APPENDIX B

Port of Hay Point –
Natural Sediment Resuspension Assessment

Royal HaskoningDHV
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Note / Memo

Haskoning Australia PTY Ltd.
Maritime & Waterways

To:	Kevin Kane
From:	Andrew Symonds
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Subject: **Port of Hay Point - Natural Sediment Resuspension Assessment**

Introduction

North Queensland Bulk Ports Corporation (NQBP) commissioned Royal HaskoningDHV (RHDHV) to undertake a study to assess sediment resuspension at the Port of Hay Point. There is a significant gap in the current understanding regarding the mass of sediment which is naturally resuspended at ports within the Great Barrier Reef World Heritage Area (GBRWHA). An improved understanding of this will allow the potential resuspension of sediment due to dredging to be put into the context of the natural environment.

The aims of the study reported in this technical note are as follows:

1. To quantify the mass of sediment naturally resuspended in the Port of Hay Point region during calm, energetic and extreme conditions and to provide confidence that the sediment resuspension estimates are realistic;
2. To estimate the annual natural resuspension of sediment in the Port of Hay Point region; and
3. To develop a relationship between natural suspended sediment concentration (SSC) and wind speed for the Port of Hay Point region and compare this to SSC resulting from maintenance dredging.

To achieve these aims the following data have been used:

- in-situ SSC data collected at seven sites (**Figure 1**) by James Cook University (JCU) as part of the Hay Point and Mackay ambient water quality monitoring program;
- numerical modelling results of the natural SSC for a range of metocean conditions; and
- MODIS satellite data, purchased from EOMAP, showing the spatial distribution of turbidity for the region.

To improve confidence in the resuspension calculations, two approaches have been adopted:

1. Measured SSC estimate: this approach relies on measured SSC data for the region to estimate the mass of sediment in suspension; and
2. Modelled SSC estimate: this approach uses a numerical model of the natural sediment transport for the region, which has been calibrated to in-situ measured SSC data and spatially validated using the MODIS turbidity images, to estimate the mass of sediment in suspension.

These two approaches are discussed in the following two sections. The relationship between natural SSC and wind speed for the region is then discussed in a separate section followed by a summary which details the key findings of the study.

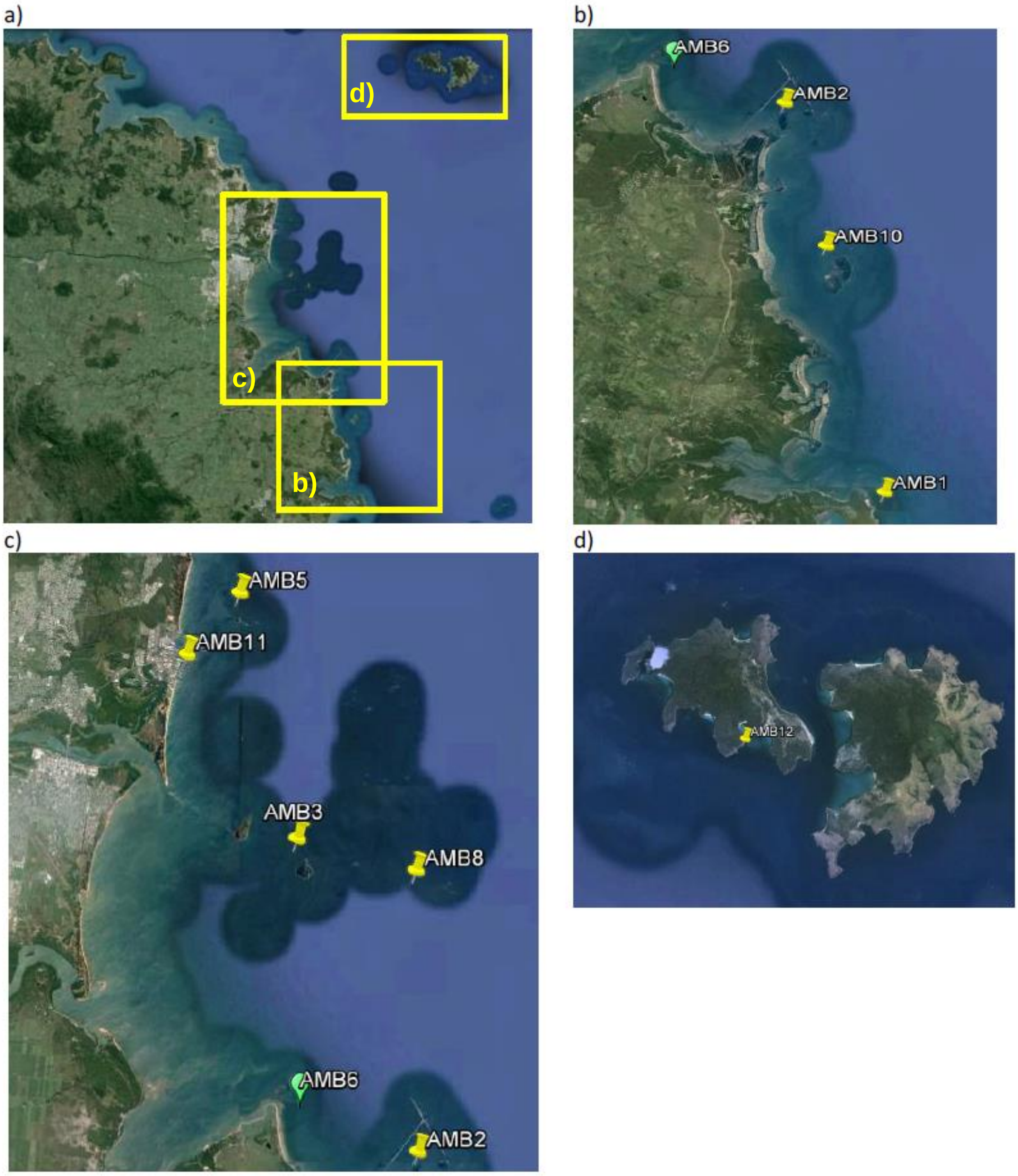

Figure 1: Location of the Hay Point and Mackay JCU ambient water quality monitoring sites. AMB1 = Freshwater Point, AMB2 = Hay Reef, AMB3 = Round Top Island, AMB5 = Slade Islet, AMB6 = Dudgeon Reef, AMB8 = Relocation Ground, AMB10 = Victor Island, AMB11 = Mackay Harbour and AMB12 = Keswick Island (taken from Waltham et al. (2016)).

Measured SSC Estimate

At the Port of Hay Point, ambient water quality monitoring has been ongoing since 2014 with SSC measured continuously[1] at seven sites. The measured SSC data from Freshwater Point, Victor Island, Hay Reef, the existing Spoil Ground, Round Top Island and Slade Island have been used to represent the Inner Shelf for the Hay Point region for the measured SSC estimate. These sites are considered to provide a good representation of the spatial variability in SSC within the Hay Point region (assumed to extend from Freshwater Point in the south to Slade Point in the north).

Based on the measured data at the six Inner Shelf sites:

- the average 50th percentile SSC (representative of ambient wind/wave conditions and regular resuspension by spring tides) is 5 mg/l,
- the average 95th percentile (representative of large wave events) is 75 mg/l, and
- during TC Debbie (representative of an extreme wind/wave event) the average SSC at the Inner Shelf sites was 1,500 mg/l in the nearshore area (to the 10m LAT contour) and 250 mg/l further offshore (from the 10 m to 20 m LAT contour). The offshore value has been determined based on the nearshore peaks relative to the peak of 115 mg/l measured at Keswick Island which is located an additional 15 km offshore from the 20 m LAT contour.

These concentrations can be used to estimate the total mass of sediment resuspended in the Hay Point region. However, it is first necessary to define the frequency that resuspension occurs for the 50th percentile and the 95th percentile cases, as follows:

- the 50th percentile SSC conditions occur for half of the year, or 182 days, so it can be assumed that the sediment in suspension is resuspended 182 times per year; and
- the natural SSC is in excess of the 95th percentile value for five percent of the year, this is equal to 18 days. From previous investigations it was found that increased resuspension due to waves occurs in the Hay Point and Mackay area when the significant wave height exceeds 0.9 m (RHDHV, 2016). Based on the measured wave data at Hay Point there were between 15 and 20 discrete events when the significant wave height (H_s) exceeded 1 m (**Figure 2**). As such, adopting a frequency of 18 times is considered to provide a realistic representation of the number of wave events when increased resuspension occurs.

The area which has been chosen as representative of the Port of Hay Point region is within the Inner Shelf (i.e. to a maximum depth of 20 m) on the basis of this being the potential area that could be impacted by any resuspension from maintenance dredging at the Port. Areas have been defined which extend approximately 20 km to the north and south of the port. The water depths which have been considered for the calculations are as follows:

- to the 10 m LAT depth contour for spring tides and ambient resuspension calculations;
- to the 15 m LAT depth contour for larger wave event calculations; and
- to the 20 m LAT depth contour for extreme wave event calculations (e.g. tropical cyclones) (**Figure 3**).

This gives areas of 230 km^2, 670 km^2 and 1,030 km^2, respectively.

[1] with gaps in data due to instrument fouling and data reliability issues.

On the basis of the above the following estimates for natural resuspension have been calculated:

- 5,750 tonnes of sediment per event resuspended by ambient wind/wave conditions and spring tides;
- 375,000 tonnes of sediment per event resuspended by large wind/wave events;
- 4,700,000 tonnes of sediment per event resuspended by an extreme wind/wave event; and
- an estimated mass of sediment naturally resuspended in the Port region in the order of 7,800,000 tonnes per year for a year without an extreme event and 12,500,000 tonnes per year for a year with an extreme event.

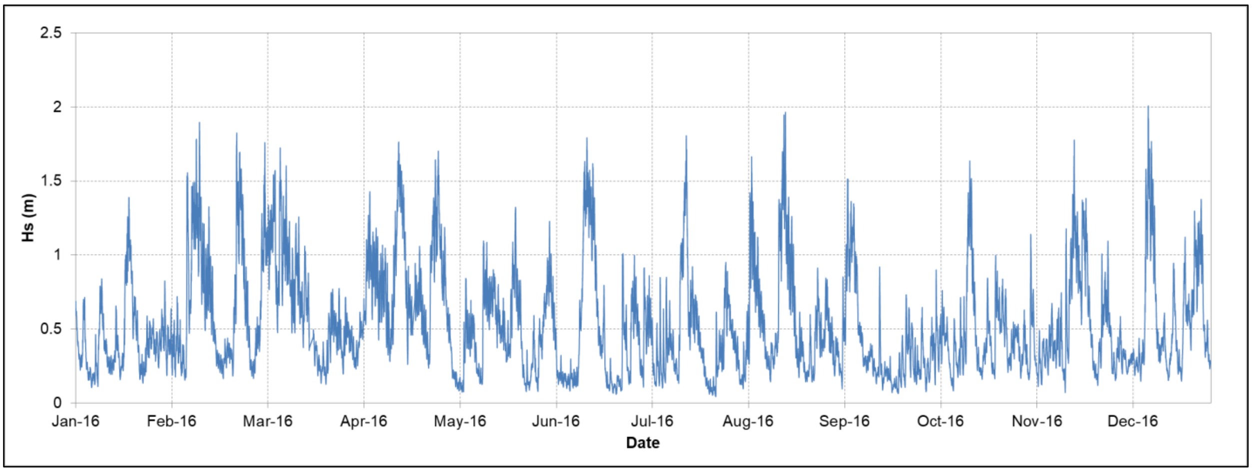

Figure 2: Measured significant wave height (H_s) at the Hay Point waverider buoy in 2016.

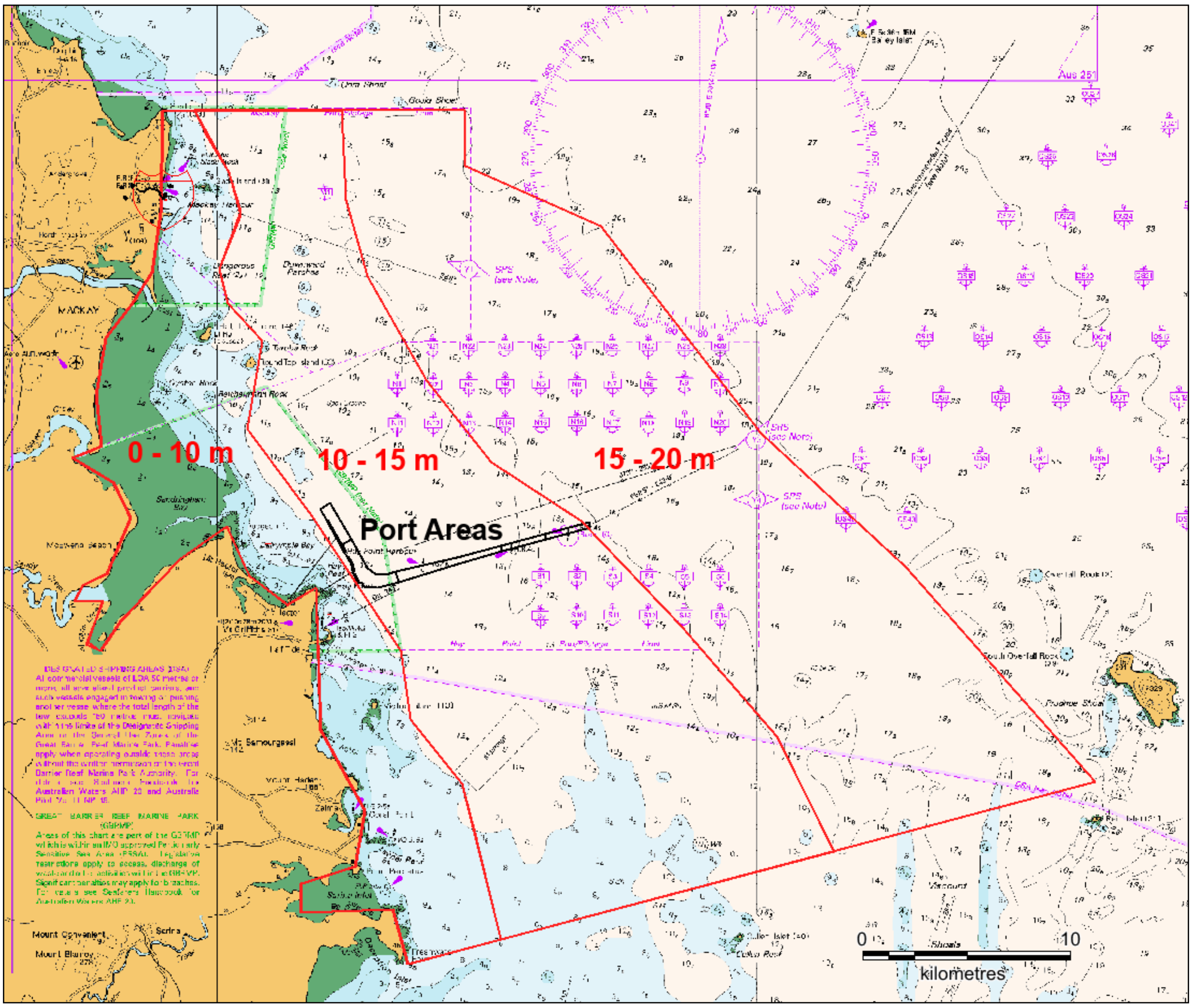

Figure 3: Polygons used to represent the different depth zones for the resuspension calculations for the Port of Hay Point.

Modelled SSC Estimate

To assess the validity of the approach described in the preceding section using measured SSC data, the RHDHV Hay Point and Mackay model (see RHDHV (2016b) for further details) was used. Output from model simulations were analysed to calculate natural sediment resuspension during:

- a spring tide,
- a large wave event; and
- during TC Debbie.

The model has been calibrated to measured SSC data collected at the ambient water quality monitoring sites for a range of conditions including a cyclonic event (**Figure 4** and **Figure 5**). The plots show that the model is able to provide a good representation of the natural resuspension processes at the sites with reliable data over the calibration period. The model is not able to represent the spikes in SSC which occur during wind and wave events at the nearshore sites (all sites excluding Keswick Island). As such, although the model is considered to provide a good representation of the timing and magnitude of the typical SSC which occurs naturally, the model does underestimate the short duration peaks in SSC which occur during cyclonic events and so will underestimate the total resuspension during large/extreme wind/wave events.

To validate the modelled spatial distribution of SSC, the modelled results have been compared with MODIS Aqua and Terra satellite image data for a range of metocean conditions. JCU has previously compared MODIS data with their in-situ measured data for the Hay Point/Mackay region and found that it was not possible to develop a good relationship between measured and MODIS derived turbidity values. As such, in this case we have not used the MODIS data to compare turbidity values, rather to use the MODIS data to inform the spatial distribution of turbidity and to compare this to the modelled spatial distribution.

EOMAP has provided processed satellite derived turbidity maps for a number of discrete dates (see **Appendix A** for further details of the MODIS data). The modelled SSC data is presented along with the corresponding MODIS data for calm (5 - 10 knots), moderate (10 - 15 knots) and strong (20 knots) winds speeds in **Figure 6** to **Figure 8**. It was not possible to identify a suitable time with very strong wind speeds as these events typically coincide with high cloud cover which the MODIS satellite cannot penetrate (i.e. it is not possible to measure the turbidity using MODIS when there is cloud cover). The comparison shows that the model provides a good representation of the spatial distribution in SSC relative to the MODIS satellite data. This comparison, combined with the comparison to the in-situ measured SSC data detailed above provides confidence that the model can realistically represent the magnitude and spatial distribution in SSC for a range of conditions.

The spatial distribution in SSC around the Port of Hay Point (with the same polygons plotted as in **Figure 3**) during a spring tide with low wind speeds, a strong wind event and a tropical cyclone (TC Debbie) are shown in **Figure 9** to **Figure 11**. The peak mass of sediment in suspension during these events in the overall polygon shown in the figures (which extends from 0 to 20 m below LAT) was as follows:

- Spring tide = 25,000 tonnes;
- Large wave event = 150,000 tonnes; and
- TC Debbie = 3,500,000 tonnes.

Assuming the same number of resuspension events in a year as adopted in the approach for the measured SSC estimate (i.e. resuspension due to strong wind/large events occurs 18 times per year and resuspension due to ambient wind/wave conditions and regular resuspension by spring tides occurs 182 times per year), the mass of sediment indicated to be resuspended is 7,250,000 tonnes per year.

The cumulative mass of sediment predicted to be resuspended over a two month simulation period by the numerical model was calculated to be 1,500,000 tonnes. Assuming this period was representative of the rest of the year (the two months contained three large wave events which can be considered typical) the mass of sediment indicated to be resuspended is 9,000,000 tonnes per year.

The model simulation was also used to estimate the net and gross longshore transport across a line extending from the shoreline to the offshore end of the Hay Point Departure Channel. Based on this simulation the net longshore transport was indicated as 690,000 tonnes/year in a northerly direction and the gross longshore transport of suspended sediment was indicated as 7,500,000 tonnes/year.

Therefore, the mass of sediment estimated to be resuspended by the modelling as well as the gross transport across the Port area agrees well with the mass of sediment estimated based on the measured SSC data, giving confidence that:

- the annual mass of sediment resuspended by typical conditions is in the order of 7,000,000 to 9,000,000 tonnes per year in the Port of Hay Point region; and
- the mass of sediment resuspended calculated using the measured SSC of 7,800,000 tonnes per year is a realistic estimate.

There is some difference between the two approaches when estimating the mass of sediment resuspended by TC Debbie (measured data approach = 4,700,000 tonnes and model approach = 3,500,000 tonnes). This is due to the numerical model underestimating the nearshore peak in SSC relative to the measured data. The measured peaks in SSC were up to 2,500 mg/l while the modelled peaks were 1,000 mg/l. As a result, the estimate based on the measured data approach of 4,700,000 tonnes/TC is considered to be more representative.

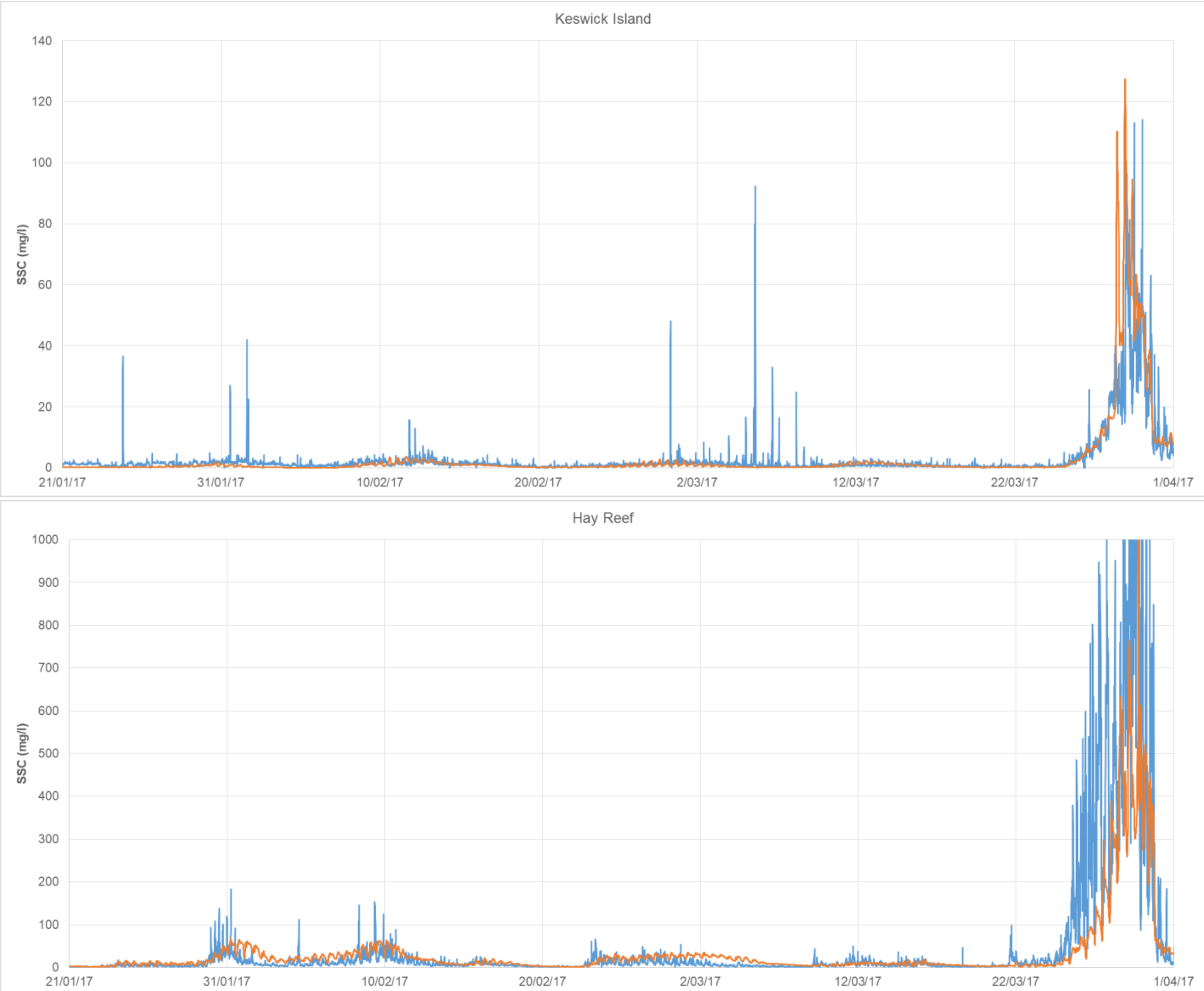

Figure 4: Comparison of measured (blue) and modelled (orange) SSC at Keswick Island (top) and Hay Reef (bottom) including TC Debbie. Note that the top plot has a different SSC scale due to the relatively lower SSC at this location which is outside of the Inner Shelf region.

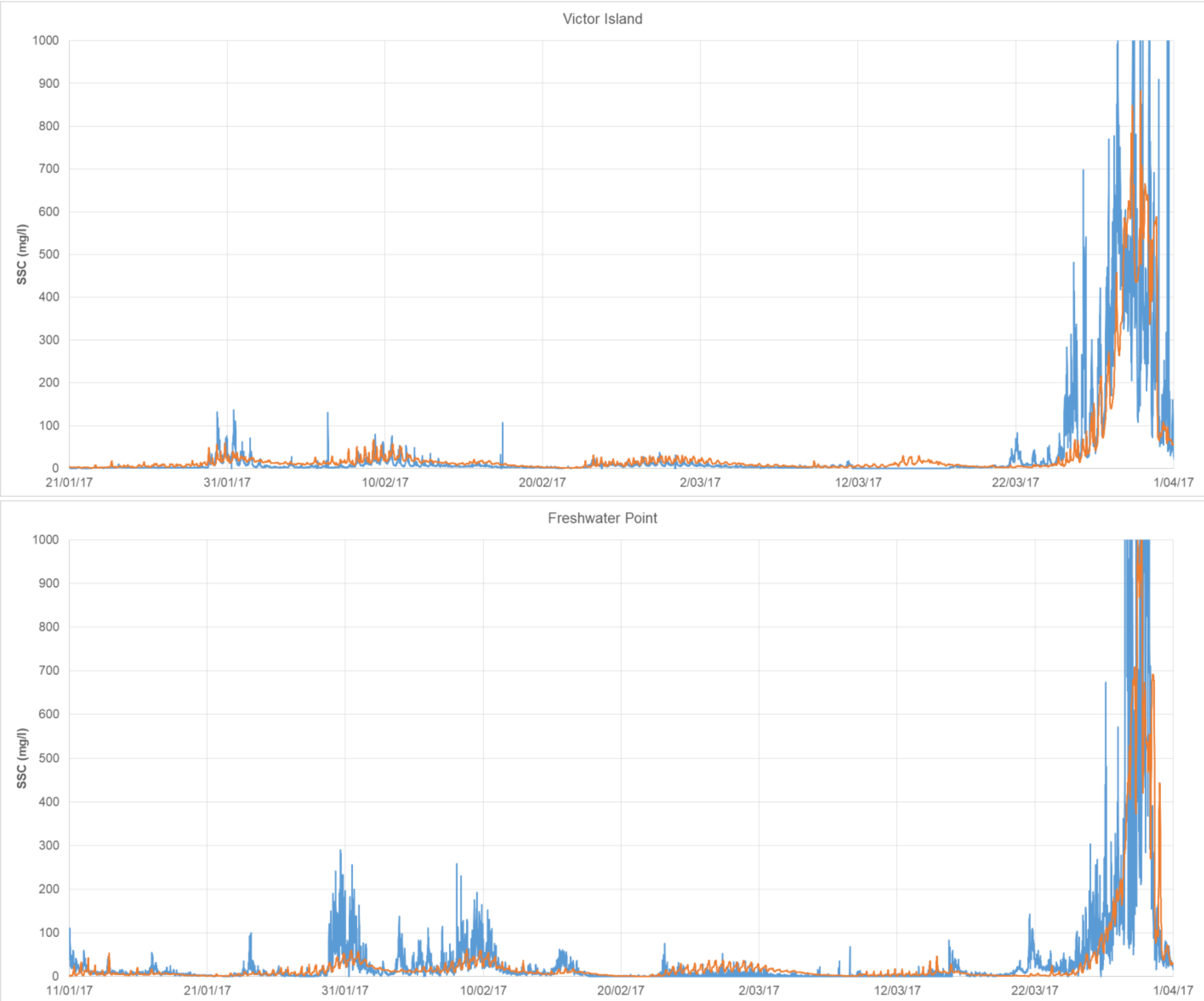

Figure 5: Comparison of measured (blue) and modelled (orange) SSC at Victor Island (top) and Freshwater Point (bottom) including TC Debbie.

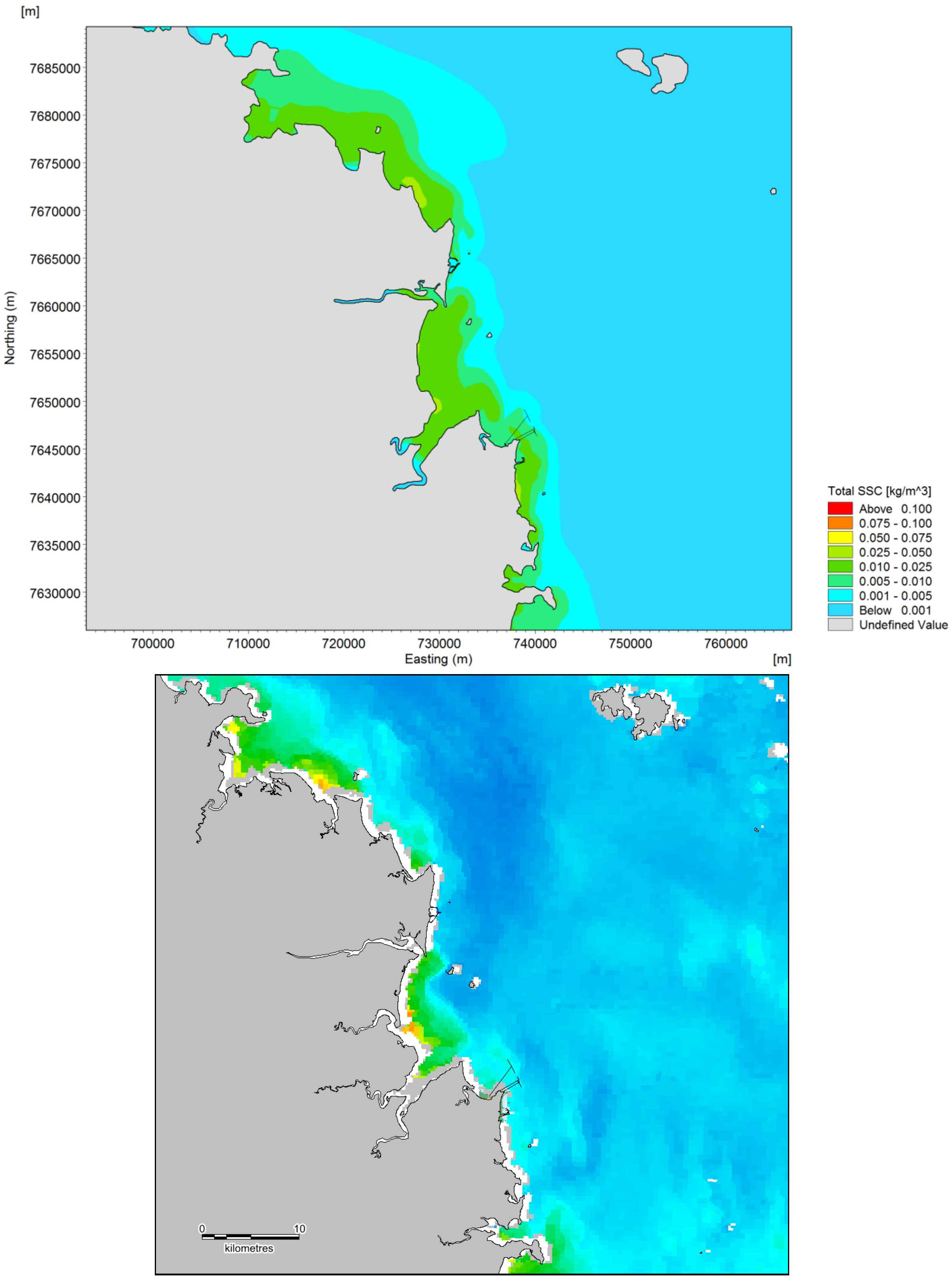

Figure 6: Comparison in spatial SSC distribution between modelled (top) and MODIS satellite data (bottom) during calm conditions. Large spring tide (HW = 6.1 m LAT), wind speed = 5 – 10 knots.

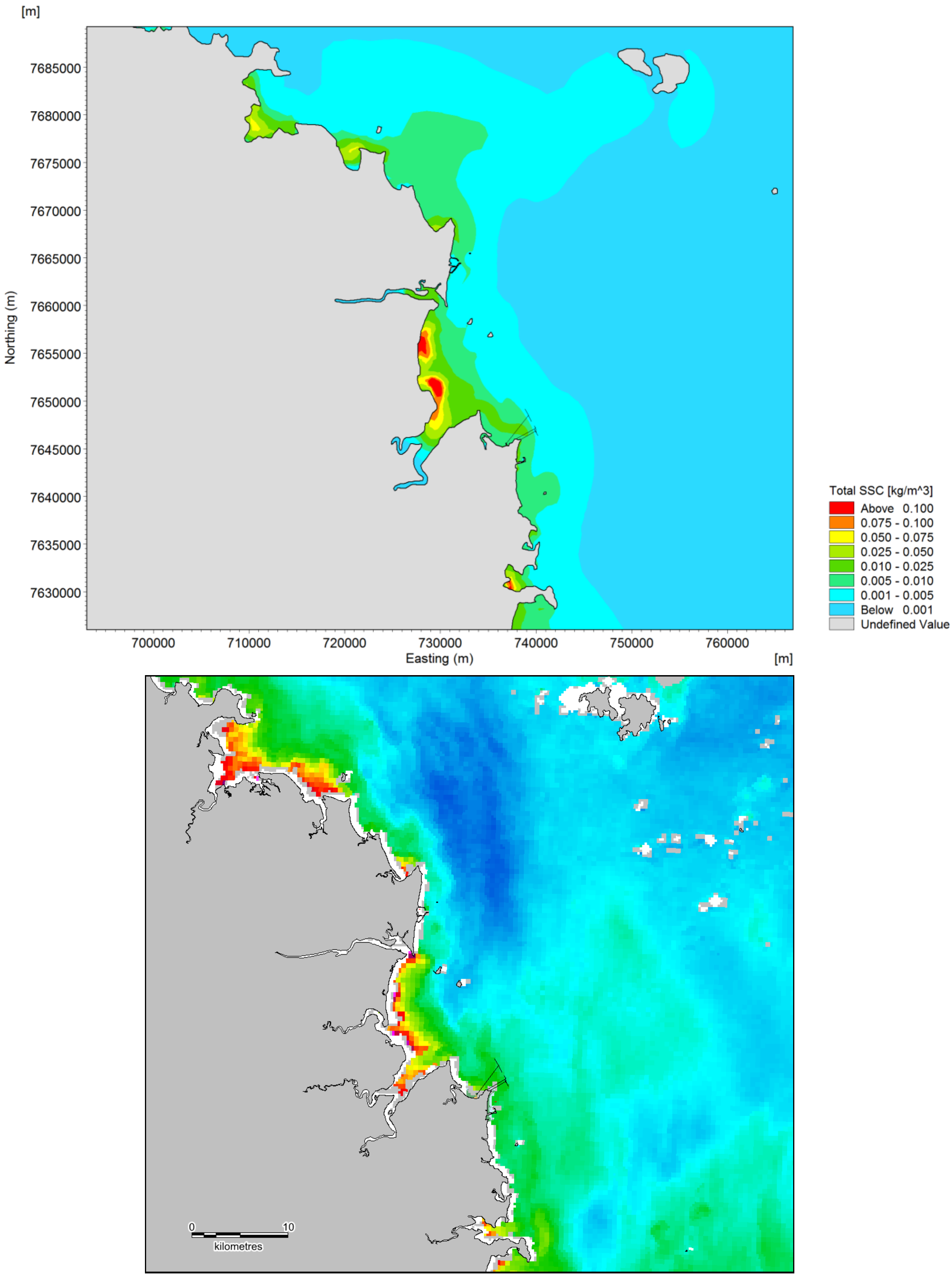

Figure 7: Comparison in spatial SSC distribution between modelled (top) and MODIS satellite data (bottom) during moderate conditions. Large spring tide (HW = 6.6 m LAT), wind speed = 10 - 15 knots.

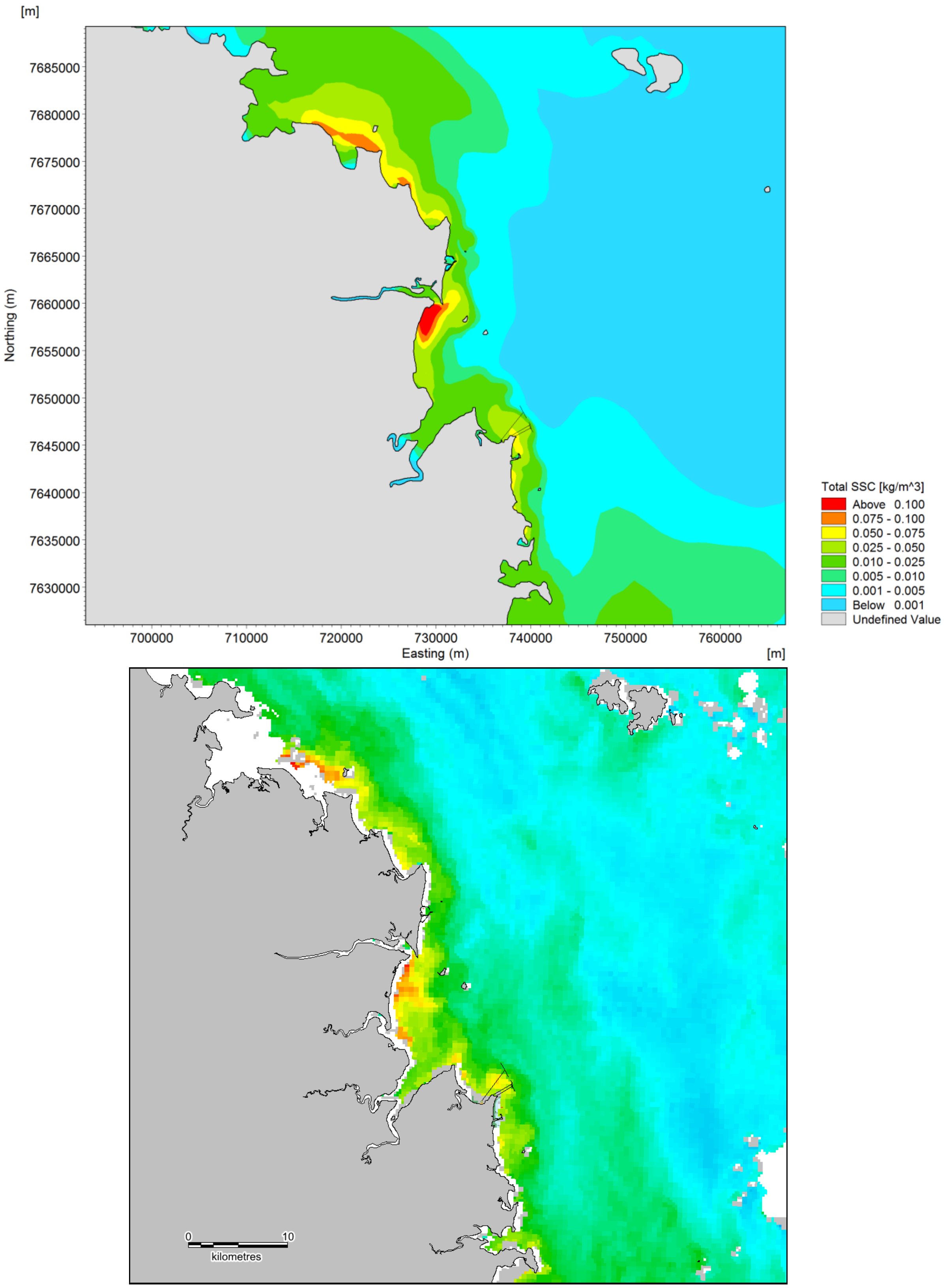

Figure 8: Comparison in spatial SSC distribution between modelled (top) and MODIS satellite data (bottom) during moderate conditions. Average spring tide (HW = 5.8 m LAT), wind speed = 20 knots.

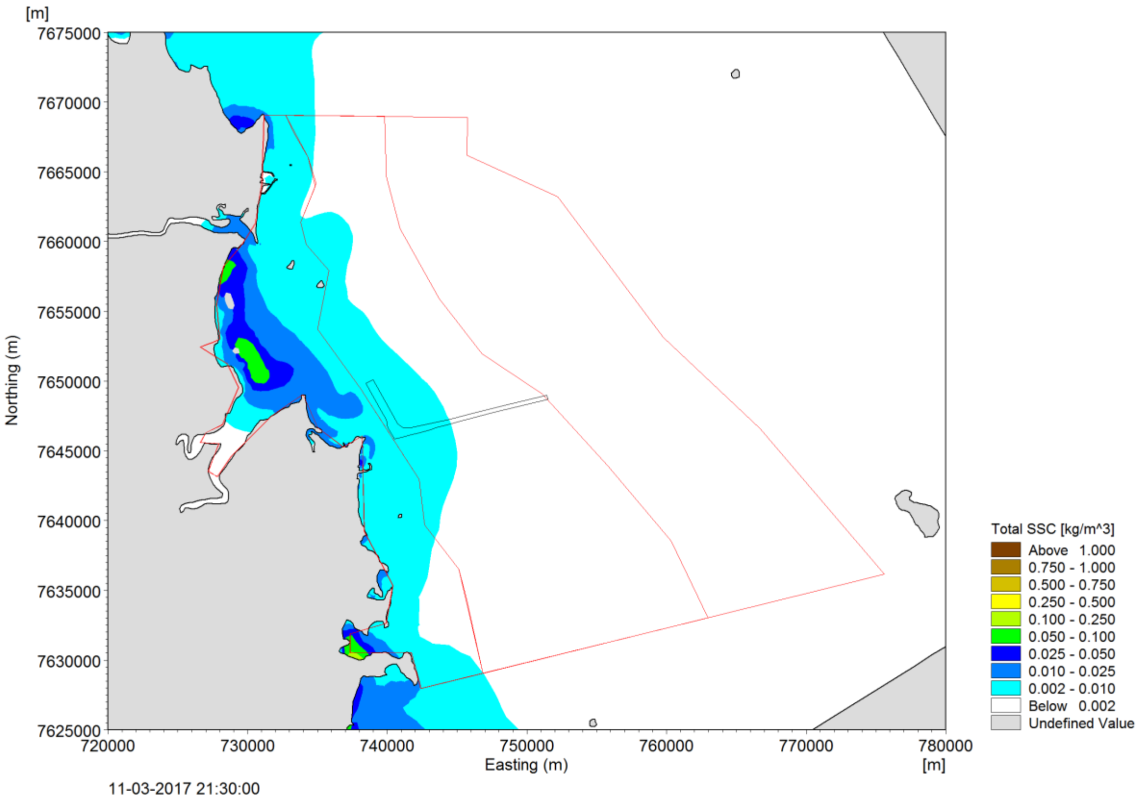

*Figure 9: Modelled SSC in the Port of Hay Point region during a spring tide with low wind speeds (5 -10 knots). The red lines represent the polygons used to represent the different depth zones for the region from **Figure 3**.*

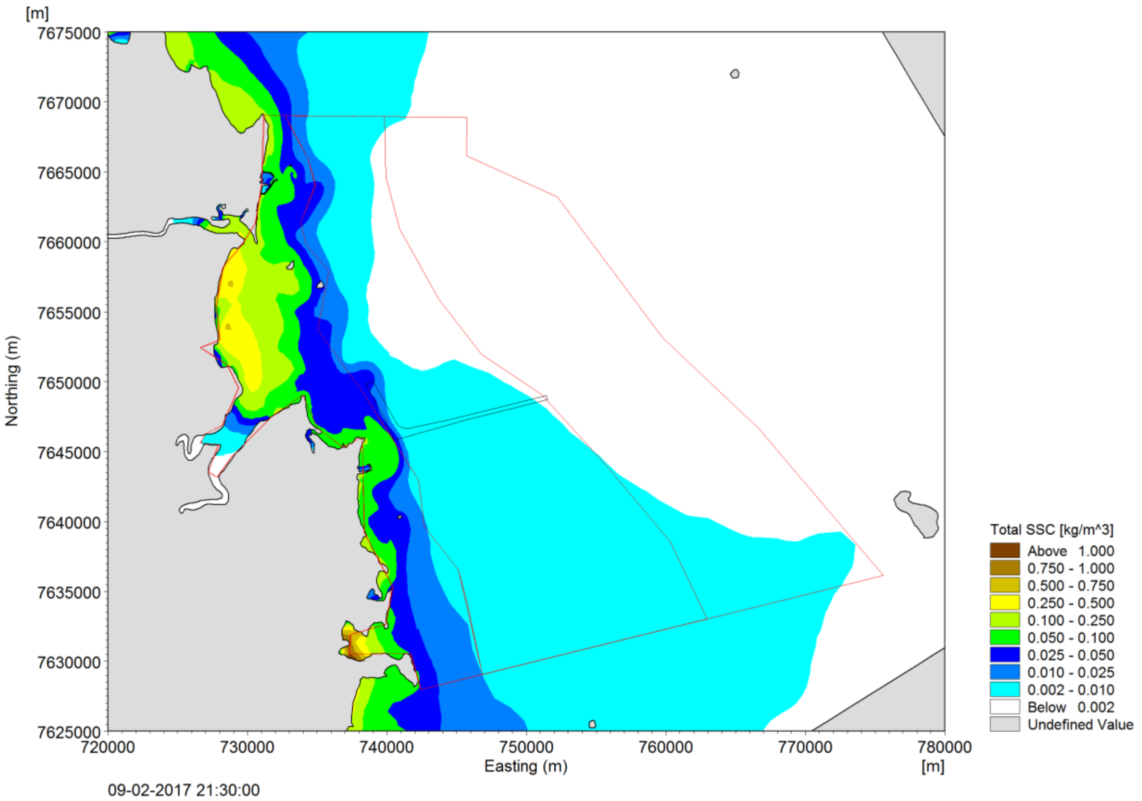

*Figure 10: Modelled SSC in the Port of Hay Point region during a strong wind (20-25 knots) event. The red lines represent the polygons used to represent the different depth zones for the region from **Figure 3**.*

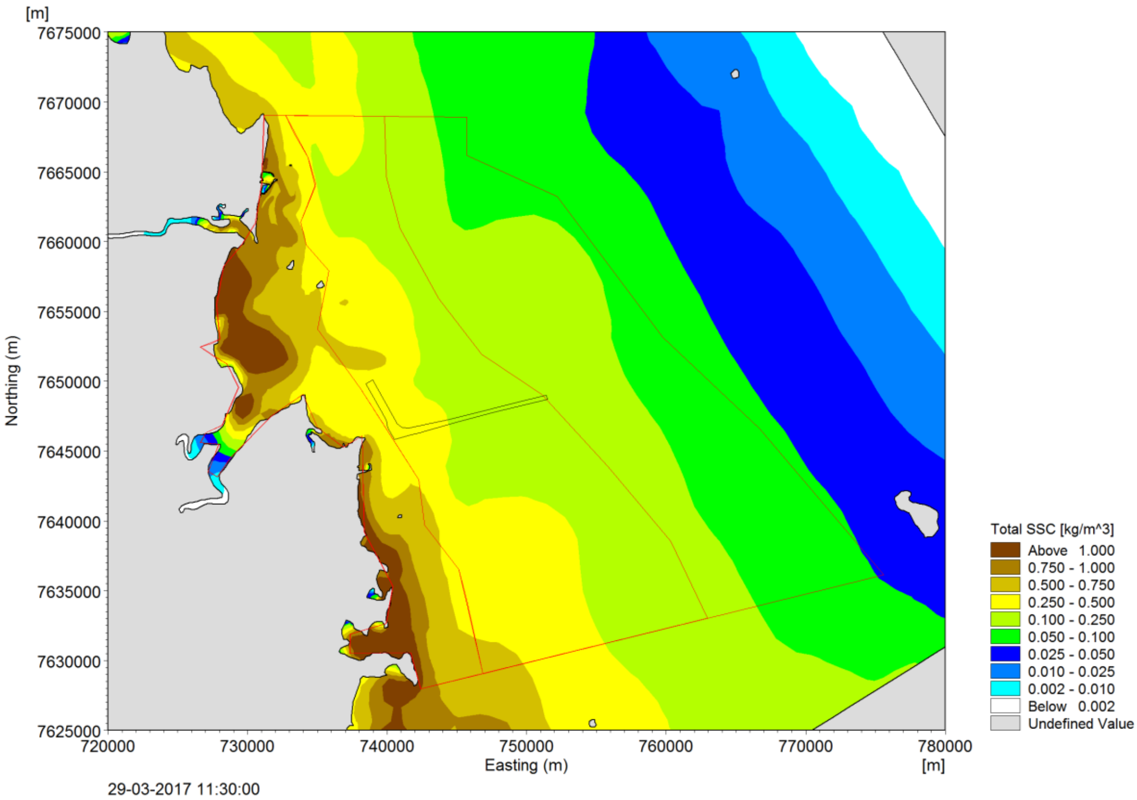

Figure 11: Modelled SSC in the Port of Hay Point region during TC Debbie (peak measured wind speed at Hay Point weather station was 50 knots). The red lines represent the polygons used to represent the different depth zones for the region from Figure ***3****.*

SSC and Wind Speed Relationship

To be able to develop a relationship between wind speed and SSC it is first necessary to establish whether there is a relationship between wind speed and wave height in the area of interest. The RHDHV model for the area does not include the full fetch extent where wave generation occurs and so to represent conditions due varying wind speeds in the model it is also necessary to have an offshore wave boundary condition which corresponds to the wind speed being applied. The relationship between wind speed and significant wave height at the Port of Hay Point is shown in **Figure 12**. This relationship is based on measured wind speed and modelled wave height over a three month period which included TC Debbie. The wave model has been calibrated to data from the Hay Point waverider buoy and has been shown to be able to reliably represent the wave conditions at Hay Point. The plot shows a clear relationship between wind speed and wave height for the area demonstrating that it is possible to realistically scale wave height to wind speed.

The RHDHV natural sediment transport model was configured to simulate a six day period which coincided with a typical representative onshore wind event (wind direction predominantly from the SE quadrant). This typical wind event formed the basis of the model setup for eight different synthesised scenarios in which the wind time series was scaled such that the peak wind speed of the event equated to a pre-defined value (every 5 knots from 5 knots to 40 knots). The wave boundary conditions were scaled relative to the resultant wind speed according to the relationship described above. This ensured that the modelled wave conditions were representative of the conditions generated from further offshore and within the model domain due to the wind speed being tested.

Review of the measured SSC data for the Hay Point and Mackay region showed that the tidal range is also important to the SSC (and therefore to the resuspension), especially for lower wind conditions. As a result, the eight wind speed scenarios were simulated during both spring and neap tidal conditions.

The wind directions from the typical event were similar for all the cases, with the strongest winds being from the south east (which is the dominant wind direction for the area; this is further discussed later in this section). It is important to note that the resuspension mass and SSC correlations to wind speeds are likely to be approximately representative for winds from the south-east to north-east (i.e. onshore) but the relationships are not expected to be valid for cross shore (northerly or southerly) or offshore (westerly) wind directions.

Results from the model simulations were processed to calculate the peak mass of sediment in suspension within the Hay Point region (0 to 20 m below LAT area in **Figure 3**) during each scenario for spring and neap tidal conditions (**Figure 13** and **Figure 14**). The plots show a relatively linear increase in SSC for wind speeds of less than 20 knots, with more of an exponential relationship when wind speeds increase above 20 knots. The results show that the tidal currents are important in terms of sediment resuspension, with the bed shear stresses from the high current speeds during spring tides combining with the bed shear stresses from the wind generated waves to resuspend more sediment than during neap tides. To understand how the SSC in the Hay Point region varies with wind speed, the peak SSC at Victor Island, Hay Reef, Round Top Island and Slade Islet from each scenario has been extracted and averaged. The relationships between wind speed and the spatially averaged peak in SSC over the four sites for spring and neap tidal conditions are shown in **Figure 15** and **Figure 16**, while site specific relationships are provided in **Appendix B**.

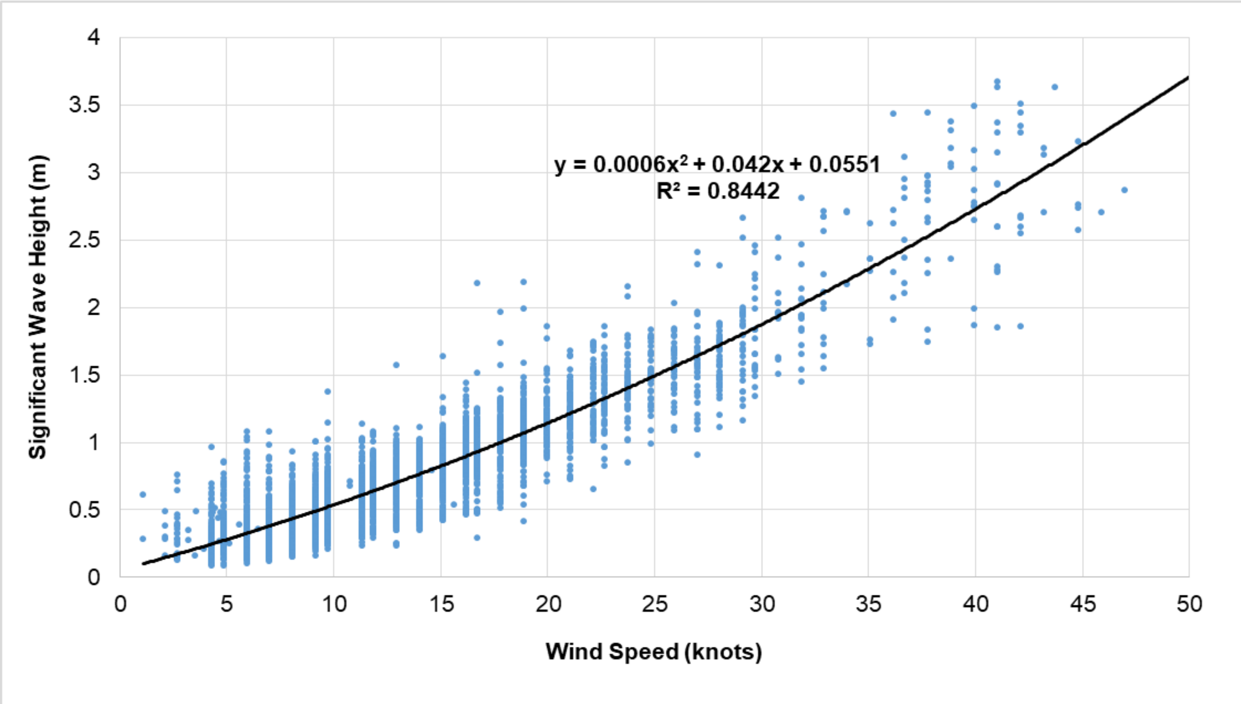

Figure 12: Relationship between wind speed and significant wave height at the Port of Hay Point.

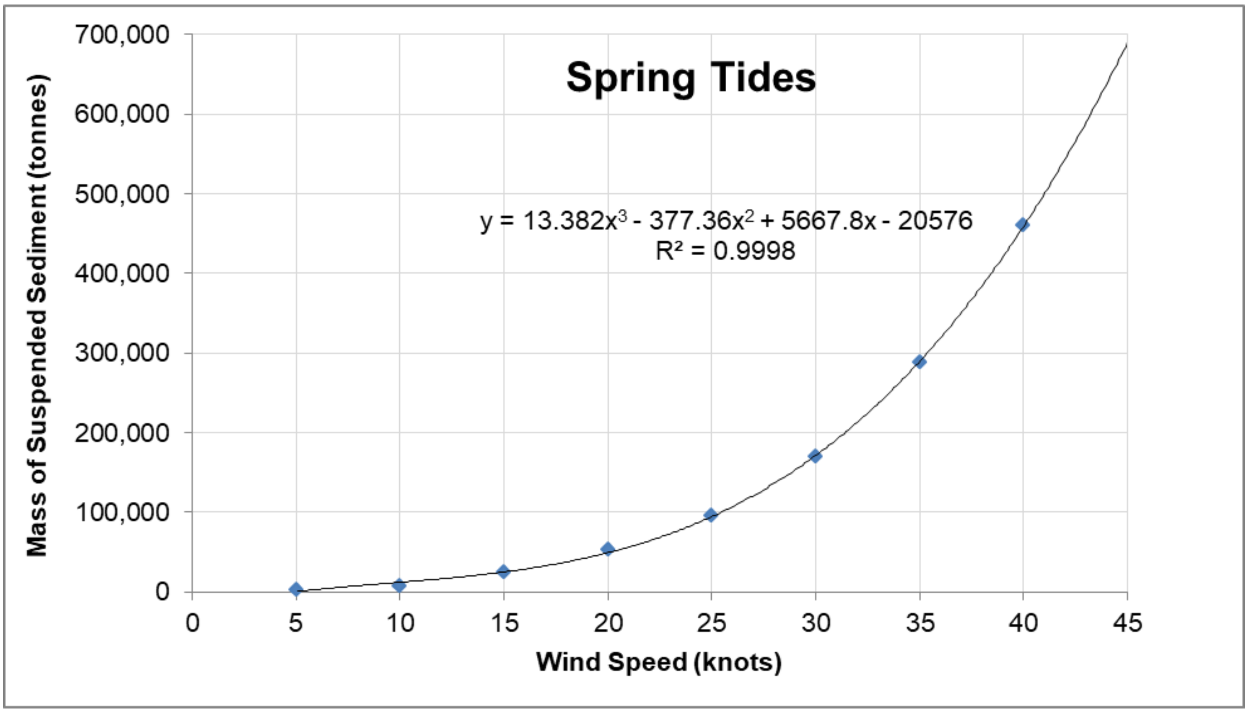

Figure 13: Relationship between wind speed and the mass of sediment in suspension within the Hay Point region during spring tides.

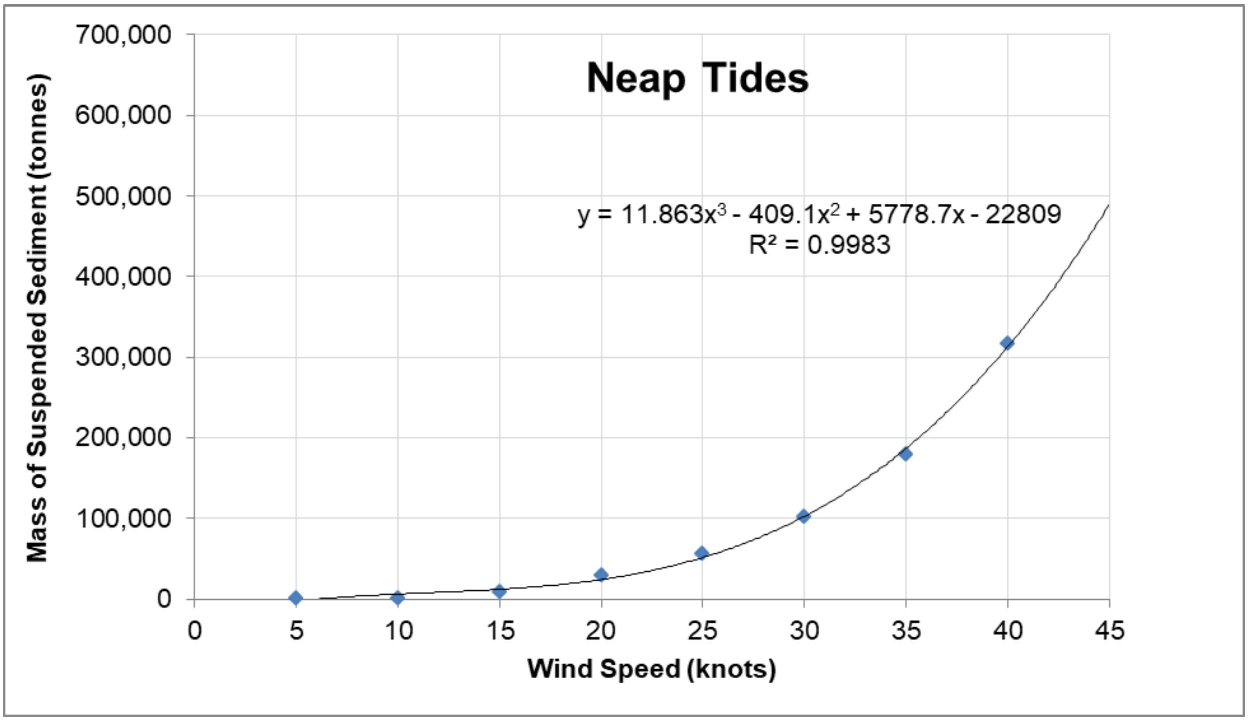

Figure 14: Relationship between wind speed and the mass of sediment in suspension within the Hay Point region during neap tides.

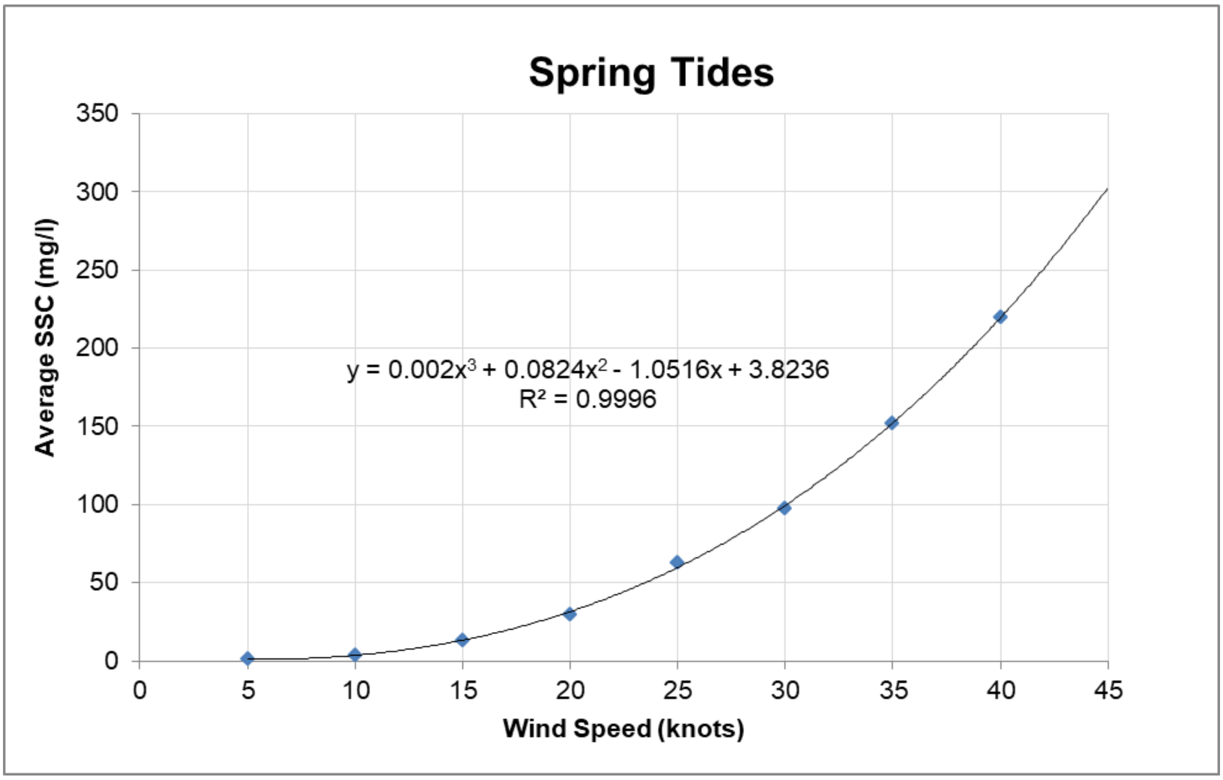

Figure 15: Relationship between wind speed and the averaged peak in SSC (averaged from Victor Island, Hay Reef, Round Top Island and Slade Islet) during spring tides.

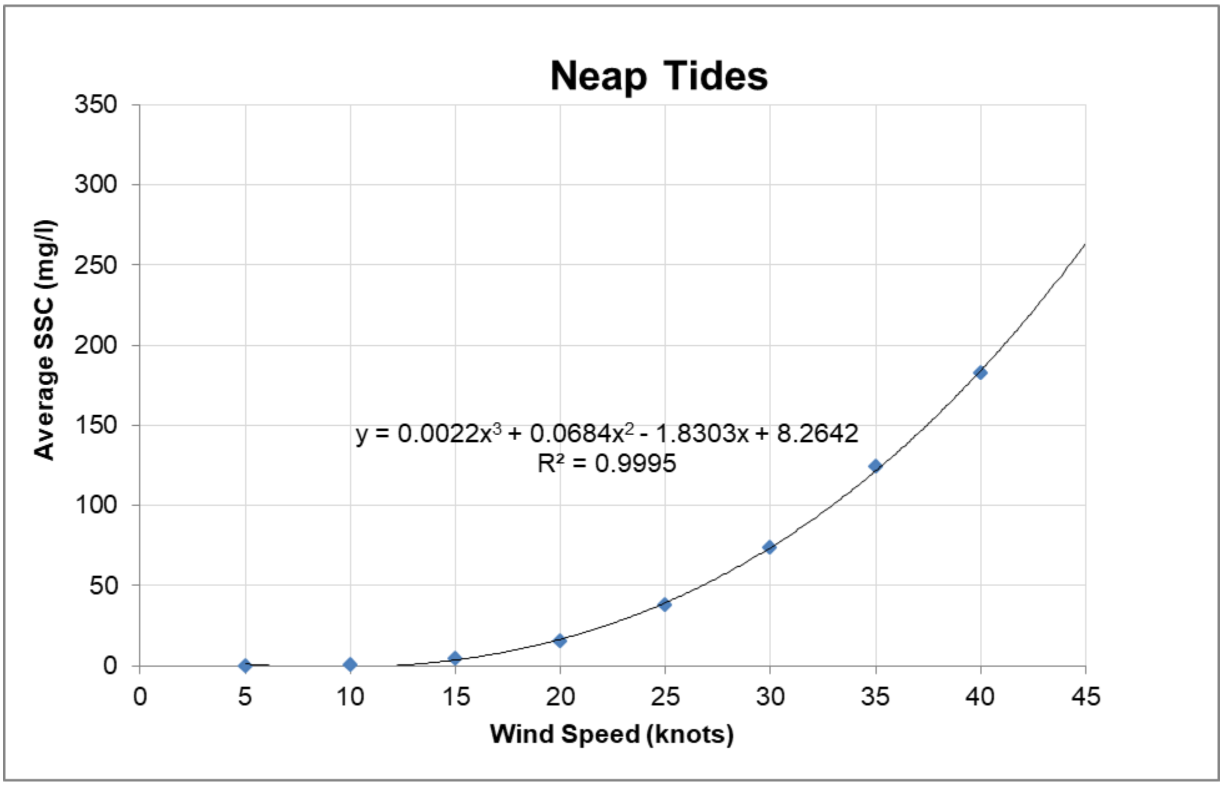

Figure 16: Relationship between wind speed and the averaged peak in SSC (averaged from Victor Island, Hay Reef, Round Top Island and Slade Islet) during neap tides.

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Wind data from the Bureau of Meteorology (BoM) weather station located at Half Tide Tug Harbour (HTTH) (referred to as the Hay Point weather station) have been processed to provide a better understanding of the wind conditions for the region. Annual and seasonal wind roses are presented in **Figure 17** and **Figure 18** and a joint frequency table of the annual wind speed and direction is provided in **Table 1**. The wind data shows that the dominant wind direction is from the south-east quadrant, but that the relative dominance varies seasonally. During autumn and winter (dry season) the dominant wind direction is from the south, while during spring and summer (wet season) winds from the north clockwise through to south east are dominant. The wind speeds are less than 10 knots for approximately 40 percent of the time, and greater than 20 to 25 knots for approximately 5 percent of the time. The average and median wind speeds are approximately 12.5 knots.

Table 1: Joint frequency table between wind speed and wind direction at the BoM Hay Point weather station.

Joint Frequency Table (%) Showing Wind Sp Against Direction for the Period 24−Nov−2005 13:48:00 to 08−May−2017 10:38:00

N=602334	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total	Cumul.
0−5	0.19	0.19	0.25	0.25	0.23	0.19	0.21	0.22	0.27	0.77	1.36	0.96	0.80	0.49	0.29	0.14	6.82	6.82
5−10	1.25	1.63	2.45	2.86	2.78	2.32	2.47	2.20	1.96	4.49	4.07	1.41	1.09	0.76	0.87	0.63	33.24	40.06
10−15	1.22	1.35	1.50	1.93	2.83	3.09	3.10	2.69	2.37	2.25	0.33	0.07	0.03	0.02	0.11	0.36	23.27	63.33
15−20	1.94	0.91	0.54	0.87	2.69	4.86	4.41	5.52	3.21	1.46	0.07	0.02	0.01	*	0.02	0.29	26.83	90.16
20−25	0.24	0.04	0.04	0.09	0.35	1.29	1.17	1.60	0.50	0.08	*	*	*	*	*	0.03	5.44	95.60
25−30	0.02	0.01	0.01	0.03	0.07	0.23	0.21	0.43	0.05	*	*	*	*	−	*	*	1.08	96.69
30−35	*	*	*	*	*	0.02	0.02	0.06	*	*	−	−	−	−	*	*	0.13	96.82
35−40	*	*	*	*	*	*	*	0.01	*	*	−	−	−	−	*	*	0.05	96.87
40−45	−	*	*	*	*	*	*	*	*	−	−	−	−	−	−	−	0.02	96.89
45−50	−	*	*	*	*	*	−	*	−	−	−	−	−	−	−	*	*	96.90
Total	4.88	4.15	4.81	6.06	8.96	12.01	11.60	12.74	8.38	9.06	5.83	2.46	1.94	1.28	1.28	1.46		
Cumul.	4.88	9.02	13.83	19.89	28.85	40.86	52.46	65.20	73.57	82.63	88.47	90.93	92.87	94.15	95.43	96.90		

* denotes values less than 0.01%   − denotes no records in bin

Metadata:
Project: PA1163
Data period: 24−Nov−2005 13:48:00 to 08−May−2017 10:38:00
Data source: BoM
Data summary: All Records
Number of Records: 602334
Missing data (%): 2.40
Calms (% <1.0m/s): 0.70

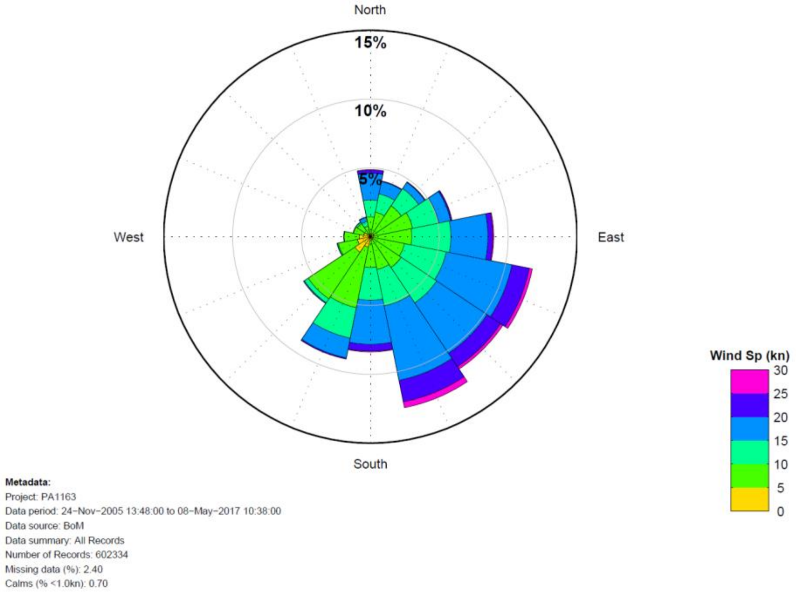


Figure 17: Annual wind rose for the BoM Hay Point weather station.

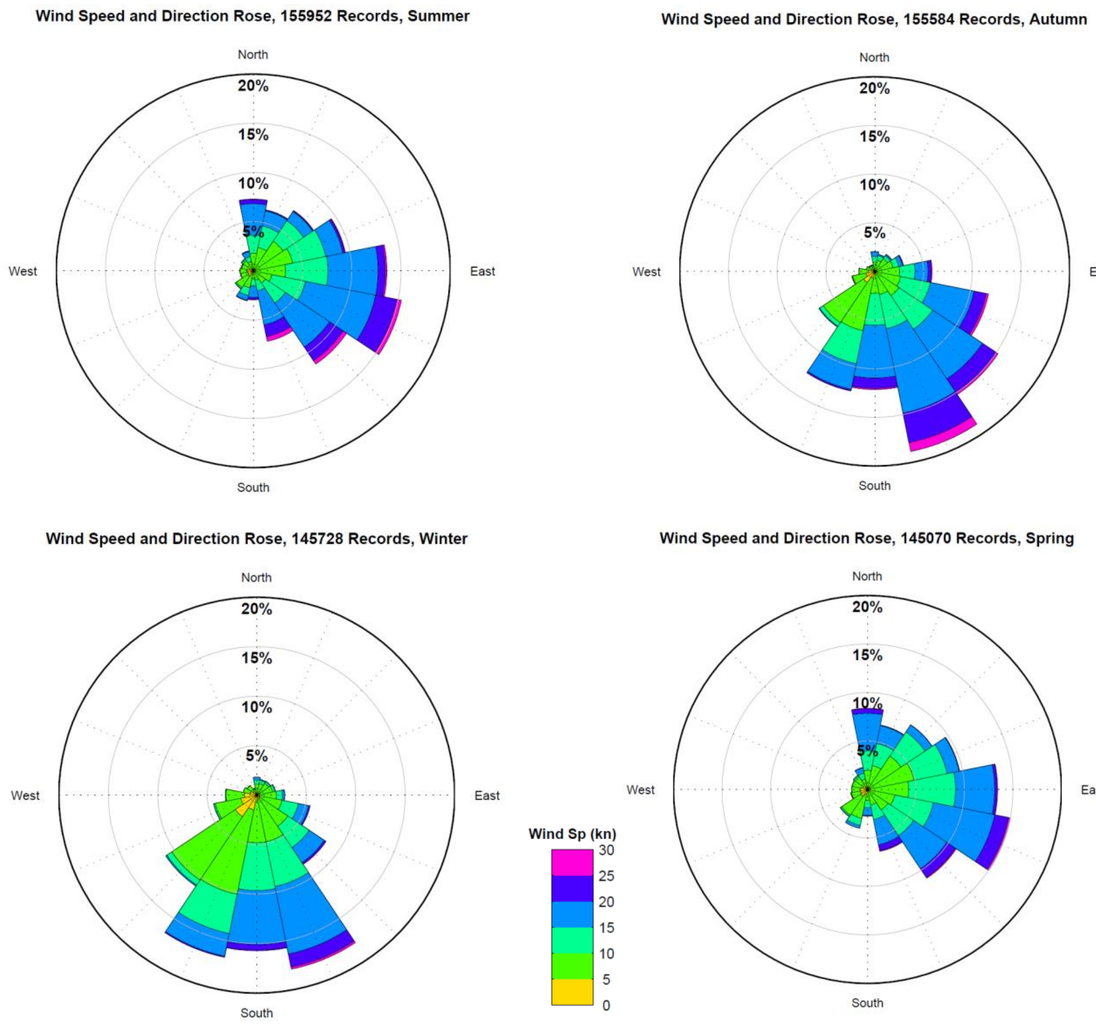


Figure 18: Seasonal wind roses for the BoM Hay Point weather station.

To show how maintenance dredging compares to the natural variability in SSC, numerical modelling results from a month long 400,000 m^3 maintenance dredging simulation using the existing material placement site have been used (the results are from the ongoing Hay Point Maintenance Dredging Modelling Assessment being undertaken by RHDHV). The output from the model simulation of excess SSC (i.e. greater than natural ambient conditions) due to the dredging was processed to calculate the 5^{th}, 20^{th}, 50^{th}, 80^{th} and 95^{th} percentile values that occurred during both spring and neap conditions over the simulated dredging duration.

The dredging related excess SSC percentiles have been compared to percentiles derived from the simulations used to develop the wind speed to natural SSC relationship described above. The natural SSC percentiles were based on three days during the peak of the eight wind scenarios for both spring and neap tidal conditions. The spatially averaged SSC percentiles from dredging and natural resuspension for the four sites considered (Victor Island, Hay Reef, Round Top Island and Slade Islet) during spring and neap tides are shown in **Figure 19** and **Figure 20**, while site specific plots are included in **Appendix B**. The plots demonstrate that the maintenance dredging results in low excess SSC at the four sites, approximately comparable to the natural SSC during calm conditions (wind speeds of 15 knots and under).

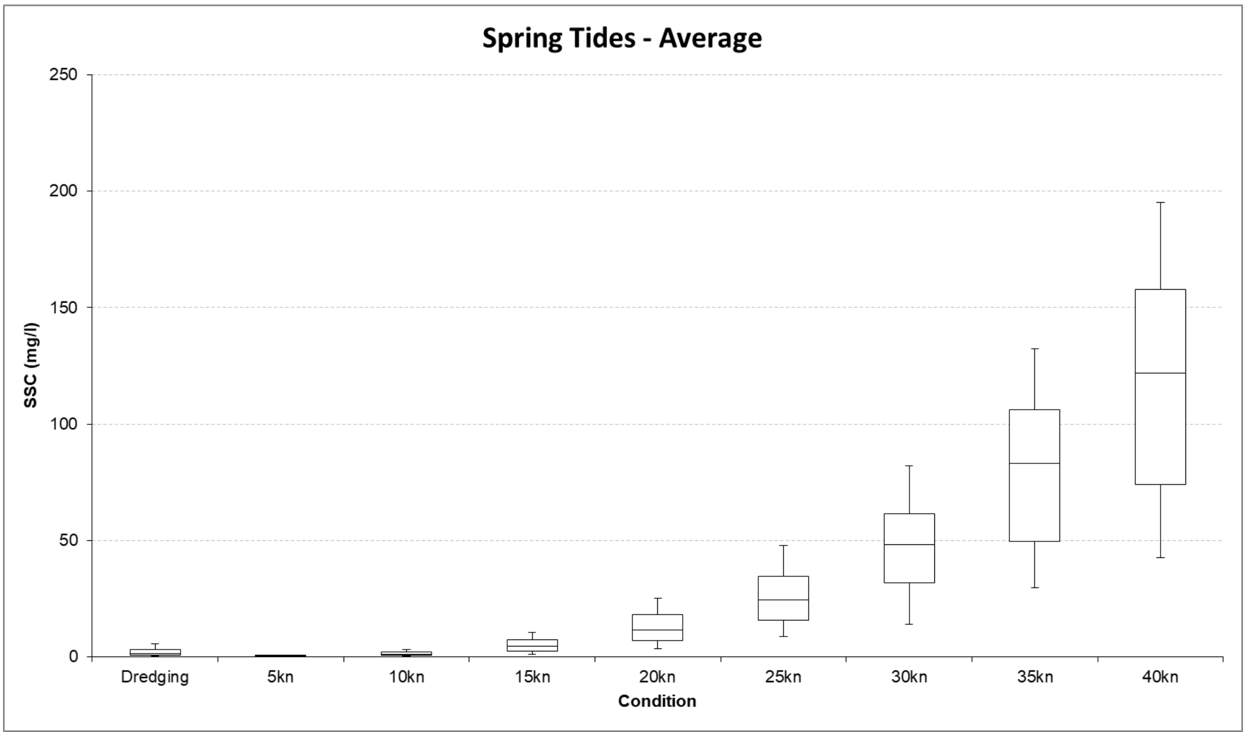


Figure 19: Box and whisker plots showing average percentiles (over the four sites) during spring tidal conditions of natural SSC during different wind speeds and excess SSC from maintenance dredging of 400,000 m^3 using the existing placement site. The box is represented by the 20^{th}, median (middle line) and 80^{th} percentiles, while the whiskers are represented by the 5^{th} and 95^{th} percentiles.

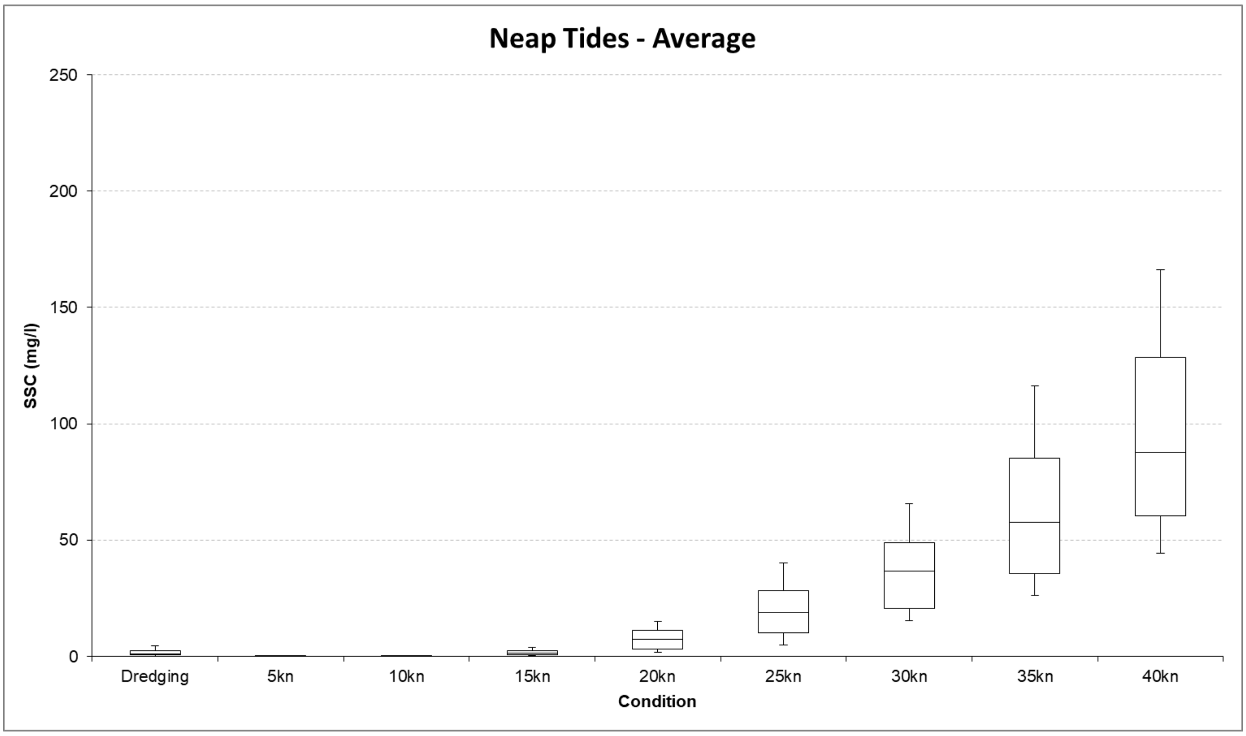


Figure 20: Box and whisker plots showing average percentiles (over the four sites) during neap tidal conditions of natural SSC during different wind speeds and excess SSC from maintenance dredging of 400,000 m^3 using the existing placement site. The box is represented by the 20^{th}, median (middle line) and 80^{th} percentiles, while the whiskers are represented by the 5^{th} and 95^{th} percentiles.

Summary

This technical note has provided details of the natural resuspension of sediment at the Port of Hay Point. The assessment has found that:

- the annual mass of sediment resuspended by typical conditions is in the order of 7,000,000 to 9,000,000 tonnes per year in the Hay Point region (to 20 m LAT and 20 km north and south of the Port); and
- approximately 4,700,000 tonnes of sediment was resuspended within the Hay Point region (to 20 m LAT and 20 km north and south of the Port) during TC Debbie. As such, during a year when a tropical cyclone occurs the natural resuspension could increase to 12,000,000 to 14,000,000 tonnes per year.

Relationships between resuspension mass/SSC and wind speed for the Hay Point region have been developed for both spring and neap tidal conditions. The relationships show a relatively linear increase in SSC for wind speeds of less than 20 knots, with more of an exponential increase when wind speeds increase above 20 knots.

A comparison of maintenance dredging relative to the natural SSC has been undertaken. This shows that the maintenance dredging scenario adopted (400,000 m^3 placed at the existing placement site) results in low excess SSC at the four sites, approximately comparable to the natural SSC during calm conditions (wind speeds of 15 knots and under).

References

RHDHV, 2016a. Hay Point Port: Bathymetric Analysis and Modelling. Reference: M&WPA1163R001F01, February 2016.

RHDHV, 2016b. Mackay Numerical Modelling Framework – Numerical Modelling Report. Reference: M&APA1510R002F0.1, July 2017.

Waltham N, Whinney J, Petus C, Ridd P 2016, Port of Mackay and Hay Point Ambient Marine Water Quality Monitoring Program July 2015 to July 2016, Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 16/54, James Cook University, Townsville, 121 pp.

Appendix A – EOMAP MODIS report

Service Provision Report

Order number:	1712
Project name:	Australia_Mackay_Hay_Point
Delivery number:	1712_Delivery_EOMAP2RHDHV_Vs1_20171006

Version	Date
1.0	2017/10/06

Date of delivery: 2017/10/06

Contact person: Karin Schenk
E-mail: schenk@eomap.de
Tel.: +49 (0)8152-99861-12

Address for Delivery:
John D. Rudolph
Aquatic Ecologist
Bioassessment Program Manager
Amec Foster Wheeler plc
9177 Sky Park Court
San Diego, CA 92123
USA

Service Provider:
EOMAP GmbH & Co. KG
Schlosshof 4a
82229 Seefeld
Germany

Content:

Content	Abbreviation	Yes / No
Turbidity	TUR	☒
Sum of Organic Absorbers	SOA	☐
Chlorophyll-a	CHL	☐
Colored Dissolved Organic Matter	CDM	☐
Harmful Algae Bloom indicator	HAB	☐
Z90	Z90	☐
Aerosol Optical Thickness	AOT	☐
Total Quality	QUT	☒
EOMAP Quality Coding	QUC	☒
RGB image	RGB	☒

List of all delivered scenes:

Sensor	Time of record
MODIS Aqua	2015-08-15 03:35:00 UTC
MODIS Aqua	2015-09-12 04:00:00 UTC
MODIS Aqua	2015-09-19 04:05:00 UTC
MODIS Aqua	2015-09-21 03:55:00 UTC
MODIS Aqua	2016-08-06 03:55:00 UTC
MODIS Aqua	2016-08-20 04:05:00 UTC
MODIS Aqua	2016-10-16 04:00:00 UTC
MODIS Aqua	2017-01-13 03:55:00 UTC
MODIS Aqua	2017-01-27 04:05:00 UTC
MODIS Aqua	2017-02-10 04:20:00 UTC
MODIS Aqua	2017-03-11 03:50:00 UTC
MODIS Aqua	2017-04-01 04:05:00 UTC
MODIS Aqua	2017-04-12 03:50:00 UTC

List of all delivered files (one example):

Filename	Format	Content
TUR_au-mackay_EOMAP_20150815_033500_MODAQ_m0250.tif	GeoTIFF	GeoTIFF, UTM coordinates, 8bit scaled
TUR_au-mackay_EOMAP_20150815_033500_MODAQ_m0250_32bit.tif	GeoTIFF	GeoTIFF, UTM coordinates, 32bit, real values
TUR_au-mackay_EOMAP_20150815_033500_MODAQ_m0250.xml	XML	Metadata
TUR_au-mackay_EOMAP_20150815_033500_MODAQ_m0250_overview.pdf	PDF	Overview PDF metadata and quicklook

Notes (e.g. technical problems, additional comments):

- RGB image taken from 500m data

Data processing:

Signature: Karin Schenk

Full name: Karin Schenk

Date: 2017/10/06

Quality control:

Signature: Hendrik Bernert

Full name: Hendrik Bernert

Date: 2017/10/06

Abbreviations:

Products:

Abbreviation	Description
ABS	Total absorption of water constituents (excluding pure water absorption)
AOT	Aerosol optical depth
CDM	Colored dissolved (organic) matter (Yellow Substance, Gelbstoff)
CHL	Chlorophyll-a
DIV	Ratio between organic absorption and TSM scattering
HAB	Harmful Algae Indicator
OWD	Optical water depth
QUT	Total quality of each pixel
QUC	EOMAP quality coding
RGB	Red-Green-Blue true color/false color composite
SDD	Secchi disc depth
SIA	Sum of inorganic absorption
SOA	Sum of organic absorption
SST	Sea surface temperature
TSM	Total suspended matter
TUR	Turbidity
Z90	Penetration depth from which 90% of the reflected light comes from

Sensors:

Abbreviation	Description
LSAT5	LANDSAT 5
LSAT7	LANDSAT 7
LSAT8	LANDSAT 8
MERIS	MERIS
MODAQ	MODIS_AQUA
MODTE	MODIS_TERRA
REYE1	RAPIDEYE1
REYE2	RAPIDEYE2
REYE3	RAPIDEYE3
REYE4	RAPIDEYE4
REYE5	RAPIDEYE5
SPOT4	SPOT4
SPOT5	SPOT5
THEOS	THEOS
WVIE2	WORLDVIEW2

Naming of the product files:

The naming of EOMAP product files follows a sequence of mandatory and optional elements.

<product>_<region>_<subregion>_<optional_ path/row(Landsat)>_<serviceprovider>_<date> _<time> _<sensor>_<resolution>_<other_information>.<ext>

Example:

<TUR>_<id>-<Sumatra><127060>_<EOMAP>_<20140409>_<032930>_<LSAT8>_<m0030>.<tif>

Appendix 1: Method and Products

1.1 Modular Inversion and Processing System MIP

For the retrieval of satellite-derived water quality data, the physics-based Modular Inversion and Processing System (MIP), developed by EOMAP, has been applied to MODIS Aqua and Terra image data. This sensor-independent approach includes all the relevant processing steps to guarantee a robust, standardised and operational retrieval of water quality parameters from various satellite data sources. The advantage of physics-based methods is that they do not require a priori information about the study area and can therefore be applied independently of satellite type and study area.

MIP is the first sensor-independent processing system that takes into account adjacency and terrain altitude impacts. The system integrates a fully coupled and bidirectional atmospheric and in-water retrieval of harmonized water quality properties, allowing for the full range of scattering and absorption in natural waters (Kiselev et al. 2014, Heege et al. 2014, Richter et al. 2014, Heege & Fischer 2000 & 2004). The MIP architecture systematically handles the independent properties of sensor parameters and specific optical properties as well as the radiative transfer relationships (at 1nm spectral resolution). The different workflow steps from satellite raw imagery import to value-added water quality retrieval are displayed in Figure 1. MIP is the most established, sensor-independent and operational aquatic remote sensing processing system for the full range of high, medium and low resolution satellite sensors. Fully-automated water monitoring processors are installed in satellite ground segments worldwide (Europe, Australia, Asia and America), to ensure fast and efficient access to a wide range of satellite data. The data processing and orchestration software, the EOMAP Workflow System (EWS) allows for continuous, daily production.

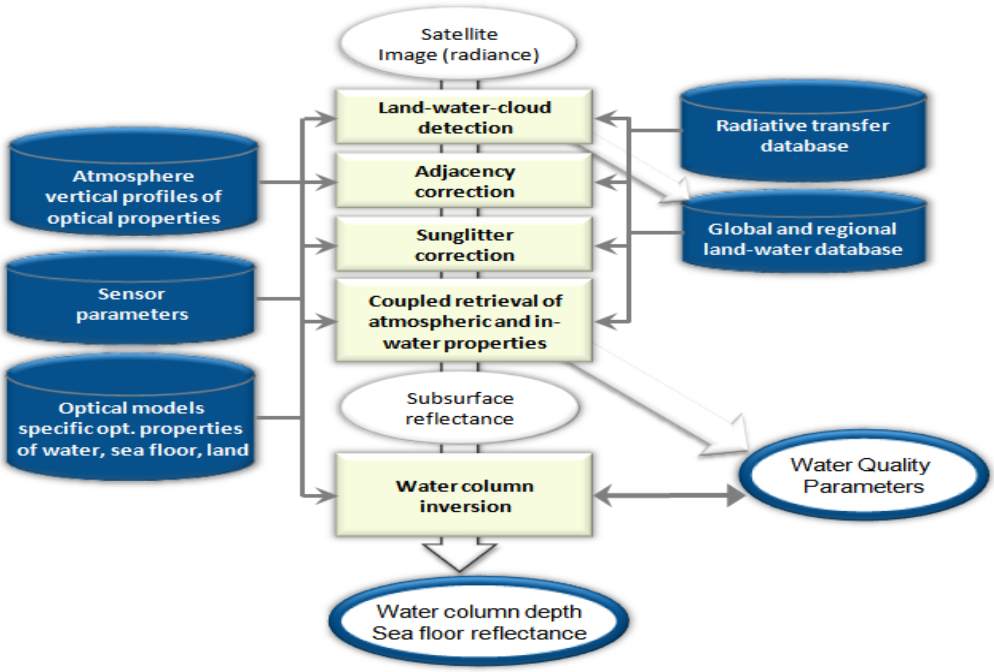


Figure 1: EOMAP's physics based workflow to derive satellite based water quality and water depth

1.2 Satellite derived water quality parameters

Turbidity (short: TUR) is a key parameter of water quality and is linearly related to the backward scattering of light of organic and inorganic particles in water. Turbidity is also linearly related to Total Suspended Matter (TSM) at low to moderate turbidity values. The measurement unit is Earth Observation Turbidity Unit (ETU), which is similar to Formazine Turbidity Unit (FTU) or Nephelometric Turbidity Unit (NTU). Satellite-derived turbidity is determined by the backward scattering of light between 450 to 800nm, which is physically retrieved using satellite data. Note that the geometrical properties of an in situ measurement device, and the wavelength used, may differ in comparison to the satellite product. For example, the standard FTU determination, a measure of turbidity similar to NTU, is based on the measurement of light scattered within a 90° angle from a beam directed at the water sample. Alongside temporal differences in satellite and in situ measurements, different sampling depths and the measurement location, this needs to be considered when comparing and interpreting satellite derived vs. in situ measured turbidity values.   The turbidity product from 2017-03-11 is shown in Figure 2.

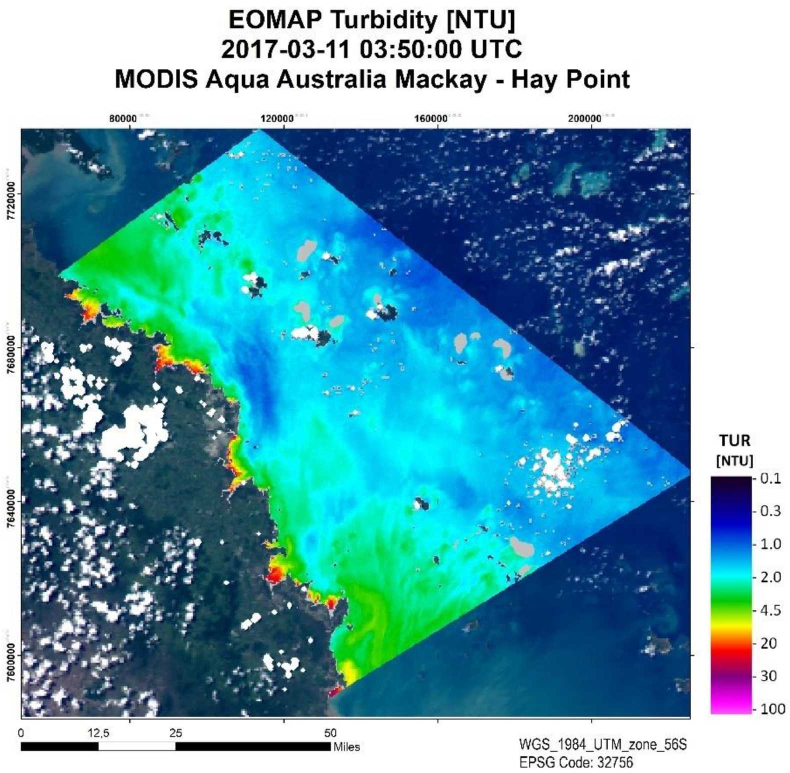


Figure 2: EOMAP Turbidity product from 2017-03-11, © Processing EOMAP, satellite data © NASA

The standard relation of EOMAP concentrations to inherent optical properties is defined as 1 NTU = 0.0118 1/m backward scattering at 550nm, or 1 NTU = 0.619 1/m total scattering at 550nm for an assumed ratio bb/b = 0.019. The linear relation between turbidity and suspended matter/solids in low to moderate concentrations is in most cases a regional constant, but can vary with particle size distribution.

1.3. Data Sources

For this study, MODIS Aqua has been selected for thirteen predefined dates. The Level 1B calibrated radiances were acquired from the Level-1 and Atmosphere Archive & Distribution System (LAADS) Distributed Active Archive Center (DAAC), located in the Goddard Space Flight Center in Greenbelt, Maryland (https://ladsweb.modaps.eosdis.nasa.gov) and has been processed with MIP-EWS.

1.4. Data Format

The water quality data is delivered as 32bit real value GeoTIFF as well as 8bit scaled and colored GeoTIFF for an easier visualization. The colours currently used are a suggestion/standard, but can be changed according to client specific request. In addition, metadata is stored in the .xml and the metadata .pdf files.

1.5. Quality Control and Masking

1.5.1 Quality Information

As a standard part of the processing, an accuracy or quality indicator is calculated for each retrieved parameter and for each detected water pixel. This measure comprises a comprehensive range of factors that can impact the derived product quality, including:

- the geometry between sun, target, and sensor,
- the estimated sun glint probability,
- the retrieved aerosol optical depth,
- residuals of the measured and modelled sensor radiances and subsurface reflectances,
- the comparison of retrieved water species concentrations to extreme values as defined in the configuration files,
- pixels affected by cloud shadow and
- shallow water areas.

The quality information is part of each standard geodata delivery and is visualized by two different 8bit GeoTIFFs:

- QUT - Total Quality, quantifying the overall quality of each pixel from low to high. Only valid water pixels - excluding land, cloud or flagged pixels - are represented in QUT indicator.
- QUC – EOMAP Quality coding, revealing the processor's internal quality check, split into the defined indicators (e.g. sunglint, shallow water risk, etc.). These are classified into 'no quality concerns', 'quality risk and 'bad quality' (flag). Note that 'quality risk' pixels are marked as such but not flagged. In Figure 5**Error! Reference source not found.** and Figure 4 products delivered are given for QUT and QUC.

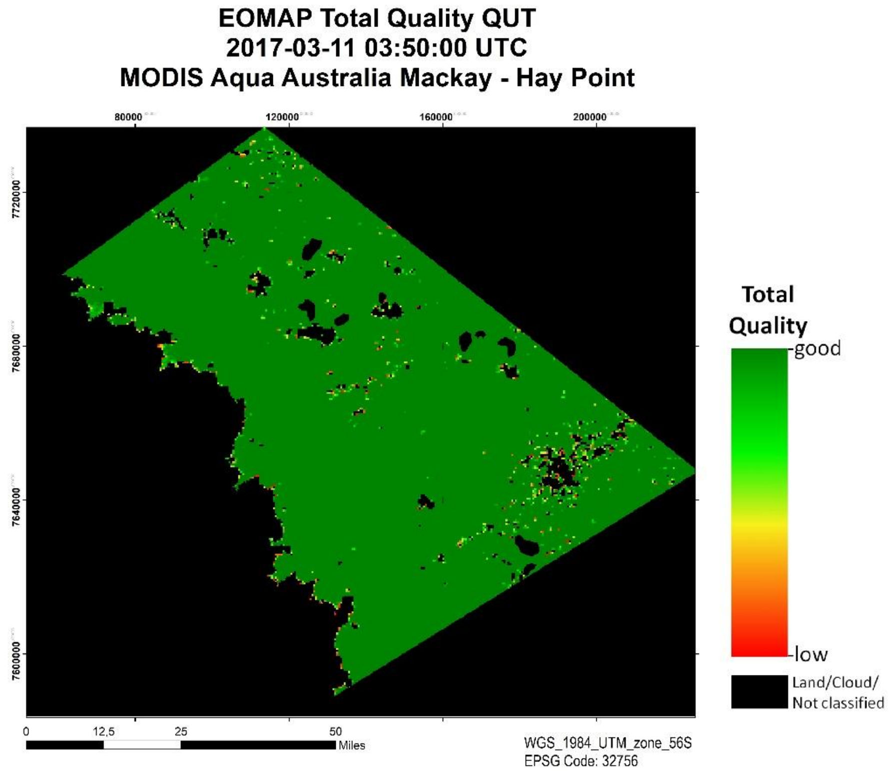


Figure 3: EOMAP Total Quality (QUT) product from 2017-09-26, © Processing EOMAP, satellite data © USGS

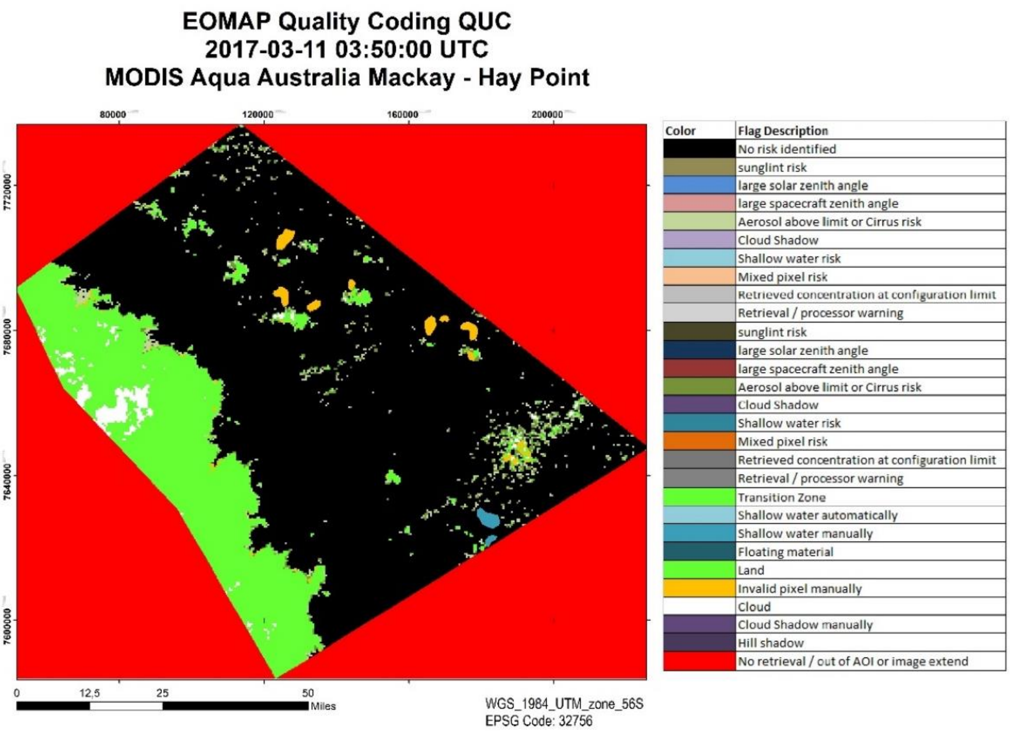


Figure 4: EOMAP Quality Coding (QUC) product from 2017-09-26, © Processing EOMAP, satellite data © USGS

1.5.2 Flagging

EOMAP's water quality products are accompanied by the processor's internal quality control mechanisms, resulting in pixel flagging in case of unreliable values. Moreover, a manual quality check and - if required - additional masking is applied to each product.

The QUC file indicates the main quality influencing parameter using a specific EOMAP quality coding classification scheme with corresponding grey values (GV), shown in Figure 5.

Professional version allow combination of the two most relevant flags:

First number = most relevant flag
1-digit-number refer to second relevant flag, e.g. 1 for sunglint risk, 2 for large solar zenith angle

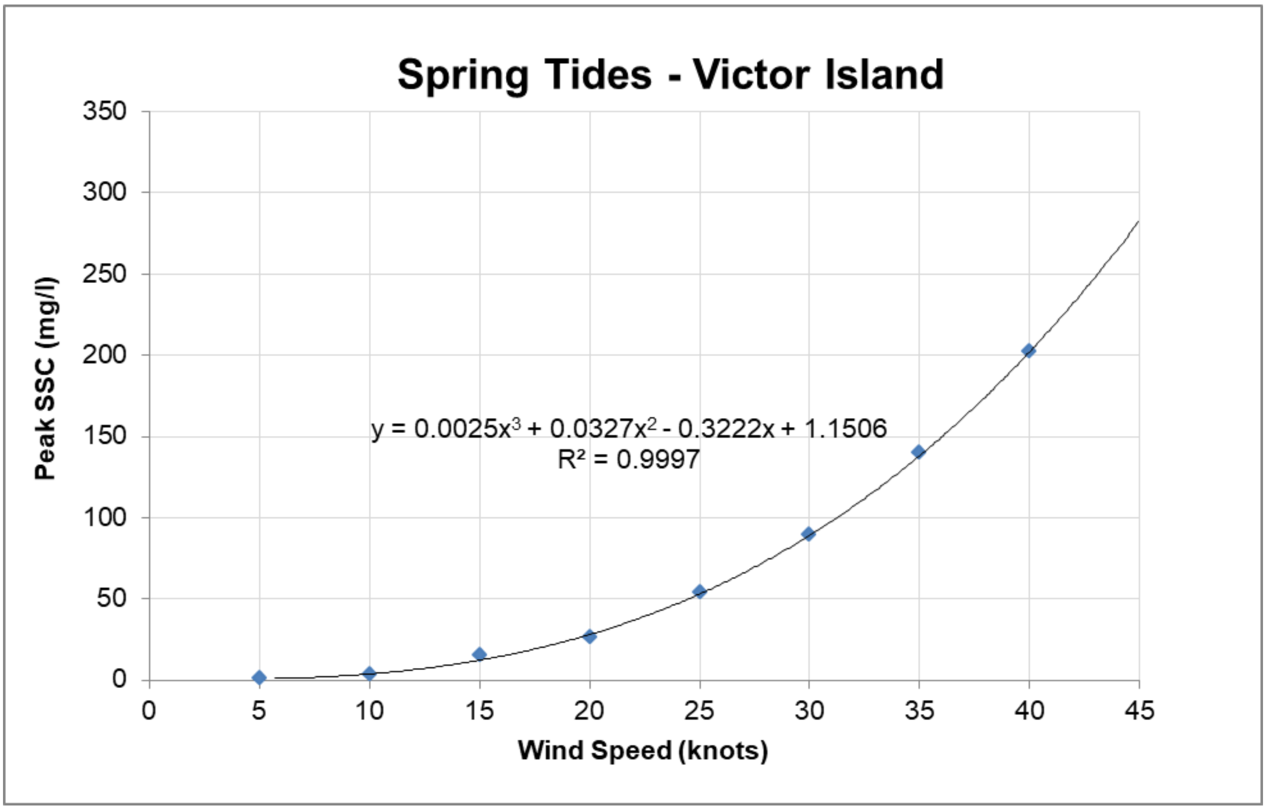
Examples: 25 Warning flag for large zenit solar angle and Whitecaps
114 Critical flag for sunglint, plus warning for aerosol above limits

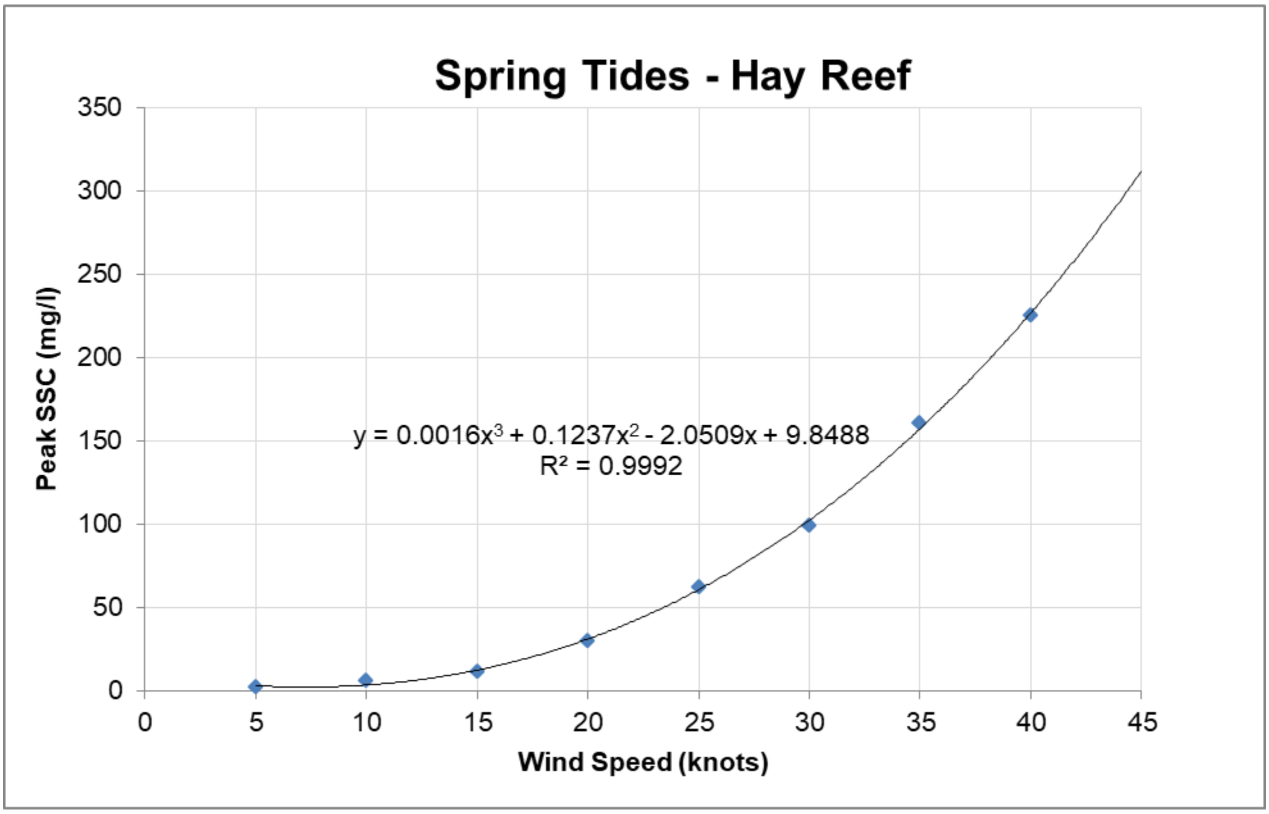
GV	GV range	Flag status	Flag description	Color code	Color
0	0	Water	No risk identified	0 0 0	
10	10 - 19	Warning	sunglint risk	148 138 84	
20	20 - 29	Warning	large solar zenith angle	83 141 213	
30	30 - 39	Warning	large spacecraft zenith angle	218 150 148	
40	40 - 49	Warning	Aerosol above limit or Cirrus risk	196 215 155	
50	50 - 59	Warning	Cloud Shadow	177 160 199	
60	60 - 69	Warning	Shallow water risk	146 205 220	
70	70 - 79	Warning	Mixed pixel risk	250 191 143	
80	80 - 89	Warning	Retrieved concentration at configuration limit	190 190 190	
90	90 - 99	Warning	Retrieval / processor warning	210 210 210	
110	110 - 119	Critical	sunglint risk	73 69 41	
120	120 - 129	Critical	large solar zenith angle	22 54 92	
130	130 - 139	Critical	large spacecraft zenith angle	150 54 52	
140	140 - 149	Critical	Aerosol above limit or Cirrus risk	118 147 60	
150	150 - 159	Critical	Cloud Shadow	96 73 122	
160	160 - 169	Critical	Shallow water risk	49 134 155	
170	170 - 179	Critical	Mixed pixel risk	226 107 10	
180	180 - 189	Critical	Retrieved concentration at configuration limit	120 120 120	
190	190 - 199	Critical	Retrieval / processor warning	130 130 130	
220	220	No value	Transition Zone	102 255 51	
221	221	Unreliable	Shallow water automatically	146 205 220	
222	222	Unreliable	Shallow water manually	60 159 186	
223	223	Unreliable	Floating material	32 95 107	
230	230	No water	Land	102 255 51	
232	232	Unreliable	Invalid pixel manually	255 192 0	
240	240	No water	Cloud	255 255 255	
242	242	Unreliable	Cloud Shadow manually	96 73 122	
244	244	Unreliable	Hill shadow	73 57 93	
250	250	No retrieval	No retrieval / out of AOI or image extend	255 0 0	

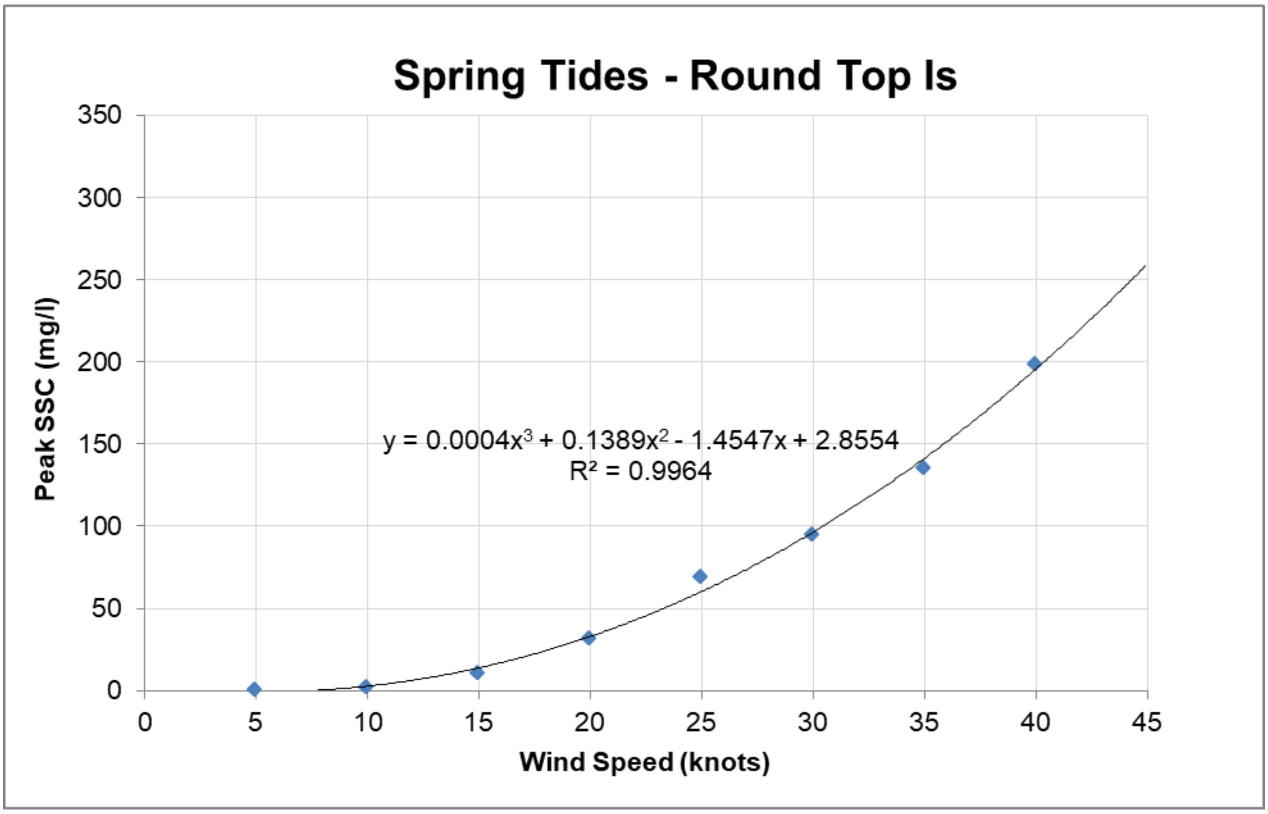
Figure 5: Description of EOMAP Quality Coding product with corresponding grey value classification

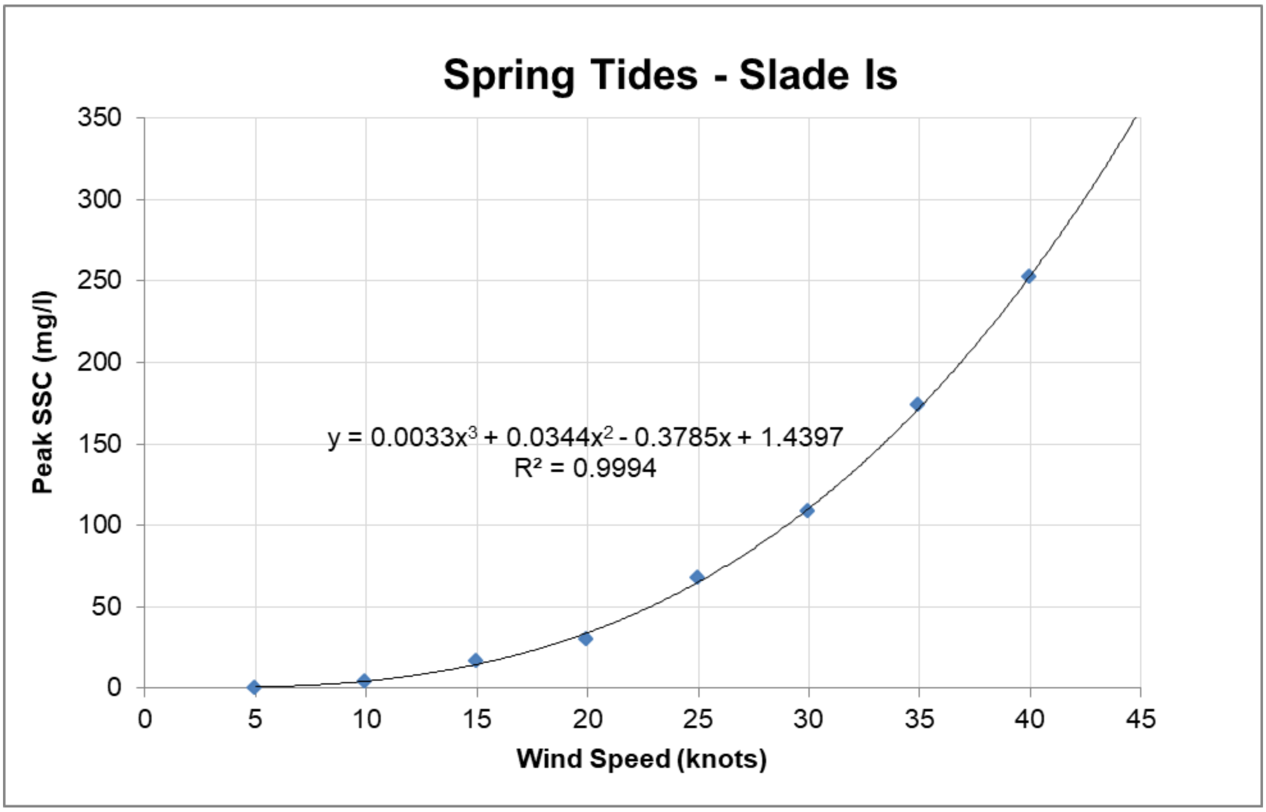
Head Office	EOMAP GmbH & Co. KG, Schlosshof 4, 82229 Seefeld, Germany
Postal Address	EOMAP GmbH & Co. KG, Schlosshof 4, 82229 Seefeld, Germany
Phone	+49 (0)8152 99861 10
Fax	+49 (0)8152 99861 29
Email	info@eomap.com
Website	www.eomap.com

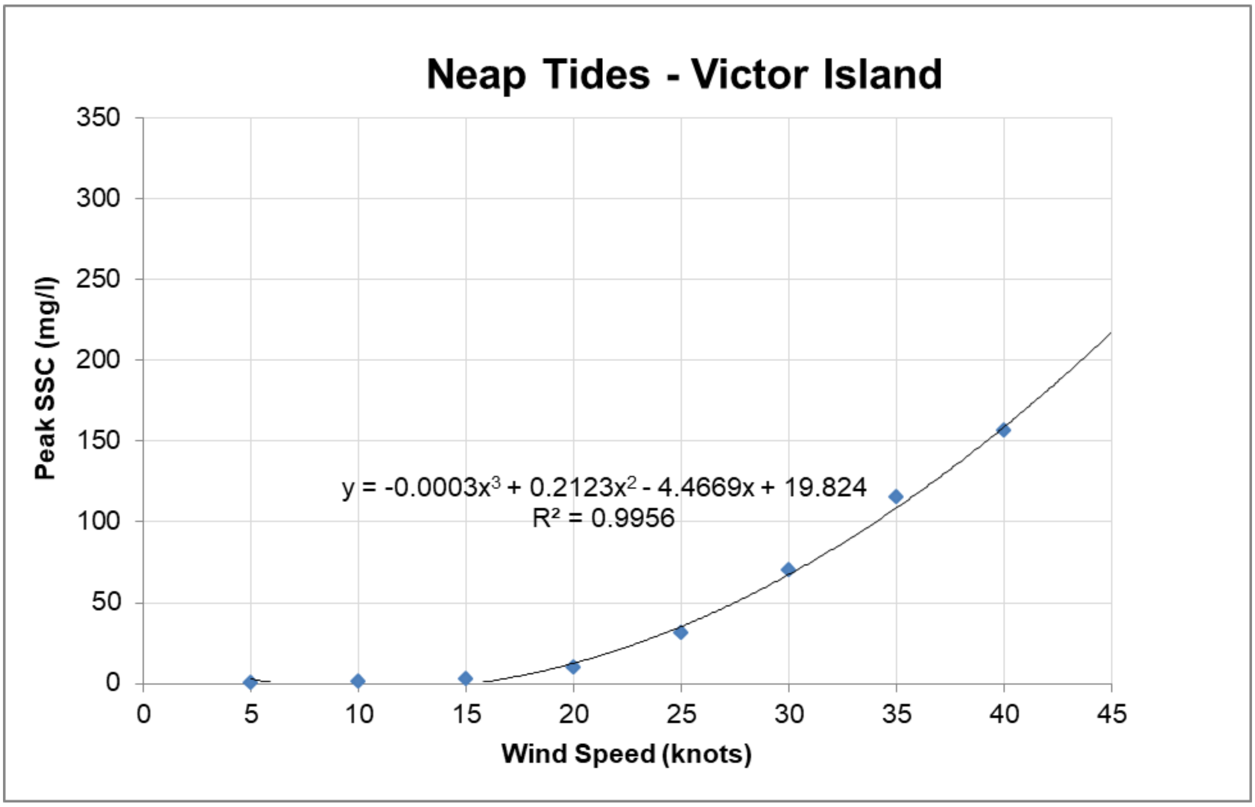
Appendix B – Wind Speed vs SSC plots

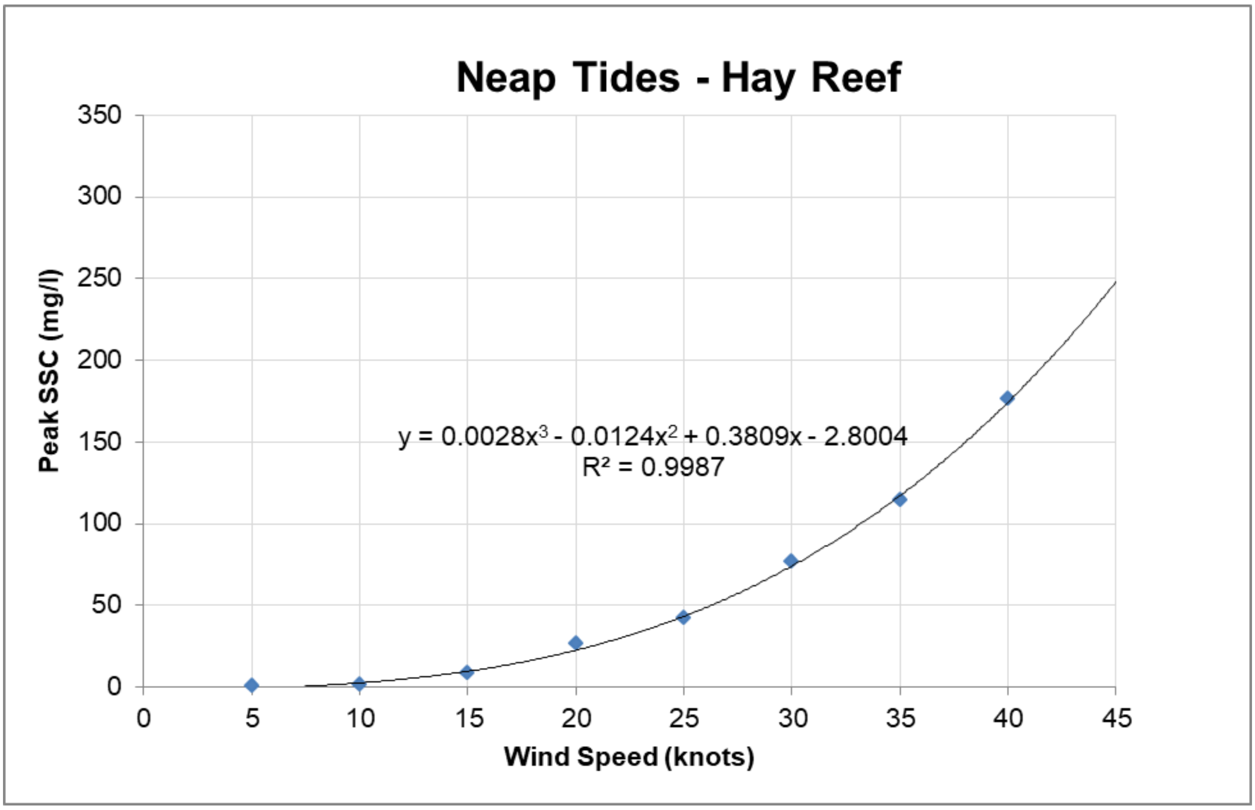


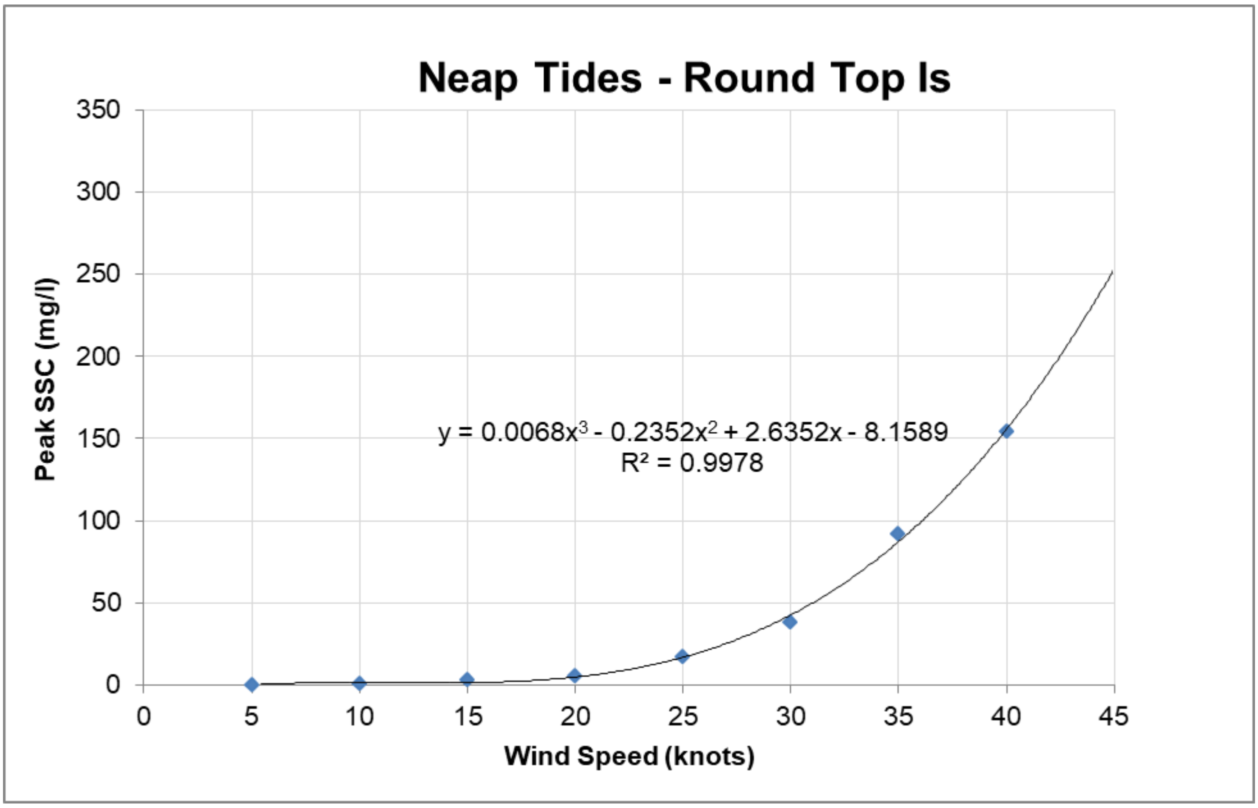



Spring Tides - Round Top Is
y = 0.0004x³ + 0.1389x² - 1.4547x + 2.8554
R² = 0.9964
Peak SSC (mg/l)
Wind Speed (knots)
0
50
100
150
200
250
300
350
0
5
10
15
20
25
30
35
40
45

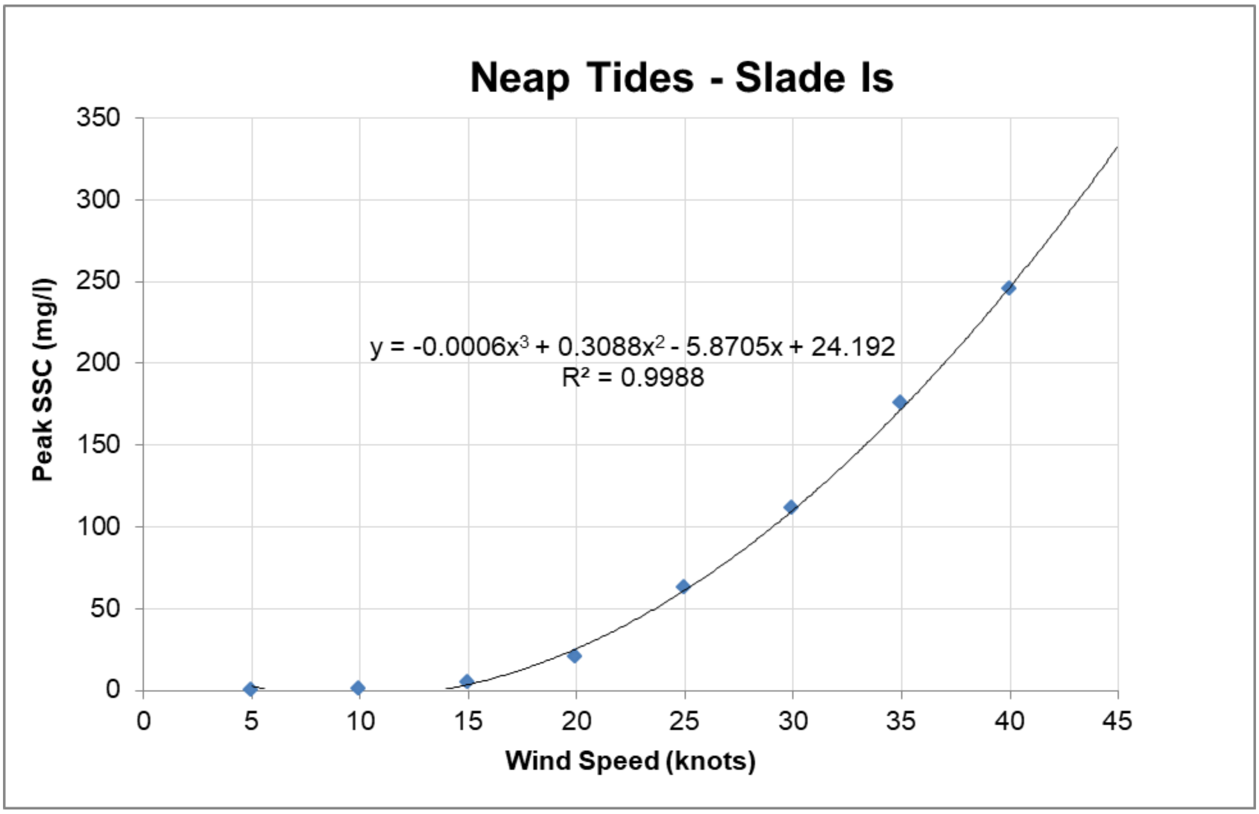

Spring Tides - Slade Is
y = 0.0033x³ + 0.0344x² - 0.3785x + 1.4397
R² = 0.9994
Peak SSC (mg/l)
Wind Speed (knots)
0
50
100
150
200
250
300
350
0
5
10
15
20
25
30
35
40
45


Neap Tides - Victor Island
Peak SSC (mg/l)
350
300
250
200
150
100
50
0
y = -0.0003x3 + 0.2123x2 - 4.4669x + 19.824
R² = 0.9956
0
5
10
15
20
25
30
35
40
45
Wind Speed (knots)

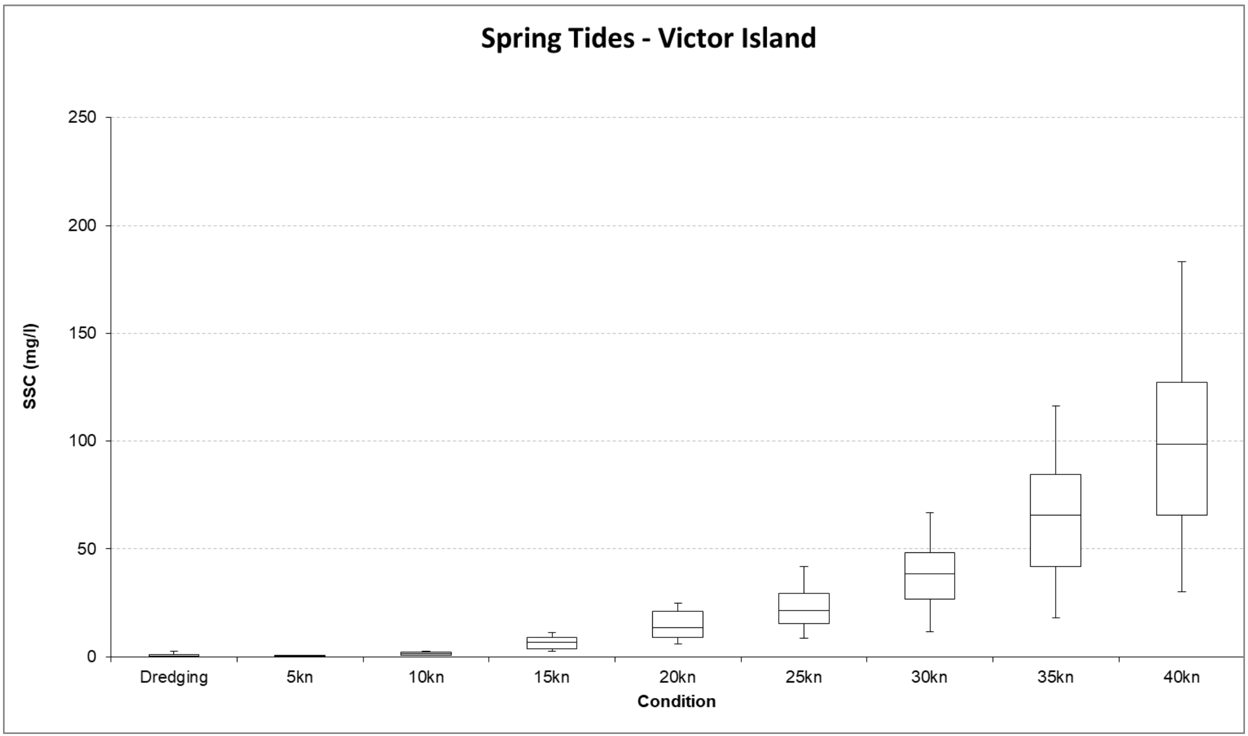

Neap Tides - Hay Reef
Peak SSC (mg/l)
350
300
250
200
150
100
50
0
y = 0.0028x3 - 0.0124x2 + 0.3809x - 2.8004
R² = 0.9987
0
5
10
15
20
25
30
35
40
45
Wind Speed (knots)

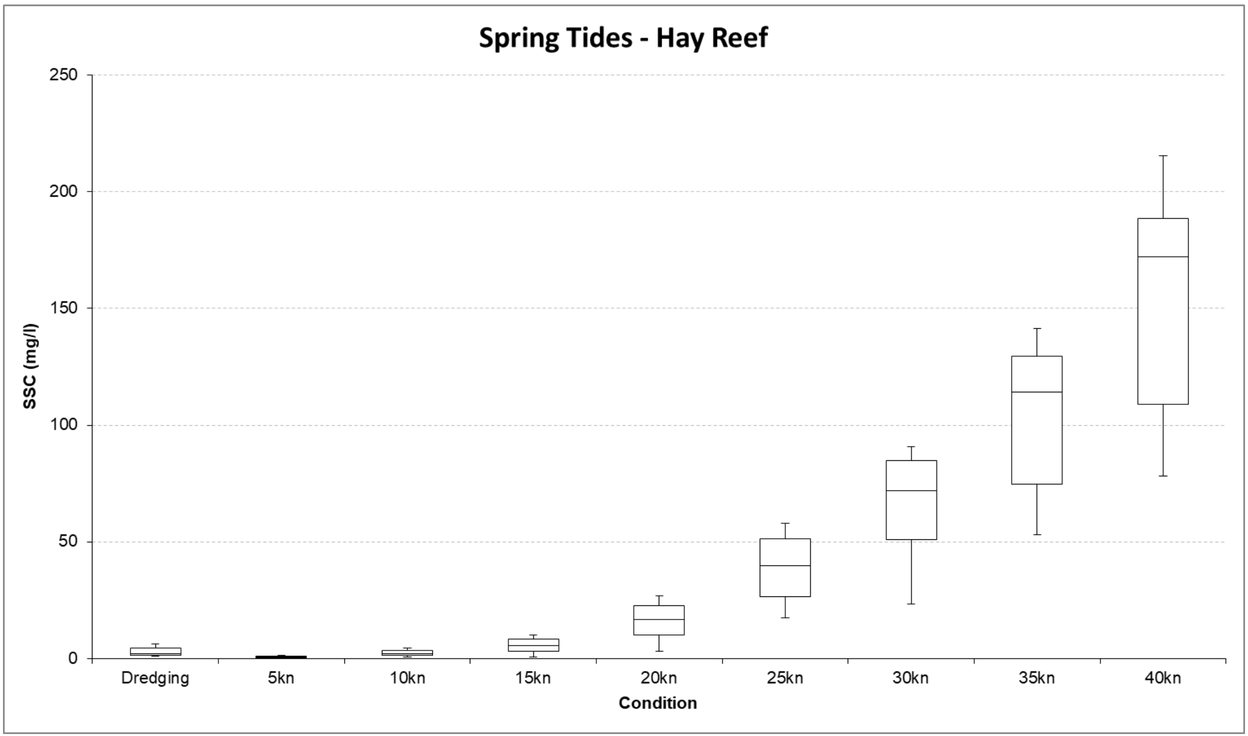


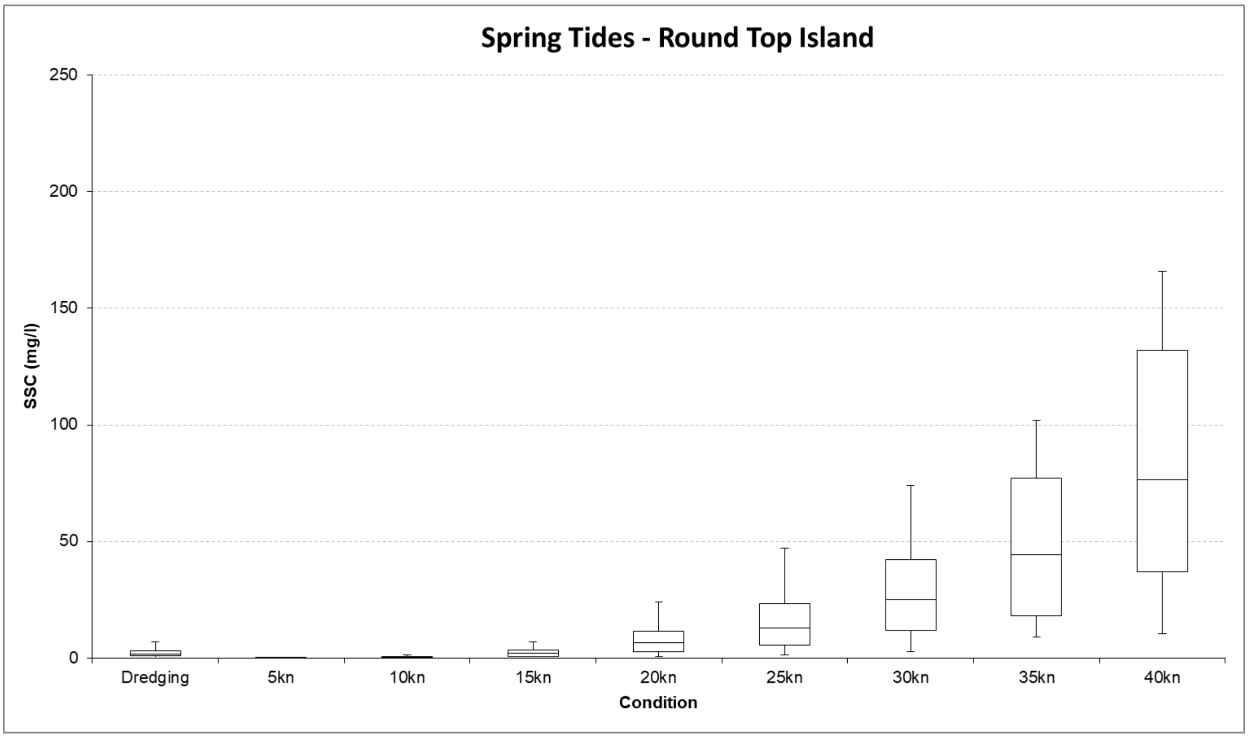
Neap Tides - Round Top Is
y = 0.0068x3 - 0.2352x2 + 2.6352x - 8.1589
R² = 0.9978
Peak SSC (mg/l)
350
300
250
200
150
100
50
0
0 5 10 15 20 25 30 35 40 45
Wind Speed (knots)

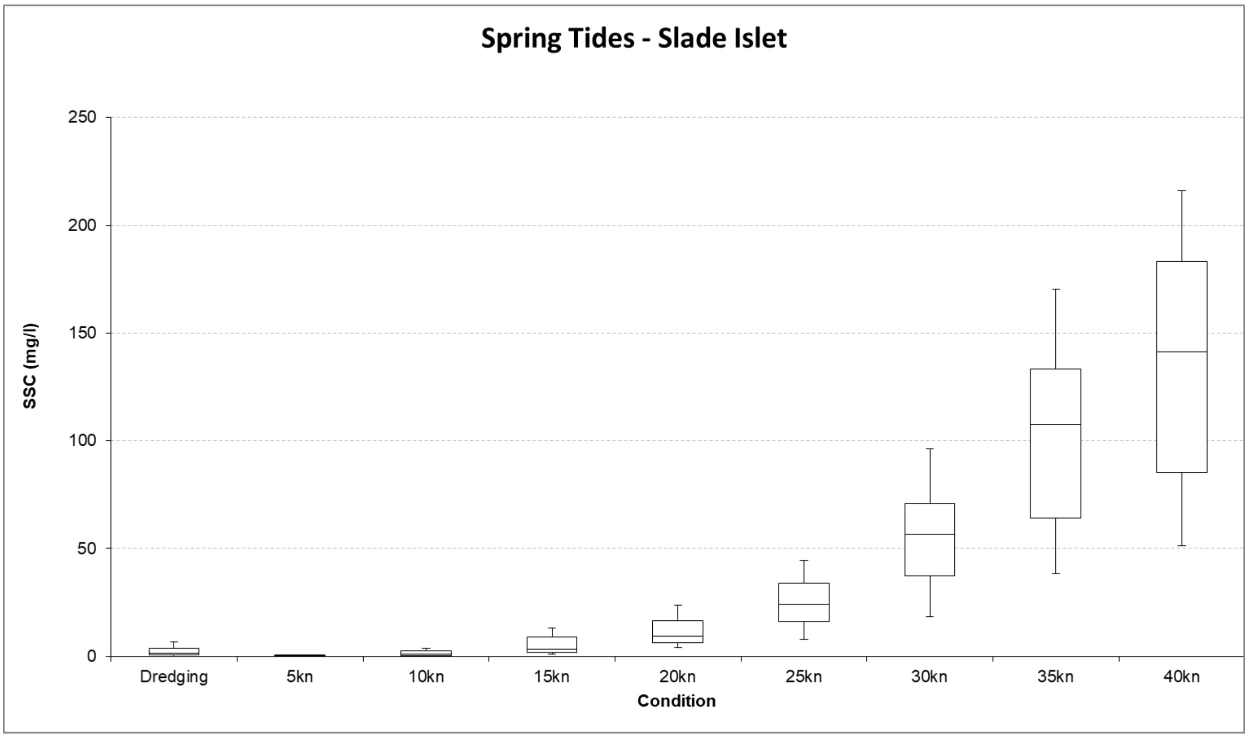


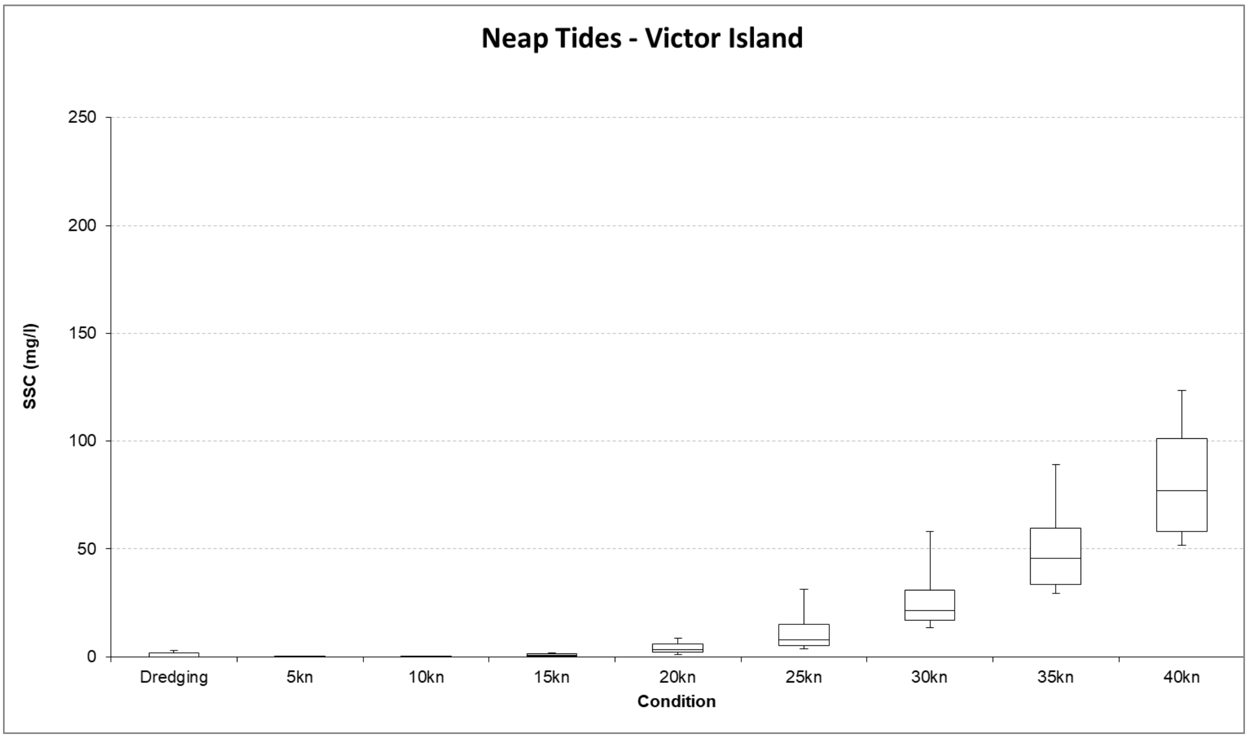
Neap Tides - Slade Is
y = -0.0006x3 + 0.3088x2 - 5.8705x + 24.192
R² = 0.9988
Peak SSC (mg/l)
350
300
250
200
150
100
50
0
0 5 10 15 20 25 30 35 40 45
Wind Speed (knots)

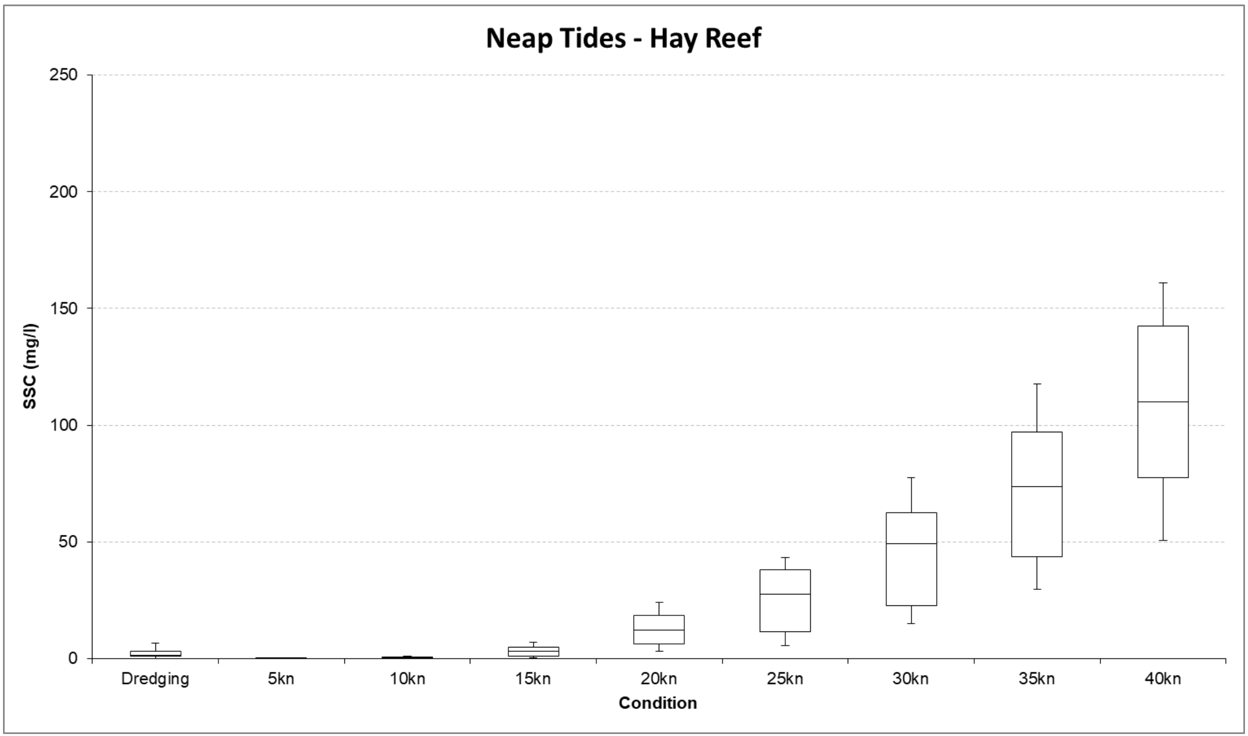

Spring Tides - Victor Island
SSC (mg/l)
250
200
150
100
50
0
Dredging
5kn
10kn
15kn
20kn
25kn
30kn
35kn
40kn
Condition

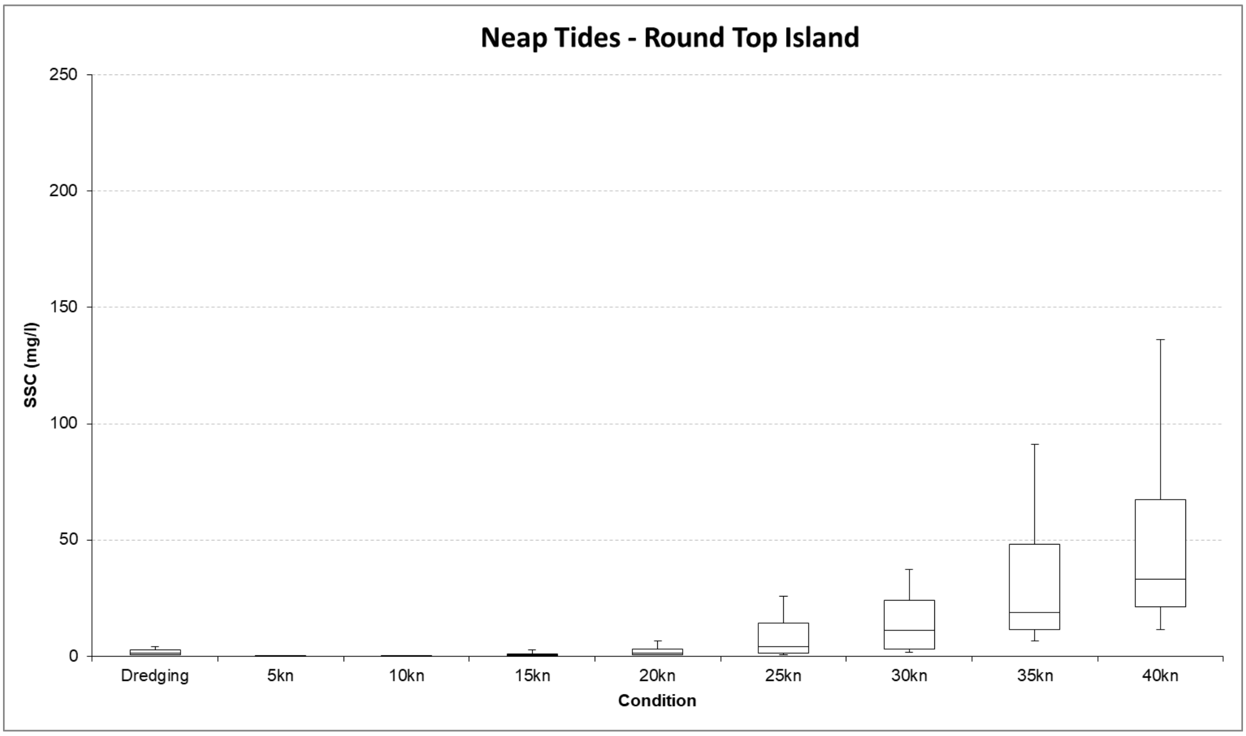

Spring Tides - Hay Reef
SSC (mg/l)
250
200
150
100
50
0
Dredging
5kn
10kn
15kn
20kn
25kn
30kn
35kn
40kn
Condition

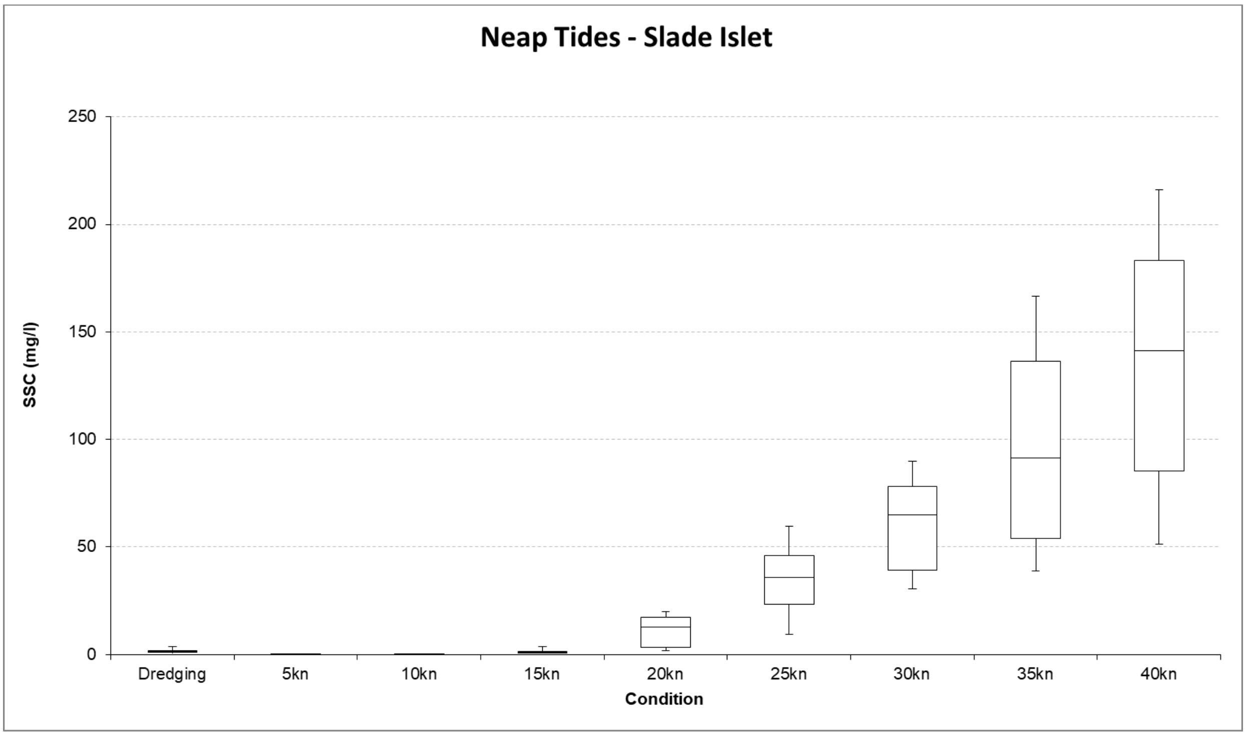

Spring Tides - Round Top Island
250
200
150
100
50
0
SSC (mg/l)
Dredging
5kn
10kn
15kn
20kn
25kn
30kn
35kn
40kn
Condition


Spring Tides - Slade Islet
250
200
150
100
50
0
SSC (mg/l)
Dredging
5kn
10kn
15kn
20kn
25kn
30kn
35kn
40kn
Condition


Neap Tides - Victor Island
250
200
150
100
50
0
SSC (mg/l)
Dredging
5kn
10kn
15kn
20kn
25kn
30kn
35kn
40kn
Condition


Neap Tides - Hay Reef
250
200
150
100
50
0
SSC (mg/l)
Dredging
5kn
10kn
15kn
20kn
25kn
30kn
35kn
40kn
Condition


Neap Tides - Round Top Island
250
200
150
100
50
0
SSC (mg/l)
Dredging
5kn
10kn
15kn
20kn
25kn
30kn
35kn
40kn
Condition


Neap Tides - Slade Islet
250
200
150
100
50
0
SSC (mg/l)
Dredging
5kn
10kn
15kn
20kn
25kn
30kn
35kn
40kn
Condition