WAMSI Dredging Science Node | Theme 2 Synthesis Report: Predicting and measuring the characteristics of sediments generated by dredging

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WAMSI Dredging Science Node

Theme 2

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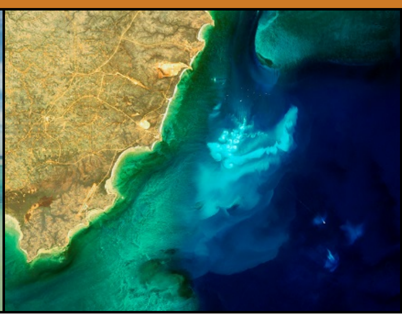


WAMSI Dredging Science Node

The WAMSI Dredging Science Node is a strategic research initiative that evolved in response to uncertainties in the environmental impact assessment and management of large-scale dredging operations and coastal infrastructure developments. Its goal is to enhance capacity within government and the private sector to predict and manage the environmental impacts of dredging in Western Australia, delivered through a combination of reviews, field studies, laboratory experimentation, relationship testing and development of standardised protocols and guidance for impact prediction, monitoring and management.

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Funding Sources

The $20million Dredging Science Node is delivering one of the largest single issue environmental research programs in Australia. This applied research is funded by **Woodside Energy, Chevron Australia, BHP Billiton and the WAMSI Partners** and designed to provide a significant and meaningful improvement in the certainty around the effects, and management, of dredging operations in Western Australia. Although focussed on port and coastal development in Western Australia, the outputs will also be broadly applicable across Australia and globally.

This remarkable **collaboration between industry, government and research** extends beyond the classical funder-provider model. End-users of science in regulator and conservation agencies, and consultant and industry groups are actively involved in the governance of the node, to ensure ongoing focus on applicable science and converting the outputs into fit-for-purpose and usable products. The governance structure includes clear delineation between end-user focussed scoping and the arms-length research activity to ensure it is independent, unbiased and defensible.

And critically, the trusted across-sector collaboration developed through the WAMSI model has allowed the sharing of hundreds of millions of dollars' worth of environmental monitoring data, much of it collected by environmental consultants on behalf of industry. By providing access to this usually **confidential data,** the **Industry Partners** are substantially enhancing WAMSI researchers' ability to determine the real-world impacts of dredging projects, and how they can best be managed. Rio Tinto's voluntary data contribution is particularly noteworthy, as it is not one of the funding contributors to the Node.

Funding and critical data

woodside Chevron WESTERN AUSTRALIAN MARINE SCIENCE INSTITUTION BHP

Critical data

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Front cover images (L-R)

Image 1: Trailing Suction Hopper Dredge *Gateway* in operation during the Fremantle Port Inner Harbour and Channel Deepening Project. (Source: OEPA).

Image 2: Dredged material from the Cutter Suction Dredge *Leonardo da Vinci* entering the hopper of the Trailing Suction Hopper Dredge *Nina* at the Port of Geraldton. Overflow plume containing high concentrations of 'fines' is visible on the port side of the *Nina*. (Source: OEPA)

Image 3: Dredge Plume at Barrow Island. Image produced with data from the Japan Aerospace Exploration Agency (JAXA) Advanced Land Observing Satellite (ALOS) taken on 29 August 2010.

Image 4: Image 4: Hopper of the Trailer Suction Hopper Dredge Nina showing overflow through the stand-pipe during the Geraldton Port Enhancement Project. (Source: OEPA)

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Executive summary

Dredge plumes are formed when dredging operations suspend rock and soil particles into the water column by mechanical, scouring and mixing actions and by direct discharges from dredging equipment. The particle size composition and settling velocity distribution of the suspended material depends on the *in situ* characteristics of the material to be dredged and on the changes to the material which occur as it is worked by the dredging equipment. Coarse particles initially present in the dredge-induced suspension settle rapidly back to the seabed, whereas slowly settling particles remain longer in suspension and are transported further by ambient currents.

The hopper overflow discharge from a Trailing Suction Hopper Dredger (TSHD) contains high concentrations of fine sediments, making it denser than the surrounding seawater. This negatively buoyant discharge forms a “dynamic plume” which descends as a bulk flow through the water column at a rate much greater than the settling velocity of the individual particles in the plume. Hence, some of the fine particles from the hopper overflow discharge may be conveyed rapidly to the seabed by the bulk flow of the dynamic plume, while some may be suspended at low concentration into the surrounding water column as the dynamic plume is mixed and decays.

In general, only the finer fraction (or a portion thereof) of the initially released dredged material is able to be transported beyond the field of turbulence induced by the dredger and to a distance where the plume buoyancy is no longer important. This distance may be several to hundreds of metres, depending on the type and size of the dredging equipment and other operational and environmental factors. The plume is then said to have left the ‘near-field’ and entered the ‘far-field’, and is described as a ‘passive plume’, its behaviour being subject only to the ambient hydrodynamics and to its particulate settling characteristics.

Fine dredged material particles entering the far-field may remain suspended for hours up to days and the passive plume may extend up to tens of kilometres from the point of release, depending on the ambient hydrodynamics. Far-field (passive) dredge plume modelling is generally used in environmental impact assessment of dredging projects to assess the potential extent, duration and influence of the dredge plume on water quality and to identify any areas where sensitive ecological communities may be impacted by significant adverse ecological pressures (e.g. reduced irradiance, sedimentation) due to the intensity and duration of their exposure to the effects of dredge plumes.

These far-field dredge plume models require the input of suspended sediment ‘source terms’ which specify the rates, vertical profiles and settling characteristics of sediment particles introduced to the water column by dredging activities. The extent and intensity of the dredge plumes predicted by these models is significantly influenced by the source term specification. However, since passive dredge plume models do not resolve density currents, propeller wash effects and other dynamic processes associated with the near field development of dredge plumes, they require source terms representing the suspended sediments entering the far-field rather than the sediment release rates directly at the dredger.

Estimation of the far-field suspended sediment source terms can be a challenging task, particularly at the EIA stage of the dredging project proposal, given project design, engineering and geotechnical uncertainties at that stage. The two basic approaches used are:

- empirical – using source term estimates previously derived from on board and dredge plume data sets collected under circumstances and conditions similar to those anticipated for the current dredging proposal; and
- process-based – using calibrated and validated numerical models based on an understanding of the physical processes and input data that determine the far-field source terms.

State of knowledge prior to the WAMSI DSN (prior to 2010)

Kemps and Masini (2017) reviewed the environmental impact assessment (EIA) documentation associated with 15 dredging projects in Australia (12 from WA) to examine the practices used to estimate suspended sediment source terms for input into far-field dredge plume prediction models. The review focused on the key source term contributions from the Cutter Suction Dredger (CSD) and the Trailing Suction Hopper Dredger (TSHD), as shown in Table 1.

Table 1. Primary source term contributions for trailing suction hopper dredgers and cutter suction dredgers that are typically used to support dredge plume modelling for environmental impact assessment and management in Australia.

Dredging Equipment	Source Term Contribution
Trailing suction hopper dredger (TSHD)	Hopper overflow Propeller wash erosion of the bed Draghead stir up
Cutter suction dredger (CSD)	Cutterhead stir up Cutterhead sidecast Pumped sidecast Hopper overflow* Propeller wash erosion of the bed*

* CSD loading to a TSHD which maintains its position with propellers and thrusters.

This review found that a diversity of approaches had been adopted for estimating far-field source terms. It was also evident that estimates for far-field source rates for each source type differed considerably between proposals. These differences are in part a reflection of the range of different substrate types between locations/proposals, the relative levels of confidence about the geotechnical (and environmental) conditions likely to be encountered, the type/size of dredger(s) and associated operating schedules. Nonetheless, some of the estimates representing the upper end of the range appeared overly conservative.

In the early stages of EIA, particularly for project proposals in green-fields sites, where there is often limited knowledge of some of the most basic elements of a dredge program – e.g. the characteristics of substrates to be dredged and the types of dredgers and work methods to be used – far-field source terms are estimated using a range of untested assumptions. The fact that many of the EIA documents reviewed were for major capital dredging proposals at green-fields sites may help to explain the variation in estimates between projects, and even within projects as the knowledge base matured (e.g. when more geotechnical data became available).

From the review of Kemps and Masini (2017) it became apparent that the absence of a common and consistently-applied framework for estimating and reporting the source terms (including documentation of the input data and underlying assumptions) was severely limiting the potential to build a knowledge and data base that could be used widely by dredging engineers and practitioners to more confidently estimate source terms for future projects.

Mills and Kemps (2016) reviewed the existing state of knowledge with regard to process understanding, measurement protocols and prediction of:

- fine particle generation when soil or rock material is processed by dredging equipment at various stages of the dredging work method;
- the introduction of particles into the water column (dredge-induced resuspension) and
- the fate of the dredge-induced resuspended material during the early stages of dredge plume development.

Knowledge in these areas is required to appropriately specify suspended sediment source terms for input to passive dredge plume prediction models that are used in environmental impact assessment of dredging proposals.

Research program

The full scope of work originally proposed for Theme 2 in the Dredging Science Node Plan (Masini et al. 2011) was not able to be undertaken due to a lack of capability and funding at the time, so it was limited to the two literature reviews (Mills and Kemps 2016, Kemps and Masini 2017) referred to in the previous section.

The Theme 2 reviews were conducted during a period when some very significant advances were being made by the international dredging science community in the area of source term estimation and prediction. We shall highlight two of these developments in the following sections.

Overview and synthesis of findings

A generic approach to far-field sources term estimation

Becker et al. (2015) proposed a framework for far-field source term estimation that can be applied and subsequently refined across successive phases in the development of a capital dredging project as more detailed data become available. The method facilitates evaluation and comparison of the amounts and locations of fine sediments released to the far-field by alternative dredging strategies and work methods.

The Becker et al. (2015) approach is based on the fines content in the dredged material, the dredging work method (its stages, locations and durations) and dredging production figures, combined with values for equipment- and condition-specific ‘source term fractions’. For each source of fine sediment released from the dredging equipment, a *source term fraction* can be defined that relates the mass of suspended sediment supply to the far-field plume to the mass of fines that is available at that stage of the dredging process. In general, values for the source term fractions may be derived empirically from field data sets. For hopper overflow discharge from a TSHD, appropriately validated process-based models may be used to estimate source term fractions.

Drawn from their professional experience and from the published literature, Becker et al. (2015), van Eekelen et al. (2015) and Laboyrie et al. (2018) provide general guidance on “realistic” ranges of values for source term fractions pertaining to several types of dredging equipment. In the early phases of the project design, source term fractions based on this guidance, or on existing field measurement datasets gathered under similar dredging operations and conditions, may be able to provide initial source term estimates. However, as further details of the dredging method, geotechnical and environmental data become available, the chosen values for the source term fractions should be reassessed and source term calculations reviewed (van Eekelen 2015).

It is good practice to conduct dredge plume and on-board monitoring campaigns during project execution phase to test and refine the far-field source term predictions and parameters, underlying assumptions and the applicability of far-field source term estimation methods. When properly executed and documented, these monitoring campaigns will add to the range of conditions and circumstances for which source term fraction values are available for future use. They will also provide further data to refine and extend the parameter domain of validation of process-based source term models. A publicly available source term parameter ‘library’ should be established to facilitate the dissemination of these findings for application to future dredging project assessments.

Near-field mixing of the dynamic plume from TSHD overflow

Often, the primary cause of increased turbidity or sedimentation from a TSHD is from the hopper overflow discharge which contains high concentrations of fines and creates an initially negatively buoyant dynamic plume under the keel of the vessel.

The mixing behaviour of the dynamic plume varies considerably from case to case, depending on a range of factors, including the relative importance of buoyancy and momentum in the hopper overflow discharge, and the ratio of vertical momentum of the overflow discharge to the horizontal momentum of the crossflow.

Turbulent mixing of the dynamic plume may be further enhanced by its proximity to the moving TSHD, by a shallow seabed, as well as by the presence of air bubbles entrained in the overflow and fluctuations in the overflow discharge. These influences can cause part of the dynamic overflow plume to be mixed up toward the free surface very close to the TSHD (Nichols et al. 1990, Spearman et al. 2011, Whiteside et al. 1995, de Wit et al. 2014c). The percentage of sediment flux in the overflow that is diverted from the dynamic (negatively buoyant) overflow plume into a passive surface plume has an important influence on the far-field source flux; it can vary significantly from one case to another.

De Wit (2010) developed a three-dimensional Computational Fluid Dynamics (CFD) model with large eddy simulation (LES) to study near-field mixing of dynamic plumes from TSHD overflow and to investigate the influence of the above-mentioned factors on the fraction of the fine sediment flux from the overflow discharge that reaches the far-field and becomes available for passive plume dispersion. The model has been successfully validated against a wide range of experimental and full-scale data sets (de Wit et al. 2014a, de Wit et al. 2014b).

De Wit et al. (2014b) ran the CFD model 136 times with different combinations of the parameter values within the demonstrated range of validity of the model. For each of the model runs the fraction of sediment flux from the overflow that enters the far-field in suspension was calculated. Least square error curve fitting was then applied to derive relationships that describe the source term fraction for the overflow as a function of the parameters. These relationships implicitly incorporate all investigated near- field processes and are robust and reasonably accurate within the demonstrated range of validity of the model. They can be used to predict the far-field source term from hopper overflow for input to a passive dredge plume model when field measurement data sets are not available for the dredging case under consideration.

De Wit (2014b) outlines a procedure for estimating the far-field source term contribution from the overflow of a TSHD. He shows how the functional relationships derived from his model parameter study can be used within a procedure that is consistent with the method of Becker et al. (2015).

Implications for management

A generic approach to far-field source term estimation

The general adoption and consistent use of the Becker et al. (2015) procedure for far-field source term estimation will facilitate:

- a standardised, transparent reporting format for far-field source term estimation;
- systematic documentation of all relevant input data, assumptions and parameter values involved in the source term calculations;
- the use of either empirical or process-based (modelling) approaches to assign values for the source term fractions;
- sensitivity analysis and the incorporation of uncertainty in source term estimation;
- comparisons of source term estimates arising from alternative dredging work methods;
- the updating of source term estimates during the planning and optimisation of dredging strategies as new data and information come to hand;
- efficient information transfer between dredging projects through the development of a publicly accessible "library" of source term fractions and parameters encompassing a wide range of dredging circumstances and environmental conditions.

Near-field mixing of the dynamic plume from TSHD overflow

The research on near-field mixing of the dynamic overflow plume has significant implications for management. As a result of this work:

- the operational and environmental factors and parameters that are influential in generating passive, plumes as a result of near-field mixing of the dynamic overflow plume are better understood. This knowledge can be used in the design, selection and operation of TSHDs to reduce the amount of fine sediment available for passive plume dispersion in the far-field.
- the percentage of sediment flux in the overflow that is diverted into the passive plume can now be calculated for a range of TSHD dredging conditions using simple relationships. This percentage, which can vary significantly from one case to another, has an important influence on the far-field source flux.

Residual knowledge gaps

The action of mechanical and hydraulic forces during dredging operations may, in some cases, significantly increase the fines fraction in the dredged material, the mass rate of fines released to the marine environment and the intensity and detectable extent of dredge plume transport from the source. There is currently very little published data that documents development in the particle size composition in dredged material as it passes through the various stages of full-scale dredging operations (Ngan-Tillard et al. 2009). Neither are there generally accepted methods of reproducing (or predicting) these changes in dredged material size composition from laboratory scale tests (Costaras et al. 2011, Barber et al. 2012).

The number of open access, comprehensive dredge plume measurement data sets available for source term estimation and the range of circumstances in which they have been collected is still limited. Further full-scale dredging measurement trials and high quality data sets are needed to: provide empirical estimates for suspended sediment source terms; improve understanding of resuspension processes; and develop, calibrate and validate improved models of dredge plume generation, particularly for site and operating conditions that have not yet been adequately represented.

Conclusions and recommendations

The source terms may vary greatly from one dredging case to another, since they depend on many factors, including: the nature of the *in situ* material to be dredged; the type and specifications of the dredging equipment; the dredging work method and dredge operating parameters; and the site conditions (including bathymetry, currents and waves).

The reviews highlighted the importance of dredge-induced sediment suspension datasets being collected according to agreed protocols and methods so that source terms calculated from these data sets can be reliably ranked and compared. Overall, the number of these datasets has increased significantly in recent years. However, many of these are not publicly available. Also, there are some relatively common dredging situations (e.g. trailing suction hopper dredging with low under keel clearance, or at an angle to the ambient current) that are not well represented by the available datasets.

The acquisition of high quality datasets, from both full-scale dredging operations and laboratory experiments, also leads to an improved understanding of the physical processes involved in the generation and release of dredged material particles and the early stages of plume formation. This enables the development of process-based source models as an additional means of estimating source terms.

It was not possible to recommend numerical values for source term parameters to use under local conditions based on these reviews, due to the paucity of relevant publicly available field data against which to compare estimates.

To address this situation it is recommended that:

- comprehensive field data sets be collected (using widely accepted protocols) during the project execution stage for major dredging projects to provide reliable source term estimates for input to passive dredge plume models and to extend the parameter domain of validation for process-based source term models;
- an open access dredge plume source term data library be established and populated over time, using the above-mentioned field data sets, to cover the different dredgers used and the various geotechnical and operational conditions encountered in capital dredging practice in Australia;
- the framework outlined by Becker et al. (2015) for calculating and reporting source term estimates for passive dredge plume modelling be generally adopted and consistently and iteratively used throughout the development and execution phases of major capital dredging projects, including the EIA stage. This consistency of approach will facilitate the development of the dredge plume source term data library.

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