Issues for the assessment of sediment plumes arising from deep sea mining operations

Dr Jeremy Spearman, HR Wallingford, Howbery Park, Wallingford, Oxfordshire OX10 8BA, UK (j.spearman@hrwallingford.com)

Introduction

As offshore mining becomes potentially more feasible for a variety of different minerals, there are increasingly more applications:

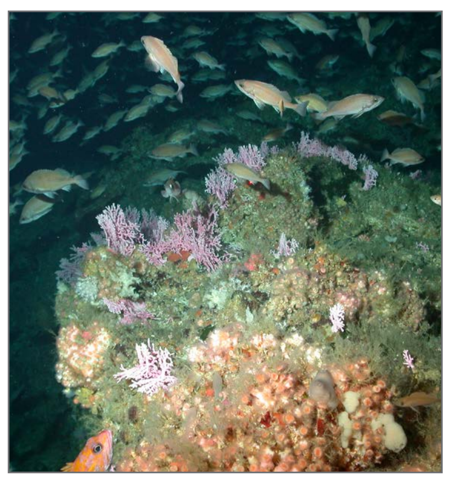
- in less well known environments;
- without the benefit of decades of monitoring;
- often with sensitive environmental issues;
- often without clearly defined path for gaining consent.

This poster considers some of the re-occurring themes that have occurred in recent offshore mining applications with regard to the physical processes and their numerical modelling.

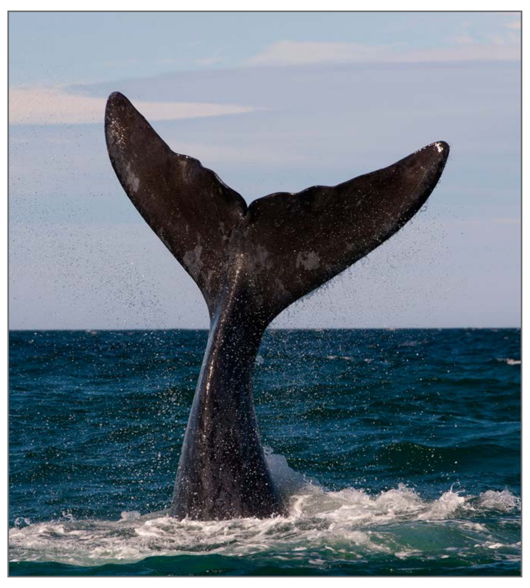
Why do projects struggle to gain consent?

- Lack of understanding and uncertainty in:
  - Fine sediment losses (particularly from discharge of tailings)
  - Settling velocity
- Over-conservative modelling approaches
- Expectations of ocean-current models
- Requirements for validation prior to consent

These issues lie alongside uncertainty in the distribution and sensitivity of benthos and in the potential effects of noise on fish and marine mammals.



Sea bed, Cortes Bank. NOAA Southwest Fisheries Science Center, Advanced Survey Technologies Group."



Discharge and near-field mixing of mine tailings

Discharge of tailings typically implemented near bed to reduce the dispersion of fine sediment into the upper water column.

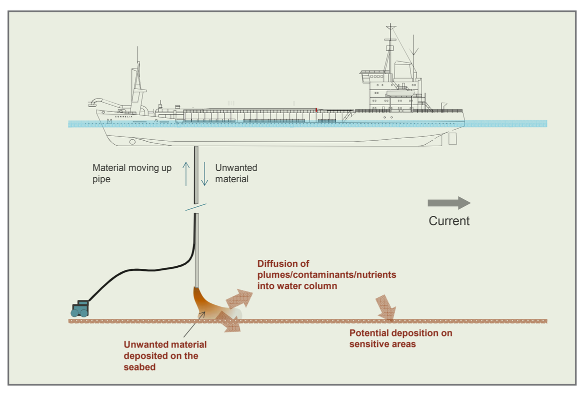
The pipe discharge has momentum and negative buoyancy and plume will move rapidly downwards, entraining water and diluting as it does so.

The plume very soon impinges on the bed forming a density current which will spread radially outwards (Spearman, 2011; de Wit, 2014).

Mixing of this density current into the overlying waters depends on the difference in density between the plume and the overlying waters and the ambient current.

This "dynamic plume" process is well known for reducing the amount of fine sediment in dredging plumes (Whiteside et al, 1995; John et al, 2000; Spearman, 2011; Aarnikhof et al, 2010).

In deep sea environments, current speeds are low: 0.1-0.2 m/s is typical near the bed. So the vast majority of released sediment remains as a near bed layer and will deposit onto the bed close to the point of release.



Summary of plume processes resulting from deep sea mining.

Physical modelling of disposal sediment plumes (Boot, 2000).

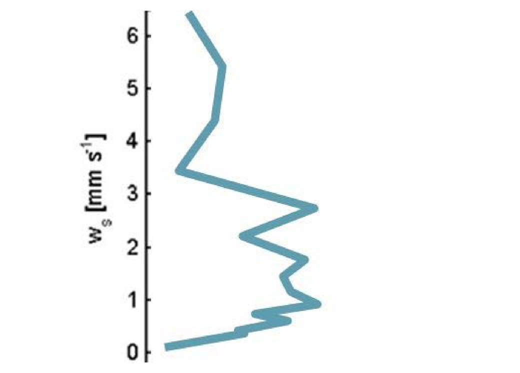
Settling velocity of fine sediment in mining plumes

Fine sediment flocculates due to electrostatic forces and biogenic sticky polymers present in the water column (Manning et al, 2011).

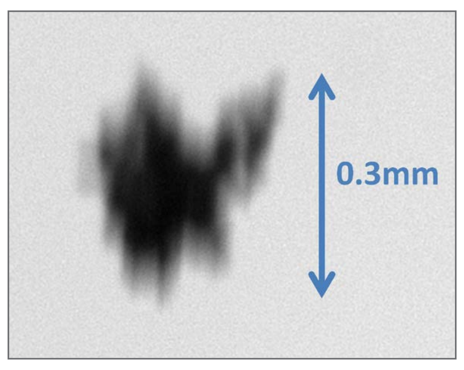
Evidence from measurements of natural background concentrations (e.g. Manning & Dyer, 2007, Soulsby et al, 2013) and dredging induced plumes (Smith and Friedrichs, 2011) indicate typical settling velocities of O(1) mm/s – i.e. one or two orders of magnitude higher than the corresponding speeds for primary fine silt and clay particles.

Where uncertainty exists reliable estimates of the settling velocity can reliably be derived from laboratory experiments (e.g. Manning et al, 2013) for a range of concentrations and relevant turbulence conditions using sea bed samples and video measurement devices.

Some recent mining studies have used the settling velocity of the primary particles rather than flocculated particles and so their predicted plume dispersion is too extensive.



Distribution of floc settling velocities in a mining plume (data reproduced from Smith and Friedrichs, 2011).



Typical video capture of a floc. The settling velocity of this floc was measured to be 1.8 mm/s.

Annular flume used for floc test under shear (Manning et al, 2013),.

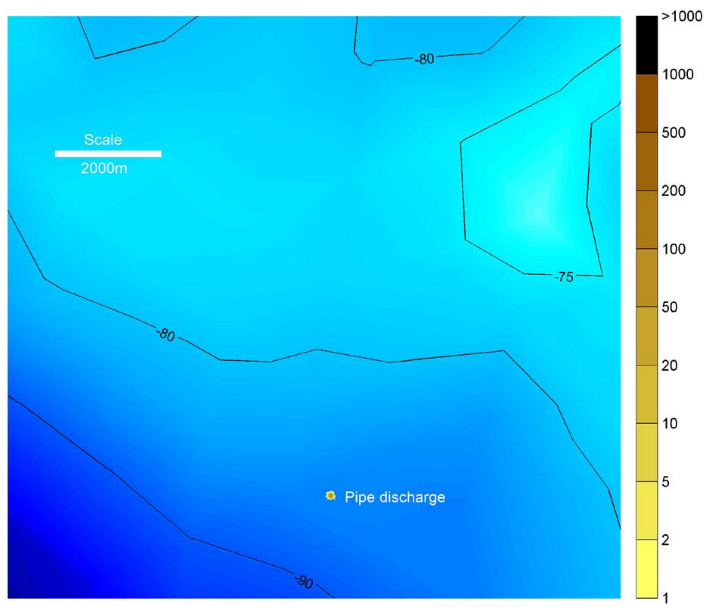
Over-conservatism

The complexity of the near-field mixing and flocculation processes present a challenge to the modeller within EIA studies. There is a temptation to simplify these processes through conservative assumptions like:

- Assuming all fine sediment released from the pipe discharge is released into the water column;
- Assuming fine sediment settles at the rate of non-flocculated individual particles.

Such simplifications can aid the EIA process if they clarify an already benign result. However, for deep sea mining studies over-conservatism results in the prediction of plume dispersion over long distances which instead contributes to regulator and stakeholder concerns and is counter-productive.

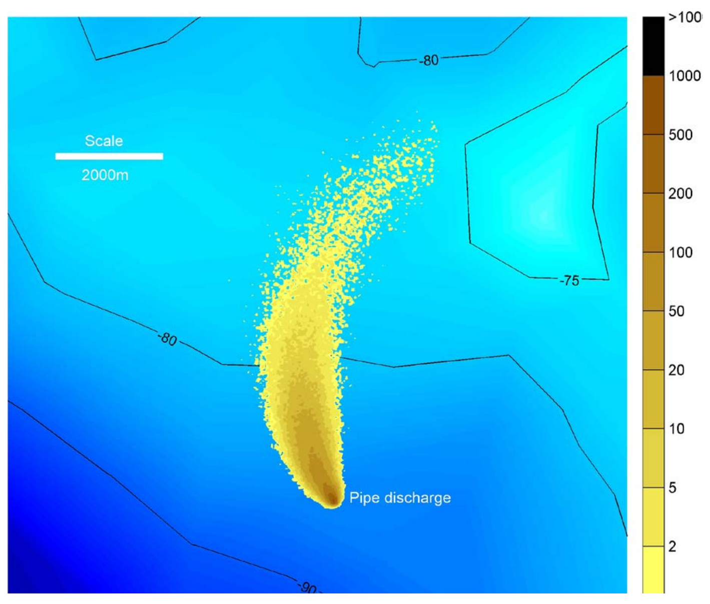
Moreover, concerned stakeholders will naturally worry that any model results presented for EIA are not conservative (even if they are) and so it is much better for all concerned to present "best estimate" rather than "worst case" results.



Correct

Snapshot of average sediment concentration (mg/l) in bottom 20m water depth, from mining tailings discharge

Modelling WITH dynamic plume, plume collapse onto bed, flocculation and turbulent damping.



Incorrect

Same snapshot

Modelling WITHOUT dynamic plume, plume collapse onto bed, flocculation or turbulent damping.

Model expectations

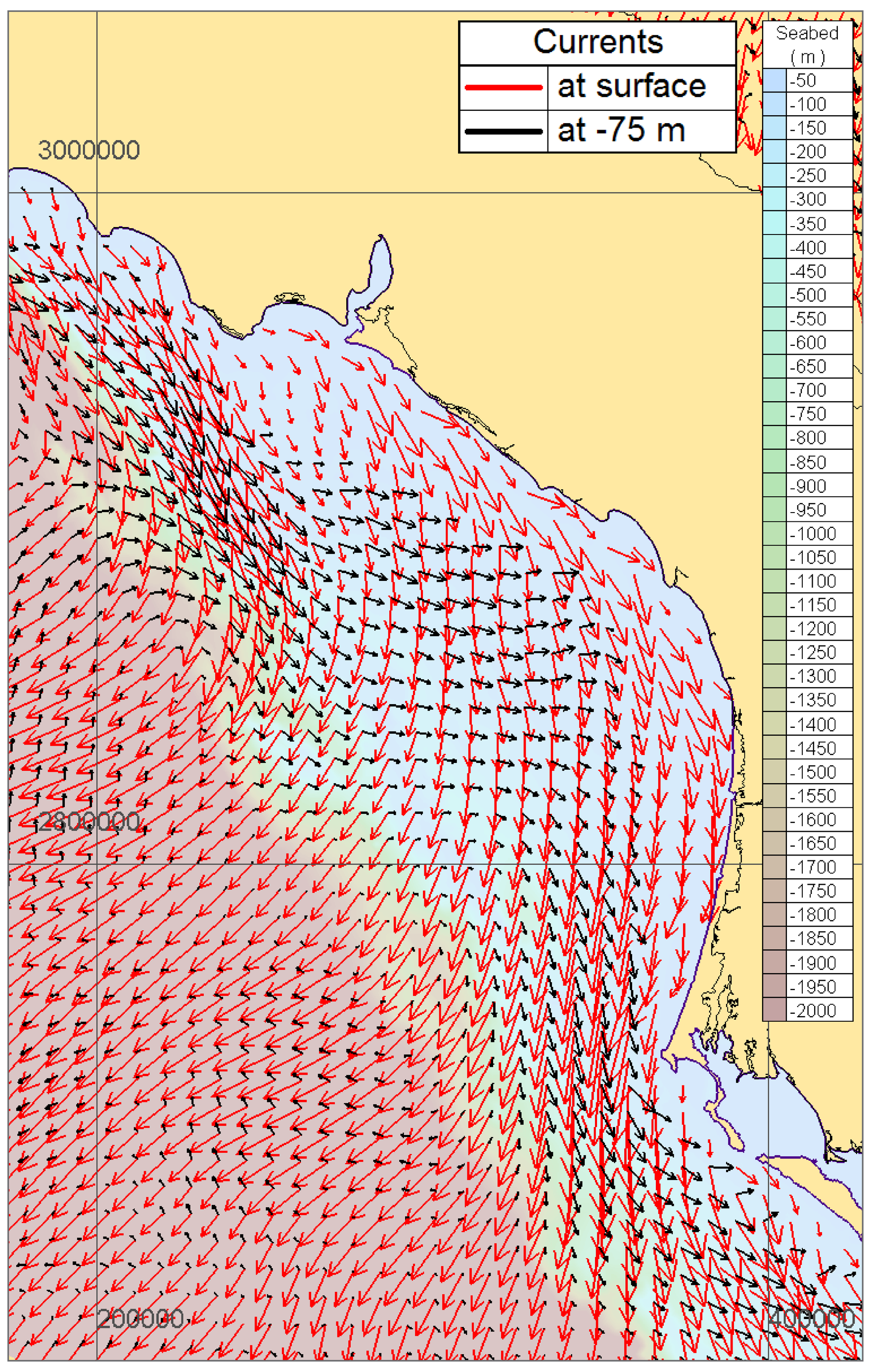
Ocean current modelling is required as input to the plume dispersion assessment to support EIA for deep sea mining.

Because of the complexity of ocean flow, these models are only accurate in a statistical sense – *they predict the right sort of currents in most places, most of the time.*

In EIA these statistically-accurate predictions of flow are compared to long data sets of current measurements expecting that these models produce an accurate reproduction of the temporal changes in measured flow.

These shortcomings can be resolved if the assessment shows that the footprint of the plume impact is local to the mining, since the detail of the flows becomes less important.

This is why the considerations of near-field mixing and settling velocity are vital to a successful assessment outcome.



HYCOM model predictions of flows along Mexican Coastline (data from hycom.org).

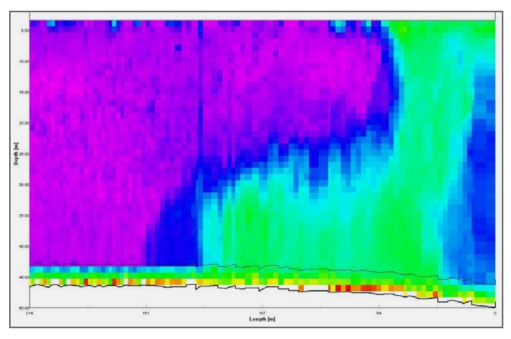
Validation

Plume behaviour cannot be verified against measured data until after consent is given and mining starts. But the regulator would like in situ verification of the plume model before consent can be given.

The absence of verification can play a significant negative role in the outcome of a mining EIA process (NZEPA, 2015).

Identifying a process satisfactory to both regulator and mining applicant alike, by which plume models can be adequately verified prior to consent, is a key issue which needs to be addressed by the industry.

Monitoring of aggregate dredging sediment plumes in the English Channel



ADCP backscatter transect image showing descent and collapse of aggregate dredging plume.

Conclusions

This paper has discussed some of the key points - including near-field mixing, settling velocity and model accuracy - which have arisen from the assessment of plume dispersion arising for deep sea mining applications to date.

Learning from these experiences, and from parallel experiences in ecological assessment not discussed here, will be important for successful deep sea mining applications in the future.

References

Aarninkhof S G J, Spearman J, de Heer A F M and van Koningsveld M (2010), Dredging-induced turbidity in a natural context, status and future perspective of the TASS Program. Proceedings of the 19th World Dredging Conference (WODCON XIX), Beijing, China.

Boot M (2000) Near-field verspreiding van het overvloeiverlies van een sleephopper zuiger, MSc thesis for the Technical Univ. Delft. (In Dutch).

de Wit L (2014) Near-field 3D CFD modelling of overflow plumes, Marine Pollution Bulletin 88 (1): 47-61.

John S A, Challinor S L, Simpson M, Burt T N, Spearman J (2000) Scoping the assessment of sediment plumes from dredging (C547). Construction Industry Research and Information Association (CIRIA). UK.

Manning A J and Dyer K R (1999) A laboratory examination of floc characteristics with regard to turbulent shearing. Marine Geology, 160, 147-170.

Manning A J and Dyer K R (2007) Mass settling flux of fine sediments in Northern European estuaries: measurements and predictions. Marine Geology 245, 107–122.

Manning A J, Baugh J V, Soulsby R L, Spearman J R and Whitehouse R J S (2011) Cohesive Sediment Flocculation and the Application to Settling Flux Modelling, In: Sediment Transport, Intech, Vienna, Austria.

Nautilus (2008) Environmental Impact Statement, Solwara 1 Project, Volume A, Main Report, September 2008.

NOAA (2013) NCOM Hi-res currents around the Hawaiian Islands, http://www.opc.ncep.noaa.gov/Loops/NCOM/currents/Ncom_Curr_Haw_03_Day_flash.shtml

NZEPA (2015) Decision on marine consent application Chatham Rock Phosphate Limited to mine phosphorite nodules on the Chatham Rise, New Zealand Environmental Protection Authority, February 2015.

Mead S T (2014) Statement of evidence of Gerard Van Raalte for Chatham Rock Phosphate, Chatham Rock Phosphate Marine Consent Application, September 2014.

Smith S & Friedrichs C T (2011) Size and settling velocities of cohesive flocs and suspended sediment aggregates in a trailing suction hopper dredge plume, Continental Shelf Research, 31: S50–S63.

Soulsby R L and Manning A J and Spearman J and Whitehouse R J S (2013) Settling velocity and mass settling flux of flocculated estuarine sediments, Marine Geology, 339:1-12.

Spearman J, De Heer and Aarninkhof S G J and Van Koningsveld M (2011) Validation of The TASS System For Predicting The Environmental Effects Of Trailing Suction Hopper Dredging, Terra et Aqua, 125 . (2011)

Spearman J (2014) Prediction of the overflow of sediment from trailer dredgers, Proceedings of the Institution of Civil Engineers, Maritime Engineering 167, Issue MA2,Pages 82–96.

Whiteside P G D, Ooms K, and Postma G M (1995) Generation and decay of sediment plumes from sand dredging overflow. In: Proceedings of 14th World Dredging Congress Amsterdam.