# Appendix 11

## Nearshore geomorphological modelling

# ICHTHYS GAS FIELD DEVELOPMENT PROJECT

# NEARSHORE GEOMORPHOLOGICAL MODELLING

**Prepared for:**

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## EXECUTIVE SUMMARY

INPEX Browse, Ltd. (INPEX) proposes to develop the natural gas and associated condensate contained in the Ichthys Field in the Browse Basin at the western edge of the Timor Sea about 200 km off Western Australia's Kimberley coast. The field is about 850 km west-south-west of Darwin in the Northern Territory.

The two reservoirs which make up the field are estimated to contain 12.8 tcf (trillion cubic feet) of sales gas and 527 MMbbl (million barrels) of condensate. INPEX will process the gas and condensate to produce liquefied natural gas (LNG), liquefied petroleum gas (LPG) and condensate for export to overseas markets.

For the Ichthys Gas Field Development Project (the Project), the company plans to install a two-train LNG plant, an LPG fractionation plant, a condensate stabilisation plant and a product loading jetty at a site zoned for development on Blaydin Point. Around 85% of the condensate will be extracted and exported directly from the offshore facilities while the remaining 15% will be processed at and exported from Blaydin Point.

Asia Pacific ASA Pty Ltd (APASA) was commissioned to carry out environmental work associated with INPEX's preparation of the EIS, and this technical report on geomorphological modelling was prepared in part fulfilment of that commission.

A study was undertaken to investigate the potential for development work proposed by INPEX within Darwin Harbour to alter a number of existing hydrodynamic processes (circulation, residence time, wave propagation and bed-shear stress) within East Arm and locally around Blaydin Point. Specifically, this study investigated the influences of dredging of navigation channels and shipping berths and the construction of a Module Offloading Facility.

The investigation of these potential effects over both the wider (East Arm) and local (Blaydin Point) scales was conducted through a comparative modelling analysis involving the generation of sample current and wave fields for pre (Base Case) and post-construction (Modified Case) scenarios and quantifying any differences imposed by the developments. The study was carried out using hydrodynamic and wave models described and validated in APASA (2010). The models were operated to simulate the hydrodynamic and wave patterns for two configurations of East Arm:

1. with present day bathymetry (Base Case)
2. present day bathymetry modified to represent the post-dredging and construction bathymetry and coastline for a dredging plan to create a shipping channel, turning basin and berthing area to access a jetty off the northern side of Blaydin Point and a small berth pocket to access a Module Offloading Facility further upstream, on the eastern side of Blaydin Point (Modified Case).

Residence times were quantified by simulating the advection of tracer particles from East Arm and quantifying their rate of removal. Relatively long residence times were predicted for East Arm under with the Base Case morphology, due to the trapping of water in the upstream section, with limited flux and dilution, due to tidal exchange, occurring at the junction of East Arm and Middle Arm. Concentrations of tracers were reduced to 37% of initial concentrations (the e-folding time) within 13 days at 500 m from the entrance to East Arm in the simulation. By comparison, at 6 km upstream from the entrance, concentrations remained at 50% after 30 days. At 11 and 15 km upstream, tracer concentrations were reduced to 80% and 95% of initial, respectively, after 30 days.

Comparisons of the residence times predicted for the two scenarios indicated that there would be relatively small and localised increases in residence time (i.e. slower exchange) following the proposed modification of the bathymetry. The largest effect was identified for the location of the proposed berthing area and turning basin off the northern side of Blaydin Point. Concentrations after 30 days were 6% higher after the modification (i.e. 85% of initial concentration for Modified Case, compared with 80% for Base Case). Effects on residence times were much reduced (less than 2% increase) in the proposed shipping channel 5 km downstream and by 4 km further upstream of the berthing area. The small changes relative to the long flushing times for the mid to upstream sections suggest there would be minimal increase in the retention of pollutants or potential for nuisance or harmful algal blooms following the development.

In terms of current speed and directions, modifications of the existing circulation patterns were indicated to be localised and confined to the dredged footprint. Current magnitudes are predicted to reduce locally to varying degrees in the deepened areas. Current magnitudes are predicted to reduce by between 10% and 50% in locations within the berthing area and turning basin due to deepening of the bathymetry. However, the predicted current speeds for the Modified Case remained high relative to the speeds necessary to mobilise finer sediments (clays and silts) found in East Arm. This outcome suggests the dredging could result in a minor increase in the rates of sedimentation into the deepened areas and a minor decrease in local sediment mobilisation. As a result, there is the potential for a detectable increase in sedimentation potential in these areas when compared to existing conditions. Although no significant environmental or engineering consequences are predicted over the scale and durations of this investigation this potential should be considered in the overall engineering assessment of the Project.

The wave climate within East Arm is dominated by locally generated waves and no significant changes in wave energy or direction were indicated beyond the dredging footprint, suggesting that there would not likely be any increase in bank erosion or sediment transport within East Arm around the Project footprint.

# 1 INTRODUCTION

INPEX Browse, Ltd. (INPEX) proposes to develop the natural gas and associated condensate contained in the Ichthys Field situated about 220 km off Western Australia's Kimberley coast and about 820 km west south west of Darwin. The field encompasses an area of 800 km$^2$ in water depths ranging from 235 to 275 m.

The two reservoirs which make up the field are estimated to contain 12.8 tcf (trillion cubic feet) of sales gas and 527 MMbbl (million barrels) of condensate. INPEX proposes to process the reservoir fluids to produce liquefied natural gas (LNG), liquefied petroleum gases (LPGs) and condensate for export to overseas markets.

For the Ichthys Project, the company plans to install offshore extraction facilities at the field and a subsea gas pipeline from the field to onshore facilities at Blaydin Point in Darwin Harbour. A two train LNG plant, an LPG fractionation plant, a condensate stabilisation plant and a product loading jetty will be constructed at a site on Blaydin Point. Around 85% of the condensate will be extracted and exported directly from the offshore facilities while the remaining 15% will be processed at and exported from Blaydin Point.

In May 2008 INPEX referred its proposal to develop the Ichthys Field to the Commonwealth's Department of the Environment, Water, Heritage and the Arts and the Northern Territory's Department of Natural Resources, Environment and the Arts. The Commonwealth and Northern Territory ministers responsible for environmental matters both determined that the Project should be formally assessed at the environmental impact statement (EIS) level to ensure that potential impacts associated with the Project are identified and appropriately addressed.

Assessment will be undertaken in accordance with the *Environment Protection and Biodiversity Conservation Act* 1999 (Cwlth) and the *Environmental Assessment Act* (NT). It was agreed that INPEX should submit a single EIS document to the two responsible government departments in the Northern Territory and the Commonwealth for assessment.

As part of the nearshore development, INPEX propose to dredge a shipping channel, approach area, turning basin and berthing area within East Arm, to provide access by tanker vessels to jetty facilities that will be constructed at Blaydin Point. In addition, dredging is proposed to create a small vessel berth for a Module Offloading Facility on the east side of Blaydin Point. Asia-Pacific ASA (APASA) was commissioned to carry out modelling studies to assess the potential for the proposed alterations of the bathymetry of East Arm to affect changes in existing hydrodynamic processes (circulation, flushing and wave propagation) within Darwin Harbour, East Arm and locally around Blaydin Point.

The investigation of these potential effects over both the wider scale (Darwin Harbour and East Arm) and local (Blaydin Point) scales was conducted through a comparative analysis conducted by operating hydrodynamic and wave models of Darwin Harbour with the identical forcing conditions (tides, winds, boundary waves) over a bathymetric grid representing both the pre and the post construction morphology for East Arm and identifying any differences in the following key parameters:

- Flushing rate (i.e. rate of exchange of water) for locations along East Arm

- Current speed and direction, both horizontally and vertically
- Wave height, direction and period
- Bed shear-stress at seabed level (due to combined current and wave action)

Increases in flushing times for locations within East Arm would have the potential to decrease local water quality by increasing the retention of pollutants and sediments entering from the catchment, or by encouraging algal blooms. Changes in the current patterns also have the potential to affect sedimentation patterns and flow paths for nutrients and progeny of marine and estuarine organisms, such as fish larvae or mangrove seedlings. Significant changes in wave energy or wave direction have the potential to alter patterns of bank erosion and accretion, and might also have undesirable effects on adjacent infrastructure. Bed shear stress is a measure of the combined effects of wave and current energy in affecting resuspension of sediments from the seabed into the water column, hence provides a measure of the composite effect of these forces. Significant changes in the combined bed shear stress pattern would indicate alterations in sedimentation and erosion patterns that could affect mangrove roots, seagrass and other intertidal/sub-tidal habitats.

# 2 METHODS

## 2.1 General approach

The modelling was undertaken using a three-dimensional hydrodynamic model (BFHYDRO) and a shallow-water wave model (SWAN), as described in APASA (2010). Models were first prepared using a digital bathymetric model representing the existing morphology of Darwin Harbour and East Arm (Base Case). Predictions for the current and wave parameters produced by these models were validated successfully against current and wave measurements made at multiple locations (APASA 2010). Modified versions of the models were then prepared that incorporated proposed channels and structures that extended into the hydrodynamic environment (Modified Case). The shape and alignment of the bathymetric modifications that were applied in this study are shown in Figure 1 and included:

a). A shipping channel, approach area, turning basin and berth area for operation of tanker vessels approaching a jetty off the northern side of Blaydin Point, which would have a uniform depth of -14 m LAT.

b) A basin for barges and vessels operating from a Module Offloading Facility on the eastern side of Blaydin Point, which would have an approach apron dredged to – 7 m LAT in front of a berth pocket dredged to 0.0 m LAT.

Based on specifications supplied by INPEX, the jetty structures for tanker vessels, on the northern side of Blaydin point, were assumed to be supported by piles of small dimensions in comparison to the horizontal scale of the hydrodynamic and wave models, hence transparent to circulation and wave patterns. The Module Offloading Facility that was investigated had a solid wharf structure with the landward face placed at mean sea level. Two transition barges, which were angled perpendicular to the wharf face and extended the width of the berth area, were included in the design as structures that were transparent at tide heights greater than 1.5 m LAT and blocking at lower tide levels.

The Modified Case model was run to produce circulation and wave data with the same metocean forcing that was applied to the Base Case simulations. Predictions from the Base Case and Modified predictions were then compared over time at each model cell and depth layer to produce estimates for any differences that would result. Differences were statistically analysed to quantitative change between the Base Case and Modified Case.

Simulations were carried out for a sample 30 day period after investigation of the effects of wind and river flow on the Base Case configuration demonstrated that hydrodynamic processes are dominated by tidal forcing, hence seasonal or inter-annual variations would be small and short-lived.

## 2.2 Flushing comparisons

Residence time is a term used by hydrodynamic modellers and environmental engineers to characterise the rate of removal of material from a semi-confined body of water (Sheldon & Alber 2002). This removal is typically produced by the exchange of water between the semi-confined area and an adjoining “source water”, an adjacent, often much larger, water body.

The rate of this removal is governed by the factors affecting the hydrodynamic flux between the two regions. Changes in the residence time-scale of a water body have the potential to affect local water quality. Rapid exchange (short residence times) result in the water quality of the partially confined water body closely matching that of the source water within a period of a few days. Where the source water has relatively low, limiting, concentrations of nutrients or pollutants, high water quality can be expected. In contrast, slow exchange (long residence times) provide the conditions for a build-up of nutrients and pollutants within the confined water body. In the presence of suitable populations of microalgae and sunlight, this can result in problematic algal blooms and/or decreases in oxygen levels.

Increases in residence time can also indicate a potential for an increase in local suspended sediment concentrations and sedimentation rates because sediment concentrations tend to build up rather than flush out of the water body and there is more time for sediments to rain out of the water column.

Local residence times for locations within East Arm were assessed using the BFMASS model, which operates as an extension to the hydrodynamic model employed in this investigation (BFHYDRO). BFMASS models the mass transport and diffusion of passive tracers using the hydrodynamic input (currents and diffusion rates in both the vertical and horizontal) predicted by BFHYDRO. By seeding a portion of the domain with an initial, uniform, concentration of an inert tracer, the rate of decrease in tracer concentrations can be calculated for individual locations in the horizontal and vertical dimension. Hence, changes in residence times can be determined for both individual locations or the confined water body as a whole. For this study, an initial, non-dimensional, concentration of 100% was defined for the entire water body of East Arm (Figure 2; area highlighted in blue) as an initial distribution of the passive tracer, and the wider harbour and approaches was treated as the source water. Hence, this part of the assessment focussed on the exchange of water between East Arm and the wider harbour. Note that residence times will vary from place to place due to circulation patterns and the proximity to the interface between the seeded area and the source water.

Residence time can be calculated in different ways. For this study, we have applied the point method of calculating the e-folding residence time (e.g. Rubash & Kilanowski 2007), which is the time interval for an initial concentration at a defined location to reduce exponentially (i.e. a factor of 1/e times the original concentration, which is approximately equivalent to a concentration that is 37% of the original concentration). This approach is more informative than calculating the residence time for an entire water body because it allows for assessment of spatial variation in flushing rates throughout the semi-enclosed water body.

Residence time simulations were carried out over 30 day durations under dry-flow conditions (i.e. no riverine discharge or land runoff), using sample tidal data (July 2007). Dry flow conditions were represented as the worst-case condition for net migration from the upper reaches of East Arm. The 30 day model duration is considered sufficient to show any variations between the two bathymetric layouts over the short to medium term, based on previously published flushing rates for the harbour as a whole (Williams *et al*. 2006).

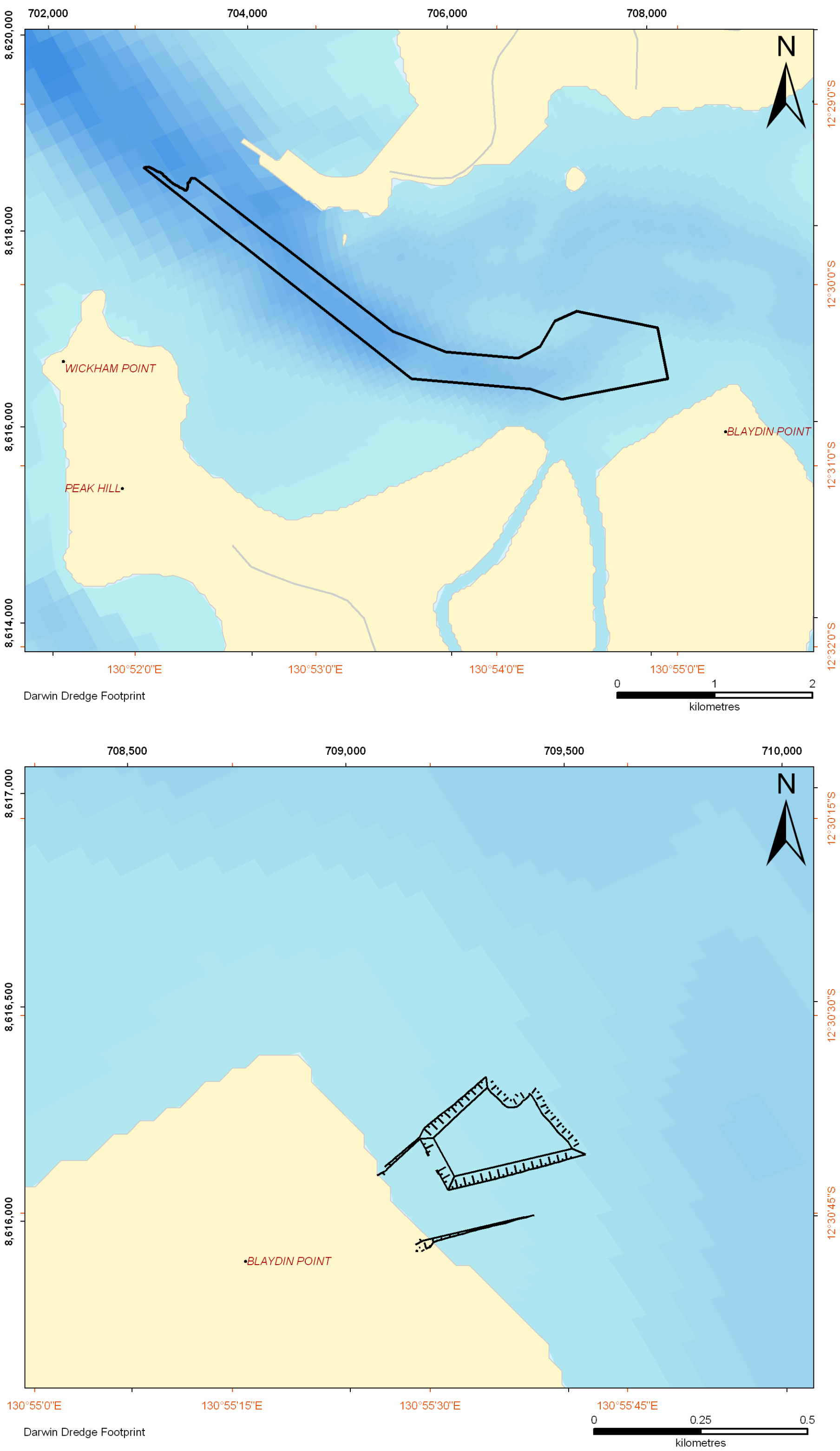



*Figure 1: Configuration of the dredging areas for the Modified Case. Upper panel shows the shipping channel, berth and turning circle approaching the northern side of Blaydin Point. Lower panel shows the basin for the Module Offloading Facility on the eastern side of Blaydin Point. Coastlines are shown at mean sea level.*

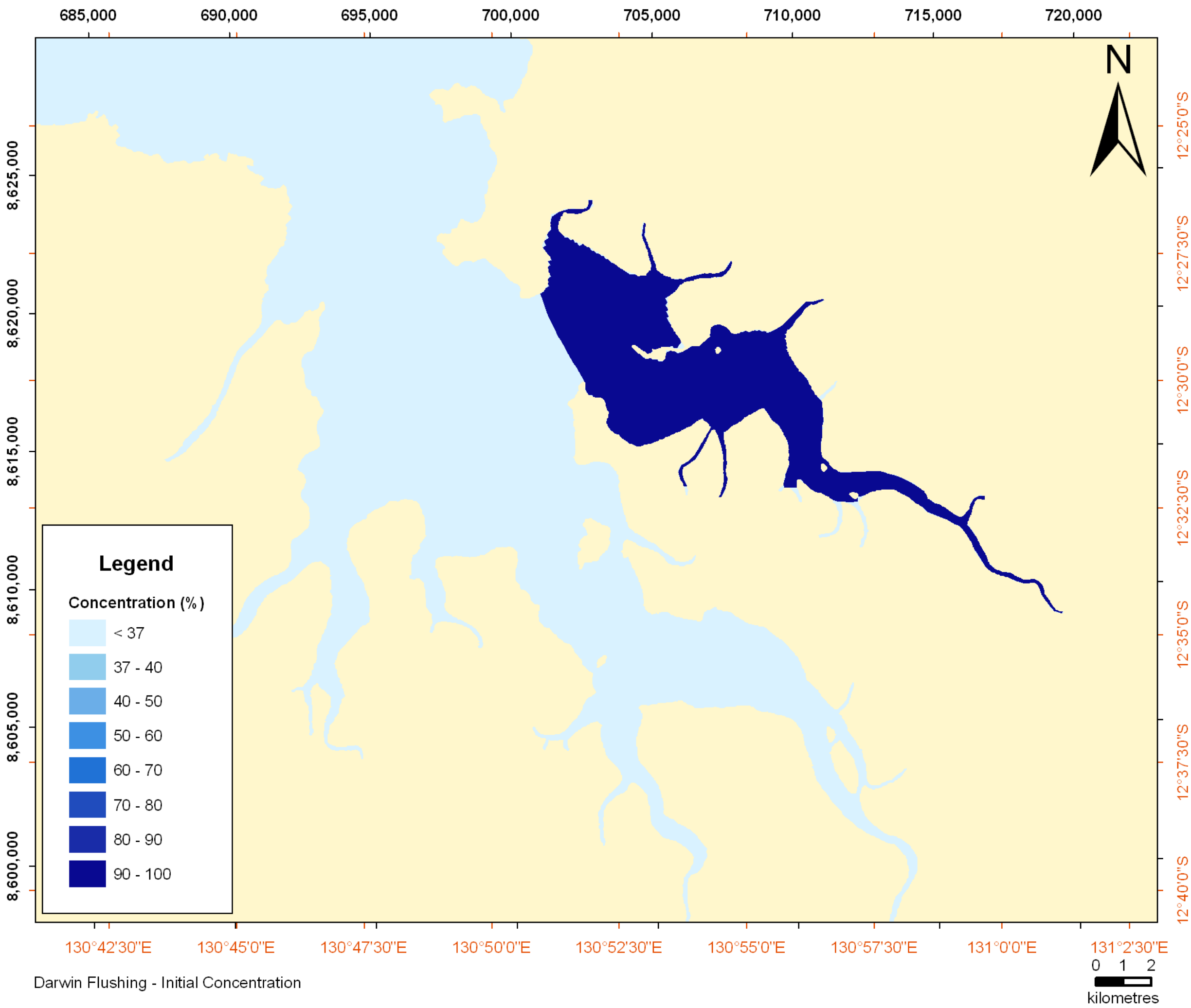



*Figure 2: Delineation of the seeding area for passive tracers at the initiation of the residence time simulation. A uniform concentration of 100% was specified horizontally and vertically within the seeding area.*

## 2.3 Modification of current patterns

Changes in circulation patterns are important for both environmental and engineering perspectives. The transport of pollutants, sediments, nutrients and dissolved substances is governed by local circulation patterns. The potential for sediments or other substances to collect in certain areas or be drawn away from others is an important process. Likewise, changes in current speeds and directions can affect ship and small boat maneuvering, mooring forces and local sediment scour.

To quantitatively estimate effects of bathymetric and morphological changes proposed by INPEX on existing circulation patterns within East Arm, comparisons were made of the Base Case and Modified Case current speeds and directions at each cell and depth level.

## 2.4 Modification of wave patterns

Changes in wave patterns or energy have the potential to alter sediment erosion and deposition rates in the study area. They can also change the wave energy at the berths, which may be important for sensitive loading operations and mooring forces.

Wave conditions within East Arm are usually short period waves propagating into East Arm or locally generated by wind with small significant wave heights of the order of a few tens of centimetres (APASA 2010). Circular water particle movements under the short period waves embrace a thin surface layer of water only. These movements rarely penetrate deep enough to “feel the bottom” and thus it is not expected that there will be significant effects in the channels due to the modifications. A comparison was conducted to confirm this by analysing spatially over East Arm, and statistically at a series of points within the areas where modifications are proposed. Maps of the mean difference in wave height between the Base Case and Modified Case were calculated by comparing mean statistics for each cell in the models. Four comparison points were selected within East Arm and histograms plotted of the distribution of significant wave heights

## 2.5 Modification of bed shear stress

The potential for sediment to remain settled and consolidated on the sea bed, or to be mobilised from the sea bed is governed externally by the effective shear stress at the sea bed. Shear stress results from the near-bed current generated by the combined action of the gross hydrodynamic flow (acting horizontally) and wave induced currents (acting orbitally). An analysis of the possible change in bed shear stress was conducted to predict the cumulative effect of changes in tidally driven currents and the wave energy at each location throughout East Arm.

Bed shear stress estimates were calculated using the spatially and temporally changing current and wave parameters predicted for the Base Case and Modified Case, following the formulation of van Rijn (2005). To compare the pre and post development cases, differences in the mean bed shear stress were calculated for each model cell and mapped.

# 3 RESULTS

## 3.1 Residence time changes

Comparative spatial plots of predicted, depth-averaged, tracer concentrations after 15 and 30 days of simulation are presented for the two model configurations (Base Case and Modified) in Figure 3. The results for the Base case configuration indicate that effective exchange of water between East Arm and Middle Arm is limited to the lower reaches of East Arm due to tidal flushing. Tracers that were initially seeded over the lower reaches of East Arm were predicted to migrate with the ebbing tide beyond the entrance to East Arm and mix with source water in Middle Arm. Hence the water returning into East Arm on the subsequent flooding tides would be diluted by source water. In contrast, tracers initially seeded further upstream are predicted to migrate downstream on the ebbing tide an insufficient distance to leave East Arm before migrating back upstream with the flooding tide, hence remain partially trapped, with only slow diffusion occurring with the water that becomes increasingly cleared of particles further downstream.

Visually, the progressive flushing images for the Base Case and Modified configuration show nearly identical results at 15 and 30 days after initialisation, with only minor differences in the extent of the 80% and 90% concentration zones around Blaydin Point (See Figure 3), indicating that there would be negligible changes in residence times at the scale of East Arm The similarity in the spatial outcomes is confirmed by a quantitative analysis of flushing at individual locations (Figure 4 and Figure 5). Site 1 was located approximately 500 m upstream of the entrance to East Arm, hence adjacent to the boundary separating the seeded area and the flushing water. For the Base Case geomorphology, tracer concentrations were predicted to decrease to the e-folding concentration within 15 days at this site but beyond 30 days at all sites further upstream. Rates of decrease in concentration slowed with distance from the entrance. At Site 2, which is within range of the flooding front on spring tides only, concentration decreased over spring tides and remained nearly stagnant over the neap tides. Concentrations of the tracer remained at 80% of the initial after 30 days.

Simulations using the modified bathymetry indicated a small increase is residence time would occur at sites over the middle and upper reaches of East Arm. At Site 1, near the entrance, effective flushing was still indicated to occur within 15 days and there was less than 0.5% increase in the tracer concentrations over 30 days compared to the Base Case. The largest effect, a 6% increase in concentration of the tracer after 30 days, was indicated for Site 3, located north of Blaydin Point and within the proposed turning basin and berthing area. This effect is interpreted to be an outcome of slowed current speeds resulting from increasing the water depth in this location. Increases in the remaining concentrations after 30 days were of the order of 2-3% for sites upstream and downstream (Sites 2 and 4).

These results, which are applicable to the individual locations, indicate that there would be relatively small increases in the residence time due to the dredging works, hence small decreases in the flushing rate, at some locations but no significant alteration to the flushing capacity of East Arm as a whole due to the proposed development, given the limited exchange that occurs with the existing geomorphology.

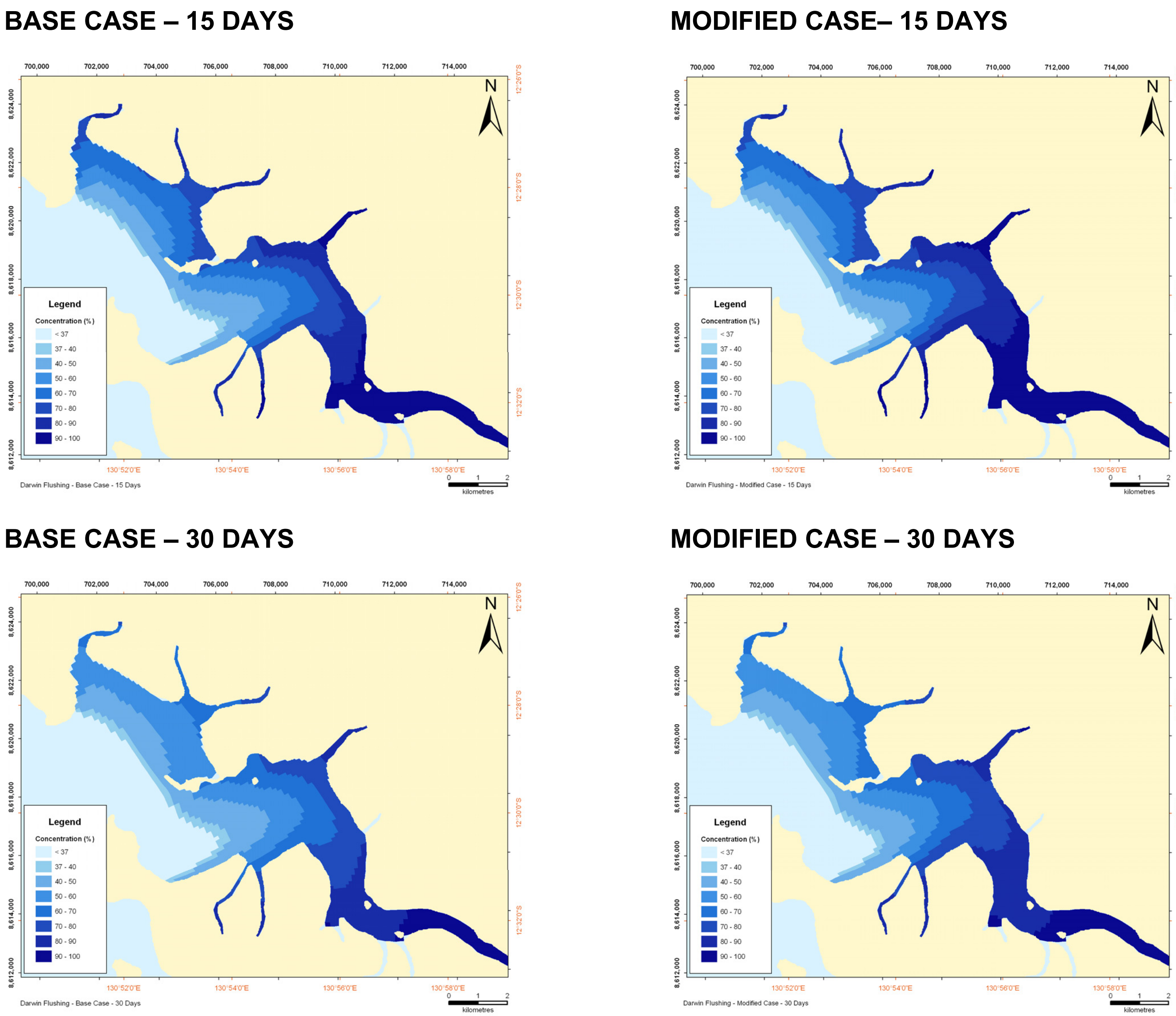



*Figure 3: Comparative tracer concentration after 15 days (top panels) and 30 days (bottom panels) for Base Case and Modified Case configurations.*

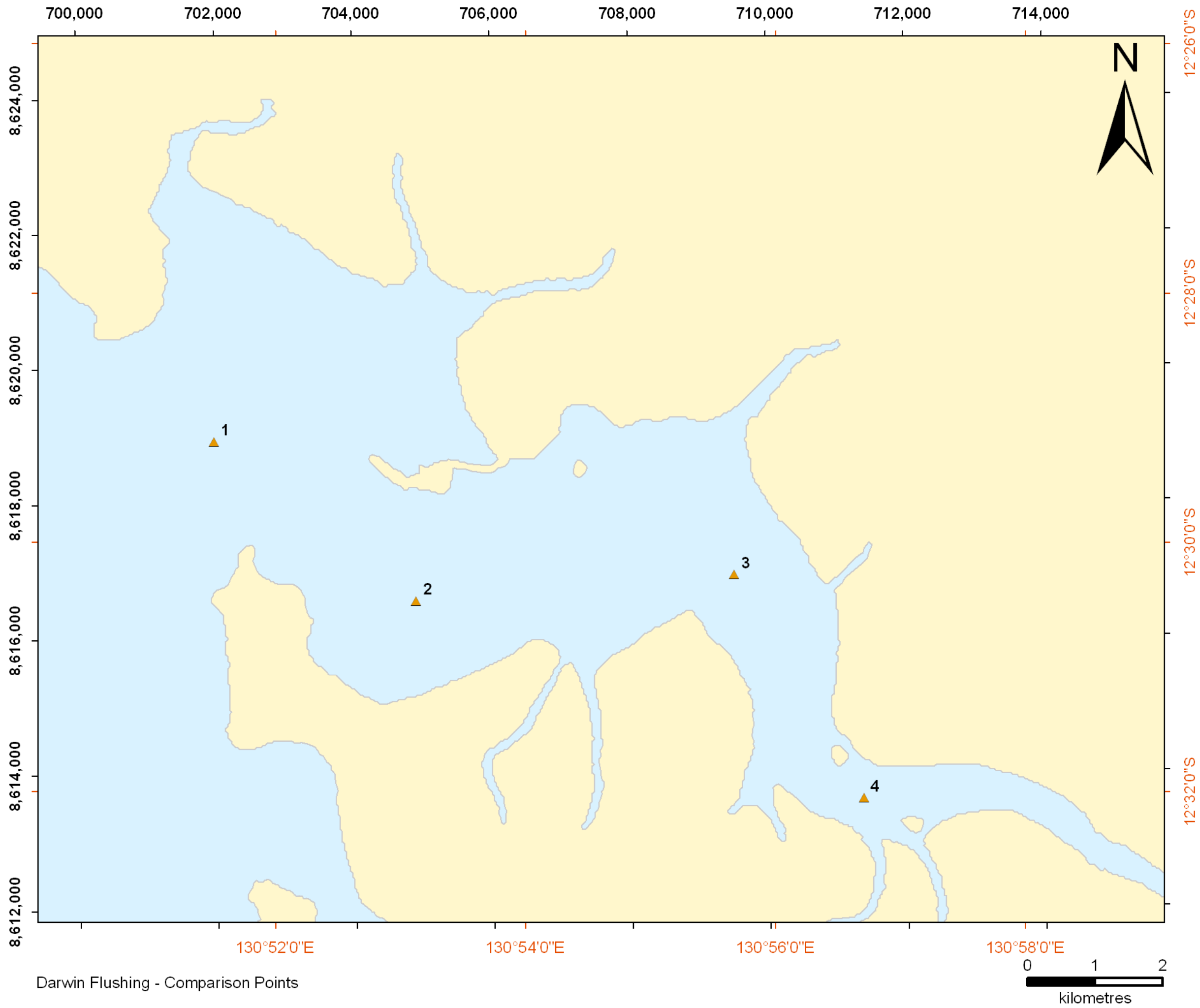



*Figure 4: Sites used to calculate rates of change in tracer concentration*

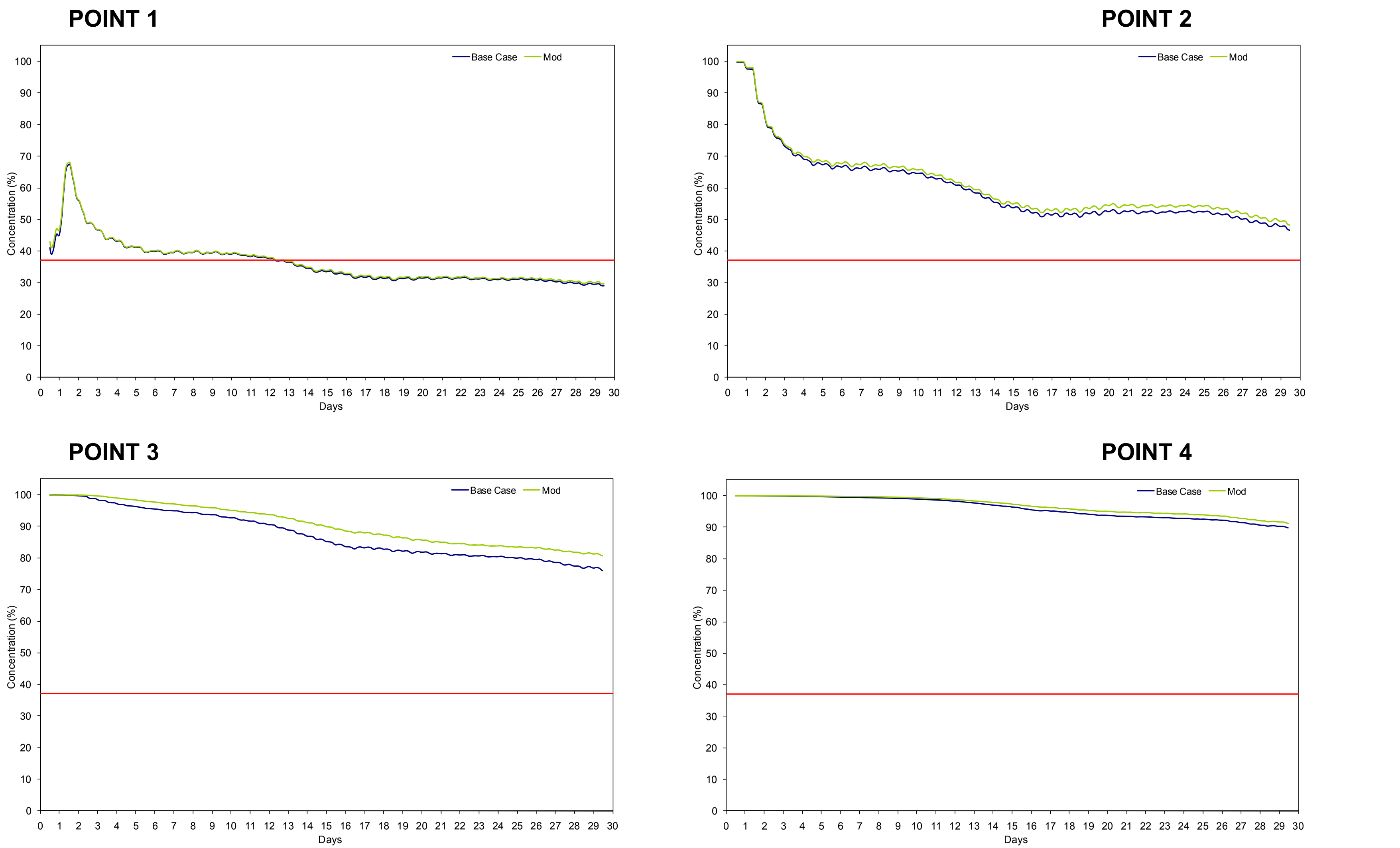


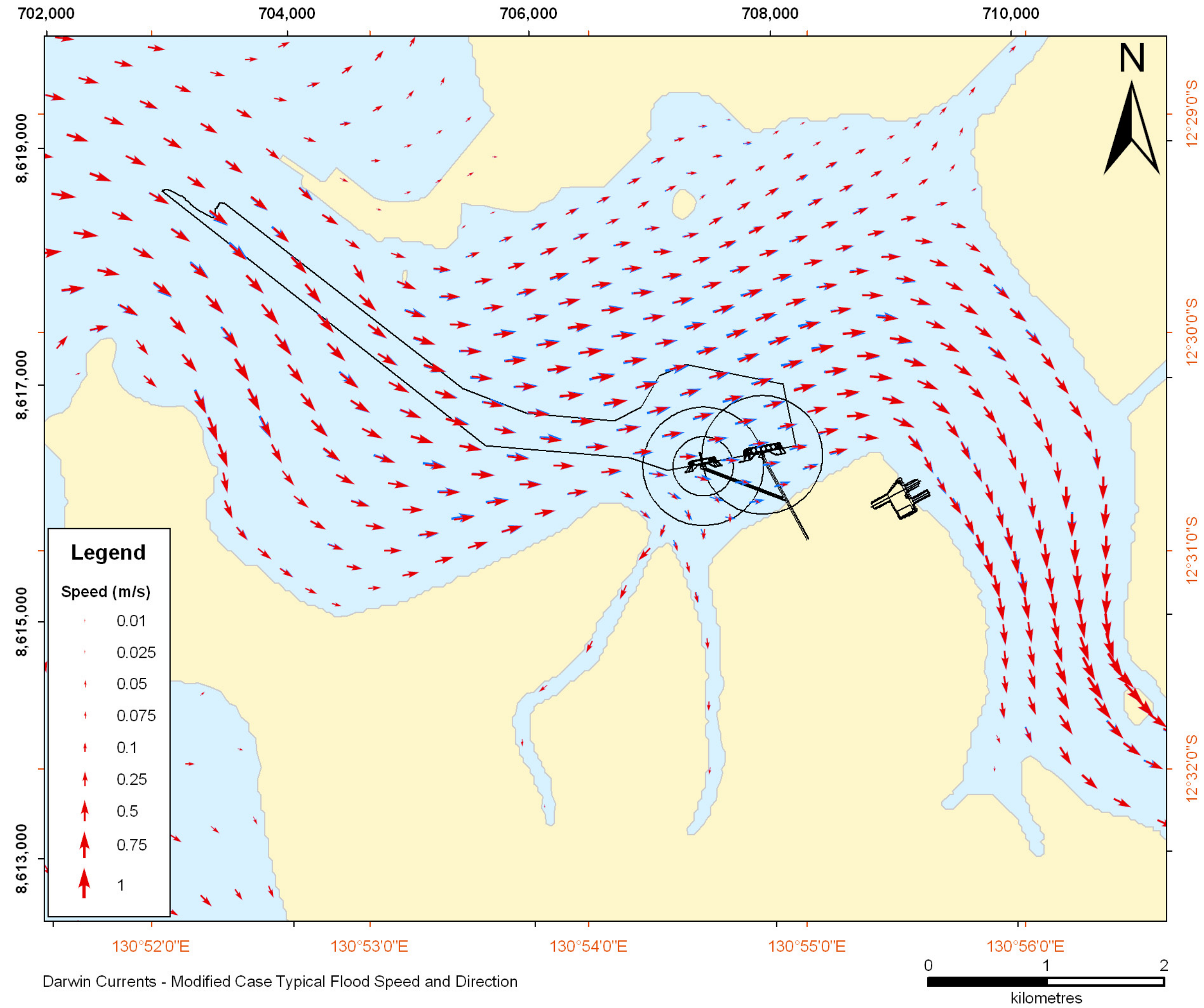

*Figure 5: Daily-averaged tracer concentrations at locations shown in Figure 4 given the Base Case (blue line) and Modified Case (green line). The red horizontal line shows the e-folding concentration (approximately 37% of initial concentration).*

## 3.2 Modifications of the current regime

Characteristic examples of the depth-averaged currents over ebbing and flooding tides are presented to provide spatial comparisons of the major current axis and magnitudes for the Base Case and Modified Case configurations in Figure 6 and Figure 7. The figures show that the bathymetric modifications proposed for the shipping channel and approach area are likely to have minor and localised steering effects on the current directions because the proposed channel alignment follows the existing current axis quite closely. The largest effects on steering are indicated for the berthing area and locations further inshore towards Blaydin Point. In these locations, current directions are expected to deviate inshore by a few degrees during the peak flood tide and offshore to a similar angle on the peak ebb tide.

Tidal current speeds through a channel are a product of the volume of water that is exchanged divided by the cross-sectional area of the channel. Deepening the bathymetry to create the turning basin and berthing area, hence increasing the cross-sectional area in these locations, was predicted to attenuate local current speeds. This is illustrated in Figure 8, which presents differences in peak ebbing and flooding current speeds between the Base Case and Modified Case scenarios. Blue shading indicates reduced current speeds compared to the Base Case, while red shading indicates increased current speeds.

Largest reductions in the depth-averaged currents (40-45% slower) are indicated for the dredging footprint within the berthing area and turning basin and within the berth pocket of the Module Offloading Facility (Table 1; Figure 9). The speed reduction in this area is due to the larger cross-section that would be available for tidal exchange of a similar mass of water. The effect on current speeds was predicted to extend across East Arm, offshore from the berthing area and turning basin, but with decreased magnitude with distance from the edge of the dredge footprint. The current reductions in this area indicates a redirection of part of the water mass moving over the middle and northern portions of the channel, with redirection of this mass to the deepened section over the berthing area and turning basin. A small increase in current speed, of the order of 20-25%, is indicated in the area between the shipping berth and the Module Offloading Facility, due to this larger mass crossing over the shallow section immediately upstream of the proposed berth. Although small, the magnitude of increase is larger in the ebbing direction (i.e. downstream). These increased current speeds could result in small increases in the mobility of sediment deposits in this area.



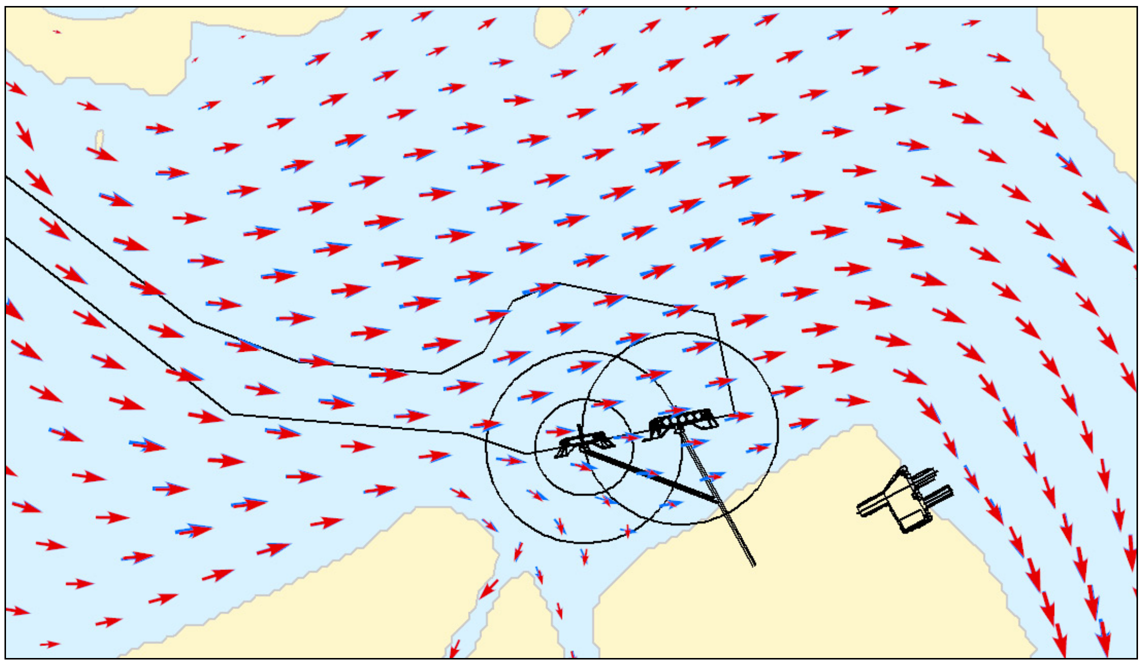



*Figure 6: Comparison of the peak flood current speed and direction for the Modified Case (red arrows) overlaying the Base Case estimates (blue arrows). Lower panel shows a zoomed image around the proposed facilities.*

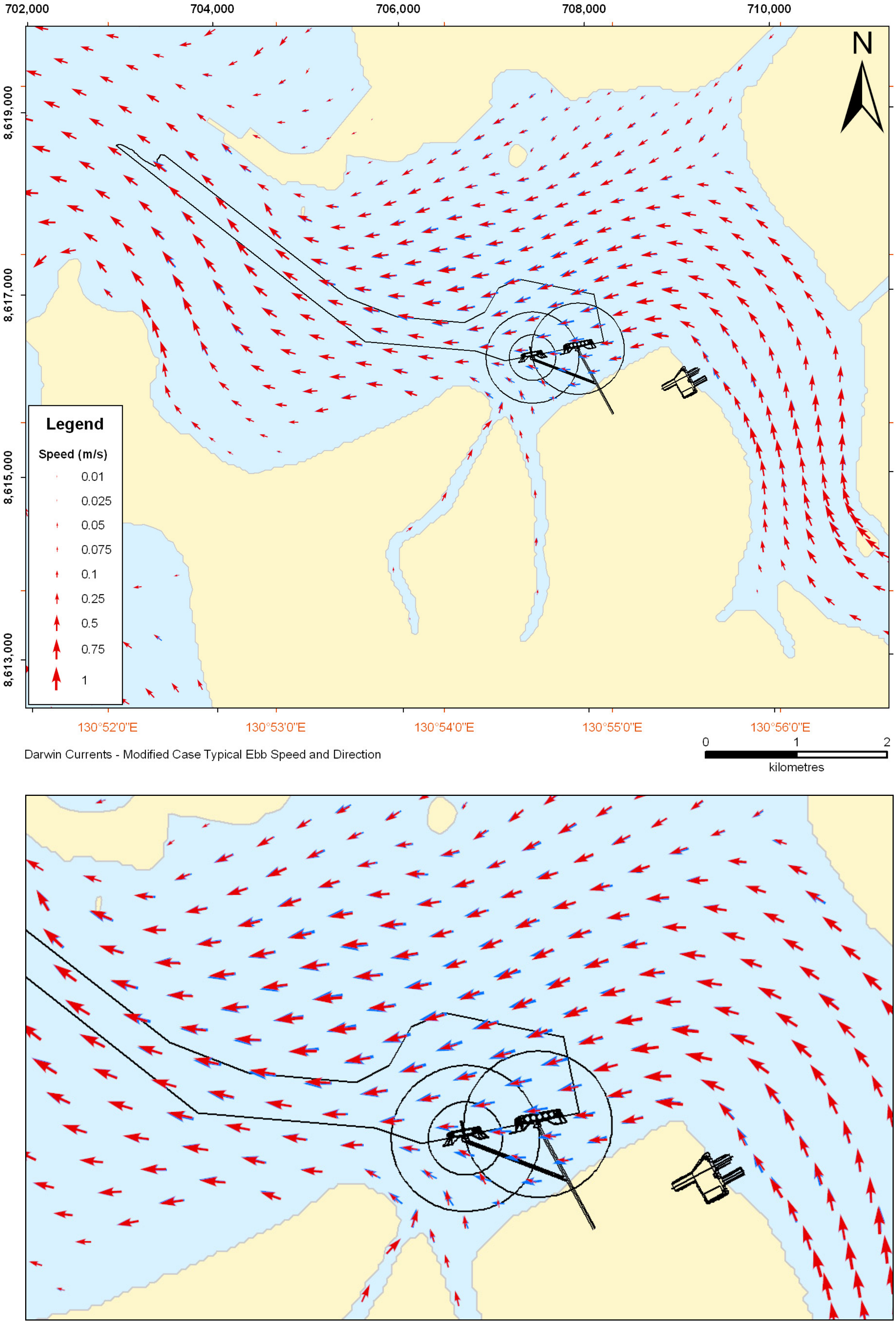



*Figure 7: Comparison of the peak ebb current speed and direction for the Modified Case (red arrows) overlaying the Base Case estimates (blue arrows). Lower panel shows a zoomed image around the proposed facilities.*

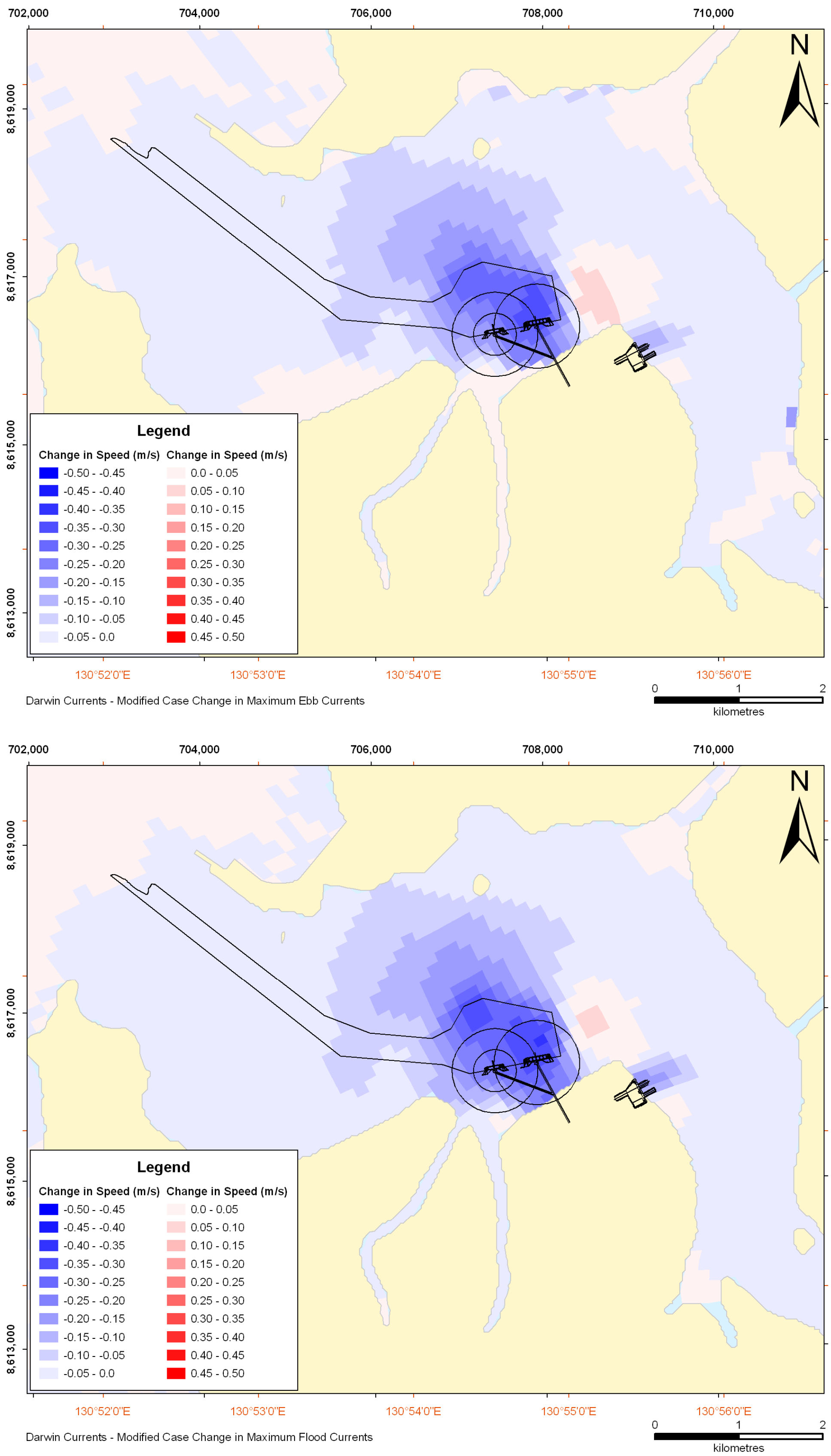



*Figure 8. Predicted modifications of the depth-averaged peak ebb (top panel) and peak flood (bottom panel) current speeds.*

Current statistics for the four identified locations are summarised in Table 1.

*Table 1: Comparisons of the maximum simulated current speeds at four output points (see Figure 9) for the Base Case and Modified Case.*

| | Latitude South | Longitude East | Base Case maximum speed surface/bottom (m/s) | Modified Case maximum speed surface/bottom (m/s) |
|---|---|---|---|---|
| Channel Bend | 12°30′44″ | 130°53′61″ | 0.45/0.28 | 0.40/0.24 |
| Berth 1 | 12°30′58″ | 130°54′51″ | 0.55/0.44 | 0.18/0.13 |
| Berth 2 | 12°30′52″ | 130°54′79″ | 0.27/0.21 | 0.16/0.11 |
| Module Offloading Facility | 12°30′72″ | 130°55′51″ | 0.25/0.20 | 0.18/0.15 |

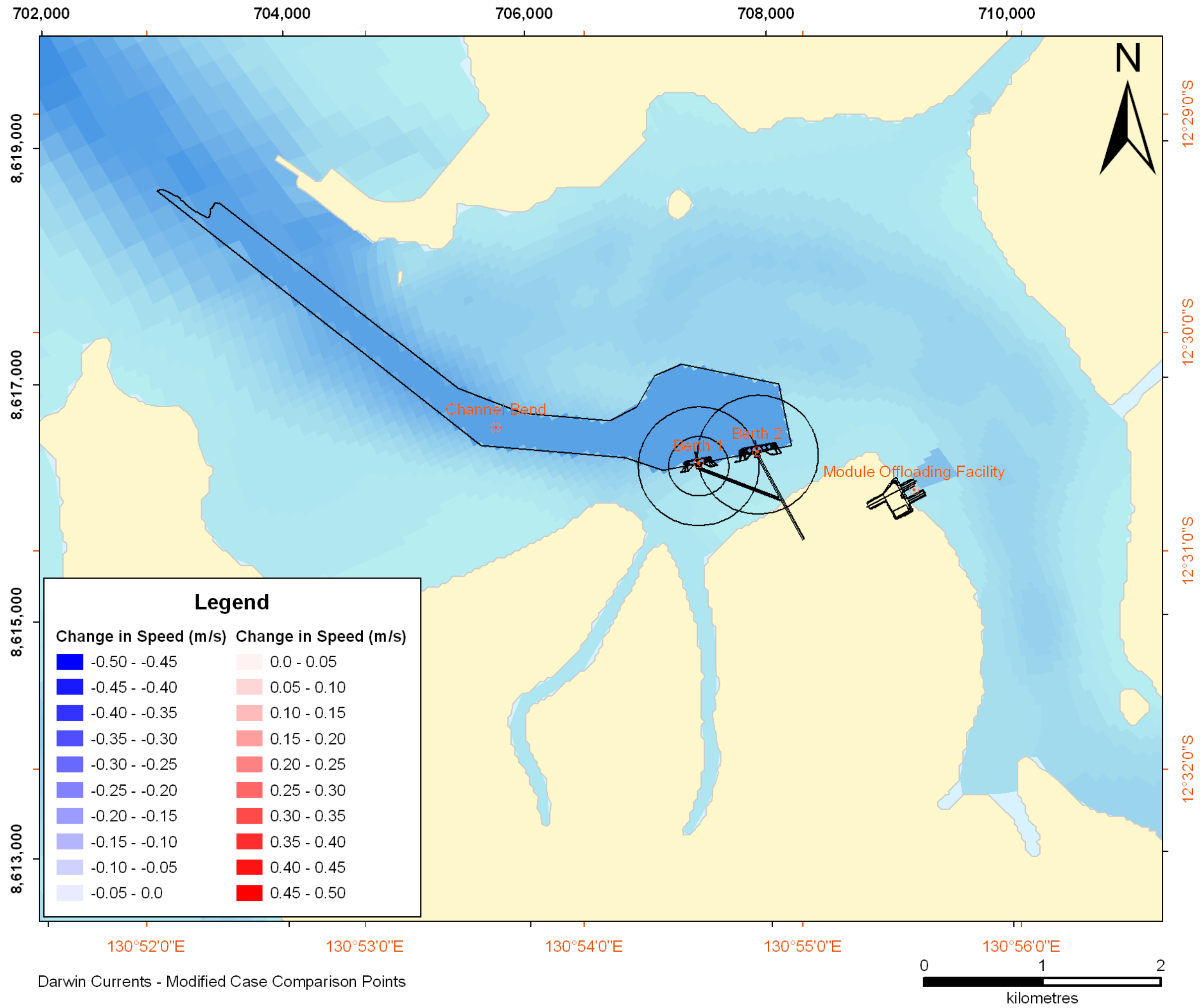



*Figure 9: Comparison locations used to compare currents between the Base Case and Modified Case. Bathymetry is shown for the Modified Case scenario.*

Histograms of the near surface and near bottom current speed and direction were prepared from the time-series data, with the results shown in Figure 10 to Figure 13 for the Channel Bend, Berth 1, Berth 2 and Module Offloading Facility locations, respectively. In each of these figures, the blue bars represent the Base Case and the red bars show the Modified Case.

After dredging of the complete dredging footprint, the maximum surface and bottom current speeds at the Channel Bend location, was indicated to decrease by 0.05 m/s (about 10%) and 0.04 m/s (about 14%) respectively, with an overall decrease in current speed over the distribution. No significant effect on the current direction is indicated.

At Berth 1, both the surface layer and bottom layer currents were indicated to reduce by more than 65% after all dredging is completed, from around 0.5 m/s to around 0.2 m/s. The frequency distribution for the current direction also indicated changes. The Base Case simulation indicates the current direction is multi-directional, which can be attributed to turning of the tidal current axis due to the input from the two nearby creeks. Following dredging, the currents are expected to shift to a more bi-directional current pattern due to a shoreward extension of the bi-directional currents operating further offshore.

At Berth 2, the proposed dredging is predicted to result in maximum current speeds decreasing by approximately 0.10 m/s (40% at the surface and 48% at the bottom). The histogram plots indicate there will be an increased frequency of slower current speeds and a shift in the axis of the unidirectional current by approximately 30 degrees.

Comparisons indicated a reduction in the current speeds at the centre of the Module Offloading Facility dredging area by approximately 25%, due to a combination of the deeper cross-section for tidal flow and partially due to the presence of the transition barge. No changes in the current directions were indicated.

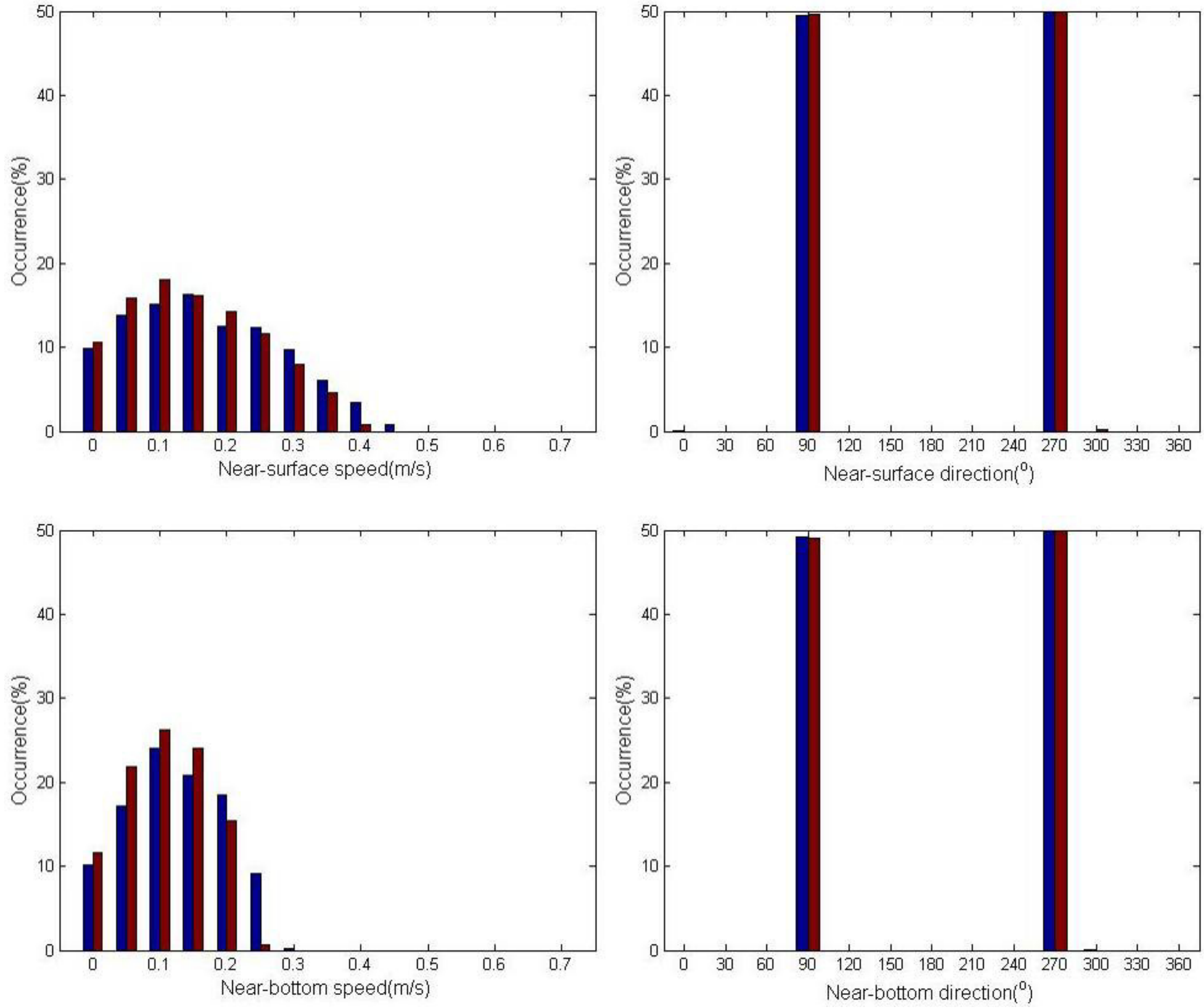



*Figure 10: Comparisons of the near-surface and near-bottom current speeds for the Channel Bend location. Base Case is represented by blue bars. The Modified Case is shown as red bars.*

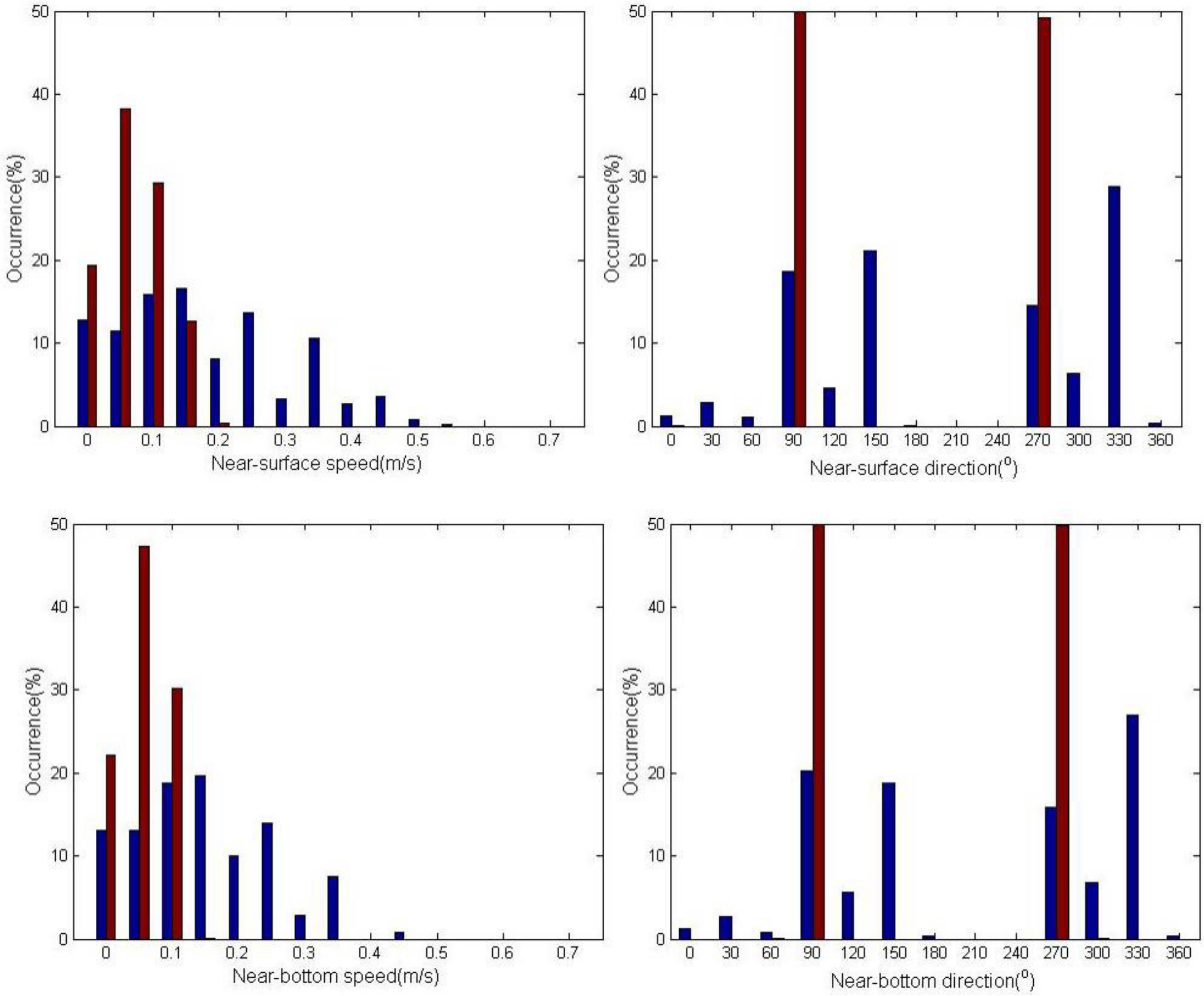



*Figure 11: Comparisons of the near-surface and near-bottom current speeds for the Berth 1 location. Base Case is represented by blue bars. The Modified Case is shown as red bars.*

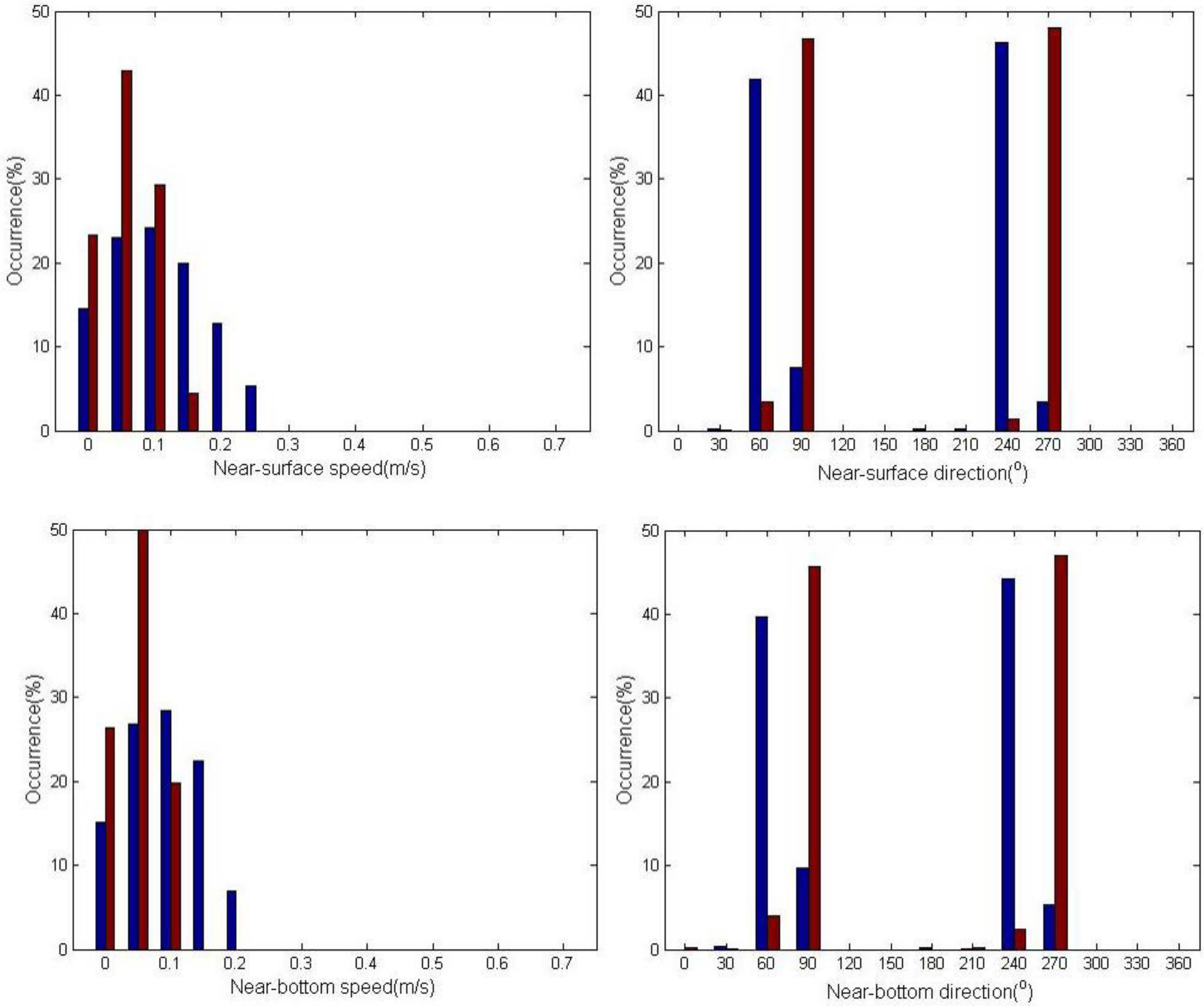



*Figure 12: Comparisons of the near-surface and near-bottom current speeds for the Berth 2 location. Base Case is represented by blue bars. The Modified Case is shown as red bars.*

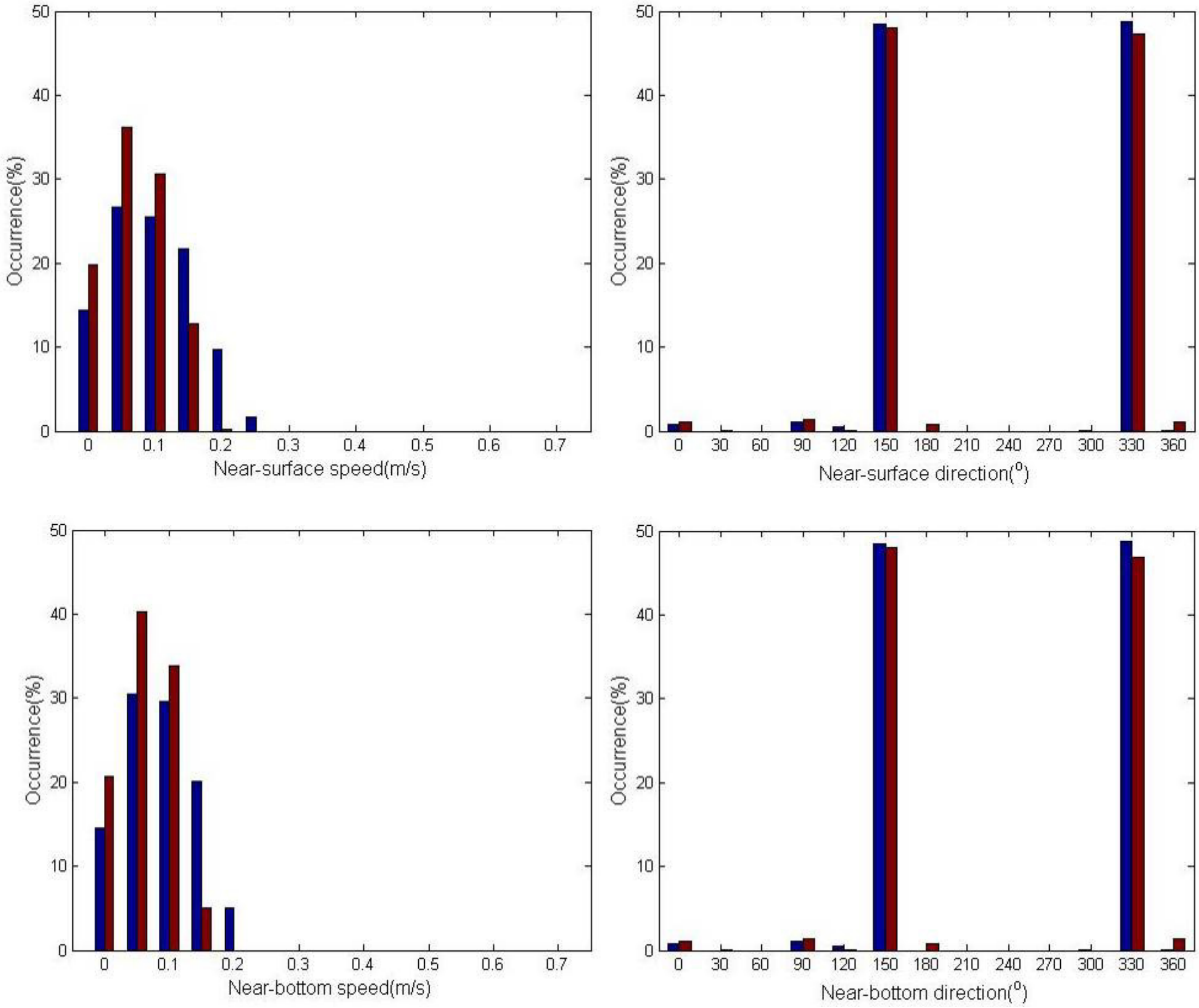



*Figure 13. Comparisons of the near-surface and near-bottom current speeds for the Module Offloading Facility location. Base Case is represented by blue bars. The Modified Case is shown as red bars..*

### 3.3 Modifications of wave patterns within East Arm

Maps of the mean difference in wave height between the Base Case and Modified Case scenarios are shown in Figure 14. The results indicate that small increases in the mean significant wave height would result from dredging of shipping channel, approach area, turning basin and berthing area. The greatest increase in magnitude, of the order of 7-8 cm (0.07 – 0.08 m) was indicated over the shallower banks to the north and east of the proposed dredging footprint, suggesting small increases in the resuspension of sediments could occur in these restricted areas. For most locations the magnitude of change was indicated at less than 3 cm (0.03 m) significant wave height. These differences are small relative to the magnitude of the waves propagating within East Arm, suggesting low potential for undesirable changes in wave-generated sediment movement or significant engineering impacts compared to the existing conditions. Histogram plots showing predicted changes in the distribution of wave heights at four comparison points within East Arm (Figure 15) indicate that there would be a small decrease in the frequency of lower height waves and an increase in the frequency of the higher wave heights. However, the distribution would remain constrained the significant wave height of approximately 0.3 m, hence there is no indication that the dredging would increase the frequency of swell waves propagating into East Arm.

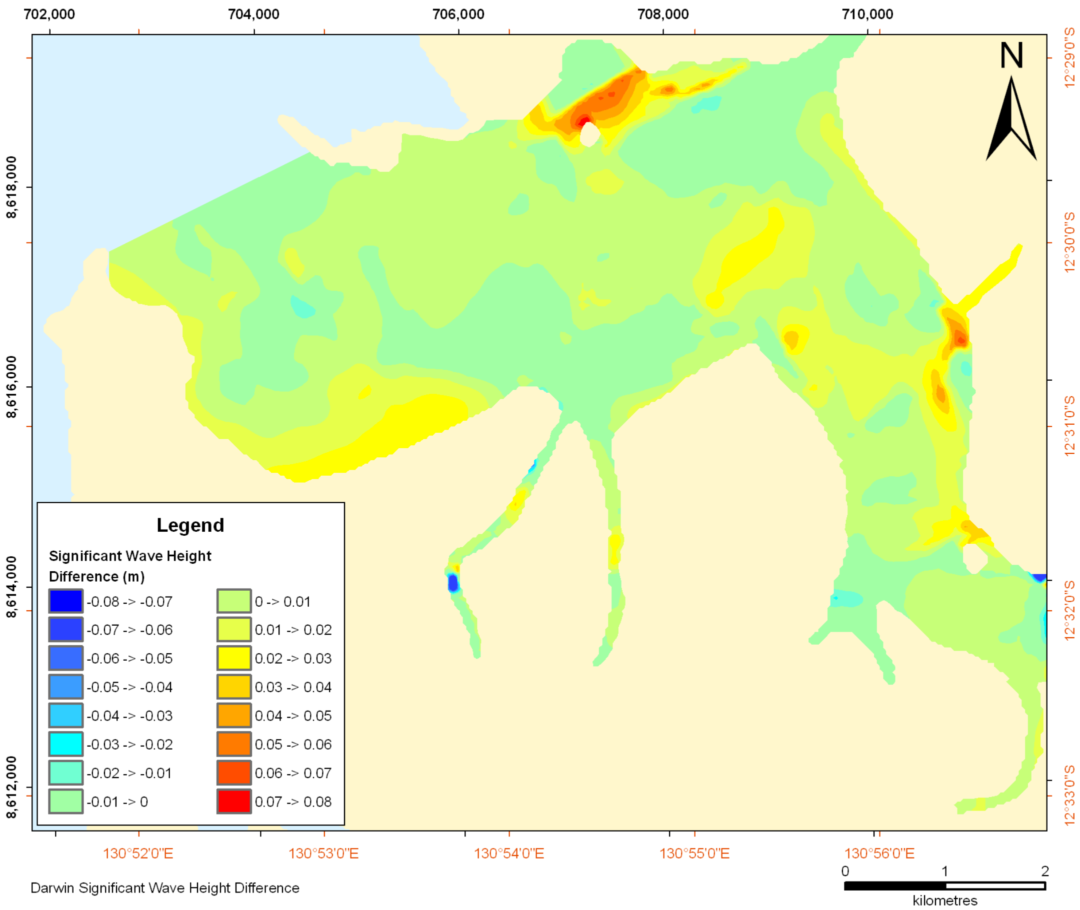
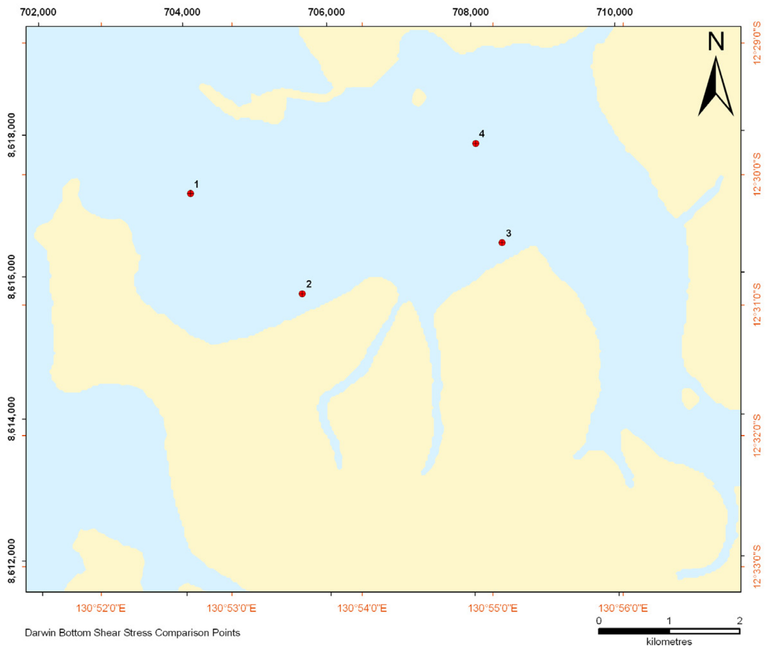



*Figure 14: Mean differences in significant wave height in East Arm between Base Case and Modified Case scenarios.*



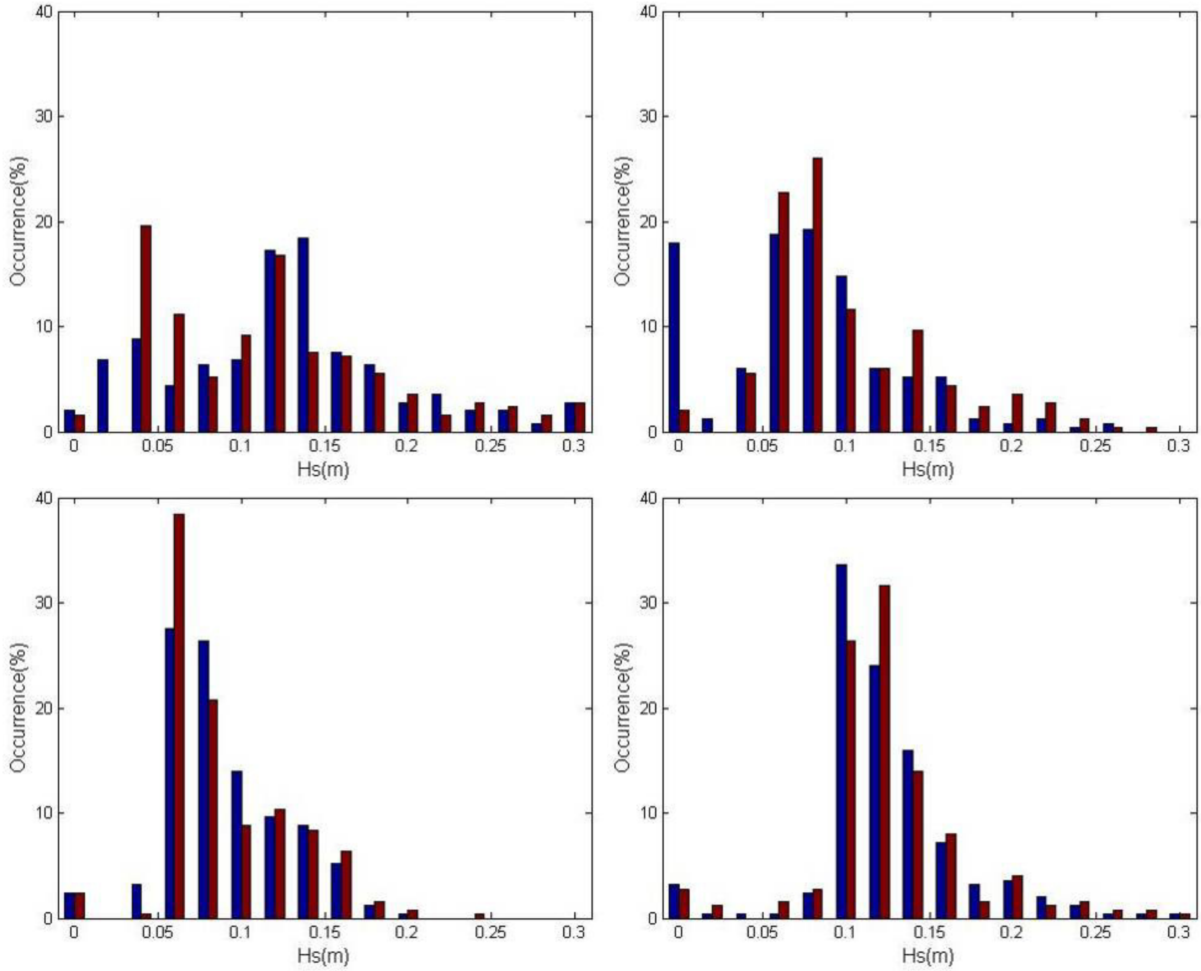




*Figure 15: Histogram plots comparing the frequency of occurrence of wave heights for the Base Case (blue bars) and Modified Case (red bars). Results are shown for points 1 (upper left), 2 (upper right), 3 (lower left), and 4 (lower right) shown in the map above.*

## 3.4 Effects on bed shear stress within East Arm

Estimates for the median levels of bed-shear stress throughout East Arm for the Base Case indicate significant spatial variation, with the highest shear-stress estimates occurring along the central portion of the channel and reduced stress over the entrances to the creeks and portions outside of the main channel flow. This pattern is illustrated in Figure 16. The selected colour scale represents the theoretical minimum thresholds for resuspension of non-cohesive clays (0.0018 Pa), fine silts (0.0091 Pa), coarse silts (0.019 Pa), fine sands (0.034 Pa), coarse sands (0.259 Pa), and beginning of erosion of cohesive sediments with bulk densities from 1100 to 1850 kg/m$^3$ (0.500 Pa). The estimates for the baseline case indicate that sediments of fine-sand size and smaller would be resuspended at least 50% of the time along the larger part of the main channel. Locations of low median sheer stress, hence higher stability for sediment deposits, correspond to the locations where the major mudflats occur, consistent with the observation that material with fine particle sizes accumulates in these regions.

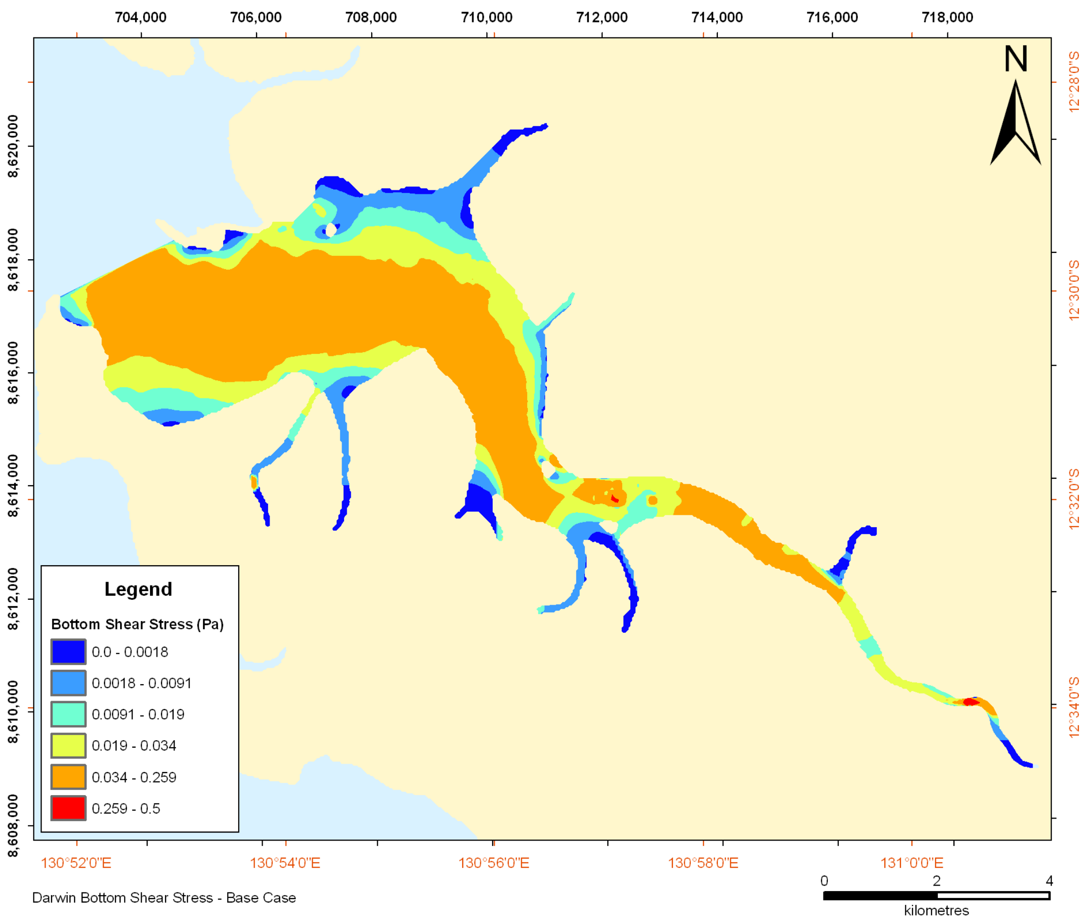



*Figure 16: Median (50th percentile) of the estimated bed shear stress for the Base Case scenario*

To compare the pre and post development cases, mean differences in bed shear stress between the Base Case and Modified Case Scenario were calculated (Figure 17). The results indicate that, overall, the magnitude of the bed shear stress in East Arm would decrease to a small extent after dredging. This decrease is attributed to the small reduction in tidal current speed predicted for the deeper areas of East Arm that would result from deepening the bathymetry in the area of the berthing area and turning basin. A relatively small and localised increase in shear stress levels was indicated for the mud bank off the eastern side of Dawson Creek due to a small increase in wave energy during part of the simulation for the Modified Case, interacting with this shallow area.

Histograms showing the distribution of shear-stress estimates at the same 4 sites previously specified for extracting wave and current estimates demonstrates that lower bed shear stress would occur more frequently and that the highest levels of shear stress should decrease marginally (Figure 18).

The predicted decrease in bed shear stress over the wider part of East Arm indicates the potential for a small increase in sedimentation potential following development. The effect is expected to be minor but should be considered in the wider engineering studies.

The comparisons indicate that the effect of the dredging for the Module Offloading Facility berth on the median seabed stress levels would be negligible on a local scale, with a net change of less than -0.003 Pa predicted on either side of the berth location. This result is likely due to the relatively small size of the dredging area.

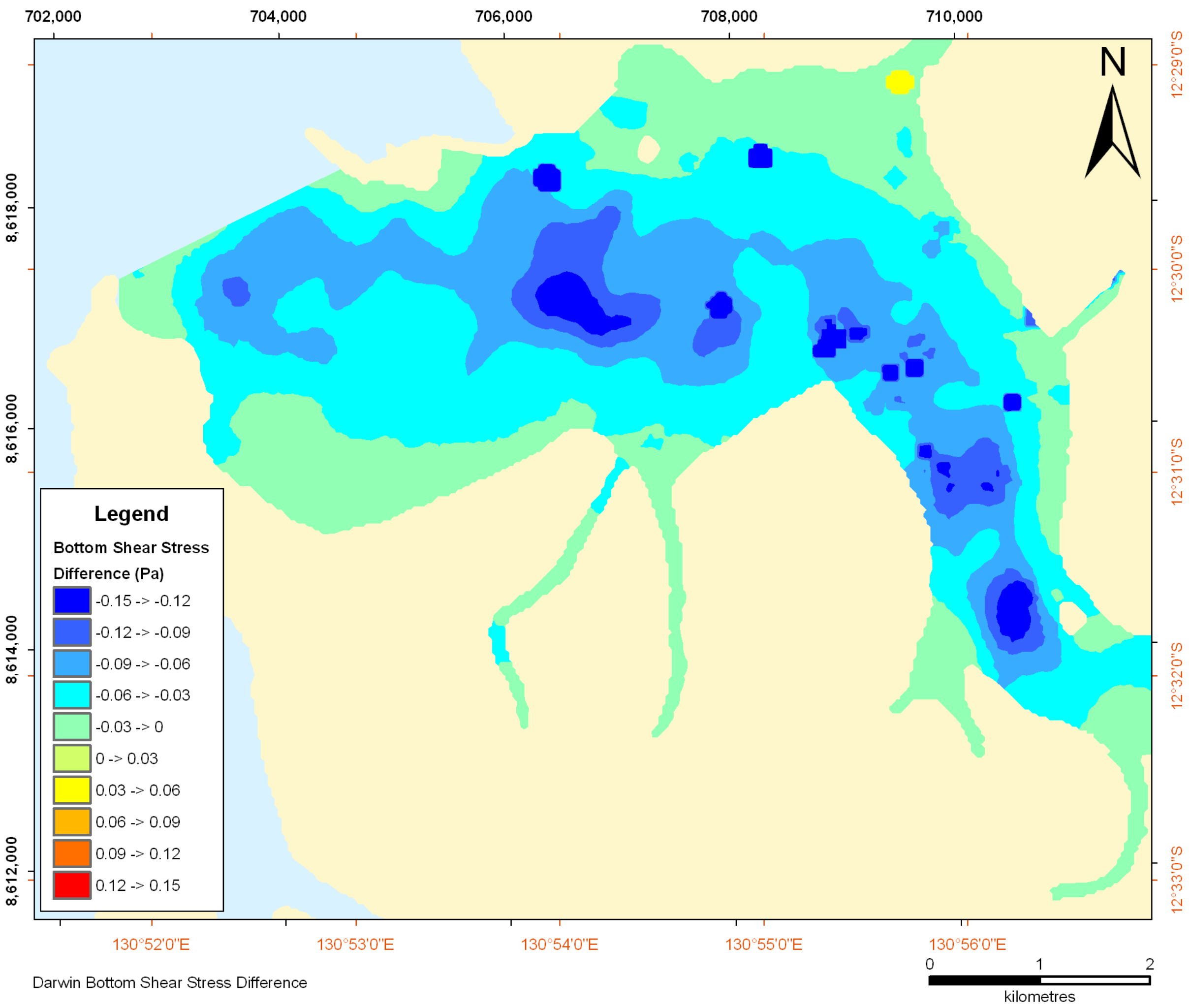
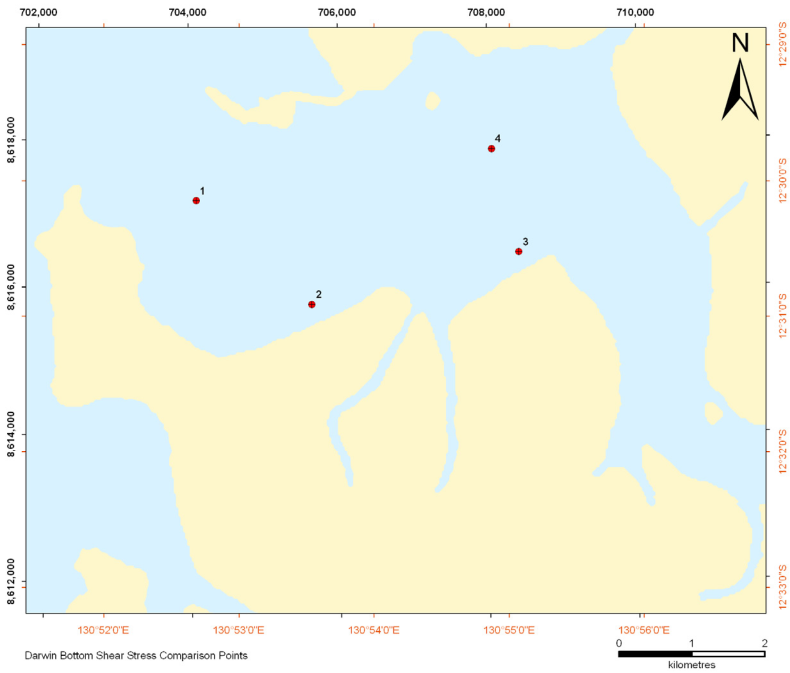



*Figure 17: Mean changes in bed shear stress estimated by comparison of predictions for the Base Case and Modified Case.*



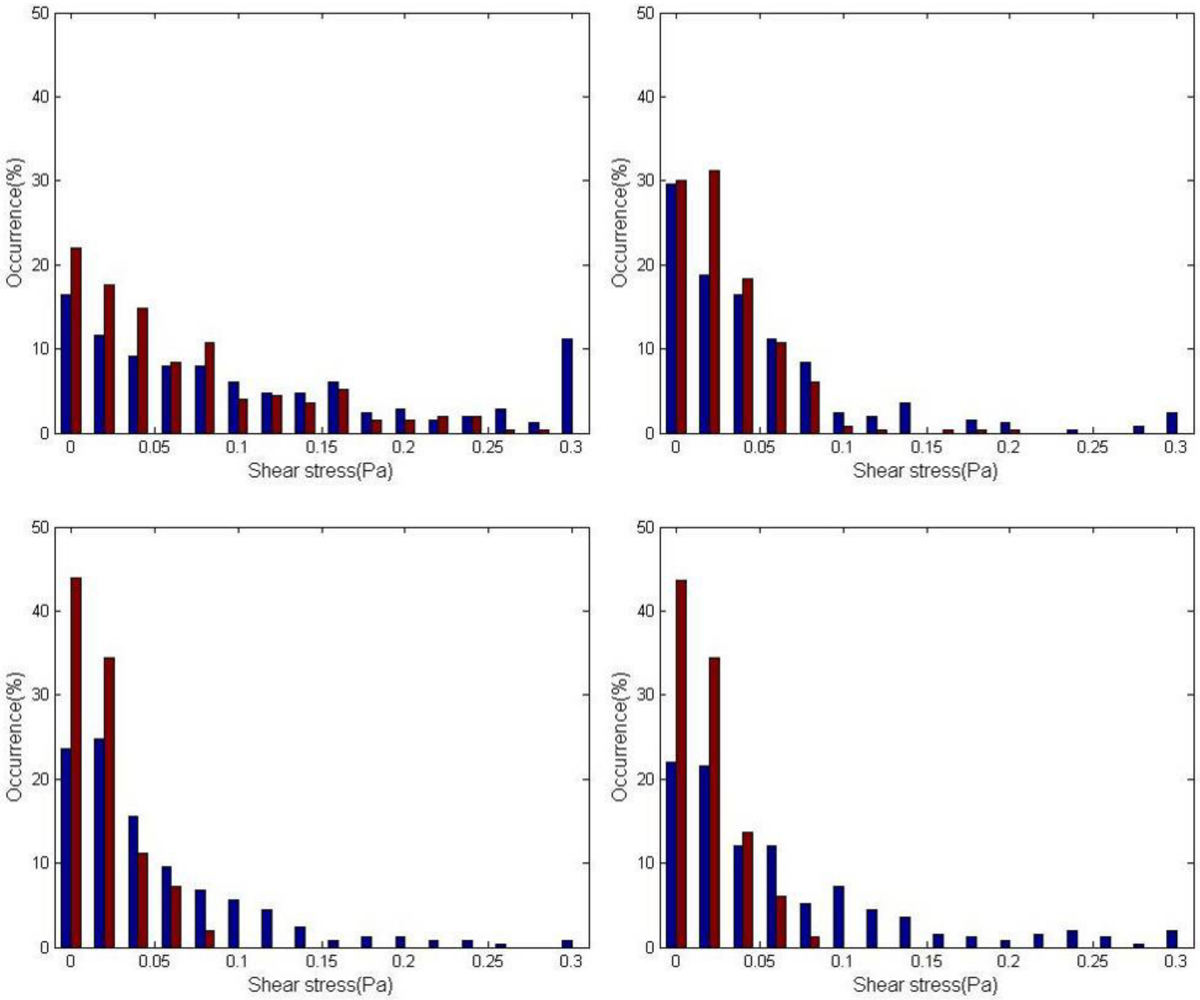




Figure 18: Histogram plots comparing the frequency of occurrence of bed-shear stress levels (units = Pascals) for the Base Case (blue bars) and Modified Case (red bars). Results are shown for points 1 (upper left), 2 (upper right), 3 (lower left), and 4 (lower right) shown in the map above.

# 4 SUMMARY AND CONCLUSIONS

In a general sense, the changes to the hydrodynamic conditions within East Arm due to the proposed development are minor. No large variations in current speeds and directions or of wave energy are predicted, and therefore only minor variations in flushing and sediment transport potential are indicated.

The flushing simulation results demonstrated that there would be no significant differences in the tracer concentration between the scenarios after one month of flushing. Thus, no essential changes in retention times would be introduced by the proposed dredging plan and, therefore, no significant increase in the risk of water quality or sedimentation problems would be anticipated.

In terms of current speed and direction, modifications of the existing circulation patterns are predicted to be localised and confined to the dredging footprint. Current magnitudes are expected to reduce locally in the deepened areas, due to increasing the cross-sectional area available to flow. The effect was also indicated to extend beyond the footprint due to redirection of a portion of the water mass flowing over the channel further north. The magnitude of the calculated reductions was relatively small. Hence, no large environmental or engineering consequences are likely, although there may be a small increase in sedimentation potential in these areas when compared to existing conditions. Further, a small increase in sediment mobilisation rates was indicated for the shallow bank immediately upstream from the proposed berth location. These indications should be considered in the overall engineering assessment of the Project.

No large changes in wave energy due to the development are indicated. In particular, there is no indication that the frequency or magnitude of swell waves will increase. Hence, there is no strong indication that there would be an increase in bank erosion or sediment resuspension within the East Arm. There are also likely to be no large vessel mooring or manoeuvring issues associated with the change in bathymetry, with conditions largely resembling those existing.

Estimates of the combined effect of modifications to currents and waves, expressed as bed-shear, similarly indicated only small modifications throughout East Arm. In general, small reductions in bed shear estimates were derived for the Modified Case, indicating a small decrease in resuspension of sediments from the seabed.

The results summarised in this report were derived using the modifications of bathymetry specified for a dredging footprint provided by INPEX. Minor variations would be expected with variations in the final footprint. Simulations indicated that modifications in current direction will be restricted to the dredging footprint, while variations in current speed and wave height varied beyond the footprint. For a similar footprint with the same channel depth, the results presented here are likely to be representative. In general, there would be a divergence of some of the water mass into the deepened sections, hence marginally reduced current speeds would be expected across East Arm, and marginally increased significant wave heights. These changes were indicated to be small relative to the magnitudes of the existing current speeds and wave heights.

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