Assessing the Impacts of Dredging in the Great Barrier Reef World Heritage Area

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Abstract
The consideration of potential impacts from maintaining and expanding port assets and associated dredging and dredge material placement situated within the Great Barrier Reef World Heritage Area has become a major environmental, social and political issue in recent times. Preceding the rise in profile of this issue, a set of *Guidelines on the use of hydrodynamic numerical modelling for dredging projects in the Great Barrier Reef Marine Park* were released by the Great Barrier Reef Marine Park Authority in August 2012. This paper looks at how technical assessments of dredging undertaken as part of Environmental Impact Assessments have evolved in the light of the new guidelines and in the broader context of increasing demand from stakeholders and government agencies for greater certainty about short and long term impacts.

Keywords: port, dredging, impact assessment, numerical modelling

1. Introduction

The Great Barrier Reef World Heritage Area (GBRWHA) encompasses the world's most extensive coral reef system, extending over 2000km and covering an area of 348,000km^2. Within this is an incredibly diverse array of ecosystems including coral reef communities, deep ocean areas, inshore mangrove communities, extensive seagrass meadows and a wide spectrum of inter-reefal benthic communities, of which coral reefs make up no more than 7% of the total GBRWHA (by area) [1]. See for example Figure 1. Within the GBRWHA is situated the Commonwealth Marine Park, which is managed by the Great Barrier Reef Marine Authority (GBRMPA). The GBR Marine Park covers 99% of the GBRWHA but excludes inter-tidal areas and a number of small areas around major ports and urban centres.

Preserving the environmental, cultural and social value of the GBRWHA is a legislated responsibility of the Australian Government under the EPBC Act and a high priority within the Australian community, as a result of its high global profile through World Heritage Listing and, more recently through the review of management arrangements by UNESCO in response to international campaigning by conservation groups that the site be listed 'In Danger'. At the same time, it is recognised that a whole range of human activities which have underpinned both past and future economic activity, have to varying extents impacted on these values, both prior to listing of the site in 1981 and continuing to the present day, including; agriculture, aquaculture, fishing, mining, energy, urban, tourism and port developments. Specific existing threats to the GBRWHA environmental values include declining water quality due to catchment runoff, crown of thorns starfish (linked to water quality), pressures from commercial/recreational fishing and coastal development impacts (including ports and shipping). Climate change, including rising ocean temperatures and related ocean acidification has also been postulated as a significant future threat [2, 3]. Despite the multitude of threats to the Reef identified in the Strategic Assessment and Outlook Report, it is port development projects and the impacts of marine placement (e.g. dumping) of dredge material that have captured the most lobby group, media and public attention in recent times.

Within this broader management context, this paper focusses on recent evolution in technical assessments underpinning Environmental Impact Assessments (EIA) for port development projects involving dredging and placement. In particular this paper showcases some of the EIA modelling and associated water quality and ecology assessment techniques that have been used in preparing EIS for the Port of Townsville Port Expansion Project [4] and the Cairns Shipping Development Project [5]. These EIA have been driven by increasing demands from stakeholders and government agencies for greater certainty about short and long term impacts to the GBRWHA and which have required a number of technical advances that are likely to have broader applications outside this specific region.

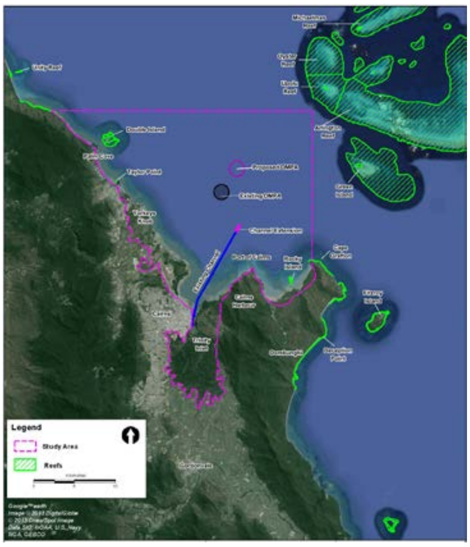

Figure 1 Gazetted Reefs in the Area Surrounding the Cairns Shipping Development Project [5].

2. Numerical Modelling

Numerical models are typically used as part of the EIA to predict project driven changes to, hydrodynamics, sediment transport and water quality (including dredge plumes).

2.1 GBRMPA Guidelines

Having identified that numerical modelling was an integral part of the port development EIS process, GBRMPA developed a set of *Guidelines on the use of hydrodynamic numerical modelling for dredging projects in the Great Barrier Reef Marine Park* [6], which have been stipulated in the Commonwealth Terms of Reference for such projects since late 2012. Key requirements of the guidelines include:

- Hydrodynamic modelling must be three-dimensional, accounting for tides, wind, waves, oceanic currents and potential stratification.
- Sediment transport modelling must consider a range of particle sizes and should include both current and wave-induced resuspension.
- Model must be calibrated and validated against site-specific baseline information, with minimum periods for data collection dependent on expected dredging campaign duration.
- Selection of dredge disposal site must be fully justified and compared to other possible sites.
- Impact modelling must cover a range of probable hydrodynamic conditions, weather events and expected dredge equipment scenarios.
- Impacts of dredging and dredge disposal should include “likely best case” and “likely worst case” scenarios.
- Model outputs should include suspended sediment concentration (mid-depth and near the seafloor) and sedimentation rate.
- Model results must be presented in a way that describes the spatial extent, severity and duration of predicted impacts of dredging.

While providing valuable guidance about minimum specifications for modelling and the associated collection of baseline data, the GBRMPA guidelines are not a comprehensive check-list of prerequisites for a robust dredging impact assessment. Nevertheless the GBRMPA guidelines are a useful tool to ensure consistency and have undoubtedly improved the rigour of numerical modelling assessments.

2.2 Hydrodynamics

The development of a 3D model is relatively straightforward, and the additional computational requirements are readily managed with current technology; however the calibration and validation of a 3D model is significantly more challenging than the validation of a 2D model [7]. Subject to site specific conditions a 3D hydrodynamic model may require boundary conditions prescribing; tidal water level variations, residual ocean currents, wind and atmospheric pressure, atmospheric bulk heat exchange, precipitation and river inflows. The 3D model vertical resolution and vertical mixing scheme should be capable of reproducing either thermal or fresh water induced stratification if these are potentially significant processes. Simply applying a sigma-coordinate 3D model with a limited number of vertical layers is unlikely to adequately capture vertical stratification within the GBR lagoon [5].

The consideration of ocean current forcing is a requirement of the recent GBRMPA guidelines. One approach is to linearly combine predictions from a data-assimilating global circulation model (e.g. HYCOM, BLUELINK) with predictions from a local area tide and wind model [6]. Shortcomings of this approach include the inadequate grid resolution (~10km) of the global models for inshore waterways such as the GBR lagoon, the potential for overestimating the influence of wind if it is being applied to both global and local models and not resolving any non-linear interactions between the tide/wind and ocean current driven currents. An alternative approach (e.g. [3]) is to apply a high-resolution model that is forced at its open boundaries by the global ocean circulation model effectively translating and downscaling this forcing into the nearshore region and at the same time integrating tide and local meteorological forcing. Figure 2 is an example of the Cairns EIS hydrodynamic model predictions with oceanic East Australia Current (EAC) driving southerly surface currents along the continental shelf margin east of the GBR lagoon. While the EAC forcing was not usually the major driver of instantaneous currents in the western GBR lagoon (these were wind and tide), it did have a significant influence on net drift predictions, and in fact tended to reduce the net NW wind-generated drift in the Cairns region.

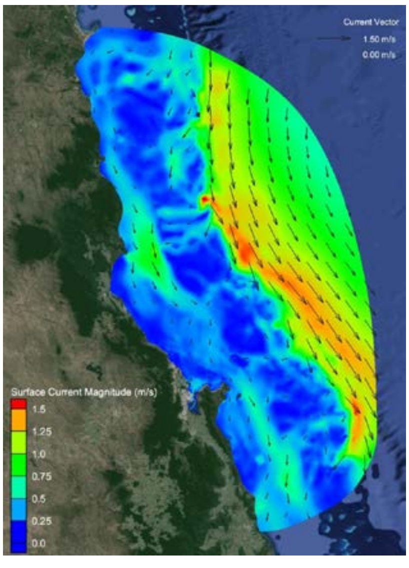

Figure 2 Example modelled currents during strong EAC.

2.3 Ambient Sediment Dynamics

Modelling of ambient sediment dynamics is not stipulated in the GBRMPA guidelines, however this has been undertaken as an integral part of the recent Cairns and Townsville port EIS assessments [4, 5]. Much of the inshore GBR lagoon waters experience highly turbid conditions due to wind-wave driven resuspension of marine silts that have been primarily sourced from catchment runoff over geological timescales [8] (refer photo in Figure 3 and turbidity model-data comparison plot in Figure 4).

Reasons for undertaking modelling of ambient sediment dynamics include the opportunity for calibration/validation of sediment resuspension predictions. Without undertaking site specific calibration the predictive capabilities of a complex wave/current/sediment model is expected to be limited. Ambient sediment transport simulations also feed in to the assessment of channel sedimentation and therefore project impacts to maintenance dredging requirements.

Figure 3 Turbid conditions in Cleveland Bay (Townsville) due to wind-wave driven resuspension of ambient sediment.

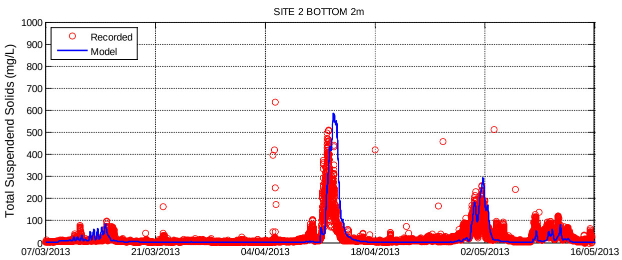

Figure 4 Measured and modelled turbidity at Cairns former DMPA site [5]. Note that turbidity is strongly (wind) event driven.

2.4 Dredge Plume Assessments

Assessing the potential risk posed by dredging and placement to GBRWHA values is often undertaken by simulating the advection, dispersion, deposition and resuspension of sediment plumes generated by the proposed dredging activities. This typically requires model schematisation of a representative dredging program and the associated sediment plume source rates. The requirement to consider a range of potential climatic conditions in combination with various dredging operations and the requirement to evaluate cumulative impacts across the entire project duration (and beyond) have driven the dredging impact assessments towards continuous simulations of hypothetical dredging programs in their entirety, rather than the previous approach of simulating a selected subset of dredging activities. The GBRMPA guidelines requirement for assessment of both “likely best case” and “likely worst case”, while somewhat ambiguous does encourage a sensitivity style assessment approach in order to explore variations due to, for instance, differing climatic conditions, dredge operations and plume loading assumptions.

Water quality impact assessments for dredging projects have traditionally been undertaken without modelling ambient sediment dynamics; however a major shortcoming of this “concrete bed” approach [9] is the lack of ambient context that is provided to the dredge plume predictions. For instance, the risk level attributed to a 20mg/L dredge plume is very different depending on whether the ambient suspended sediment is at the same time either 1mg/L or 100mg/L. Coupled simulation of ambient sediment and dredge plume sediments [5] has meant that the model predictions could be interrogated in order to derive the incremental impact of dredging on the ambient turbidity and sedimentation climate. Both acute (short-term, high-intensity) and chronic (long-term, low-intensity) perturbations to turbidity and sedimentation rate due to dredging are to be considered under the guidelines.

The question of how to robustly assess dredging impacts in the context of long simulations, often spanning in excess of 12 months, has led to the adoption of a moving 30-day window analysis approach. In each 30-day window a range of percentile (or exceedance duration) turbidity and sedimentation rate model results were analysed to determine the severity of chronic (e.g. 50th percentile) and acute (e.g. 95th percentile) impacts due to dredging. The moving windows were shifted in 10-day increments through an entire simulation, and the most severe impact at each point in the model was determined. Some example results from the CSDP EIS [5] are shown in Figure 5 for 50th percentile turbidity impacts and Figure 6 for 95th percentile impacts. Note that the two percentile plots have very different turbidity contour scales, which can be understood in the context of the different exceedance durations that they represent. The contour scales for each percentile (or exceedance duration) were selected based on the results of statistical analysis of the baseline turbidity measurements (refer Section 3 for more discussion). It is also worthwhile noting that the more significant impacts occur in the context of long-term, low-intensity turbidity perturbations. Impact assessments that are based only on short-term, high-intensity metrics can fail to account for these chronic impacts.

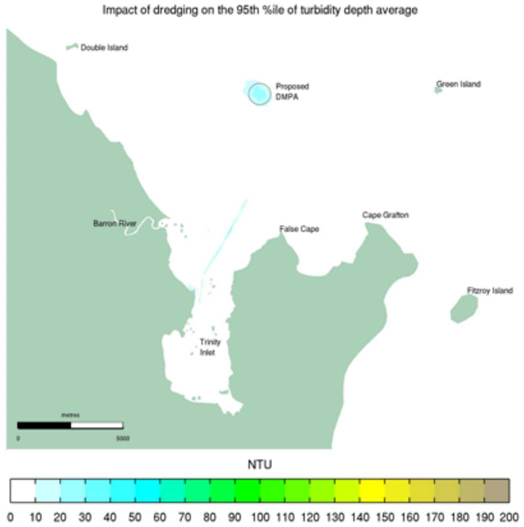

Figure 5 Impact of Dredging on 50th percentile Turbidity (scale: 2 to 40 NTU)

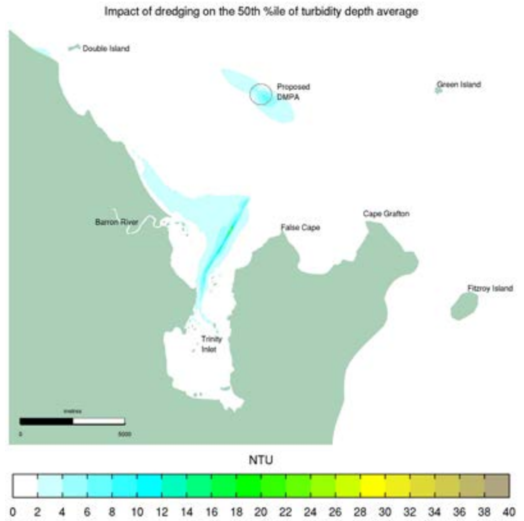

Figure 6 Impact of Dredging on 95th percentile Turbidity (scale: 10 to 200 NTU)

2.5 DMPA Resuspension Assessment

Recent EIS Terms of Reference and the GBRMPA guidelines have emphasised the importance of undertaking DMPA site selection studies. These are initially undertaken as high-level multi-criteria screening studies before selecting a number of short-list DMPA sites for detailed assessment. Detailed assessments have typically included long term (typically 12 months) simulations of resuspension and dispersal of material from the DMPA/s, and have been undertaken simulating both ambient and placed sediment (each represented by multiple size fractions). The consolidation, assimilation and armouring of DMPA material are complex processes and remain a significant open research question, however in order to simplify the assessments and introduce a degree of conservatism it has been assumed that the placed material has a higher (e.g. 50%) resuspension potential than the surrounding ambient material [5].

DMPA and residual dredge spill dispersion impacts on ambient turbidity and sedimentation were analysed using the moving window approach, with 95th percentile impacts shown in Figure 7 below. No significant water quality impacts are predicted at the DMPA site, while some very low level impacts are predicted due to resuspension of residual spill material in the vicinity of the proposed channel widening. The corresponding 50th percentile turbidity impact plots have not been shown here as they do not show any significant water quality perturbations.

The important role of Tropical Cyclones in shaping the physical and biological environment must also be accounted for as part of a robust EIA within the GBRMP region. For instance, the CSDP EIS [5] considered a “worst case” resuspension simulation for a hindcast period that included severe TC Yasi. The DMPA material contribution to elevated levels of suspended sediment and subsequent sedimentation through this event was shown to be very minor in the context of the levels generated by ambient material re-suspension and settling during the same event.

The assessed water quality impacts due to DMPA resuspension were generally very low in the context of the ambient turbidity signal where the DMPA was located in sufficiently deep water and the placed material was physically similar to the ambient benthos. It was found that DMPA options located in relatively shallow water were much more dispersive (often by an order of magnitude or more) than the deeper placement sites.

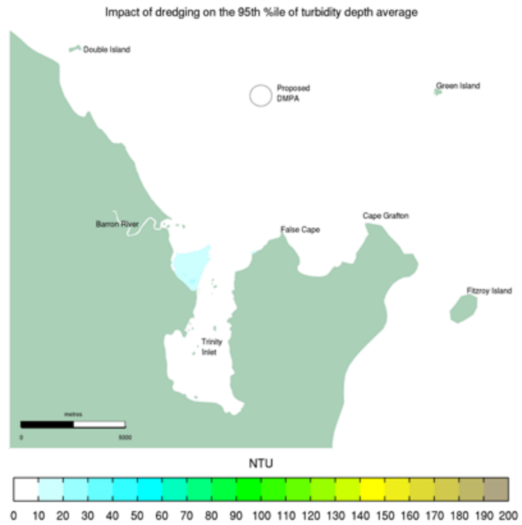

Figure 7 Impact of DMPA (and Residual Dredge Spill) Resuspension on 95th percentile Turbidity (scale: 10 to 200 NTU)

3. Dredging and Placement Risk Assessment

The assessment of environmental risk goes beyond the numerical modelling assessments described above and benefits from a multi-disciplinary approach to considering the multiple lines of effect by which dredging activities can impact physiochemical and ecological system/s. Challenges include; developing a set of risk assessment criteria (or threshold values) that are relevant to the local environmental conditions (e.g. turbidity, sedimentation and light); consideration of relevant biological tolerance information; and consideration of the full range of potential perturbation durations and intensities that my lead to impacts.

The collection of comprehensive baseline water quality datasets has been a critical undertaking in meeting these challenges through providing the basis for deriving a statistical description of (for instance) spatial and temporal turbidity variability. The temporal variability of turbidity statistics were analysed using a moving 30-day window, with the summary results at one CSDP EIS monitoring location shown in Figure 8. The x-axis represents the different percentile values extracted from the moving 30 day window analysis moving from frequently exceeded on the left to rarely exceeded on the right. The different curves are statistics representing the variability of the percentile analysis results across the different 30 day periods (making up the 12 month baseline monitoring period). The lower curve represents the least turbid conditions experienced across the 12 month period while the upper limit is conversely the most turbid conditions. The solid green line is the mean of the different 30 day window conditions.

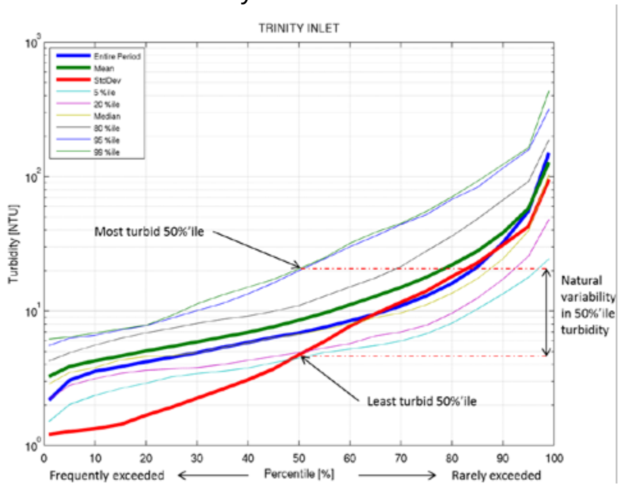

Figure 8 Summary of 30-day Moving Window Analysis of 12 month Baseline Turbidity Dataset for Trinity Inlet [5].

A description of the threshold values for the three zones of impact and how they relate to the natural variability is provided in Table 1. The approach used to determine the threshold level for the 'zone of low to moderate impact' (i.e. when water quality extends beyond natural variation and impacts to ecological receptors may begin to occur) involve using one standard deviation from the natural background mean at each percentile (i.e. 20th, 50th and 80th percentiles). This is similar to an approach developed to assess impacts from construction-related turbidity increases in Townsville [10], which suggested using one standard deviation from ambient conditions as a possible conservative upper limit of an acceptable increase in turbidity.

Extending this method out, threshold levels for the 'zone of high impact' were determined using three standard deviations from the mean. The 'zone of influence' was defined as the probable maximum extent of detectable plumes due to the proposed dredging. Turbid plumes were conservatively assumed to become detectable once they were 10% above background conditions. Descriptions of the zones of impact and how they relate to water quality (turbidity) thresholds are included in Table 1. Also included in this table are biological tolerance values for seagrass provided by JCU, which were used to test the zones of impact to ensure the zones were biologically relevant. The results of applying these water quality risk assessment criteria to a scenario assessment from the CSDP EIS are shown in Figure 9.

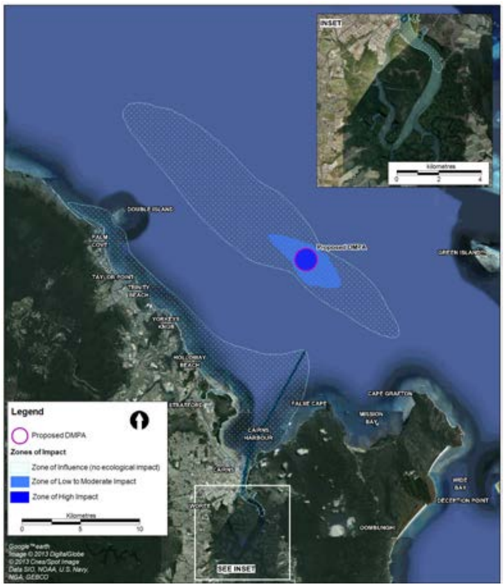

Figure 9 Example Water Quality Zones of Impact from the CSDP EIS [5].

In practice, any risk assessment that defines allowable perturbation thresholds needs to also be supported with an effective Dredge Management Plan based on reactive monitoring and tiered response actions.

4. Conclusions

The standard of EIS assessments related to port dredging and placement projects has benefited from the more rigorous assessment requirements as outlined in the GBRMPA hydrodynamic modelling guidelines. Challenges related to the application of these guidelines to the marine environment typical of the inshore GBR lagoon have driven the need to introduce substantive innovations, including:

- Advanced 3D modelling, dynamically integrating forcing from tide, wind, atmospheric heat exchange, river runoff and oceanic circulation;
- Simulation of ambient sediment transport coupled with dredge plume inputs, which supports model validation and also interpretation of impacts as a perturbation in the context of the ambient turbidity climate;
- Simulation of entire synthesised dredge campaigns, therefore sampling a large range of operational and environmental factor combinations;
- Consideration of both “expected case” and “worst case” conditions;
- Derivation of dredging impacts to the ambient turbidity and sedimentation climate using a 30-day moving window and a range of percentiles relating to chronic (low-intensity, sustained) impacts through to acute (higher-intensity, short-term) impacts;
- Analysis of baseline water quality datasets to link perturbation thresholds with risk levels based on the locally measured turbidity climate across the full spectrum of baseline conditions (i.e. calm through to energetic resuspension);
- The additional cross-referencing of biological tolerances in prescribing risk levels to dredging related perturbations;
- The derivation of spatial impact zones in accordance with the Western Australian Environmental Protection Authority Guidelines, based on locally derived impact thresholds, relevant to the endemic physical and biological environment.

5. Ongoing Challenges

Despite these advances in the scientific robustness of technical assessments and associated baseline data collection that have been driven by the GBRMPA Modelling Guidelines, the EIA process is becoming more and more influenced by the broader social context and entrenched stakeholder and political policy positions. In this context, a key challenge for the future lies in not only further improving our scientific understanding and methodologies but also in raising the profile of these scientific arguments in the development of balanced environmental policy and decision making.

Some of the key points from the assessment undertaken as part of the two EIA processes described herein that have not been considered in the current debate about dredging and material placement in the GBRWHA are as follows:

- Plumes generated during dredging and from tailwater discharges associated with reclamation and land based placement in more sensitive inshore environments (where seagrass and corals are present) often pose greater environmental risks than offshore placement.
- The broadscale impacts on water quality and sensitive receptors associated with resuspension of placed capital and maintenance dredging material at marine placement areas are generally low (particularly compared to ambient conditions) where they have been selected based on:
    - having a high degree of retentiveness;
    - compatible benthic characteristics; and
    - sufficient remoteness from nearshore sensitive receptors.
- Equating a tonne of sediment introduced into the marine system from catchment runoff with a tonne of sediment shifted to a placement area by dredging activities is a fundamentally invalid argument since the potential impact depends completely on how much of that tonne of sediment is likely to remain in suspension (or be resuspended) in the water column. It is within our present capabilities to undertake robust assessments which quantify the spatial and temporal impacts of dredging and placement activities on both water quality and biota.

These findings are indicative of the need to continue to challenge public and stakeholder perceptions about the impacts of dredging and at sea placement with robust technical assessment methods and approaches. In this context, decision making will require improved collaborative engagement across scientific and engineering communities in both academia and industry in order to better inform the public debate on this issue.

6. References

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Table 1 Description of Water Quality Impact Assessment Threshold Values (CSDP EIS [5]).

Zone of Impact	Water Quality (Turbidity)	Biological Tolerances (Seagrass)
Zone of High Impact	Excess turbidity causes total turbidity to go beyond natural variation Threshold value = excess turbidity greater than three standard deviations from the natural background mean	Light Requirement (LR) for *Zostera* (4.5-12 mol/m^2/day rolling 2 week average) is not met for more than 6 weeks LR for *Halophila ovalis* (2.8-4.4 mol/m^2/day) not met during the growing season (July-Dec) for more than 21 days Resulting in total loss of seagrass and no recovery within 1 year (reliant on new recruitment)
Zone of Low to Moderate Impact	Excess turbidity *may* push total turbidity beyond natural variation Threshold value = excess turbidity greater than one standard deviation from the natural background mean	LR for *Zostera* (4.5-12 mol/m^2/day rolling 2 week average) is not met for 1 week (low impact) to 6 weeks (moderate impact) LR for *Halophila ovalis* (2.8-4.4 mol/m^2/day) not met for 1 week (low impact) to 3 weeks (moderate impact) during the growing season (July-Dec). Resulting in declines in seagrass but some recovery within one month likely for moderate impacts; management action can occur avoiding declines in seagrass cover for low impacts.
Zone of Influence	Extent of detectable plumes Dredging related turbidity exceeds 10% of the ambient turbidity level for more than 5% of the time	Light does not fall below the LR for *Halophila ovalis* (2.8-4.4 mol/m^2/day) for more than 7 consecutive days. Light does not fall below the LR for *Zostera* (4.5-12 mol/m^2/day) for more than 7 consecutive days.