S	Utne-Palm 1999	A		x		
S	van Dalfsen 1999	Rep				2014a
S	Westerberg et al. 1996	A			x	

[13] Not listed in the bibliography but incorrectly referred to in text as Newcombe (2003).
[14] Not listed in the bibliography but referred to in the text.
[15] Listed in bibliography but its content was not referred to in the text
[16] Listed in the bibliography but not referred under the topic in question.

15 Appendix E. Important literature not cited

Literature about effects on estuarine or marine fish, but not cited by the reports from NIVA and DNV GL. However, one of the listed papers, Johnston & Wildish (1982), was cited by DNV GL (2014a) but incorrect. Not all results of the cited papers are presented, especially from Petereit & Franke (2012).

Species & life stages	Particle (type; size); concentrations; exposure time	Effects	Reference
Atlantic herring (*Clupea hargenus* L.) Juvenile	Digdeguash Estuary sediment; fine (4.5 µm); Pottery Creek sediment; coarse (10 µm);	Avoidance thresholds at 19±5 & 35±5 mg/L, respectively	Wildish et al. 1977
American shad (*Alosa sapidissima*), larvae Results for two other species and for eggs not presented	Chesapeake Bay sediment; primarily three clay minerals; 1-4 µm; 0, 25, 50, 100, 500 & 1000 mg/L; 96 h	95-96% survival in controls, 93% in 50 mg/L, 82% in 100 mg/L, 64% in 500 mg/L and 66% in 1,000 mg/L. Mortality in 100 mg/L was significant ($p<0.025$).	Auld & Schubel (1978)
Atlantic herring Eggs	4.0-4.5 µm	Increased mortality due to deposition of sediment. Conc. >7.000 mg/L did apparently not affect hathching success.	Messieh et al. 1981
Atlantic herring Larvae	Undefined silty sediment; 0 & 1.0-6.0 mg/L	Reduced feeding on *Artemia*, threshold at ≥ 3 mg/L	Messieh et al. 1981
Atlantic herring Juvenile	Miramichi Estuary sediment; 2.5-55.3 mg/L	Avoidance threshold between 9.5 and 12 mg/L	Messieh et al. 1981
Atlantic herring Juvenile	Miramichi Estuary sediment; (median 6.2 µm & sorting coefficient of 1.52, i.e. poorly sorted. 3.3% organic carbon)	Avoidance threshold between 9 and 12 mg/L	Johnston & Wildish 1981
Atlantic herring Larvae	Digdeguash Estuary sediment; (median 7.9 µm, 3.1% organic carbon); 0, 4, 8 & 20 mg/L; 3 h	Reduced feeding on *Artemia* at 20 but not 4 & 8 mg/L	Johnston & Wildish 1982 Experiment no 1
Atlantic herring Larvae	Same as above 0, 10 & 20 mg/L for 3 h	Avoidance at 10 and 20 mg/L	Johnston & Wildish 1982 Experiment no 3 (table 2)
Rainbow smelt (*Osmerus mordax*), adult	Miramichi River Estuary sediment (silty clay, 3.3% organic carbon); 14, 19, 22, 24 & 40 mg/L	Avoidance threshold around 20 mg/L	Wildish & Power 1985
Rainbow smelt, adult	Miramichi River Estuary sediment; median 6.2 µm; 0, 10, 20 & 40 mg/L; salinity 20‰; 30 min repeated exposures in a current gradient	Increase in swimming activity at 10-40 mg/L	Chiasson 1993
Atlantic cod (*Gauds morhua*) "pelagic" eggs	Øresund glacial clay & grounded Copenhagen limestone, both passed through 38 µm filter. Particles < 1.75 µm amounted 50-65% of total concentration; 0-approx 75h	Sinking at 5 mg/L (buoyancy loss estimated to 0.02 psu per hr per mg/L under **these** conditions)	Westerberg et al. 1996 (fig. 5)
Atlantic cod "fixed" eggs	Glacial clay, limestone	35% mortality after 3 days at 200 mg/L limestone but not clay	Westerberg et al. 1996 (fig. 6)
Atlantic cod "fixed" eggs	Glacial clay	15% mortality after 3 days at 200 mg/L clay	Westerberg et al. 1996 (fig. 7)

Atlantic cod “fixed” yolk sac larvae	Glacial clay	50% mortality after 1 day at 200 mg/L clay	Westerberg et al. 1996 (fig. 7)
Atlantic cod “fixed” yolk sac larvae	Limestone	30% mortality after 6 days at 10 or 20 mg/L, inconclusive at 40 mg/L	Westerberg et al. 1996 (figs. 8-10)
Atlantic cod Adult	Glacial clay, limestone	Avoidance threshold at 3 mg/L in daylight & dark	Westerberg et al. 1996
Atlantic herring (*Clupea arengus*) Adult	Glacial clay, limestone	Avoidance threshold at 3 mg/L in daylight	Westerberg et al. 1996
Threeline grunt (*Parapristiopoma trilineatum*) Pelagic larvae. Results about most tolerant species not presented	Kaolinite; 0.63-12.7 µm; 0, 32, 100, 320, 560, 1000, 3200, 5600 & 10,000 mg/L; 1, 3 & 12 h in rotating tubes	12 h at 32 mg/L, rotation: About 20% mortality. Estimated LC_{50}=170mg/L (95% confidence limits 140-220 mg/L).	Isono et al. 1998
Red seabream (*Pagrus major*), black seabream (*Acanthopagrus schlegeli*), striped beakperch (*Oplegnathus fasciatus*). Pelagic eggs	Kaolinite; 0.63-12.7 µm; 0, 32, 100, 320, 1000, 3200 & 10,000 mg/L; 12 h in static tubes	Numbers of settled eggs increased with concentration. Eggs of *P. major* & *A. schlegeli* settled significantly at > 320 mg/L. Effects were lesser in *O. fasciatus.*	Isono et al. 1998
Pacific herring (*Clupea pallasi* Valenciennes) Benthic eggs	San Francisco Bay dredged sediment & Fuller’s earth; 7.6 µm (2-47 µm); 0, 65, 125, 250 & 500 mg/L; 0-2h etc.	Exposure at 0-2 h post fertilization: At 125 mg/L indicated and at 250 & 500 mg/l stat. signific. increased self-aggregation of eggs and sublethal and lethal effects during development and hatching.	Griffin et al. 2009
Pink snapper (*Pagrus auratus* Foster) Pelagic eggs	Grounded calcarenite (2-140 µm, 4-25 µm > 80%); 0, 32, 100, 320, 1000, 3200, 10,000 mg/L; 12 & 24 h	Sediment adhered to eggs. No effects on sinking, survival or hatch rates	Partridge & Michael 2010 Exp 1
Pink snapper Larvae, mouth **open**	Grounded calcarenite (2-140 µm, 4-25 µm > 80%); 0, 32, 100, 320, 1000, 3200, 10,000 mg/L; 12 h	Mortality about 24% at 32 mg/L; estimated FOEC=4mg/L & LC_{50}=157mg/L. In a replicate experiment the respective values were 14 & 142 mg/L. Accumulation of particles in the mouth cavity.	Partridge & Michael 2010 Exp 2
Pink snapper Larvae, mouth **closed**	Grounded calcarenite (2-140 µm, 4-25 µm > 80%); 0, 32, 100, 320, 1000, 3200, 10,000 mg/L; 12 h	Mortality about 6-7% at 32 mg/L; estimated FOEC=150mg/L & LC_{50}=2020mg/L	Partridge & Michael 2010 Exp 2
Pink snapper Larvae, mouth open	Grounded calcarenite (2-140 µm, 4-25 µm > 80%); 0, 32, 100, 320, 1000, 3200, 10,000 mg/L; 3, 6, 9, 12 h	Mortality continued following transfer from turbid to clean water	Partridge & Michael 2010 Exp 4
Pink snapper Larvae, 10 & 15 days post hatch (dph)	Grounded calcarenite (2-140 µm, 4-25 µm > 80%); 0, 50, 100, 150 & 200 mg/L; 3 h	10 dph larvae: Non-significantly reduced ingestion. 15 dph larvae: Ingestion of *Gladioferens imparipes* nauplii reduced by about 30-70% at 50-200 mg/L.	Partridge & Michael 2010 Exp 5-6
Coral reef spiny damselfish *Acanthochromis polyacanthus*, juvenile	Eckalite kaolin clay; 0 mg/L (4.5 NTU), 9 mg/L (8.8 NTU), 41 mg/L (24 NTU); chemical alarm cues added; 5 min	Fish exposed to 41 mg/L displayed antipredator response twice as strong as in 9 or 0 mg/L	Leahy et al. 2011

Atlantic cod Eggs	Fehmarnbelt sediment – fine (<1->100µm): conc. in mg/L (exp. duration, h); 4 (70), 8 (27), 18 (8), 28 (3) & 49 (2)	Buoyancy decrease and sinking at all concentrations	Petereit & Franke (2012) Chapter 7.1 Cod egg buoyancy
Atlantic cod Eggs	Fehmarnbelt sediment – fine 0, 5, 10, 25, 50 & 200 mg/L, coarse 0, 25, 50, 200, 500 & 1000 mg/L; **early** egg phase; 54 h for mortality, 54 h + 9.5 d sediment-free incubation for hatchability, & 54 h + period until hatch	Mortality, hatching & larval survival, all independent of sinking: No significant differences between exposures and control.	Petereit & Franke (2012) Chapter 7.2.1 Early egg phase 54-hour rotation trial
Atlantic cod Eggs	Fehmarnbelt sediment; fine; 0, 5, 10, 25, 50, 200 & 1,000 mg/L; **late** egg phase; 24 h, 24 h + 2 d sediment-free incubation	24 h: Sediment accumulation at surface. 24 h: No stat. significant effect on hatching. Stat. significant effects on survival. 24 h + 2 d: No stat. significant effect on hatching and survival	Petereit & Franke (2012) Chapter 7.2.2 Late egg phase 24-hour rotation trial
Atlantic herring Eggs	Fehmarnbelt sediment; fine; 0, 5, 10 & 50 mg/L; 14 d	Mortality & hatch rate: No stat. sign. differences. But large variations between offspring from different females.	Petereit & Franke (2012) Chapter 7.9 Herring egg exposure trials
Atlantic herring Larvae	Fehmarnbelt sediment; fine & coarse; 0, 5, 10, 25, 50, 200, 500 & 1000 mg/L; 3 & 24 h	3 h: 100% survival. Few larvae at 200 mg/L with fine sediment in mouth region. 24 h: Mortality: inconsistent data set. Accumulation of fine particles in the mouth cavity at 25 mg/L (ca. 5%), 50 mg/L (ca. 5%), 200 mg/L (50%) or higher concentrations but not at 5 and 10 mg/L. Not coarse sediment.	Petereit & Franke (2012) Chapter 7.10 Herring larval exposure trials
Coral reef fishes *Pomacentrus amboinensis* and *P. moluccensis*, larvae	Bentonite**;** 45, 90 & 180 mg/L;	Exposure impaired habitat choice at all concentrations tested	Wenger et al. 2011
Planktivorous coral reef damselfish (*Acanthochromis polyacanthus*), juvenile	Bentonite (the fish were only exposed during feeding, once per day); 0mg/L, 45m g/L(7.5NTU), 90mg/L(15NTU), 180 mg/L(30NTU); 42 days	Cumulative mortality < 10% at 45 & 90mg/L, and 42% at 180 mg/L. Also observed altered foraging behavior and reduced growth at 45-180 mg/L.	Wenger et al. 2012
Predator: *Pseudochromis fuscus* (75-80 mm). Prey: Coral reef damselfish (*Chromis atripectoralis*), juvenile (15-20 mm)	Bentonite; 0 mg/L, 30 mg/L, 45 mg/L, 60 mg/L; 12 h	Altered predator–prey interactions with significantly lower survival of the prey at 45 mg/L	Wenger et al. 2013
Coral reef damselfish (*Pomacentrus moluccensis*), juvenile	Bentonite; 0 mg/L (0 NTU), 10 mg/L (~1.7NTU), 20 mg/L (~3.3NTU), 30mg/L (~5NTU); 90 min	Altered habitat choice at 30 but not 10 and 20 mg/L	Wenger & McCormick 2013

Coral reef damselfish (*Amphiprion Percula*), larvae	Bentonite; 0 mg/L (0 NTU), 15mg/L (~2.5NTU), 30mg/L (~5.0NTU), 45mg/L (~7.5NTU); 22 days	Prolonged larval development in all treatments. Median values 11 and 12 days for control and exposed larvae, respectively. Increased range of variation	Wenger et al. 2014

16 Appendix F. Tanslation of selected text from NIVA (2008a)

Only selected texts are presented and translated. Text copied by DNV GL (2014a) is marked with yellow background.

Sammenfatning (Summary of the report)

Two of three paragraphs are quoted and translated.

§ 1 - Norwegian:
I denne arbeidspakken har vi gjennomgått relevant faglitteratur omkring effekter av metaller og suspenderte partikler på fisk og blåskejell. Litteraturgjennomgangen danner bakrunnsmateriale for risikovurderingene. Søkevalget er i utgangspunktet begrenset til litteratur nyere enn 10 år, og kun litteratur publisert i internasjonale tidskrift med referee. Litteratursøkene er primært gjort i ISI Web of Science, og Swetswise. Gjennomgangen av litteratur viste at en betydelig andel av relevant litteratur er utgitt før 1998. Vi har derfor inkludert noe sentral eldre litteratur i betraktningene omkring mulige effekter. Noe ”grålitteratur” (dvs litteratur som ikke har referee) er indirekte inkludert da data fra slike arbeider tidvis er inkludert i andre publiserte arbeider. Det er også inkludert noe grålitteratur der vi ikke har funnet litteratur i tidskrift med referee.

§ 1 - English:
This work package contains a review of relevant literature about effects of metals and suspended particles on fish and blue mussel. The literature survey provides background knowledge for the risk assessments. The search is initially limited to literature published during the past 10 years and in per-reviewed international journals only. The search is primarily performed on ISI Web of Science and Swetswise. The survey revealed publication of a significant portion of relevant literature before 1998. Therefore, some older but important publications were included in our considerations of possible effects. Also, some data from non-per-reviewed sources are indirectly included by their use in other publications. Additionally, some literature not found in per-reviewed journals was included.

§ 2 - Norwegian: Handlar om metall og er difor ikkje teke med.
§ 2 - English: Not included because it conciders metals.

§ 3 - Norwegian:
Materialet som skal deponeres har en kornfordeling som er sammenliknbar med sand, hvor hovedvekten av partiklene ligger fra 100-250 µm. Partiklene er i all hovedsak ovale, med en svært liten andel nåleformede. Litteraturen viser at eventuelle effeketer av suspenderte partikler på fisk og blåskjell avhenger av konsentrasjon, eksponeringstid, artikkelstørrelse/form samt egnenskaper ved dyret selv slik som alder/livstadium. Det skal gjennomgående svært høye partikkelkonsentrajoner til for å forårsake akutt dødelighet hos laksefisk og blåskjell (>1000 mg/L). For torsk finnes det ikke data. Ved lenger tids eksponering (uker til måneder) har man imidlertid observert dødelighet ved betydelig lavere konsentrasjoner (55-400 mg/L). Subletale effekter som redusert vekst, stress og endret adferd inntreffer også ved konsentrasjoner som er flere størrelseordeneer lavere enn det som gir akutt dødelighet, og litteraturen dokumenterer tilfeller av subletale effekter på under 10 mg/L ved lang tids eksponering (uker til måneder). Både for fisk og blåskjell viser litteraturen at små partikler er mindre skadelig enn store. I denne sammenhengen vil hovedvekten av partiklene fra Engebø komme i kategorien store. Litteraturen påpeker imidlertid også at runde partikler, som utgjør hovedvekten av massene fra Engebø er mindre skadelige enn nåleformede partikler.

§ 3 - English:
The material to be disposed has a grain size distribution which is comparable with that of sand, in which the main bulk of particles range 100-250 µm. The particles are mainly oval but with a very small fraction being needle-shaped. The literature shows possible effects of suspended particles on fish and blue mussels to depend on concentration, exposure time, particle size/shape as well as characteristics of the animal itself such as age/life stage. Generally, only very high particle concentrations may cause acute mortality in salmonids and blue mussels (> 1,000 mg/L). No data exist for Atlantic cod. However, after prolonged exposure (weeks to months) has been observed mortality at significantly lower concentrations (55-400 mg/L). Sublethal effects such as reduced growth, stress and altered behavior also occur at concentrations of significantly lower orders of magnitude than that causing acute mortality. And the literature documents cases of sublethal effects below 10 mg/L at prolonged exposure (weeks to months). According to the literature smaller particles are less harmful than larger ones in fish and blue mussels. In this context the main bulk of particles from Engebø will be large. The literature also points out, however, that round particles, which constitute most of the tailings from Engebø are less harmful than needle-shaped particles.

1. Beskrivelse av utslippets egenskaper (Description of the properties of the tailings to be discharged)

Two paragraphs are quoted and translated.

2.2 Kornstørrelser og kornform (grain size and grain shape)

§ 4 - Norwegian:
Figur 2 viser kornstørrelsen av det oppknuste materialet som antas å brukes som avgang ved Engebøfjellet. Dette er en liten fraksjon av materialet som er svært finkornet, hovedvekten ligger mellom 100µm og 250 µm, dvs det er som sand.

§ 4 - English:
Figure 2 depicts the grain size distribution of grinded material anticipated to represent tailings from Engebø. A small fraction of the material is very fine whereas the main bulk of particles range 100-250 µm, i.e. it is like sand.

§ 5 - Norwegian:
Analyser fra SINTEF (Figur 3) viser at kornene i all hovedsak er ovale, med en rundhet (”roundness”) rundt 0.6. Det er en svært liten del av avgangsmaterialet som er nåleformet (rundhet ned mot null) mens noe er nært kulerundt (rundhet på 1), noe som reflekterer de runde granatkornene.

§ 5 - English:
Analyses by SINTEF (figure 3) reveal mainly oval particles, with a roundness about 0.6. A very low fraction of the tailings is needle-shaped (roundness close to zero) whereas some particles are nearly spherical (roundness of 1) reflecting the rounded grains of garnet.

4. Mulige effekter av partikler (Possible effects of particles)

Selected paragraphs are quoted and translated.

§ 6 - Norwegian:
I litteraturen brukes "partikler" om mange typer ikke-løste aggregater av variabel størrelse. Begrepet kan inkludere levende organismer som bakterier og plankton. Døde partikler er av både organisk og uorganisk opprinnelse. Denne gjennomgangen har fokusert på litteratur som omhandler uorganiske partikler. Fisk kan påvirkes av suspenderte uorganiske partikler både direkte og indirekte, og litteraturen beskriver letale, sub letale og adferdsmessige effekter. Klogging og irritasjon av gjeller kan gi subletale effekter som svekket immunsystem (Herbert & Merkens 1961, Redding et al. 1987) og problemer med osmoregulering. Av adferdsmessige effekter er det vist at suspenderte uorganiske partikler kan påvirke fiskens bevegelsesmønster (Robertson et al. 2007), vandringsmønster (Bisson & Bilby 1982)(Whitman et al. 1982), reproduksjonsevne (gir ugunstige forhold på gytegrunner)(Walling et al. 2003, Greig et al. 2005), næringstilbud (Shaw & Richardson 2001) og evnen til å finne næring (Robertson et al. 2007).

§ 6 - English:
In the literature the term «particles» denotes a number of non-dissolved aggregates of different sizes. The term may include living organisms like bacteria and plankton. Dead particles are of organic and inorganic origin. This review has focused on literature about inorganic particles. Suspended inorganic particles may affect fish directly and indirectly, and the literature describes both lethal, sublehtal and behavioral effects. Clogging and irritation of gills may result in sublethal effects such as impaired immune system (Herbert & Merkens 1961, Redding et al. 1987) and osmoregulatory problems. Behavioral effects following exposure to inorganic particles include altered movement pattern (Robertson et al. 2007), migration pattern (Bisson & Bilby 1982, Whitman et al. 1982), ability to reproduce (causes unfavorable conditions at spawning grounds) (Walling et al. 2003, Greig et al. 2005), available food resources (Shaw & Richardson 2001) and the ability to search for food (Robertson et al. 2007).

4.1 Laks (Salmon)

§ 7 - Norwegian:
Det er en betydelig litteratur som omhandler effekter av oppløste uorganiske partikler/sedimenter på laksefisk. Det er imidlertid få arbeider som er gjort på Atlantisk laks (*Salmo salar*). De fleste studiene som refereres i det videre er gjort på ulike arter av stillehavslaks, samt på annen laksefisk. Det er videre en stor andel av disse studiene som omhandler avsetning og sedimentasjon av partikler på elvebunn, og hvilke effekter dette kan få for overlevelse og utvikling av egg og larver (se review av Billotta & Brazier 2008). Denne litteraturen refereres i liten grad.

§ 7 - English:
A substantial amount of literature deals with effects of dissolved inorganic particles/sediments on salmonids. There are, however, few studies on Atlantic salmon (*Salmo salar*). Most studies to be cited further in this report pertain to different species of Pacific salmon as well as other salmonids. Moreover, a large proportion of these studies concern deposition and sedimentation of particles on riverbeds, and what effects this may have on survival and development of eggs and larvae (ses review by Billotta & Brazier 2008). This literature is referred to a minor extent.

§ 8 - Norwegian: Not quoted.
§ 8 - English: Not translated.

§ 9 - Norwegian:
Newcombe & Jensen (1996) gjennomførte en metaanalyse over 80 ”published and adequately documented reports” på effekter av suspendert sediment på fisk i elver og estuarier. Basert på data fra disse arbeidene laget de modeller (likninger) som forsøkte å gi sammenhengen mellom biologisk respons, partikkelkonsentrasjon og varighet på eksponeringen. Summert opp gir modellen følgende grenseverdier for letal effekter voksen laksefisk: Eksponeringstid 1-7 timer, letal effekter ved henholdsvis >22.000 og >3000 mg/L. Eksponeringstid 1 til 6 dager, letaleffekter ved henholdsvis >3000 og > 400 mg/L. Eksponeringstid i 2-7 uker, letaleffekter ved henholdsvis >400 og > 55 mg/L. Juvenil laksefisk kom ut med omtrent samme grenseverdier.

§ 9 - English:
Newcombe & Jensen (1996) conducted a metaanalysis of 80 ”published and adequately documented reports” on effects of suspended sediment on fish in rivers and estuaries. Data from these investigations were used to establish models (mathematical equations) aimed at describing the association between biological response, particle concentration and exposure duration. In summary, the model provides the following thresholds[17] for lethal effects in adult salmonids: Exposure for 1-7 hours, lethal effects at >22,000 and >3,000 mg/L, respectively. Exposure for 1 to 6 days, lethal effects at >3,000 and > 400 mg/L, respectively.
Exposure for 2-7 weeks, lethal effects at >400 and > 55 mg/L, respectively. Thresholds were approximately the same for juvenile salmonids.

§ 10 & 11 - Norwegian: Not quoted.
§ 10 & 11 - English: Not translated.

§ 12 - Norwegian:
Modellene til Newcombe & Jensen (1996)(beskrevet over) foreslå også grenseverdier for subletale direkte effekter. Summert opp gir modellen følgende grenseverdier for voksen laksefisk: Eksponeringstid 1-7 timer, effekter ved henholdsvis >403 og >55 mg/L. Eksponeringstid 1 til 6 dager, effekter ved henholdsvis >55 og > 7 mg/L. Eksponeringstid i 2-7 uker, effekter ved henholdsvis >7 og > 3 mg/L. Juvenil laksefisk kom ut med omtrent samme grenseverdier.

§ 12 - English:
The above-described models of Newcombe & Jensen (1996) also proposed thresholds[18] for direct sublethal effects. In summary, the model provides the following thresholds for adult salmonids: Exposure for 1-7 hours, effects at >403 and >55 mg/L, respectively. Exposure for 1 to 6 days, effects at >55 og > 7 mg/L, respectively. Exposure for 2-7 weeks , effects at >7 og > 3 mg/L, respectively. The thresholds were approximately the same in juvenile salmonids.

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[17] Newcombe & Jensen (1996) used the term “thresholds of ill effect (N: terskler for skadelig effect)” whereas NIVA translated this by “limit values (N: grenseverdier)”. However, limit value as defined by EC directives has another meaning than threshold (IUPAC 2009). Therefore, in order to avoid confusion, it has been translated by threshold.

[18] See footnote 17.

§ 13 - Norwegian:

Det er flere faktorer som kan forklare det store spennet i konsentrasjoner som gir direkte effekter (både letale og subletale) hos laksefisk. Noe av variasjonen er selvsagt reelle forskjeller mellom arter, som igjen skyldes at ulike arter er tilpasset habitat med forskjeller i naturlig turbiditet. Men litteraturen viser også forskjeller innenfor samme arten. Ulik eksponeringstid i studiene forklarer trolig en god del av dette. I meta analysen til Newcombe & Jensen 1996 viser modelleringen av empiriske data betydningen av eksponeringstid. Selv ved lik eksponeringstid kan det hos en spesifikk art være stort sprik i toleranse (se over for coho laks). Disse forskjellene kan knyttes til egenskaper ved selve partikkelen, slik som størrelse og form: små partikler ser ut til å gjøre mindre skade enn store (Servizi & Martens 1987) og avrundede partikler gjør mindre skade enn kantete (Lake & Hinch 1999). Det ser videre ut til at toleransen er lavere i studier hvor man har brukt naturlig elvesediment sammenliknet med studier hvor man har brukt "kunstig" menneskeskapt sediment (Lake & Hinch 1999). Naturlig elvesediment er ladet og tiltrekker seg tungmetaller og store organiske partikler. Konsentrasjonene av disse forbindelsene kan være høy i sediment selv om konsentrasjonen i vannet er lav (Giesy & Hoke 1991). Lake & Hinch (1999) foreslo at dette kunne være en mulig årsak til lavere LC50 i forsøk med Coho laks hvor naturlige elvesedimenter ble brukt. Pyle et al. (2002) viste at økte konsentrasjoner av uorganiske partikler reduserte giftigheten for Ni. Partiklene "fjernet" nikkel fra vannet og dermed reduserte mengden toverdig Ni tilgjengelig for fisken. Den positive effekten avtok imidlertid når partikkelkonsentrasjonene økte opp mot 100 mg/L, noe som underbygger forklaringsmodellen til Lake & Hinch (1999). Forskjeller innenfor samme arten kan også knyttes til egenskaper ved dyret slik som livstadium, hvor tidlige livstadier tenderer til å være mer følsomme (Servizi & Martens 1991). Forsøksbetingelser som eksempelvis årstid og temperatur spiller også inn, hvor samme arten viser seg å ha ulik respons ved ulik årstid (Robertson et al. 2007) og ved ulike temperaturer (Servizi & Martens 1991). Hos Coho laks fant eksempelvis Servizi & Martens (1991) en LC50 ved 1 og ved 18 °C som var henholdsvis 47 og 33 % av LC50 ved 7 °C som var den temperaturen hvor toleransen var høyest.

§ 13 - English:

A number of factors may explain the large interval of concentrations causing direct effects (lethal and sublethal) on salmonids. Part of this variation of course represents real inter-species differences, which in turn are due to the adaptation of different species to habitats with different levels of natural turbidity. However, the literature also reports differences within the same species. Different exposure durations probably explain a substantial part of this variation. The modeling of empirical data in the meta analysis by Newcombe & Jensen (1996) demonstrates the significance of exposure duration. The tolerance may vary considerably in one particular species even if exposed for the same period of time (see above about coho salmon). These differences can be attributed to properties of the particle itself, such as size and form: small particles seem to do less harm than large particles (Servizi & Martens 1987) and rounded particles do less harm than angular (Lake & Hinch 1999). Studies also indicate a lower tolerance to natural riverine sediment compared with "artificial" anthropogenic sediment (Lake & Hinch 1999). Natural riverine sediment is charged and attracts heavy metals and large organic particles. The concentrations of these compounds can be high in sediment even when the concentration in the water is low (Giesy & Hoke 1991). Lake & Hinch (1999) suggested this may explain a lower LC50 in experiments with Coho salmon exposed to natural riverine sediment. Pyle et al. (2002) demonstrated reduced toxicity of Ni due to increased concentrations of inorganic particles. The particles «removed» nickel from the water and thereby reduced the amount of divalent Ni available to fish. The positive effect diminished, however, when the particle concentrations increased up to 100 mg/L, thus supporting the explanation model of Lake & Hinch (1999). Intra-species differences may also associate with properties of the animal, such as life stage, of which the earlier stages appear more sensitive (Servizi & Martens 1991). Experimental conditions such as season and temperature also influence the outcome, as the same species displays different responses depending on season (Robertson et al. 2007) and different temperatures (Servizi & Martens 1991). In coho salmon was for instance by Servizi & Martens (1991) at 1 and 18 °C observed a LC50 being 47 and 33 %, respectively, of the LC50 at 7 °C, at which temperature the tolerance peaked.

§ 14 - Norwegian:

En godt dokumentert indirekte subletal effekt er redusert vekst. Det kan se ut til at redusert vekst inntreffer ved relativt lave konsentrasjoner. Hos coho laks ble vekstreduksjon observert ved 84 mg/L (Sigler et al. 1984). Eldre arbeider på ulike arter ørret viser at vekstreduksjon observeres allerede ved konsentrasjoner rundt 50 mg/L (Herbert & Richards 1963, Sykora et al. 1972). Hos harr ser toleransen ut til å være noe større, med en 6 % reduksjon i vekstrate ved 100 mg/L (McLeay et al. 1987). Redusert vekst kan være et resultat av redusert fødeinntak og/eller økte metabolske kostnader (McLeay et al. 1987). Hos Atlantisk laks er det vist at fødeinntaket øker opp til konsentrasjoner på 180 mg/L, for så å gå ned ved en ytterligere økning i partikkelkonsentrasjon (Robertson et al. 2007). Tilsvarende effekter er også vist hos stillehavslaks (økt fødeinntak opptil 150 NTU deretter reduksjon)(Gregory 1994, Gregory & Northcote 1993). En moderat økning i partikkelkonsentrasjon (og dermed turbiditet) gir fisken en oppfatning av redusert predasjonsrisiko. Over et spesifikt nivå blir imidlertid denne effekten utjevnet ved at fisken selv får økende problemer med å se (redusert reaktiv distanse) eget bytte (gjelder for en visuell predator)(se Shaw & Richardson 2001). Hos regnbueørret og coho laks gikk fødeopptaket ned ved konsentrasjoner på 2-3000 mg/L, mens ingen effekter på fødeopptaket ble observert ved 600 mg/L (Redding et al. 1987).

§ 14 - English:

A well-documented indirect sublethal effect is reduced growth, which appears to occur at relatively low concentrations. This was observed in coho salmon exposed to 84/mg/L (Sigler et al. 1984). Older studies on different species of trout demonstrates reduced growth at concentrations as low as 50 mg/L (Herbert & Richards 1963, Sykora et al. 1972). Grayling is apparently more tolerant, with a 6 % reduced growth rate at 100 mg/L (McLeay *et al*. 1987). Reduced growth might be a result of reduced feed uptake and/or increased metabolic costs (McLeay et al. 1987). Increased feed uptake was demonstrated in Atlantic salmon exposed to particle concentrations up to 180 mg/L for thereafter to decrease at further increasing concentrations (Robertson *et al*. 2007). Corresponding effects were also demonstrated in Pacific salmon (increased feeding up to 150 NTU and thereafter reduction) (Gregory 1994, Gregory & Northcote 1993). A moderate increase in particle concentration (and thereby turbidity) gives the fish a perception of reduced predation risk. Above a specific level, however, this effect is leveled out because it becomes increasingly difficult for the fish to see (reduced reactive distance) its prey (applies to a visual predator) (see Shaw & Richardson 2001). In rainbow trout and coho salmon the feeding rate diminished at concentrations of 2-3,000 mg/L, whereas no effects on feeding were observed at 600 mg/L (Redding et al. 1987).

§ 15 - Norwegian:

En siste type indirekte subletal effekt er adferdsrespons. Hos Atlantisk laks er det vist at sammenbrudd i dominans hierarki og reduksjon i territoriell adferd inntreffer ved konsentrasjoner >60 mg/L (Robertson et al. 2007). Tilsvarende effekt er også vist for coho laks men effekten inntraff først ved konsentrasjoner rundt 130 mg/L (Berg & Northcote 1985). Unnvikelses/flukt respons (fisken prøver å komme unna vannet med høy turbiditet) er også ser også ut til å inntreffe i spennet 60-180 mg/L hos Atlantisk laks ((Robertson et al. 2007). Også flukt respons ser ut til å inntreffe ved lavere konsentrasjon hos Atlantisk laks enn eksempelvis coho laks (respons inntreffer rundt 180 mg/L)(Bisson & Bilby 1982, Berg & Northcote 1985, Servizi & Martens 1992). Det er også eksempel på andre typer adferdsmessig respons som kan endre predasjons risiko, konkurranse med andre arter etc. Utfallet av denne type respons er umulig å forutse uten å se på andre elementer i økosystemet og blir ikke gått nærmere innpå her.

§ 15 - English:
A final kind of indirect sublethal effect is altered behavior. Breakdown of hierarchical dominance and reduced territorial behavior have been observed in Atlantic salmon exposed to >60 mg/L (Robertson *et al*. 2007). Corresponding effect has also been demonstrated in Coho salmon but first at concentrations about 130 mg/L (Berg & Northcote 1985). Avoidance/escape response (the fish attempts to escape water with high turbidity) also seems to occur in the range 60-180 mg/L in Atlantic salmon (Robertson *et al*. 2007). Also escape response appears to occur at lower concentrations in Atlantic salmon compared with e.g. coho salmon (response occurs around 180 mg/L) (Bisson & Bilby 1982, Berg & Northcote 1985, Servizi & Martens 1992). There are also examples of other types of behavioral response which can alter the risk of predation, competition with other species etc. The outcome of this kind of response is impossible to predict without considering other elements of the ecosystem but this is not further adressed in this context.

§ 16 - Norwegian: Tabell 2. Not quoted.
§ 16 - English: Not translated.

4.2 Torsk (Cod)

All text in Norwegian is quoted and translated.

§ 17 - Norwegian:
Brorparten av vår nåværende kunnskap om effekter av uorganiske partikler på fisk kommer fra studier på laksefisk i ferskvann (Au et al. 2004), og antallet studier på estuarin/marin fisk er lavt. Så vidt vi kan se finnes bare ett arbeid som omhandler effekter av uorganiske partikler på torsk. I denne studien ble torsk utsatt for en partikkelkonsentrasjon på 550 mg/L over periode på 10 dager uten at det ble observert dødelighet (Humborstad et al. 1996). Hos Atlantic silverside (*Menidia Menidia*) ble det observert dødelighet ved bare 580 mg/L ved 24 timers eksponering, mens tannkarpe (mummichog; *Fundulus heteroclitus*) overlever 300.000 mg/L under samme eksponeringstid (Newcombe & Jensen 1996). I en eldre studie er det utarbeidet dødelighetskurver for seks arter. Disse artene ble klassifisert i henhold til sin LC10 konsentrasjon (Sherk et al. 1975) hvor arter med 24 t LC10 >10.000 mg/L ble klassifisert som tolerante, arter med 24 t LC10 fra 1000 til 10.000 mg/L som sensitive og arter med 24 t LC10 < 1000 mg/L som svært sensitive. Av de artene som hadde høy toleranse var alle bunnfisk eller arter med sterk tilknytting til bunn (se review Wilber & Clark 2001).

§ 17 - English:
Our existent knowledge about the effects of inorganic particles on fish is mainly based on studies of salmonids in freshwater (Au et al. 2004), and there are few studies on estuarine/marine fish. There is, to the best of our knowledge, only one study dealing with effects of inorganic particles on Atlantic cod. Cod was in that study exposed to a concentraion of 550 mg/L for a period of 10 days without any mortality being observed (Humborstad et al. 1996). Mortality was observed in Atlantic silverside (*Menidia menidia*) following exposure for 24 hours to a concentration as low as 580 mg/L, whereas mummichog (*Fundulus heteroclitus*) survives 300.000 mg/L for 24 hours (Newcombe & Jensen 1996). Mortality curves were established for six species in an older study, in which these species were classified according to their LC 10 concentration (Sherk et al. 1975). Species with 24 h LC 10 >10,000 mg/L were classified as tolerant, species with 24 h LC 10 from 1,000 to 10,000 mg/L

as sensitive and species with 24 h LC 10 < 1,000 mg/L as very sensitive. The species with high tolerance were all bottom-living or strongly associated with the bottom (see review Wilber & Clark 2001).

§ 18 - Norwegian:

Humborstad et al. (2006) observerte sub-letale effekter hos torsk ved en partikkelkonsentrajon på 550 mg/L. Histologiske undersøkelser viste skader på gjellene allerede ved 24 timers eksponering. Skadene på gjellene var blant annet hyperplasi, hypertrorfi og økt antall slimceller, og skadeomfanget økte med økt eksponeringstid (Humborstad et al. 2006). Forfatterne antok likevel at skadene ikke ville hatt signifikant betydning for respirasjon, ekskresjon og osmoregulering, og at skadene trolig var reparerbare. Humborstad et al. (2006) påpekte videre at torsk har stor mulighet til å unngå ”skyer” av vann med høy turbiditet. Humborstad et al. 2006 undersøkte ikke lavere konsentrajoner enn 550 mg/L. Hos green grouper ble det observert gjelleskader allerede ved 50 mg/L men disse var svært begrenset. Mer omfattende skader ble først observert på konsentrasjoner over 200 mg/L. I den tidligere refererte sammenlikningen av seks ulike arter (Sherk et al. 1975), ble det ikke hos noen av artene observert subletale effekter under 650 mg/L.

§ 18 - English:

Humborstad et al. (2006) observed sublethal effects in cod following exposure to a particle concentration of 550 mg/L. Histological examinations revealed damage to the gills following exposure for 24 hours only. The damage included e.g. hyperplasia, hypertrophy and increased numbers of mucous cells, and the degree of damage increased with increasing exposure time (Humborstad et al. 2006). Nevertheless, the authors assumed that the damages would not have been of significant importance for respiration, excretion and osmoregulation, and that they probably would repair. Humborstad et al. (2006) further highlighted that cod has great opportunity to avoid «clouds” of high turbidity water. Humborstad et al. 2006 did not expose cod to lower concentrations than 550 mg/L. Gill damages were observed in green grouper exposed to a concencentration as low as 50 mg/L but these were very limited. More extensive damages were first observed at concentrations above 200 mg/L. In the above-mentioned comparison of six different species (Sherk et al. 1975) sublethal effects were not observed below 650 mg/L in any species.

§ 19 - Norwegian: Berre to rader med referanse til Au et al. (2004) er tekne med.

Tabell 3. Tabellen oppsummerer data på effekter fisk (ikke laksefisk) eksponert for ulike konsentrasjoner av uorganiske partikler over ulike tidsrom. F= ferskvannsfisk, M = marin fisk, J = juvenil fisk.

Art	Livs stadium	Konsentrasjon uorganiske partikler (mg/L)	Eksponerings-tid (timer)	Effekt på organismen	Referanse
Grønn grouper (M) (*Epinephlelus coioides*)	J	50	1008	> 20 % dødelighet. (LC50 var på 1400 mg/L)	Au et al. 2004
Grønn grouper (M) (*Epinephlelus coioides*)	J	2000 2000 >50 > 200	1008 1008 1008 1008	Redusert ATPase aktivitet Økt antall klorid celler Hyperplasi Løsning av epitel	Au et al. 2004

§ 19 - English: Only two rows with reference to Au et al. (2004) are included.

Table 3. The table summarizes data about effects on fish (not salmonids) exposed to different concentrations of inorganic particles for different time periods. F = freshwater fish, M = marine fish, J = juvenile fish.

Species	Life stage	Consentration inorganic particles (mg/L)	Exposure duration (hours)	Effect on the organism	Reference
Green grouper (M) (*Epinephlelus coioides*)	J	50	1008	> 20 % mortality. (LC50 was 1400 mg/L)	Au et al. 2004
Green grouper (M) (*Epinephlelus coioides*)	J	2000 2000 >50 > 200	1008 1008 1008 1008	Reduced ATPase activity Increased number of chloride cells Hyperplasia Exfoliation of epithelium	Au et al. 2004

17 Appendix G. Translation of selected text from DNV GL (2014a)

All text in part 3.1, 3.2 and 3.2.1, i.e. on page 25 – 28, has been translated. Text copied from NIVA (2008a) is marked with yellow background in the Norwegian text. The English versions of copied text is not necessarily identical in translations of these two reports.

3 EFFEKTVURDERING AV FJORDDEPONI (EFFECT EVALUATION OF TAILINGS DISPOSAL AT FJORD SEA BED)

3.1 Innledning (Introduction)

§ 1 - Norwegian:

DNV GL har gjennomført en vurdering av potensielle effekter som følge av deponering av overskuddsmasser. Effektvurderingen er basert på kunnskap om marinbiologi og modellerte konsentrasjoner av partikler i vannmassene, og sedimentering på fjordbunnen som følge av deponeringen. Effekter diskuteres ut fra gjeldende kunnskap om tålegrenser for partikler og sedimentasjonsrater for ressurser som ansees som relevante i Førdefjorden.

Følgende komponenter i avgangen er modellert av SINTEF (DNV GL, 2014-1244 *Strømforhold og spredning i Førdefjorden*) og ansees som relevante i en effektvurdering av Førdefjorden:

- **Effekter som følge av økt partikkelkonsentrasjon i vannsøylen**
  Det skilles ikke mellom forskjellige partikkelstørrelser. Total konsentrasjon av svævende partikler i SINTEF's modelleringer ansees som biologisk relevant og effektvurderingen er basert på disse. DNV GL betrakter modellerte partikler som inerte mineralpartikler uten spesifikk innhold eller form.

- **Effekter som følge av nedslamming av sjøbunn («begravelse»).**
  Her er fokus på modellert sedimenteringsrate for total partikkelmengde, det skilles ikke mellom forskjellige partikkelstørrelser. I forbindelse med nedslamming vil effektgrensen defineres ut fra akutte tålegrenser.

§ 1 - English:

DNV GL has evaluated potential effects of submarine tailings disposal of surplus masses. The effect evaluation is based on knowledge within marine biology and on modeled particle concentrations in the water body, and on sedimentation at the seabed following disposal. The discussion of effects on resources deemed relevant in the Førde Fjord is based on current knowledge about tolerance limits for particles and rates of sedimentation.

The following components of the tailings are modeled by SINTEF (DNV GL, 2014-1244 *Water current conditions and dispersion in the Førde Fjord*) and considered relevant in an effect evaluation of the Førde Fjord:

- **Effects due to increased concentration of particles in the water column**
  No distinction is made between different particle sizes. Total concentration of suspended particles, which is used in SINTEF's modeling, is considered biological relevant and is used as the basis for the effect evaluation. DNV GL considers modeled particles to be inert mineral particles without any specific content or form.

 Effects due to smothering of the sea bed ("burying")
Modeled rate of sedimentation for the total amount of particles is focused. It is not differentiated between different particle sizes. The effect limit associated with smothering will be defined from acute tolerance limits.

3.2 Bakgrunn (Background)

§ 2 - Norwegian:
Følgende ressurser er identifisert som relevante i en effektvurdering av fjorddeponi:

 Voksen og juvenil fisk

 Fiskelarver

 Filtrerende organismer på hardbunn

 Alle typer bunnlevende bløtbunnsorganismer

DNV GL har gjennomført et litteratur- og erfaringsstudie og bruker i effektvurderingen laveste rapporterte effektkonsentrasjon for relevante ressurser og for relevante komponenter i avgangen fra Engebø. Litteraturstudien omfatter effektstudier av både naturlige sedimenter fra elver og estuarier, og boreslam fra boreoperasjoner offshore. I effektvurderingen skilles det mellom effektkonsentrasjon for akutte (letale) og kroniske (subletale) effekter i publiserte studier. Det er viktig å merke seg at kroniske effekter er et resultat av eksponering for lave konsentrasjoner over lang tid (mange dager).

Det er ikke identifisert artsspesifikke effektgrenser. DNV GL har i effektvurderingen brukt lavest rapportert effektkonsentrasjon i de organismegrupper som er nevnt ovenfor. Det blir da mulig å gi et bilde av risikoen for voksen fisk i vannsøylen som er forskjellig fra fiskelarver som kun er tilstede i vannsøylen under deler av året, og for bentiske (bunnlevende) organismer på bløt- og hardbunn. Denne type risikovurdering er etter DNV GLs oppfatning mer relevant enn en PNEC-tilnærming for den planlagte avgangen fra Engebø, hvor artsammensetning godt kartlagt og kan ses i forhold til spesifikke effektgrenser.

Effektvurderingen er fokusert på modelleringsresultater som modellerer en typisk deponeringssituasjon med variasjoner over ett år.

§ 2 - English:
The following resources were identified as relevant in an evaluation of effects of fjord disposal:

- Adult and juvenile fish
- Fish larvae
- Filtering organisms on hard seabed (rocky seabed)
- All types of soft bottom-living organisms

DNV GL has performed a study of literature and experiences. The evaluation of effects is based on the lowest-reported-effect concentration for relevant resources and relevant components of the mine tailings from Engebø. The literature study includes studies of effects of natural sediments from rivers and estuaries, and drilling muds from offshore operations.

It is distinguished between acute (lethal) and chronic (sublethal) effect concentrations as published. Importantly, chronic effects result from the exposure to low concentrations for a long time (many days).

There has not been identified species-specific effect limits. DNV GL has evaluated effects by using the lowest reported effect concentration for the above-mentioned groups of organisms. This gives the opportunity to consider the risk in adult fish present in the water column, which is different from that of fish larvae present in the water column during parts of the year only. Moreover, for benthic (bottom-living) organisms at soft and rocky seabed. DNV GL considers this kind of risk assessment more relevant than a PNEC approach for the planned tailings from Engebø, where species composition is well documented and can be related to specific effect limits.

The effect evaluation is focused on modeled results, which model a typical disposal situation with seasonal variations throughout one year.

3.2.1 Effektgrenser for fisk som følge av økt partikkelkonsentrasjon i vannsøylen (Effect limits for fish subsequent to increased particle concentration in the water column)

§ 3 - Norwegian:

Effektstudier med en blanding av attapulgitt (magnesium/aluminium fyllosilikat) har vist at høye partikkelkonsentrasjoner som følge av oversvømmelse, oppmudring og deponering kan gi økt dødelighet i voksen fisk. I forsøk med syv forskjellige amerikanske fiskearter ble det påvist signifikant dødelighet i fem arter, med effektgrenser (LC10) mellom 580 mg/L i Silversides (*Atheriniformes*) og 2450 mg/L i Mummichog (*Fundulus heteroclitus*), med et høyere toleransnivå i bunnlevende fisker og fisker som er tilknyttet estuarier enn typisk pelagiske fisker (Sherk et al., 1975).

§ 3 - English:

Effect studies have shown that a mixture of attapulgitt (magnesium/aluminium phyllosilicate) in high particle concentrations, due to flooding, dregding or disposal, may result in increased mortality in adult fish. Experiments on seven different species of American fish revealed significant mortality in five of the species, with effect limits (LC10) varying between 580 mg/L in silversides (*Atheriniformes*) and 2,450 mg/L in mummichog (*Fundulus heteroclitus*) (Sherk et al., 1975). Bottom-living and estuarine fishes, however, displayed a higher tolerance level when compared with typical pelagic fishes.

§ 4 - Norwegian[19]:

I torsk er det observert dødelighet ned til 550 mg/L (Humborstad et al., 1996). I laksefisk er det observert betydelig dødelighet (LC10) som følge av eksponering for suspenderte partikler ved 1400 mg/L (Herbert & Merkens 1961). Det er stort sprik i toleranse mot partikler hos laksefisk og mange studier viser tålegrenser på titusentalls mg/L. Disse forskjellene kan knyttes til egenskaper ved selve partikkelen, slik som størrelse og form; små partikler ser ut til å gjøre mindre skade enn store (Servizi & Martens 1987) og avrundede partikler gjør mindre skade enn kantete (Lake & Hinch 1999). Det ser ut til at toleransen er lavere i studier hvor man har brukt

[19] The text copied from NIVA (2008a) is also marked in § 13 of Appendix E.

naturlig elvesediment sammenliknet med studier hvor man har brukt kunstig sediment (Lake & Hinch 1999). Naturlig elve-sediment er for eksempel ladet og tiltrekker seg tungmetaller og store organiske partikler. Lake & Hinch (1999) foreslo at dette kunne være en mulig årsak til lavere LC50 i forsøk med Coho laks hvor naturlige elvesedimenter ble brukt. Forsøksbetingelser som eksempelvis årstid og temperatur spiller også inn, hvor samme arten viser seg å ha ulik respons ved ulik årstid (Robertson et al. 2007) og ved ulike temperaturer (Servizi & Martens 1991).

§ 4 - English:

In cod has been observed mortality down to 550 mg/L (Humborstad et al., 1996). In salmonids has been observed significant mortality (LC10) following exposure to 1,400 mg/L of suspended particles (Herbert & Merkens 1961). The tolerance of salmonids for particles varies significantly and many studies show tolerance limits at tens of thousands mg/L. These differences can be attributed to properties of the particle itself, such as size and form; small particles seem to do less harm than large particles (Servizi & Martens 1987) and rounded particles do less harm than angular (Lake & Hinch 1999). Studies indicate a lower tolerance to natural riverine sediment compared with artificial sediment (Lake & Hinch 1999). Natural riverine sediment is e.g. charged and attracts heavy metals and large organic particles. Lake & Hinch (1999) suggested this may explain lower LC50 in experiments with Coho salmon exposed to natural riverine sediment. Experimental conditions such as season and temperature also influence the outcome, as the same species displays different responses depending on season (Robertson et al. 2007) and different temperatures (Servizi & Martens 1991).

§ 5 - Norwegian[20]:

Newcombe (2003) gjennomførte en studie på effekter av suspenderte mineralpartikler på laksefisk basert på en rekke vitenskapelige artikler. Basert på data fra disse arbeidene laget de modeller (likninger) som forsøkte å gi sammenhengen mellom biologisk respons, partikkelkonsentrasjon og varighet på eksponeringen. Summert opp gir modellen følgende grenseverdier for letaleffekter i voksen laksefisk:

• Eksponeringstid 1-7 timer, letaleffekter ved henholdsvis >22.000 og >3000 mg/L.
• Eksponeringstid 1 til 6 dager, letaleffekter ved henholdsvis >3000 og > 400 mg/L
• Eksponeringstid i 2-7 uker, letaleffekter ved henholdsvis >400 og > 55 mg/L

Juvenil fisk kom ut med omtrent samme   mens tålegrenser for fiskelarver ikke ble evaluert.

§ 5 - English:

Newcombe (2003) conducted a study on effects of suspended mineral particles on salmonids based on a number of scientific articles. Data from these investigations were used to establish models (mathematical equations) aimed at describing the association between biological response, particle concentration and exposure duration. In summary, the model provides the following thresholds[21] for lethal effects in adult salmonids:

- Exposure for 1-7 hours, lethal effects at >22,000 and >3,000 mg/L, respectively.
- Exposure for 1 to 6 days, lethal effects at >3,000 and > 400 mg/L, respectively.
- Exposure for 2-7 weeks, lethal effects at >400 and > 55 mg/L, respectively.

Thresholds were approximately the same for juvenile salmonids, whereas tolerance limits for larvae were not evaluated.

[20] The text copied from NIVA (2008a) is also marked in § 9 of Appendix E.

[21] Newcombe & Jensen (1996) used the term "thresholds of ill effect (N: terskler for skadelig effect)" whereas NIVA translated this by "limit values (N: grenseverdier)". However, limit value as defined by EC directives has another meaning than threshold (IUPAC 2009). Therefore, in order to avoid confusion, it has been translated by threshold.

§ 6 - Norwegian[22]:

En godt dokumentert indirekte subletal effekt i fisk er redusert vekst, som ansees å være et resultat av redusert fødeinntak og/eller økte metabolske kostnader (McLeay *et al*. 1987). Det kan se ut til at redusert vekst inntreffer ved kronisk eksponering for relativt lave konsentrasjoner hos noen arter. Hos Coho laks ble vekstreduksjon observert ved 84 mg/L etter eksponering i 2 uker (Sigler *et al*. 1984). Hos atlantisk laks er det vist at fødeinntaket øker opp til konsentrasjoner på 180 mg/L, for så å gå ned ved en ytterligere økning i partikkelkonsentrasjon (Robertson *et al*. 2007). Eldre arbeider på ulike arter ørret viser at vekstreduksjon observeres allerede ved konsentrasjoner rundt 50 mg/L (Herbert & Richards 1963, Sykora *et al*. 1972). Hos harr ser toleransen ut til å være noe større, med en 6 % reduksjon i vekstrate ved 100 mg/L (McLeay *et al*. 1987).

§ 6 - English:

A well-documented indirect sublethal effect in fish is reduced growth, which is considered to result from reduced feed uptake and/or increased metabolic costs (McLeay *et al*. 1987). Reduced growth seems to occur at chronic exposure to relatively low concentrations in some species, and was observed in Coho salmon after 2 weeks of exposure to 84 mg/L (Sigler *et al*. 1984). Increased feed uptake was demonstrated in Atlantic salmon exposed to particle concentrations up to 180 mg/L for thereafter to decrease at further increasing concentrations (Robertson *et al*. 2007). Older studies of different species of trout demonstrates reduced growth at concentrations as low as 50 mg/L (Herbert & Richards 1963, Sykora et al. 1972). Grayling is apparently more tolerant, with a 6 % reduced growth rate at 100 mg/L (McLeay *et al*. 1987).

§ 7 - Norwegian[23]:

En annen type indirekte subletal (kronisk) effekt er adferdsrespons. Hos atlantisk laks er det vist at sammenbrudd i dominans hierarki og reduksjon i territoriell adferd inntreffer ved konsentrasjoner >60 mg/L (Robertson *et al*. 2007). Tilsvarende effekt er også vist for Coho laks men effekten inntraff først ved konsentrasjoner rundt 130 mg/L (Berg & Northcote 1985). Unnvikelses-/fluktrespons (fisken prøverå komme unna vannet med høy turbiditet) ser også ut til å inntreffe i spennet 60-180 mg/L hos atlantisk laks (Robertson *et al*. 2007).

§ 7 - English:

Another kind of indirect sublethal (chronic) effect is behavioral response. Breakdown of hierarchical dominance and reduced territorial behavior have been observed in Atlantic salmon exposed to >60 mg/L (Robertson *et al*. 2007). Corresponding effect has also been demonstrated in Coho salmon but first at concentrations about 130 mg/L (Berg & Northcote 1985). Avoidance/escape response (the fish attempts to escape water with high turbidity) also seems to occur in the range 60-180 mg/L in Atlantic salmon (Robertson *et al*. 2007).

§ 8 - Norwegian[24]:

Modellene til Newcombe (2003) foreslo også grenseverdier for subletale effekter. Summert opp gir modellen følgende grenseverdier for voksen laksefisk:

- Eksponeringstid 1-7 timer, effekter ved henholdsvis >403 og >55 mg/L
- Eksponeringstid 1 til 6 dager, effekter ved henholdsvis >55 og > 7 mg/L
- Eksponeringstid i 2-7 uker, effekter ved henholdsvis >7 og > 3 mg/L.

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[22] The text copied from NIVA (2008a) is also marked in § 14 of Appendix E.
[23] The text copied from NIVA (2008a) is also marked in § 15 of Appendix E.
[24] The text copied from NIVA (2008a) is also marked in § 12 of Appendix E.

Juvenil fisk kom ut med omtrent samme grenseverdier.

§ 8 - English:

The models of Newcombe (2003) also proposed thresholds[25] for sublethal effects. In summary, the model provides the following thresholds for adult salmonids:

- Exposure for 1-7 hours, effects at >403 and >55 mg/L, respectively.
- Exposure for 1 to 6 days, effects at >55 and > 7 mg/L, respectively.
- Exposure for 2-7 uker, effects at >7 and > 3 mg/L, respectively.

The thresholds were approximately the same in juvenile salmonids.

§ 9 - Norwegian:

Ovenstående sammenstilling viser at mesteparten av studiene er gjort på laksefisker som derfor blir «dimensjonerende» for effektgrensen. Imidlertid indikerer ikke studier gjennomført på andre pelagiske arter at disse er mer følsomme enn laks. Subletale effekter og adferdsrespons er beskrevet i flere fiskearter ved en partikkelkonsentrasjon på 50-60 mg/L, og dødelighet i de mest følsomme artene sees omtrent ved en faktor 10 høyere konsentrasjoner. Effektkonsentrasjonen er imidlertid avhengig av flere parametere og særlig eksponeringstiden, noe som gjenspeiles i effektgrenser foreslått av Newcombe (2003). Det er kjent at voksen og juvenil fisk unngår mange typer eksponering (kjemisk og mekanisk) ved å svømme vekk fra influensområdet. Effektgrensen for fluktrespons hos laks er rapportert til 60-180 mg/L og det ansees derfor som usannsynlig at juvenil og voksen fisk vil bli eksponert for partikkelskyen over lang tid

§ 9 - English:

The above-presented compilation shows that most of the studies pertain to salmonids, which therefore become "determinants" of the effect limit. However, studies conducted in other pelagic species do not indicate higher sensitivity than in salmon. Sublethal effects and behavioral response have been described in a number of fish species exposed to particle concentrations of 50-60 mg/L, and mortality in the most sensitive species is seen at approximately 10 times as high concentrations. The effect concentration, however, depends on a number of parameters and especially the exposure duration, as reflected in effect limits proposed by Newcombe (2003). Adult and juvenile fish are known to avoid a number of types of exposure (chemical and mechanical) by swimming away from the impacted area. The reported effect limit for escape response in salmon is 60-180 mg/L and, therefore, it is regarded unlikely that juvenile and adult fish will be long exposed to the particle cloud.

§ 10 - Norwegian:

Med utgangspunkt i resultater beskrevet ovenfor settes effektgrensen for *subletale effekter* i juvenil/voksen fisk til **50 mg/L**, tilsvarende lavest rapporterte partikkelkonsentrasjon som gir vekstreduksjon i en kronisk eksponeringssituasjon. Imidlertid forventes ikke lange eksponeringstider for kunstig høye partikkelkonsentrasjoner, og derfor heller ingen effekter fordi voksen fisk forventes å svømme vekk fra partikkelskyen ved et konsentrasjonsvindu som kan være litt forskjellig i forskjellige arter (rapporterte verdier 60-180 mg/L). Effektgrensen 50 mg/L er derfor snarere en konservativ effektgrense for unnvikelse.

§ 10 - English:

Based on the above-described results is concluded an effect limit for *sublethal effects* at **50 mg/L** in juvenile/adult fish. This corresponds to the lowest reported particle concentration that

[25] See footnote 21.

results in reduced growth in chronically exposed fish. However, long periods of exposure to artificial high particle concentrations are not expected, and thus no effects because adult fish is expected to swim away from the particle cloud at a concentration window that may be slightly different in different species (reported values are 60-180 mg/L). The effect limit of 50 mg/L is therefore a rather conservative[26] effect limit for avoidance.

§ 11 - Norwegian:

Effektgrensen for *letaleffekter* i voksen fisk settes konservativt til **400 mg/L**, basert på Newcombe (2003) og 6 dagers eksponeringstid. Fordi voksen fisk forventes å unngå partikkelskyen ved betydelig lavere konsentrasjoner og derfor ikke vil bli eksponert for høye konsentrasjoner over lang tid, blir letalgrensen i pelagisk fisk snarere en pseudogrense, mens den reelle effekten vil være at det ikke vil være voksen fisk tilstede i vannmasser med høyt partikkelinnhold. Det er også kjent at fiskearter med sterk tilknytning til bunn har høyere toleranse mot løste partikler i vann enn pelagisk fisk (Sherk *et al.*, 1975; Wilber & Clark 2001). Dette må også forventes i fisker tilknyttet sjøbunn i Førdefjorden hvor silt- og leirfraksjonen er helt dominerende (68-92 %). Ved å bruke en effektgrense for pelagisk fisk er det derfor rimelig å anta at bunnlevende fisk ligger godt innenfor effektgrensen.

§ 11 - English:

The effect limit for *lethal effects* in adult fish is set conservatively at **400 mg/L**, based on Newcombe (2003) and exposure duration of 6 days. Because adult fish expectedly avoid the particle cloud at significantly lower concentrations and will, therefore, not be exposed to high concentrations for a prolonged time, the lethal limit in pelagic fish is rather a pseudo limit, whereas the real effect will be the absence of adult fish in water with a high content of particles. Strongly bottom-associated fish species also display higher tolerance to dissolved particles than pelagic fish (Sherk *et al.*, 1975; Wilber & Clark 2001). The same should be expected for fishes associated with the Førde Fjord's sea bed, in which the silt and clay fraction is totally dominating (68-92%). By using an effect limit for pelagic fish it is therefore reasonable to assume that bottom-living fish are well within the effect limit.

§ 12 - Norwegian:

Fiskeegg og larver er generelt mer følsomme for endringer i det naturlige vannmiljø enn voksen fisk. I tillegg har ikke fiskelarver evnen til å svømme vekk fra en partikkelsky på samme måte som voksen fisk og kan derfor potensielt bli eksponert over lang tid. Økt dødelighet i fiskelarver er rapportert ned til 100 mg/L (Van Dalfsen, 1999; Kiørboe *et al.*, 1981). Sildelarver (*Clupea harengus*) foret i vann med 20 mg/L suspenderte sedimenter spiste mindre *Artemia* enn larver fra kontrollgruppen, noe som også ble gjenspeilet i en lavere vekstrate i eksponerte larver (Johnston & Wildish, 1982).

§ 12 - English:

Fish eggs and larvae are generally more sensitive than adult fish to changes in the natural aquatic environment. Additionally, fish larvae do not have the ability to swim away from a particle cloud in the same way as adult fish, and can therefore become exposed for a potentially long time. Increased mortality in fish larvae has been reported down to 100 mg/L (Van Dalfsen, 1999; Kiørboe *et al*., 1981). Herring larvae (*Clupea harengus*) fed in water with 20 mg/L of suspended sediments ate lesser amounts of *Artemia* than larvae in the control group, as also reflected in a reduced growth rate in the exposed larvae (Johnston & Wildish, 1982).

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[26] For safety sake

§ 13 - Norwegian:

Med utgangspunkt i disse resultatene settes effektkonsentrasjoner i fiskelarver til **20 mg/L** for subletale effekter, og **100 mg/L** for letale effekter. Den subletale effektgrensen finner støtte i kanadiske vannkvalitetskriterier på 25 mg/L for total partikkelkonsentrasjon i lakseelver (Canadian Council of Ministers of the Environment, 2002).

§ 13 - English:

Based on these results is effect concentrations in fish larvae set to **20 mg/L** for sublethal effects, and to **100 mg/L** for lethal effects. This sublethal effect limit is supported by Canadian water quality criteria at 25 mg/L for the total particle concentration in salmon rivers (Canadian Council of Ministers of the Environment, 2002).