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**HYDRODYNAMIC MODELLING OF THE INFLUENCE OF
DREDGING AT OAKY ISLAND IN WALLIS LAKE ESTUARY**

by

B M Miller, K M Hawker and I P King

Technical Report 2006/07

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SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING
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1. INTRODUCTION

The Water Research Laboratory (WRL) has previously developed a calibrated hydrodynamic model of the Wallis Lake estuary system (Cox, 2001). Geolyse Pty Ltd commissioned WRL to use this modelling tool to assess the hydrodynamic and possible sedimentation changes that may occur as a result of dredging north of Oaky Island near the confluence of the Wallamba and Cooloongolook Rivers. This dredging has been proposed to allow further oyster leases to be developed. Figure 1.1 shows a location plan of the site.

The Wallis Lake estuary is a complex system of channels and islands subjected to tidal gradients resulting in changing flow regimes. A detailed discussion of the flow behaviour and model calibration can be found in Cox, 2001. In summary, the flow is typically depth averaged, with ocean waters on the incoming tide moving to the Wallamba River (north), the Cooloongolook River (west) and Wallis Lake (south). There are significant energy losses throughout the system and the tidal range and mean tidal level vary significantly throughout the estuary.

The hydrodynamic model was calibrated against measured water levels, velocities and discharges taken at 32 sites throughout the estuary. The modelling tool used was RMA-10. This is a three dimensional finite element hydrodynamic model. In this instance, RMA-10 was used in a depth averaged mode. This modelling tool is well suited to assessing changes in hydrodynamic behaviour due to changed geometry such as increased depth due to dredging.

Results from three model configurations are analysed and presented in this report. The first model configuration (“previously calibrated”) was as presented in Cox, 2001. The second model configuration (“pre-dredge”) was the same as the previously calibrated model with the exception that additional resolution was added in the area of interest and the bathymetry was updated to reflect data collected in January 2006. The “pre-dredge” results were compared with the “previously calibrated” results to ensure that the additional resolution and new bathymetry had not changed the overall model calibration. The third model configuration (“post-dredge”) used the resolution and bathymetry of the “pre-dredge” configuration with the exception that the area to be dredged was deepened to -2 metres relative to Australian Height Datum (i.e. -2 m AHD). Differences between the “pre-dredge” and “post-dredge” results can therefore be attributed only to the increased depth. This allowed for a direct assessment of the influence of this dredging activity. Comparison was made only under dry weather tidal conditions.

As stated above, the Wallis Lake estuary has significant energy losses throughout. It is possible that significantly reducing the friction by deepening or widening river channels, could modify the conveyance and hence change the amount of water moving through an area. Analysis of the model results, however, indicated that while there were some changes in flow preference around Oaky Island and Native Dog Island, the overall conveyance is not changed.

Sediment transport, erosion and deposition modelling was not undertaken as part of this investigation. The time and expense were not considered warranted due to uncertainties associated with the sediment budget and the localised changes in hydrodynamics. Rather, the changes in peak bed shear in and adjacent to the dredging site has been analysed to determine which areas may have become more susceptible to erosion or deposition. In summary, the dredged area will be expected to have deposition at the north west corner of Native Dog Island. The rates or to what degree have not been determined. The peak bed shears in the existing channel north of Oaky Island are also marginally decreased, but the effect of this on deposition are not considered significant. Increases in bed shear occurred only in the southern part of the channel between Oaky Island and Native Dog Island.

2. MODEL CALIBRATION

2.1 Previous Modelling

Wallis Lake is a large coastal lake on the mid north coast of NSW (Figure 1.1) about 120 km north of Newcastle. It covers an area of approximately 73 km² and produces 25% of the total oyster harvest in New South Wales. The four main tributaries of the lake and estuary system are the Wallamba, Wang Wauk, Coolongolook and Wallingat Rivers.

A data collection exercise in Wallis Lake undertaken by Manly Hydraulics Laboratory (MHL) between 25 March and 10 June 1998 (Allsop and Kadluczka, 1998) provided detailed information on the tidal characteristics of the estuary. A two-dimensional RMA-10 hydrodynamic model of Wallis Lake was established by Wang and King (1998) following the oyster contamination incident in November 1996. This model was refined and calibrated to the MHL data by Cox (2001) as a tool to provide assessment of possible sources and causes of the viral contamination.

RMA-10 is a three-dimensional finite element model capable of modelling stratified flows (King, 1999). The model solves the shallow water form of the three dimensional Navier-Stokes equations together with the continuity equation to obtain velocities and water surface elevations at each node on the finite element mesh. One, two and three-dimensional elements may be combined in the same mesh to enable the amount of detail to be varied according to the dominant processes and importance of different areas in the model. In this application only two-dimensional depth averaged approximations have been used. Areas of wetting and drying in the model are included by means of a 'marsh element' formulation whereby an element gradually drops out of the model as the water level falls.

This report does not attempt to describe all of the previous modelling. For further details, the reader is directed to WRL Technical Report 2000/16, Cox (2001).

2.2 Model Geometry

The original RMA finite element mesh was based on a detailed hydrosurvey undertaken in October and November 1998. A further hydrosurvey was commissioned by Geolyse and carried out in January 2006 in the area of the proposed dredge to provide recent, more detailed information on bed elevations. Figure 2.1 shows the transect locations where additional survey data was provided.

The existing RMA mesh based on the 1998 survey information was modified to provide sufficient detail to investigate circulation changes and possible erosion or accretion around the proposed dredge area for the oyster lease. The cells of the mesh were refined, and elevations updated based on the 2006 survey in the area of the proposed dredging.

Figure 2.2 shows the entire RMA-10 hydrodynamic model mesh, and a detail of the refined model mesh at the site of the proposed dredge is shown in Figure 2.3.

A Triangulated Irregular Network (TIN) of elevations of each mesh was generated in a GIS using the details of the nodes and interpolating between nodal values. Figures 2.4 and 2.5 show the TIN of elevations for the mesh from WRL's previous work, and the refined mesh respectively. The difference in elevations between these two meshes is shown in Figure 2.6. It can be seen from Figure 2.6 that the elevations about the proposed dredging site are higher in the new survey. This may either be due to sediment deposition in the region of the proposed dredge, or more likely, the recent survey simply has more detail in this area.

2.3 Model Calibration

The RMA-10 hydrodynamic model was run for a 7 day spring tide period matching the observations from 26th March 1998 to 2nd April 1998. This is the same period as that used in WRL's previous modelling investigations. The model was only run for dry weather conditions and as such, the only boundary condition was the ocean tide. Data used for the tidal boundary is shown in Figure 2.7.

The hydrodynamic mesh was refined for the dredging site and surrounding area to provide greater resolution than previously modelled. The bathymetry in this area was also updated to the most recent hydrosurvey. As the "previously calibrated" model showed good calibration, checks were undertaken to ensure that this additional resolution and changed bathymetry did not adversely effect the calibration. Water level calibration checks were made against selected measurement sites at the entrance, on the Wallamba River and southern Wallis Lake. Figure 2.8 shows the location of the water level calibration sites. The water level calibration plots (Figures 2.9 and 2.10) show the measured water levels, the results from the previously calibrated model and the results from the refined model, for selected sites. There is no change in predicted water levels between the refined 2006 model and the calibrated 2001 model and there remains a good match with observations.

A comparison of discharges across various sections was made in the immediate area close to the entrance to the Wallamba River and the dredging site. Predicted flows in the

“previously calibrated” and refined 2006 models were compared at ten channel locations defined by continuity lines in the RMA model runs. The locations of Lines 2 to 10 are shown in Figure 2.11. Line 1 is located at the entrance to the estuary. Figures 2.12 and 2.13 show the time series of discharge at each section. The differences in peak flow across Lines 4 and 8 are expected due to the modifications to bed elevation made around the site of the proposed dredge based on the updated hydrosurvey. Changes to flow patterns in this area have also resulted in a modified flow shape at Line 10. Predicted flows extracted at the other 7 channel locations are unchanged by the mesh refinements. Importantly, the discharge across the Lower Wallamba River (Line 2) did not change.

Given that the overall flow discharges have not changed between model configurations and that the water levels remain in agreement with calibration, the refined 2006 model has been adopted as the “pre-dredge” condition.

3. CHANGES IN HYDRODYNAMICS RESULTING FROM THE DREDGE PROPOSAL

In order to assess the changes resulting from the dredge proposal, only the depths of nodes within the dredge area were modified to create a “post-dredge” configuration. All other model parameters, mesh resolution and boundary conditions remain the same. Differences between the pre-dredge and post-dredge results can therefore be attributed only to the deepened water. This allows for a direct assessment of the influence of the dredge activity. Comparison was made only under dry weather tidal conditions.

The impact of the proposed dredge for the oyster lease on water levels, flow and velocity was investigated. The dredge was simulated by setting the elevation of the nodes within the dredge area to -2 m AHD. A TIN of elevations of the mesh geometry was generated in the GIS and is shown in Figure 3.1.

Figures 3.2 to 3.13 show vector plots of velocity for pre- and post-dredge conditions at hourly intervals over a 12 hour tidal cycle. These provide a graphical representation of how the waters move through this area. Importantly, currents move eastward and westward along the main channel, and currents move northward and southward into the Wallamba River. This complex flow behaviour results in the conditions where the flow directions in the western channels are often opposite to those in the eastern channels. Note that the results presented in these figures are derived from the finite element mesh but interpolated onto a regular grid for ease of viewing.

Figures 3.14 and 3.15 show predicted water levels for pre- and post-dredge models at the selected calibration sites (locations shown on Figure 2.8). These sites are distant from the proposed dredging, and as expected the modelling predicts that there is no impact on water levels.

To investigate the local impact on water levels, six locations were selected in the immediate vicinity of the dredging site. The locations of the selected nodes are shown in Figure 3.16. The results are shown in Figure 3.17 and indicate that there is no change in predicted water levels at these sites between pre- and post dredge conditions.

Local changes in flows were assessed at the continuity lines presented in Figure 2.11. Time series of discharges are shown in Figures 3.18 and 3.19. Importantly, the total discharge across the Lower Wallamba River (Line 2) has not varied indicating that the overall efficiency of the entrance to the Wallamba River has not changed. The largest change can

be observed at Line 8 being the channel between Oaky Island and Native Dog Island. Lines 4, 5, 9 and 10 (being the other channels into the Wallamba) each change subtly in balance with Line 8.

On the basis of the assessment above, no change is expected to the hydrodynamic behaviour outside the immediate area of the dredging site. To further assess these local changes, contours of the pre- and post-dredge peak velocities and unit discharge (velocity multiplied by depth) are presented in Figures 3.20 to 3.23.

The maximum velocity experienced at each node throughout the 7 day simulation for the pre- and post-dredge conditions are contoured in Figure 3.20. The difference between the two scenarios is presented in Figure 3.21. There are four locations where maximum velocity is predicted to change. The velocities are predicted to decrease in the channel to the north of the dredge site and at the north-western end of Native Dog Island. The velocities are predicted to increase in the southern part of channel between Oaky Island and Native Dog Island and in a small area immediately north-west of the dredge site.

To understand why these changes in maximum velocities have been predicted, it is useful to understand where the changes to peak flow have occurred. As the system is unstratified and depth averaged, a measure of the unit discharge is simply velocity multiplied by depth, presented as $\text{m}^3/\text{s}/\text{m}$. The maximum flow per unit width experienced at each node throughout the 7 day simulation for the pre- and post-dredge conditions are contoured in Figure 3.22. The difference between the two scenarios is presented in Figure 3.23. There is clearly an increased conveyance of water through the channel between Oaky Island and Native Dog Island and in the dredge site once it has been deepened. There is a corresponding decrease in conveyance through the channel to the north of the dredge site. This indicates that locally there will be a change in flow balance between the western and eastern sides of Native Dog Island.

As a final test on model sensitivity, the post-dredge model was run with increased friction in the dredging site to simulate the likely effect of dense oyster lease racks. Comparison of Frame (a) of Figure 3.24 and Frame (b) of Figure 3.20 shows the maximum velocities are insensitive to increased friction. Comparison of Frame (b) of Figure 3.24 and Frame (b) of Figure 3.22 shows the maximum unit discharges are also insensitive to increased friction.

4. CHANGES IN DEPOSITION OR EROSION OF SEDIMENTS

Sediment transport occurs when the movement of water has enough energy to entrain sediment materials from the bed and transport these materials in the water column. Similarly, deposition of sediments occurs when there is no longer sufficient energy and the materials are redeposited onto the bed.

Complex sediment transport models can be established but were not considered necessary for this investigation. Rather, consideration has been given to the changes in energy available for sediment transport, known as bed shear (τ_b). Increases in bed shear indicate a greater potential for erosion and sediment transport. Decreases in bed shear indicate a greater potential for deposition.

Sediment transport occurs when the movement of water above the bed creates a shear stress (τ_b) on the bed that is capable of moving sediments. Peak shear (when the velocity is maximum) is the most important shear parameter as this is the shear most likely to initiate motion.

Bed shear stress caused by tidal currents was calculated using the following equation:

$$\tau_{b,c} = \rho u^2 f_c / 8 \quad (1)$$

where:

ρ = density of water

u = depth-averaged velocity

f_c = friction factor

$$f_c = 0.24 \ln^{-2}(12h/k_s) \quad (2)$$

where:

h = water depth

k_s = effective bed roughness (a function of sediment size and bed form)

From Equations 1 and 2 we can see that bed shear stress is proportional to the velocity squared, though water depth, sediment size and bed form also influence bed shear but to a lesser degree.

The actual transport will depend on the type of materials and the shear stress required to move that material. The particular shear stress for a particular material is known as the critical shear stress.

For sandy materials, the critical shear stress is predominantly related to the grain size. For a cohesive sediment, the critical shear stress will be dependent on its degree of consolidation. The amount of consolidation is time dependent and higher values of critical shear stress are required to initiate erosion for more highly consolidated material. Table 4.1 is from Neilson and Miller (2001) who used equations and data from Van Rijn (1989) to calculate critical shear stresses based on the degree of consolidation.

Table 4.1
Critical Shear Stresses for Different Sediment Types

Material Type	Degree of Consolidation	Critical Shear Stress (N/m ²)
Medium Silty Sand (D ₅₀ =0.2mm, D ₉₀ =0.5mm)	-	0.16
Medium Sandy Silt (D ₅₀ =0.05mm, D ₉₀ =0.2mm)	Freshly Consolidated (1 day)	0 – 0.3
	Weakly Consolidated (1 week)	0.3 – 1
	Medium Consolidated (1 month)	1 – 3.
	Highly Consolidated (1 year)	10 – 20
	Stiff Mud (10 years)	20 – 30
	Hard Mud (100 years)	> 30

The impact of the proposed dredge on bed shear stress was investigated at six (6) selected nodes within or near to the proposed region of dredge. The locations of the nodes is shown in Figure 4.1. Figures 4.2 to 4.5 show the results of calculated bed shear stress for the selected nodes for the pre- and post dredging.

These changes in bed shears can be compared with the critical shears listed in Table 4.1. It can be seen that at all locations within the dredge site, the peak bed shear is reduced and hence accretion of medium sandy silts may be possible over time. In the channel between Oaky Island and Native Dog Island, the peak bed shear has increased from 0.3 to 0.4 N/m² indicating that some further sediment transport may be initiated of consolidated silts if any are present.

The North Western end of Native Dog Island has reduced peak velocities and may be expected to also accrete over time.

A sensitivity test was carried out on the post-dredge model. In the original scenario, the bed level was set at a uniform elevation of -2 m AHD throughout the area of the proposed dredge, irrespective of original elevations. In the sensitivity test, the existing bed elevations in the area of the proposed dredge were deepened by 2 m. Thus, the resultant bed elevations following deepening were between -2.1 to -3.4 m AHD with an average elevation of -2.3 m AHD. On average, bed elevations for this sensitivity model were 0.3 m

deeper than the original scenario. Figures 4.6 to 4.9 show the calculated bed shear stress at the six (6) selected nodes for the two post-dredge models and the pre-dredge model. The difference in bed shear stress between the two post-dredge scenarios is shown to be insignificant.

5. CONCLUSIONS

A detailed and calibrated RMA-10 hydrodynamic numerical model was used to assess changes in the flow regimes that may occur as a result of dredging about Oaky Island. This investigation determined that the changes would be localised and would have no effect on the overall conveyance of the Wallamba River entrance.

Numerical model simulations predicted an increased conveyance of water through the channel between Oaky Island and Native Dog Island and also across the area of the dredge site. There was predicted to be a corresponding decrease in the conveyance through the channel to the east of Native Dog Island and through the channel to the north of the dredge site. Hence, it is predicted that locally there will be a change in flow balance between the western and eastern sides of Native Dog Island. Other than these immediate areas, the dredging will not change regional velocities.

The peak bed shear is reduced at all locations within the dredge site and hence accretion would be expected over time. In the channel between Oaky Island and Native Dog Island, the peak bed shear has increased indicating that some further sediment transport may be initiated and erosion may occur. The North Western end of Native Dog Island has reduced peak velocities and may possibly accrete sediment over time.

The dredge hole would be expected to have accretion of medium sandy silts over an extended period of time.

In summary, the dredging would have no effect on the flows or hydrodynamics of the overall Wallamba River or Wallis Lake estuary. There would be some localised effects to the channels on either side of Native Dog Island, but these are not expected to be significant.

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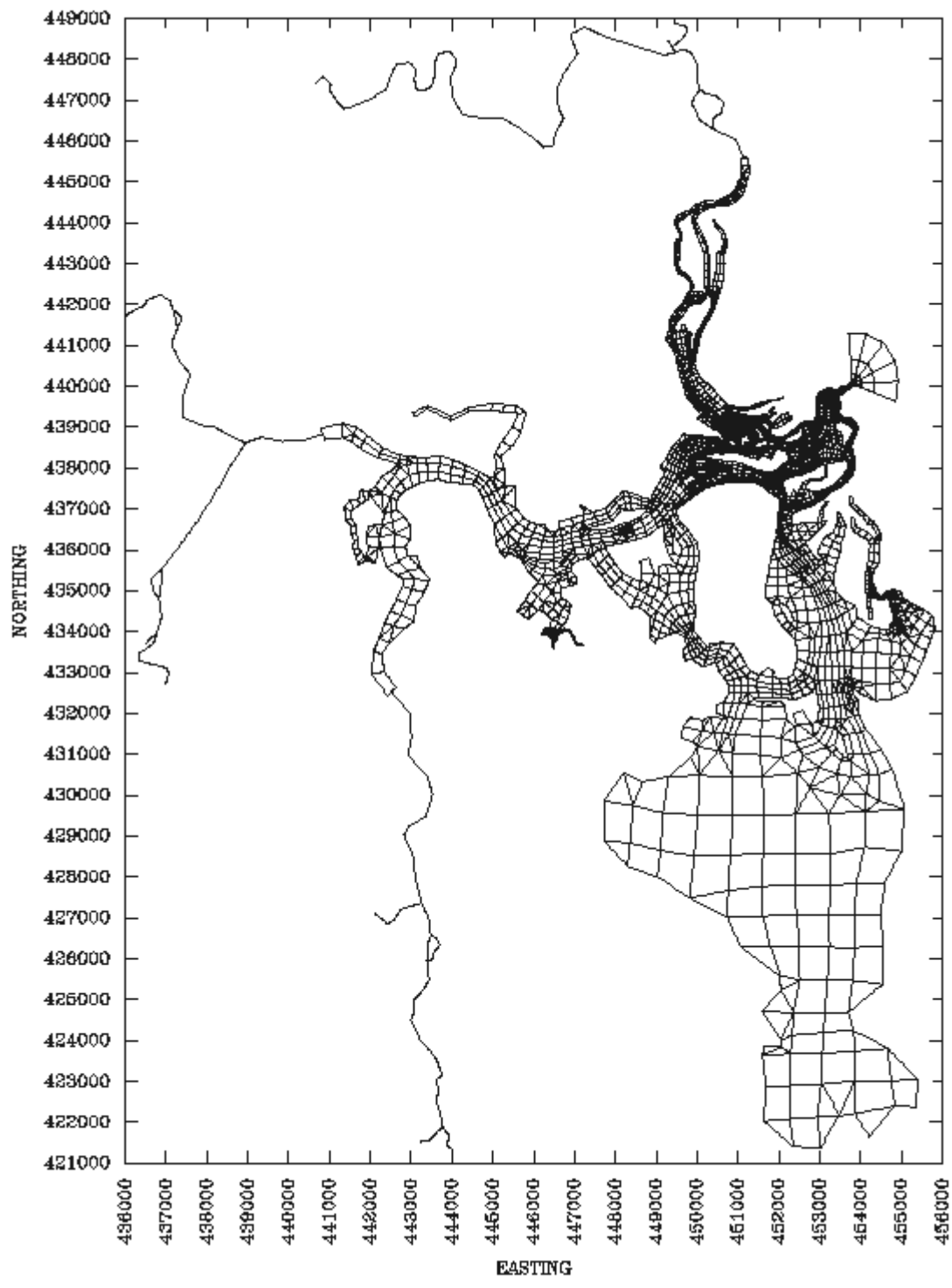
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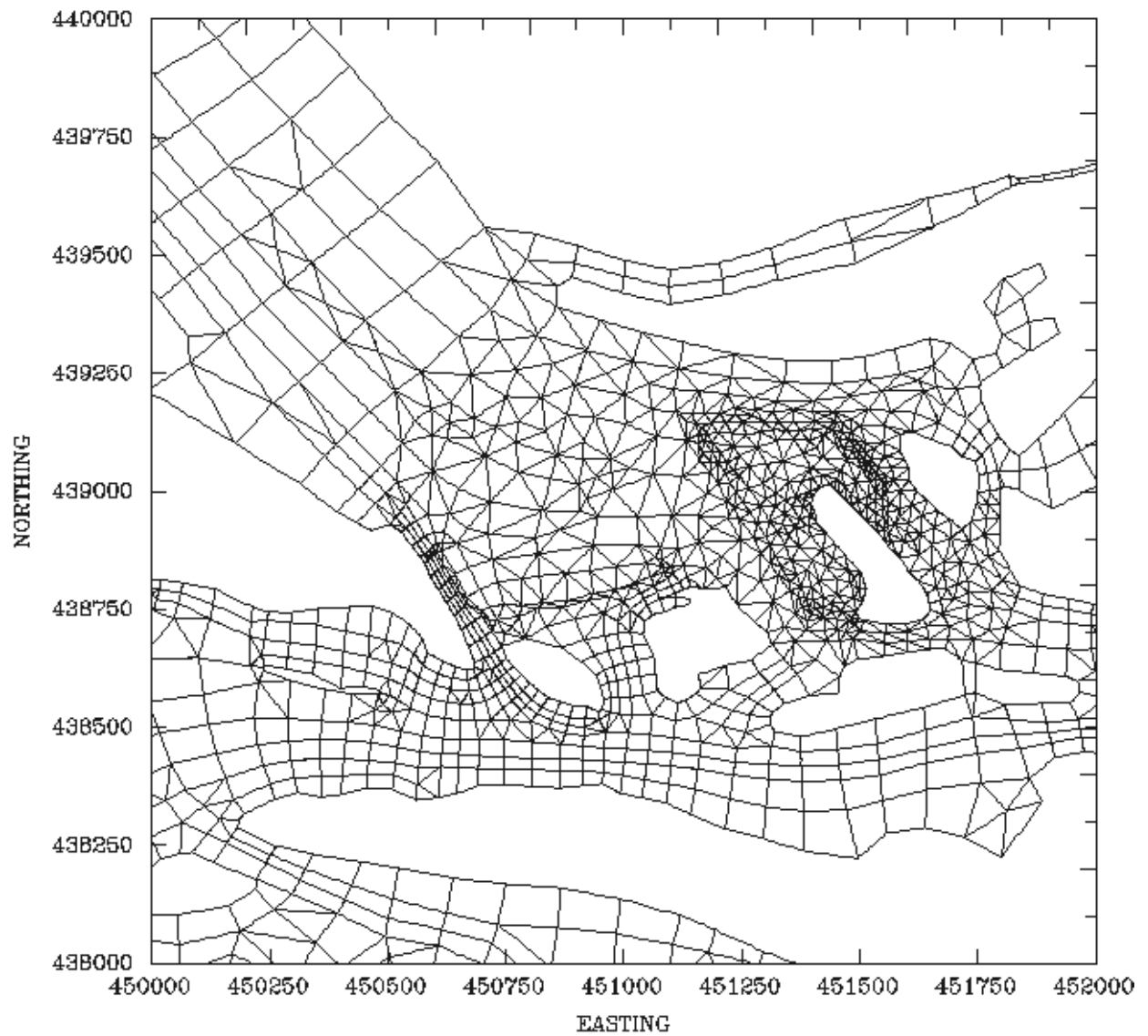
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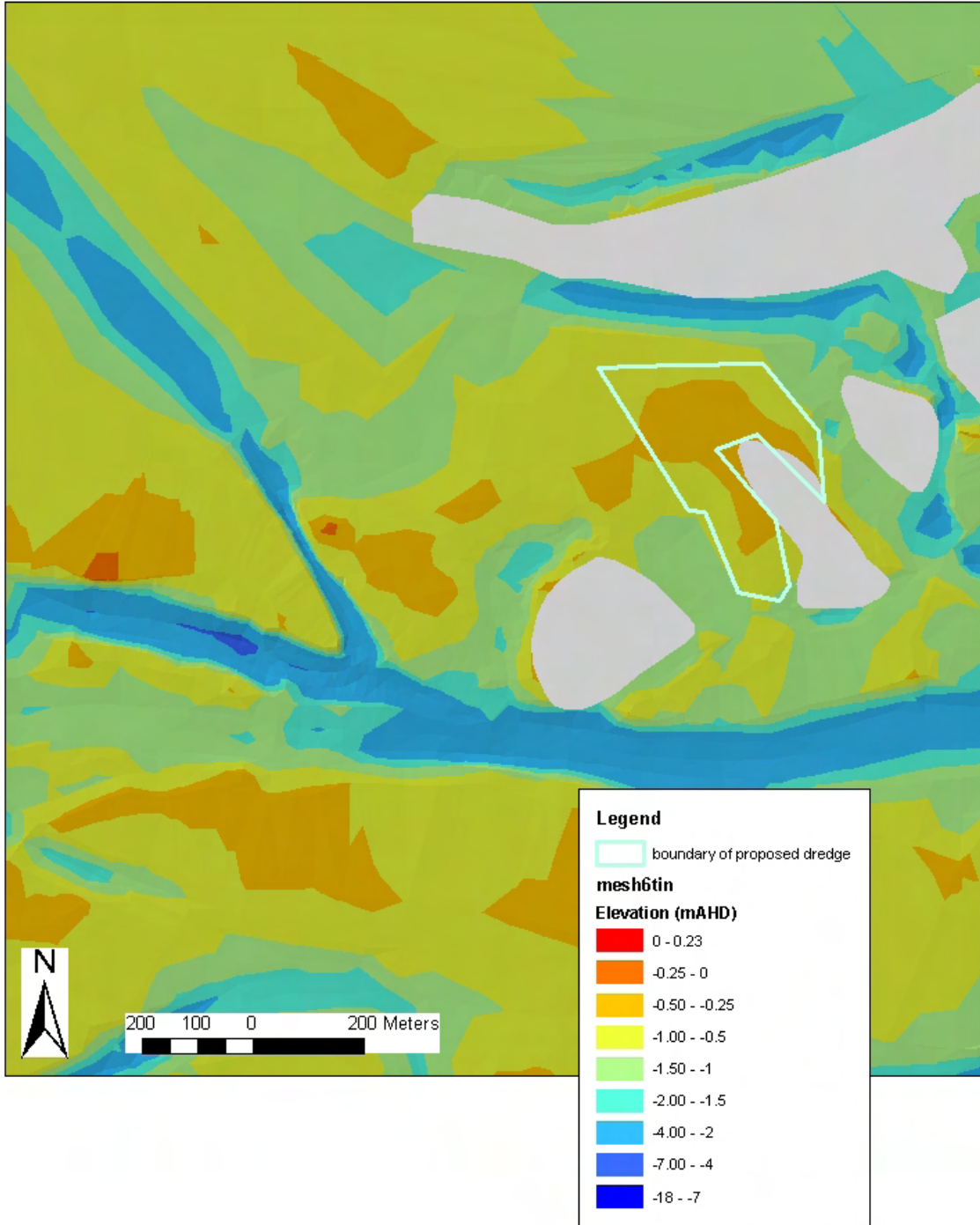


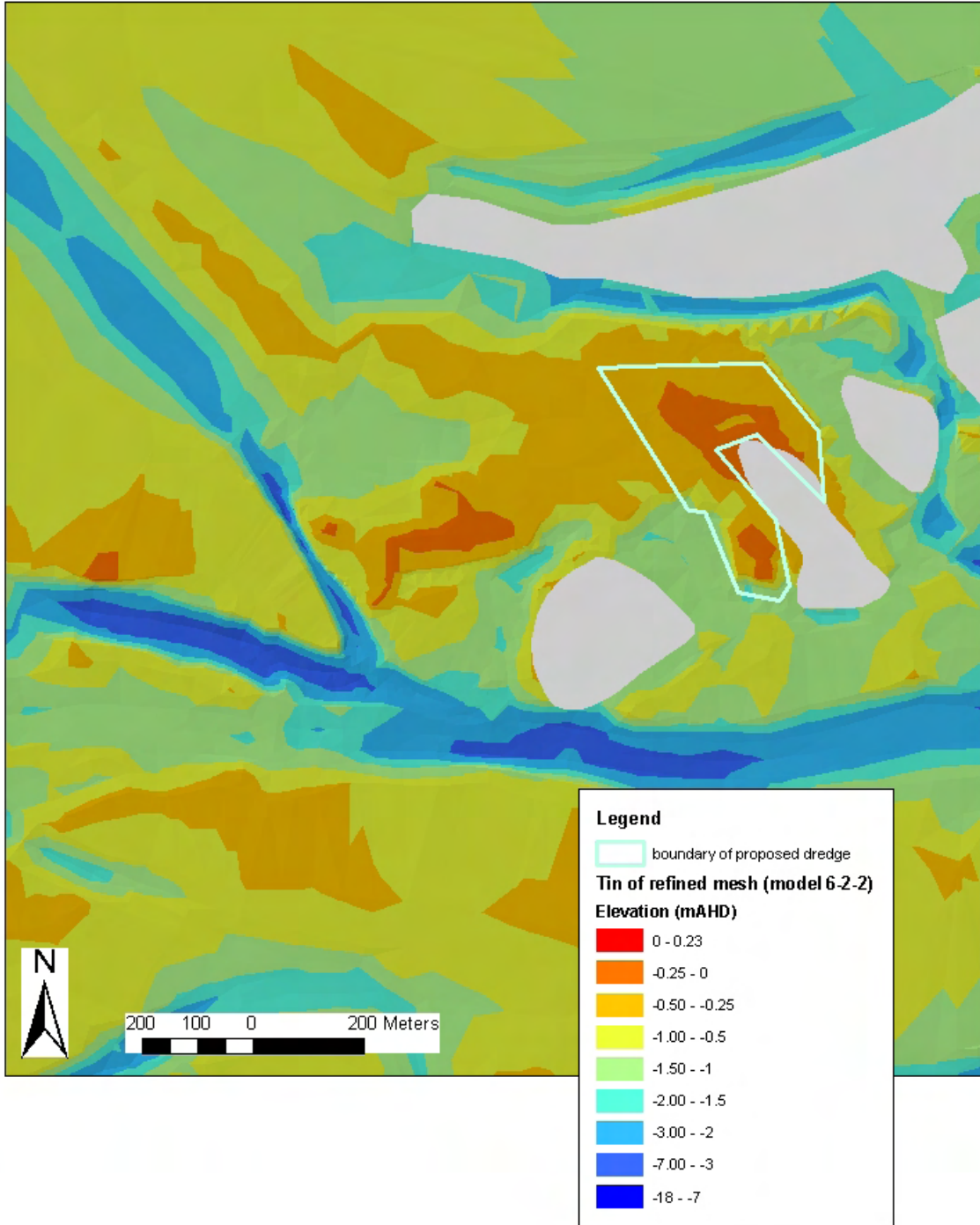


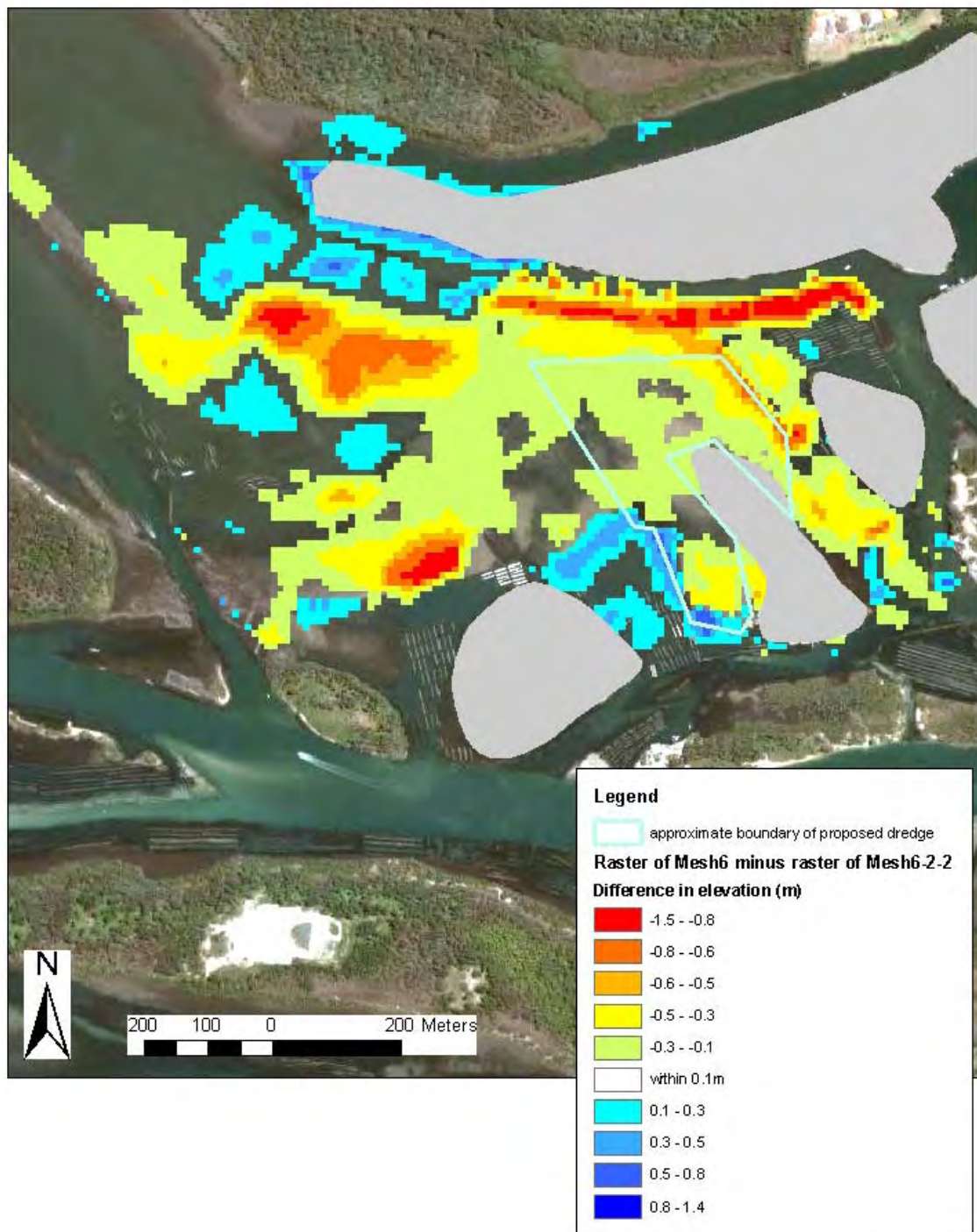
Note: AMG coordinates. Northings preceded by a "6".



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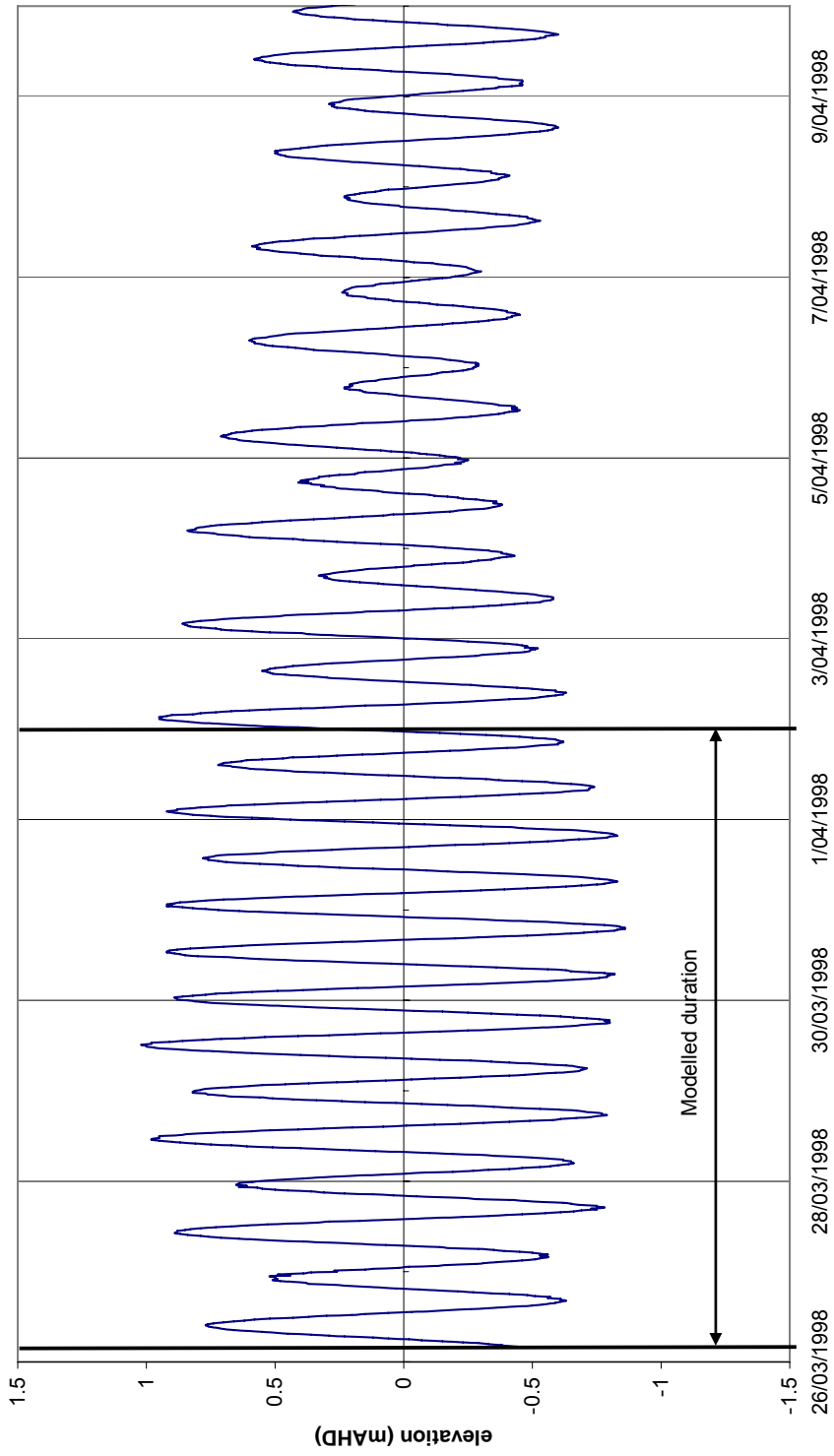


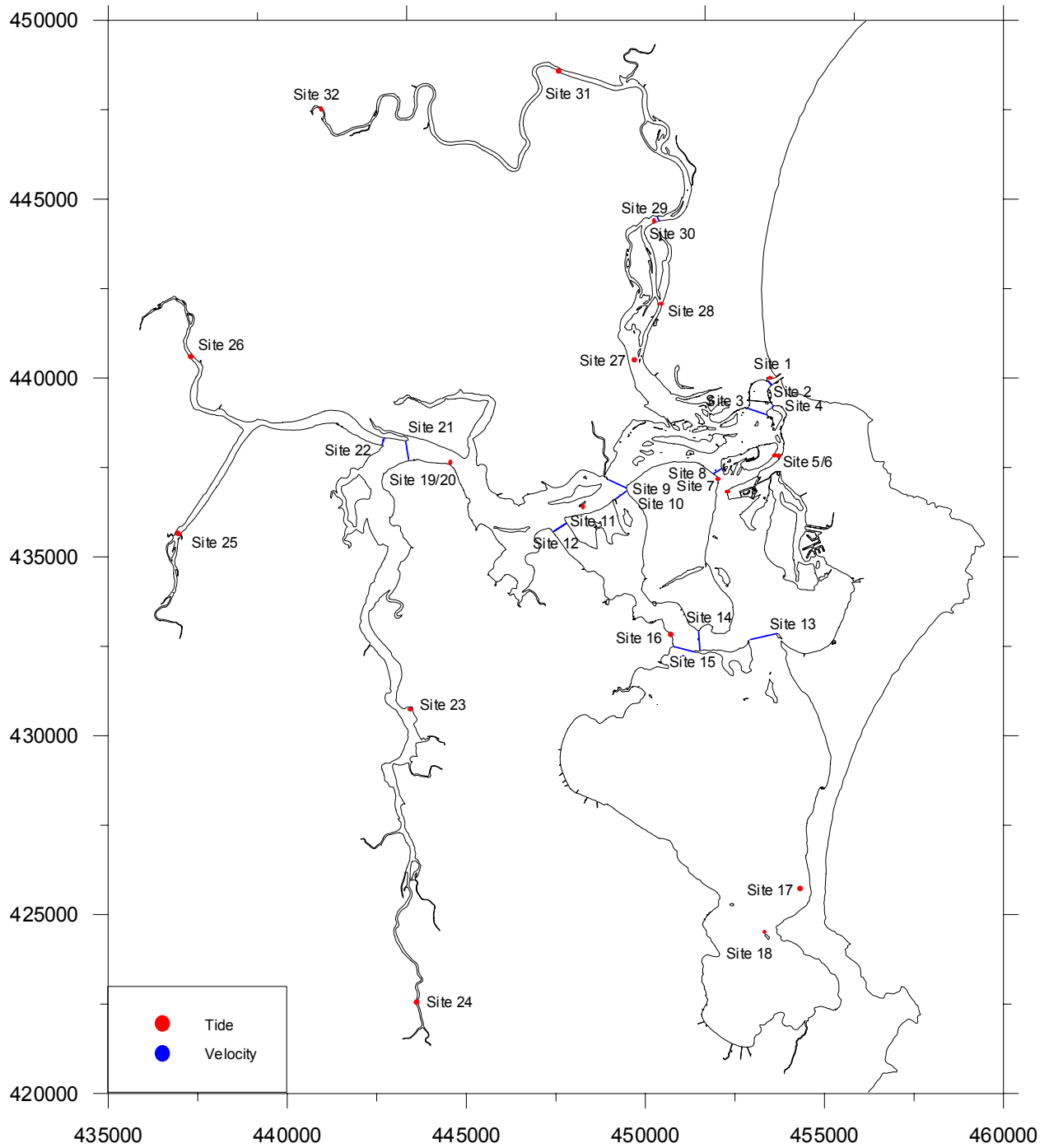




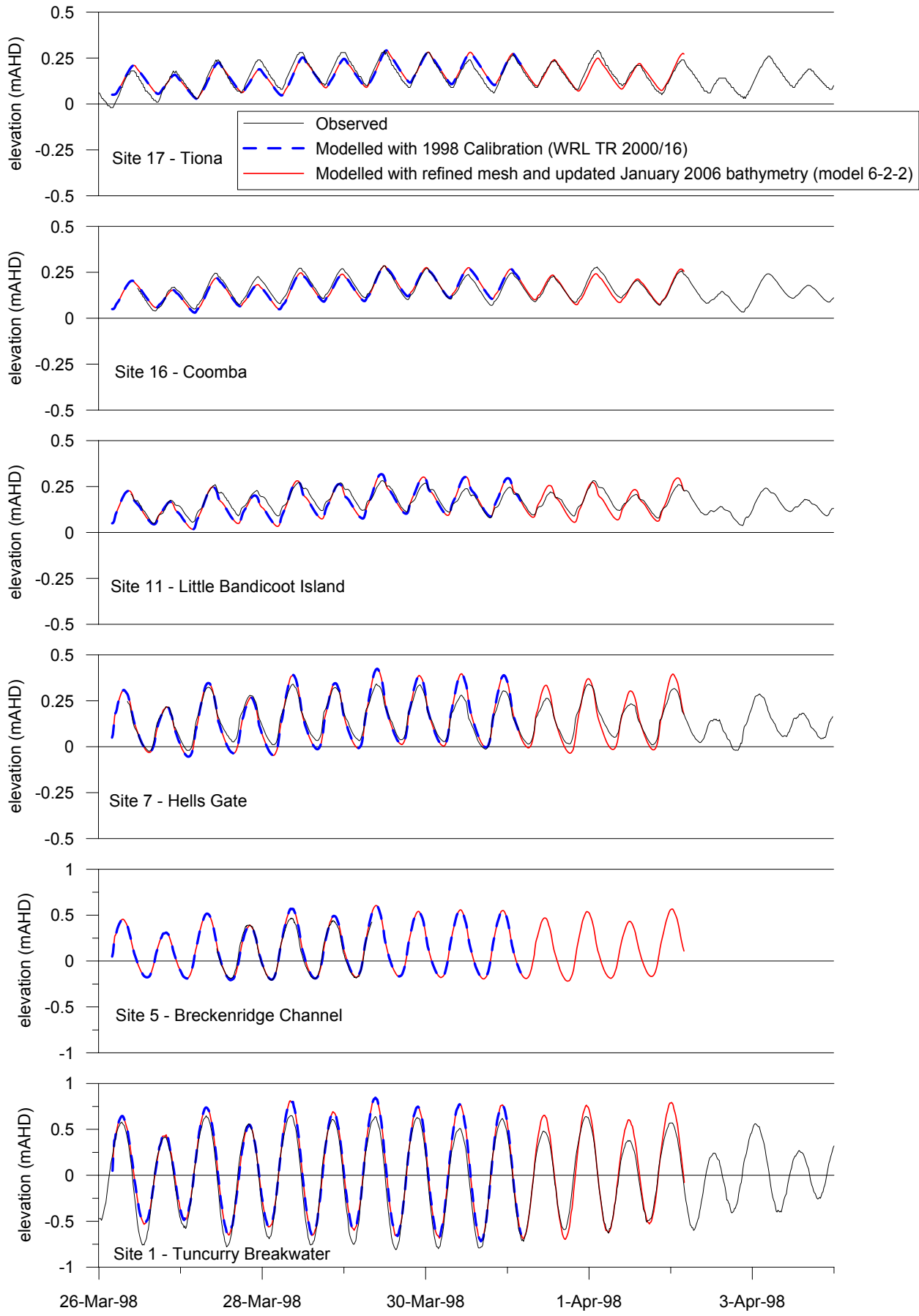
Note: Positive change equates to a loss of elevation, negative change to an increase in elevation, from elevations used in the 1998 calibration mesh.

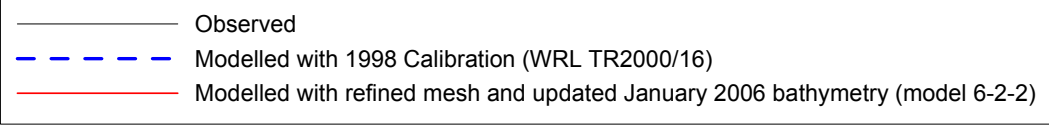
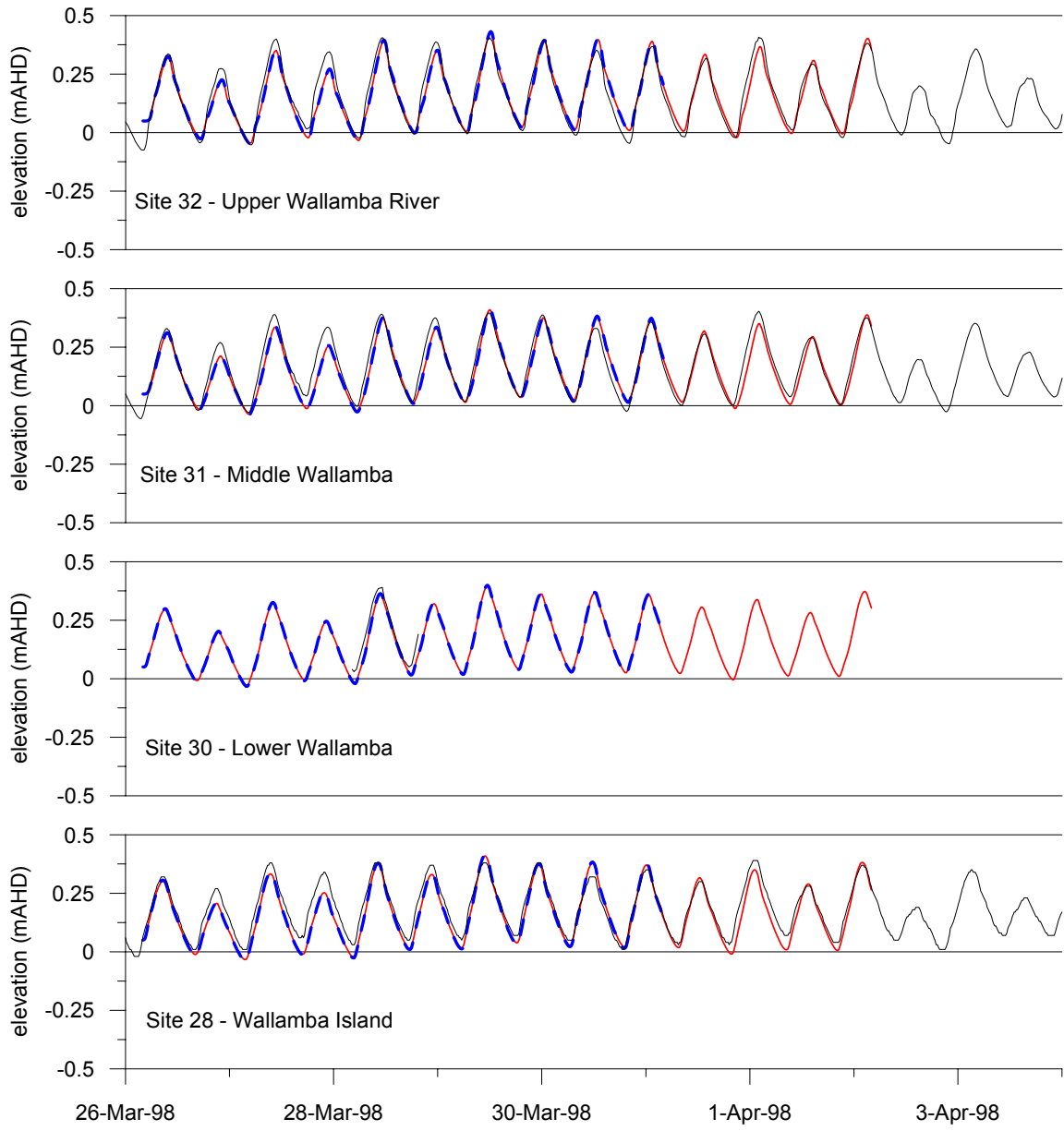
Tidal boundary (Crowdy), March 1998

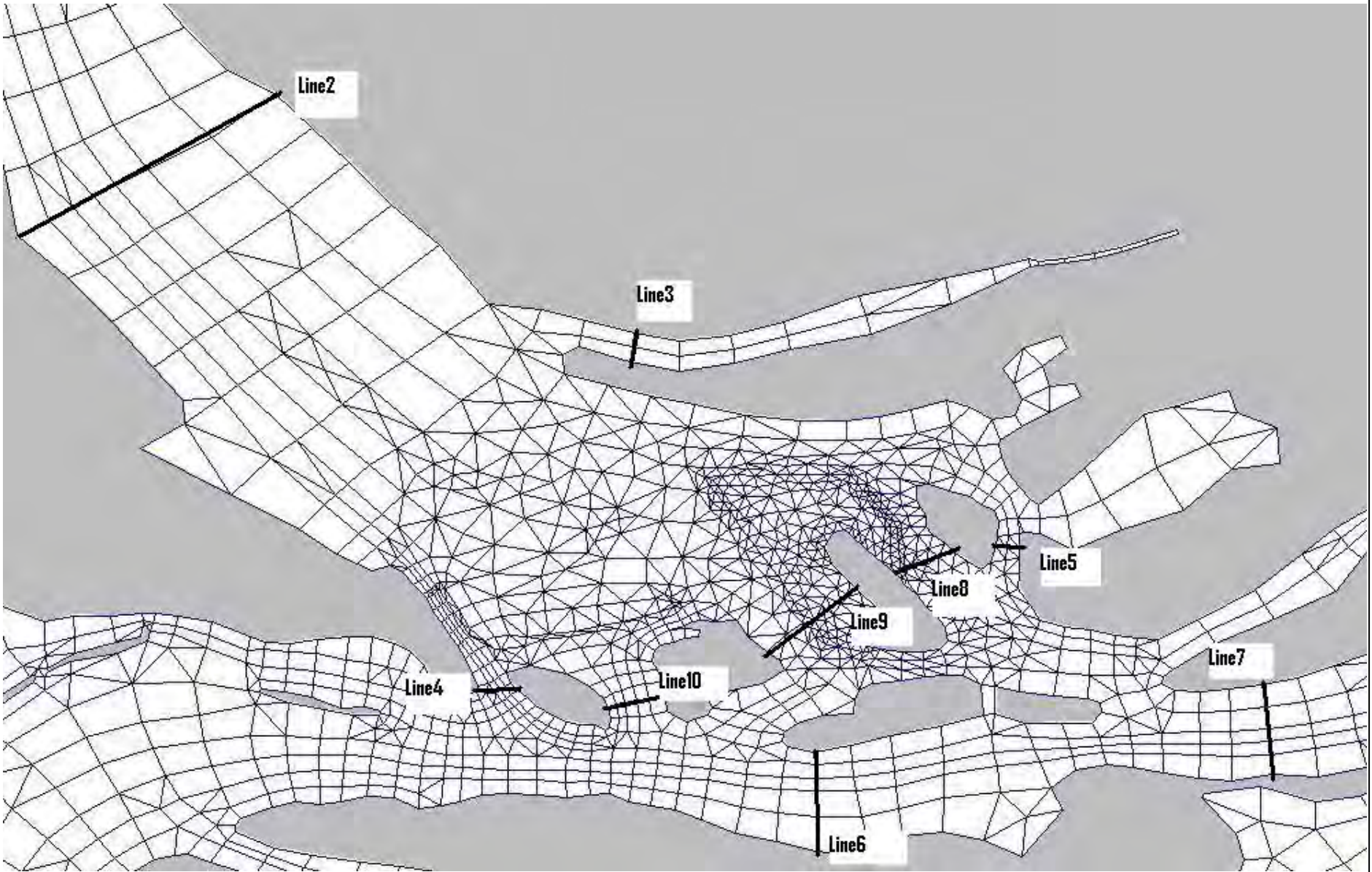


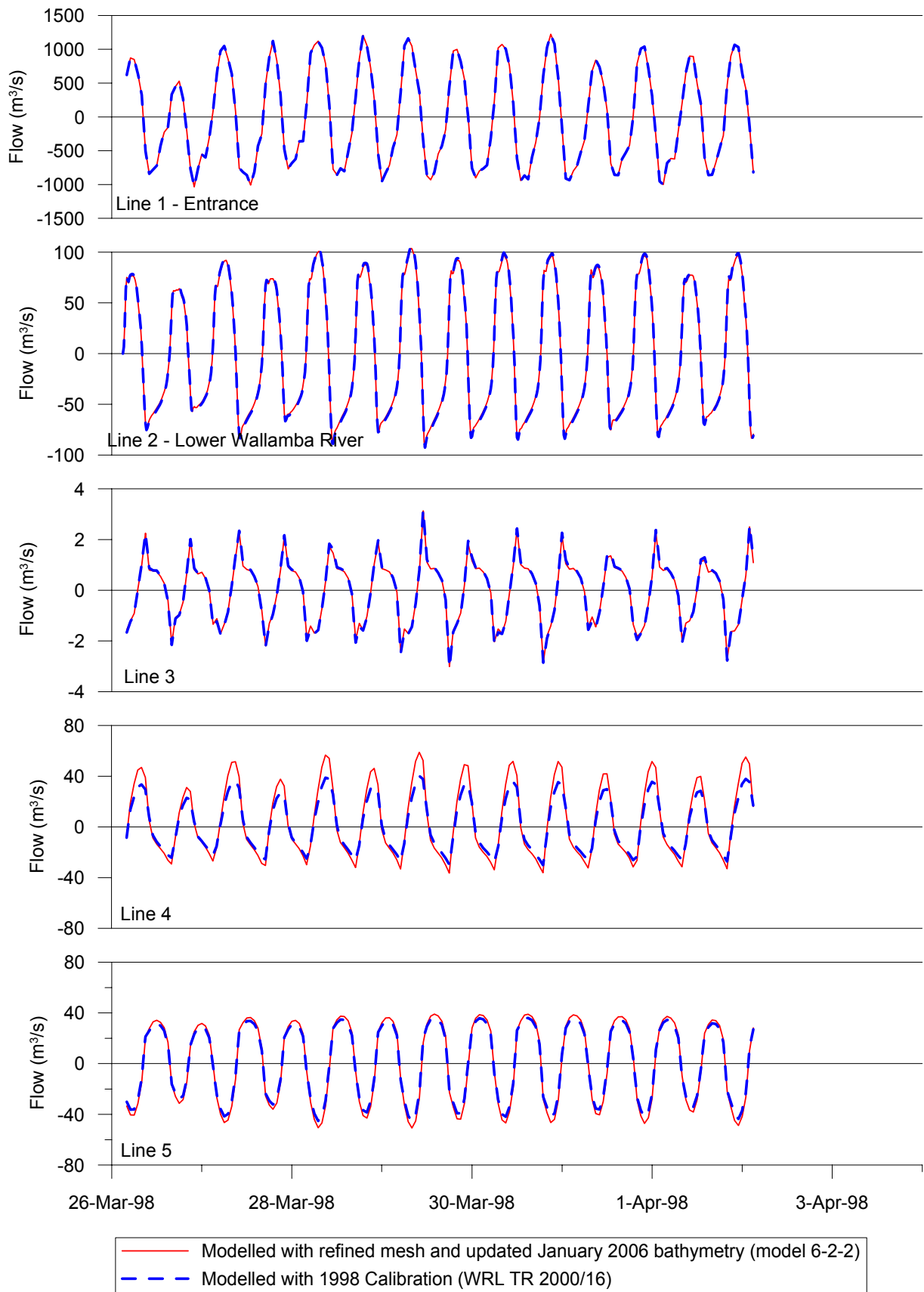


Source: WRL TR 2000/16

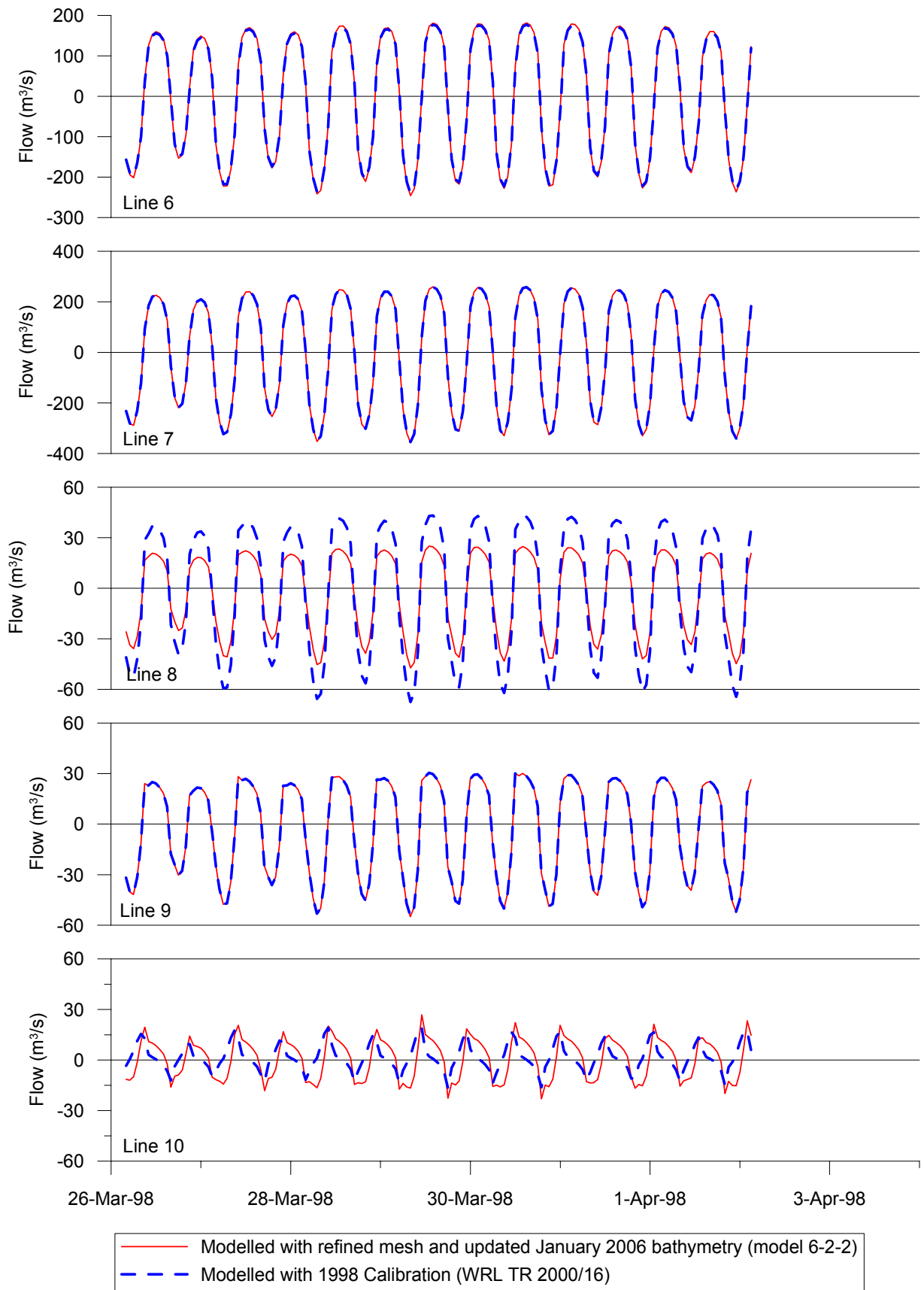




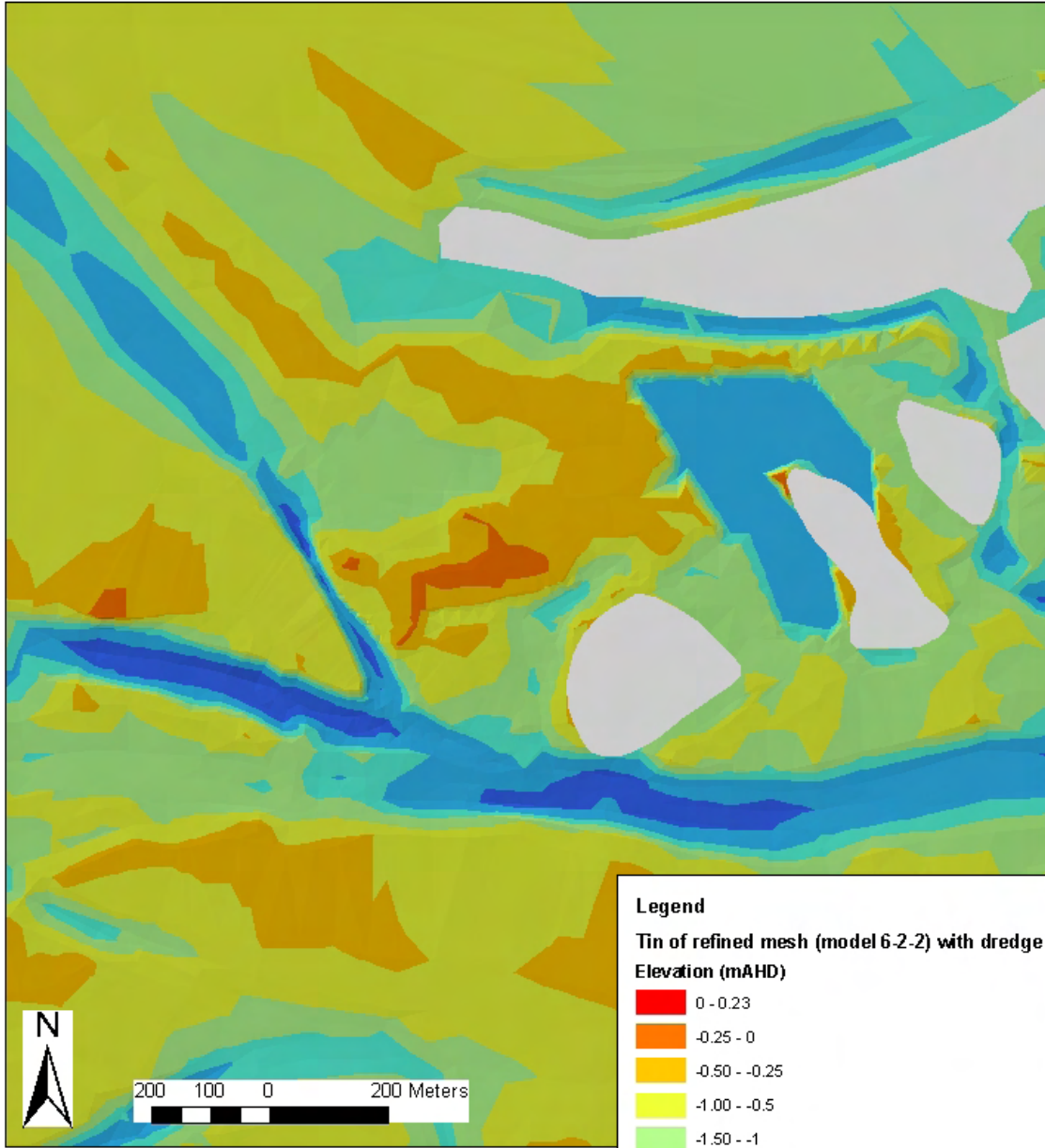


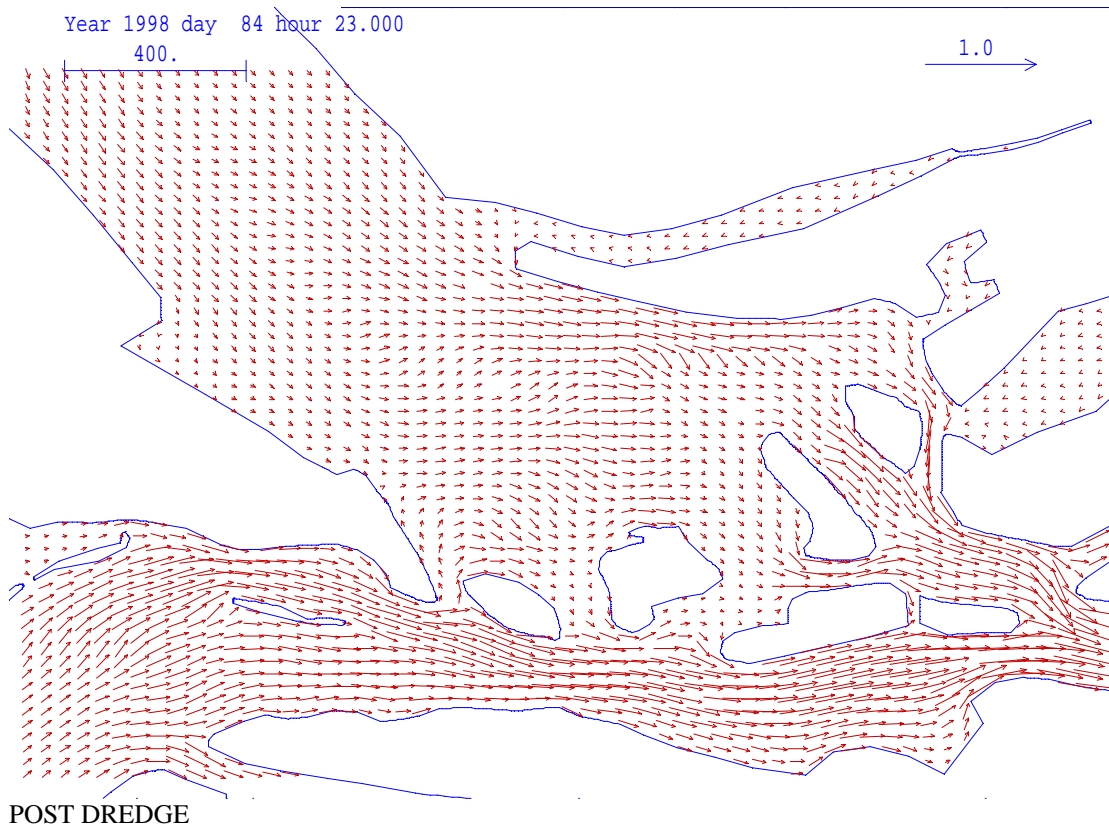
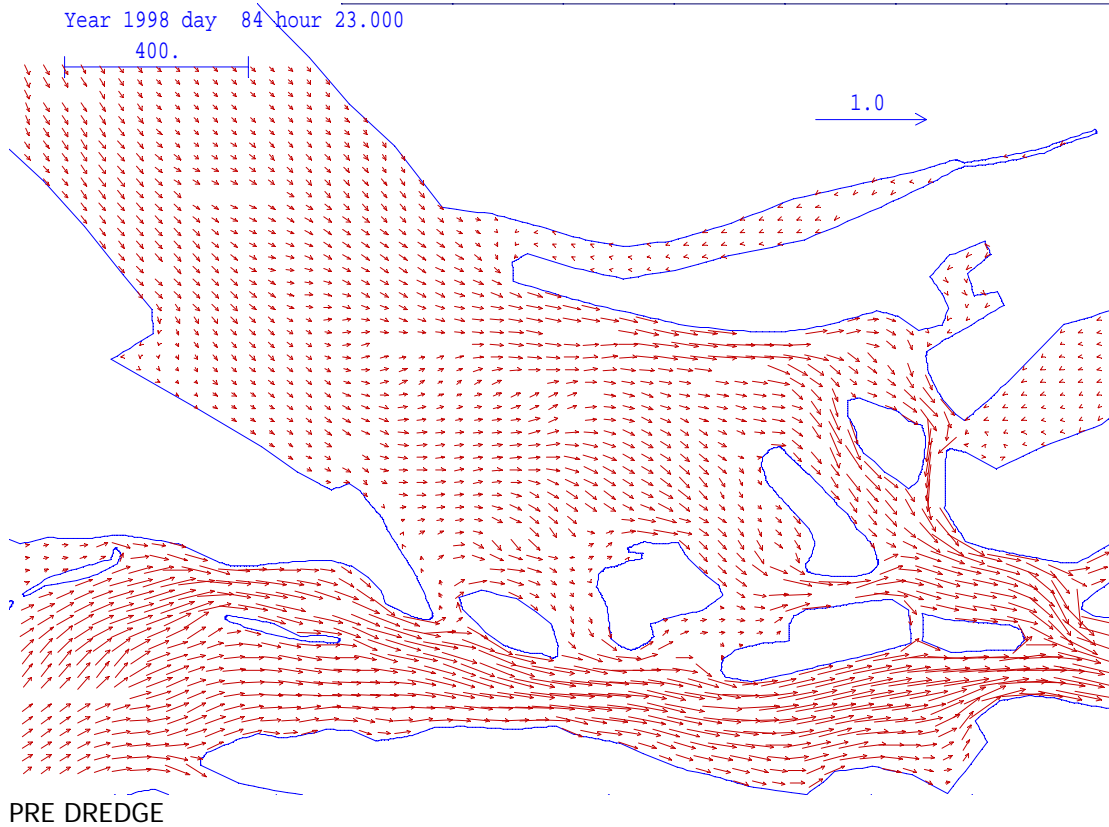


Note: Positive flow is upstream

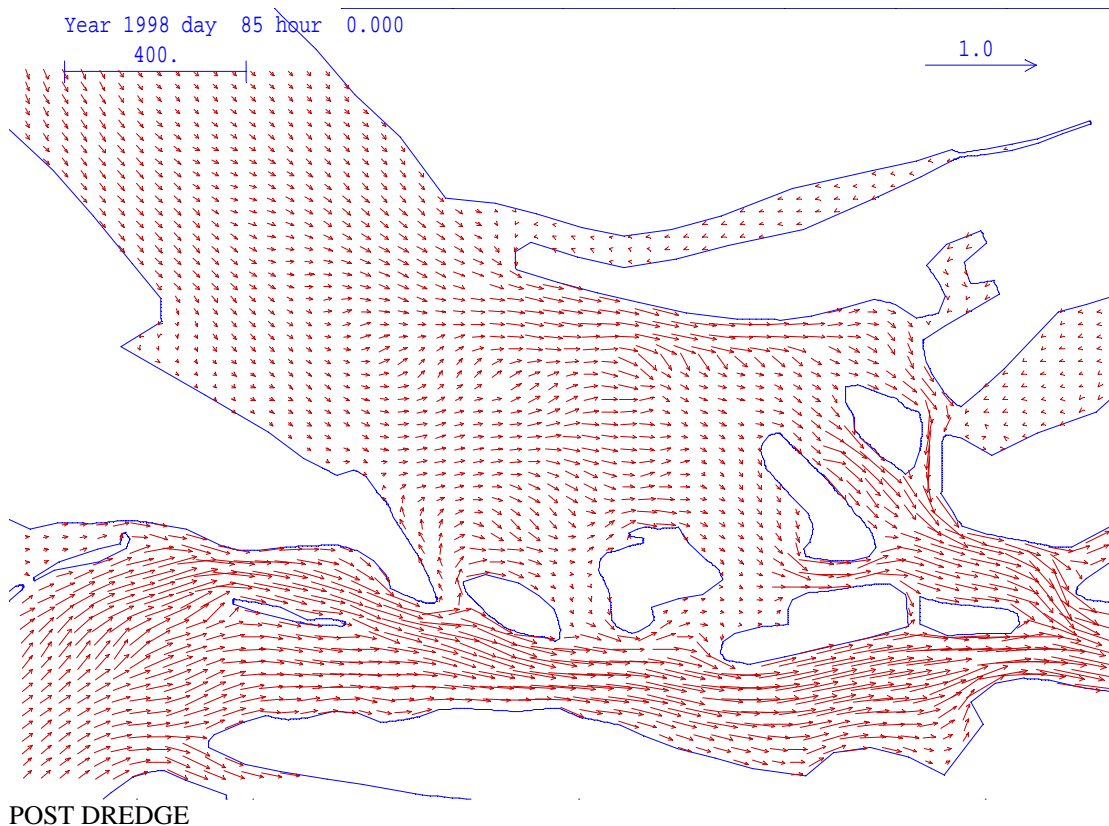
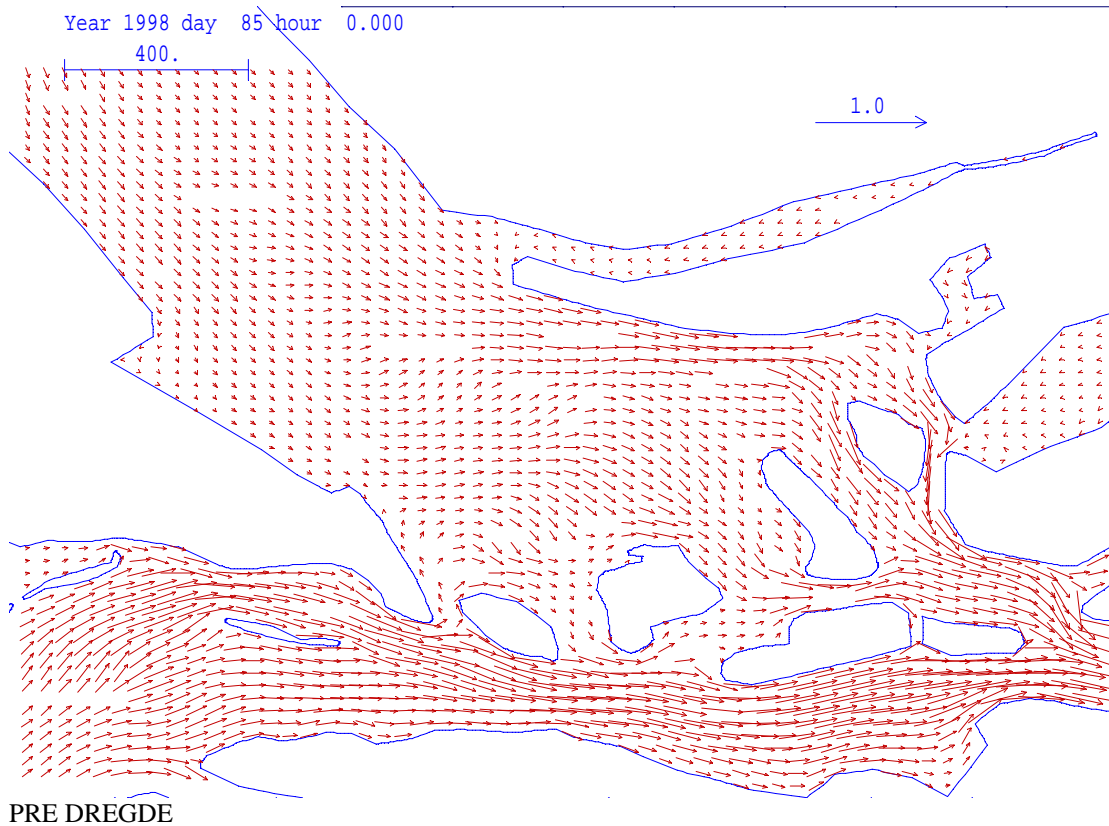


Note: Positive flow is upstream

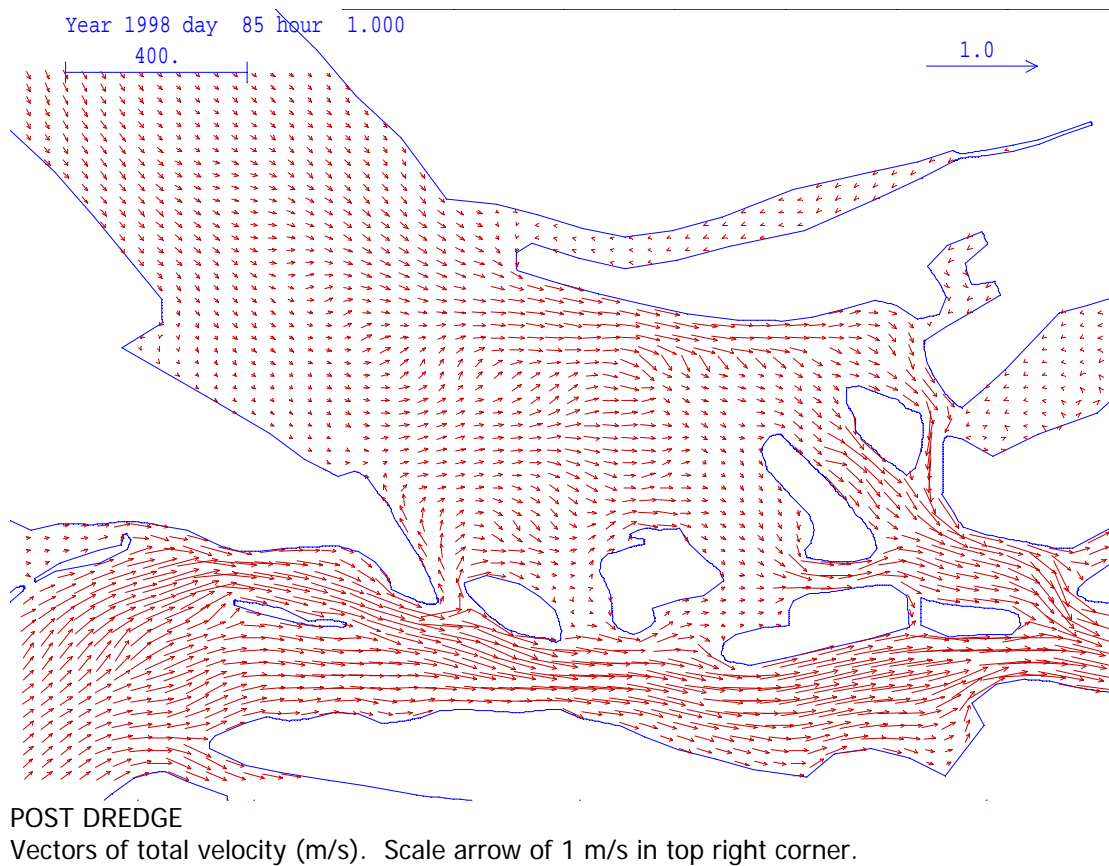
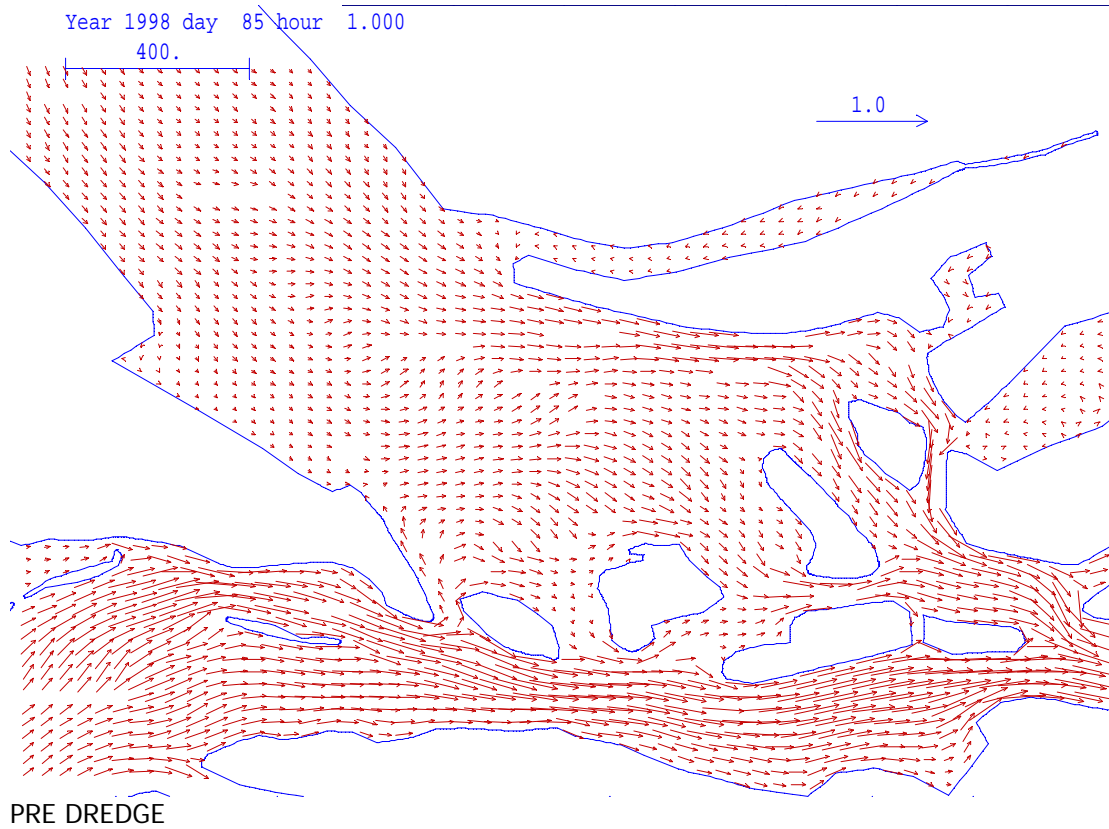


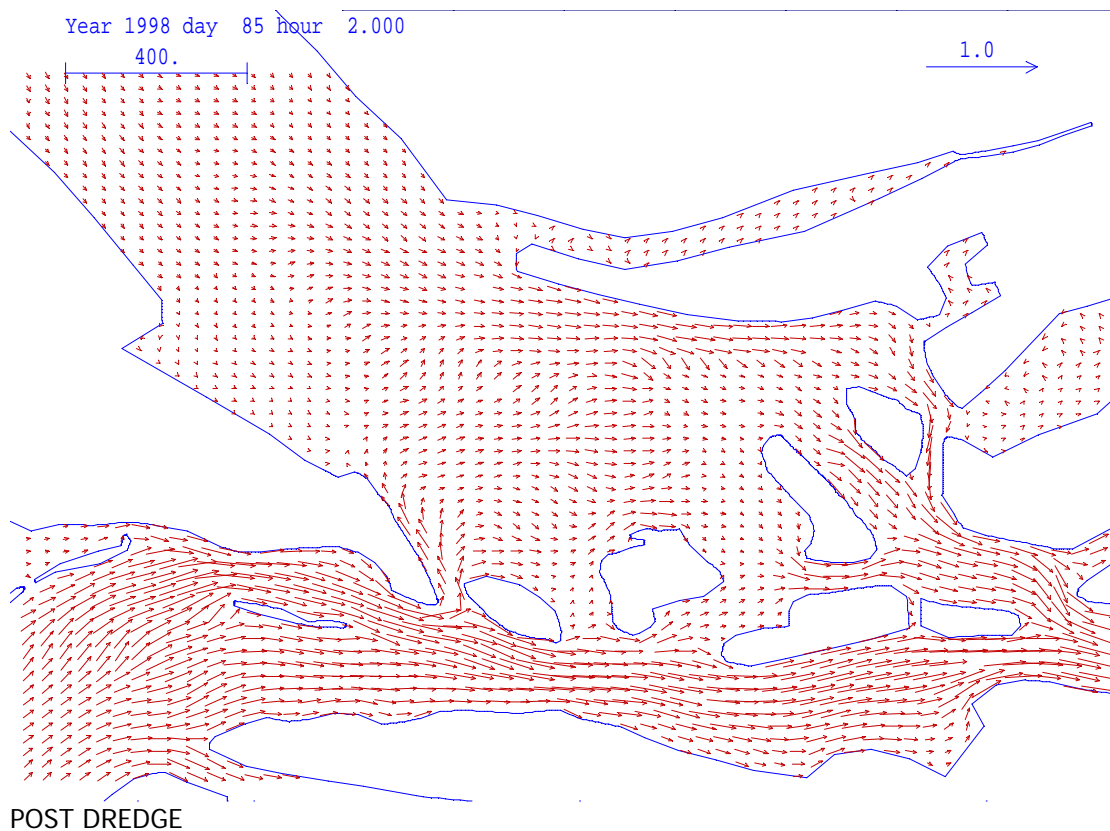
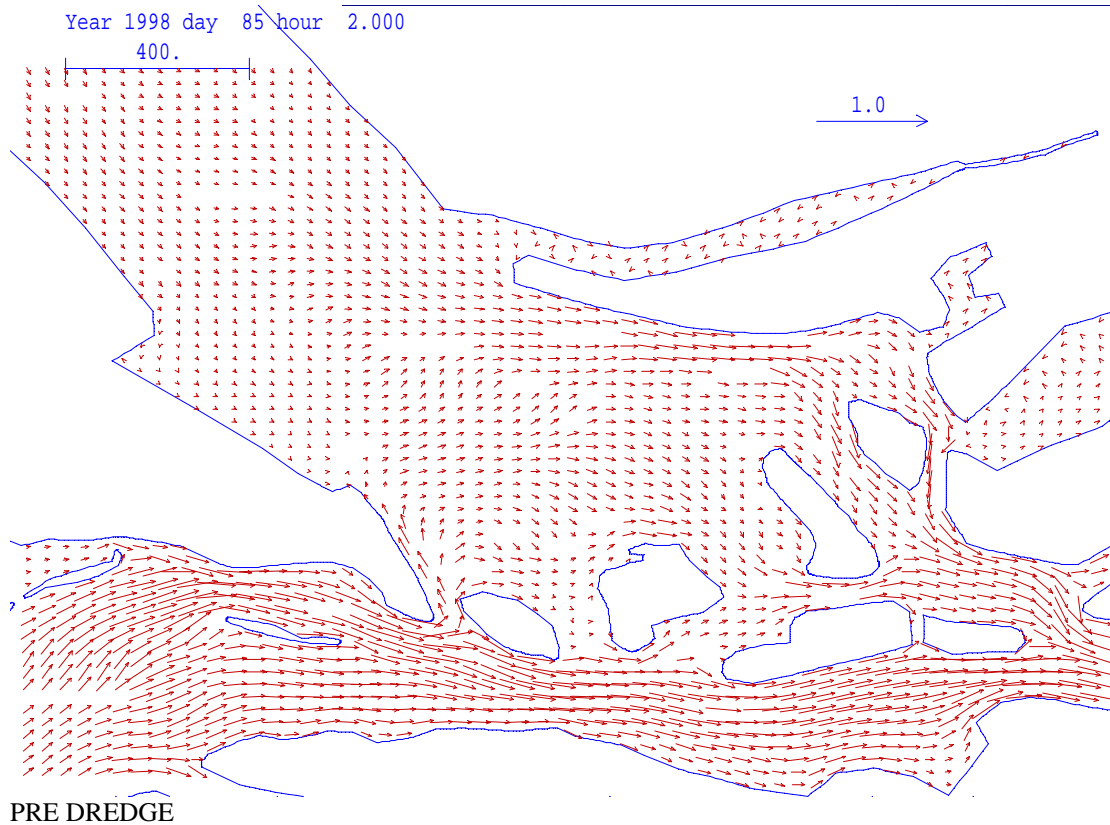


Vectors of total velocity (m/s). Scale arrow of 1 m/s in top right corner.

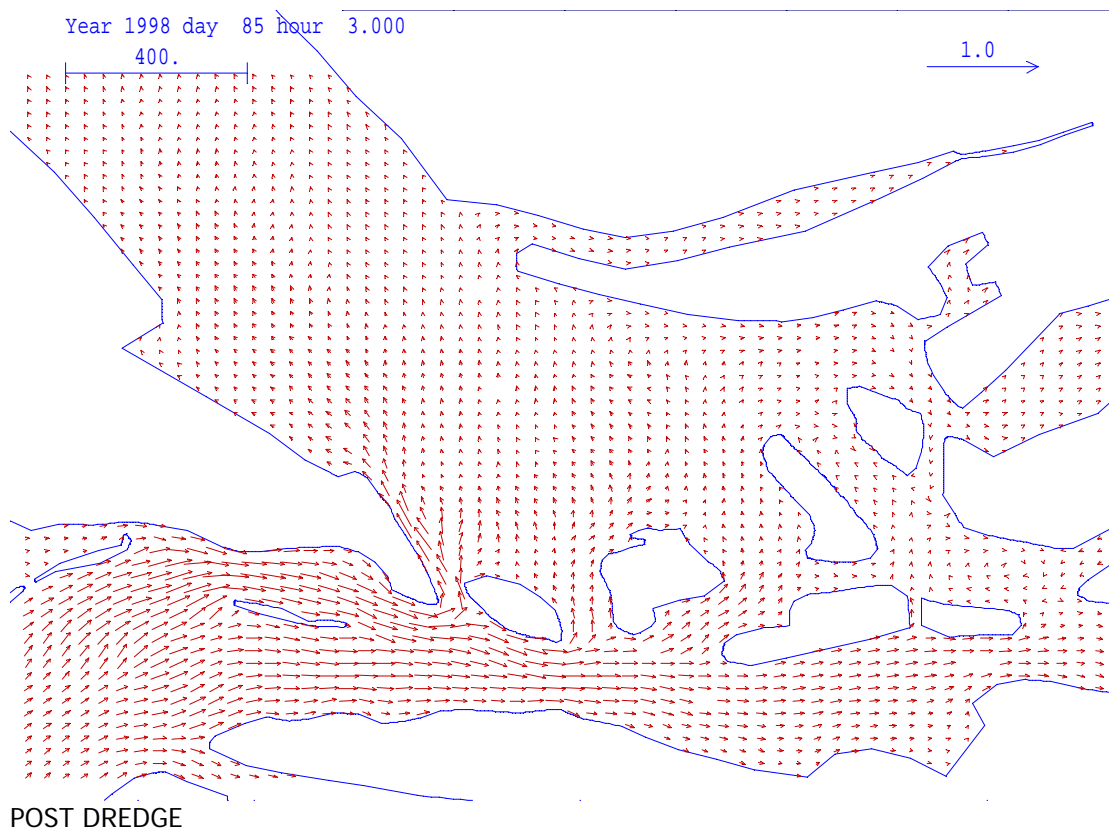
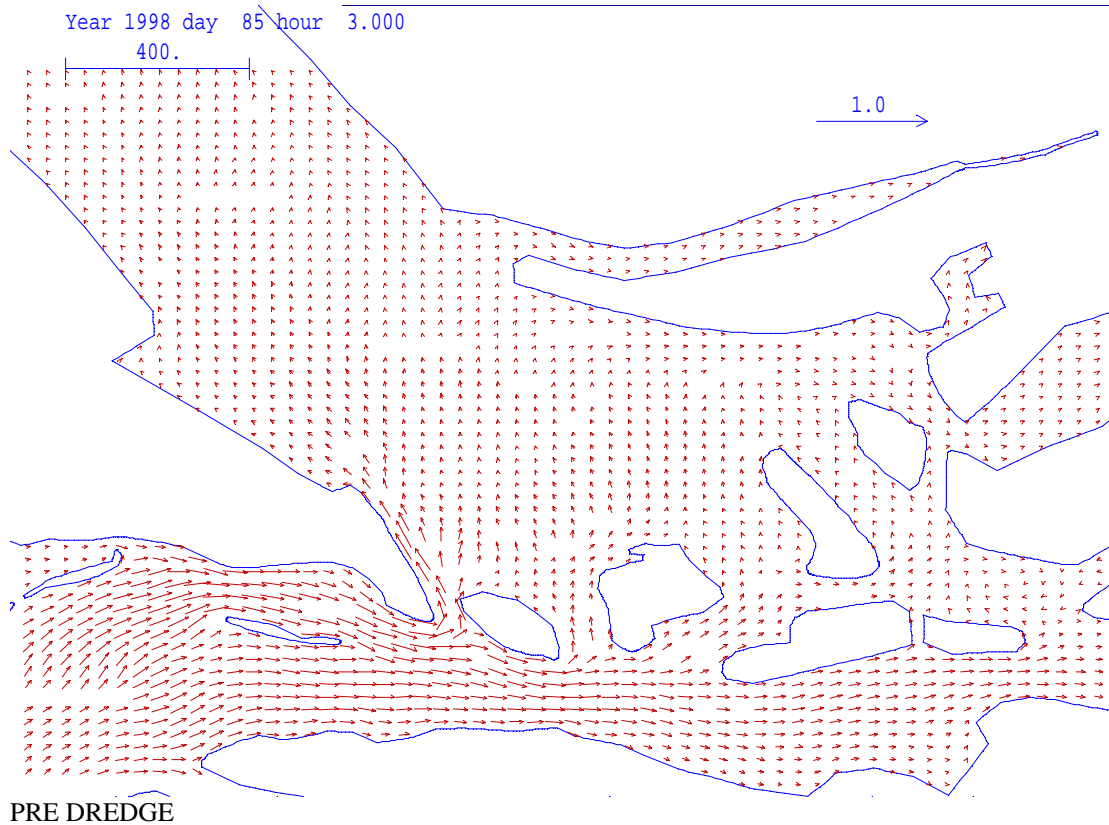


Vectors of total velocity (m/s). Scale arrow of 1 m/s in top right corner.

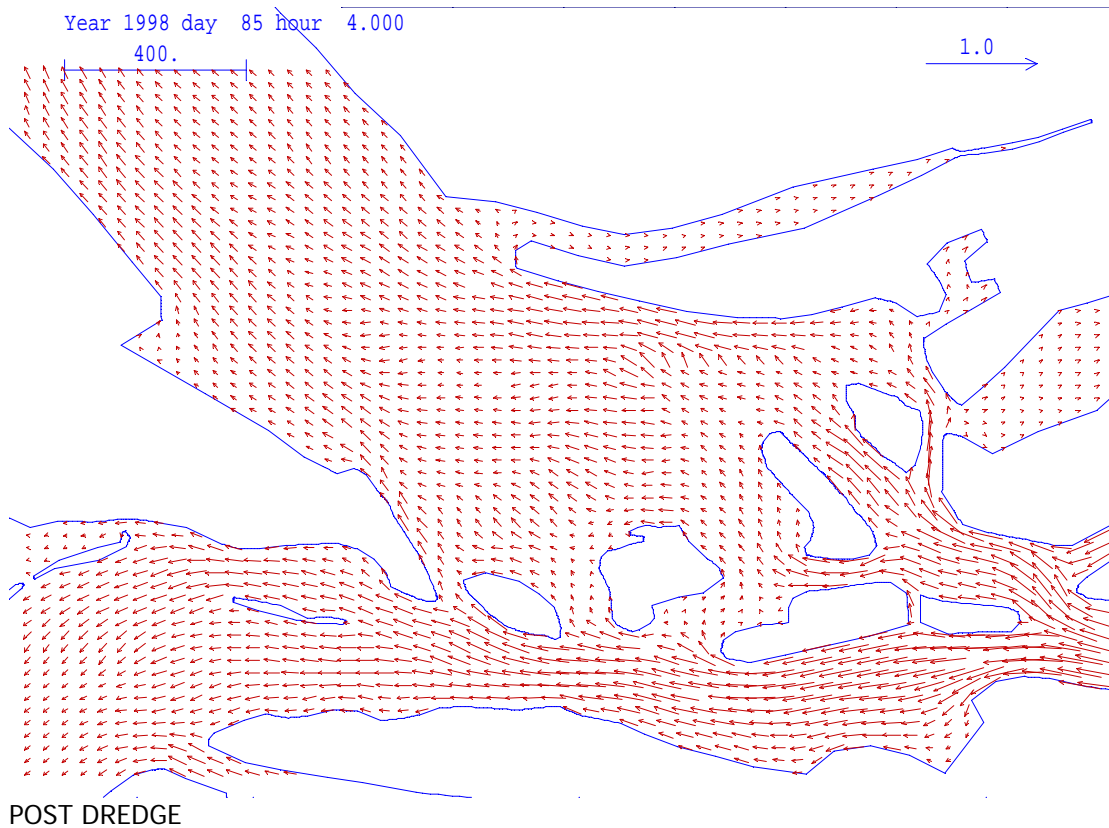
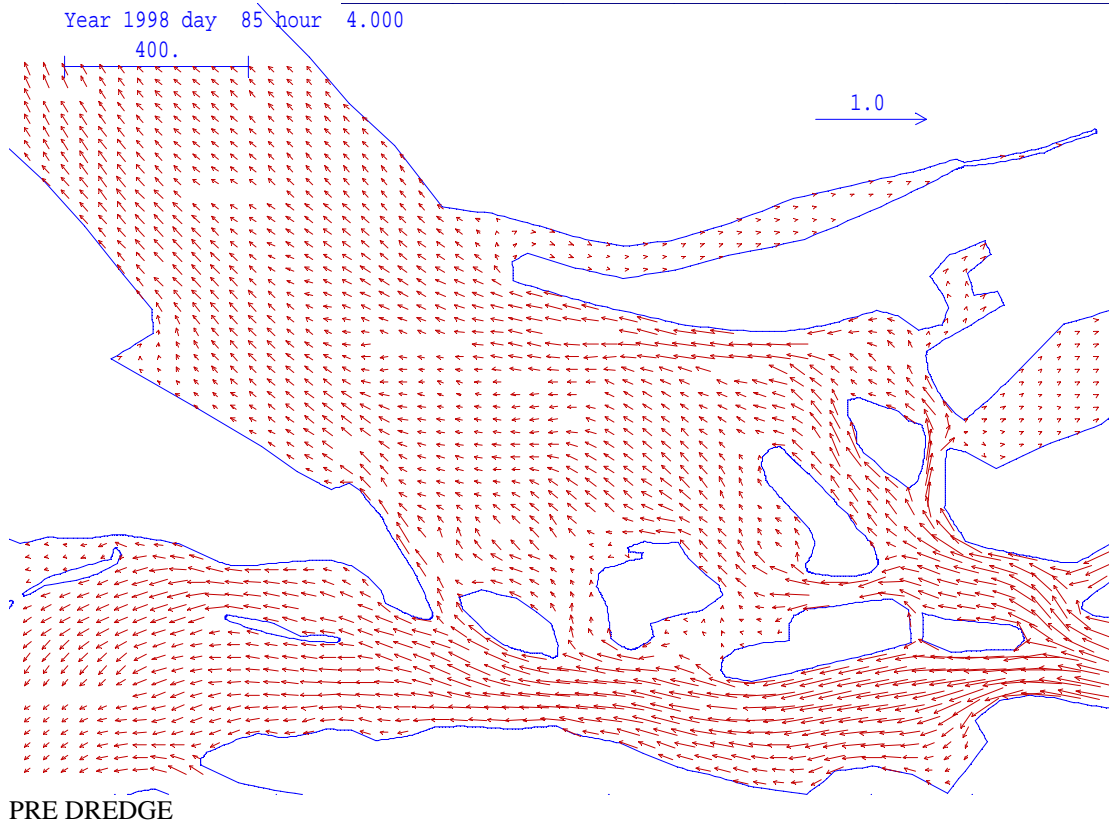




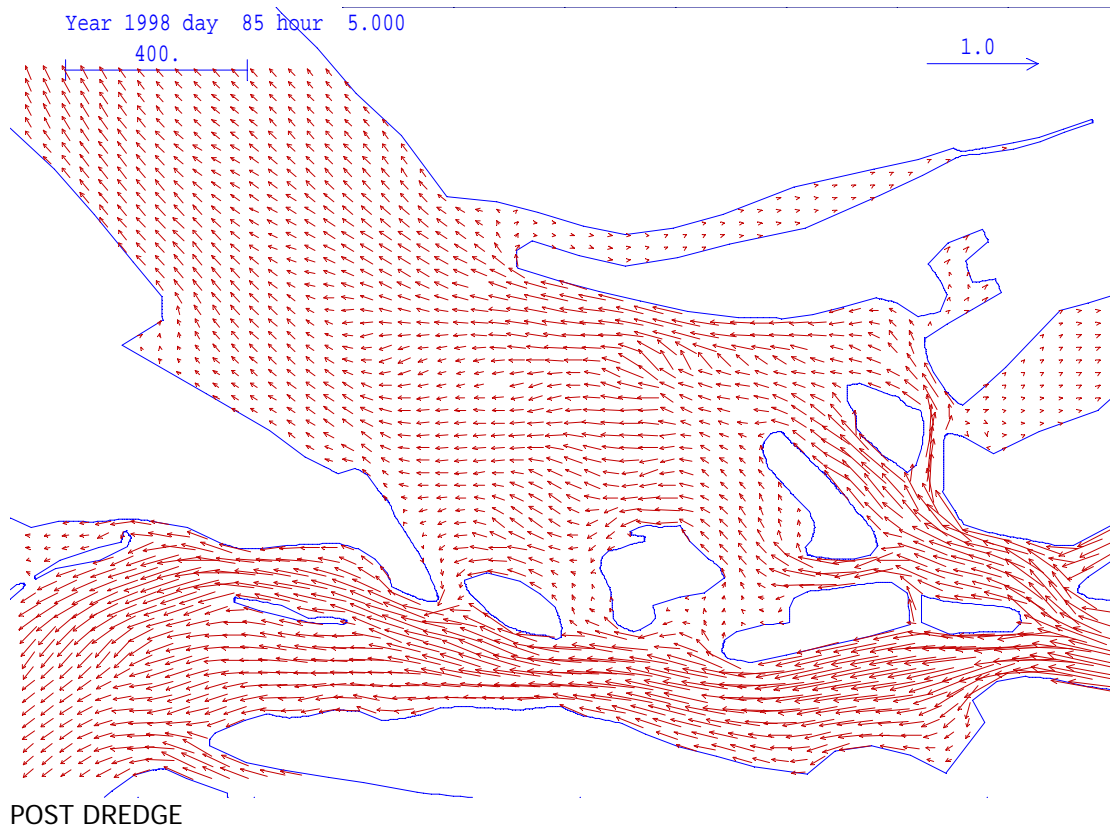
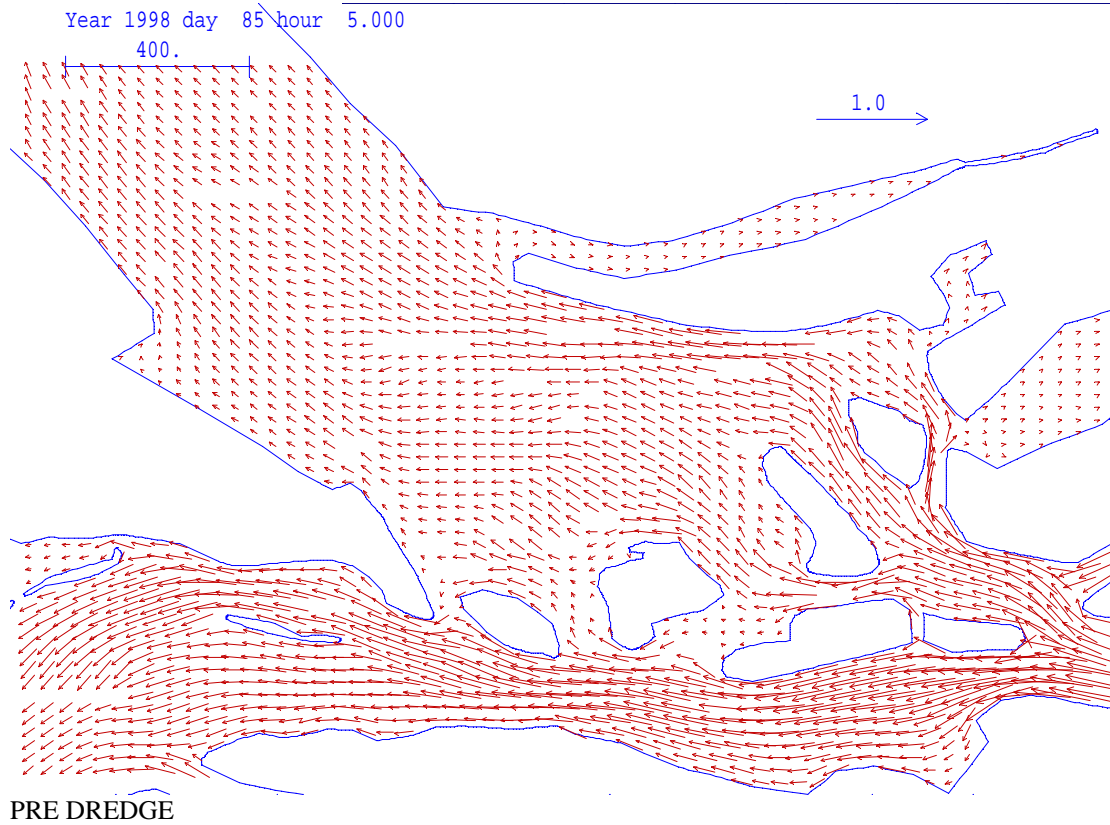
Vectors of total velocity (m/s). Scale arrow of 1 m/s in top right corner.



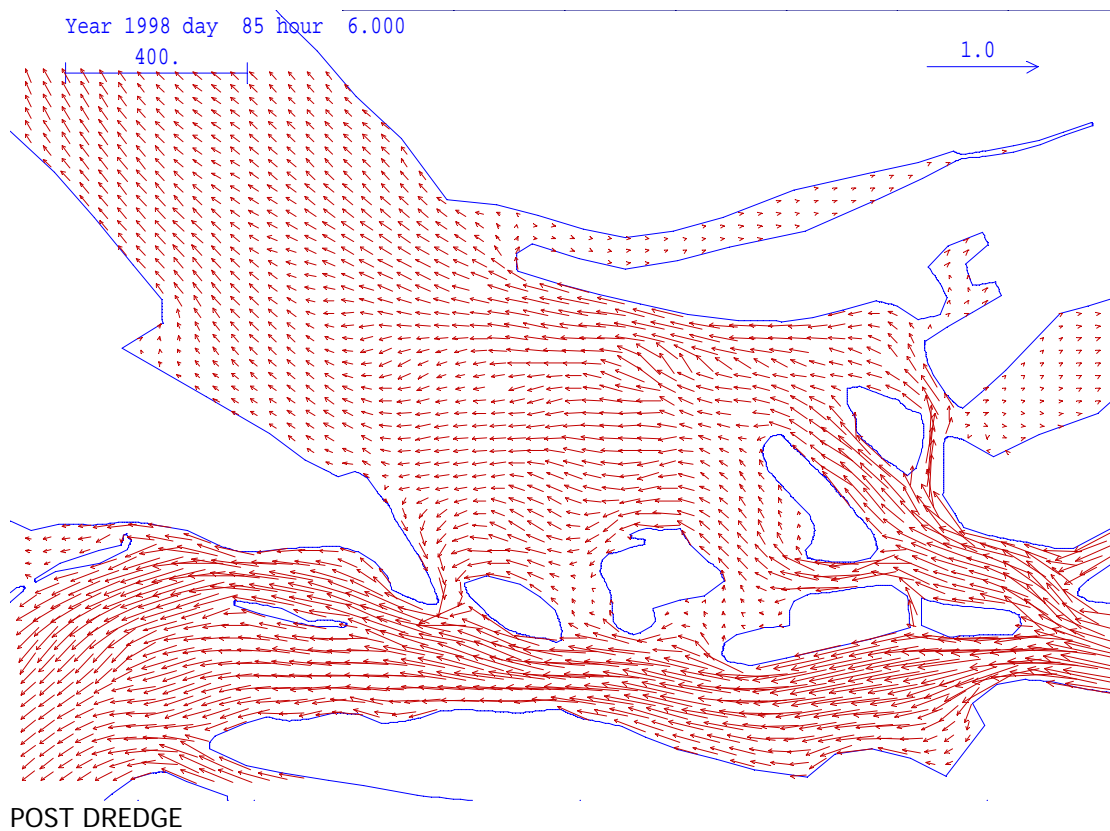
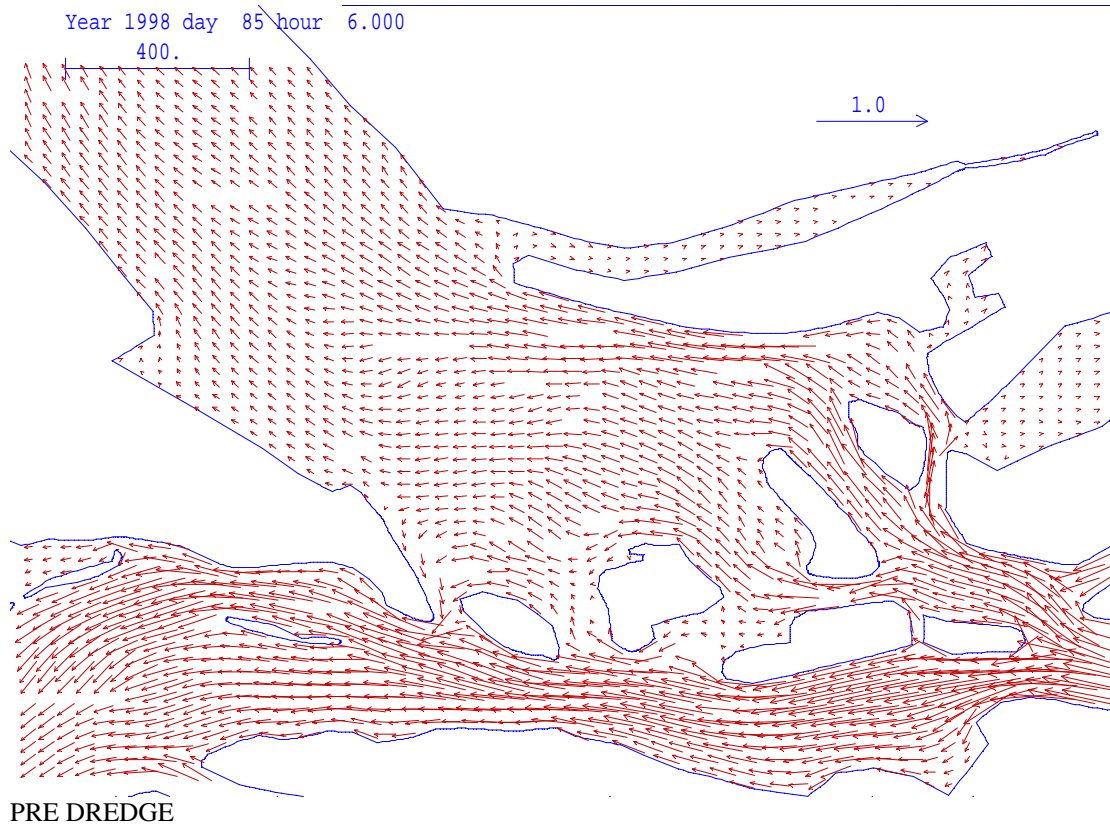
Vectors of total velocity (m/s). Scale arrow of 1 m/s in top right corner.



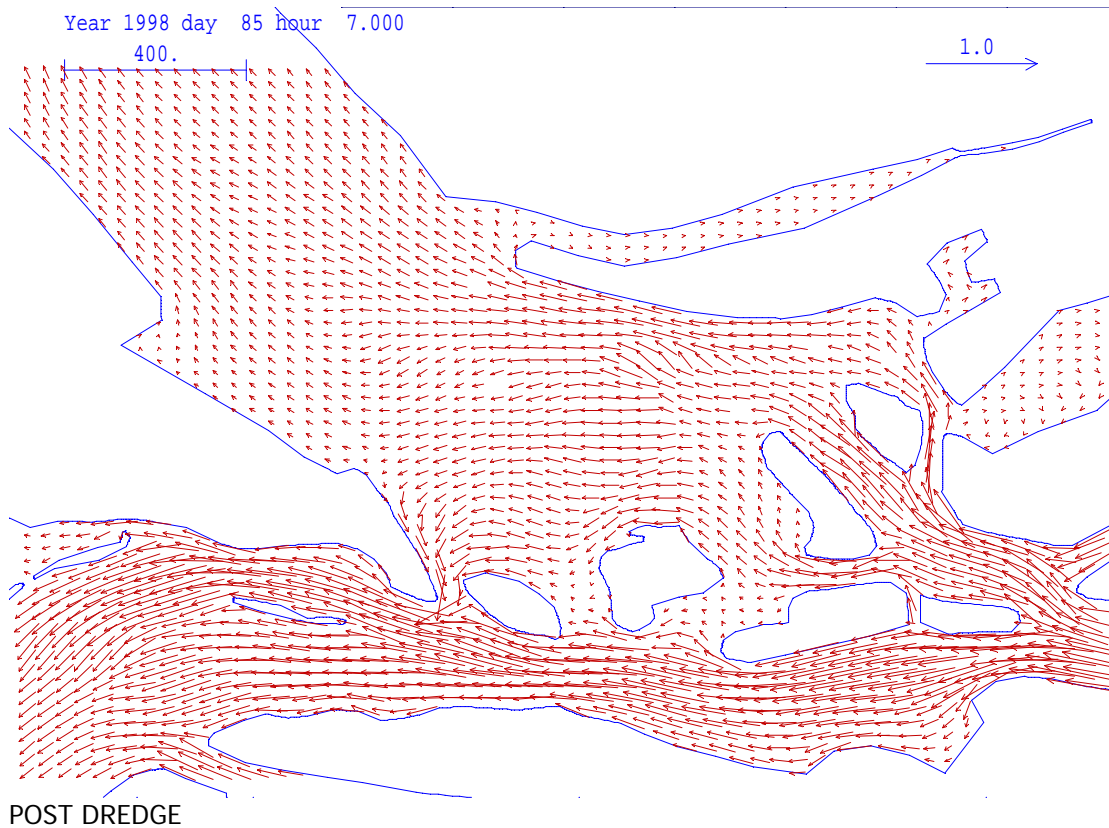
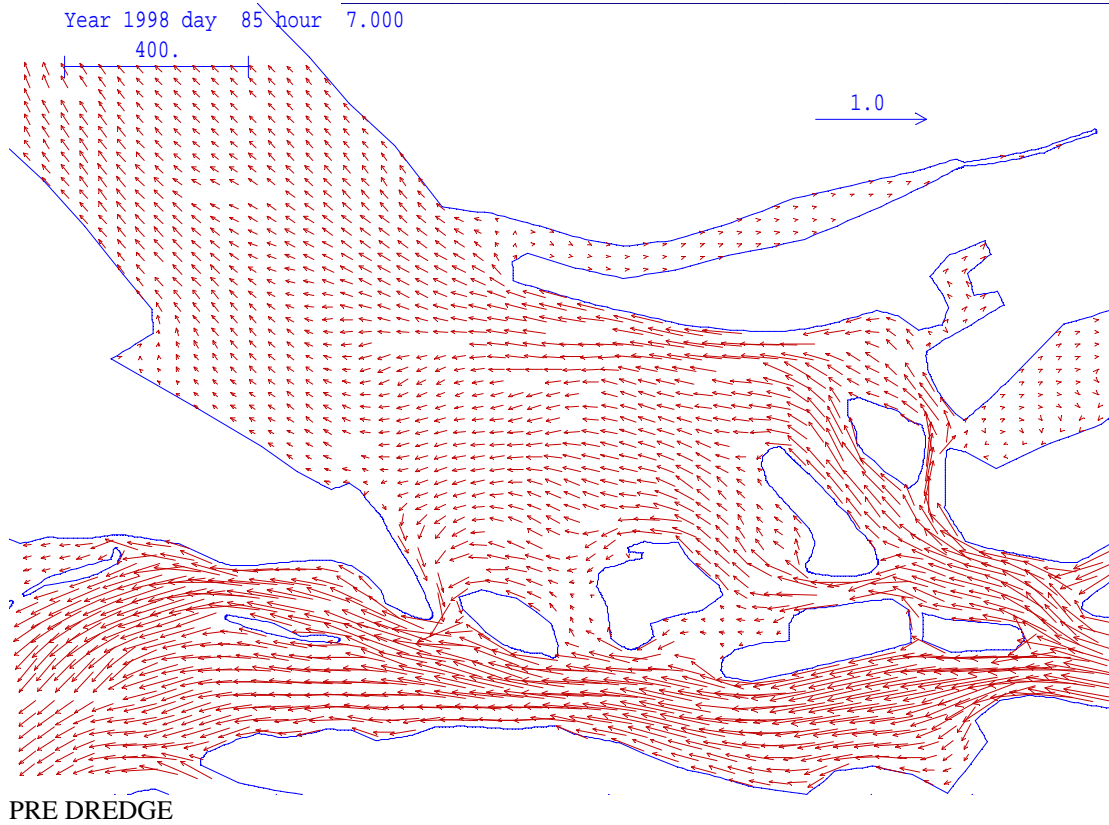
Vectors of total velocity (m/s). Scale arrow of 1 m/s in top right corner.



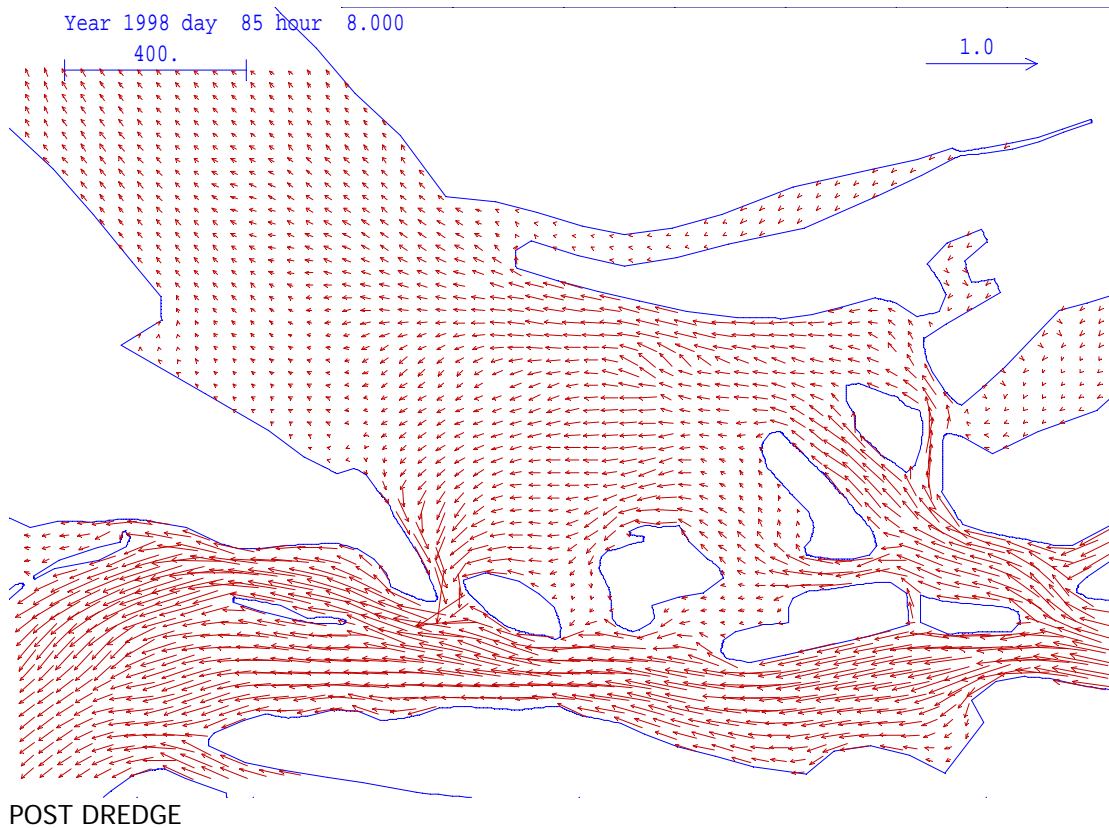
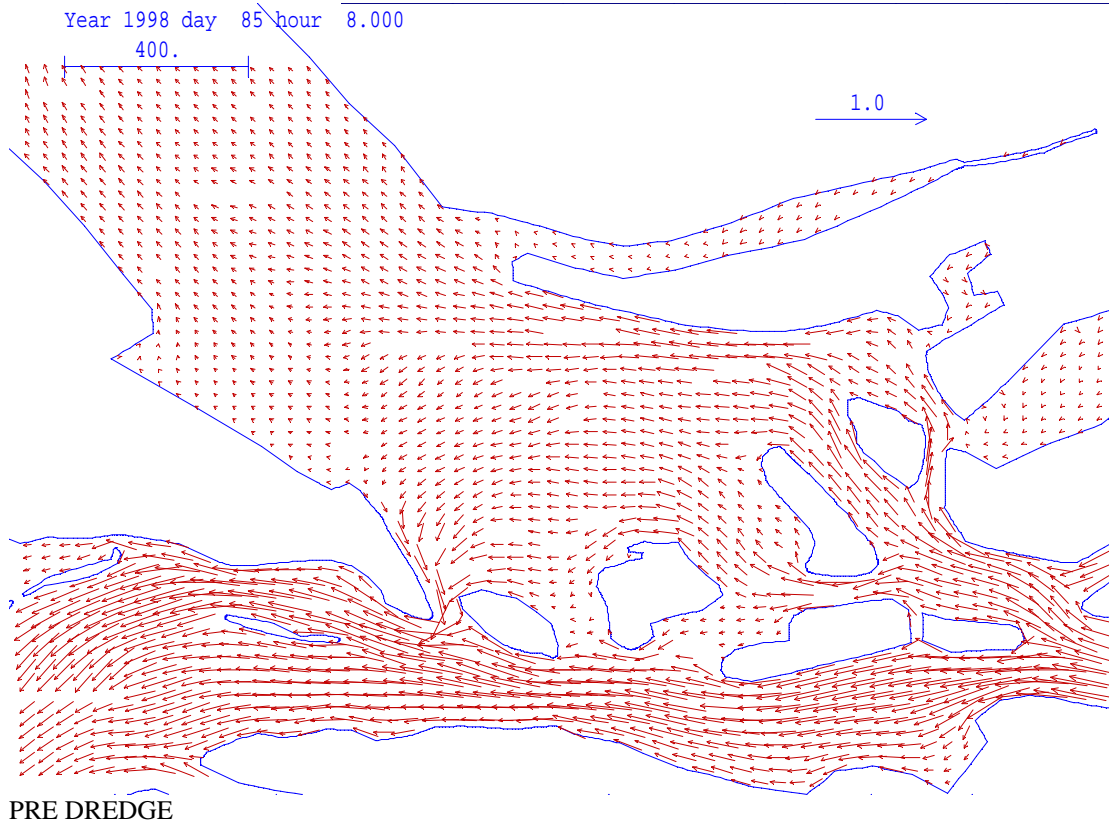
Vectors of total velocity (m/s). Scale arrow of 1 m/s in top right corner.



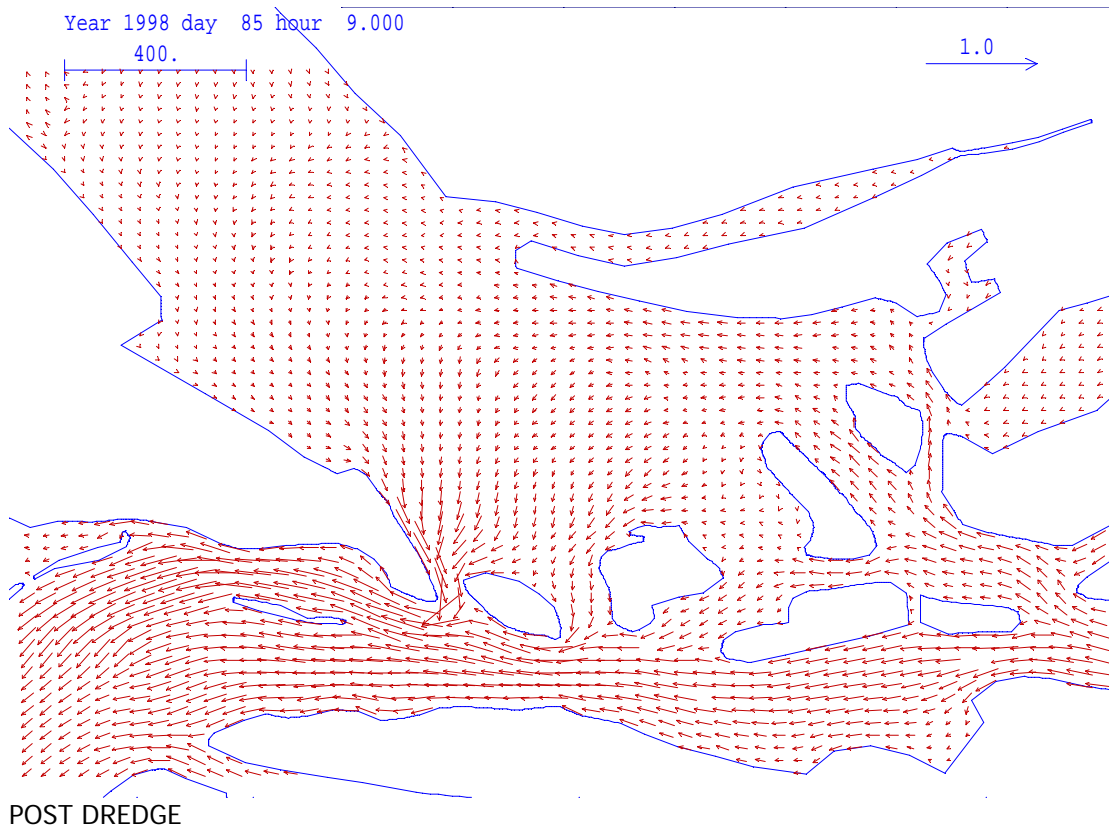
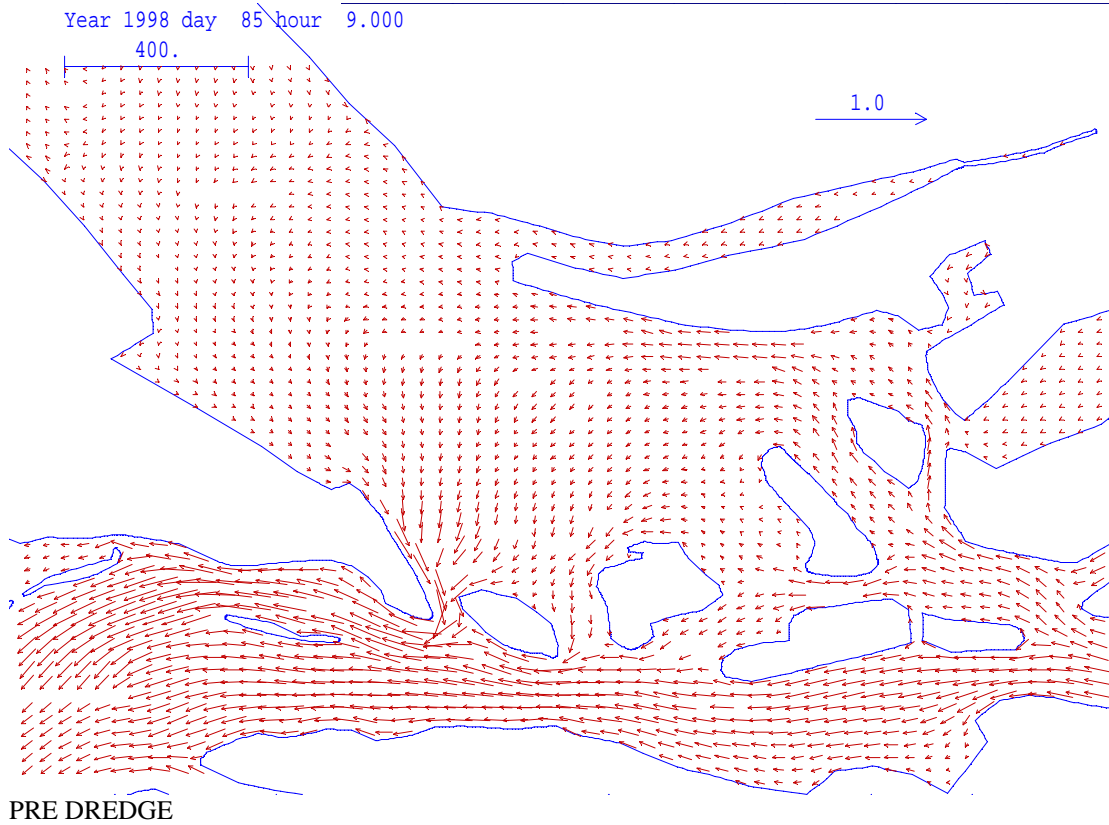
Vectors of total velocity (m/s). Scale arrow of 1 m/s in top right corner.



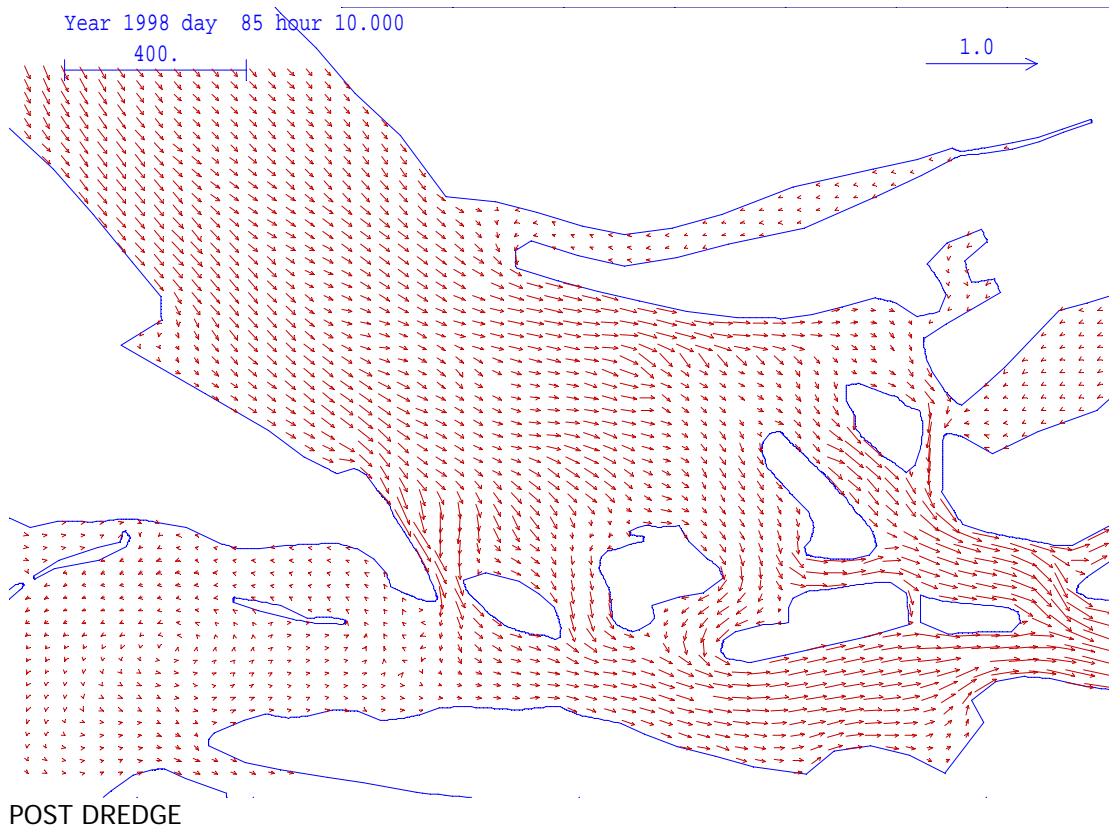
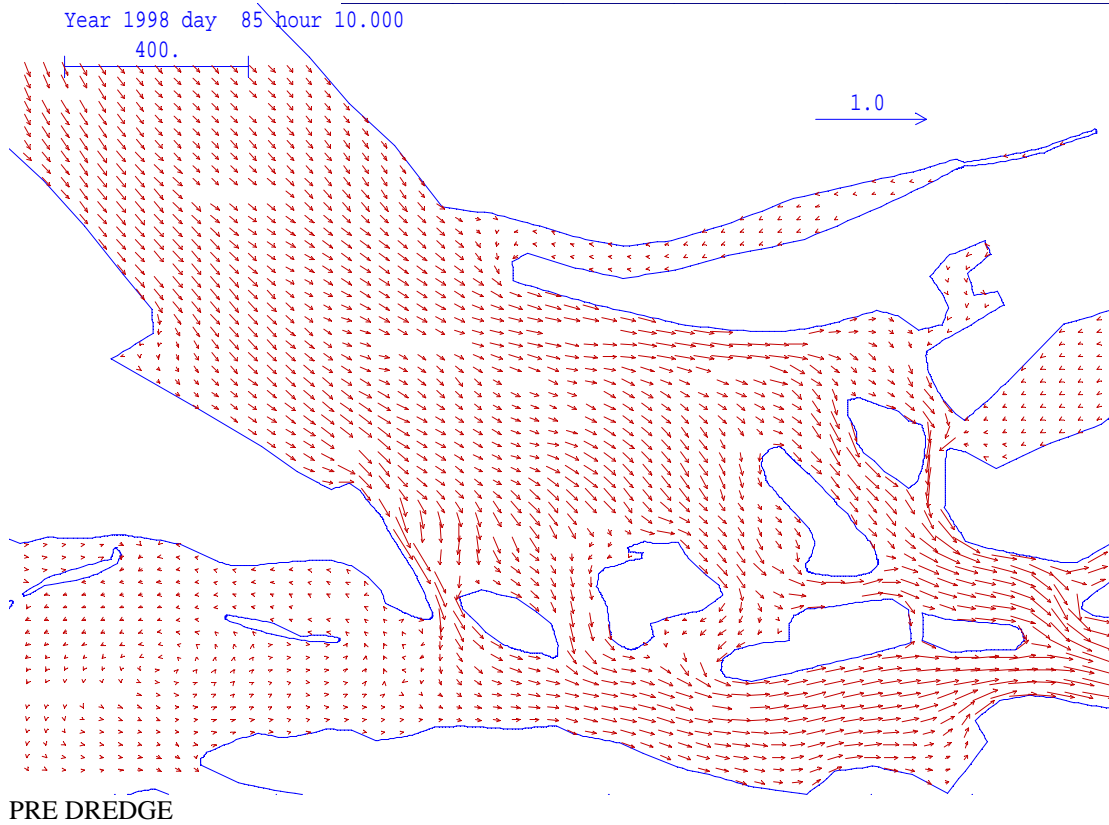
Vectors of total velocity (m/s). Scale arrow of 1 m/s in top right corner.



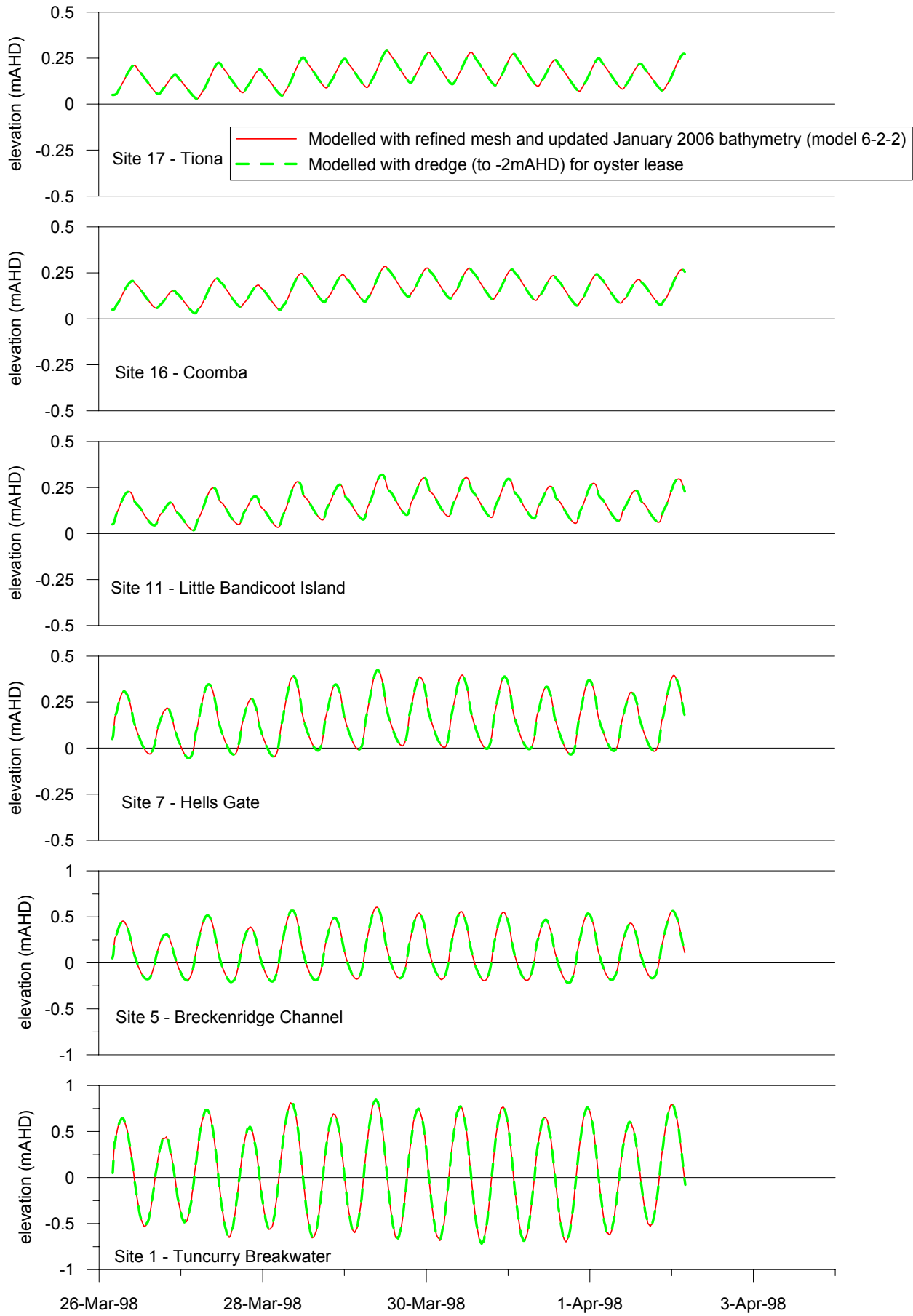
Vectors of total velocity (m/s). Scale arrow of 1 m/s in top right corner.

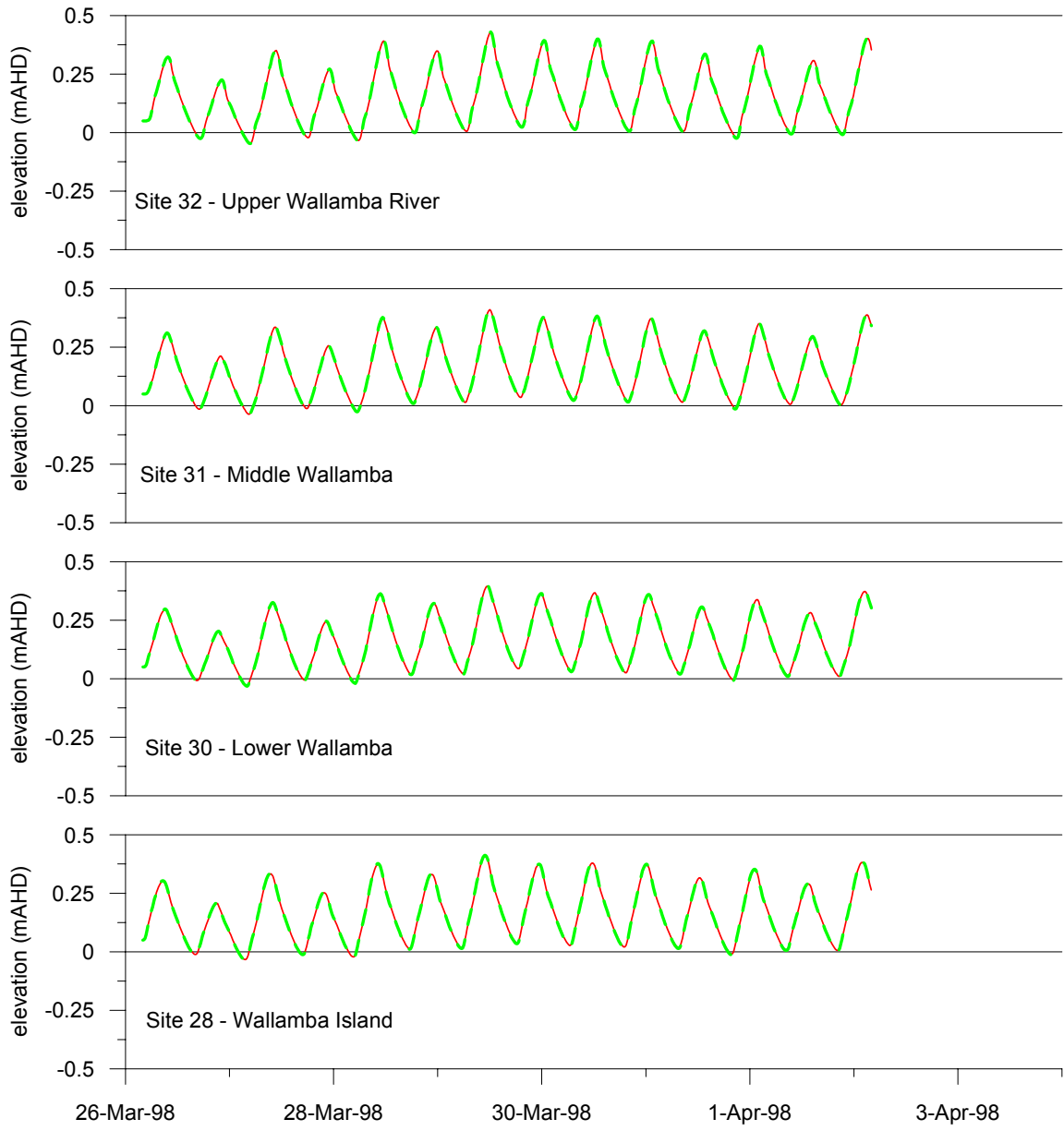


Vectors of total velocity (m/s). Scale arrow of 1 m/s in top right corner.

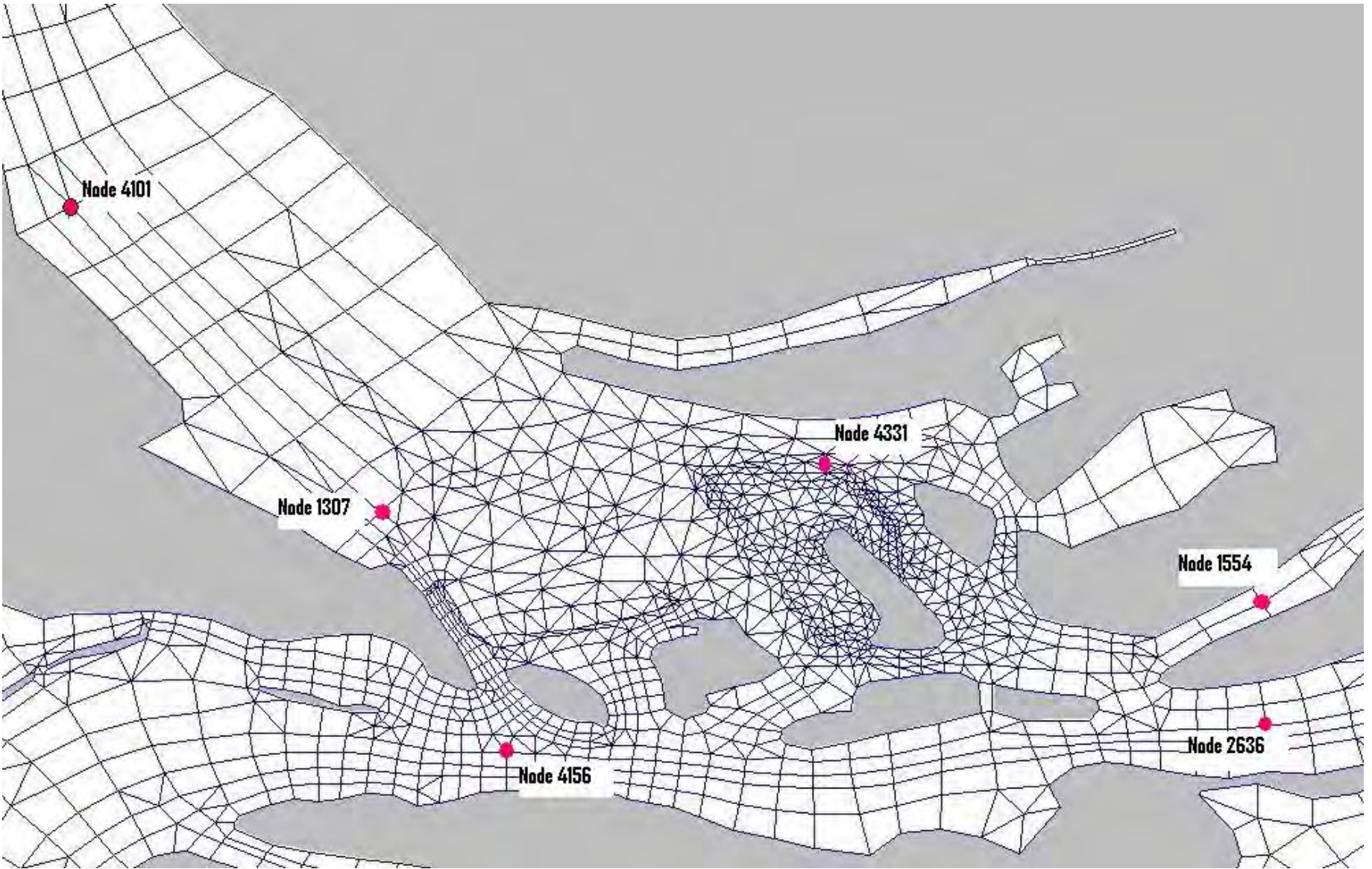


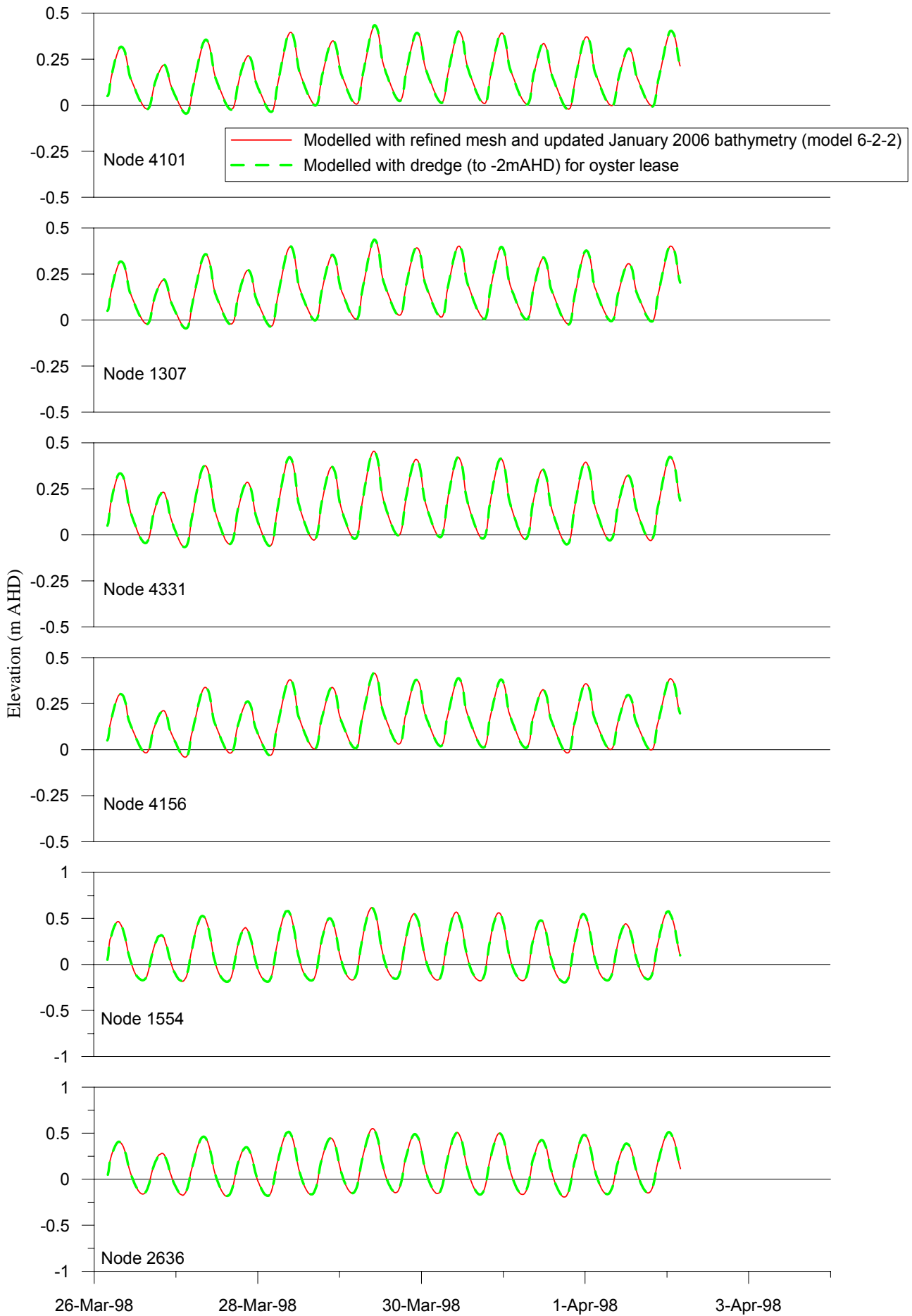
Vectors of total velocity (m/s). Scale arrow of 1 m/s in top right corner.

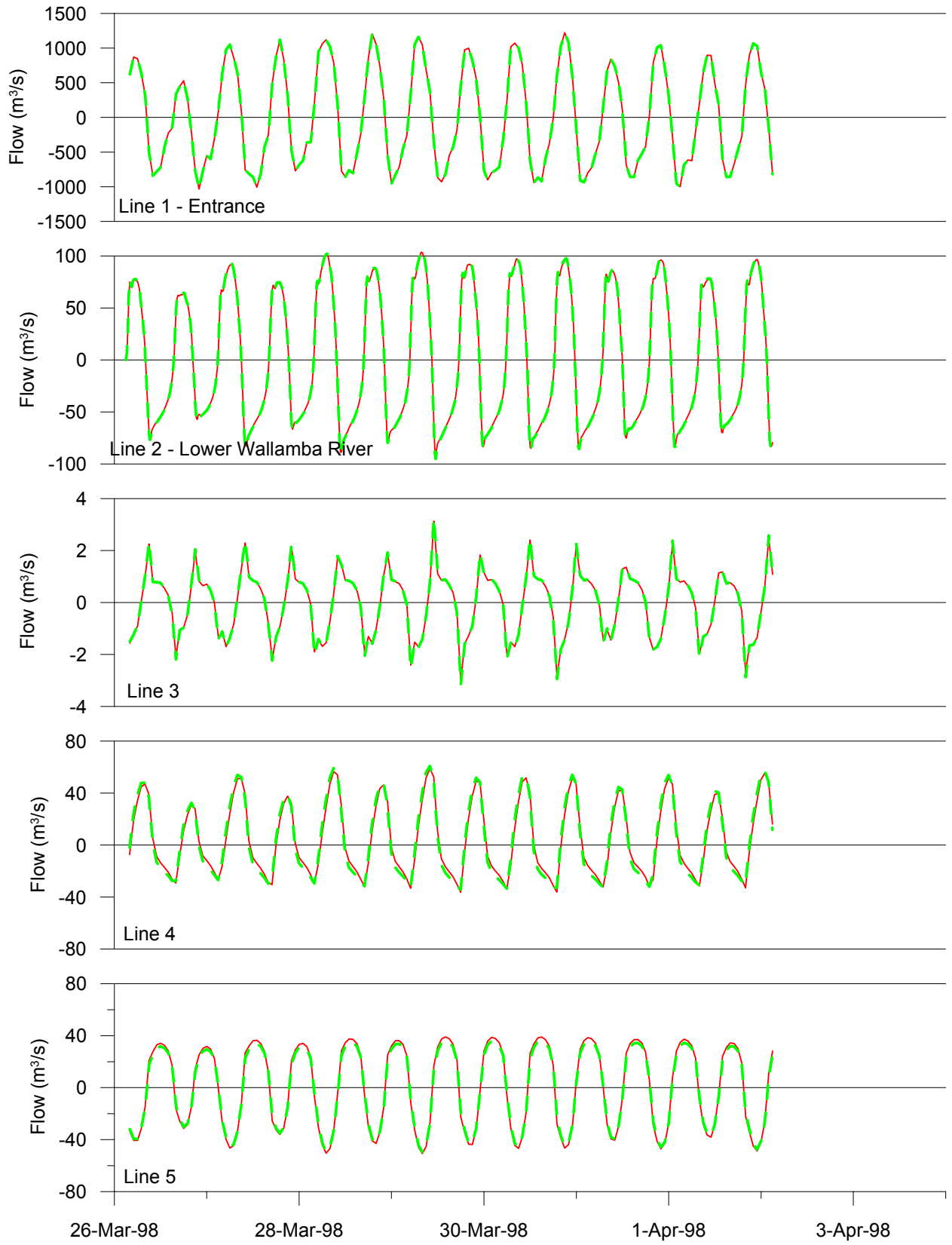




— Modelled with refined mesh and updated January 2006 bathymetry (model 6-2-2)
- - - Modelled with dredge (to -2mAHD) for oyster lease

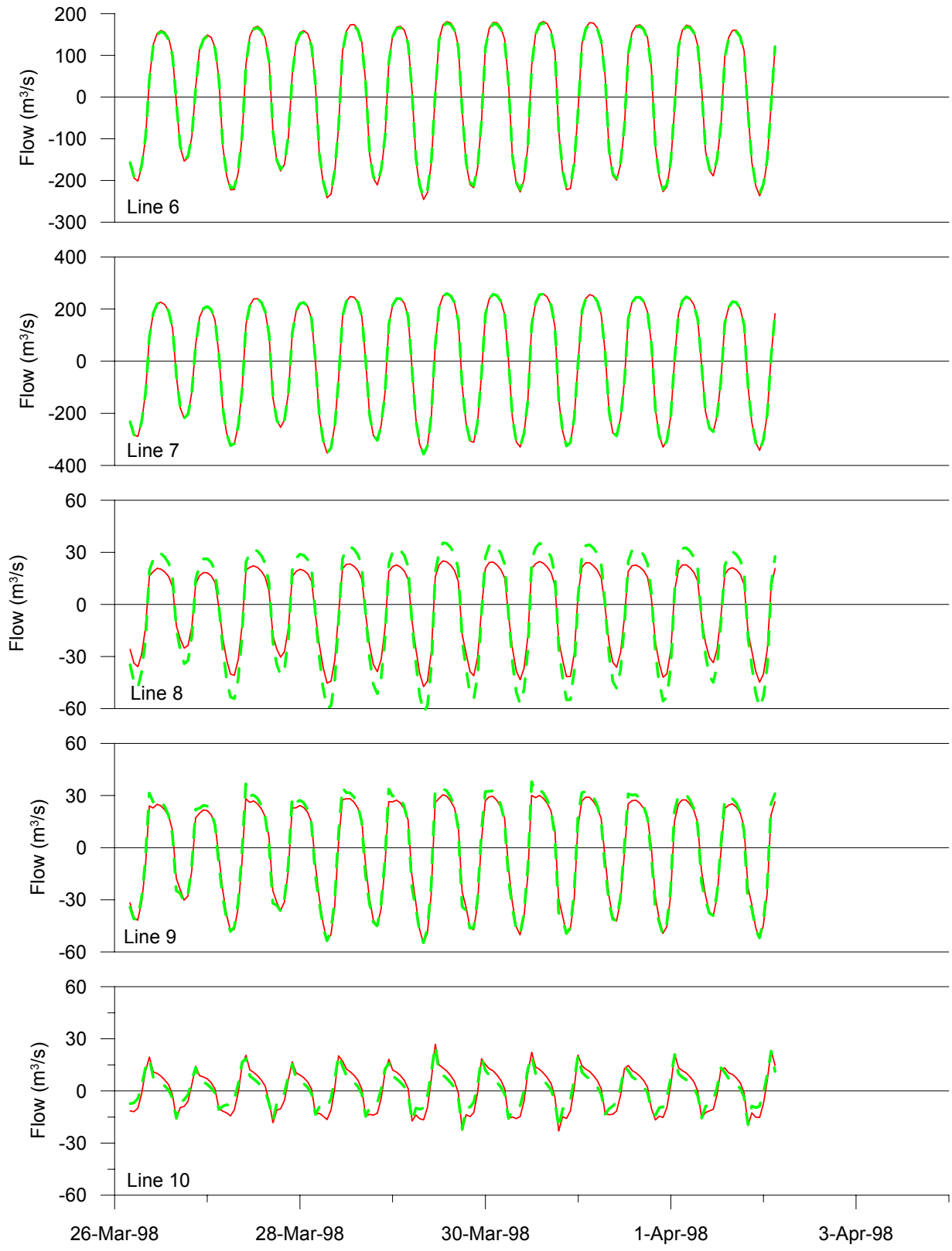






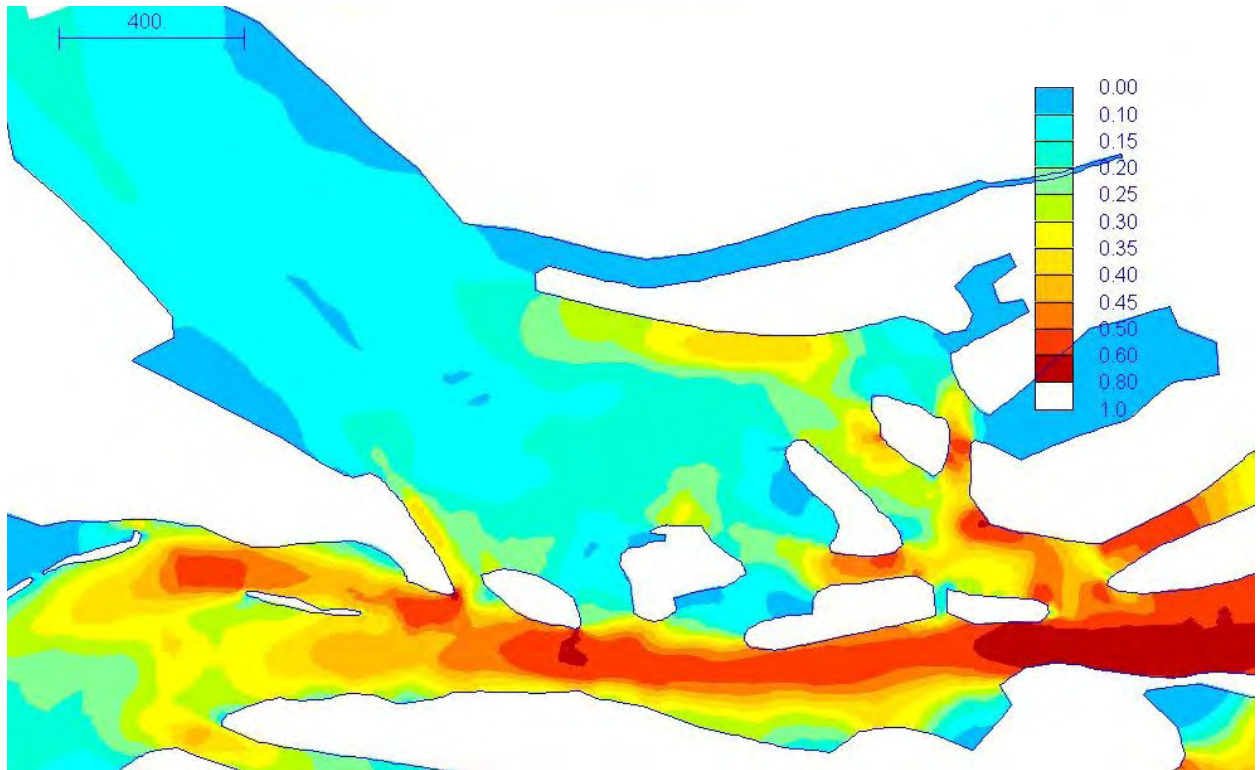
— Modelled with refined mesh and updated January 2006 bathymetry (model 6-2-2)
 - - - Modelled with dredge (to -2mAHD) for oyster lease

Note: Positive flow is upstream

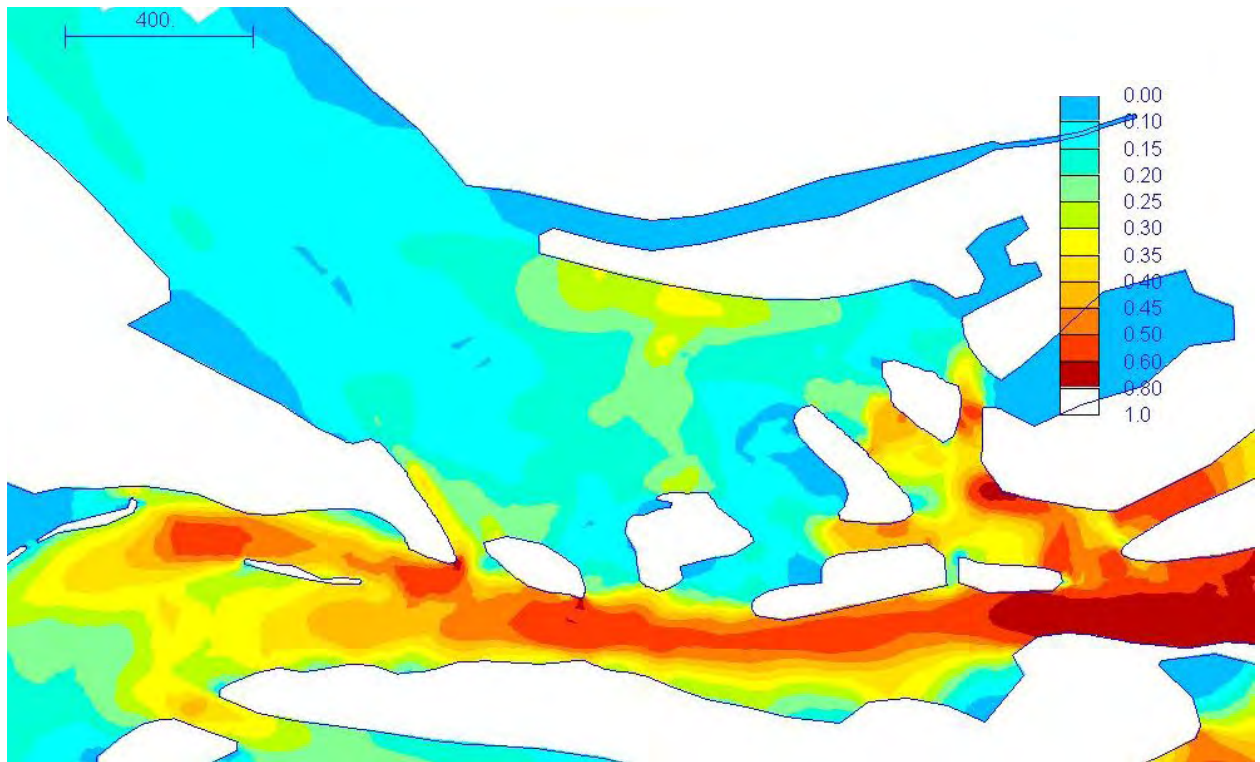


— Modelled with refined mesh and updated January 2006 bathymetry (model 6-2-2)
- - - Modelled with dredge (to -2m AHD) for oyster lease

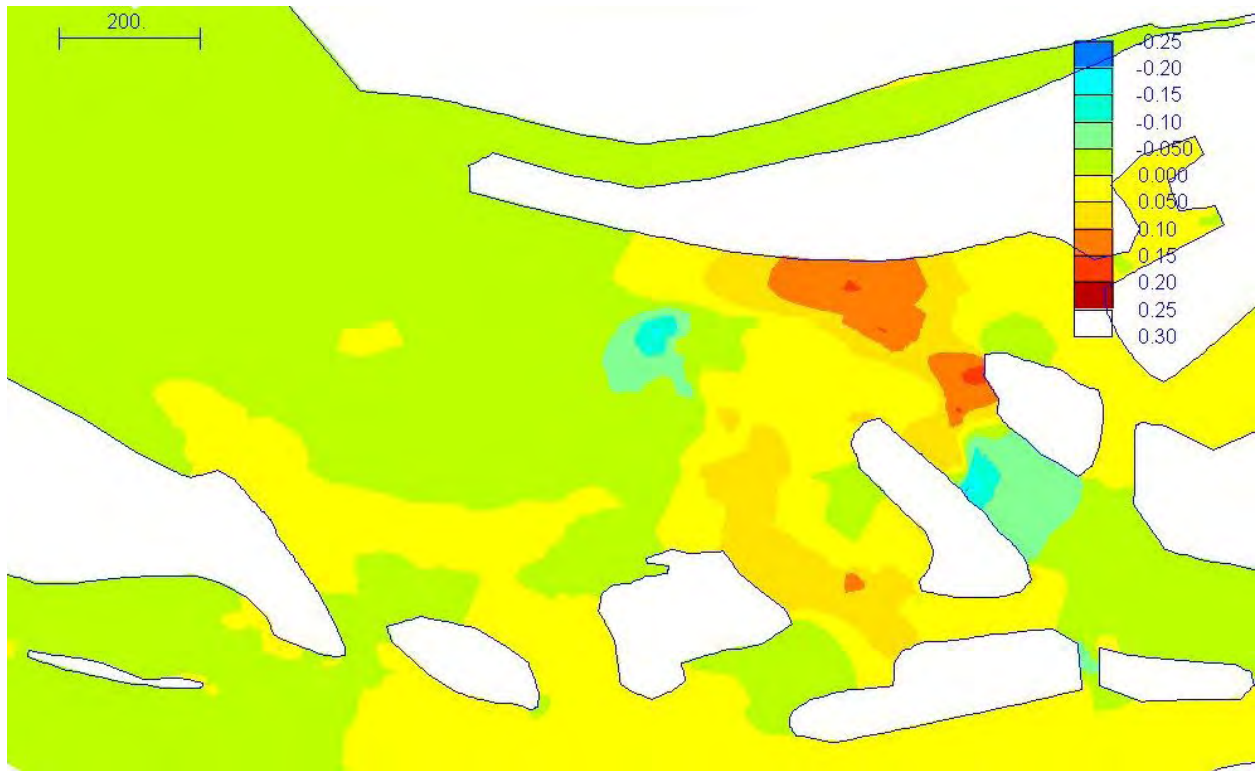
Note: Positive flow is upstream



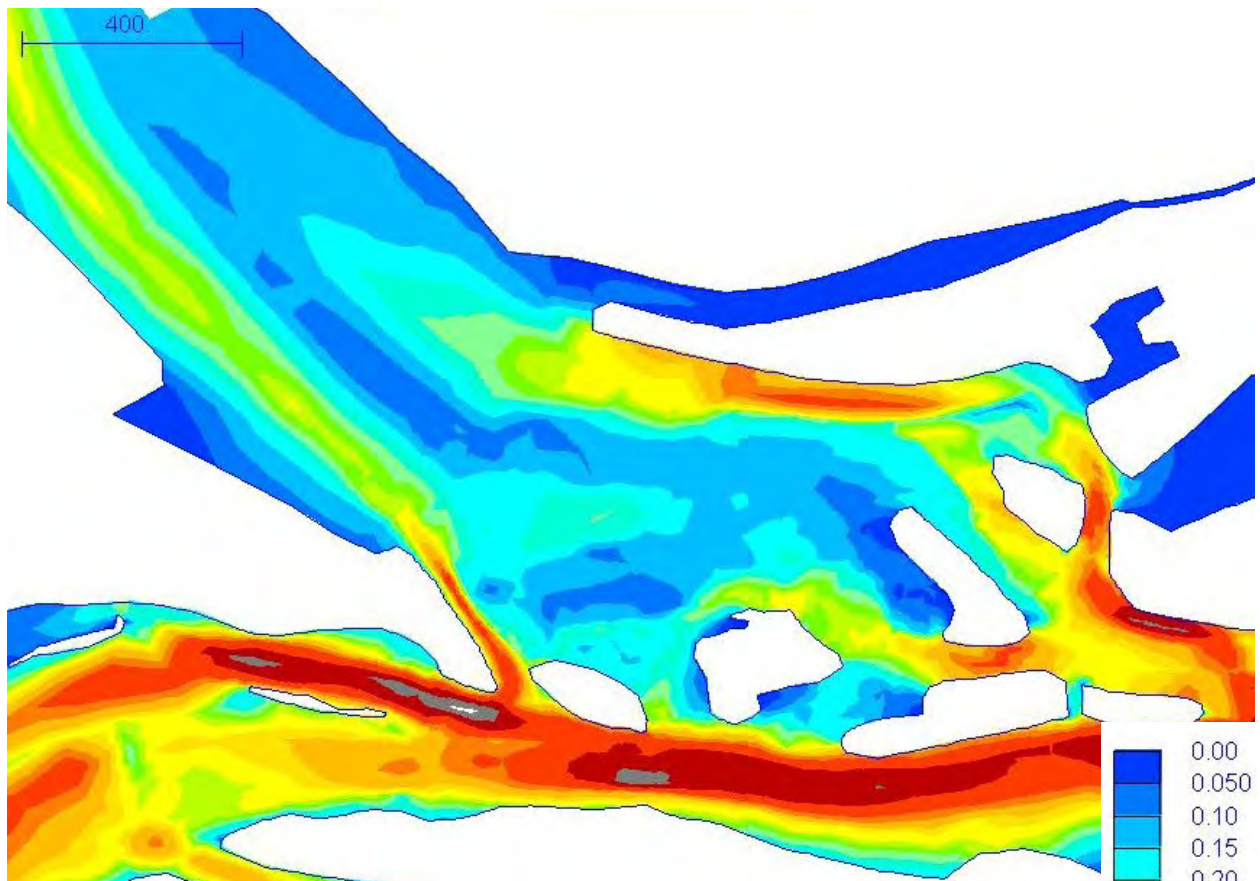
(a) Pre-dredge site. Velocity in m/s



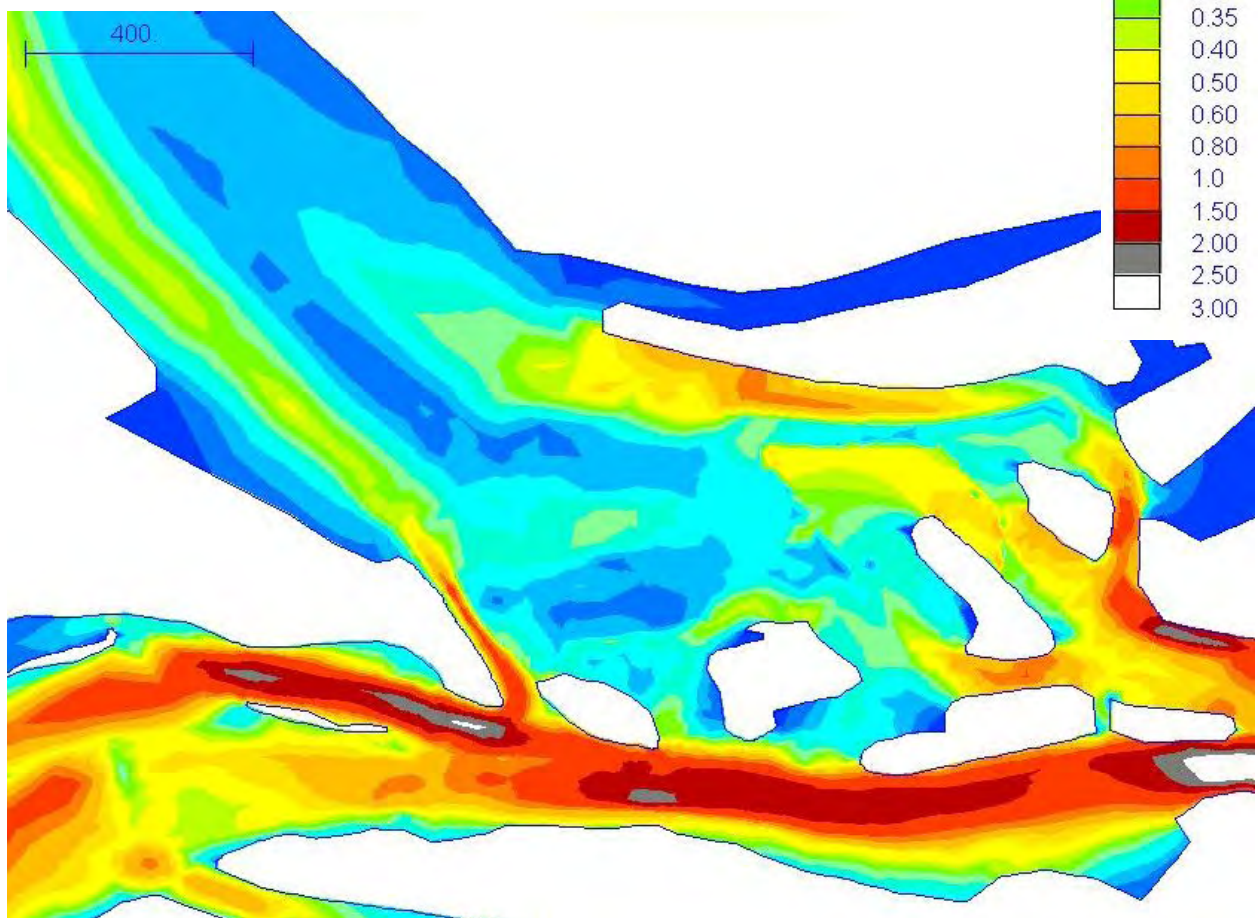
(b) Post dredge. Velocity in m/s.



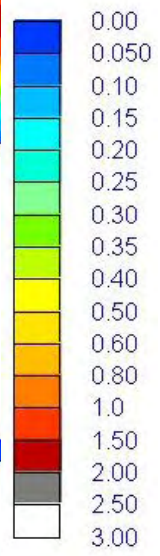
Contour units in m/s.
Negative difference is an increase in velocity from pre- to post dredge.

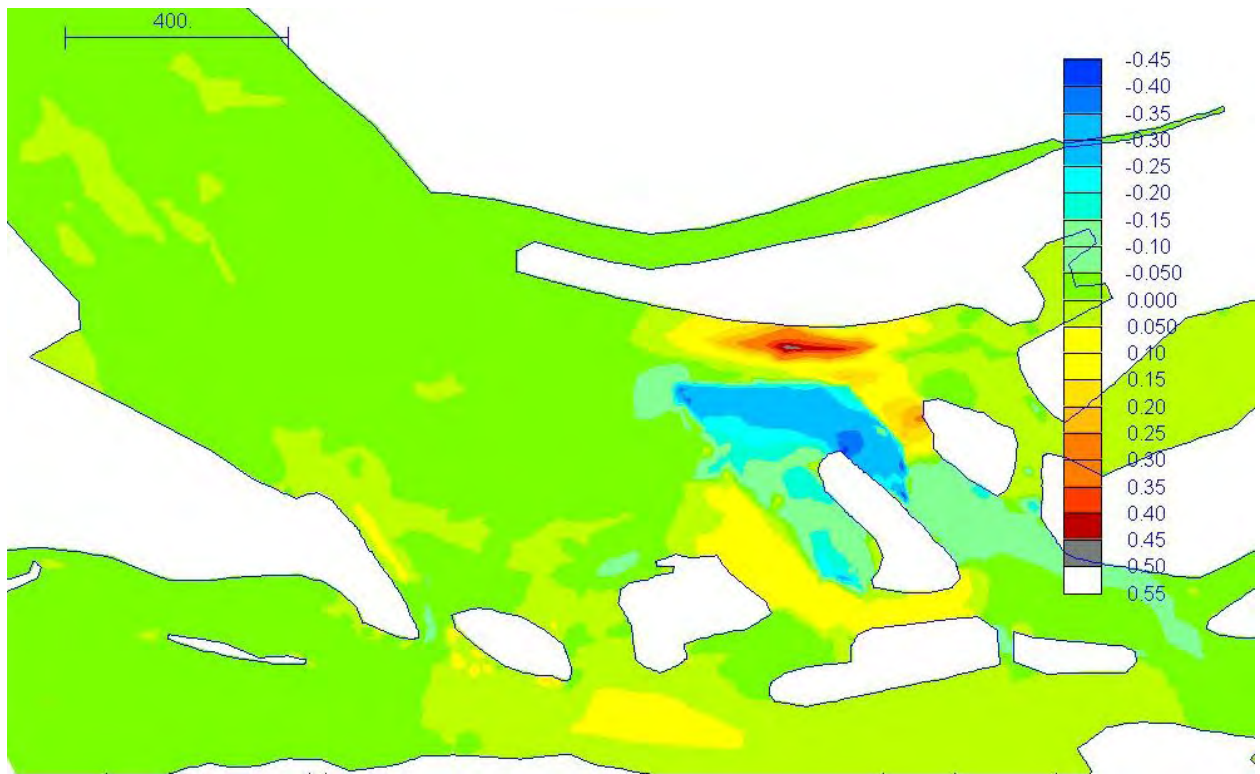


(a) Pre-dredge site. Flow in $\text{m}^3/\text{s}/\text{m}$

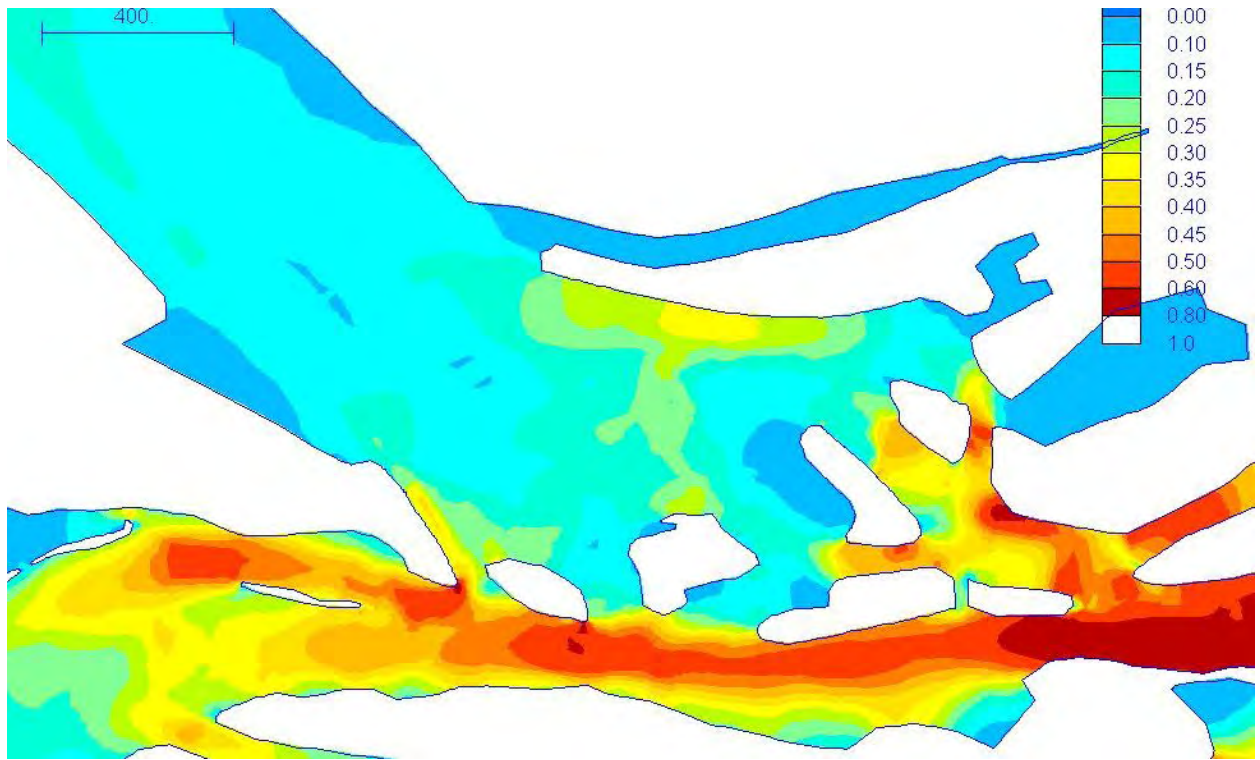


(b) Post 2m dredge for oyster lease. Flow in $\text{m}^3/\text{s}/\text{m}$

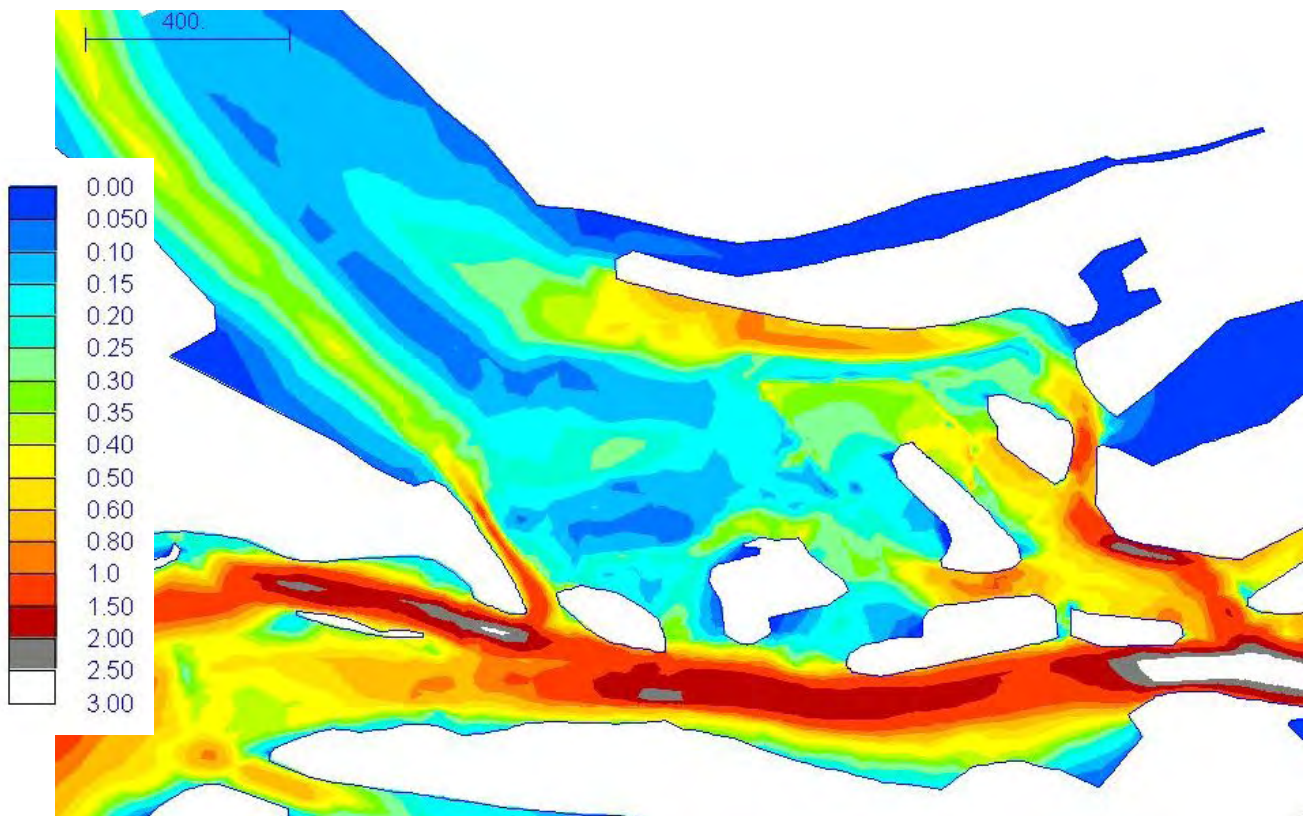




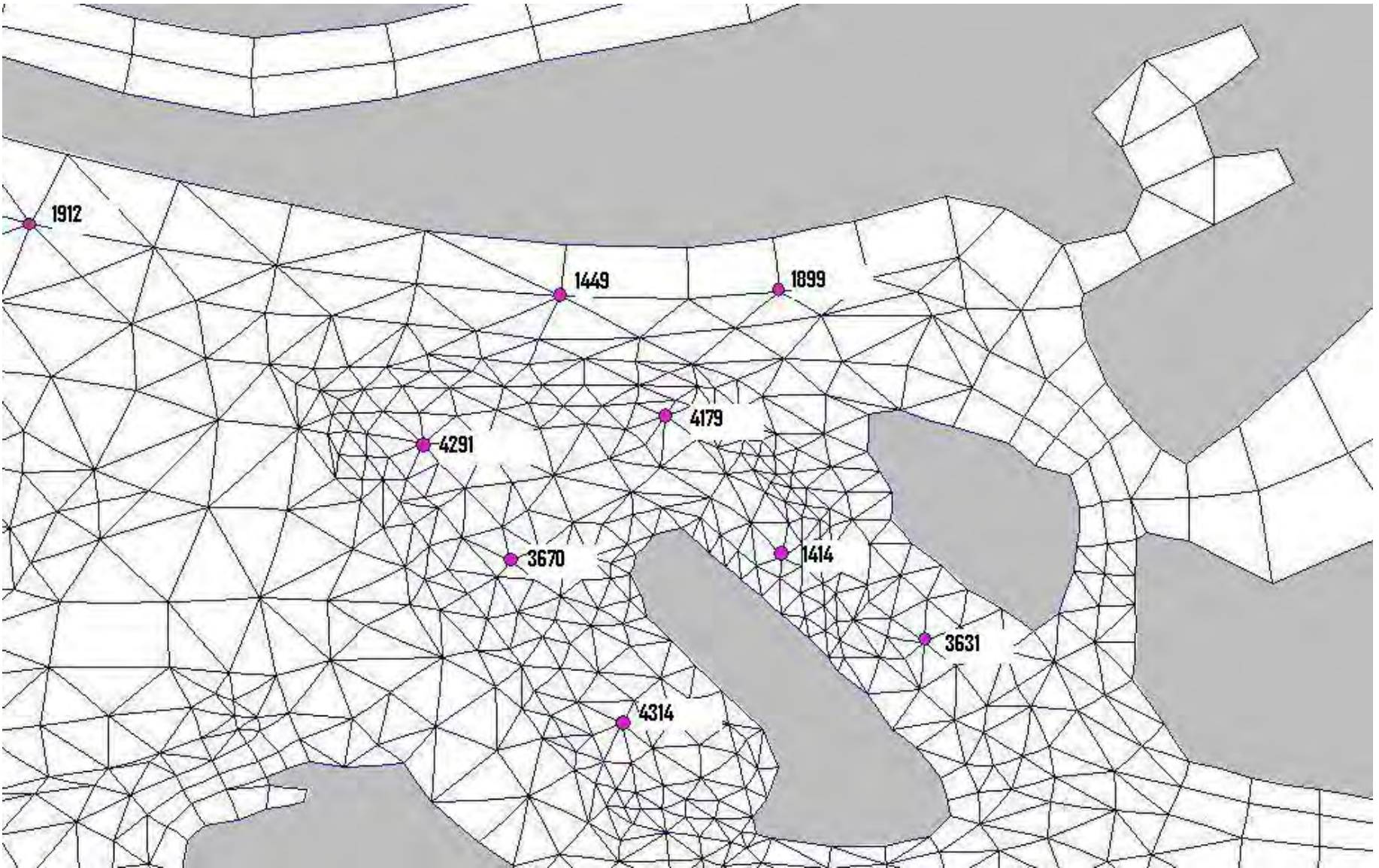
Contour units in $\text{m}^3/\text{s}/\text{m}$
 Negative difference is an increase in flow from pre- to post-dredge conditions.



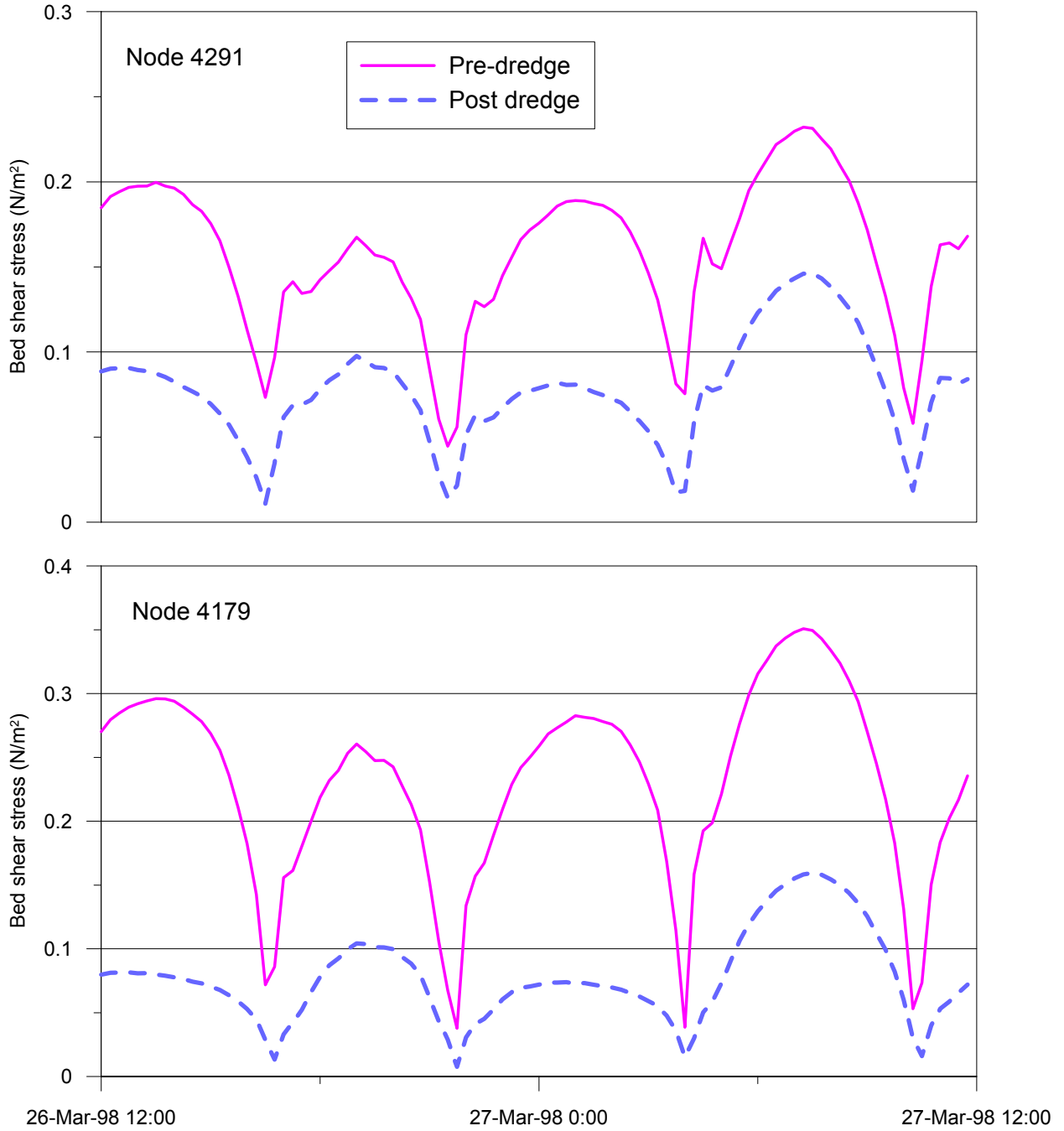
(a) Maximum velocity (m/s): Post dredge with increased roughness in dredge.



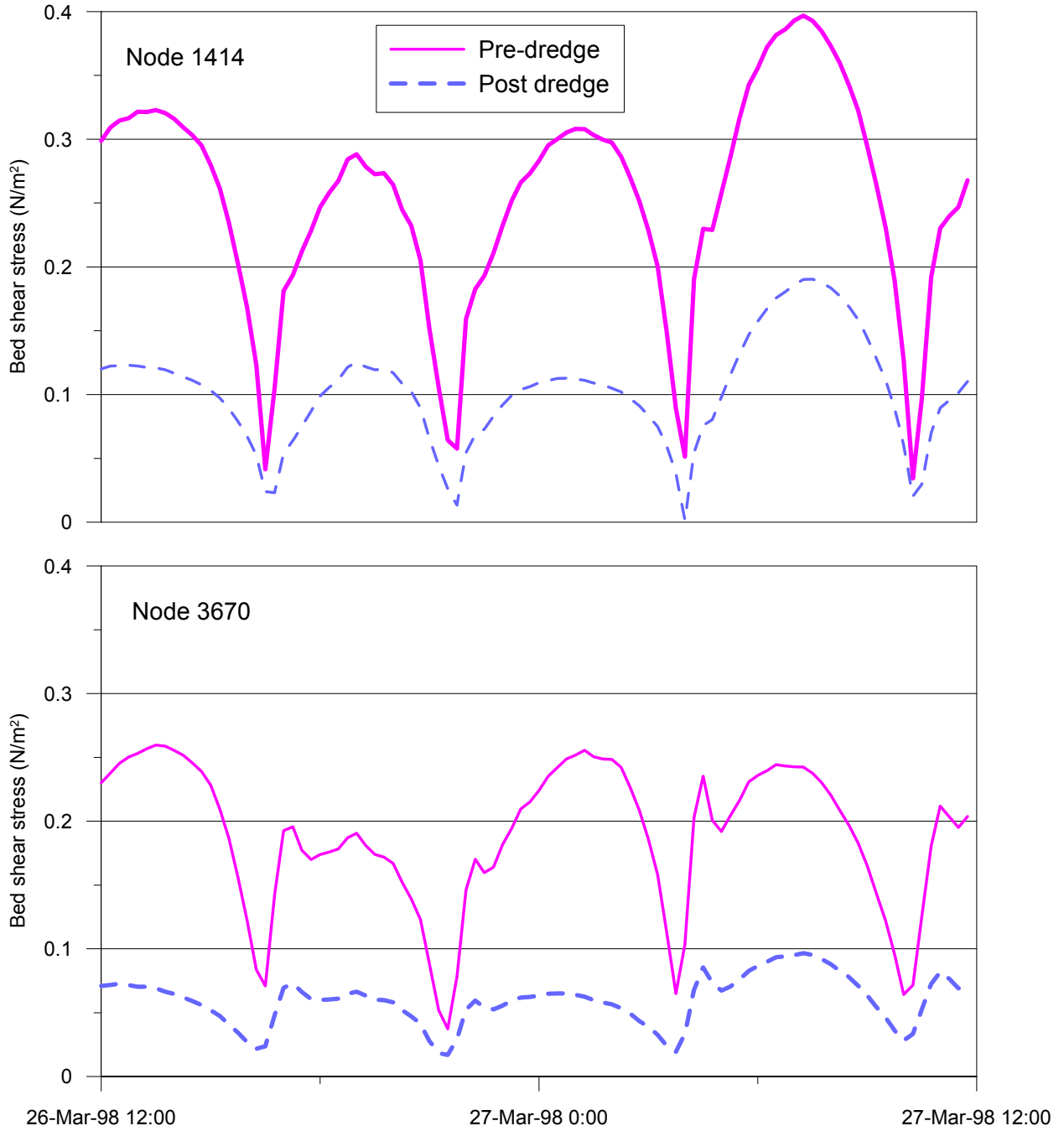
(b) Maximum flow (m³/s/m): Post dredge with increased roughness in dredge.



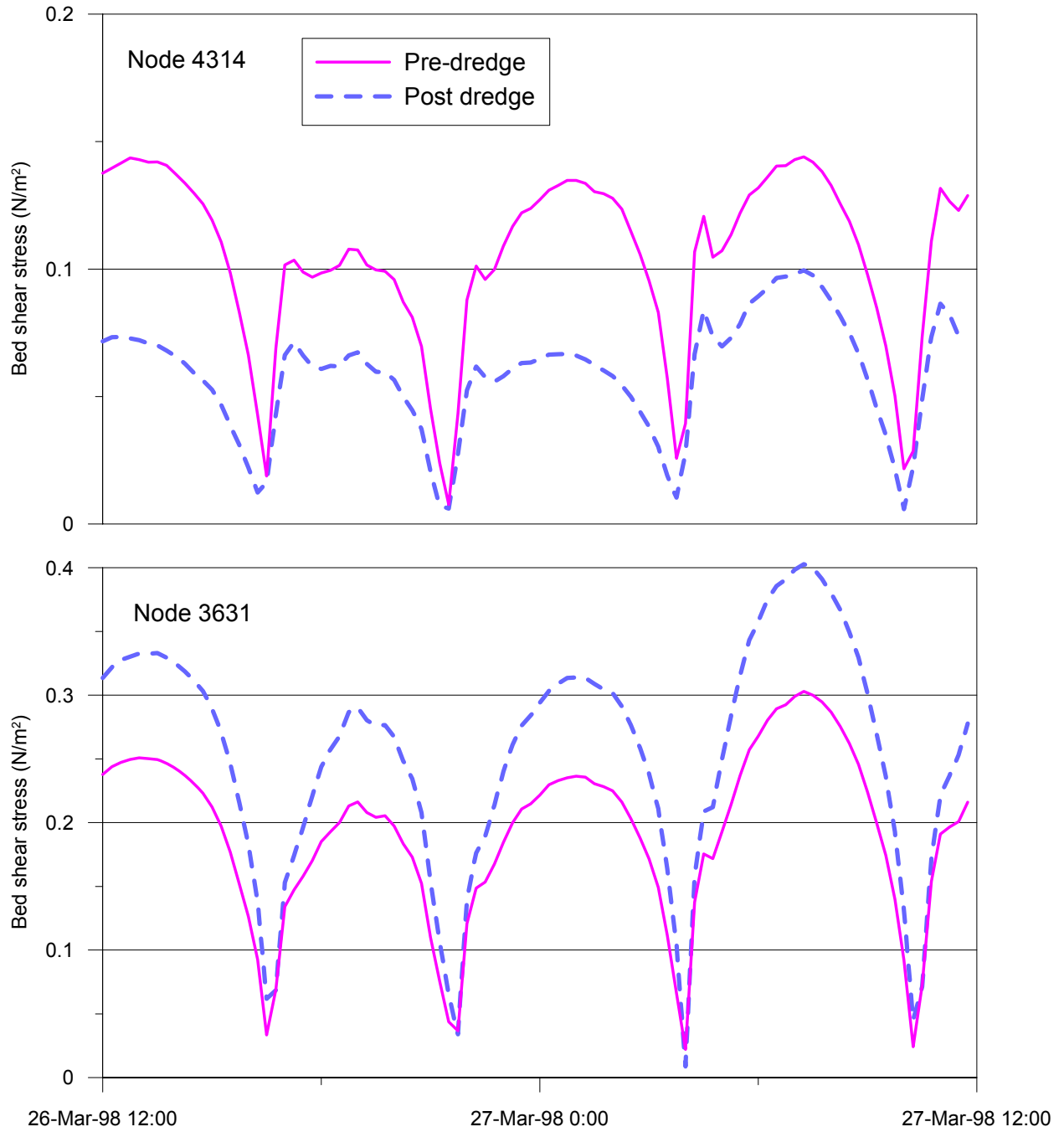
Bed shear stress for selected nodes pre- and post dredge



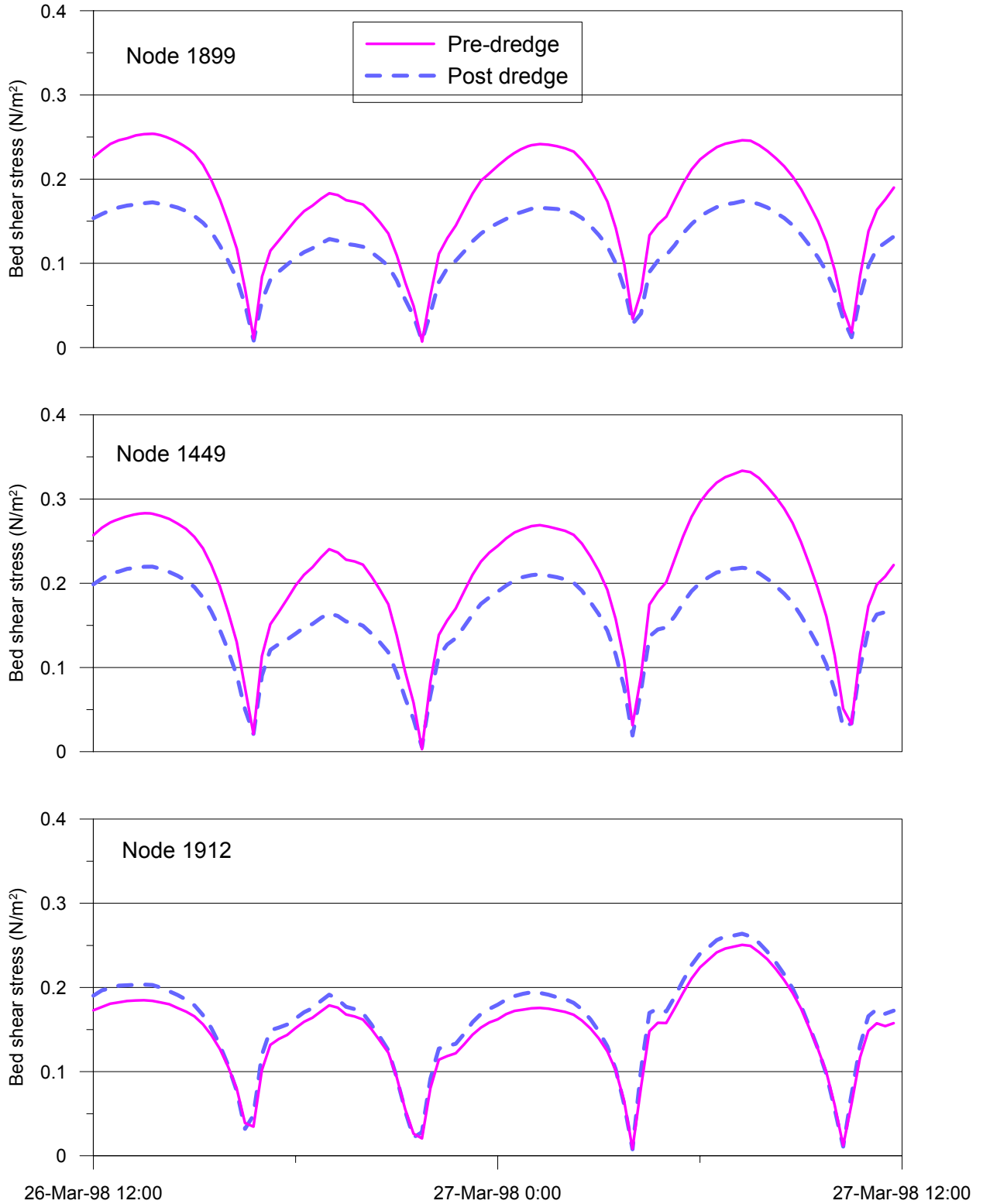
Bed shear stress for selected nodes pre- and post dredge



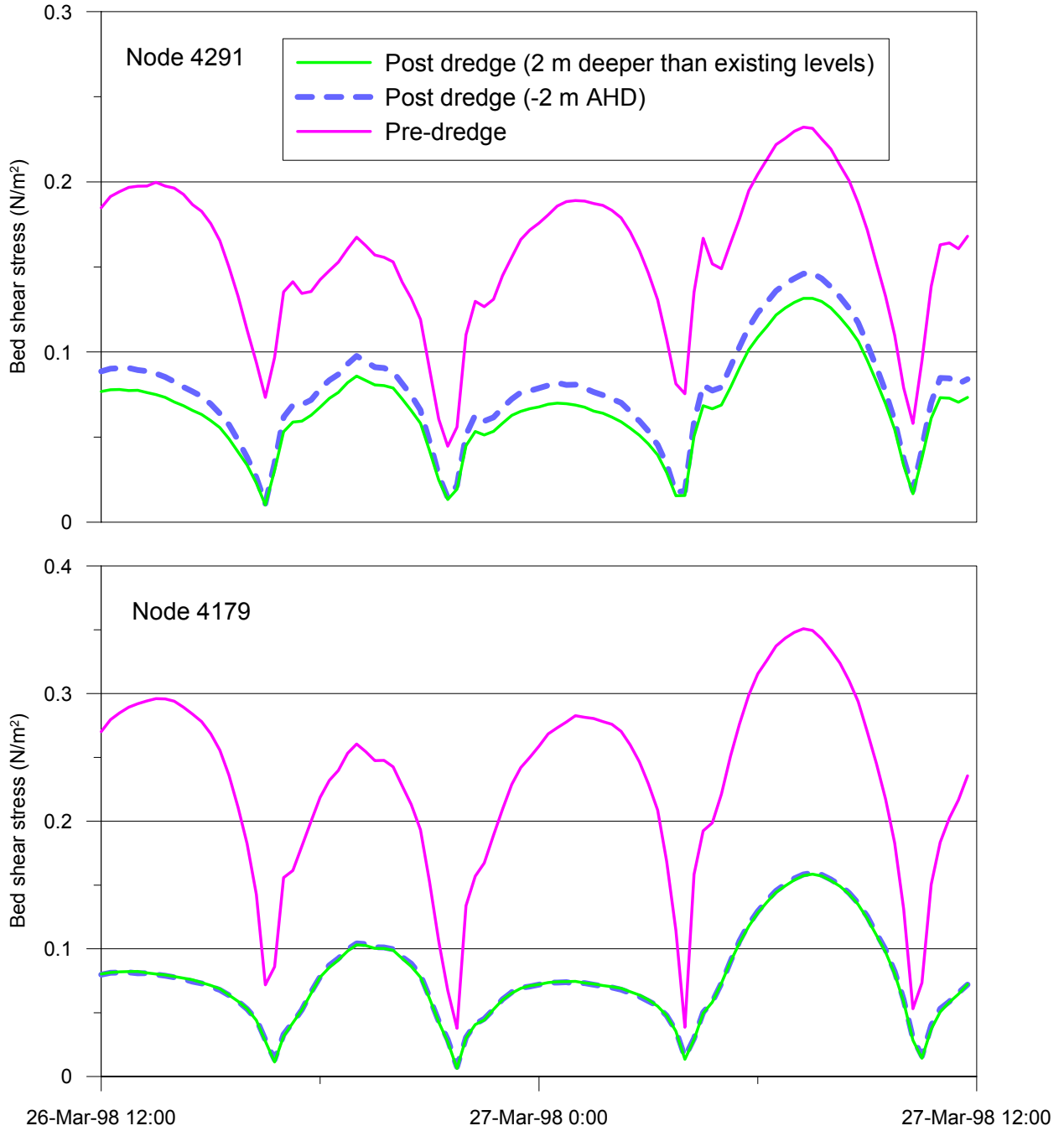
Bed shear stress for selected nodes pre- and post dredge



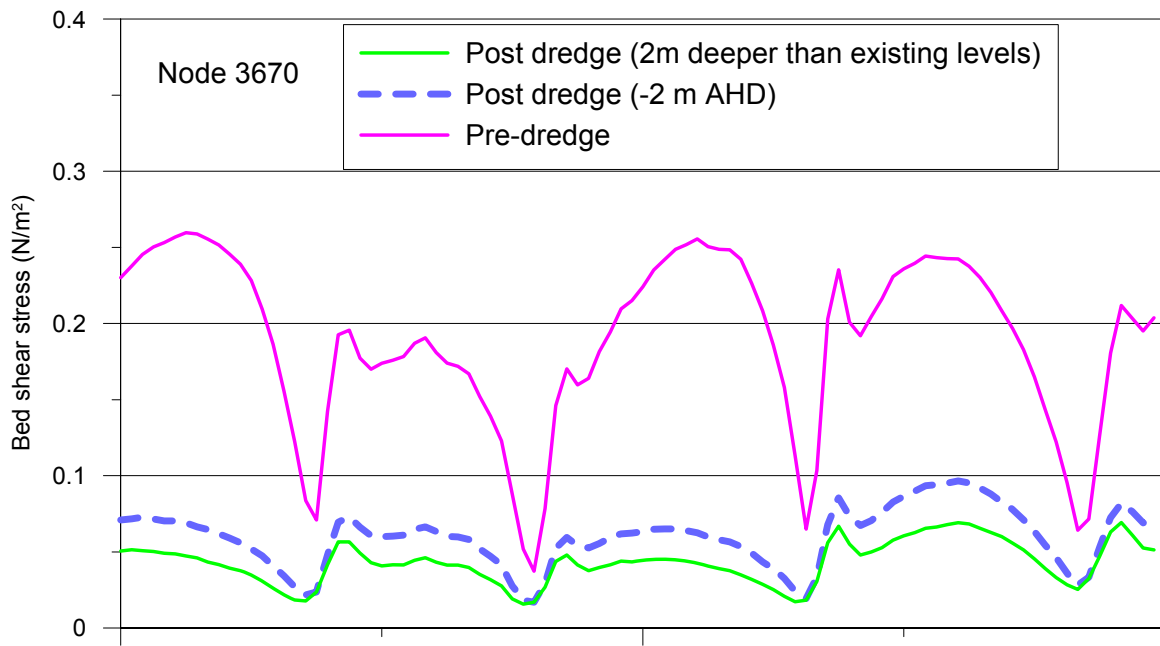
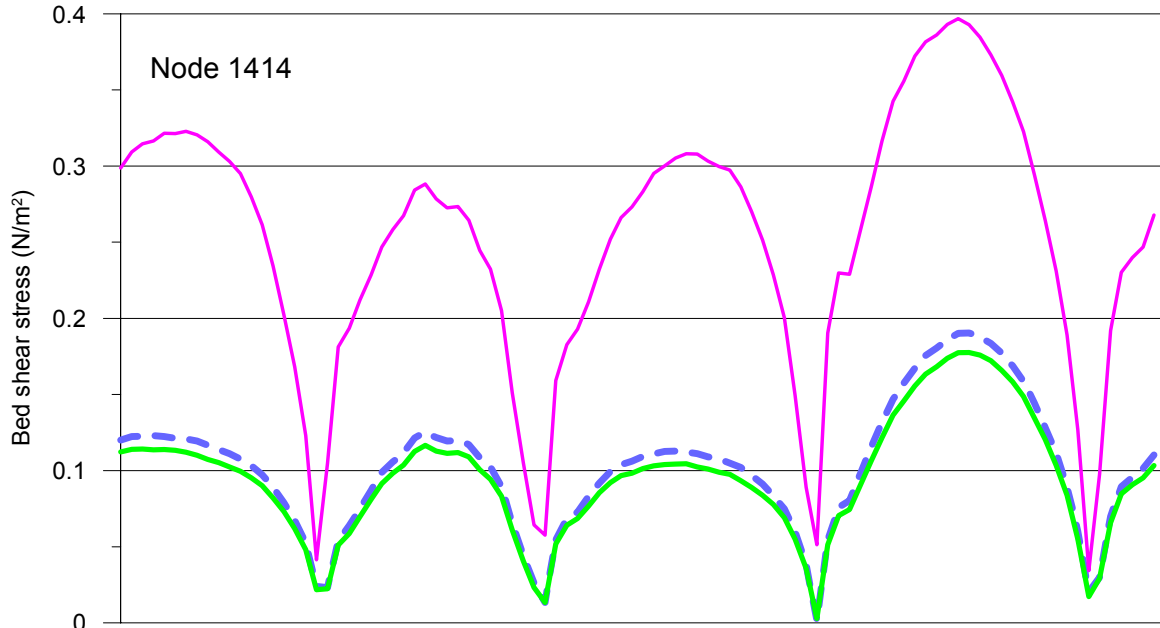
Bed shear stress for selected nodes pre- and post dredge



Bed shear stress for selected nodes pre- and post dredge



Bed shear stress for selected nodes pre- and post dredge



26-Mar-98 12:00

27-Mar-98 0:00

27-Mar-98 12:00

Bed shear stress for selected nodes pre- and post dredge

