MOTT MACDONALD

New Islay Vessel Enabling Works

Dredge Dispersion Modelling: Kennacraig

March 2023

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Issue and Revision Record

Revision	Date	Originator	Checker	Approver	Description
P01	14/3/2023	Rachel White Andy Symonds	Darren Price, Jon Williams	Ben Radcliffe	First Issue

Document reference: 105612 | 105612-MMD-KE-ZZ-RP-O-0007-S2-P01 |

Information class: Standard

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Executive Summary

In support of the detailed design of pier infrastructure upgrade works required for the New Islay Vessel Enabling Works (the Project), Mott MacDonald Ltd (MML) has been commissioned to assess the sediment dispersion associated with the proposed capital dredging for the Project. Numerical modelling has been undertaken to simulate the transport of suspended sediment released into the marine environment by dredging of approximately 7,000 m^3 of sediment required at the Kennacraig Ferry Terminal. The results from the study are presented in this report.

The dredging method will likely require a backhoe dredger (BHD), with sediment placed on barges and transported to a disposal site located southwest of the Isle of Islay, approximately 67 km from the Kennacraig Ferry Terminal. It was assumed that the BHD could operate 24 hours daily until the dredging was completed to ensure a conservative assessment. Based on this assumption, the dredging would take 6.5 days to complete.

The model simulations considered the dispersion of the fine-grained sediment fractions of less than 63 µm, classified as silts and clays on the Wentworth scale. Particles of this size have the potential to remain in suspension and disperse away from the disturbance site during the dredging and placement activities.

The dredging was simulated during both spring and neap tides to assess the plume dispersion under tidal conditions likely to occur during the dredging programme. In addition, to indicate the influence of different wind conditions on plume dispersion, the dredging was simulated for three different wind conditions: no wind, mean non-winter winds, and strong non-winter winds. This work required six Particle Tracking (PT) model runs. The simulations released sediment into the water to represent: (a) the disturbance of fine sediment from the bucket; and (b) the placement of the dredged sediment at the disposal site.

An additional model simulation using the Mud Transport (MT) model was used to represent sediment behaviour better and fully capture the potential for resuspension of sediment placed at the disposal site.

The modelling showed:

- The sediment suspended during the dredging and material placement activities results in relatively localised and short-lived plumes;
- Maximum increases in suspended sediment concentration (SSC) from the dredging exceed 1 mg/l over an area of approximately 1 km^2. In comparison, higher increases in SSC (of more than 10 mg/l) are constrained to a much smaller area, mainly within the dredge footprint and adjacent model cells. Some shallow coastal areas also show an increase of more than 10 mg/l as a result of the shallow water depth in these areas (reducing water volume for dilution);
- Once dredging has been completed, the SSC at the dredge site quickly returns to background levels of around 1 mg/l. The low flow speeds, floc formation due to high sediment concentrations and the shallow water depths all contribute to the rapid deposition of sediment on the bed;
- Sedimentation exceeding 1 mm was constrained to an area within approximately 100 m of the dredge footprint;
- No increases in SSC and no sedimentation were predicted at the blue mussel beds to the northwest of Kennacraig;
- Maximum increases in SSC of up to 30 mg/l occur from the placement of dredged sediment from the barges. This movement of this material is constrained within the disposal site.

Outside of the disposal site, the maximum SSC associated with the placement activity is less than 10 mg/l;

- The relatively strong tidal currents which occur at the disposal site are predicted to disperse the plume so that maximum SSC increases above 1 mg/l extends up to 8 km to the northwest and 4 km to the east of the disposal site;
- The elevated SSC due to the disposal only remains in a single location for a short time;
- Time series plots of SSC at the disposal site show intermittent peaks up to a day after the last barge load is placed. In contrast to the dredge site, these peaks result from the fast flows and advection of the plume around the disposal site rather than the settling of the sediment to the bed;
- Although resuspension of sediment placed at the disposal site can occur, the resultant plume has very low concentrations (less than 0.2 mg/l) due to the relatively fast flows in the area and the limited mass of sediment predicted to be resuspended at any time; and
- Eroded sediment is rapidly dispersed away from the disposal site, with no areas of sedimentation deposition above 0.01 mm occurring.

As it is possible that the TSHD *Shoalway* may be working locally and could be used with little or no mobilisation costs, consideration has also been given to this method of dredging. However, it is considered very unlikely that using this dredger would be practical at Kennacraig, and for this reason, modelling has not been undertaken to simulate this dredge method. However, if it were to be used, it would result in higher plume concentrations than those predicted for dredging with the BHD locally at the dredging site and the disposal site. However, due to scale, only two dredger loads are required meaning the dredging would take less than a day to complete, reducing the impact duration.

The results presented in this report will be used to assess the potential for disturbance to sensitive receptors at both the dredge and disposal sites. MML will undertake this work.

Glossary

ATT	Admiralty Total Tide
BHD	Backhoe Dredger
BM	Blue Mussel
CD	Chart Datum
CFSv2	Climate Forecast System Version2
CMAL	Caledonian Maritime Assets Ltd
CO_2	Carbon Dioxide
DHI	Danish Hydraulic Institute
FM	Flexible Mesh
HAT	Highest Astronomical Tide
HD	Hydrodynamic
H_s	Significant wave height
kg	kilograms
km	kilometres
l	litre
LAT	Lowest Astronomical Tide
m	metres
mg	milligrams
mm	millimetres
MHWS	Mean High Water Spring
MLWS	Mean Low Water Spring
MML	Mott MacDonald Ltd
MT	Mud Transport
ODN	Ordnance Datum Newlyn
PSD	Particle Size Distribution
PT	Particle Tracking
s	second
SSC	Suspended Sediment Concentration
T_p	Peak wave period
TSHD	Trailing Suction Hopper Dredger
UKWC	UK West Coast

The following conventions are adopted throughout (unless otherwise stated):

- Volumes are *in-situ* cubic metres (m^3);

- Depths are provided relative to the local Chart Datum (CD). For reference, CD is 0.4 m below Ordnance Datum Newlyn (ODN) at Kennacraig;
- Current directions are quoted as directions to; and
- Wave and wind directions are quoted as directions from.

1 Introduction

Mott MacDonald Ltd (MML) has been appointed by the Caledonian Maritime Assets Ltd (CMAL) to undertake the detailed design of pier infrastructure upgrade works required for the New Islay Vessel Enabling Works (the Project) at four terminals on the Islay ferry route. This work includes the capital dredging, which will be required at three terminals (Kennacraig, Colonsay and Port Ellen) to access new, larger vessels.

MML was able to utilise a calibrated regional hydrodynamic (HD) model of the Scottish west coast developed for previous investigations. The model was using the MIKE software suite, developed by the Danish Hydraulic Institute (DHI) using the Flexible Mesh 3D (FM3D) module. This study has updated the model to better represent the bathymetry, hydrodynamics and sediment dispersion at the three terminals and the proposed offshore placement site. The hydrodynamics from this updated model has been used to drive the DHI Particle Tracking (PT) module to simulate the dispersion of sediment disturbed during the dredging activity.

Separate reports have been prepared for each of the three terminals, with this report focusing on the dredging at **Kennacraig Ferry Terminal**.

1.1 Project Background

Dredging is required at Kennacraig, Colonsay and Port Ellen to enable larger ferries to operate. The location of the three terminals is shown in Figure 1.1.

- **Kennacraig:** located on the southern shoreline of West Loch Tarbert, 8 km southwest of Tarbert on the Kintyre peninsula in the west of Scotland. As the terminal is located in a loch, it is considered to be in a sheltered location;
- **Colonsay:** located on the east coast of the island of Colonsay, adjacent to the village of Scalasaig, in a small, relatively sheltered bay; and
- **Port Ellen:** located on the south coast of the Isle of Islay in a relatively sheltered bay.

Aerial imagery based on Microsoft Bing maps, extracted from the Delft Dashboard

Figure 1.1: Study location

The volume and depth of sediment requiring dredging vary between the three locations as follows:

- **Kennacraig:** dredging to a depth of -5.5 m Chart Datum (CD) with an estimated total dredge volume of just under 7,000 m^3 (actual volume calculated to be 6,747 m^3). Most of the dredge area requires a depth of less than 1.5 m of sediment to be removed, although some areas along the eastern and southern edges will require a depth of up to 2.5 m of sediment;
- **Colonsay**: dredging to a depth of -5.5 m CD with an estimated total dredge volume of just under 6,000 m^3 (actual volume calculated to be 5,851 m^3). The majority of the dredge area requires a depth of less than 1.5 m of sediment to be removed, although a small area along the south-western edge will require a depth of more than 3 m of sediment to be removed; and
- **Port Ellen**: predominantly dredging to a depth of -5.5 m CD with a small area around the pier (currently around -5.0 m CD) to be dredged to -6.0 m CD. The area to be dredged to -6.0 m CD required removing existing rock scour protection. The estimated total dredge volume is just under 16,000 m^3 (actual volume calculated to be 15,711 m^3). Almost all the dredging will require a depth of less than 1.5 m of sediment to be removed. There is a localised area at the northern end of the dredge area, where dredging of a depth of up to 3 m will be required.

The dredged sediment from all three ferry terminals is proposed to be placed at a disposal site 4 km south of the south-western corner of the Isle of Islay and approximately 67 km (in a straight line) from the Kennacraig Ferry Terminal (Figure 1.1.).

This study considers the dispersion of sediment dredged from Kennacraig and placed at the disposal site to the south of the Isle of Islay.

1.2 Report Structure

The report herein is set out as follows:

- The hydrodynamic model is introduced in Section 2
- Site conditions are described in Section 3;
- A description of the assumed dredging methodology is provided in Section 4;
- The dredging simulations are defined in Section 5;
- The results of the numerical modelling are provided in Section 6; and
- The conclusions from the study are presented in Section 7.

2 Hydrodynamic Model

2.1 Introduction

This section details the setup of the hydrodynamic model which has been used in this study.

2.2 Software

The MIKE software suite developed by the Danish Hydraulics Institute (DHI) has been used for the assessment. The MIKE software is widely recognised as state-of-the-art and has been used internationally for similar projects. The MIKE suite includes HD and PT modules applied in the present study.

2.3 Model Configuration

The calibrated regional HD model of the UK West Coast (UKWC) developed by MML was adopted for this project. The UKWC model adopts a coarse resolution in the deeper offshore waters and a higher resolution in the network of channels and straits along the eastern model boundary. The model extends across the west coast of Scotland, England and Wales, Ireland's east coast, and the Hebrides Archipelago in the west.

The UKWC model is forced by predicted tidal elevations from DTU10 (Cheng & Andersen, 2011) along the open boundaries, which are located between the Isle of Lewis and Cape Wrath in the north, between West Barra Head and Northern Ireland in the west and between Hartland and Dunmore in the south (Figure 2.1). As part of previous work, the UKWC model has been calibrated and validated against the predicted astronomical tide at 22 tide stations from the ATT software package distributed over the entire model domain and is reported to meet stringent model performance metrics taking account of limitations in the reliability of ATT predictions.

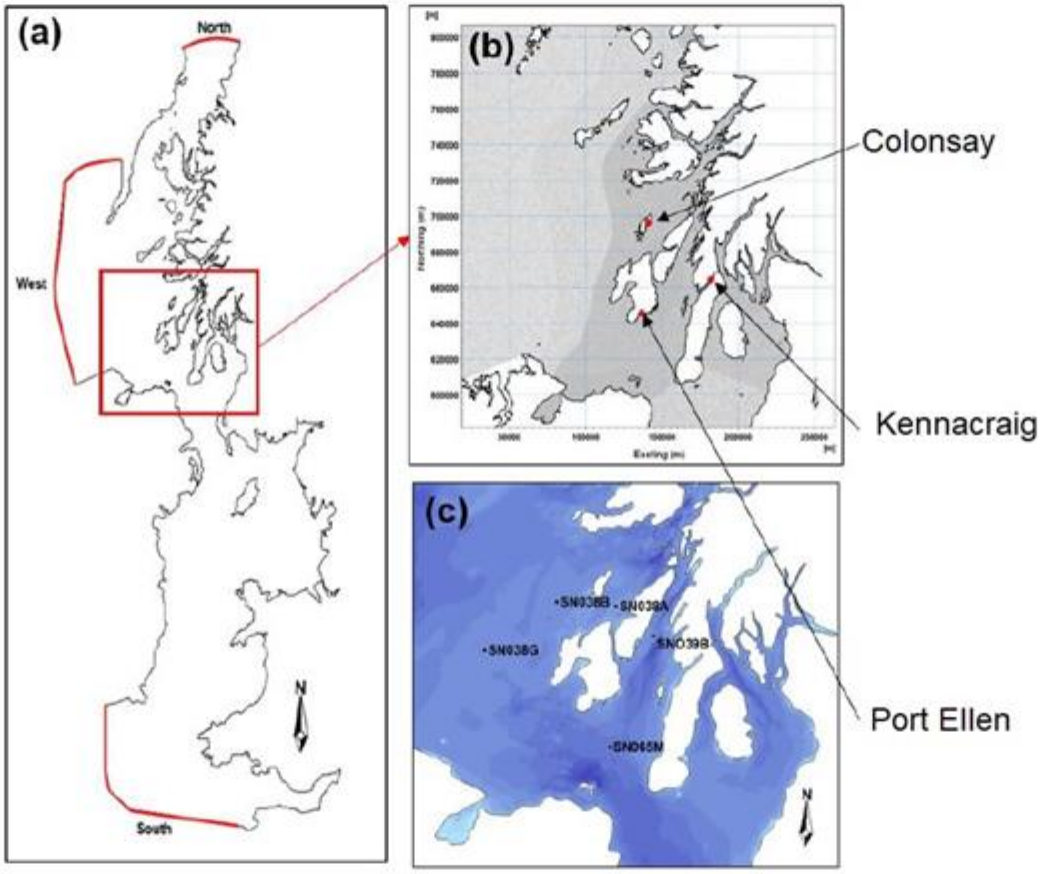


Figure 2.1: a) MML UKWC model domain and boundaries, b) detail of the model mesh at the ferry terminals and c) model bathymetry at the ATT locations.

Some modifications to the original hydrodynamic model setup were required for this assessment to ensure that the model could accurately represent the proposed dredging and disposal activities. The modifications included:

- An update of the mesh at the three ferry terminals and at the disposal site to increase model resolution. The updated mesh resolution varies from 3,000 m in the offshore areas to 10 m in the dredge areas and 80 m at the disposal site;
- An increase in the vertical layers from one to five uniformly spaced sigma layers to run in 3 dimensional (3D) mode; and
- The bathymetry at the three ferry terminals and adjacent areas was updated to ensure it was represented by the most recent/reliable available data. Measured bathymetric data was spatially limited within West Loch Tarbert, so the navigational chart from Navionics was digitised to represent this area.

The updated model mesh and bathymetry around the ferry terminal are shown in Figure 2.2. Following the updates, the modelled water levels and flows were compared against those from the original model at the ATT sites to ensure that the model calibration was not adversely affected.

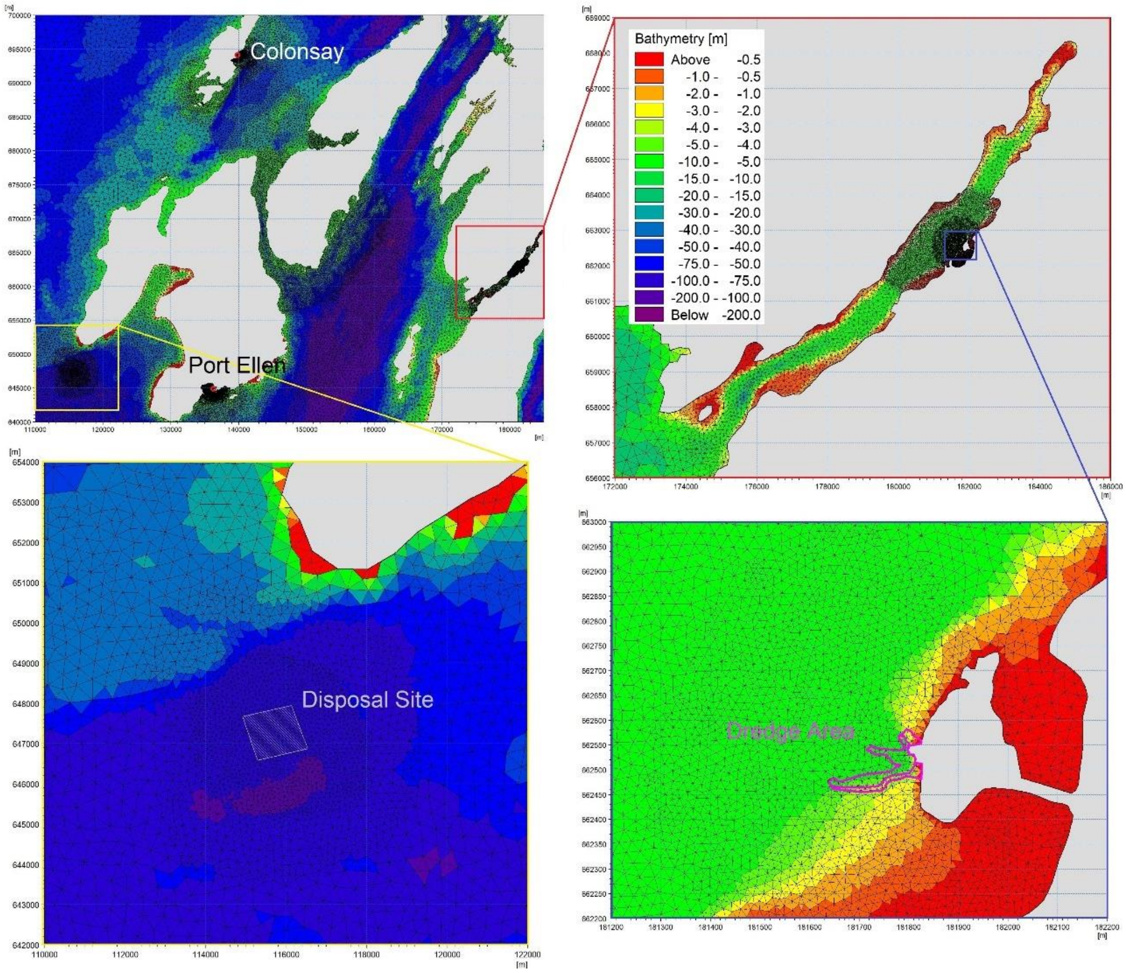


Figure 2.2: Model mesh and bathymetry at the dredge and disposal location.

The HD model was set up to simulate a 15-day spring-neap tidal cycle. The run period was selected to start and finish on neap tides.

Winds from Colonsay (located between Kennacraig and Port Ellen) were taken to represent conditions at all three ferry terminals[1] to identify suitable wind conditions for the 'mean' and 'strong' winds simulations. An extremes analysis of winds from Colonsay for the 11.7 years of data was undertaken, yielding a 10 in 1 year (exceeded ten times in a year) wind condition of 19.0 m/s (37 knots). Winds above this threshold value were considered to limit dredging and were removed from the dataset.

The mean wind conditions were identified as the fifteen days with the best fit to the percentile winds from the full record for the non-winter months (from March to November). The stronger winds were identified as being the strongest mean winds for the non-winter months (from March to November).

The period spanning 25 September to 10 October 2020 was identified as a period of mean wind conditions, while between 9 November and 24 November 2020 was identified as a period of stronger wind conditions. The percentile winds are shown for each period in Figure 2.2. Winds are also shown as time series in Figure 2.3 and as wind roses in Figure 2.4. These plots show

[1] Due to the similarity in winds between the three dredge sites and the large temporal variation in winds that occurs, the adoption of a single set of wind conditions for all three dredge sites was considered appropriate.

that the wind conditions selected represent a range of both wind speeds and directions which can occur outside of the winter months.

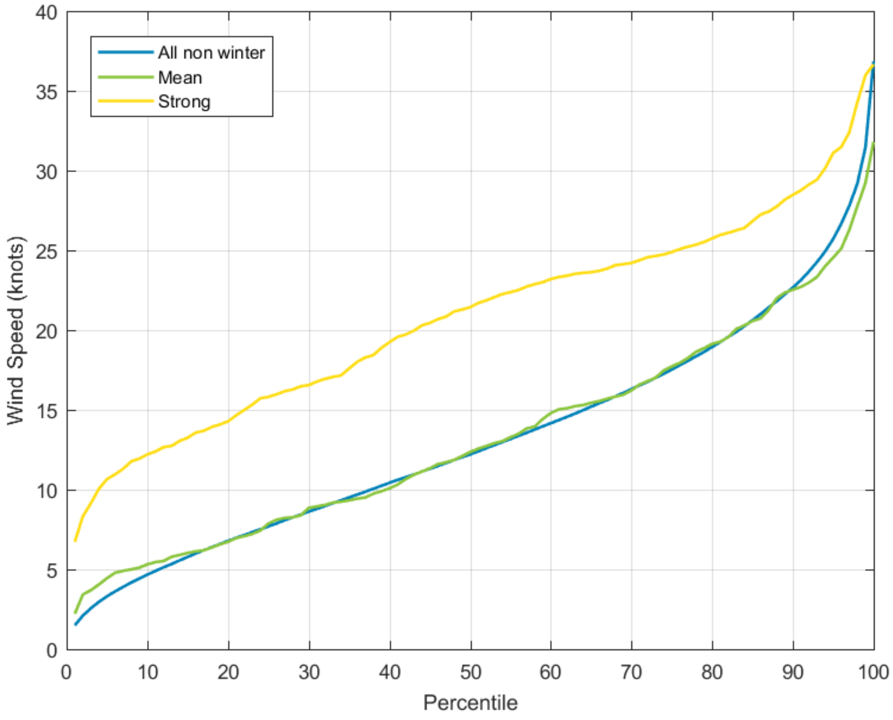


Figure 2.3: Wind conditions during the selected wind periods.

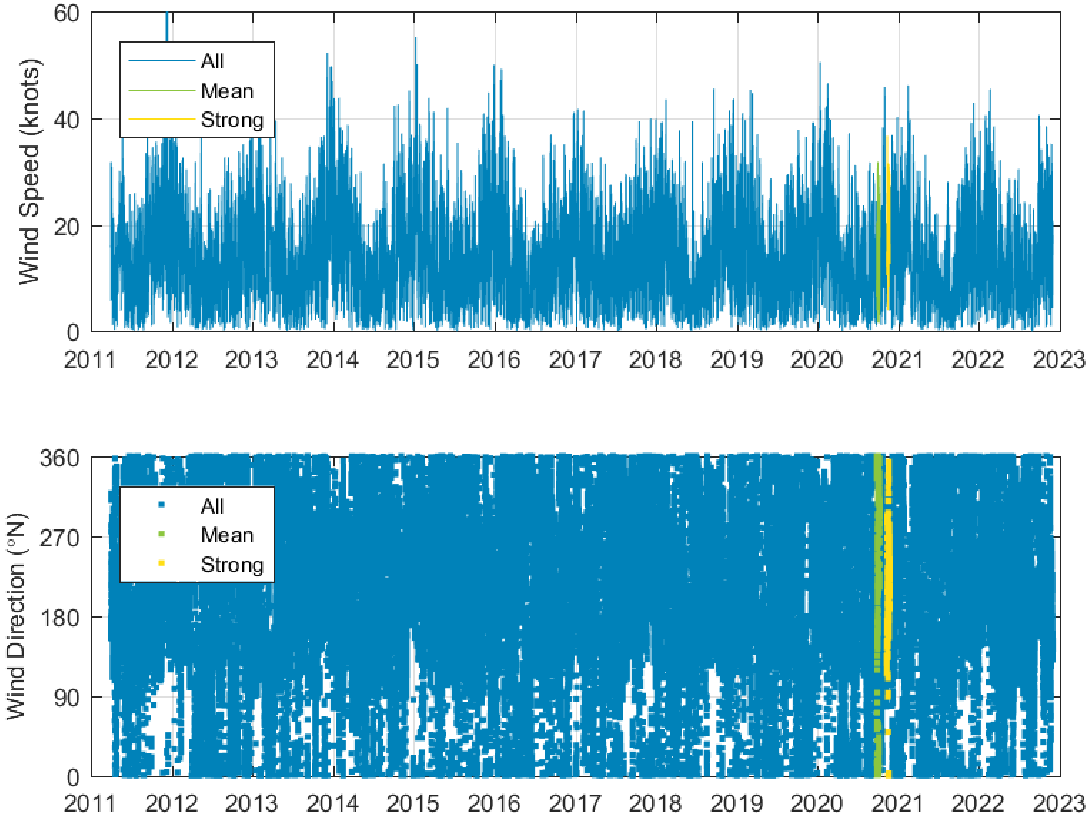


Figure 2.4: Time series of winds.

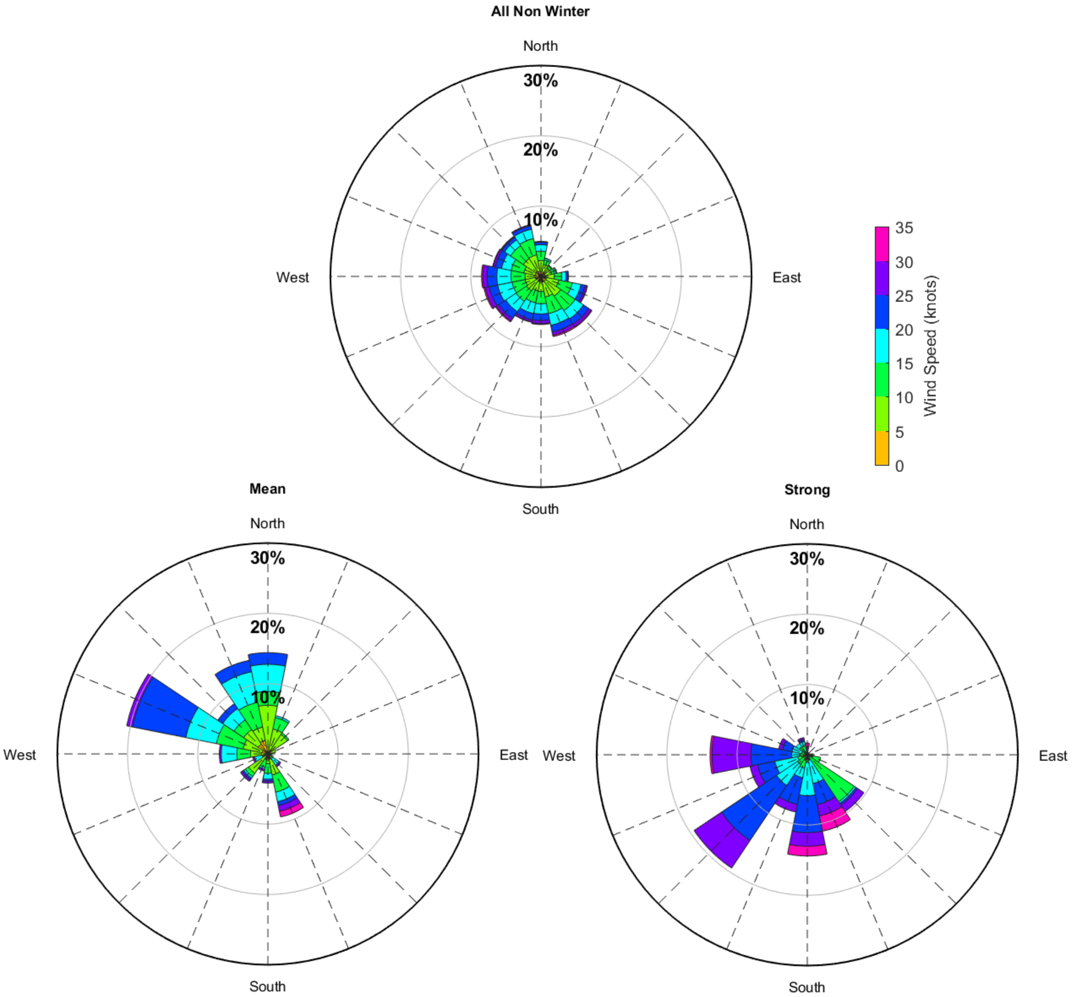


Figure 2.5: Wind roses for the full record during non-winter months and for mean wind and strong wind periods.

3 Site Conditions

This overview of the baseline conditions at the Kennacraig ferry terminal site has been used to define the parameters applied in the numerical modelling and to provide context for the plume dispersion assessment. Different datasets' locations are shown relative to the terminal ferry layout in Figure 3.1. Where relevant, details on the dredge disposal site are also provided.

Figure 3.1: Location of datasets used for site characterisation.

The only receptors identified within 50 km of the dredge site are blue mussels beds, the closest of which is located approximately 750 m to the northwest of Kennacraig (Figure 3.1).

3.1 Wind

Winds were extracted from the Climate Forecast System version 2 (CFSv2) from April 2011 to November 2022 to characterise the local wind conditions. The CFSv2 wind data has a spatial resolution of 0.5 degrees and a temporal resolution of one hour. Winds were extracted from the closest grid point to each of the three ferry terminal locations. Variations between the sites were relatively small, with slightly higher wind speeds at Port Ellen and slightly lower wind speeds at Kennacraig (Table 3.1). A rose plot of winds at Kennacraig is shown in Figure 3.2. Winds from the south to northwest sectors dominate both frequency and speed.

Table 3.1: Wind climate at each of the three locations.

Location	Mean wind (knots)	Median wind (knots)	75th percentile wind (knots)
Kennacraig	13.0	12.2	17.7
Colonsay	14.6	13.6	19.6
Port Ellen	15.7	14.9	20.8

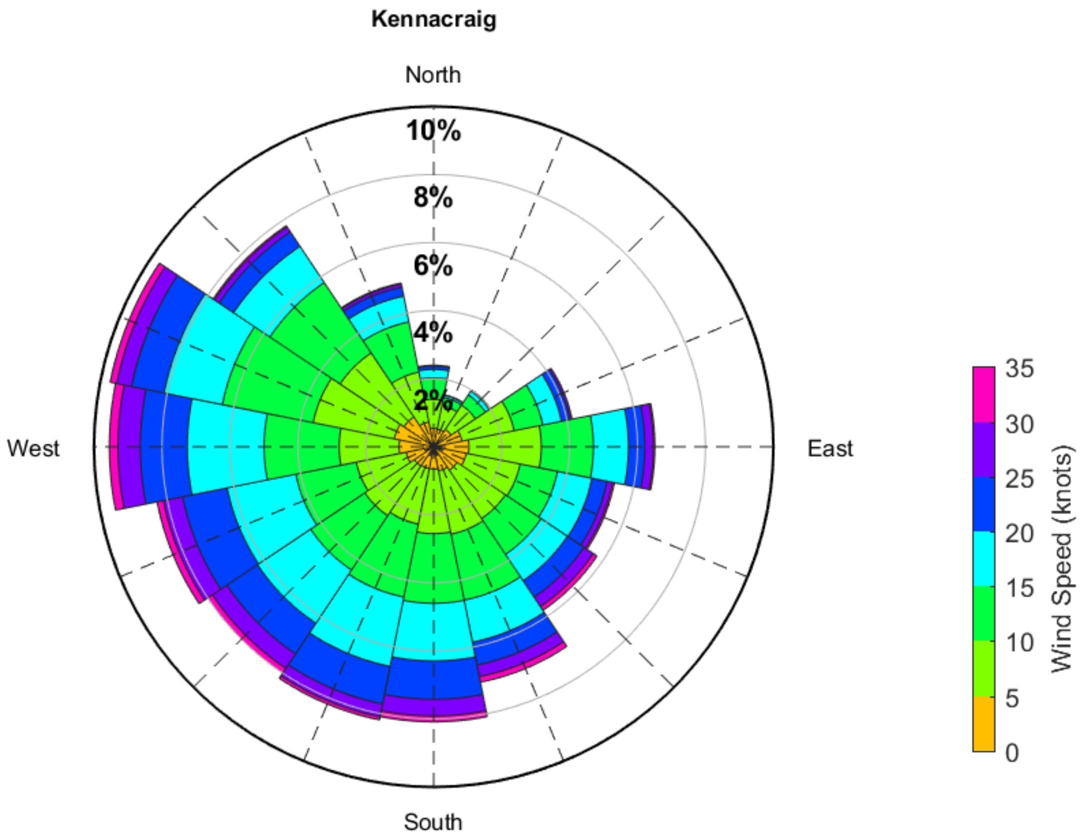


Figure 3.2: Wind rose at Kennacraig from CFSv2.

For the ferry terminal mooring assessment (Royal Haskoning DHV, 2020), winds were provided by CalMac, based on *Meteoblue* winds (CalMac, 2020). The *Meteoblue* model data shows wind conditions consistent with CFSv2 winds in terms of wind speeds. Dominant wind directions are also consistent, although CFSv2 shows dominant winds to be aligned more west and east than west-southwest and east-northeast for *Meteoblue* winds. The *Meteoblue* winds are more closely aligned with the loch orientation. They are, therefore, more likely to represent local wind conditions, while the CFSv2 winds most likely represent the regional scale conditions less affected by the local topography.

3.2 Waves

Indicative wave conditions at Port Kennacraig were derived by Royal Haskoning DHV (2020) for a range of wind speeds, with the winds assumed to be aligned with the orientation of the Loch (235°N). The resultant wave conditions were defined as:

- Significant wave height (H_s) = 0.5m & T_p = 2.7s for 20 knots wind speed;
- H_s = 0.8m & T_p = 3.3s for 30 knots wind speed; and
- H_s = 1.1m & T_p = 3.8s for 40 knots wind speed.

3.3 Hydrodynamics

3.3.1 Dredge Area

Tidal levels at Kennacraig are as follows (Royal Haskoning DHV, 2020):

- Highest Astronomical Tide (HAT): +1.26m ODN;
- Mean High Water Spring (MHWS): +0.69m ODN;
- Mean Low Water Spring (MLWS): +0.15m ODN; and
- Lowest Astronomical Tide (LAT): -0.40m ODN.

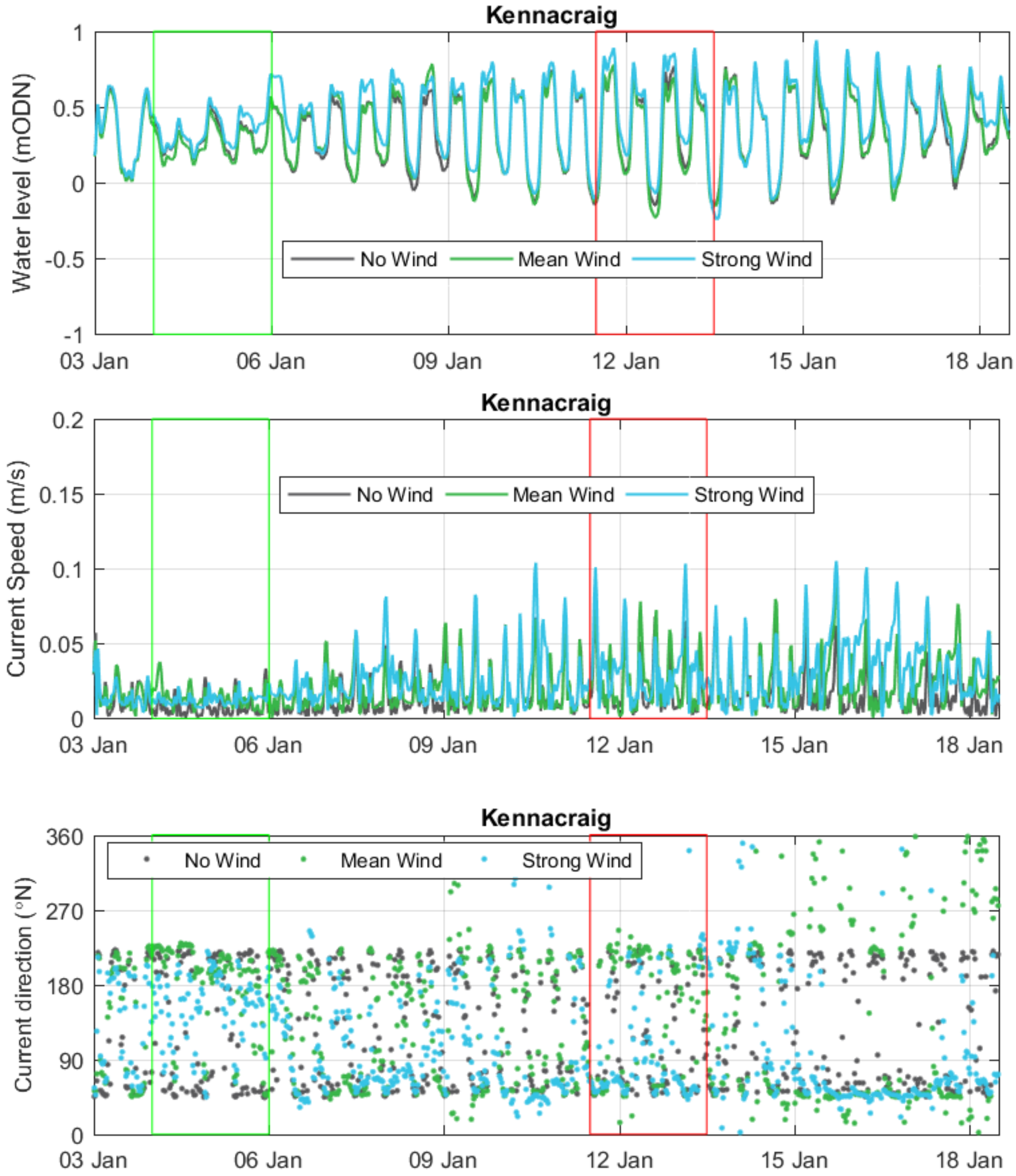
No observational time series of water level or flow data is available at the Kennacraig ferry terminal. Therefore, water levels and flows have been extracted from the HD model (Section 2.3). Time series of tidal water levels and flows are shown at a site located approximately 200 m offshore in a water depth of 5.7 m ODN (5.3 m CD) over a 15-day spring-neap tidal cycle in Figure 3.3, with enlarged plots showing the hydrodynamics in more detail on spring and neap tides in Figure 3.4 and Figure 3.5, respectively. The site has a small tidal range (around 0.7 m on the larger spring tides) and very slow flow speeds (typically less than 0.1 m/s). Tidal flows are aligned with the shoreline (i.e. along the main axis of West Loch Tarbert) and have a slight flood dominance.

Tidal flows in a wider spatial context in the form of map plots at peak flood and peak ebb on a spring tide are shown in Figure 3.6. The plots show that the flows are particularly slack in the proposed dredge area, most likely due to the deeper water depths relative to the surrounding bed levels combined with the configuration of the shoreline in the area.

In addition to tidal forcing, other metocean factors, including winds and freshwater inputs, can influence flows. Model simulations have been undertaken with wind forcing applied for two different wind conditions ('mean' and 'strong' winds, Section 2.3). Water levels and depth-average flows are shown for these simulations in Figure 3.7 and Figure 3.8. The plots show that the current speed and direction at Kennacraig vary depending on the wind conditions, with consistently higher current speeds occurring during the period with strong winds when the current speed can be doubled due to the wind. However, the current speeds at Kennacraig are still predicted to remain low regardless of the wind, with speeds remaining below 0.1 m/s most of the time for all wind conditions.

Map plots are shown in Figure 3.8 for the no wind and strong wind simulations during the flood and ebb stages of a neap tide to show the effect of wind forcing on flows in a wider spatial context. During the period shown, winds applied in the strong wind simulation were from the southeast quadrant, with a mean wind speed of 27.2 knots. These plots show the much greater spatial variation in flows when winds are applied, with variations in flow speed across the Loch and a complex flow pattern capturing eddies and near-shore flow reversals. Despite this complexity, flows typically remain low in and around the dredge area.

No river flow gauge data source was identified for the rivers flowing into Loch Tarbert upstream of Kennacraig. The closest gauged river is the Carradale at Dippen which has a catchment area of 58.5 km^2 and a 5% exceedance (Q5) of 9.5 m^3/s. Adopting a crude approach (i.e. not taking account of differences in the geometry or geology of the catchment) and scaling the Q5 from the Carradale by the estimated catchment area for Kennacraig gives a Q5 of the order of 15 m^3/s at Kennacraig. At Kennacraig, Loch Tarbert is approximately 1370 m wide. If it is assumed that any freshwater flow is constrained to the top 1 m, freshwater Q5 flows in this layer would be of the order of 0.01 m/s and are therefore not expected to influence flows significantly at Kennacraig except during extreme conditions . Further, any freshwater flows would likely be constrained to the surface layer, resulting in any suspended sediment being flushed out of the Loch. This process would reduce any potential impacts at the mussel beds across the Loch from where the dredging is proposed.



Note: the neap (green box) and spring (red box) periods are shown in more detail over a two-day period in the following figures.

Figure 3.3: Time series of water levels and depth-average flows at Kennacraig over a spring-neap cycle.

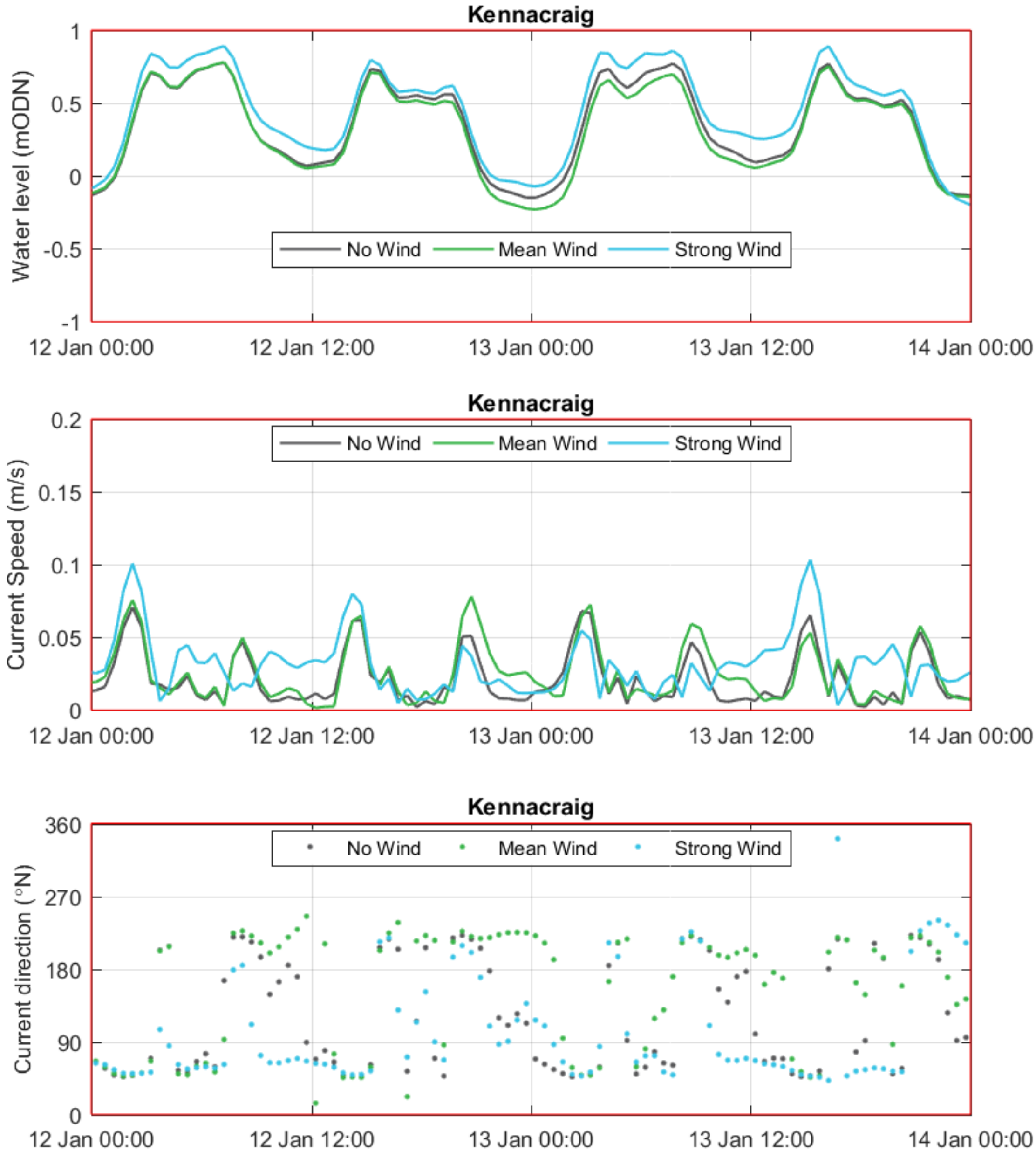


Figure 3.4: Time series of water levels and depth-average flows at Kennacraig on spring tides.

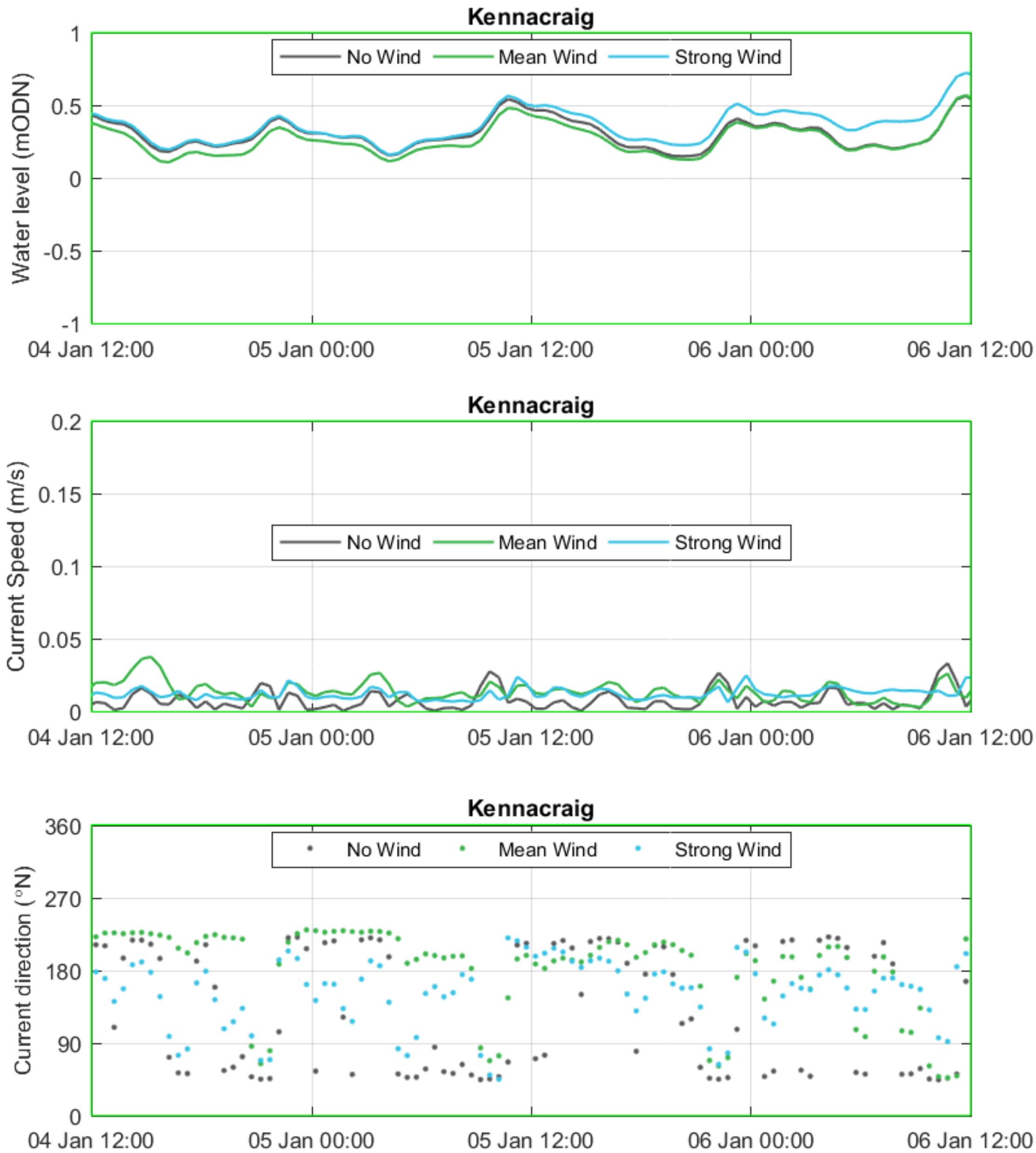


Figure 3.5: Time series of water levels and depth-average flows at Kennacraig on neap tides.

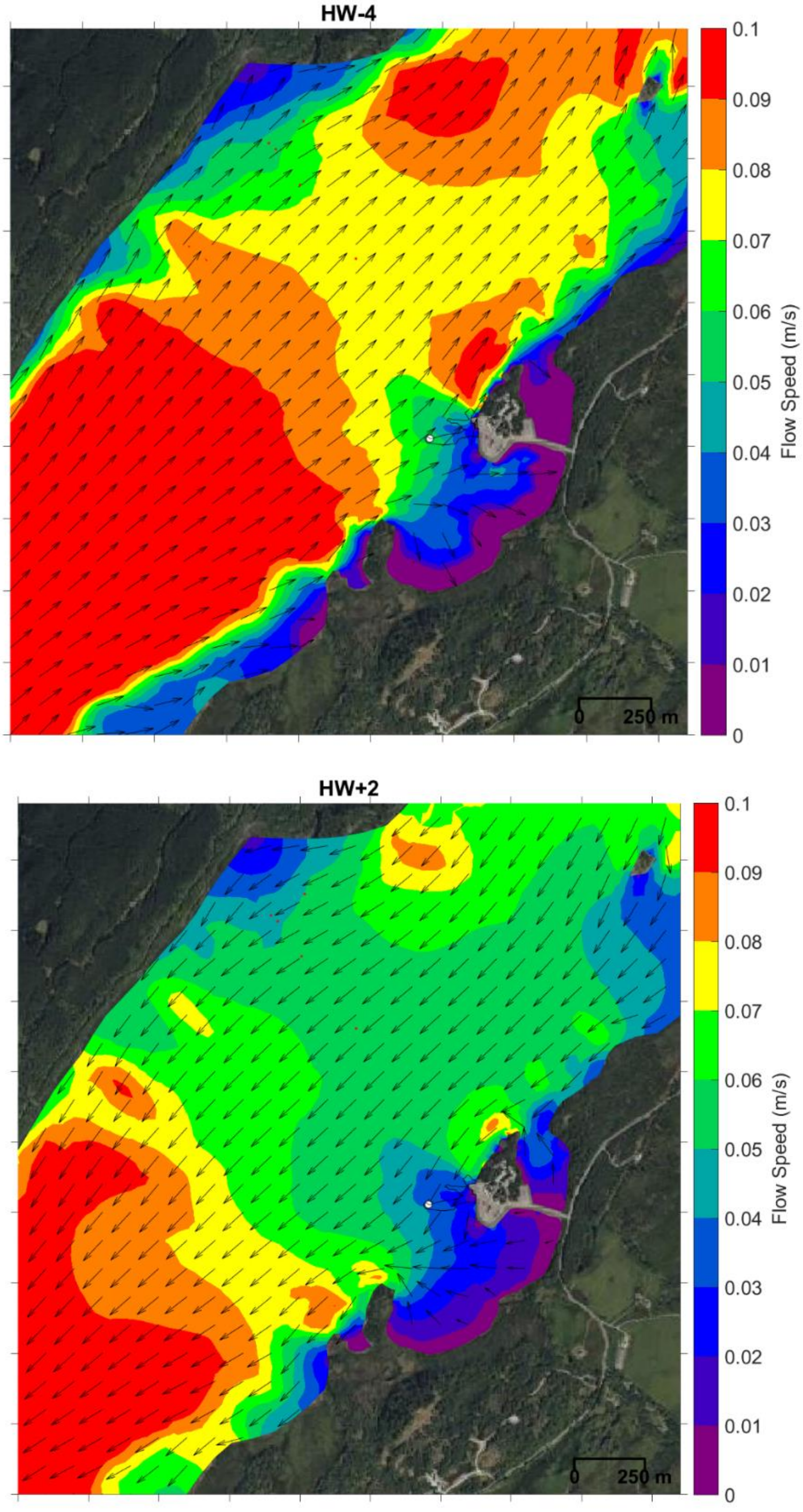


Figure 3.6: Map plots of spring tide flows with no wind forcing at peak flood (upper) and peak ebb (lower).

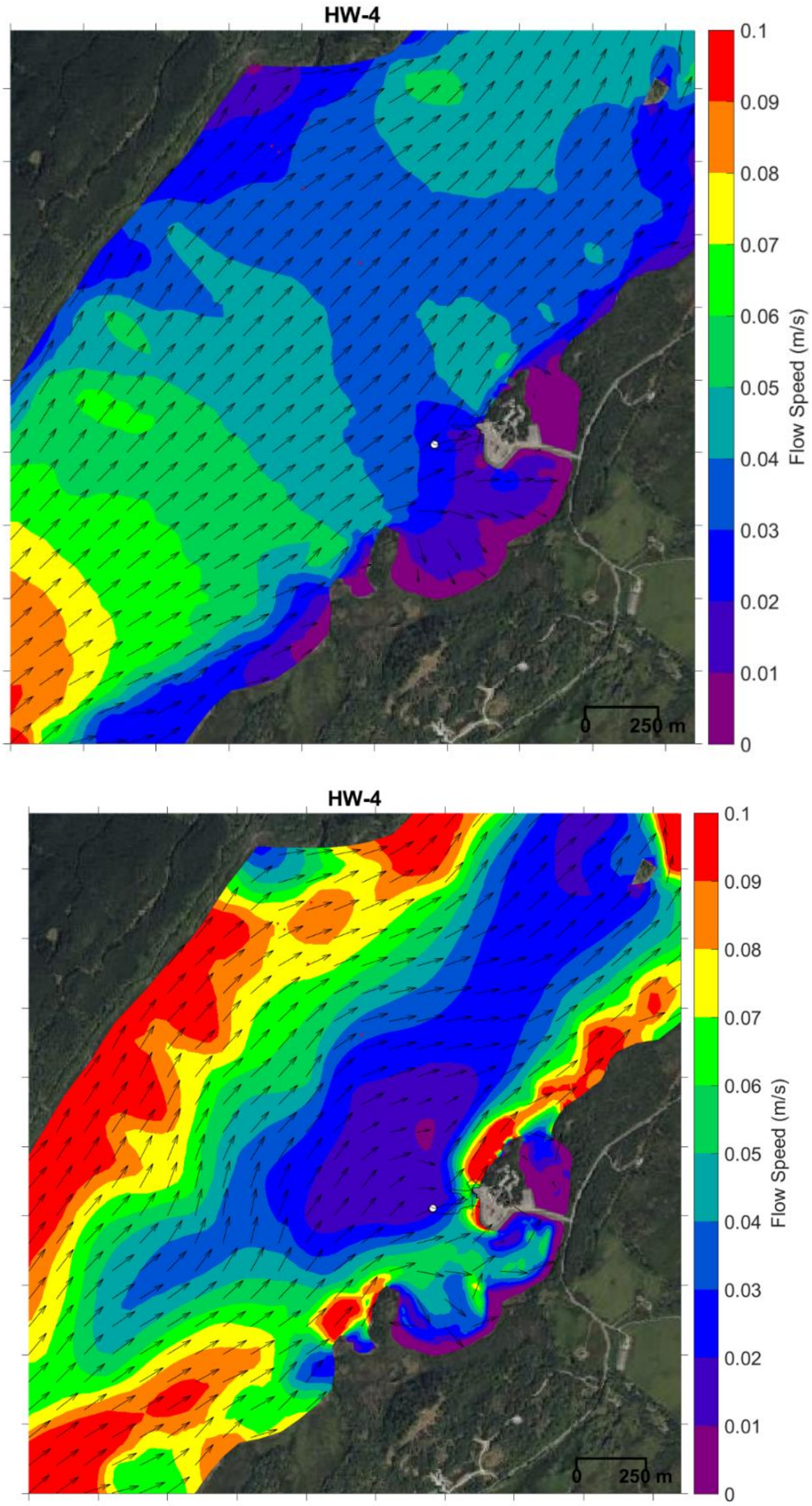


Figure 3.7: Map plots of neap flood tide flows with no wind forcing (upper) and strong wind forcing (lower).

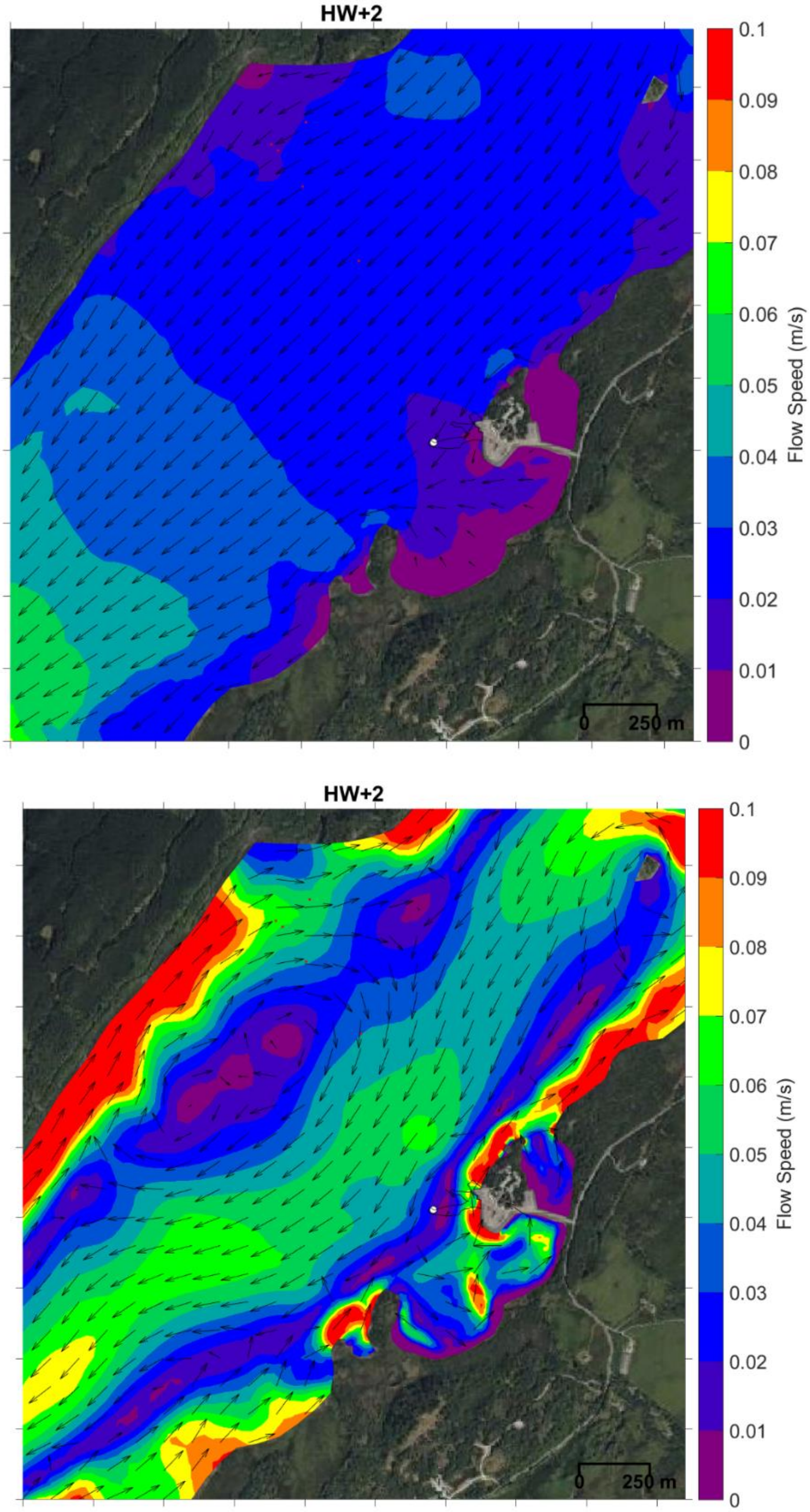
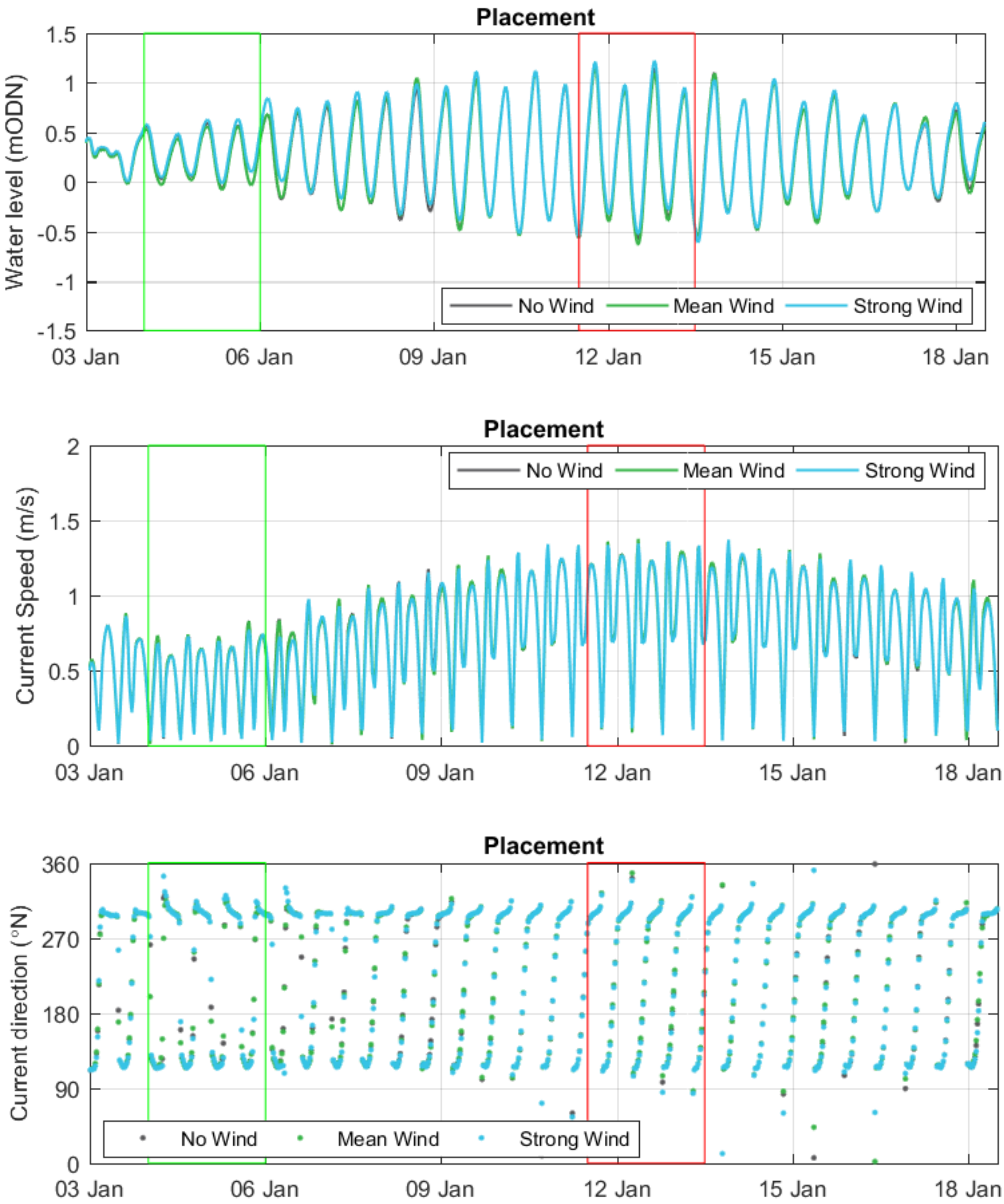


Figure 3.8: Map plots of neap ebb tide flows with no wind forcing (upper) and strong wind forcing (lower).

3.3.2 Disposal Site

Tidal flow data are available from the Admiralty TotalTide (ATT) package at locations approximately 65 km northwest (SN038G) and 34 km southeast (SN065M) of the disposal site. Flows at these locations are much faster than within West Loch Tarbert, with spring tidal peaks of around 1.3 m/s and 1.0 m/s at SN038G and SN065M, respectively.

Water levels and flows have also been extracted from the HD model from a location within the disposal site. The time series of tidal water levels and depth-average flows in the disposal site over a 15-day spring-neap tidal cycle are shown in Figure 3.9. Enlarged plots show the hydrodynamics in more detail on spring and neap tides in Figure 3.10 and Figure 3.11, respectively. The plots show that the tidal curve at the disposal site has a more typical sinusoidal shape (compared to that at Kennacraig) and a larger tidal range of around 1.8 m on spring tides. At the disposal site, the peak current speeds are much faster than at Kennacraig, ranging from 0.6 m/s on neaps to 1.4 m/s on springs. The applied wind conditions do not significantly change the current speed at the disposal site, with changes of up to about 10% of the peak flow speed and no change in current directions during peak flows. These results indicate that the astronomical tide predominantly drives flows.



Note: the neap (green box) and spring (red box) periods are shown in more detail over a two-day period in the following figures.

Figure 3.9: Time series of water levels and flows at the disposal site over a spring-neap cycle.

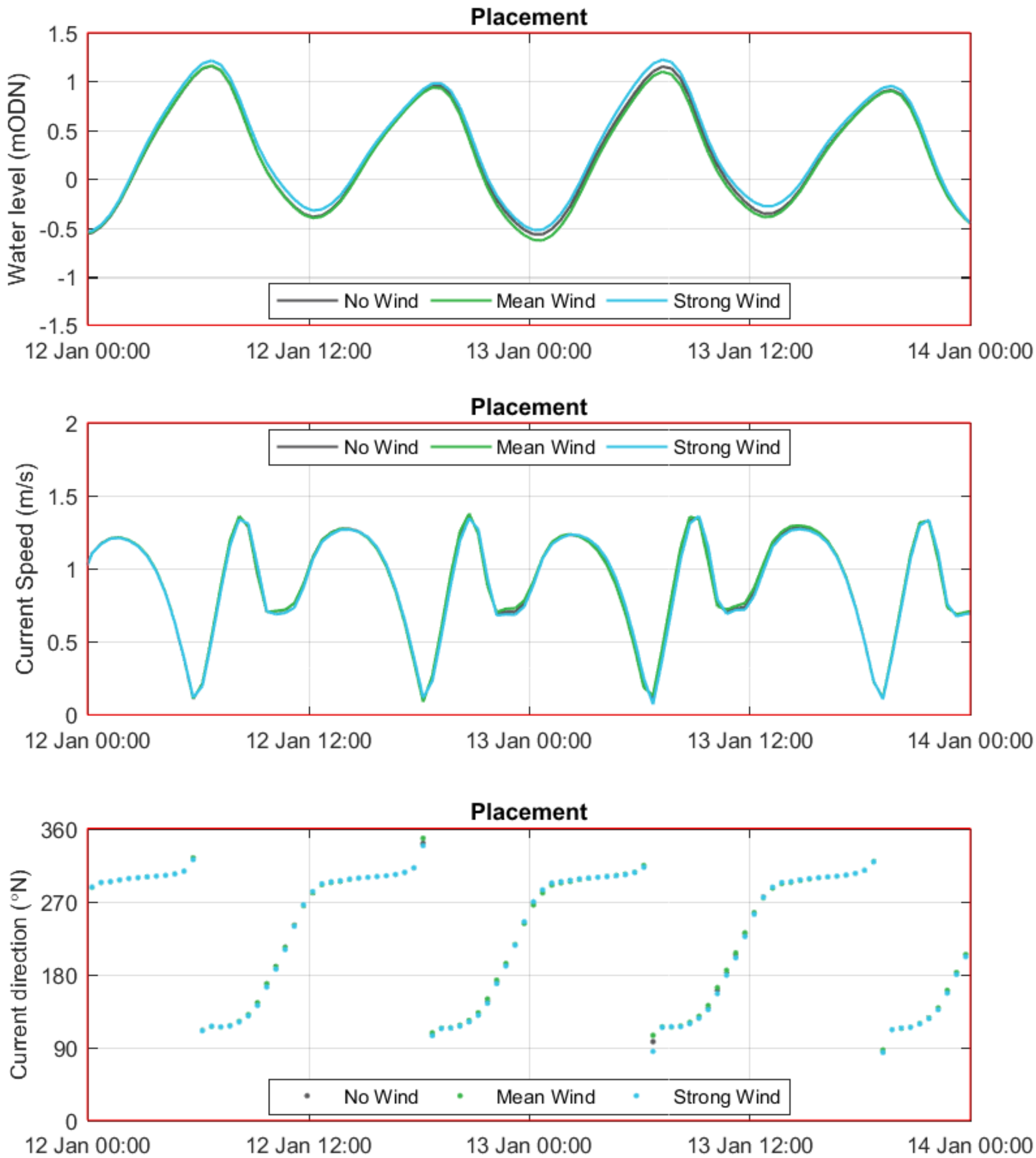


Figure 3.10: Time series of water levels and flows at the disposal site on spring tides.

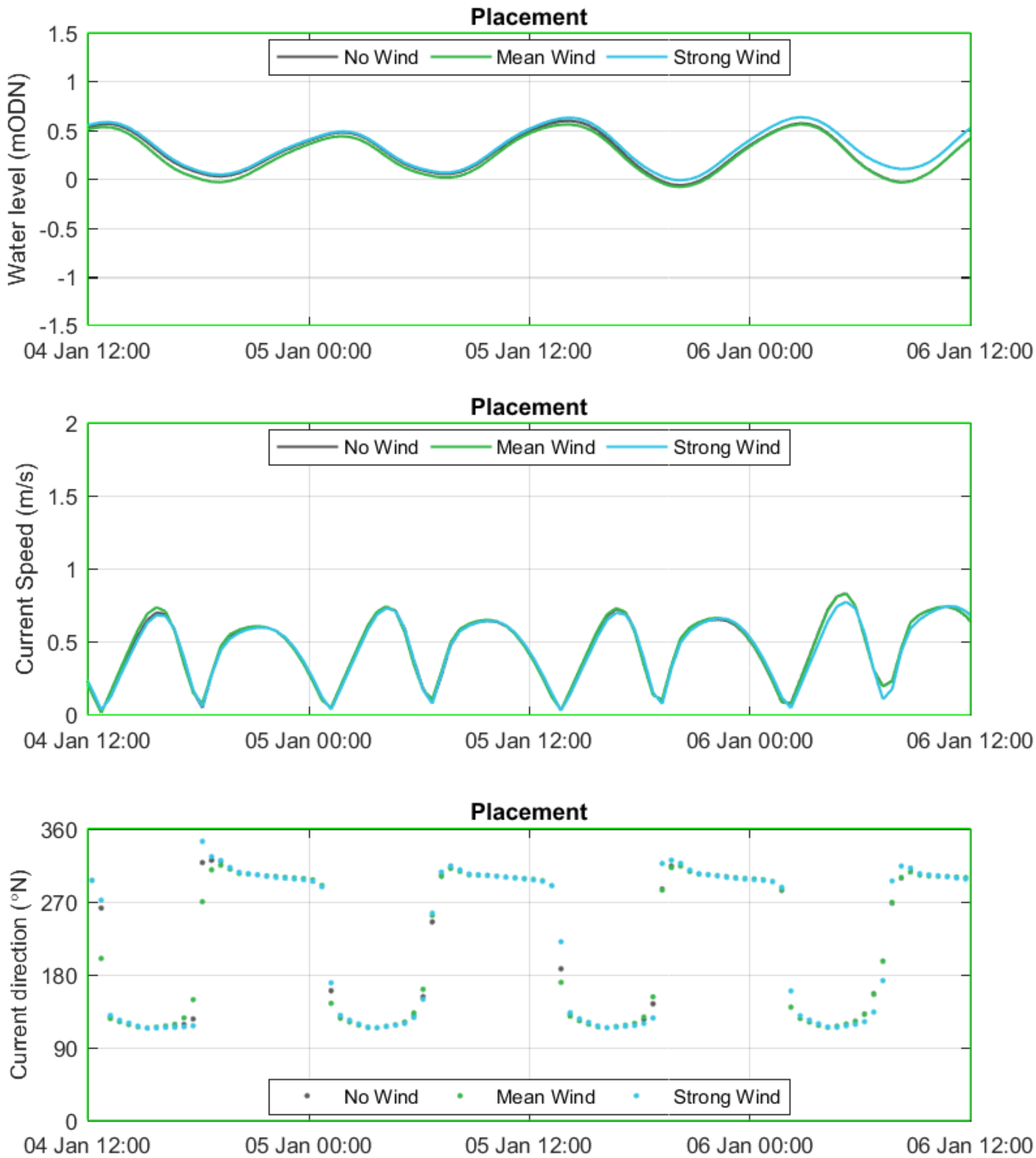


Figure 3.11: Time series of water levels and flows at the disposal site on neap tides.

3.4 Sediment Data

Boreholes have been collected at Kennacraig as part of previous investigations. The sediment is predominantly silty clay, extending to a depth below the seabed of between 1.9 and 4.5 m. In some locations, a surface layer (0 to 0.5 m in depth) of sandy, clayey gravel or gravelly silty sand exists. Based on the dredge depths (mainly less than 1.5 m depth, but up to 2.5 m), it can be assumed that most of the dredge sediment will be silty clay, with some sandy, clayey gravel or gravelly silty sand also present.

Boreholes were collected at the terminal in 2022, and a series of sediment samples from these were analysed to obtain the particle size distribution (PSD). PSD analysis was undertaken on 13 sediment samples from four different boreholes at Kennacraig (see Figure 3.1 for locations), the results of which are plotted in Figure 3.12. The depths of the samples ranged from the surface layer (0 m) down to 1.5 m below the surface, with most samples obtained between the surface layer and a depth of 1.0 m below the surface. As the dredging is predominantly less than 1.5 m in depth, the samples can be considered to provide a good representation of the PSD of the dredged sediment. The PSD from all 13 sediment samples were averaged to provide a PSD representing the dredged sediment at Kennacraig. Based on these samples, the average composition of the sediment to be dredged at Kennacraig is provided in Table 3.2. These percentages have been adopted when determining the dredge source terms for the modelling.

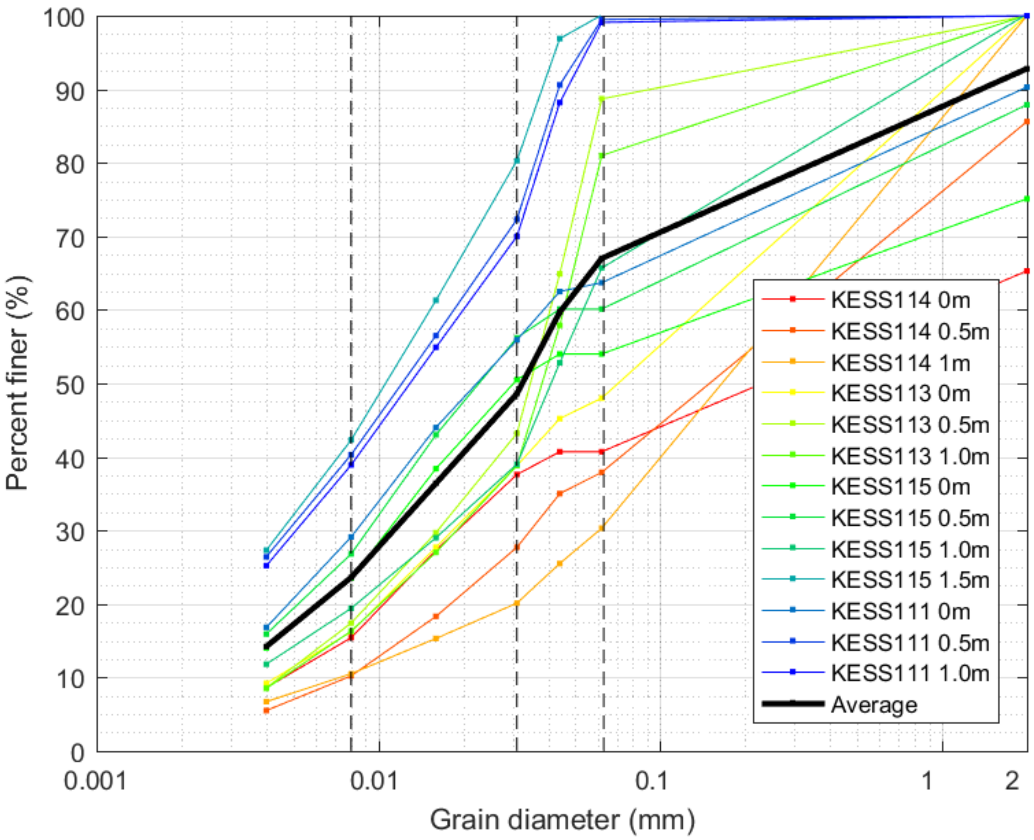


Figure 3.12: PSD plot of sediment samples from Kennacraig.

Table 3.2: Average percentage of fine-grained sediment present at Kennacraig.

Sediment Classification	Coarse Silt (31-63µm)	Fine to Medium Silt (8-31µm)	Clay to very fine silt (<8µm)	All Silt and Clay (<63µm)
Silty Clay	18	25	24	67

3.5 Turbidity

Local turbidity data at Kennacraig were not available. Still, regional data indicates that the turbidity in the coastal waters off of the Minches and Western Scotland is generally low (*c*. 1 mg/l) (Cefas Marine Online Assessment Tool, accessed March 2023).

4 Dredging Description

4.1 Introduction

In dredge modelling, it is necessary to conceptualise operations while ensuring that the dredge timings and release rates assumed in the model are realistic and based on the available information. This approach ensures the numerical model's best representation of dredging and disposal activities.

4.2 Dredging Approach

The dredging at the three ferry terminals is proposed by a backhoe dredger (BHD). There is also a possibility that dredging could be undertaken by a trailing suction hopper dredger (TSHD). A TSHD can dredge much faster than a BHD, but unlike the BHD, a TSHD can only be used to dredge soft materials such as sand, clay, sludge and gravel, and it is not suitable for dredging harder materials like rock. Therefore, a TSHD will only be suitable for dredging some sediment at the terminals. As a result, a BHD would also be required to dredge any rock if a TSHD was adopted. The assumptions adopted in deriving disturbance rates of fine sediment for each method are given in the subsections below.

Due to the region's high potential for adverse weather conditions, dredging is not expected to be undertaken during the winter months from December to February. Therefore, all the modelling assumes that dredging will be undertaken between March and November.

4.2.1 Backhoe Dredger

The dredging is proposed using a BHD with a split hopper barge transporting the dredged sediment to the approved marine disposal site. In areas with hard bedrock which the BHD cannot remove, CO_2 injection of the rock may be used to break it up before removal by the BHD. Limited information is available to detail exactly how the dredging will be undertaken, and so the following assumptions have been made:

- The BHD will use a 2.5 m^3 bucket. Bucket sizes on small and medium BHDs vary from 1.5 to 2.5 m^3. Consideration of the larger bucket provides a conservative assessment (with a higher production rate and greater sediment release rate);
- The BHD will dredge continuously for 25 minutes, reposition for 5 minutes and then dredge continuously for a further 25 minutes, repeating this cycle over the dredging period. There would likely be additional operational downtime, but the modelling will assume this cycle to represent the worst case;
- Each bucket load will dredge 1.75 m^3 of sediment (*in-situ* volume), assuming an average bucket efficiency of 70%, and the BHD works at a rate of 25 bucket loads per hour[2]. The BHD will therefore have a production rate of approximately 45 m^3 (*in-situ* volume) per hour;
- The BHD will operate for 24 hours each day and seven days a week, which provides a worst-case (conservative) assessment;
- Based on the above assumptions, the time taken to complete dredging would be 6.5 days at Kennacraig. In reality, downtime resulting from weather, vessel movements and/or plant maintenance will result in a longer dredge period than this;
- The split hopper barge will have a hopper size of 450 m^3. Assuming the hopper capacity is 70% of the *in-situ* volume dredged (to account for seawater and bulking), the barge is

[2] as specified in the productivity rates provided in the Technical Guidelines for Environmental Dredging of Contaminated Sediments (US Army Corps ERDC/EL TR-08-29).

expected to require emptying approximately every seven hours. Assuming an average barge speed of 9 knots (loaded and unloaded), the vessel times to travel to or from the disposal sites is 4.75 hours;

- Based on the estimated barge loading time (seven hours) and the estimated travel time to and from the disposal site, three barges would be required for dredging at Kennacraig to ensure the dredger could continuously dredge; and
- The CO_2 injection used to break up the rock can be undertaken at the same time as the BHD (as long as there is a certain distance between the two), meaning that there would be no downtime to the BHD while this activity was being undertaken.

The above assumptions provide a worst-case assessment, yielding a high release intensity and the greatest potential for higher plume concentrations.

4.2.2 Trailing Suction Hopper Dredger

It is believed that the TSHD *Shoalway* could be working locally to the Kennacraig ferry terminal and, therefore, could be opportunistically used to undertake the proposed dredging work. Therefore, this vessel's specifications have been assumed when determining the dredge cycle and source terms. Details of the vessel are:

- Length overall: 90.0 m;
- Breadth: 19.0 m;
- Max draft International load line (i.e. unloaded): 5.9 m;
- Max draft dredging (i.e. loaded): 6.8 m;
- Hopper capacity: 4,500 m^3; and
- Sailing speed loaded: 11 kn.

The dredge cycle is estimated to be as follows:

- **Loading hopper:** this is estimated to take 100 minutes to complete. This time would vary between loads and depend on parameters such as the sediment type and length of possible dredge runs. It is assumed that there would be no overflow for the first 20 minutes of dredging, and then overflow would occur for the following 80 minutes;
- **Sailing:** The vessel will sail to/from the disposal site at 11 knots, and it will take 240 minutes each way to or from the disposal site; and
- **Disposal:** the hopper would be emptied by opening the hydraulic doors, with sediment released over 10 minutes.

Based on the above, the total dredge cycle time at Kennacraig will be 580 minutes (nine hours and 40 minutes). The proposed dredge could be completed by two dredger loads yielding a total dredge time of less than a day (if the bed material is suitable for TSHD operations).

4.3 Source Terms

The rate of sediment released into suspension by the dredger (known as the source term or 'S' factor) can be estimated based on the sediment composition, the production rate of the dredger and the rate at which sediment is lost from that type of dredger. The rate at which different dredgers lose sediment has been summarised by Becker et al. (2015).

4.3.1 Backhoe Dredger

Becker et al. (2015) suggest that the following percentages of the fine-grained silt and clay present in the sediment being dredged could be suspended during dredging by a BHD and disposal using a barge with hopper doors:

- Bucket Drip: 0 to 4% of the fine-grained silt and clay present in the sediment; and

- Disposal through hydraulic hopper doors: 0 to 5% of the fine-grained silt and clay in the sediment placed for sediment dredged by a BHD.

No information is available to estimate source terms resulting from using CO_2 injection to break up the rock. However, given that the rock is metamorphic, it is not expected that a significant amount of fine-grained sediment will either be released or created by the process. Based on this, the sediment generated by rock breakup using CO_2 injection will be assumed to be representative of the typical sediment in the region.

For this assessment, the upper limits of the suggested percentages have been adopted to represent a conservative approach (i.e. 4% for bucket drip and 5% for disposal). Based on this and adopting the dry bed density of 900 kg/m^3 (Van Rijn, 1993), the source terms are:

- bucket drip = 0.4 kg/s; and
- disposal = 15.8 kg/s.

The bucket drip source terms have been applied in the model continuously for 25 minutes, followed by five minutes of no release to represent times when the BHD is being repositioned. This cycle has been repeated for the duration of the dredging period. The disposal source terms are applied for 10 minutes when the hopper barge is at the disposal site. The first disposal release is 11.75 hours after the commencement of the dredging, with releases occurring every seven hours after that.

4.3.2 Trailing Suction Hopper Dredger

Becker et al. (2015) suggest that the following percentages of the fine-grained silt and clay present in the sediment being dredged could be suspended during dredging and disposal by a TSHD:

- Draghead: 0 to 3% of the fine-grained silt and clay present in the sediment;
- Overflow: 0 to 20% of the fine-grained silt and clay present in the sediment; and
- Disposal through hydraulic hopper doors: 0 to 10% of the fine-grained silt and clay present in the placed sediment.

Adopting the upper limits would represent a conservative approach (i.e. 3% for draghead, 20% for overflow and 10% for disposal). Based on this, and assuming sediment particle size distribution as specified in Section 3.4 and adopting the dry bed density from Van Rijn (1993) (900 kg/m^3), the source terms for dredging with a TSHD are provided below:

- draghead = 11.0 kg/s;
- overflow = 73.5 kg/s; and
- disposal = 326.5 kg/s.

The draghead source term will be released near the bed for the entire duration that the TSHD is dredging. The overflow source term will be released near the surface after the first 20 minutes of dredging and continuing until the end of the dredging (i.e. 20 minutes to 100 minutes of the hopper loading). The disposal source term will be released throughout the water column over the 10-minute disposal duration.

5 Dredging Simulations

The Particle Tracking (PT) module was coupled to the HD model for simulating sediment dispersion from the defined source terms for the dredging and subsequent disposal of dredged material. The model was set up to simulate the dredging by a BHD working with split hopper barges. While consideration was also given to dredging by a TSHD such as the *Shoalway*, the vessel particulars (draught of 5.93 m unloaded and up to 6.82 m loaded) and site conditions (depths of 6 m CD approaching Kennacraig) mean it is unlikely to provide a viable option for dredging at Kennacraig.

As the dredge duration is less than seven days, the dredging period does not cover the entire range of tidal conditions. As a result, the model was set up to simulate the dredging activity separately during neap tides (disposal commencing on 3 January) and during spring tides (disposal commencing on 9 January).

The local flow characteristics determine how sediment suspended during dredging will disperse in the marine environment. The tidal flows in the region of the dredge are relatively low, and winds can have a notable influence on the local flow conditions. Several model scenarios have been undertaken to ensure the sediment dispersion is simulated for the full range of potential environmental conditions.

For both the neap and spring dredging periods, three separate hydrodynamic simulations were undertaken (i.e. six simulations in total):

- No wind: this simulation represents the plume dispersion under the action of only tidal conditions;
- Time-varying mean wind: this simulation represents the plume dispersion under the combined action of tidal forcing and mean wind conditions; and
- Time-varying strong wind: this considers the plume dispersion under the combined action of tidal forcing and strong wind conditions.

The dredging and disposal activity releases were applied as moving source terms to simulate the dredger and barge location throughout the dredging period. Three sediment fractions were represented in the PT model – coarse silt, fine to medium silt and clay to very fine silt, with the distribution in Table 3.2. The settling velocities applied in the model for the different sediment fractions are provided in Table 5.1.

Table 5.1: Settling velocity values used in the simulations

Sediment fraction	Settling velocity (m/s)
Coarse Silt	0.0015
Fine to Medium Silt	0.0005
Clay to very fine silt	0.0001

PT provides an accurate method of simulating the dispersion of disturbed sediment that accounts for the effects of flocculation and settling. However, PT is limited in its ability to simulate erosion processes, with all particles on the bed instantaneously being resuspended if the user-specified critical erosion threshold is exceeded. Erosion was, therefore, not included in the PT simulations. Within the dredge area, the potential for resuspension is limited (with flow speeds typically less than 0.1 m/s). However, there is more potential for the resuspension of sediment from the bed for sediment placed at the disposal site where tidal flows can exceed

1.3 m/s on spring tides. To properly account for this process, the Mud Transport (MT) module was applied to simulate the dispersion of sediment deposited on the bed at the disposal site.

A single model simulation was undertaken with a uniform layer of sediment on the bed across the disposal site. The volume of sediment present at the disposal site at the start of the MT simulation was the total volume of clay, silt and sand-sized sediment placed at the site from all three dredge locations combined[3]. The sediment composition was representative of sediment dredged from each ferry terminal. Due to the dominance of tidal flows at the disposal site, the MT simulation was undertaken for only one HD scenario - the 'no wind' condition. The model setup parameters applied in the MT simulation are provided in Table 5.2.

Table 5.2: MT model setup parameters

Parameter	Value
Critical shear stress for deposition (N/m^2)	0.2
Critical shear stress for erosion (N/m^2)	0.3
Erosion coefficient ($kg/m^2/s$)	2×10^{-7}
Power of erosion	4

[3] Excluding gravel which is not expected to be mobile, this makes up approximately 23% of the total volume

6 Results

6.1 Introduction

This section presents results from the plume dispersion model simulations of the sediment suspended during the dredging and disposal activities and the simulation of the resuspension of the dredged sediment from the disposal site. The results from the dredging and disposal activity simulations and the sediment resuspension from the disposal site simulation are presented in separate sections below.

6.2 Dredging and Disposal Activity

The results from the dredging and disposal activity model simulations are presented in the form of:

- Spatial maps of the maximum predicted increase in SSC due to dredging and disposal activity;
- Spatial maps of the SSC exceedance for the predicted increase in SSC due to the dredging and disposal activity. The SSC which is exceeded for three hours and 24 hours over the 15-day model duration are presented to provide an indication of the short duration (three-hour exceedance), and longer duration (24-hour exceedance) increases in SSC which can occur due to the dredging and disposal activities. These exceedances are cumulative and may represent a continuous or intermittent exceedance;
- Time-series plots of the predicted increase in SSC due to the dredging and disposal activity at discrete locations around the dredge footprint, the disposal site and at the nearby sensitive receptors;
- Spatial maps of the sediment deposited due to dredging and disposal activity. These plots show the thickness of sediment on the seabed at the end of the model simulation; and
- Time-series plots of the sediment deposited due to the dredging and disposal activity at discrete locations around the dredge footprint, the disposal site and the sensitive receptors.

It is important to note that the spatial maps of the SSC do not show an actual representation of the SSC at any point in time; rather, they are duration-based plots which show statistical-based summaries of the SSC over defined periods. Further, the natural SSC is not simulated in the model, and all SSC results shown indicate predicted increases above the background concentrations.

Results from the simulations with different wind conditions were similar but with a slightly larger extent of elevated SSC for the strong wind condition and a small reduction in peak SSC within the dredge footprint. This increase is attributable to stronger winds that drive faster and more variable flows. Strong winds can also increase vertical shear adding to greater longitudinal dispersion. These, in turn, increase the advection of suspended sediment from the dredge area. Based on this, results from the strong wind scenario are presented in the main body of the report, while results from the mean and no wind scenarios are included in Appendix A.

Results from the simulations when the dredging and disposal occurred during neap and spring tides were very similar, with a slightly larger extent with elevated SSC predicted during spring tides (due to the higher current speeds over this period). Based on this, results during spring tides are presented in the main body of the report, while the results during neap tides are included in Appendix A.

6.2.1 Map Plots of SSC

A map plot of the maximum increase in SSC in Figure 6.1 shows a very high SSC within the dredge footprint. While these high SSCs extend beyond the dredge footprint, this modelling artefact results from releases being made in grid cells extending beyond the dredge footprint and interpolating these high values across adjacent cells where the values are much lower. The maximum SSC in the map plot is 100 mg/l, but modelled SSC was much higher than this, up to 10,000 mg/l. These very high SSCs are likely to be an overprediction of the SSC, which will occur since the model releases all sediment suspended by the dredging in a single model timestep (five minutes) into one grid cell. Given the high grid resolution and shallow water depth, there is only a low volume for dilution available. In reality, the sediment will settle and disperse as it is released so that peak concentrations will be significantly lower than this maximum within the dredge footprint at the plotting to a maximum of 100 mg/l is reasonable.

Maximum increases in SSC exceed 1 mg/l over an area of approximately one km^2. In comparison, higher increases in SSC (of more than 10 mg/l) are constrained to a much smaller area, mainly within the dredge footprint and adjacent model cells. Some shallow coastal areas also show an increase of more than 10 mg/l due to the reduced water depth and, therefore, the reduced water volume for dilution.

SSC exceedance for a short duration (three hours) and a longer duration (24 hours) are shown for the strong wind scenario during spring tides in Figure 6.2 and Figure 6.3. The plots show the following:

- **3-hour exceedance:** the area where the SSC exceeds 1 mg/l for three hours is predicted to remain within 200 m of the dredge footprint predominantly. However, a small localised plume extends further to the next headland to the south. The SSC is predicted to remain below 10 mg/l across most of the dredge area, except in a localised area adjacent to the shoreline where the SSC is up to 60 mg/l; and
- **24-hour exceedance:** the area where the SSC exceeds 1 mg/l for 24 hours is predicted to remain within 100 m of the dredge footprint typically. The SSC remains below 3 mg/l within the dredge footprint and adjacent areas and below 10 mg/l along the shoreline adjacent to the east side of the dredge footprint.

The areas with elevated SSC due to the dredging remain localised to the dredge footprint and adjacent areas. No elevated SSC is predicted to influence the blue mussel beds northwest of the dredge area.

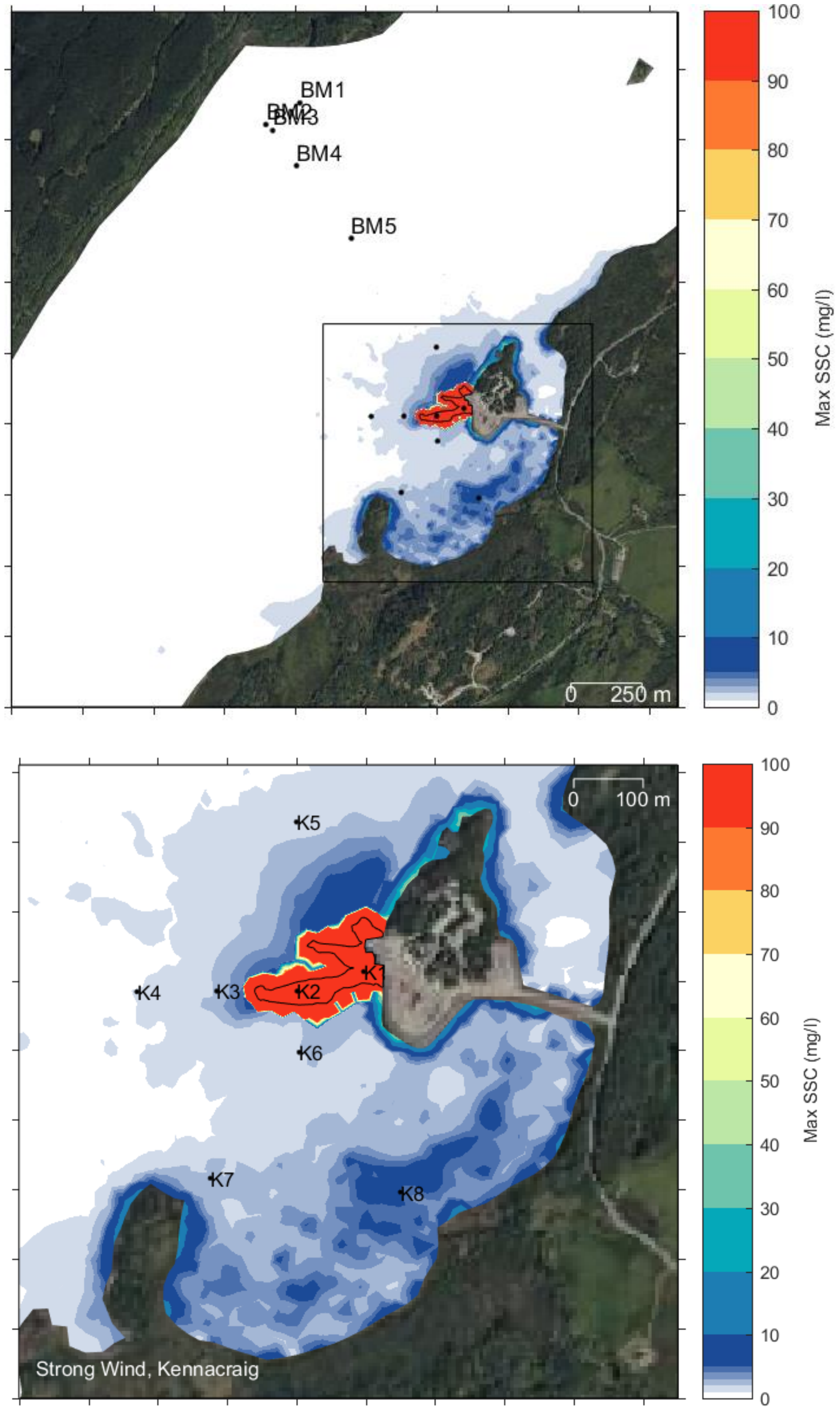


Figure 6.1: Modelled maximum SSC at the dredge area.

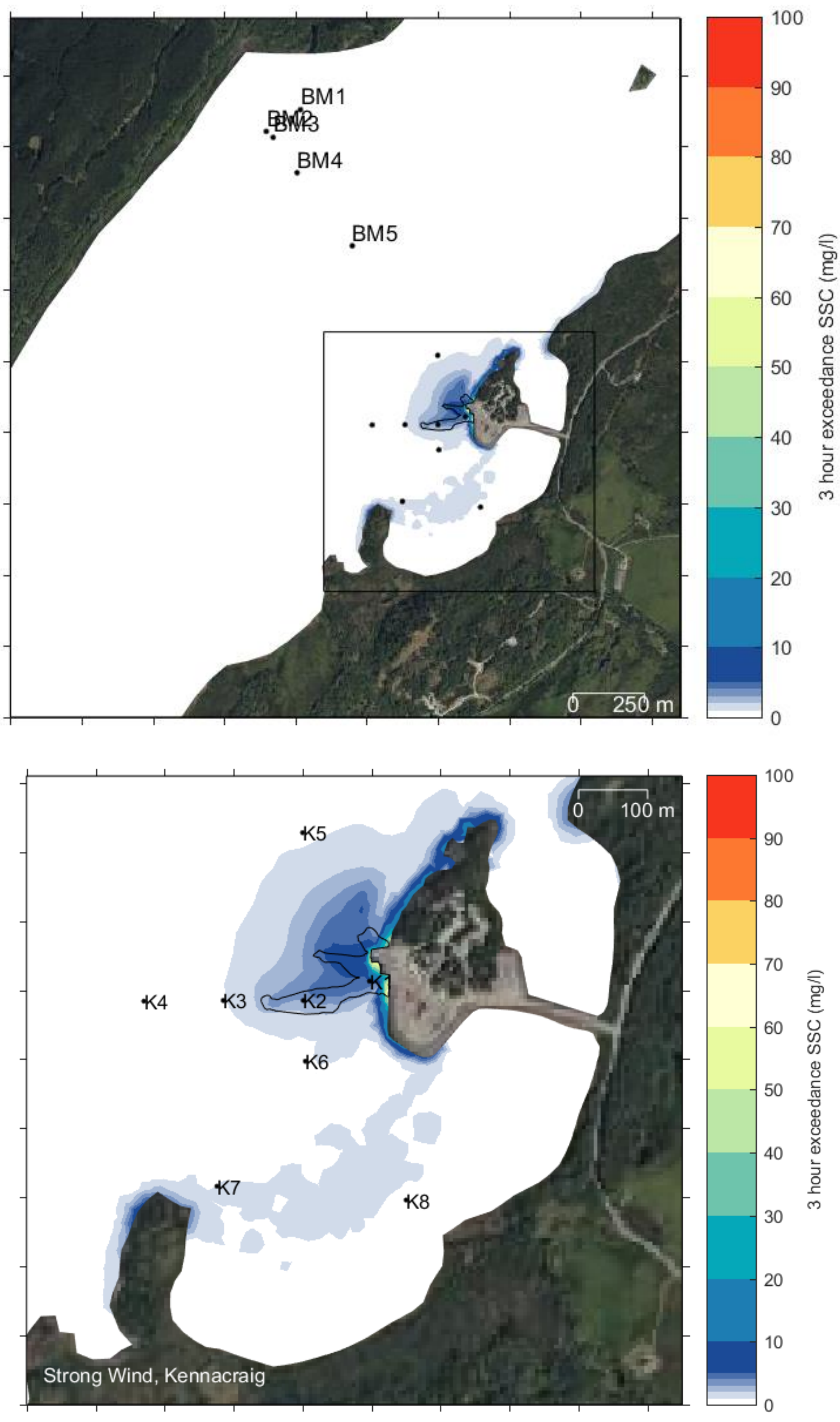


Figure 6.2: Modelled 3-hour exceedance SSC at the dredge area.

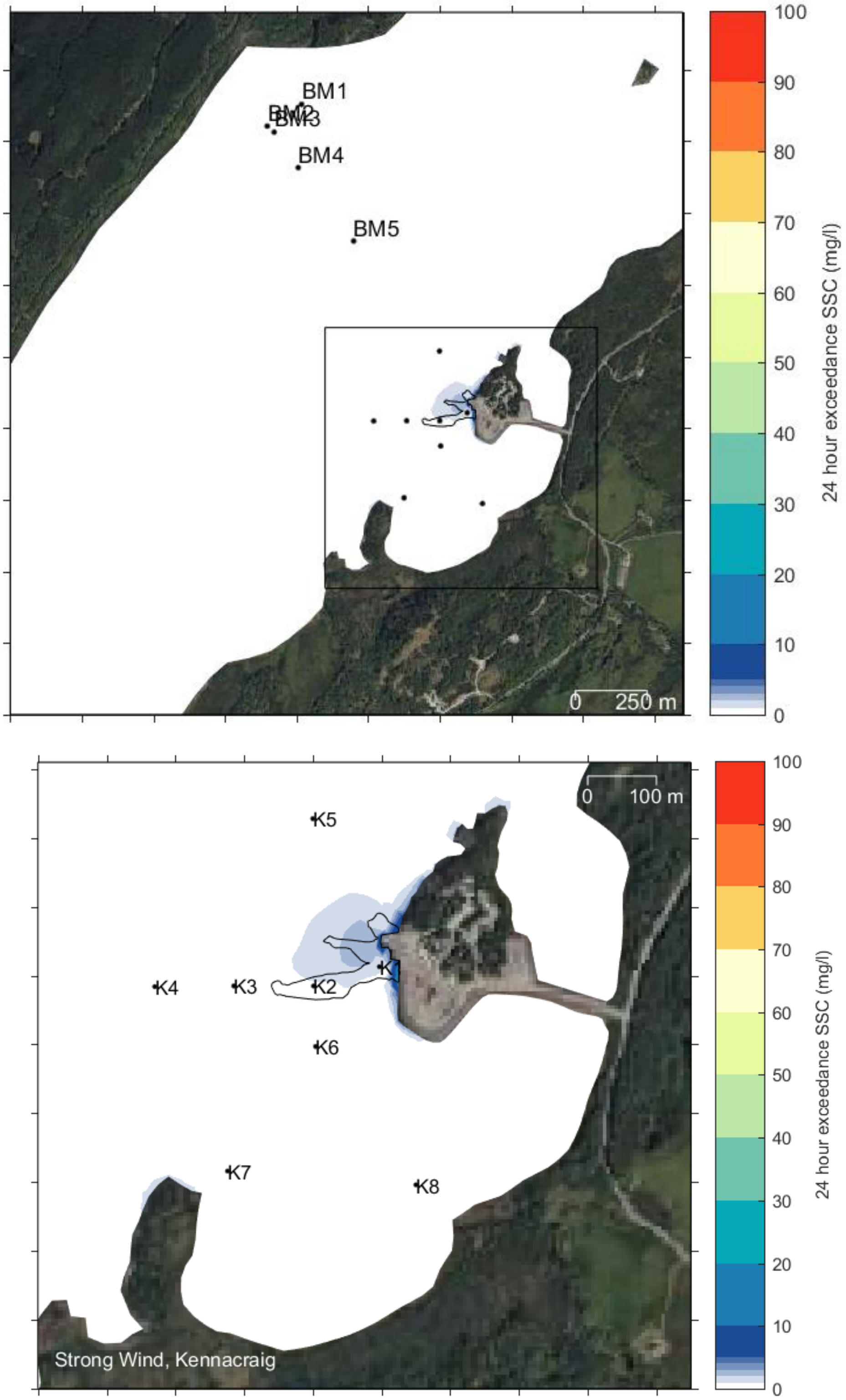


Figure 6.3: Modelled 24-hour exceedance SSC at the dredge area.

The maximum SSC throughout the dredging due to the relocation of dredged sediment to the disposal site is shown in Figure 6.4. The plot shows:

- The highest SSC occurs within the disposal site, where a maximum SSC of up to 30 mg/l can occur. Outside of the disposal site, the maximum SSC is predominantly less than 10 mg/l; and
- The relatively strong tidal currents at the disposal site are predicted to disperse the plume so that maximum SSC increases above 1 mg/l and extends up to 8 km to the northwest and 4 km to the east of the disposal site. The extent of the area where the maximum SSC is more than 3 mg/l is less than half of these distances.

The three-hour and 24-hour exceedance SSC at the disposal sites are below 1 mg/l, so they do not show any area with elevated SSC. This result indicates that the elevated SSC due to the disposal only remains in a single location for a short duration.

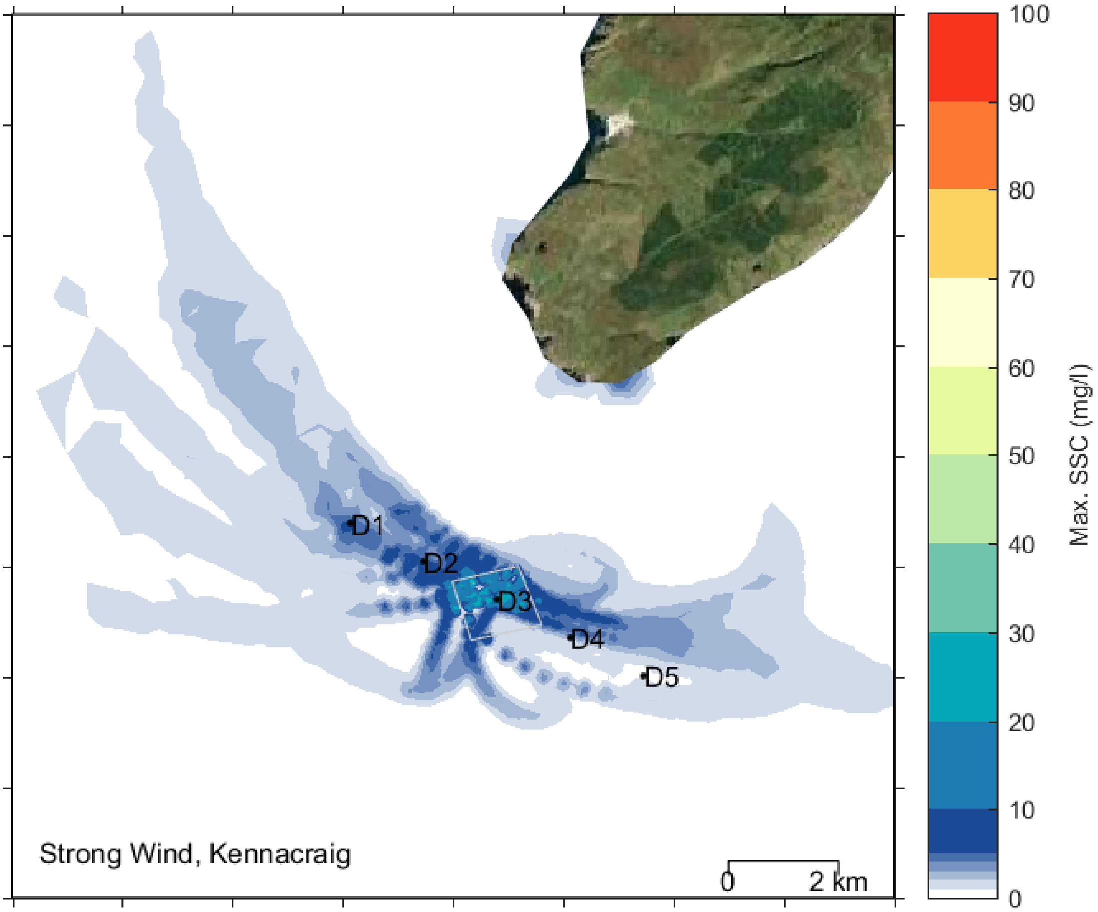


Figure 6.4: Modelled maximum SSC at the disposal site.

6.3 Map Plots of Deposition

The predicted deposition resulting from the sediment suspended by the dredging is shown in Figure 6.5. Deposition of more than 0.05 mm was predicted only to occur close to the dredge footprint (with no deposition above 0.05 mm at the blue mussel beds), so only the enlarged plot of the dredge area is included. The plot shows the following:

- The sedimentation is predicted to remain localised to the dredge footprint and adjacent areas;

- Sedimentation of more than 10 mm is predicted to occur within the dredge footprint predominantly. It is, therefore, likely that much of this will be re-dredged throughout the dredging campaign; and
- Sedimentation of more than 1 mm extends up to approximately 100 m from the dredge footprint.

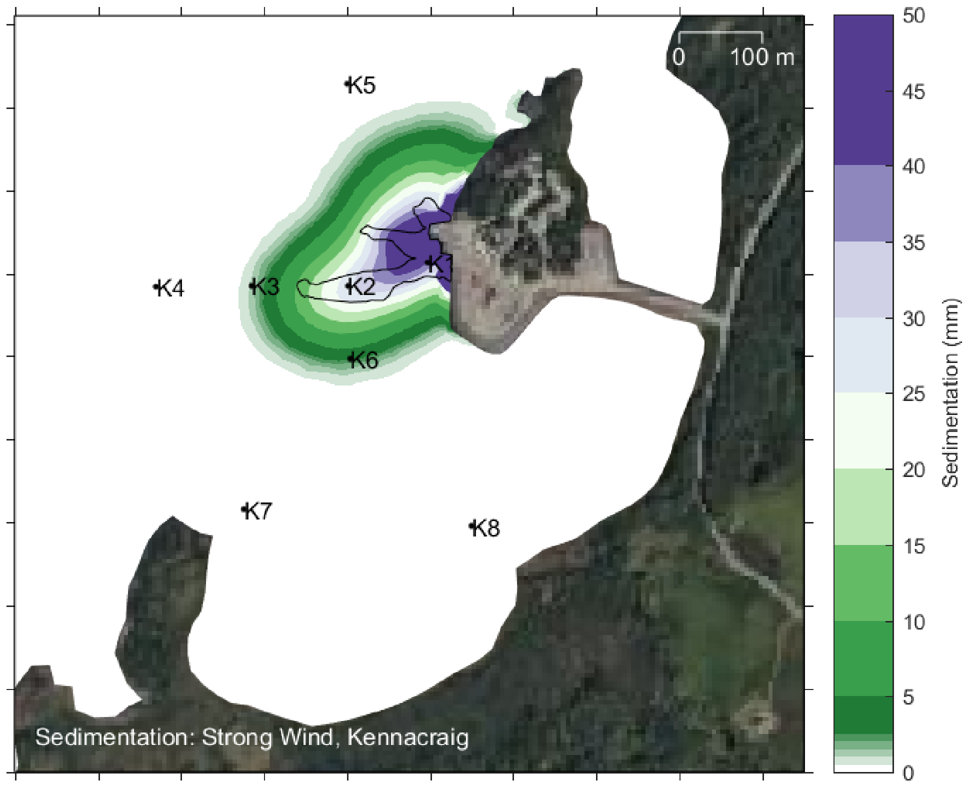


Figure 6.5: Modelled sedimentation at the end of the dredging.

6.3.1 Time Series Plots of SSC and Deposition

The modelled SSC and deposition for the strong wind case at selected locations close to the dredge area are shown in Figure 6.6 to Figure 6.9 and at selected locations close to the disposal area in Figure 6.10 to Figure 6.12. Results are also plotted for the 'no wind' and 'mean wind' simulations' to indicate variability in plume dispersion arising from different wind forcing scenarios.

Although blue mussel beds are located 600 to 1,200 m north of the dredge footprint (sites BM1 to BM5 in Figure 6.3), the model predicts no increase in SSC or sedimentation at any of these sites due to the dredging at Kennacraig. Therefore, no time series plots are presented for these sites. The time series plots presented show:

- Applying different wind-forcing conditions does not significantly affect the SSC or the sedimentation at any sites. This result is attributable to the flows remaining low for all conditions simulated;
- Within the dredge footprint (at K2), there are very short-lived spikes in SSC, but for the most part, the SSC remains low (around 5 mg/l during dredging) and rapidly returns to zero following the completion of the dredging campaign;

- Sedimentation within the dredge footprint (at K2) occurs at a rate of around 10 mm per day when the dredger is working close by. It is expected that this sediment will be re-dredged by subsequent bucket loads;
- For the sites outside of the dredge footprint, there are no spikes in SSC coinciding with the high peaks in SSC at K2, further confirming that the increases in SSC are local to the dredger. SSC remains below 3 mg/l at K3 (approximately 50 m to the west of the dredge footprint and below 2 mg/l at K5 (approximately 150 m to the northwest of the dredge footprint) and K6 (70 m to the south of the dredge footprint);
- In common with the sites within the dredge footprint, the SSC at the sites outside the dredge footprint rapidly drops to zero following the completion of the dredging campaign;
- The only sites outside the dredge footprint where sedimentation is predicted are the two sites within 100 m of the dredge footprint (K3 and K6). At these sites, the sedimentation is predicted to occur towards the end of the dredging campaign and remain below 4 mm in total; and
- Consistent with the results presented in the statistical map plots, the time series of SSC at extraction points in and around the disposal site show that increases in SSC are very short-lived. There are some peaks in SSC approximately one day after the final barge load was placed, indicating that the short-duration peaks result from the fast flows and advection of the plume around the disposal site rather than from the settling of sediment to the bed.

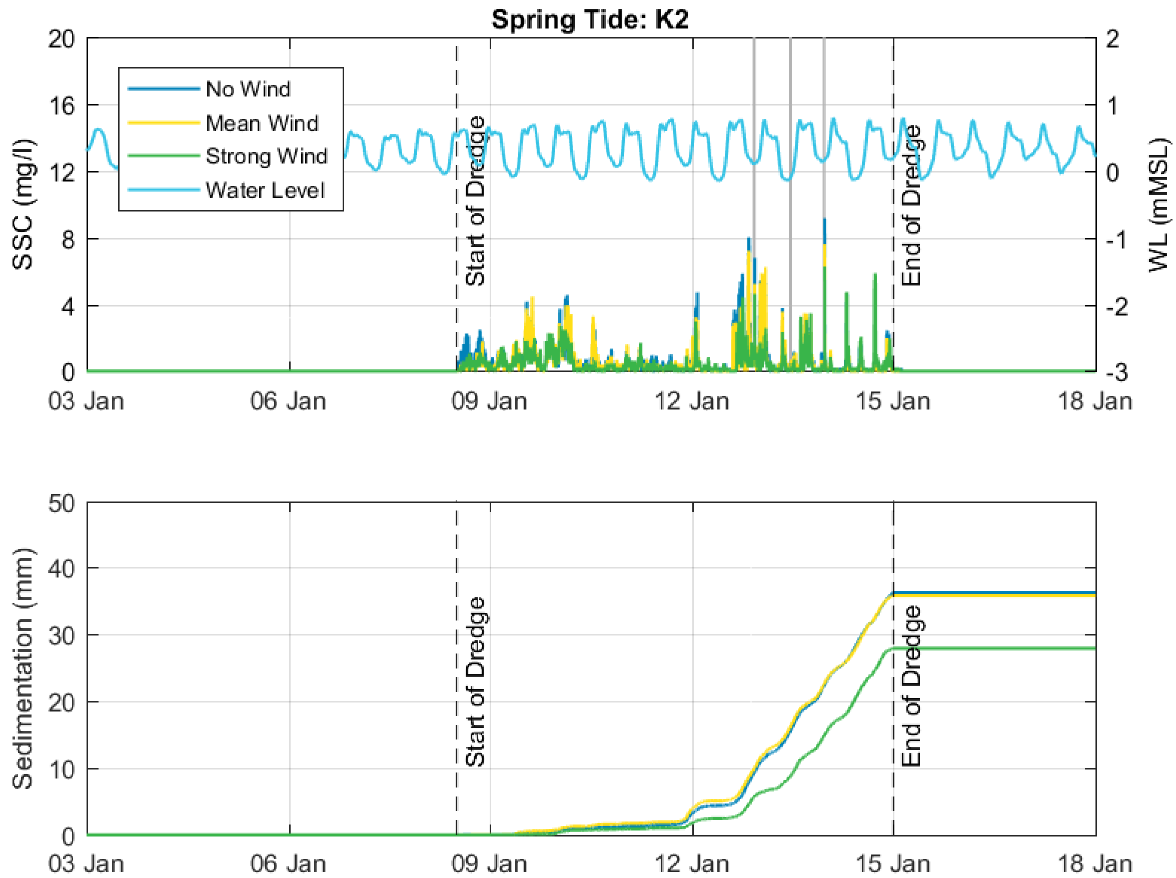


Figure 6.6: Modelled SSC (top) and sedimentation at K2 over the 15-day model simulation. Note: grey lines show high SSC when sediment was placed in this model cell.

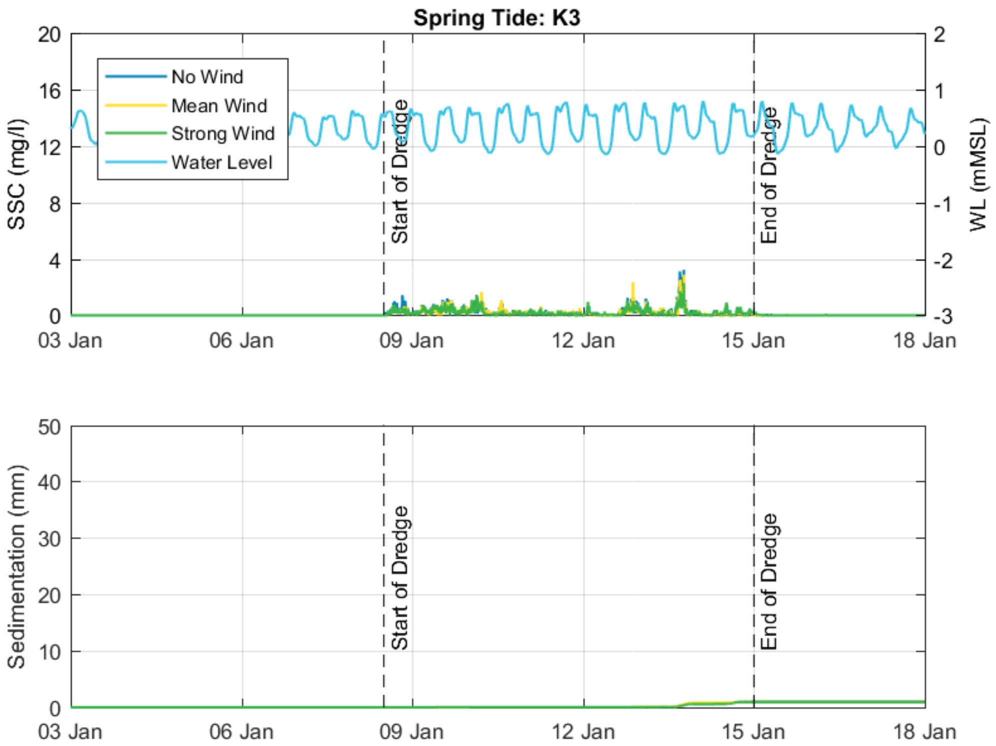


Figure 6.7: Modelled SSC (top) and sedimentation at K3 over the 15-day model simulation.

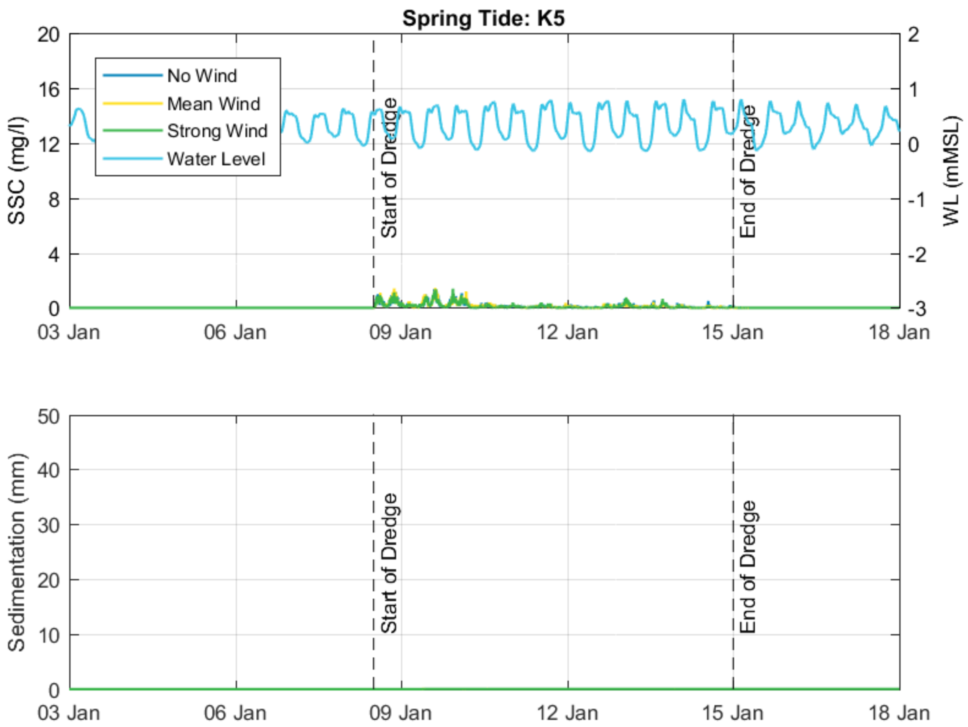


Figure 6.8: Modelled SSC (top) and sedimentation at K5 over the 15-day model simulation.

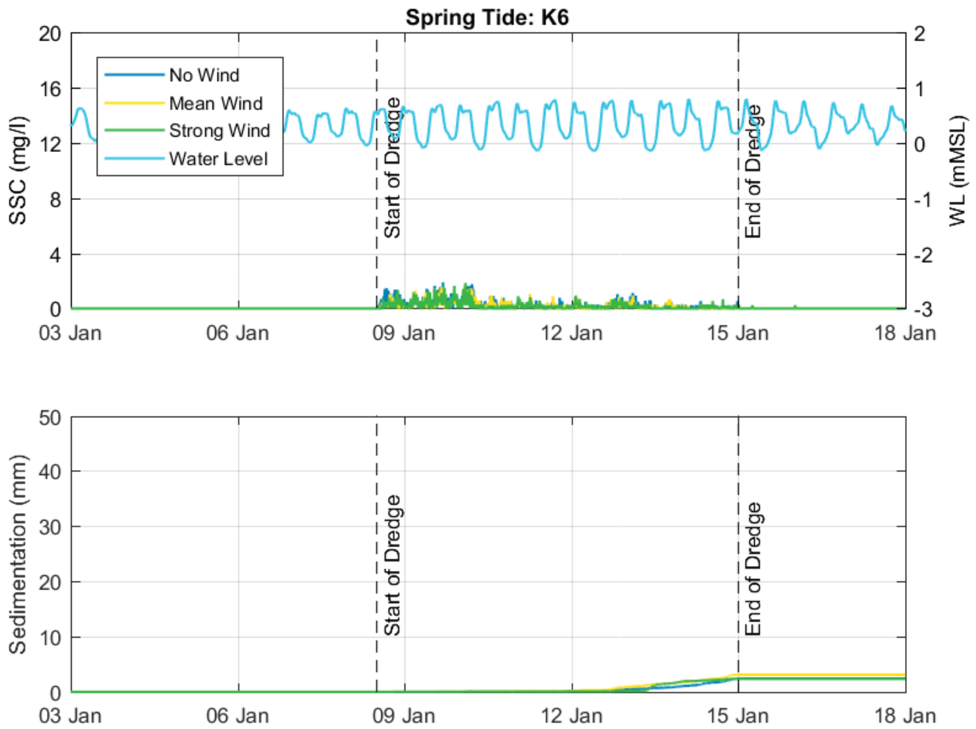


Figure 6.9: Modelled SSC (top) and sedimentation at K6 over the 15-day model simulation.

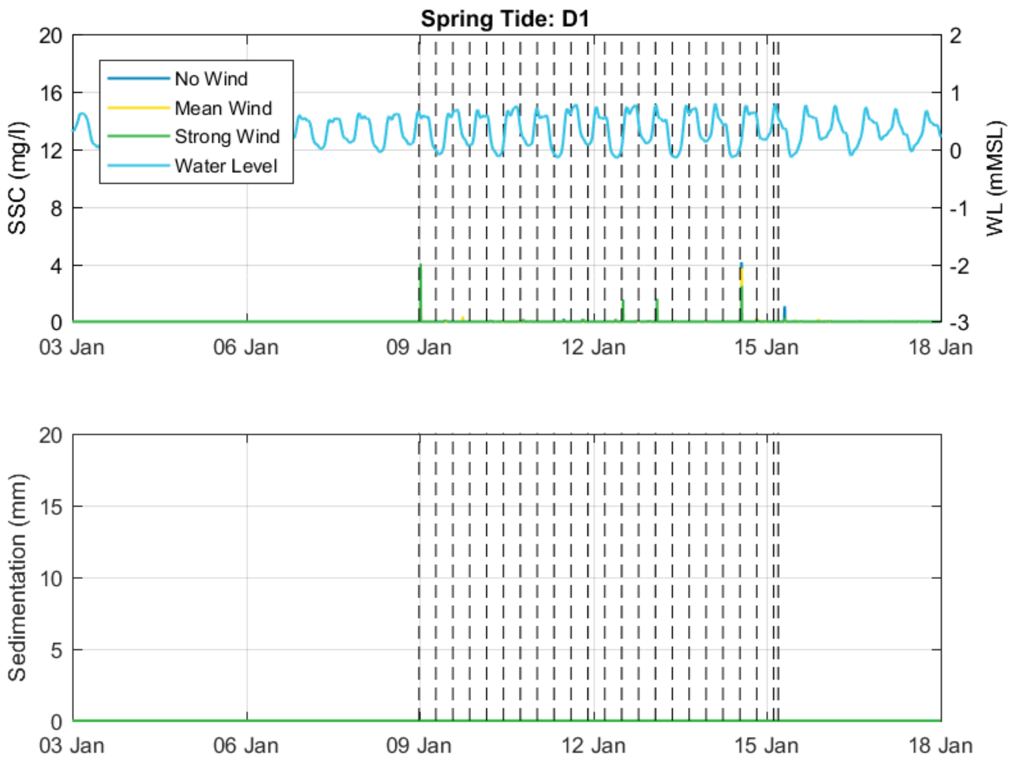


Figure 6.10: Modelled SSC (top) and sedimentation at D1 over the 15-day model simulation. Note: the dashed lines show when disposals occurred.

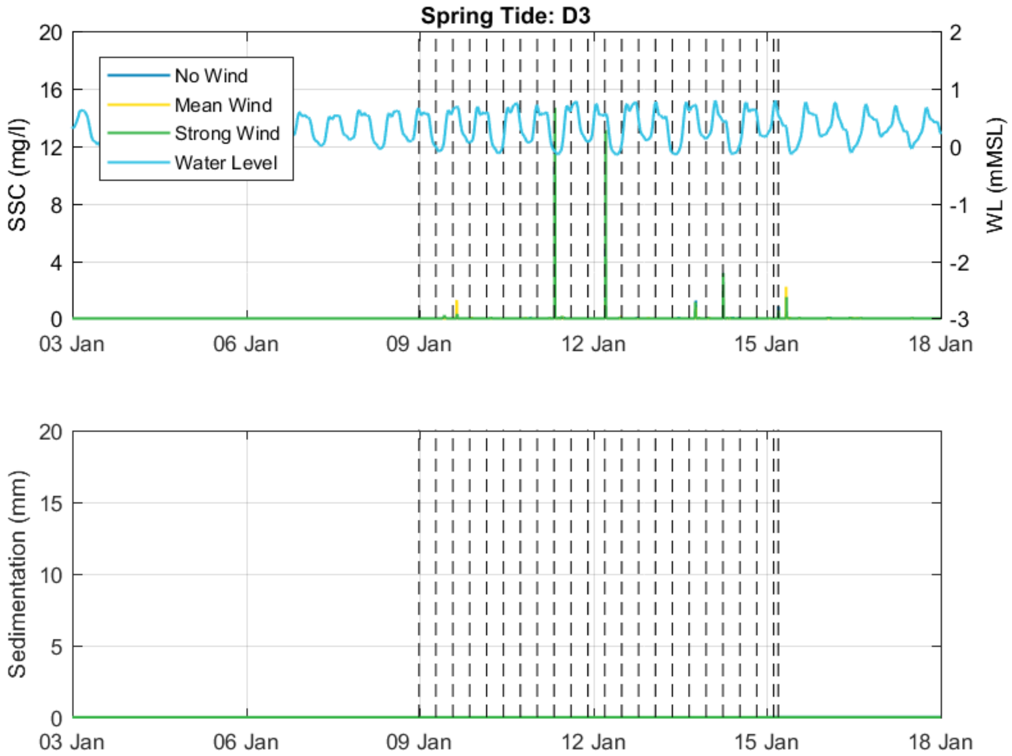


Figure 6.11: Modelled SSC (top) and sedimentation at D3 over the 15-day model simulation. Note: the dashed lines show when disposals occurred.

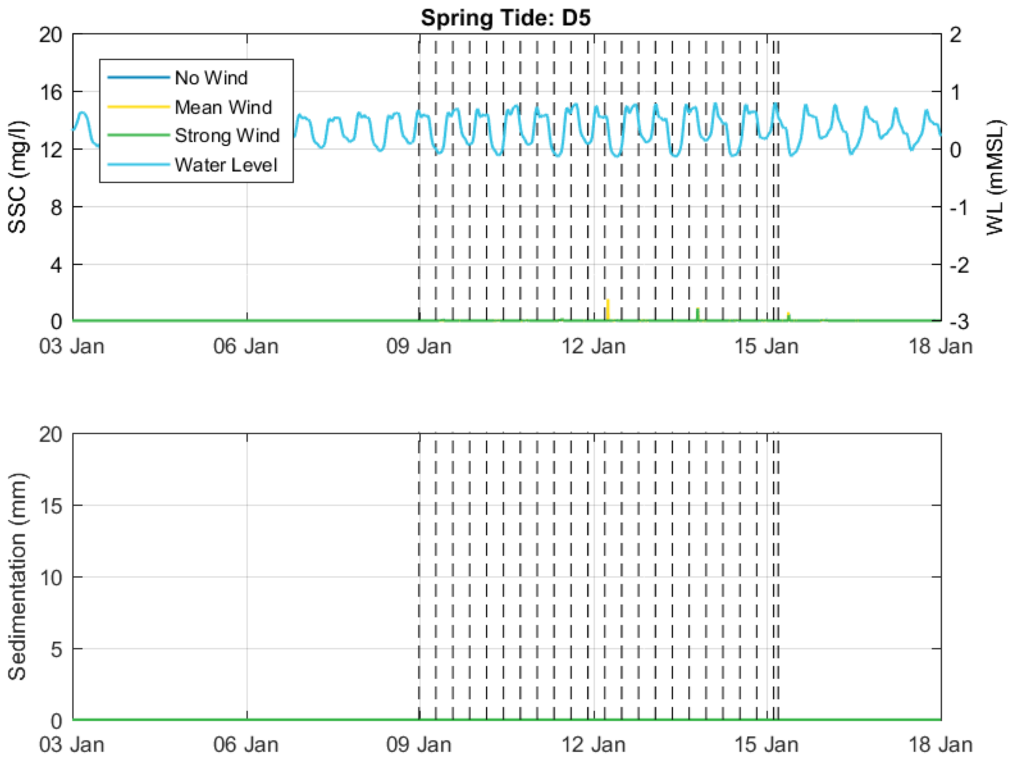


Figure 6.12: Modelled SSC (top) and sedimentation at D5 over the 15-day model simulation. Note: the dashed lines show when disposals occurred.

6.4 Sediment Resuspension from the Disposal Site

Results from the sediment resuspension from the disposal site are presented in this section in the form of the following plots:

- spatial map of the maximum SSC throughout the simulation (Figure 6.13);
- spatial map of the change in sediment thickness throughout the simulation (Figure 6.14); and
- time series plot of the SSC and sediment thickness within the disposal area (at extraction point D3) throughout the simulation (Figure 6.15).

The plots show that although sediment resuspension at the disposal site can occur, the resultant plume has very low concentrations (less than 0.2 mg/l) due to the relatively fast flows in the area and the limited sediment mass predicted to be resuspended at any time. Eroded sediment is rapidly dispersed away from the disposal site, with no sedimentation areas above 0.01 mm occurring. Over the 15-day simulation, the thickness of the deposit on the bed reduced from 14 mm to approximately 12 mm, indicating that approximately 15% of the placed clay, silt and sand was eroded over a spring neap cycle. Based on this rate of erosion, all of the clay, silt and sand could potentially be eroded from the placement site over a 3.5-month period.

However, as the placed sediment contains approximately 23% gravel, it is expected that as the finer-grained clay, silt and sand are eroded from the placement site, the gravel in the surface layer of the placed sediment will remain. This layer of immobile gravel would then act to limit further erosion of any clay, silt and sand located below, meaning that it is unlikely that all of the placed clay, silt and sand would be eroded from the placement site.

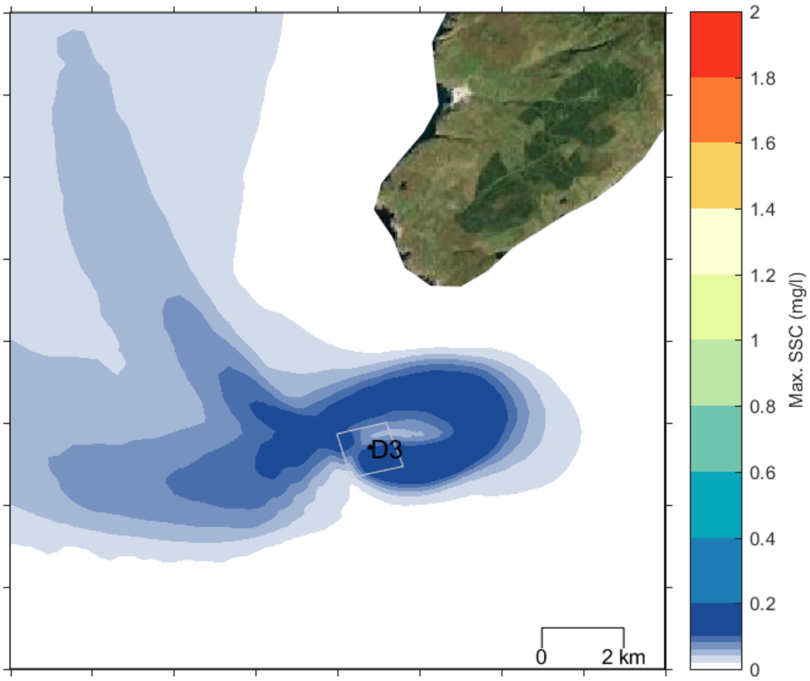


Figure 6.13: Modelled maximum SSC at the disposal site for the resuspension run.

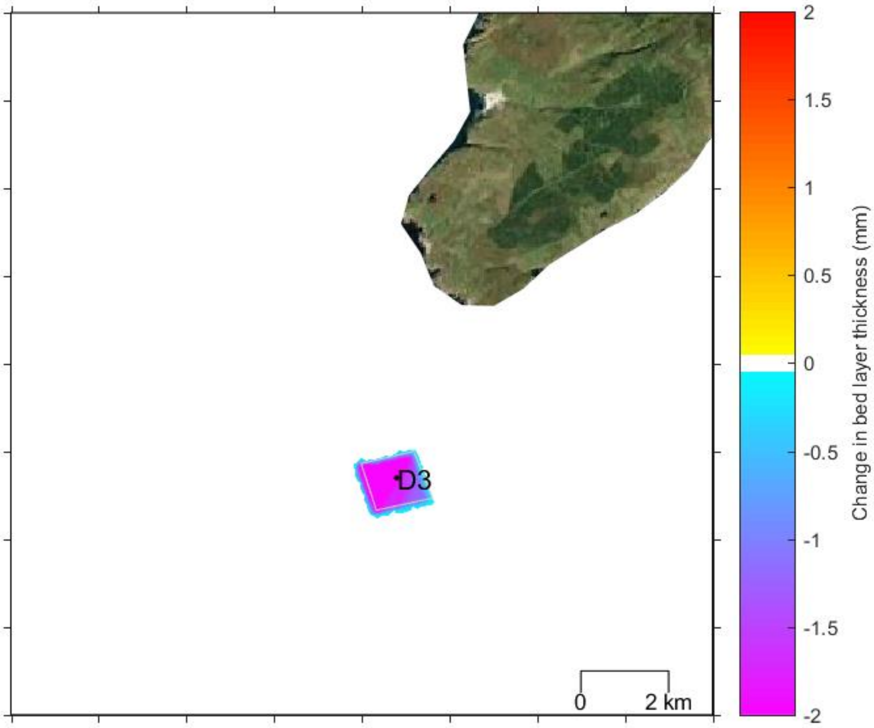


Figure 6.14: Change of sediment thickness at the disposal site for the resuspension run.

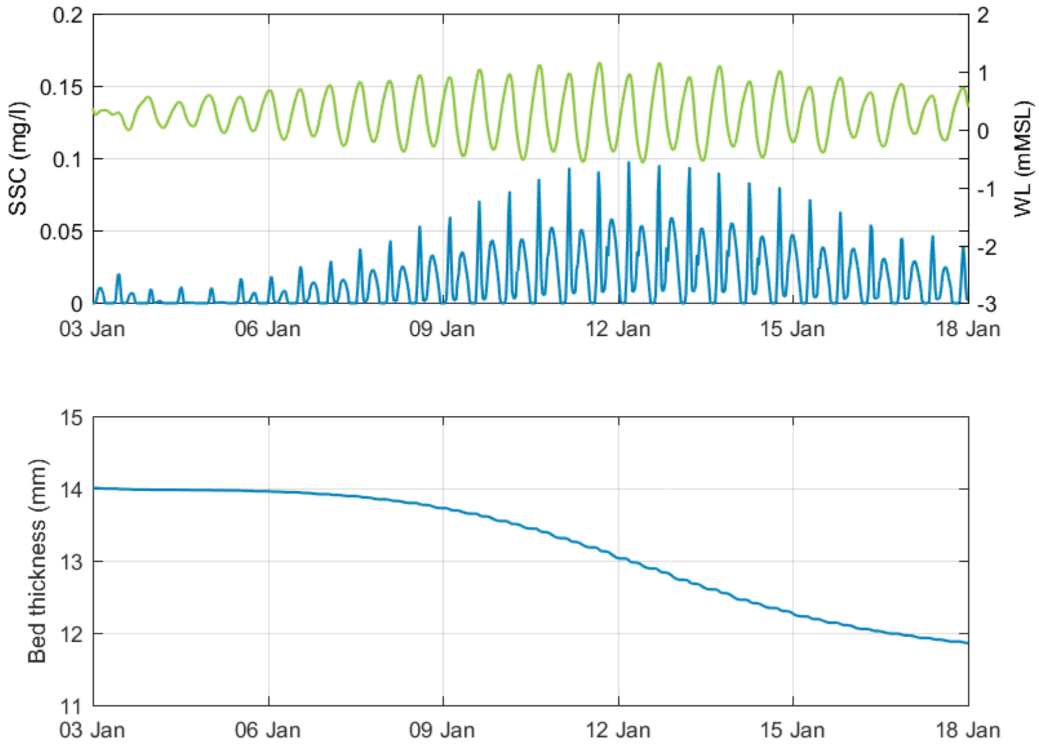


Figure 6.15: Modelled SSC (top) and sedimentation at D3 over the 15-day model simulation.

7 Conclusions

This report has presented results from numerical model simulations of the transport of suspended sediment released into the marine environment by dredging required at the Kennacraig Ferry Terminal. Approximately 7,000 m^3 of sediment requires dredging *in-situ* to deepen the area by 1.5-2.5 m. The dredged material will predominantly comprise fines (silt and clay).

The dredging method is not fully defined but will likely require a backhoe dredger (BHD), with sediment placed on barges and transported to a disposal site located southwest of the Isle of Islay, approximately 67 km from the Kennacraig Ferry Terminal. It has been assumed that the BHD could operate 24 hours daily until the dredging is completed to ensure a conservative assessment. Based on this assumption, the dredging would take 6.5 days to complete.

The model simulations consider the dispersion of the fine-grained sediment fractions (of less than 63 µm, classified as silts and clays on the Wentworth scale) arising from the dredging and placement activity as particles of this size have the potential to remain in suspension.

So that the plume dispersion was assessed under the range of tidal conditions which could occur during the dredging programme, the dredging was simulated during both spring and neap tides. In addition, the dredging was simulated for three different wind conditions: no wind, mean non-winter winds and strong non-winter winds. In total, six Particle Tracking (PT) model runs were undertaken. The simulations released sediment to represent the disturbance of fine sediment from the bucket and from the placement of the dredged sediment at the disposal site.

An additional model simulation using the Mud Transport (MT) model to represent erosion better was also undertaken to fully capture the potential for resuspension of sediment placed at the disposal site.

The modelling has shown the following:

- The sediment suspended during the dredging and material placement activity results in relatively localised and short-lived plumes;
- Maximum increases in SSC from the dredging exceed 1 mg/l over an area of approximately 1 km by 1 km, while higher increases in SSC (of more than 10 mg/l) are constrained to a much smaller area, mainly within the dredge footprint and adjacent model cells. Some shallow coastal areas also show an increase of more than 10 mg/l as a result of the shallow water depth in these areas (reducing water volume for dilution);
- Once dredging has been completed, the SSC quickly returns to background levels at the dredge site, with the low flow speeds, high sediment concentrations (resulting in the formation of flocs) and the shallow water depths all contributing to the rapid deposition of sediment on the bed;
- Sedimentation above 1 mm was constrained to an area within approximately 100 m of the dredge footprint;
- No increases in SSC and no sedimentation were predicted at the blue mussel beds to the northwest of Kennacraig;
- Maximum increases in SSC of up to 30 mg/l are attributable to the placement of dredged sediment from the barges and are constrained within the disposal site. Beyond the disposal site, the maximum SSC associated with the placement activity is predominantly less than 10 mg/l;

- The relatively strong tidal currents which occur at the disposal site are predicted to disperse the plume so that maximum SSC increases above 1 mg/l extend up to 8 km to the northwest and 4 km to the east of the disposal site;
- The elevated SSC due to the disposal only remains in a single location for a short duration;
- Time series plots of SSC at the disposal site show intermittent peaks up to a day after the last barge load is placed. This indicates that the short-duration peaks result from the fast flows and advection of the plume around the disposal site rather than the settling of the sediment to the bed (unlike around the dredge site);
- The resuspension of sediment placed at the disposal site can occur, but the resultant plume has very low concentrations (less than 0.2 mg/l) due to the relatively fast flows in the area and the limited mass of sediment predicted to be resuspended at any time; and
- Eroded sediment is rapidly dispersed away from the disposal site, with no sedimentation areas above 0.01 mm occurring.

Consideration has been given to the potential for using a Trailing Suction Hopper Dredger (TSHD) as it is possible that the TSHD *Shoalway* may be working locally and could therefore be used with little or no mobilisation costs. It is considered very unlikely that using this dredger would be practical at Kennacraig, and for this reason, modelling has not been undertaken to simulate this dredge method. However, if it were to be used, it would result in higher plume concentrations local to the dredger and at the disposal site than those predicted for dredging with the BHD. However, elevated SSC would be much shorter as only two dredger loads would take less than a day to complete.

The results presented in this report will inform the assessment of the potential for disturbance to sensitive receptors at both the dredge and disposal sites, which MML will undertake.

8 References

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Appendices

A. Plume dispersion results

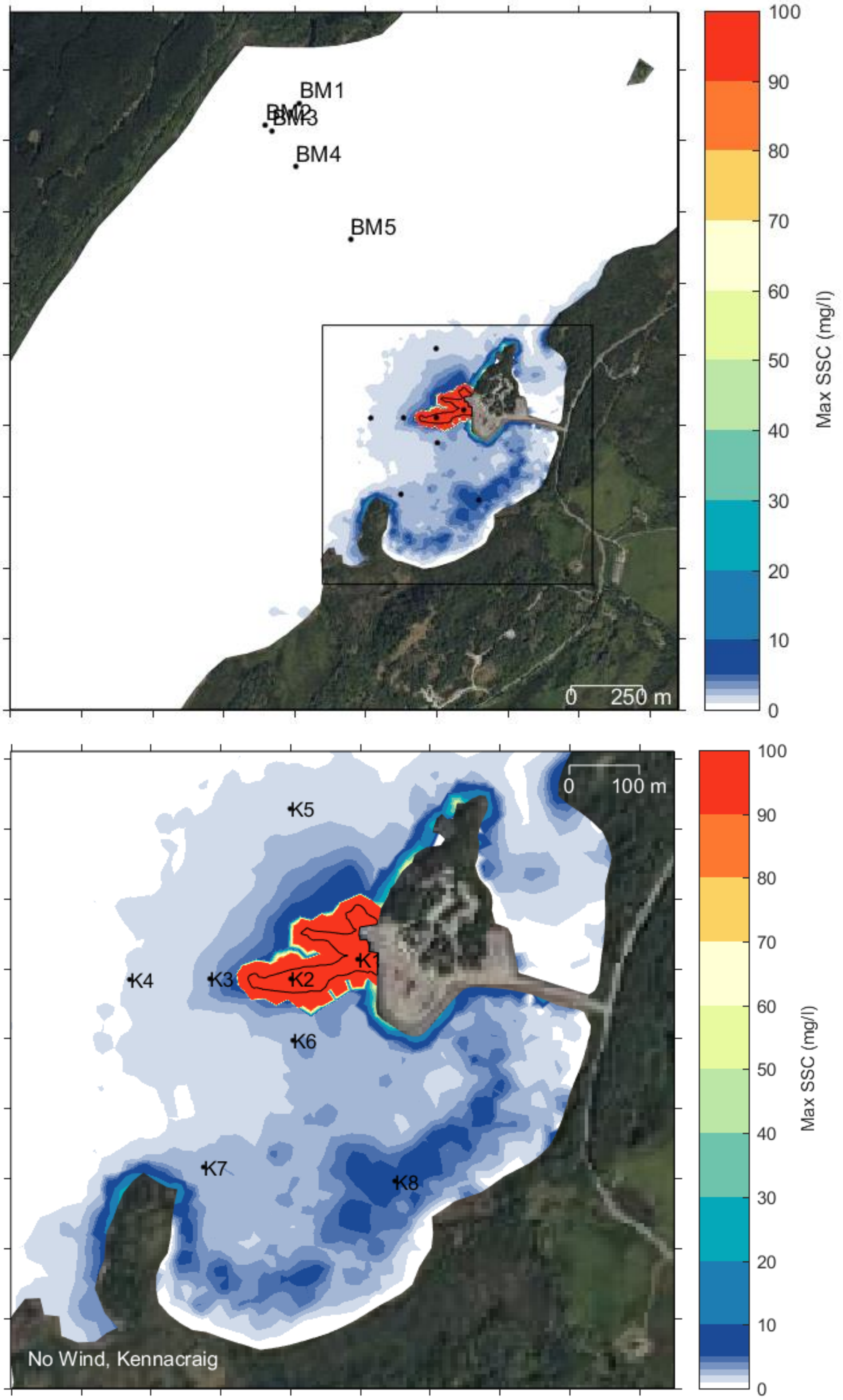

Figure A.1: Modelled maximum SSC at the dredge area for a neap tide with no wind.

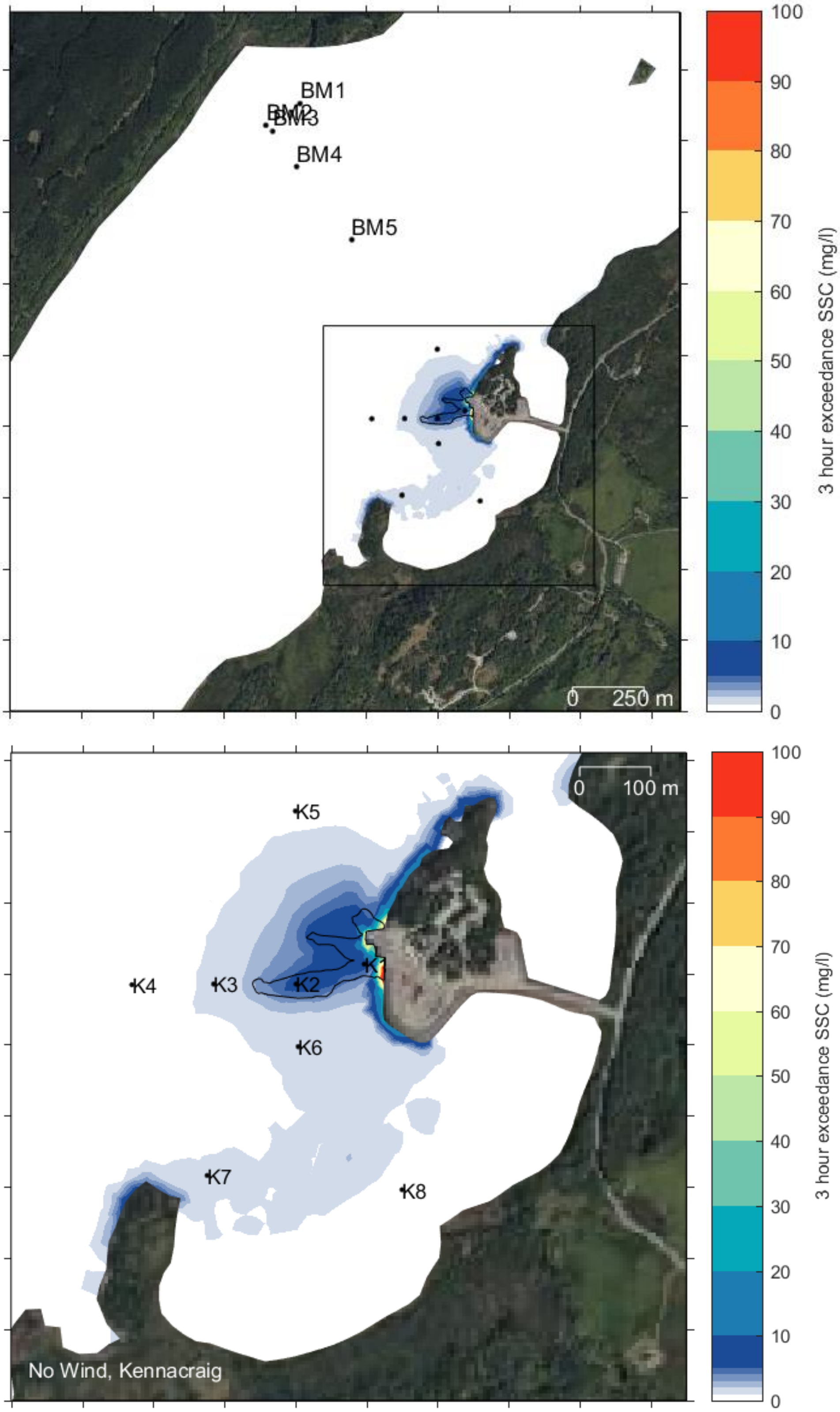

Figure A.2: Modelled 3-hour exceedance SSC at the dredge area for a neap tide with no wind.

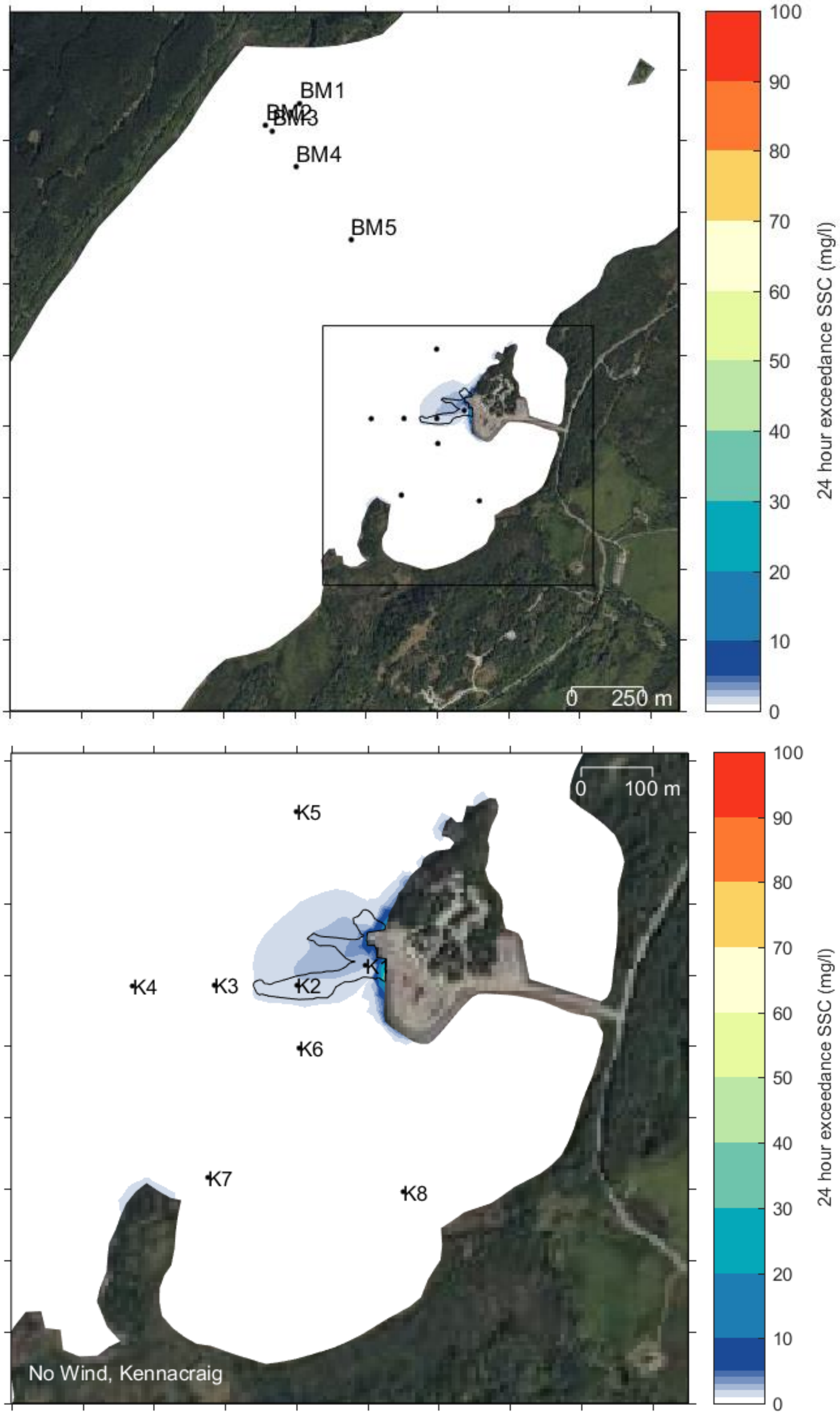

Figure A.3: Modelled 24-hour exceedance SSC at the dredge area for a neap tide with no wind.

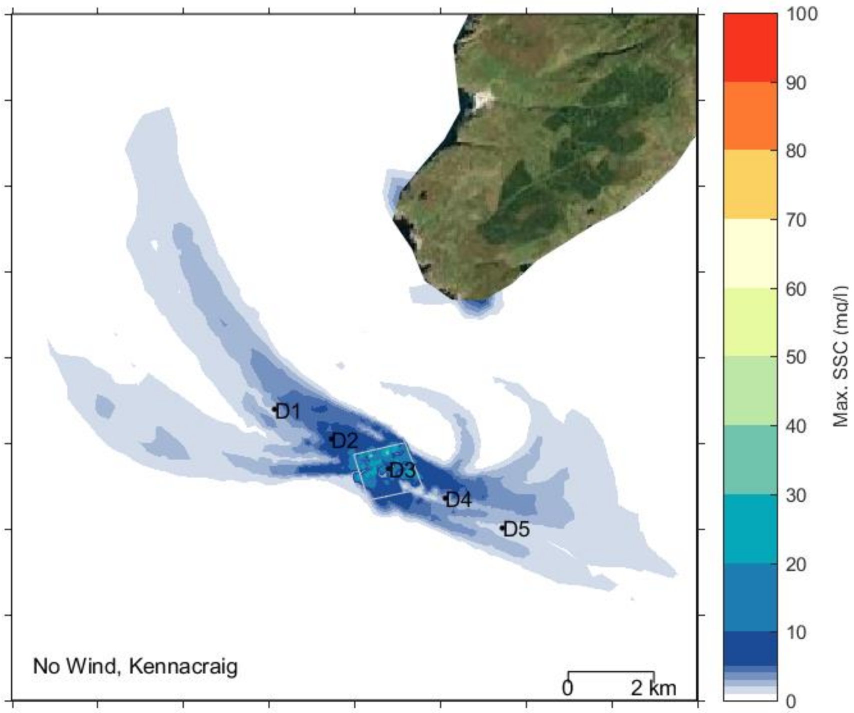

Figure A.4: Modelled maximum SSC at the disposal site for a neap tide with no wind.

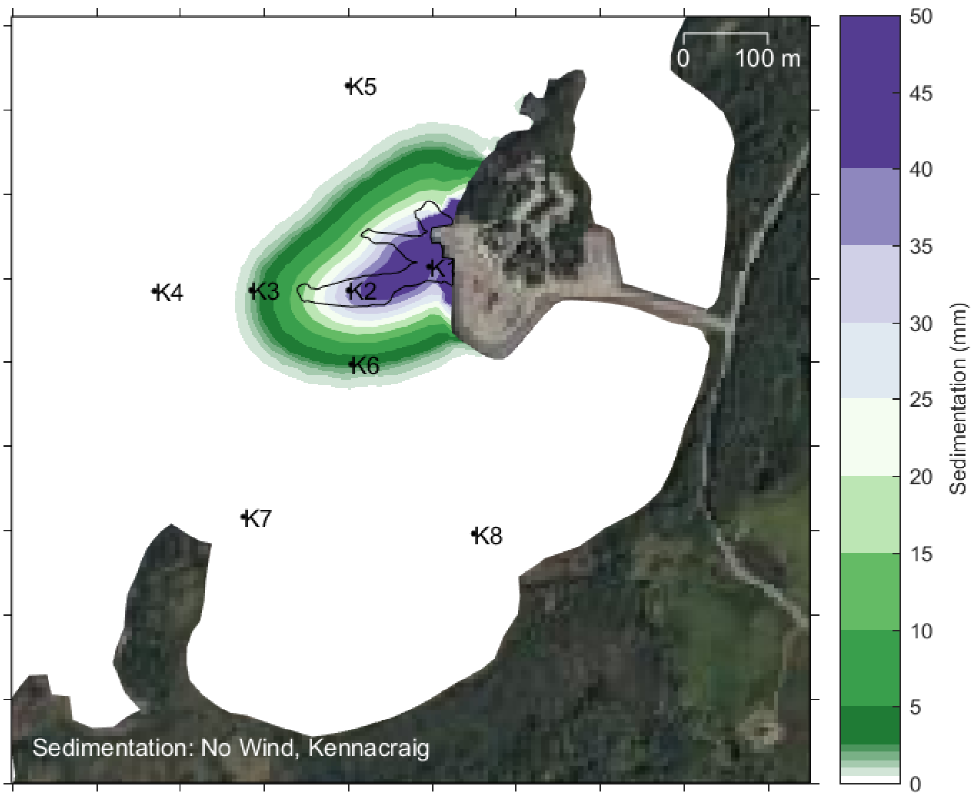

Figure A.5: Modelled sedimentation at the end of the dredging for a neap tide with no wind.

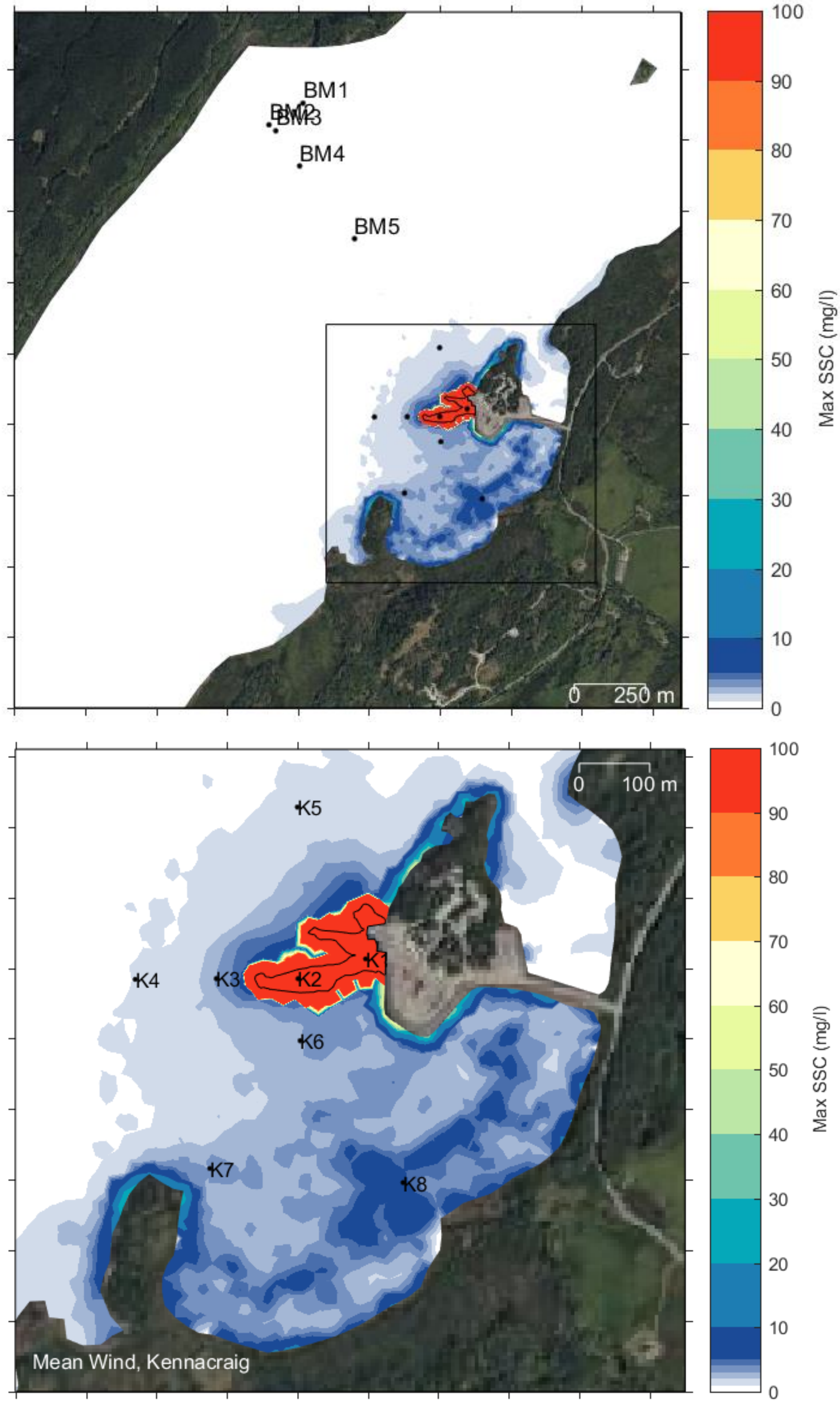

Figure A.6: Modelled maximum SSC at the dredge area for a neap tide with mean winds.

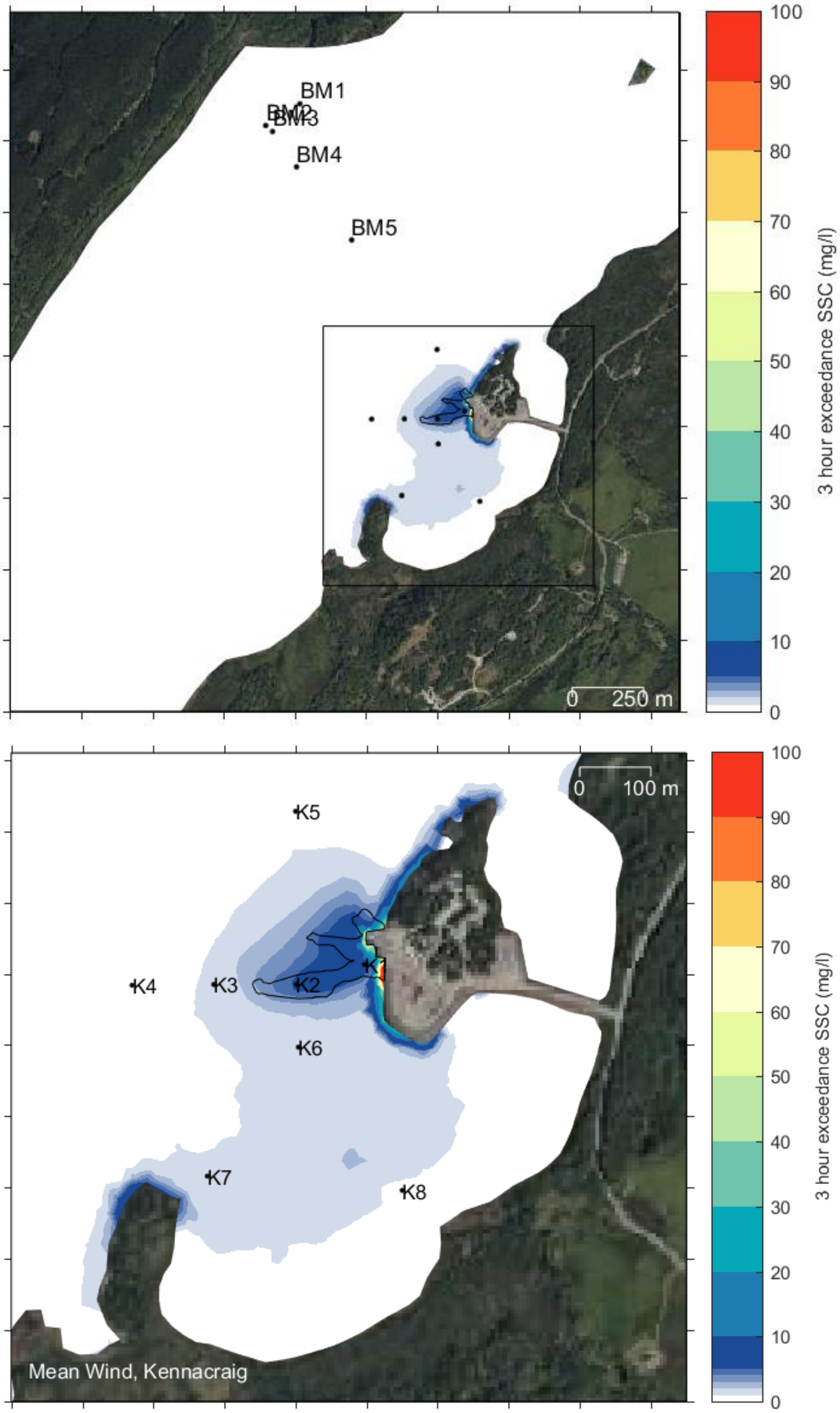

Figure A.7: Modelled 3-hour exceedance SSC at the dredge area for a neap tide with mean winds.

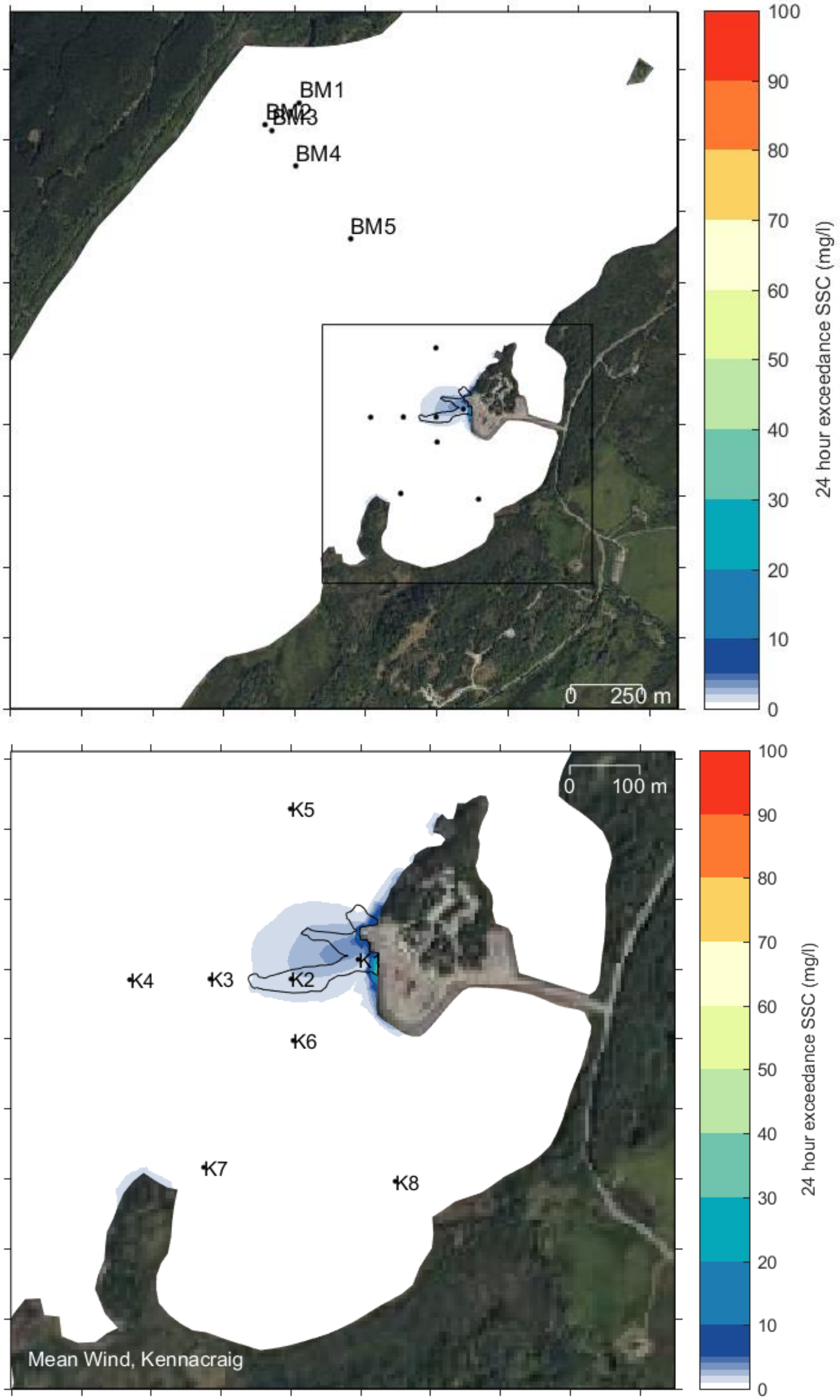

Figure A.8: Modelled 24-hour exceedance SSC at the dredge area for a neap tide with mean winds.

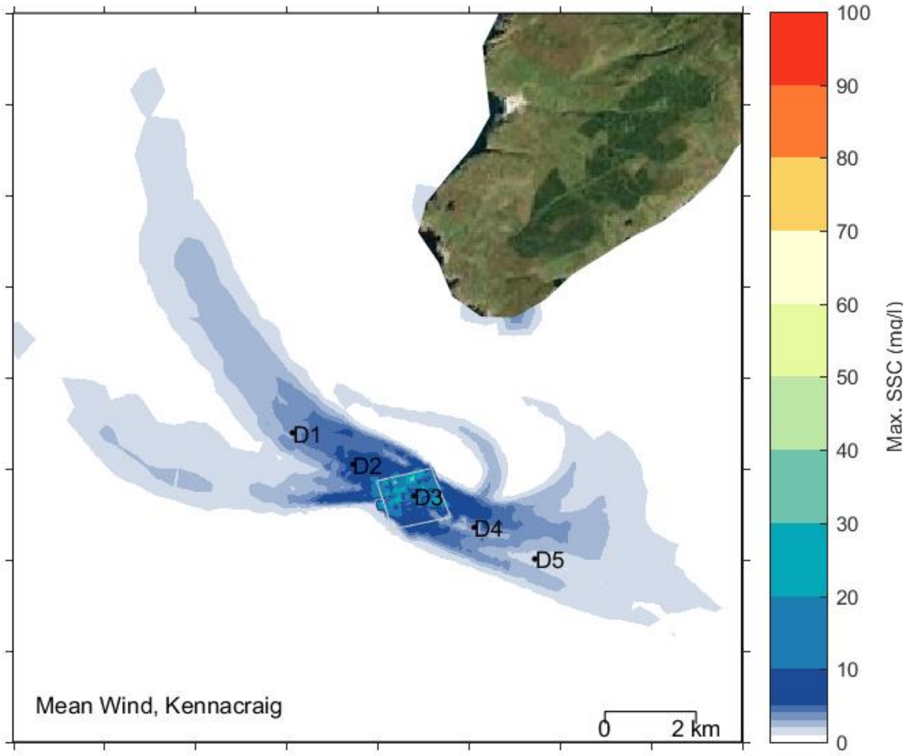

Figure A.9: Modelled maximum SSC at the disposal site for a neap tide with mean winds.

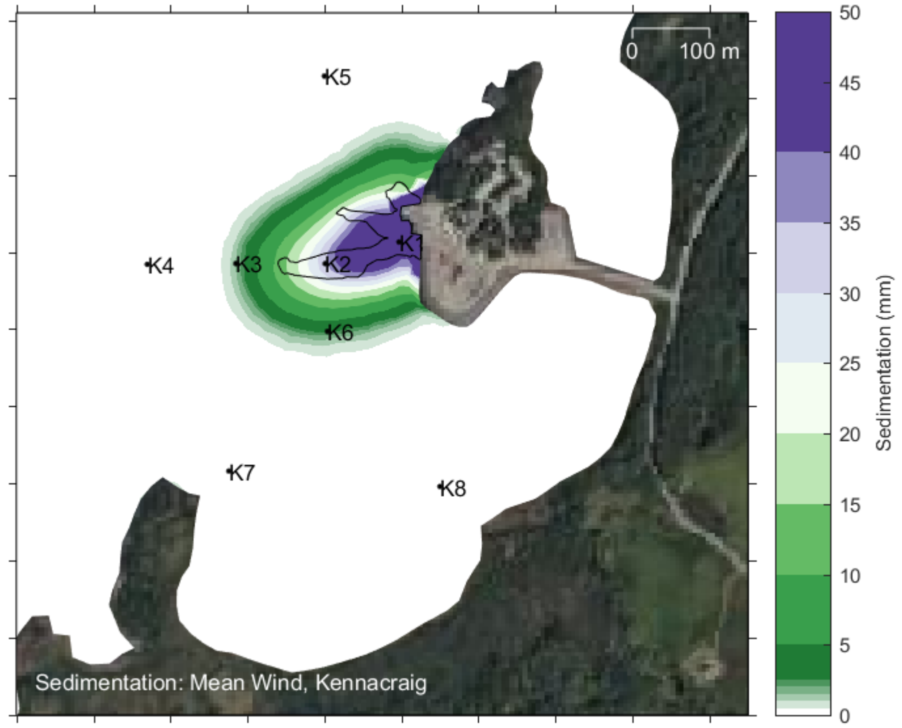

Figure A.10: Modelled sedimentation at the end of the dredging for a neap tide with mean winds.

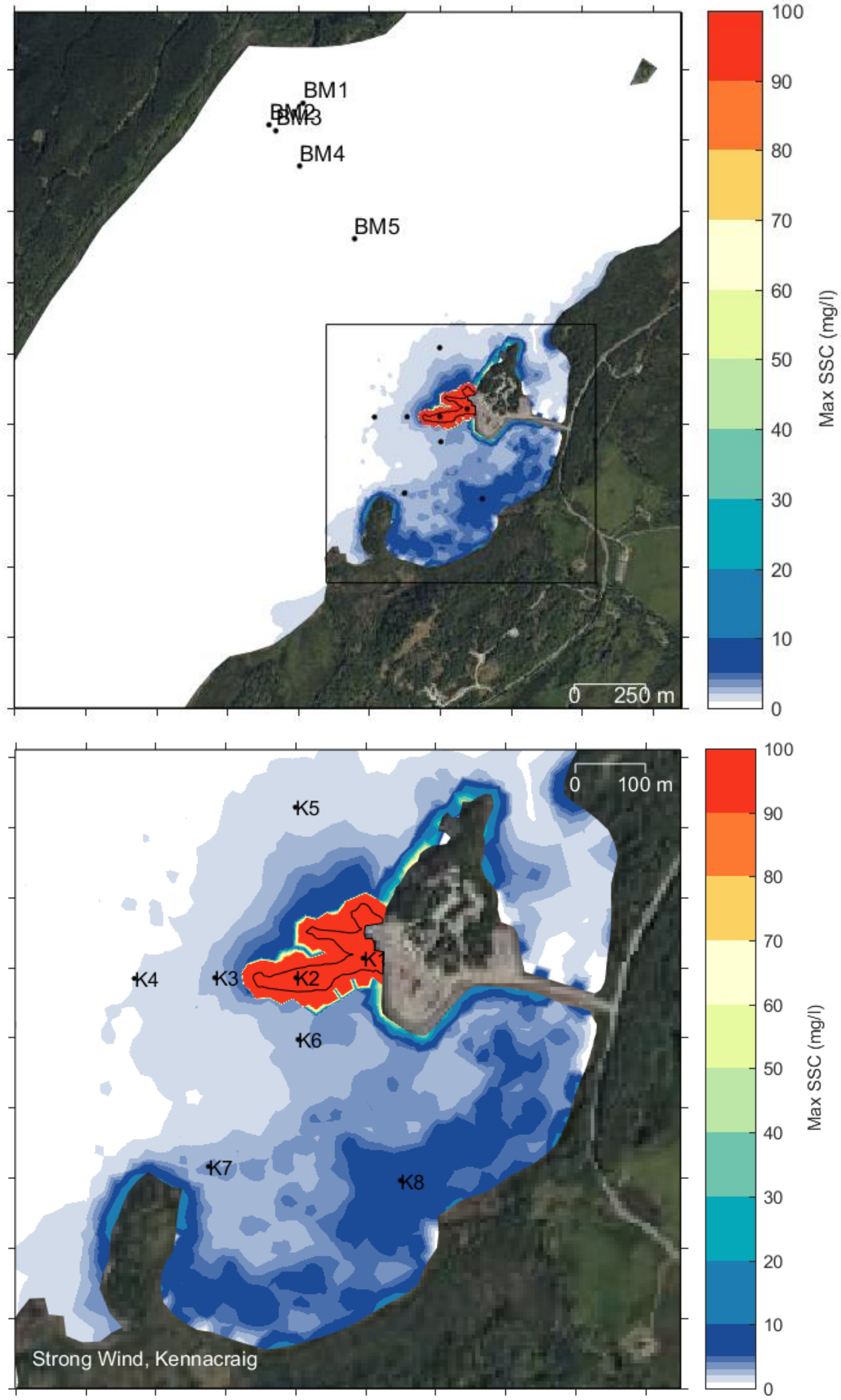

Figure A.11: Modelled maximum SSC at the dredge area for a neap tide with strong winds.

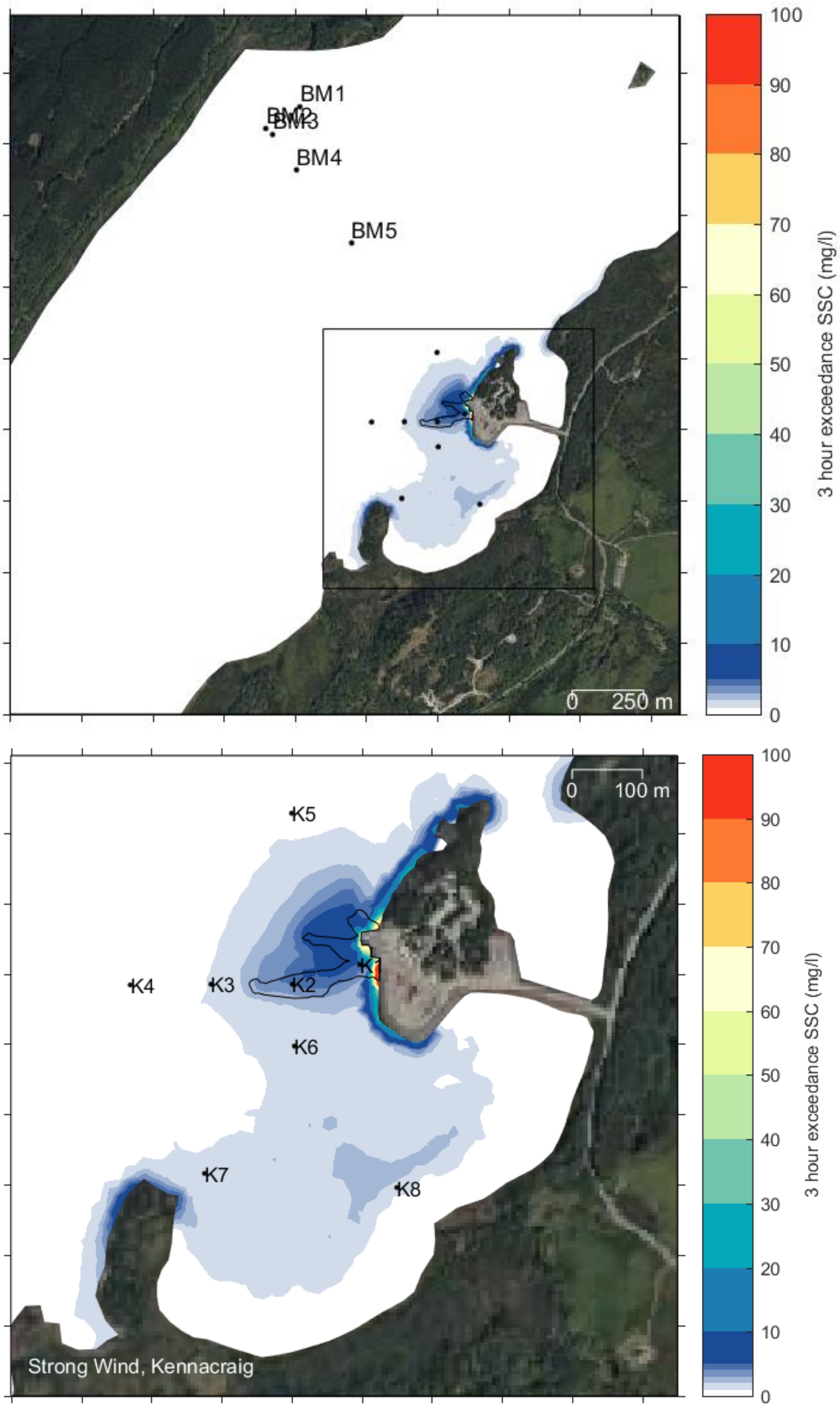

Figure A.12: Modelled 3-hour exceedance SSC at the dredge area for a neap tide with strong winds.

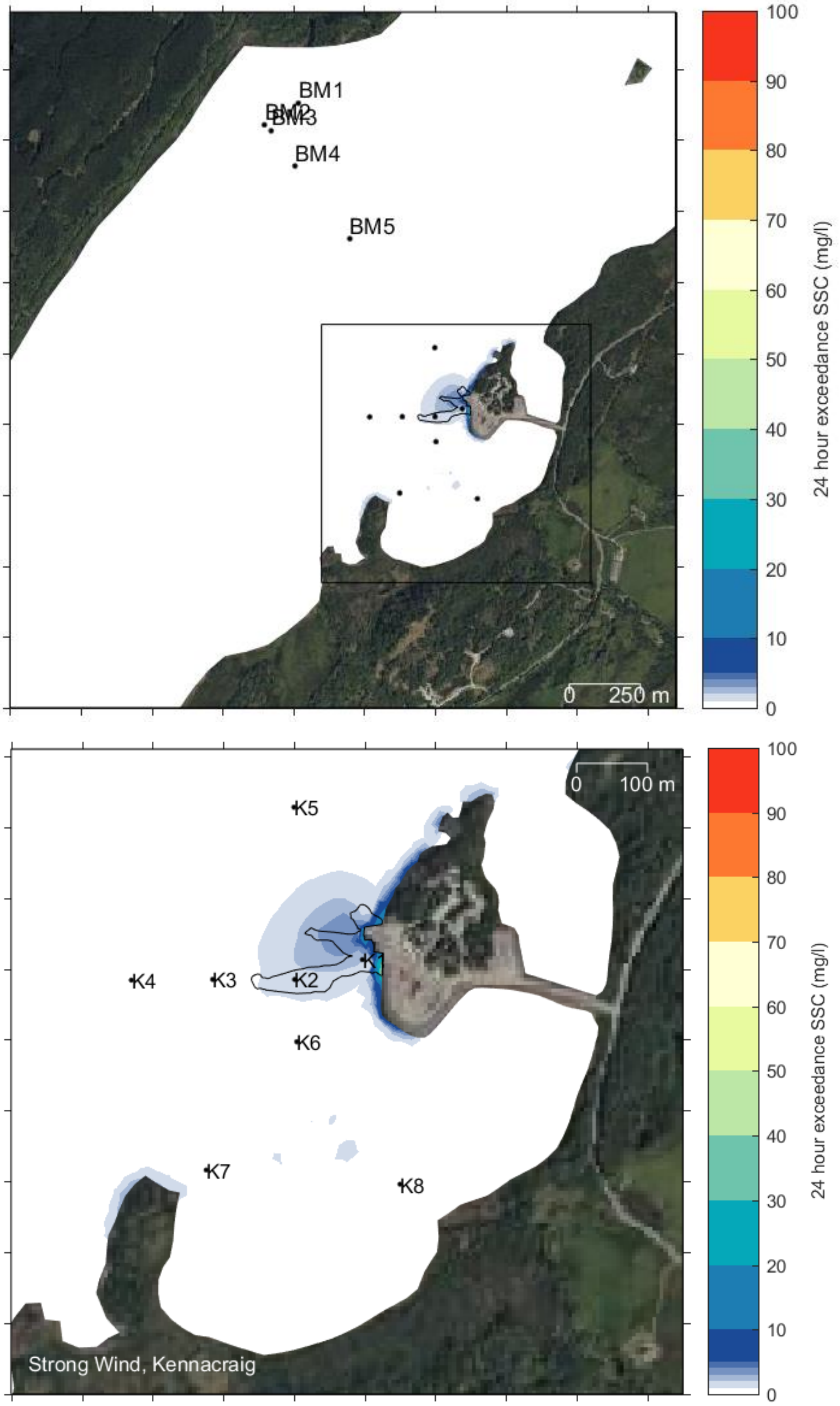

Figure A.13: Modelled 24-hour exceedance SSC at the dredge area for a neap tide with strong winds.

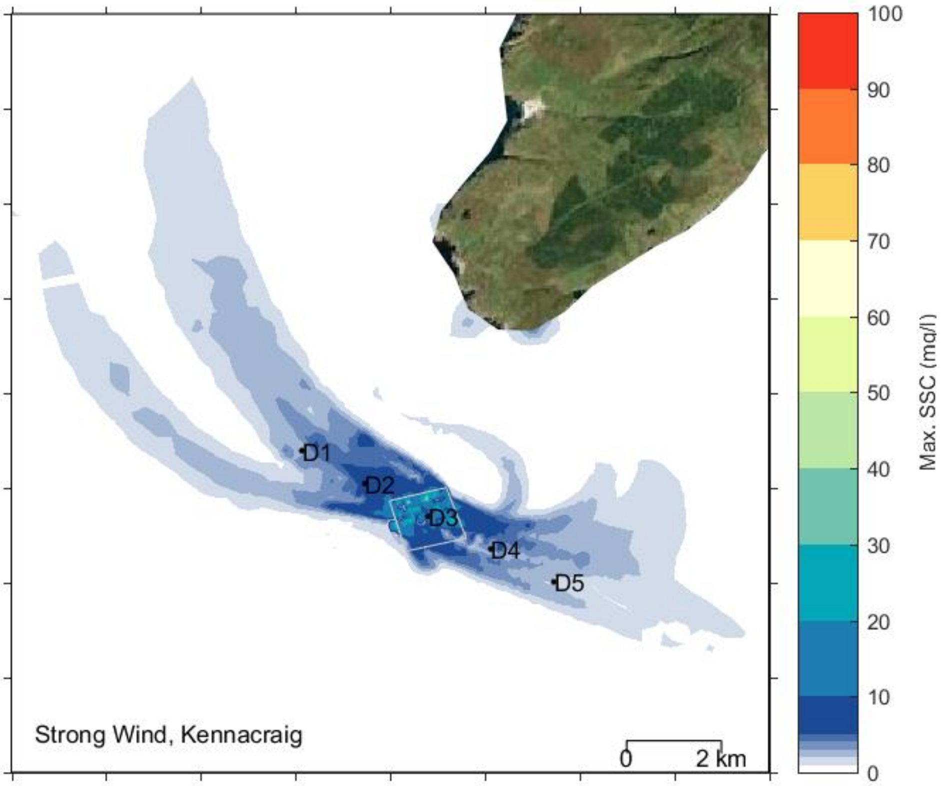

Figure A.14: Modelled maximum SSC at the disposal site for a neap tide with strong winds.

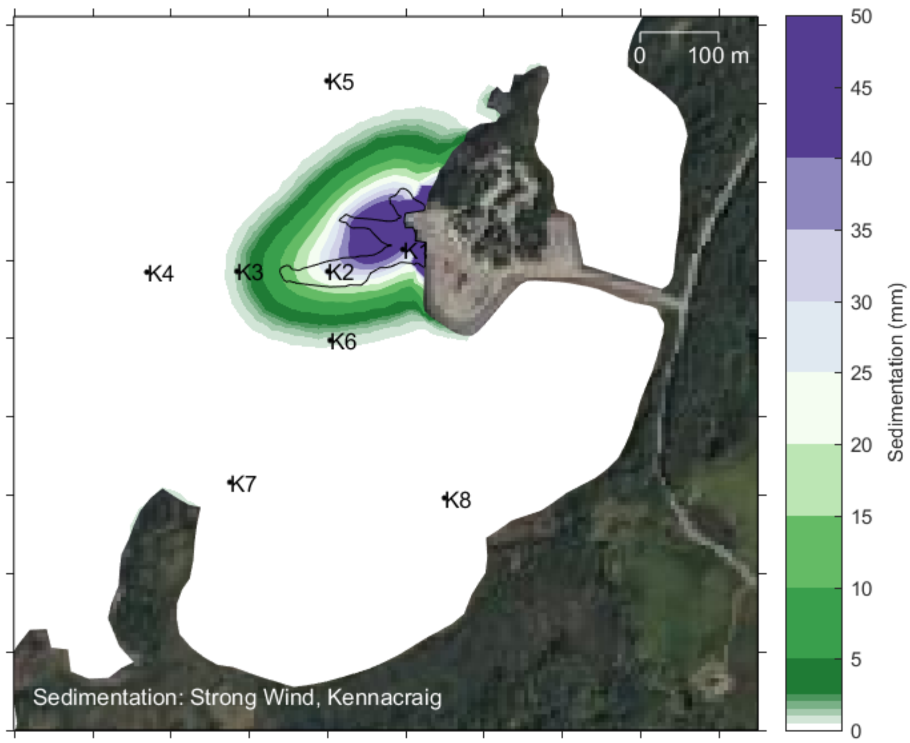

Figure A.15: Modelled sedimentation at the end of the dredging for a neap tide with strong winds.

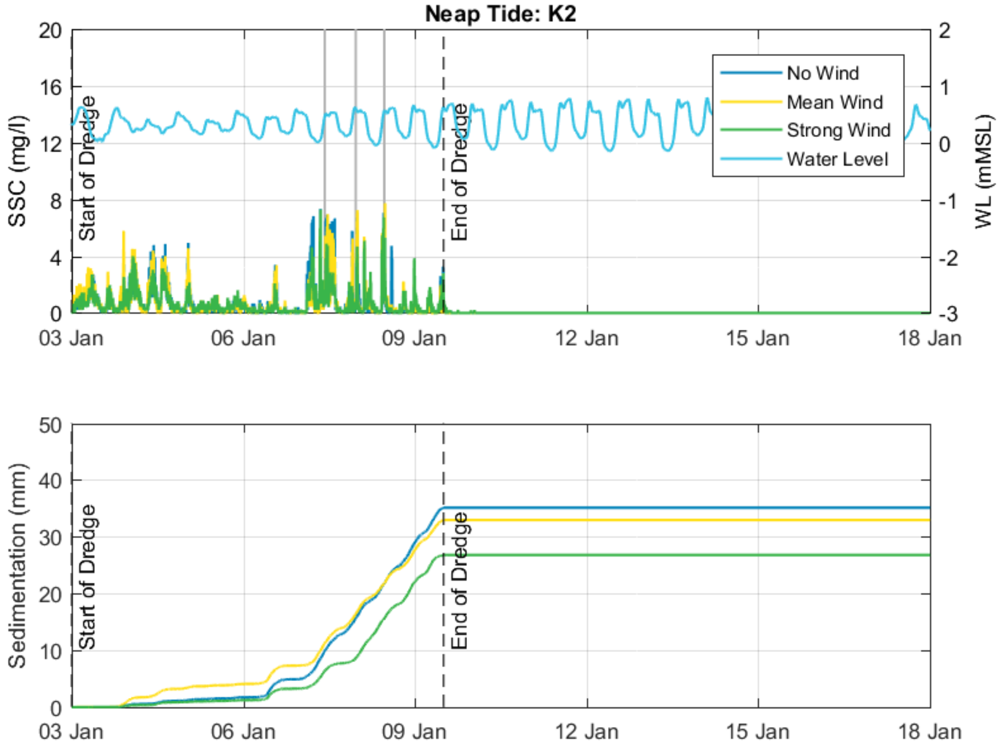

Figure A.16: Modelled SSC (top) and sedimentation at K2 over the 15-day model simulation.

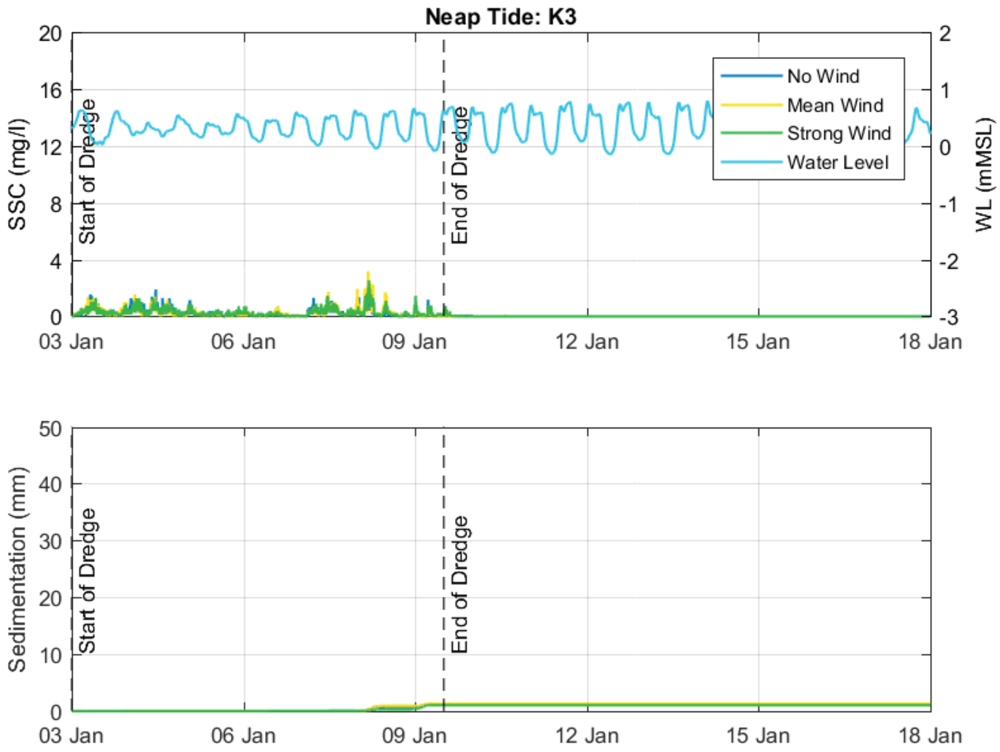

Figure A.17: Modelled SSC (top) and sedimentation at K3 over the 15-day model simulation.

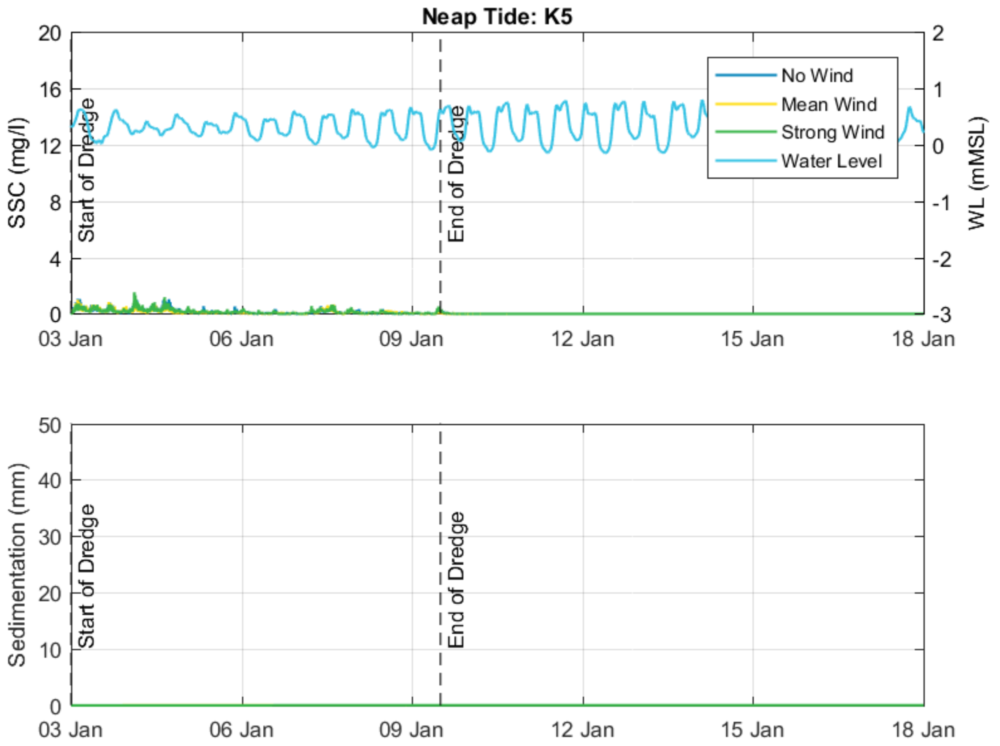

Figure A.18: Modelled SSC (top) and sedimentation at K5 over the 15-day model simulation.

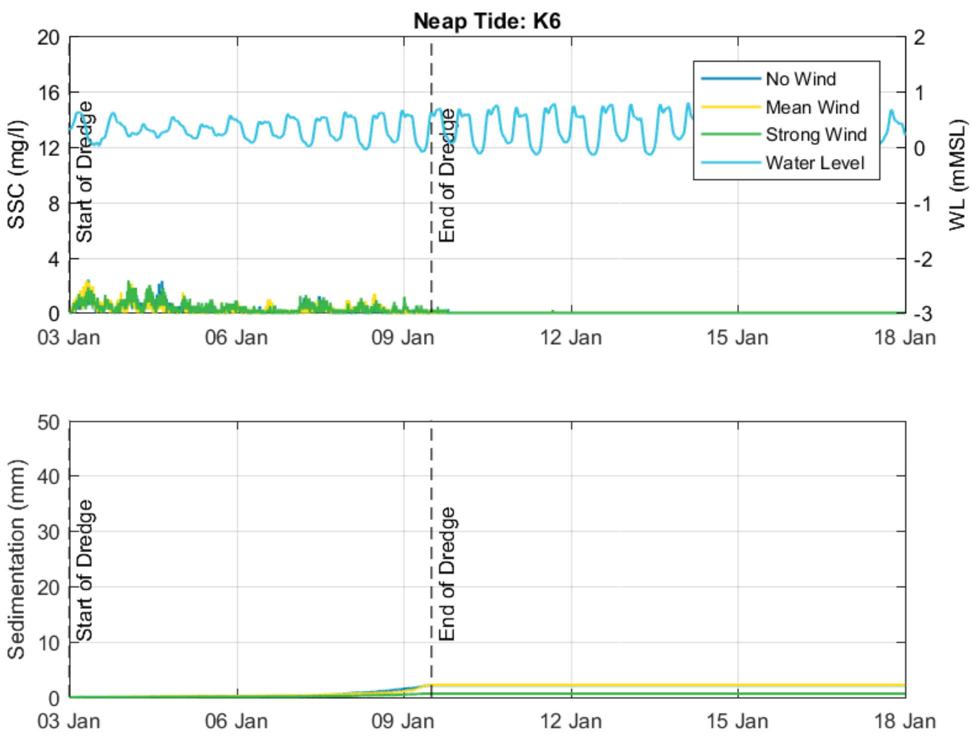

Figure A.19: Modelled SSC (top) and sedimentation at K6 over the 15-day model simulation.

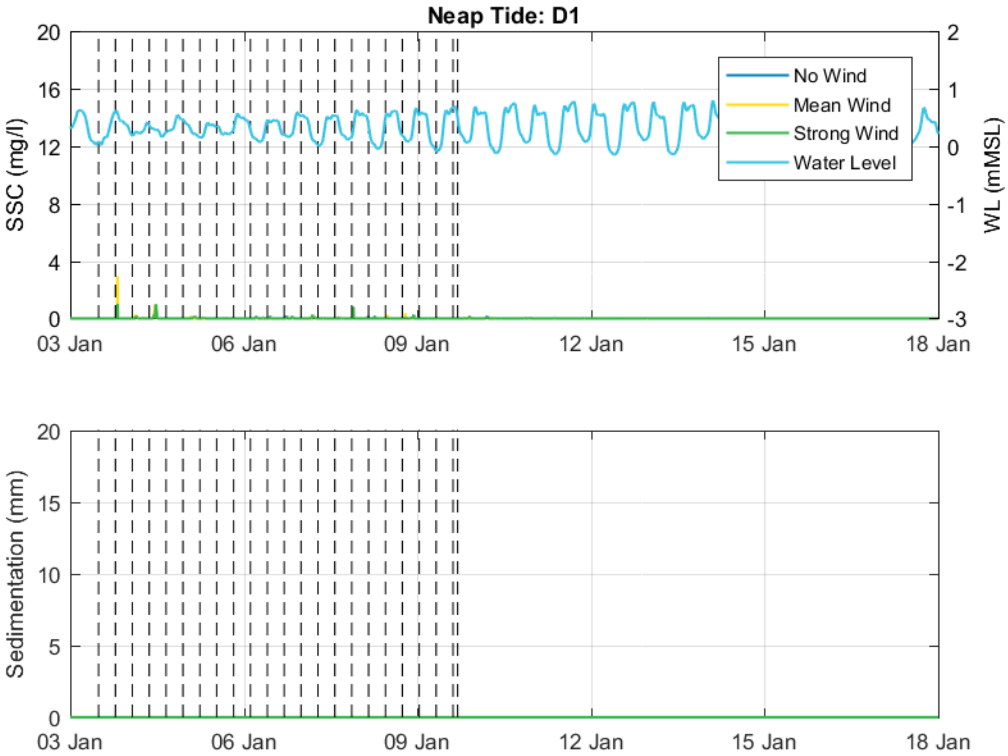

Figure A.20: Modelled SSC (top) and sedimentation at D1 over the 15-day model simulation.

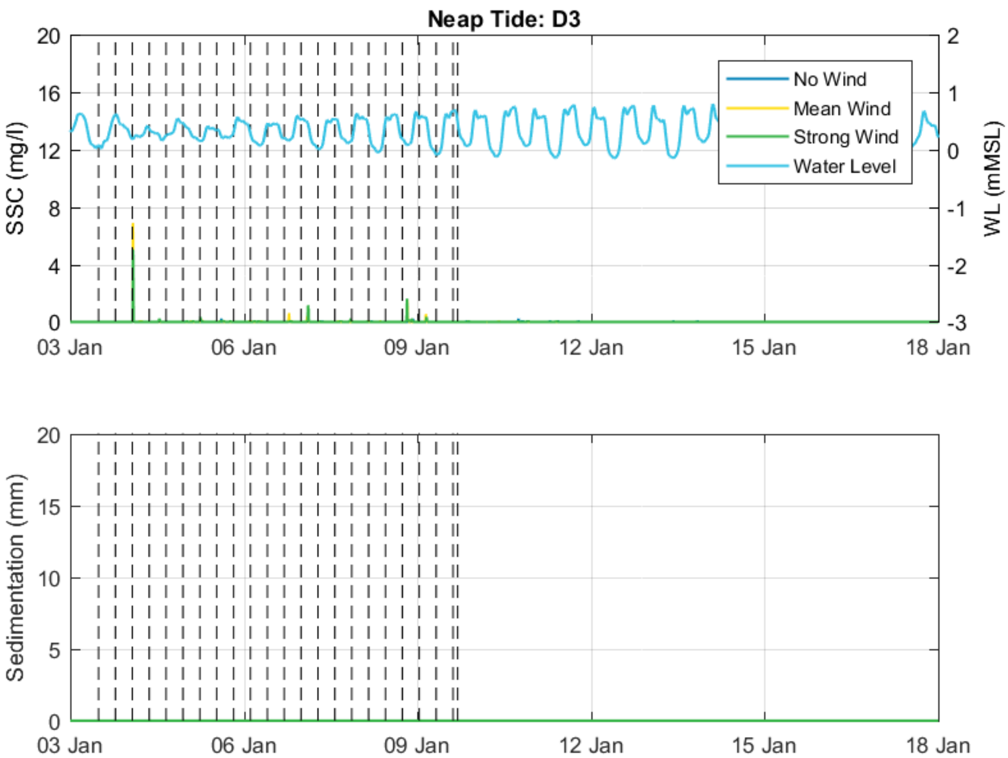

Figure A.21: Modelled SSC (top) and sedimentation at D3 over the 15-day model simulation.

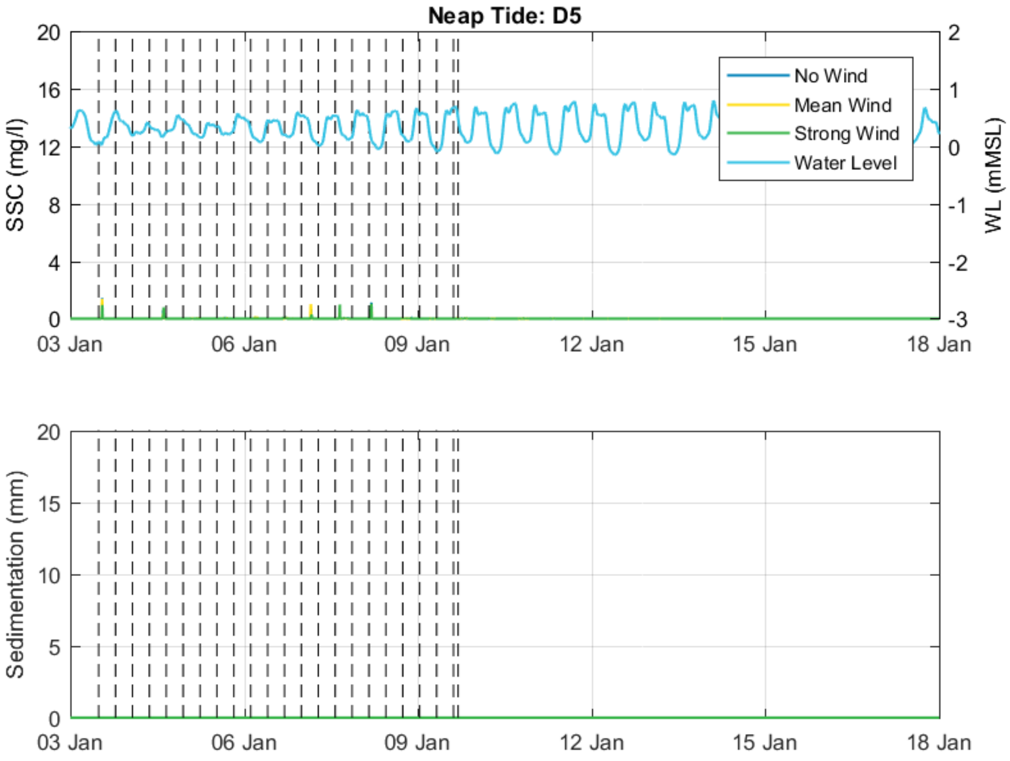

Figure A.22: Modelled SSC (top) and sedimentation at D5 over the 15-day model simulation.

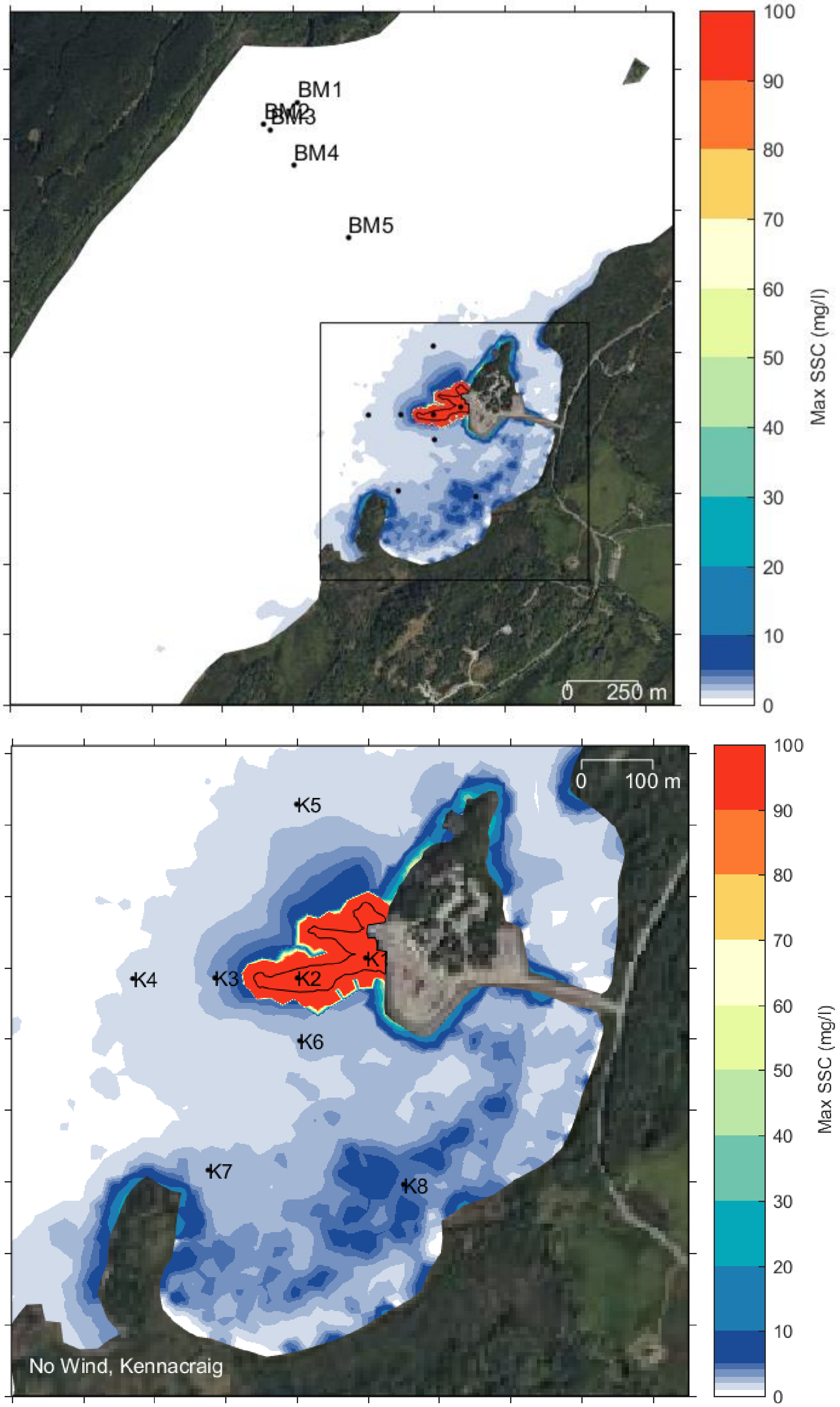

Figure A.23: Modelled maximum SSC at the dredge area for a spring tide with no wind.

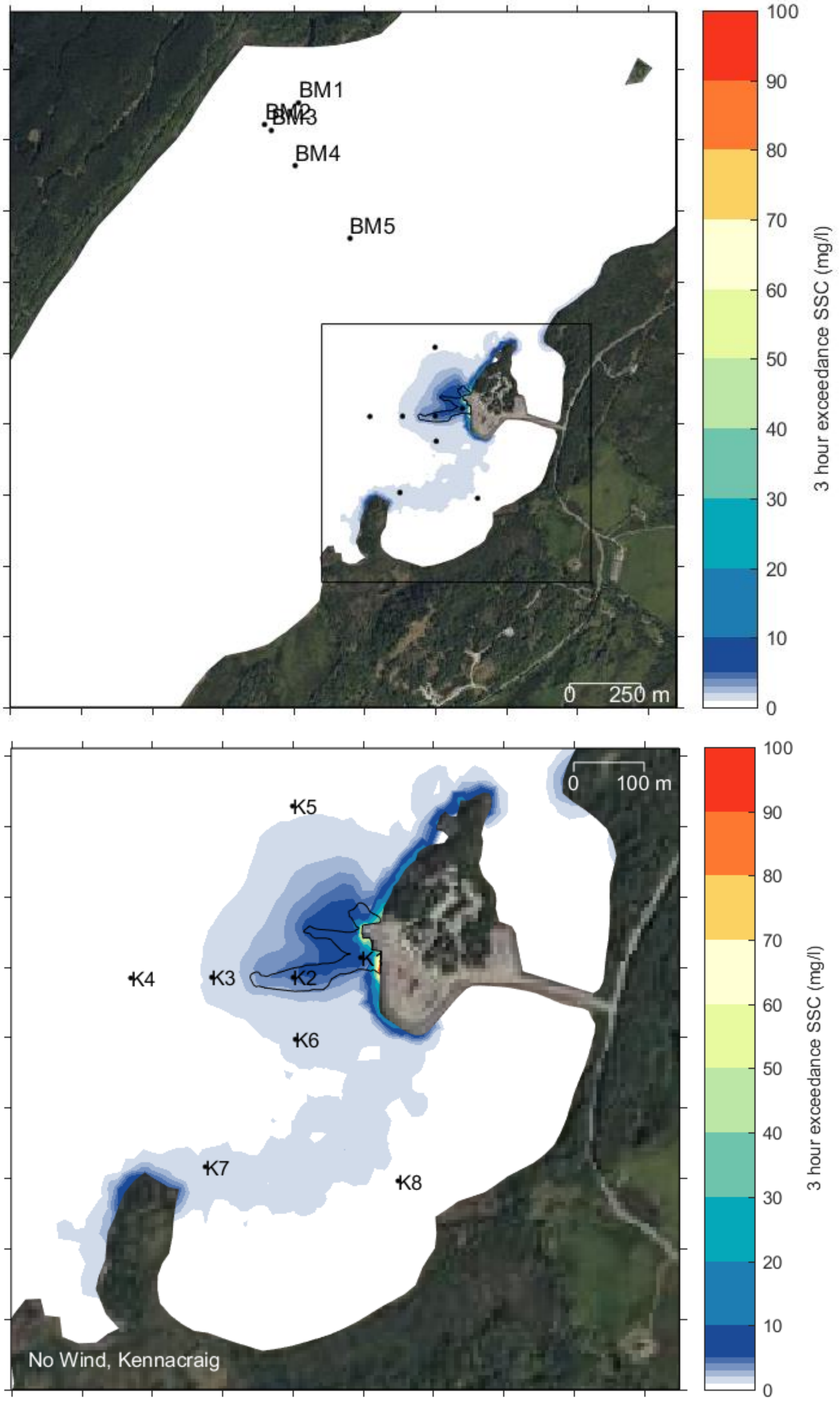

Figure A.24: Modelled 3-hour exceedance SSC at the dredge area for a spring tide with no wind.

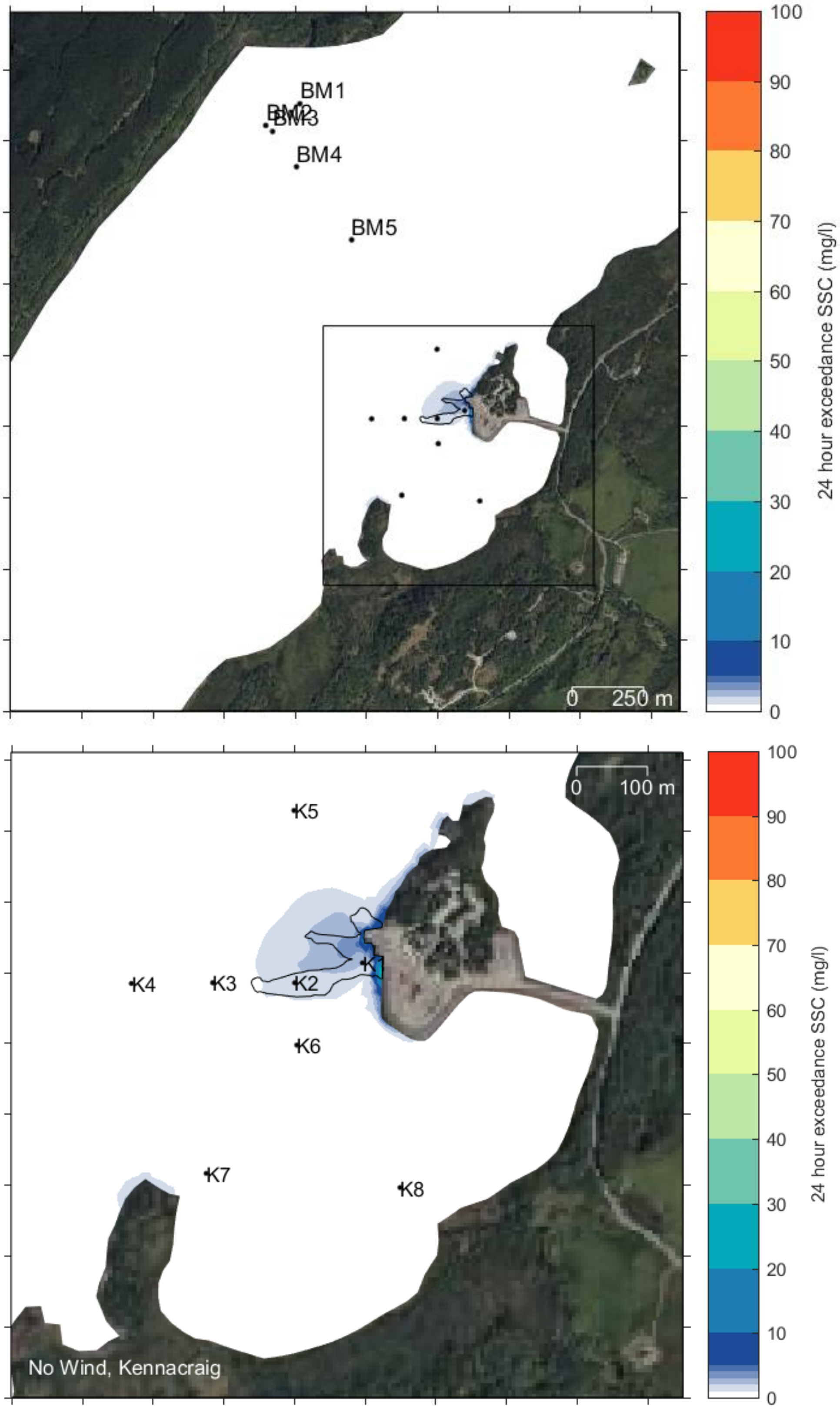

Figure A.25: Modelled 24-hour exceedance SSC at the dredge area for a spring tide with no wind.

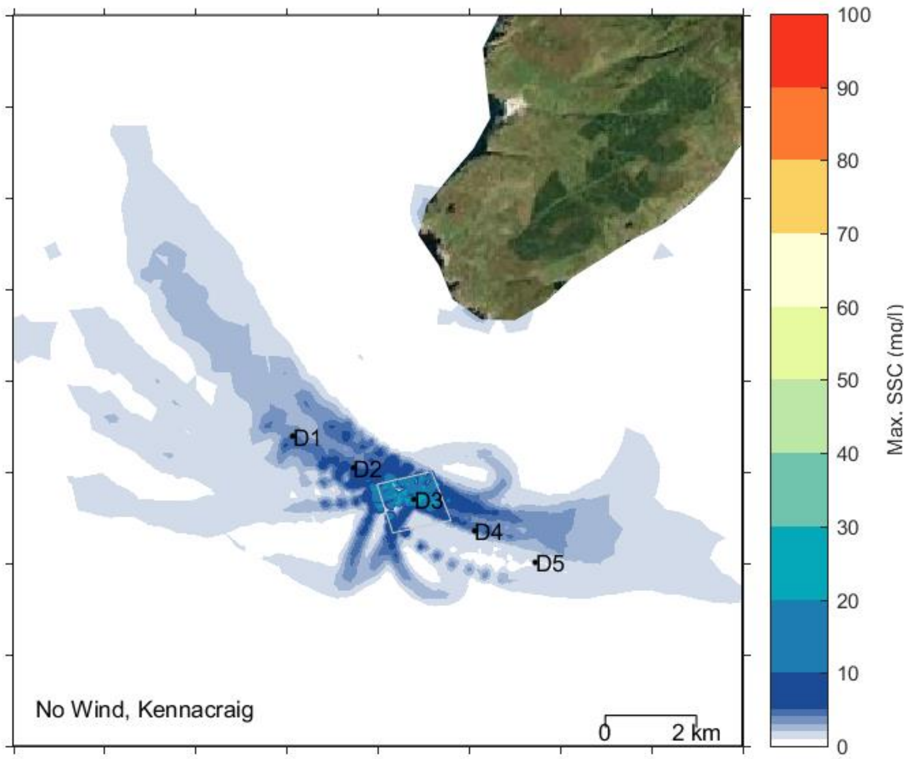

Figure A.26: Modelled maximum SSC at the disposal site for a spring tide with no wind.

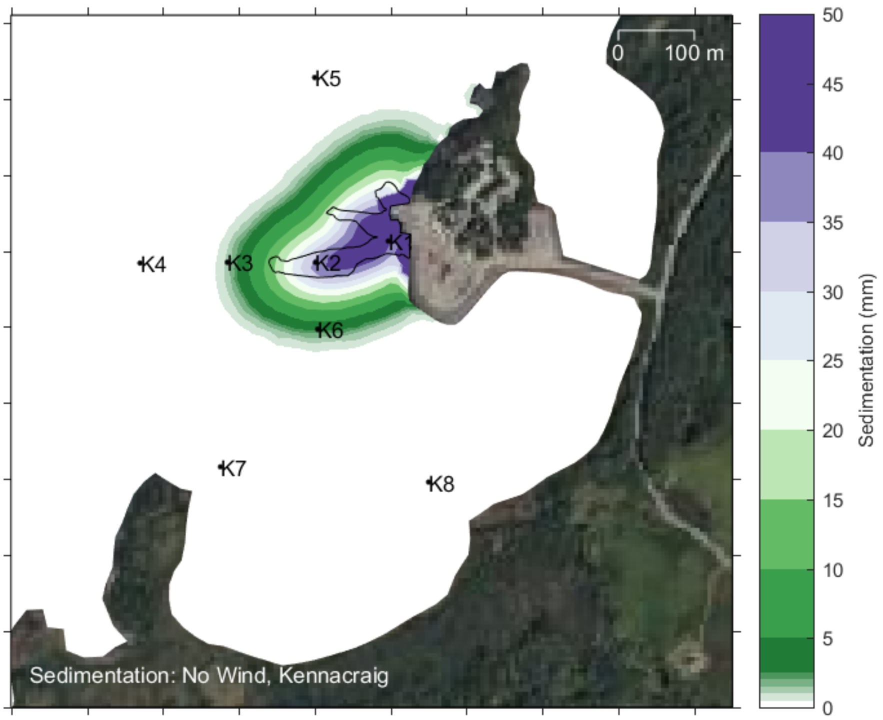

Figure A.27: Modelled sedimentation at the end of the dredging for a spring tide with no wind.

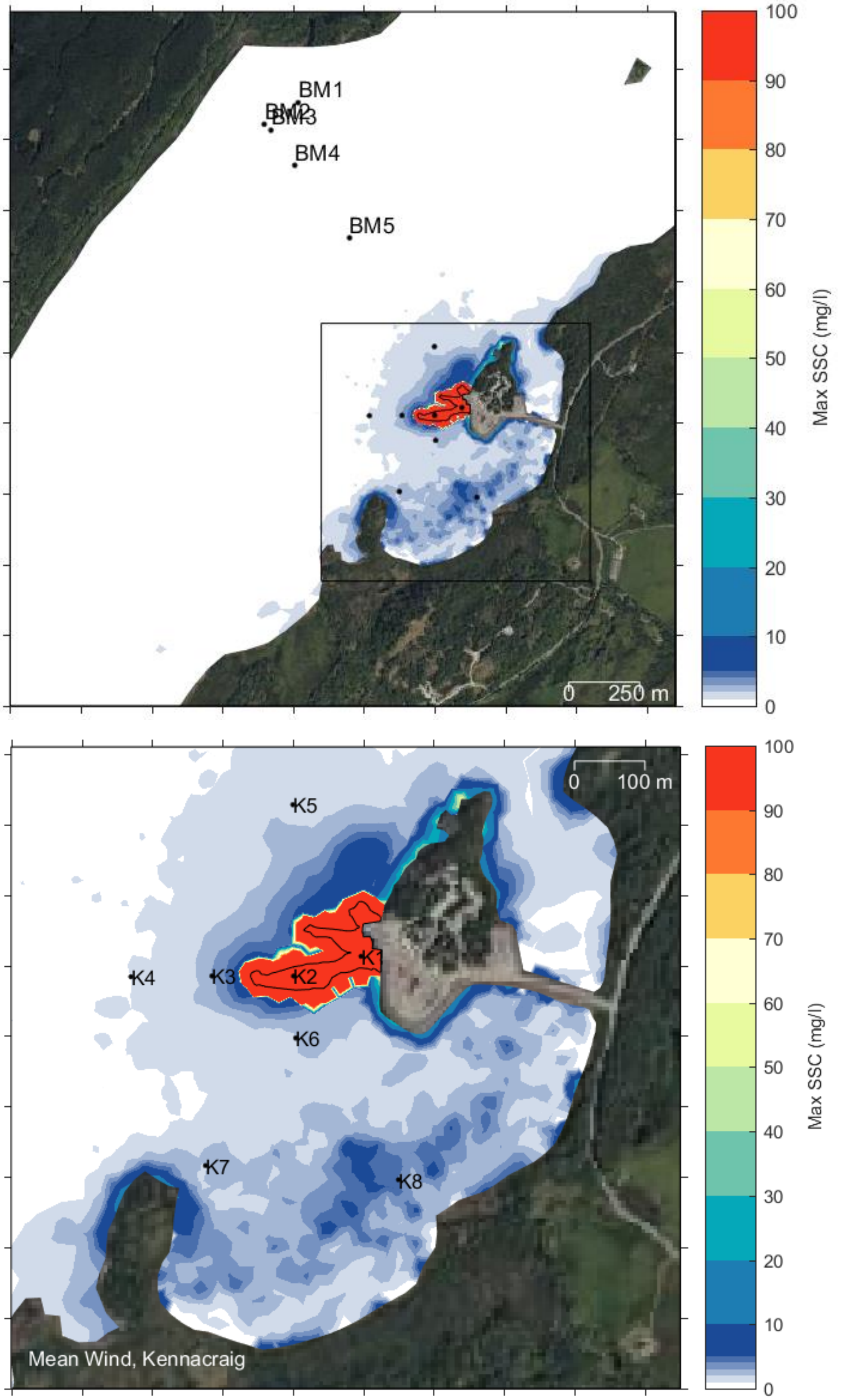

Figure A.28: Modelled maximum SSC at the dredge area for a spring tide with mean winds.

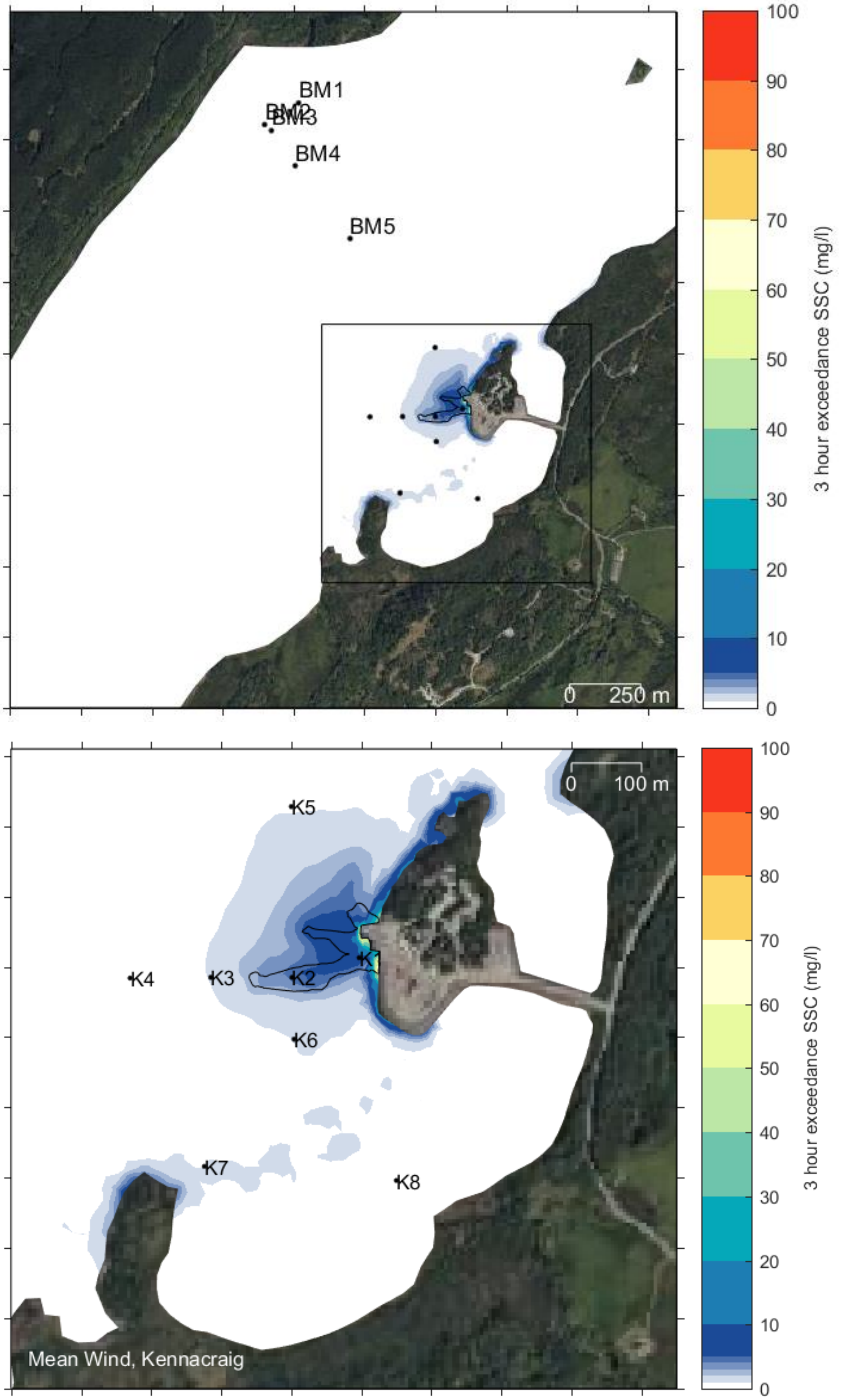

Figure A.29: Modelled 3-hour exceedance SSC at the dredge area for a spring tide with mean winds.

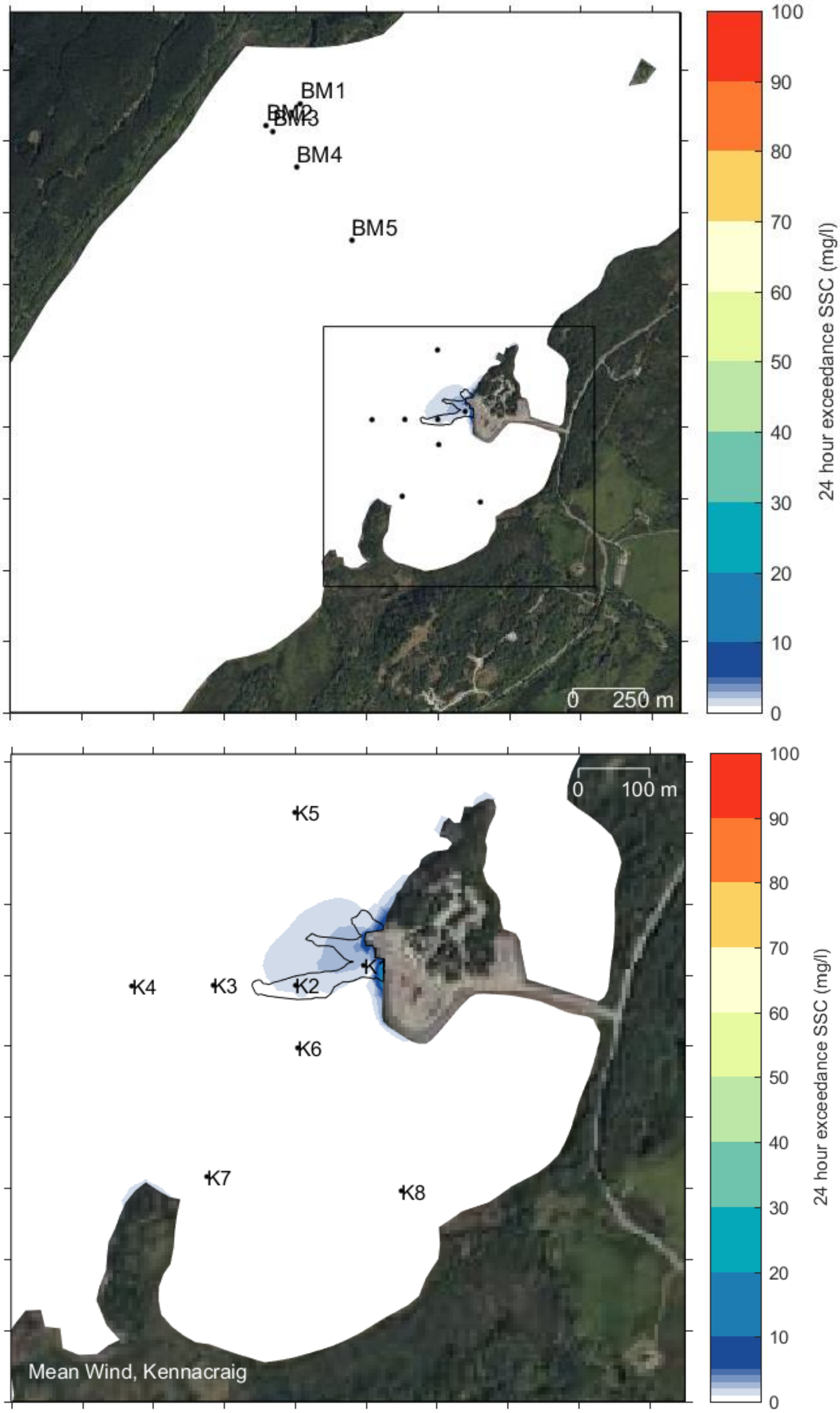

Figure A.30: Modelled 24-hour exceedance SSC at the dredge area for a spring tide with mean winds.

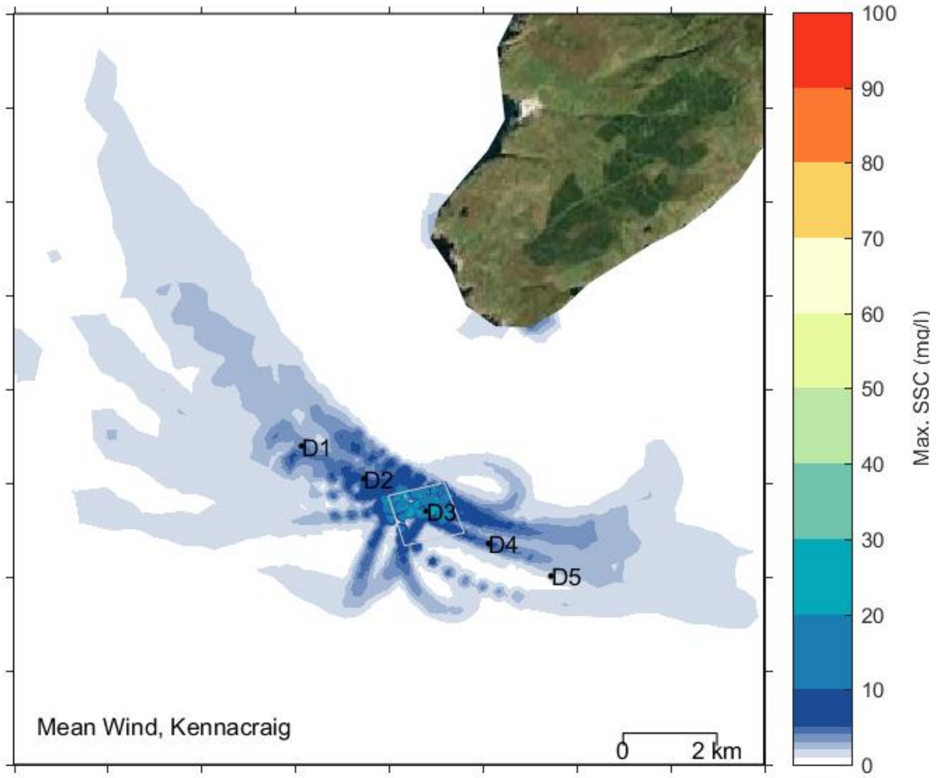

Figure A.31: Modelled maximum SSC at the disposal site for a spring tide with mean winds.

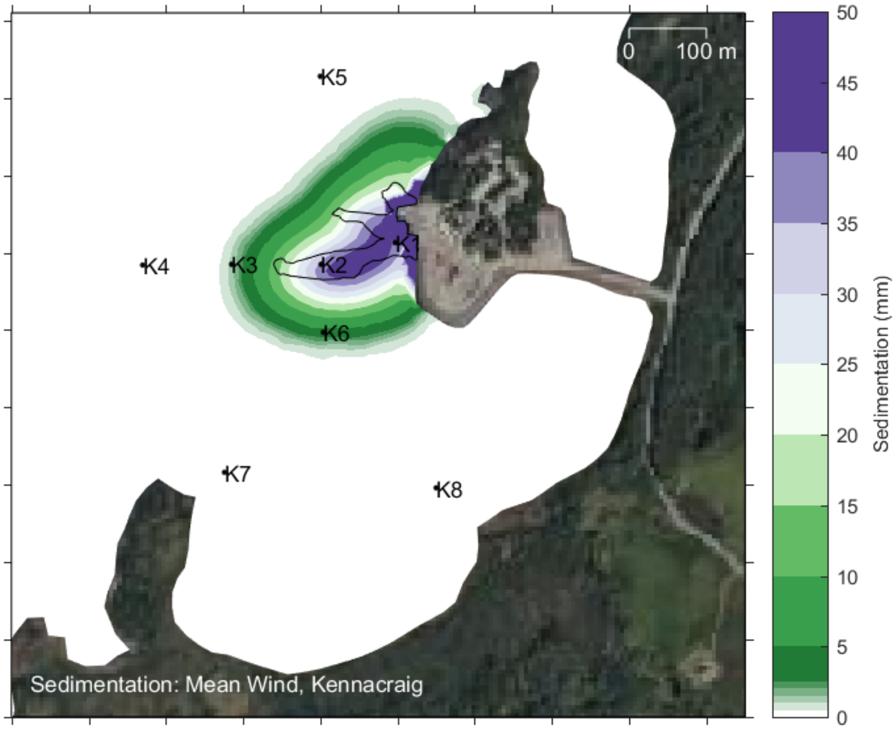

Figure A.32: Modelled sedimentation at the end of the dredging for a spring tide with mean winds.

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