Deltares

Memo

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Subject
Sediment dispersion study dredging and beach nourishment West Beach in Adelaide, Australia - Quick AREM simulations for optimal placement WQ monitoring stations

1 Introduction

The Department of Environment and Water (DEW) South Australia is investigating a plan to execute a 500,000 m^3 beach nourishment at Adelaide West Beach. The sediment can be dredged at a location about 20 km south near Port Stanvac, see Figure 1.1 for the dredge location under consideration and both nourishment sites. DEW asked Deltares to perform a quick modelling exercise of the sediment dispersion round the dredge location and placement location by using the existing AREM (Adelaide Receiving Environment Model) model.

The purpose of the modelling is to help DEW selecting optimal locations for placement of water quality monitoring instruments for background data collection and dredging monitoring. DEW only needs the patterns/gradients, not actual numbers, using the data already in the model.

Figure 1.1 Beach nourishment West Beach indicated with a yellow line and possible dredge location near Port Stanvac indicated by a red outline

2 Model set up

2.1 AREM model description

For the coastal waters of Adelaide, Deltares has developed the Adelaide Receiving Environment Model (AREM) model for SA Water (Van Gils et al. 2017). In 2019 Deltares updated the silt model of AREM with the two-layer buffer sediment bed approach by Van Kessel et al. (2011). The silt two-layer buffer model of AREM is used for the simulations of plume dispersion for dredging at Port Stanvac and nourishment of West Beach. The model is used as is with boundary conditions, grid, settings and bathymetry as now incorporated, no further re-calibration is carried out. The AREM model has been compared with observed hydrodynamics (water levels, velocities, salinity and water temperature) nearby Adelaide and can reproduce these reasonably well. The AREM model has not yet been fully calibrated and validated for fine sediment transport. Therefore, fine sediment results have to be interpreted with care. Hence, AREM is used in a comparative manner – comparing model results with and without dredging to have a sense of the excess suspended sediment concentrations (SSC) caused by dredging and nourishment.

The different components of the AREM model and their interactions are given in Figure 2.1. The spatial extent of the AREM model is shown in Figure 2.2. While developing the AREM model, simulations have been carried out for the year 2011. Transport of fine sediments is modelled by the Delft3D WAQ model using hydrodynamic forcing from the 3D flow model with waves. As interactions of sediment transport on hydrodynamics are expected to be negligible Delft3D WAQ is used off-line to speed up calculation times. The high resolution local Delft3D flow model employs 20 equidistant layers in the vertical and the Delft3D WAQ model uses 5 equidistant layers in the vertical. Three different sediment classes are used in AREM and the sediment settings are summarized in Table 2.1. AREM was run for a quasi-historical time series spanning 1940-2018 with an approximate time line of sediment loads from rivers, STPs and Penrice. For the dredge plume simulations, the 2018 situation is used as sediment spin-up in the water column and in the bed. This 2018 situation is modelled twice – once with and once without additional sediment sources from dredging and nourishing and the difference in SSC (i.e. the excess SSC) is shown as dredge plume.

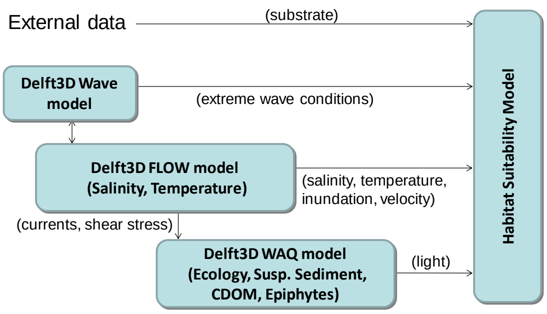

Figure 2.1 Overall set-up of the Adelaide Receiving Environment Model

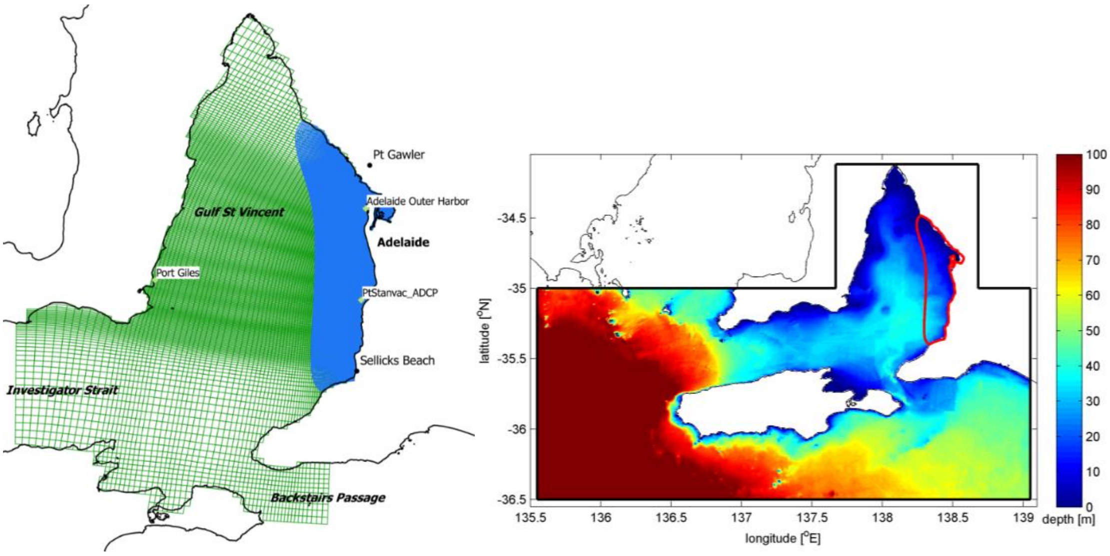

Figure 2.2 Image left: High resolution local flow model grid (blue) and overall model grid (green); image right: Region covered by the Extended Wave Model (outlined in black) and the detail model (outlined in red).

Table 2.1 Overview of AREM sediment input settings for overall and detail model domain

Item[1]	Overall model	Detail model
Wave driven currents	Not included	Included
Settling velocities (w_s)	1, 21.6, 86.4 m/d for IM1/2/3	1, 21.6, 86.4 m/d for IM1/2/3
Fraction of settling flux reaching buffer layer (α)	0.1 (-)	0.1 (-)
Buffer layer porosity	0.4 (-)	0.4 (-)
Buffer layer thickness	0.05 m	0.05 m
Critical shear stress for resuspension	Spatially variable between 1-10 Pa as in existing AREM for fluff and buffer layers (	Homogeneous, 0.2 Pa for fluff layer, 2.0 Pa for buffer layer
Erodibility of fluff layer (M_1)	2.0 (d^{-1})	0.2 (d^{-1})
Erodibility of buffer layer (M_2)	3.5 10^{-6} (-)	3.5 10^{-8} (-)

1 Where relevant the symbol in van Kessel et al. (2011) is mentioned.

2.2 Sediment sources dredging and beach nourishment

In the AREM model two extra sediment source fluxes are applied, one to incorporate the influx of fine sediment while dredging and another to incorporate the spill of fine sediment from the nourished sediment on the beach. It is assumed that a 2000 m^3 TSHD (Trailing Suction Hopper Dredger) will be used for dredging 500,000 m^3 sediment with a project duration of 70 days. The sediment will be placed on the beach via pipelines. The assumed dredge cycle time is 5 hours from loading near Port Stanvac, sailing to West Beach, unloading via a pipeline towards the beach, sailing back to Port Stanvac and start loading again. While dredging with a TSHD, the main source of fine sediment is coming from the overflow (a shaft in the hopper used to release excess process water) and a smaller amount of fine sediment can be stirred up by the draghead. During unloading the sediment via a pipeline on the beach some of the fines will flow back to the sea. The approach of Becker et al. (2015) is used in combination with the analytical formulas for a near field overflow dredge plume in De Wit et al. (2014) to derive the sediment source fluxes. In the AREM model the sediment spill starts august 1st of hydrodynamic year 2011 (sediment year 2018) and ends 70 days later. Because of variations in hydrodynamics over the year and variations over different years resulting plume contours would be (slightly) different when a different period in the year or a different hydrodynamic year would have been used.

DEW provided data on 42 sediment samples taken in the dredge area, see Figure 2.3. The fine content (<63µm) of all 42 samples varies between 0-62%. When dredging for a beach nourishment the best quality sediment will be selected. The 11 samples near a strip of 'simple sands' going from SSW to NNE in front of the old jetty contain on average 11% fines and all samples with higher quality sand containing <30% fines have on average 10% fines. Therefore, a representative fine content of 11% of the source sediment is used in our simulation.

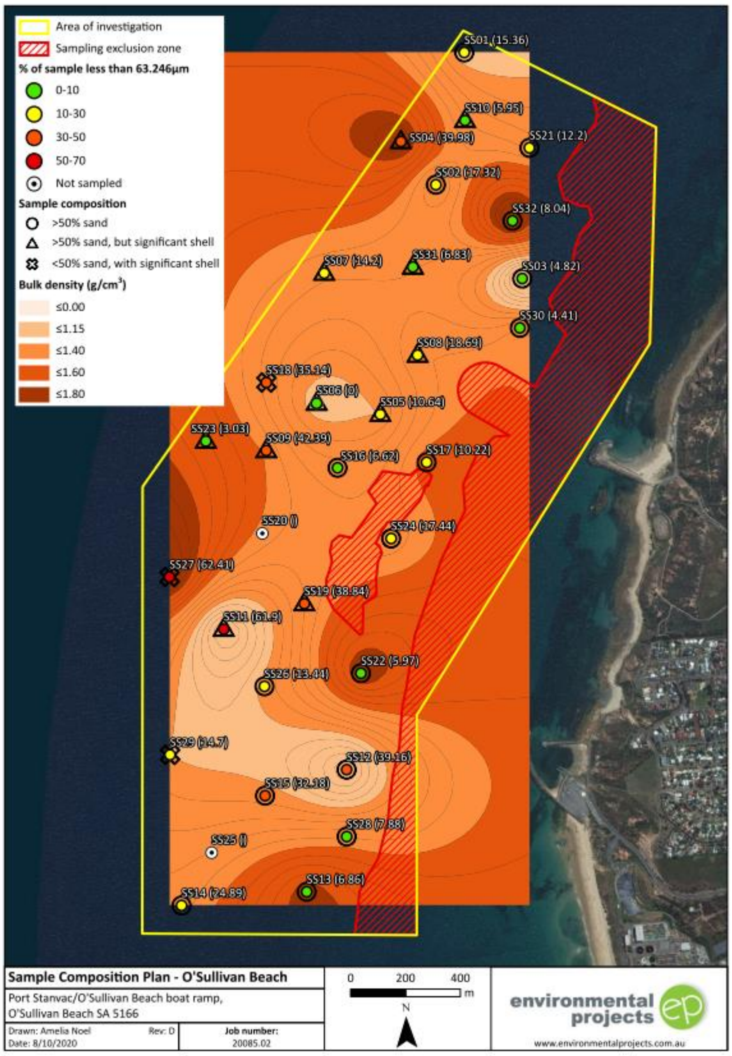

Figure 2.3 Location sediment samples taken in dredge area Port Stanvac (data and image provided by DEW)

The resulting source fluxes of sediment from dredging and nourishing have the following characteristics:

- Dredging period 70 days starting August 1st
- Cycle time of 5 hours
- Loading takes 1 hour (15 min without overflow and 45 min with overflow)
    - Source flux of fines from draghead 2.2 kg/s (60 min per cycle)
    - Source flux of fines from overflow 39 kg/s (45 min per cycle)

- Unloading takes 1 hour
    - Source flux of fines from the beach during unloading 7 kg/s (60 min per cycle) assuming a conservative spill rate of 20% of the fines being transported onshore

The total amount of fines spilled via these three sources is just over half (53%) of the total amount of fines in the source sediment. The source fluxes are divided over the three sediment classes IM1/IM2/IM3 with 10%/45%/45%. The majority is assigned to the sediment classes with higher settling velocity because flocculation of fine sediments in a dredge plume is likely and has been observed (Smith and Friedrichs 2011).

The dredging may take place near Port Stanvac within 500m north or south of the old jetty between 10 and 20m water depths. A TSHD is moving while dredging and therefore the sediment source of the plume is moving as well. At West Beach, the dredge spoil might be placed anywhere along the ~2.8km stretch of beach from the West Beach harbour (south) to where Lexington Road meets the Esplanade north of the Torrens Outlet. It may be placed in multiple locations on multiple occasions. For both locations (dredge and placement location) one representative fixed location of the sediment source is used, see Figure 2.4. This is adequate for present stage of modelling the dredge plumes, but when judging plume concentration near the source location please keep in mind that the source locations in reality will vary during the project. The AREM model grid resolution near the Adelaide coast is 50m East-West and 200m North-South. For local plume details the first few hundred meters E-W and few km N-S this grid resolution is too coarse anyway and extra diffusion/decrease of concentration will occur in the model. The results do provide patterns/gradients and show how quickly particle concentrations diminish away from the source to assess the impact zones of dredging at larger distances.

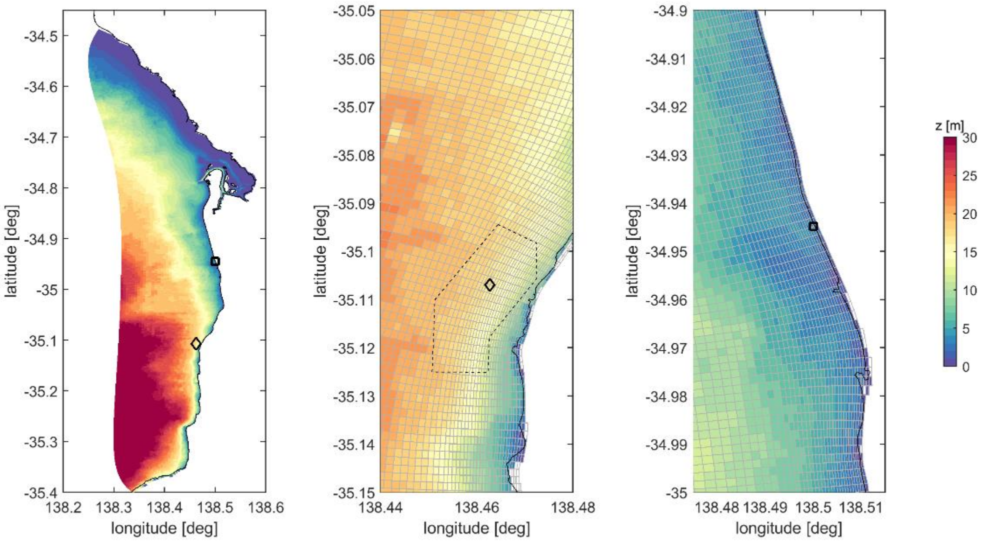

Figure 2.4 Source location for dredging spill indicated with a black diamond and for placement spill with a black square. Left image shows the full AREM high resolution detail model, middle image shows a zoom near the dredge area at Port Stanvac and the right image shows a zoom near the placement area at West Beach. The complete dredge area contour is indicated with a black dashed line, the computational grid is indicated with grey lines and the bathymetry is indicated in color.

The draghead spill source is prescribed in the lowest near bed layer; the overflow spill source is prescribed with the following distribution over the five vertical layers from top to bottom: 3.3%/3.3%/3.3%/30%/60%; and the unloading spill source is assigned uniformly over the vertical (20%/20%/20%/20%/20%). The vertical distribution of the overflow spill source follows a typical TSHD overflow plume in the vertical with the majority of the plume being close to the bed and a small amount of sediment near the surface, see the work of De Wit (2014). The draghead plume is close to the bed and the loss of fines during the beach nourishment is assumed to be fully mixed over the vertical by the waves on the beach.

3 Excess turbidity plume results

Hourly dredge plume excess SSC fields have been analyzed for the computational surface layer and near bed layer for 1680 flow maps over the 70 days of the dredging period. Dredge plume excess SSC fields have been calculated by subtracting the SSC of a simulation with dredge and nourishment source fluxes and a simulation without these dredge and nourishment source fluxes. For the 1680 SSC dredge plume maps during the 70 day dredge period the average and standard deviation of dredge plume excess SSC is determined. The resulting mean dredge plume excess SSC maps are shown in Figure 3.1 and the mean+standard deviation dredge plume excess SSC maps in Figure 3.2.

The AREM model is uncalibrated for dredge plumes and realistic, but conservative input numbers have been used for the dredge spill source terms. Additional research on the dredge process, sediment characteristics and near field plume behavior or optimizing the dredge process could lead to lower excess SSC values. Selecting only sediment from the borrow area with less fines than the assumed 11% would also lower the excess SSC values. Please note that the local resolution of the AREM model is too coarse for local plume details and keep in mind that the source locations in reality will vary during the project leading to local plumes with varying initial locations. The objective of this quick assessment is not to produce exact excess SSC values, but to show the patterns/gradients indicating how the dredging and placement excess turbidity plumes are spreading and where they are moving to.

The figures show that the dredge plume excess SSC contours follow the coastline as the dominant tidal flow is following the coastline. The excess SSC is increasing towards the coast. The near bed excess SSC values are larger as the near surface SSC values; this is caused by the settling behavior of the sediment particles. The zone with excess turbidity is larger near the dredging zone as near the nourishment zone. This has two causes: 1) the fine sediment source flux during dredging is much larger than during placement and 2) dredging takes place further offshore at deeper water with larger tidal flow velocities.

As the figures give an indication where the dredge plume excess turbidity can be expected, they can be used for optimal placement of the water quality monitoring stations for a combination of locations inside the dredge plume and outside the dredge plume for proper background turbidity monitoring. As the SSC will vary over the water column, it is advised to deploy turbidity sensors at different vertical positions in the water column.

For illustrative purpose an animation of the excess plume in the initial phase (first week) of the dredging project is provided separately from this memo. This initial phase is the period where individual plumes can still be recognized. Please note that the resolution is inadequate for local plume details and keep in mind that the source locations in reality will vary during the project leading to local plumes with varying initial locations. Additionally, the initial plume movement is dependent on the moment in the daily tidal cycle and the two-weekly neap spring tide cycle. Whether the plume moves initially northward or southward and how far the plume gets from the start location before the tidal flow reverses direction and the dredge plume is moved back typically is dependent on the moment in the daily and spring/neap tidal cycle and is therefore different for different moments. Nevertheless, the animation gives a nice illustration of what kind of dredge plume behavior can be expected.

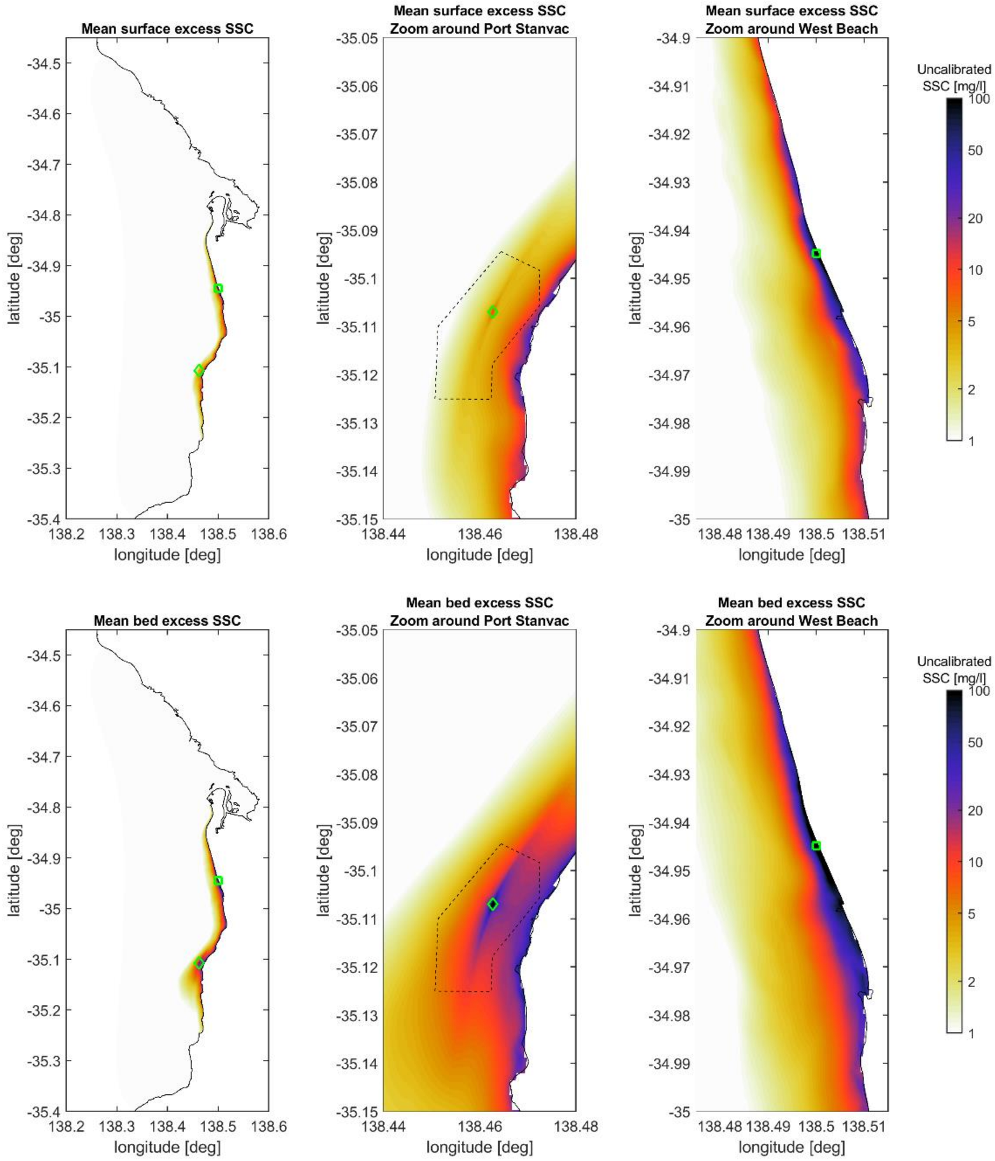

Figure 3.1 Mean surface (top figures) and near bed (bottom figures) uncalibrated dredge plume excess SSC contours. Please note the logarithmic color scale used to provide information over a wide range of SSC.

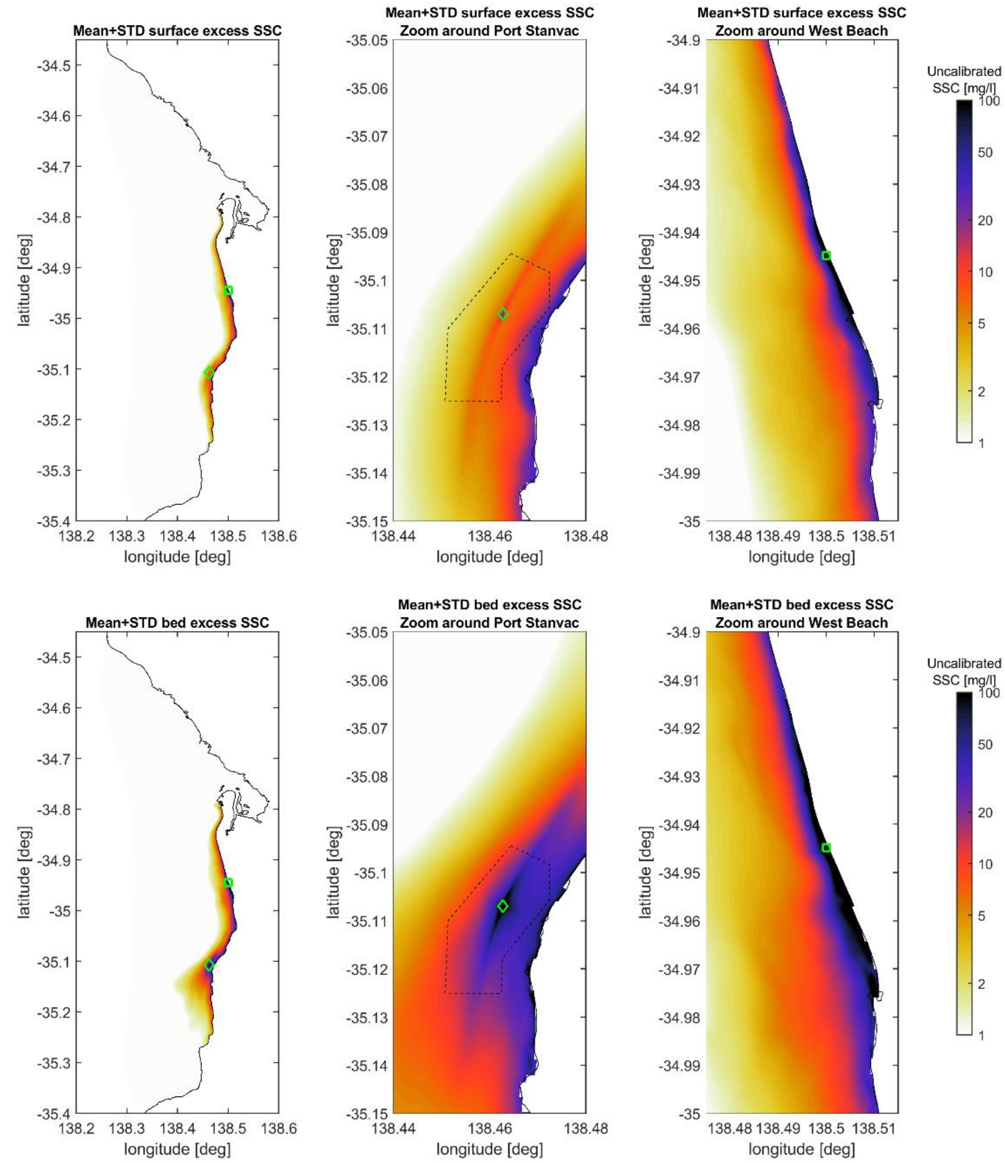

Figure 3.2 Mean+standard deviation surface (top figures) and near bed (bottom figures) uncalibrated dredge plume excess SSC contours. Please note the logarithmic color scale used to provide information over a wide range of SSC.

4 Conclusions

The Department of Environment and Water (DEW) South Australia is investigating a plan to execute a 500,000 m^3 beach nourishment at Adelaide West Beach. The existing AREM model is used to simulate the sediment dispersion around the dredge location near Port Stanvac and placement location at West Beach. Dredge plume patterns have been produced to assist DEW in optimal selection of water quality monitoring locations for background data collection and dredging data collection.

5 References

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