Monitoring Dredge Placement Operations through Fine-Scale Suspended Sediment Observations within a Shallow Coastal Embayment

R. Beecroft[1], A. Grinham[1], C. Heatherington[1], Craig Wilson[2] and R. Cossu[1]

ABSTRACT

The design and application of a near-bed monitoring system was an important component for identifying key sediment transport processes within a dredge placement area. Fine temporal and spatial scale current velocity measurements indicated that inequalities in the characteristics of the flood-ebb tidal regime was a contributing factor in the transport of material at the site. As a result, the net transport of suspended sediment was an estimated 610 tons per m^2 at 0.6 m above the bed, oriented in the direction of the principal flood tidal axis. Total suspended solid concentrations were obtained through an array of acoustic and optical instrumentation, providing direct links between the locality of dredge placement operations and increases in near-bed concentration. The application of a vertical suction profiling system enabled concentration estimates from 0.1-0.8 m above the bed, an area particularly complex in nature and difficult to monitor. The study underlines the need to develop near-bed monitoring approaches associated with dredging operations, whereby the majority of the sediment is transport during placement operations or later re-entrained during energetic hydrodynamic periods.

KEYWORDS

Dredge Monitoring, Suspended Sediment, Dredge Disposal

1 INTRODUCTION

Management of dredging operations is a key procedural obligation for both dredge operators and ports around the world. In particular, the assessment of dredge placement area's (DPA's), whereby large quantities of dredged material are relocated and placed at sea. As part of the continual management of dredging operations, so to ensure limited impact on the surrounding environment, intensive environmental monitoring and the development of numerical modelling approaches are tools frequently utilized within the industry. However, the complex nature of both the suspended sediment regime and hydrodynamic conditions governing transport are major contributors to uncertainty surrounding the assessment of dredging operations. Particularly the inability to distinguish between the natural variability of the site and concentration spikes related to the placement of dredge material (Fettweis et al., 2011; Onuf, 1994; Orpin et al., 2004). If insufficient field data within DPA's remains a common trend, how may dredge operators accurately assess the transport of dredge material from within these areas into the surrounding environment?

One of the areas requiring a greater degree of investigation is the transport of suspended sediment in the bottom boundary layer (BBL). The transport of dredge material within this region is typically overlooked, partly due to the logistical difficulties associated with deploying instruments at close proximity to the bed. Elevated suspended sediment concentrations and extreme variability in particle size characteristics also contribute to measurement uncertainty, especially during periods influenced by dredge operations (Agrawal & Traykovski, 2001; Mikkelsen & Pejrup, 2000; Smith et al., 2008). The majority of sediment placed within DPA's is initially transported to the bed as a turbidity current (Gordon, 1974; Johnson & Fong, 1995); hence, it is important to develop robust methodologies to monitor the continual transport of dredge material within this region. By continual transport, this study presents measurements related to the initial dispersion of material during placement operations and the entrainment of unconsolidated dredge material under more energetic hydrodynamic conditions.

Total suspended solid (TSS) concentration measurements presented within this study were obtained during a period of extensive dredge placement operations within Moreton Bay. Traditional measurement turbidity measurements within the BBL were complimented by a vertical array of suction intakes, validating TSS

[1] The University of Queensland, Australia, r.beecroft@uq.net.au
[2] Port of Brisbane Pty Ltd, Australia

concentration estimates under extreme suspended sediment regimes. Section 2 outlines the extensive monitoring approach, highlighting a simplistic and cost effective method to obtain TSS concentration estimates as close as 0.1 m above the bed. The results and analysis of the intensive data series are presented in sections 3 and 4, where transport processes and future recommendations for monitoring approach form key outcomes of the study.

2 INSTRUMENTATION AND METHODOLOGY

2.1 SITE DESCRIPTION

The Mud Island Dredge Placement Area (MI DPA) located within Moreton Bay, Queensland, Australia, is an example of an environmentally sensitive and complex area as it is subject to tides, winds, river run-off and intensive dredging operations. Strategically situated on the western side of Mud Island (Figure 1), the area is easily accessible from the Port of Brisbane. As Australia's largest cargo port, continual requirement for maintenance dredging results in the placement of large quantities of fine silts and clays (*d_{50} = 5 µm*) within the area. An example of the operational intensity within the MI DPA is provided in Figure 1, with 43 placements conducted during the 7-day monitoring period. Bathymetry at the site is relatively flat, with the bottom-mounted frame deployed 10 m below mean water level. Current velocities and water level fluctuations were driven by a semi-diurnal tidal regime orientated NNW (flood) and SSE (ebb) direction. Dominant local winds are responsible for the small period (T_p <4 secs) wind waves and significant wave heights typically less than 1.2 m. The locality of the Brisbane River was identified as a possible source of sediment to the site during flood events, yet it has no impact on the observations presented within this study.

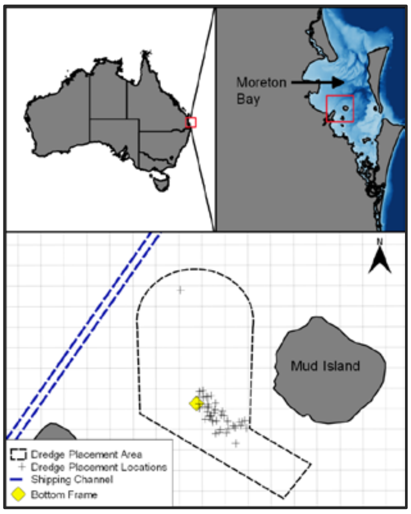

Figure 1: Moreton Bay and Mud Island Dredge Placement Area

2.2 FIELD DEPLOYMENT

Field observations presented within this study were obtained throughout a 7-day period spanning the 8th - 15th February 2018, referred to hereafter as day-of-year (DOY) 38 – 46. The range of instrumentation, respective configurations and elevations above the seabed are outlined in Table 1, with all instruments situated within 1 m of the bed. Three independent methods were employed to estimate TSS concentrations including optical backscatter (*Turner Designs Turbidity Sensor*), acoustic backscatter (*Nortek Vector ADV*) and laser diffraction (*Sequoia Scientific LISST-100X type C*). In addition, a vertical array of 4 mm (inside diameter) suction tubes were also fixed to the bottom mounted frame (Figure 2). The array of tubes were orientated perpendicular to the primary flood-ebb flow direction with the assistance of scientific divers, typically taking 1 minute to fill a 1 L bottle. Physical water samples were pumped to the surface via a constant pressure pumping station located onboard the University of Queensland research vessel and gravimetric filtered through 0.7 µm nominal diameter Whatman GF/F microfiber filters

Instrument	***Configuration***	
Laser In-Situ Scattering and Transmissometry (LISST)-100X *(Sequoia Scientific)*	Sampling frequency (Hz)	1
	Burst interval (mins)	30
	Samples per burst	120
	Elevation (m)	0.25
Acoustic Doppler Velocimeter (ADV) *(Nortek)*	Sampling frequency (Hz)	16
	Burst interval (mins)	10
	Samples per burst	30
	Elevation (m)	0.6
HR Acoustic Doppler Current Profiler (ADCP) *(Nortek)*	Sampling frequency (Hz)	1
	Profiling range (m)	1.05
	Cell size (m)	0.03
Concerto CTD *(RBR Ltd.)*	Sampling frequency (Hz)	6
	Burst interval (mins)	10
Cyclops 7 Turbidity Probe *(Turner Designs)*	Samples per burst	540
	Elevation (m)	0.5

Table 1: Instrument Configuration

One of the major advantages of using LISST measurements is the ability to estimate both suspended sediment concentration and distribution of particle sizes in-situ. The LISST relies on small angle forward particle scattering along the 0.05 m measurement cell length, whereby light is scattered onto 32 ring detectors with logarithmically spaced radii at the cell end. Particle shape effects are also considered through a "random shaped" kernel matrix developed by Sequoia Scientific and Agrawal et al. (2008). The random shaped kernel matrix was used to perform the inversion from scattered light intensity on each of the rings to a distribution of volumetric concentration based on the known light scattering properties of these random particles (Andrews et al., 2010). The LISST deployed during this field study recorded estimates for the particle size distribution in the range of 1.9-381 µm. Measurements exceeding the recommended optical transmission (τ) limits ($0.2 < \tau < 0.98$) were also removed from the data series.

The 2 MHz downward facing HR ADCP measured current velocities and directionality within the bottom meter using a pulse-coherent Doppler system. Analysis of the data series indicated that velocity measurements within 0.2 m of the bed were subject to exceedance of the ambiguity velocity as described in detail by Lohrmann and Nylund (2008), resulting in measurements within this region omitted from the analysis. Validation of the HR ADCP velocity magnitude and direction in (bin 12) were also evaluated through cross correlation with the ADV point source velocity measurements situated 0.6 m above the bed ($R^2 = 0.88$). Friction velocity (u_*) estimates were derived from HR ADCP velocities in bins 1-25 (0.2 -1 m above the bed). The procedure assumes the boundary is rough and the flow fully turbulent, thus the near-bed velocity distribution were approximated by the law-of-wall velocity distribution *(1)* in accordance with the *"conventional method"* outlined by Cheng et al. (1999).

$$U(z) = \frac{u_*}{\kappa} \ln\left(\frac{z}{z_0}\right) \qquad (1)$$

Profiles not consistent with *(1)* ($R^2 = < 0.90$) were excluded from the analysis, resulting in u* estimates with error of ±12% at the 95% confidence interval. The influence of waves not considered due the short period ($T_p < 4$ *secs*) wind waves and deep-water wave regime.

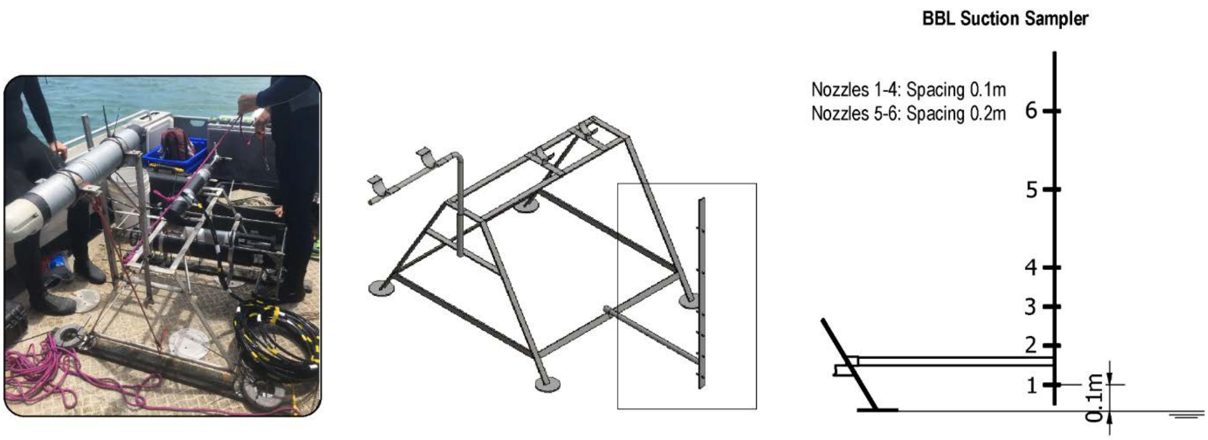

Figure 2: Deployment Frame and BBL Suction Profiler

2.3 INSTRUMENT CALIBRATION

TSS calibrations were conducted for both the LISST and turbidity sensor using sediment obtained from the site. Linear regression between a known TSS concentration, LISST volume concentration (*µl/l*) and turbidity (*NTU*) resulted in multipliers of 1.90 ($R^2 = 0.64$) and 4.07 ($R^2 = 0.75$) respectively. Calibration of ADV acoustic backscatter intensity (BSI) was performed by first analyzing the correlation between BSI and NTU. BSI is defined here,

$$BSI = 1E - 5 * 10^{0.043*Amp} \qquad (2)$$

where *Amp* refers to the mean acoustic signal strength (*dB*) across the three acoustic heads (Nikora & Goring, 2002).The calibration process assumes that under the low TSS concentrations observed during the deployment period, the difference in concentration between the ADV ($z = 0.6$ *m*) and turbidity sensor (*z = 0.5 m*) were small. The correlation between the BSI and NTU for the range of concentration observed during the field deployment was high ($R^2>0.99$), resulting in an estimation for TSS derived from the BSI-NTU relationship in the field.

3 RESULTS

The near-bed velocity regime was governed by mixed semi-diurnal tidal velocity fluctuations, with maximum velocities of 0.35 ms^{-1} most prevalent during flood tides (Figure 3b). Neap tides were observed towards the beginning of the deployment period, resulting in smaller current velocities and little velocity shear close to the bed. As the tidal fluctuations transition towards the spring cycle, current velocities during both the flood and ebb periods increased, with tidal mean u_* estimates increasing by up to 0.015 ms^{-1} during flood tidal periods (Figure 3c). Inequality between the flood-ebb tidal periods were identifiable in the u_* estimates, indicating that the flood tidal period possesses a greater potential for entrainment and transport of sediment in the area. Generally, significant Northerly wind events between days 42 – 45, contributed to a secondary wind driven flow acting constructively with the flood tidal regime. Similar processes have been identified within the upper water column during southerly wind periods that coincided with the ebb tidal regime during deployments conducted in 2017. The data series presented here is the first indication that wind driven flows may be factor within the bottom boundary layer at the MI DPA.

Forty-three dredge placement operations occurred within the MI DPA throughout the deployment period, with the closest located within 100 m of the deployment site. Figure 1 provides a schematic of the placement locations relative to the frame, with majority of the placements located in the south-eastern corner of the DPA. Figure 4a, b presents a direct comparison between the locality of the dredge placements and near-bed TSS estimates derived from the LISST, insinuating the impact of dredge placement operations in the area. Events represented in black refer to placement events upstream of the frame (relative to tidal direction), while those in red refer to events downstream of the frame. From a conceptual standpoint, placement events within close proximity and upstream of the frame should be more likely to register elevated TSS concentrations. The results presented in Figure 4 support this hypothesis, with more pronounced TSS spikes correlated with dredge placements upstream of the frame. Furthermore, the time-series of TSS concentrations underline a clear trend, indicating that the frequency of dredging in the area was associated with larger TSS spikes and an increased standard deviation of the time averaged TSS concentrations. Days 41– 45 for example included both an increased frequency of dredge placement events combined with more energetic hydrodynamic conditions compared to the days prior. As a result, mean TSS concentrations during days 39 – 41 were in the range of 30±16 mgL^{-1}, significantly increasing to 82 ±70 mgL^{-1} during day 41. There are number of instances where TSS concentrations exceeded 250 mgL^{-1} remaining elevated throughout the majority of the more frequent dredge placement period.

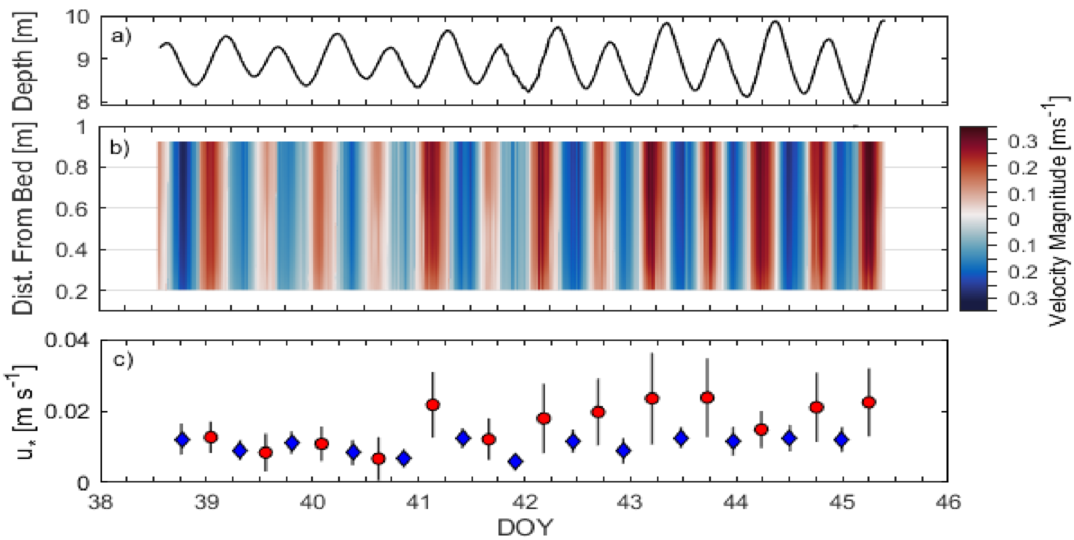

Figure 3: (a) Water Level Fluctuations (b) Near-Bed Horizontal Velocity Magnitude (North-East) and (c) Friction Velocity Estimates

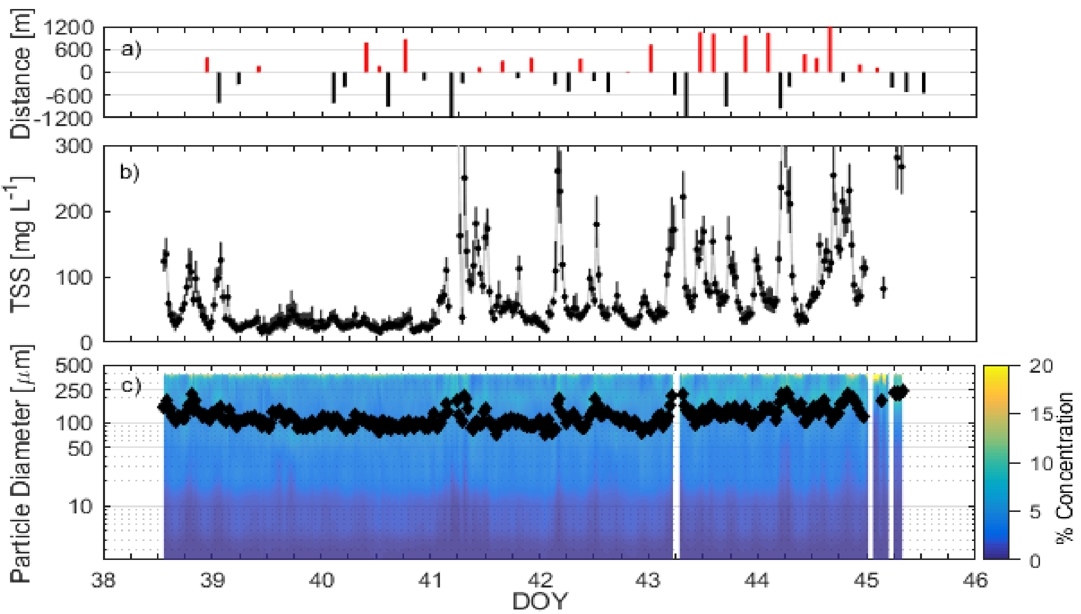

Figure 5: a) Location of Dredge Placements Relative to Frame (b) LISST TSS Concentration Time-Series (c) LISST Particle Size Distribution and d_{50} Estimates

Figure 4c visualizes the distribution of TSS concentration across the measurement range of the LISST (1.9-381 µm) as a percentage of the total TSS concentration. Black markers plotted over the percentage concentration distribution indicate the mean particle diameter (d_{50}). A distinguishable feature of the particle size results is the direct correlation of increasing d_{50} with increasing TSS concentration, especially during the period after day 41. During some of these instances, d_{50} is as much as 150 µm larger than those observed during the lower concentration periods (DOY 39-41). The d_{50} value is a good first order estimate for describing the distribution of suspended particle sizes, yet it may not be entirely representative of the physical nature in which the sediment exists in suspension. For example, the LISST particle size measurements indicate bias towards the upper limits of the LISST measurement range. Generally, larger values within this upper region are associated with large particles outside the measurement range of the LISST (Agrawal & Pottsmith, 2000; Mikkelsen, 2002). Scattered light from these large particles leaks into the largest measurement cell, resulting in the observed bias. Video imagery recorded by divers during the frame deployment and retrieval confirm this hypothesis, with evidence of particle sizes exceeding 1 mm diameter in suspension. Particle size analysis of bed sediment surrounding the MI DPA and dredge material

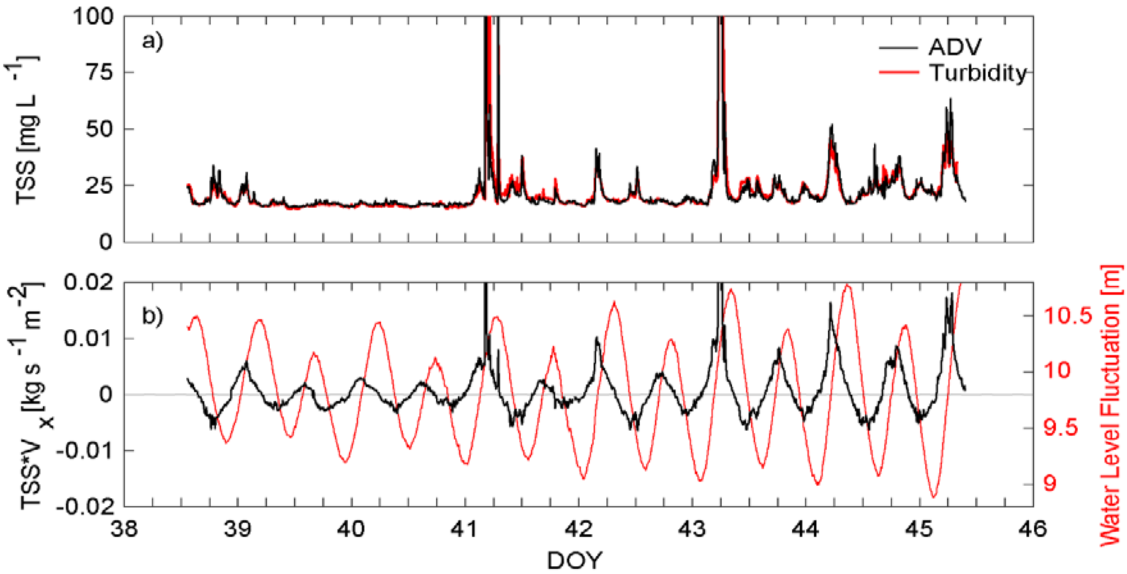

Figure 4: a) Calibrated TSS Concentration Time-Series b) Horizontal Concentration Flux Along the Principle Flood/Ebb Axis

placed within the DPA indicated that the material was comprised of mostly fine silts and clays with d_{50} in the range of 15 µm and 5 µm respectively (Beecroft et al., 2017; Lockington et al., 2016).

In alignment with the LISST measurements, TSS concentration estimates derived from the ADV BSI and turbidity sensor also identify a number of significant TSS peaks post day 41 (Figure 5a). Although the magnitude of these peaks are consistently smaller than those of the LISST, the locality and duration of such peaks align extremely well. Both the turbidity sensor and ADV were approximately 0.25 - 0.3 m above the LISST, hence TSS concentrations can be expected to be comparatively lower. One of the major advantages of the calibration of ADV BSI was the ability to measure TSS concentration fluxes at high frequencies 0.6 m above the bed. Figure 5b shows the TSS concentration flux per m^2 throughout the entire deployment period, with positive values referring to a flux along the flood tidal axis and negative values along the ebb tidal axis. TSS concentration flux results support the findings from the HR ADCP, with the largest flux estimates occurring during the flood tidal periods. The largest flux peaks occurred during days 41, 43 and 44, which also aligned with dredge placement events upstream of the ADV. This suggests that material already in suspension due to dredge placement operations or unconsolidated dredge material re-entrained from the bed may have contributed to the intensity of these larger TSS fluxes. As an estimate for net transport through the monitored site, TSS fluxes were integrated throughout the entire 7-day monitoring period, indicating a net transport of 610 tons per m^2 orientated along the flood tidal axis.

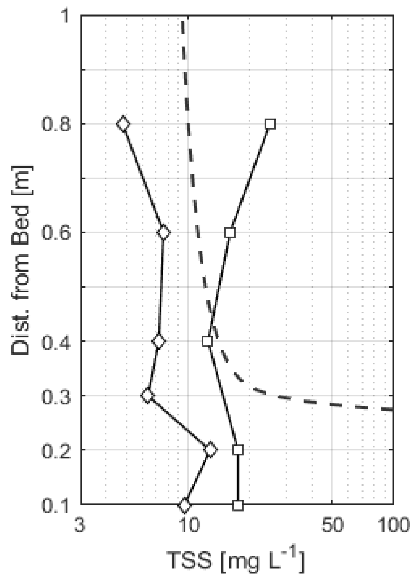

Figure 6: BBL Suction Profiler and Rouse Concentration Profile

Figure 6 presents the results from two BBL suction profiles taken during slack tidal periods on day 38 (squares) and day 45 (diamonds). TSS concentrations at 0.1 m above the bed in the range of 10 mgL^{-1} and 18 mgL^{-1} respectively. Characteristics of the profiles within this region indicated that little to no gradient in TSS concentration existed beyond 0.1 m above the bed. An alternate and frequently employed method to describe the vertical distribution of sediment refers to the simple Rouse formulation of concentration expressed as,

$$\frac{C}{C_a} = \left(\frac{H-y}{y} \cdot \frac{a}{H-a} \right)^{\frac{w_s}{\kappa u_*}} \tag{3}$$

Where C_a refers to the reference concentration at height *a* above the bed, *H* the water level, κ von Karman constant (=0.41) and *C* the concentration at height *y (Dey, 2014).* Figure 6 presents this approximation (dashed line) throughout the neap tidal period spanning days 38 – 41 as a comparison to the BBL suction sampler results. The time averaged u_* estimates were derived from the HR ADCP profiles, while the reference TSS concentration and settling velocity estimates (w_s) were approximated from the LISST particle size distributions. The Rouse approximation provides similar estimates for TSS concentrations above 0.3 m from the bed, yet discrepancies between this theoretical approximation and our observations exists below this level.

4 DISCUSSION

Our observations demonstrate that the placement of fine silts and clays within the dredge placement area affected TSS concentrations and associated transport rates. Evidence for this is provided in Figures 4 and 5, where an increase in TSS concentration and frequency of concentration spikes were identified by all instruments at the onset of more intensive dredge placement operations after day 41. Generally, TSS concentration spikes were relatively short-lived and aligned with placement events located both upstream and within close proximity to the bottom-mounted frame. Although no direct measurements regarding the dispersion of dredge plumes during placement events is presented here, it is likely that the majority of deposited material is transported near the bed and remains in close proximity to the initial placement location (Gordon, 1974). Thus, observed short-term spikes in TSS concentration are believed to represent only a minimal percentage of the total quantity of dredge material placed within the MI DPA. Current estimates for the net transport of sediment through the site (610 tons per m^2) would be an important tool to confirm this hypothesis, yet information regarding the exact quantity (tonnage) of dredge material placed during the deployment period was unavailable.

Dredge material that does not initially settle to the bed remains in suspension as a turbid cloud. Particle sizes indicated that a large percentage of this turbid cloud was transported as larger flocculated particles. The direct correlation between TSS concentrations and d_{50}, combined with bias at the upper limit of the LISST measurement range were clear indicators for flocculation of the suspended sediment. Furthermore, video imagery (not shown here) also identified larger flocculated particles with particle diameters in the order of millimeters. Smith and Friedrichs (2011) presented similar results within dredge plumes, reporting increased particle diameters associated flocculation processes during dredge operations. As a result, settling velocities associated with these flocculated particles are expected to far exceed that of the primary particles ($d_{50} = 5$ µm), limiting transport potential of the suspended dredge material. While in-situ measurements regarding particle size and settling velocities are vital for the development of dredge plume and sediment transport models within coastal regions, evidence of these dynamic particle processes also gives indication to the location within the water column in which the majority of dredge material is transported. In the case of the MI DPA, previous concentration profiling periods confirms that the higher concentration suspension associated with the placement of dredge material was located in the lower 2-3 m of the water column (Beecroft et al., 2017).

The BBL suction profiler was developed as a tool to better understand the transport of material within the bottom-boundary layer, with previous monitoring attempts using alternate methods hindered due to extremely high TSS concentrations and an inability to place instruments close to the bed. Although the process is more tedious compared to optical and acoustic methods, suction profiling enables discrete TSS concentration estimates under extremely high concentration conditions and at a fraction of the cost. The results presented in Figure 6 provided valuable information regarding the distribution of suspended sediment within the near-bed region, indicating that theoretical approximations for the distribution of suspended sediment may not take into consideration the range of physical processes driving TSS concentrations. Hence, considerable differences were observed between TSS profiles obtained via suction sampling and those derived in accordance with *(3)* at distances less than 0.3 m above the bed. To improve understanding of transport rates within the MI DPA, measurements located closer to the bed (< 0.1 m), where TSS concentration fluxes are expected to be largest require further investigation.

5 CONCLUSIONS

Detailed measurements located within 1 m of the bed at the MI DPA unveiled key processes influencing the local transport of dredge material. Tidally driven currents dominate the net transport of suspended sediment, with a net flux orientated along the flood tidal axis. Furthermore, periods influenced by wind driven flows and an approaching spring tidal cycle were also attributed to an increase in transport potential from the site. The application of the LISST provided in-situ measurements related to the distribution of particle sizes, confirming flocculation as a major driver influencing the vertical distribution of suspended sediments. The ability to provide some fundamental understanding to the manner in which the dredge material is transported, is an important finding for the development of future sediment transport models in the area. Current modelling approaches which do not consider the gravity driven transport of material to the bed and the degree of flocculation would ultimately under predict the quantity of dredge material retained within the DPA.

This study has identified the need to extend both TSS concentration estimates and HR velocity profiling closer to the bed (< 0.1 m). Measurements within this region may be achieved through the application of high frequency acoustic devices such as ADVs or the HR ADCP. However, the BBL suction profiler is an extremely simple and cost effective tool for profiling TSS concentrations close to the bed, a method deployable under higher TSS concentrations compared to both optical and acoustic methods. More TSS suction samples are required under a broader range of hydrodynamic conditions and influence of dredge placement activities in order to provide representative estimates of TSS concentration fluxes at the site. Thus, future application of the near-bed monitoring system within the MI DPA and surrounds will form a key component of the ongoing research within Moreton Bay.

6 REFERENCES

Agrawal, Y. C., & Pottsmith, H. C. (2000). Instruments for particle size and settling velocity observations in sediment transport. *Marine Geology, 168*(1), 89-114.

Agrawal, Y. C., & Traykovski, P. (2001). Particles in the bottom boundary layer: Concentration and size dynamics through events. *Journal of Geophysical Research: Oceans, 106*(C5), 9533-9542.

Agrawal, Y. C., Whitmire, A., Mikkelsen, O. A., & Pottsmith, H. C. (2008). Light scattering by random shaped particles and consequences on measuring suspended sediments by laser diffraction. *Journal of Geophysical Research: Oceans, 113*(C4), n/a-n/a.

Andrews, S., Nover, D., & Schladow, S. G. (2010). Using laser diffraction data to obtain accurate particle size distributions: the role of particle composition. *Limnology and Oceanography: Methods, 8*(10), 507-526.

Beecroft, R., Cossu, R., Grinham, A., Perez, L., & Albert, S. (2017). *Cohesive suspended sediment observations in a dredge disposal area within Moreton Bay, Queensland.* Paper presented at the Australasian Coasts and Ports Conference, Cairns.

Cheng, R. T., Ling, C.-H., Gartner, J. W., & Wang, P. F. (1999). Estimates of bottom roughness length and bottom shear stress in South San Francisco Bay, California. *Journal of Geophysical Research: Oceans, 104*(C4), 7715-7728.

Dey, S. (2014). Suspended-Load Transport *Fluvial Hydrodynamics: Hydrodynamic and Sediment Transport Phenomena* (pp. 327-415). Berlin, Heidelberg: Springer Berlin Heidelberg.

Fettweis, M., Baeye, M., Francken, F., Lauwaert, B., Van Den Eynde, D., Van Lancker, V., . . . Michielsen, T. (2011). Monitoring the effects of disposal of fine sediments from maintenance dredging on suspended particulate matter concentration in the Belgian nearshore area (southern North Sea). *Marine Pollution Bulletin, 62*(2), 258-269.

Gordon, R. B. (1974). Dispersion of Dredge Spoil Dumped in Near-shore Waters. *Estuarine and Coastal Marine Science, 2*, 349-358.

Johnson, B. H., & Fong, M. T. (1995). Development and Verification of Numerical Models for Predicting the Initial Fate of Dredged Material Disposed in Open Water. Report 2. Theoretical Developments and Verification Results. In M. S. Army Engineer Waterways Experiment Station Vicksburg (Ed.).

Lockington, J. R., Albert, S., Fisher, P. L., Gibbes, B. R., Maxwell, P. S., & Grinham, A. R. (2016). Dramatic increase in mud distribution across a large sub-tropical embayment, Moreton Bay, Australia. *Marine Pollution Bulletin*.

Lohrmann, A., & Nylund, S. (2008, 17-19 March 2008). *Pure coherent Doppler systems - how far can we push it?* Paper presented at the 2008 IEEE/OES 9th Working Conference on Current Measurement Technology.

Mikkelsen, O. A. (2002). Examples of spatial and temporal variations of some fine-grained suspended particle characteristics in two Danish coastal water bodies. *Oceanologica Acta, 25*(1), 39-49.

Mikkelsen, O. A., & Pejrup, M. (2000). In situ particle size spectra and density of particle aggregates in a dredging plume. *Marine Geology, 170*(3), 443-459.

Nikora, V. I., & Goring, D. G. (2002). Fluctuations of Suspended Sediment Concentration and Turbulent Sediment Fluxes in an Open-Channel Flow. *Journal of Hydraulic Engineering, 128*(2), 214-224.

Onuf, C. P. (1994). Seagrasses, Dredging and Light in Laguna Madre, Texas, U.S.A. *Estuarine, Coastal and Shelf Science, 39*(1), 75-91.

Orpin, A. R., Ridd, P. V., Thomas, S., Anthony, K. R. N., Marshall, P., & Oliver, J. (2004). Natural turbidity variability and weather forecasts in risk management of anthropogenic sediment discharge near sensitive environments. *Marine Pollution Bulletin, 49*(7), 602-612.

Smith, G. G., Weitz, N., Soltau, C., Viljoen, A., Luger, S., & Maartens, L. (2008). Fate of fine sediment from dredger- based mining in a wave- dominated environment at Chameis Bay, Namibia.(Report). *Journal of Coastal Research, 24*(1), 232.

Smith, S. J., & 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*(10), S50-S63.