Dredging of Sand from Darwin Harbour, Hydrographic and Marine Life

Part 1

Hydrodynamics and Sediment Transport

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Executive Summary

The Northern Territory Government requires suitable foundation material for the expansion of the East Arm wharf complex. Suitable material is situated in the sandbar in East Arm. It is proposed to dredge the sandbar and contain the material within the wharf complex so it can be readily accessed during construction. Several issues were identified in relation to the removal of the sandbar.

1. Changes to hydrodynamics within the East Arm of Darwin Harbour
2. Dispersion and settling of fine sediments as a result of the dredging process
3. Long term sediment pathways and the potential re-establishment of the sandbar

Part 1 of this report investigates issues 1 – 3 above and part 2 of this report investigates issue 4.

The Darwin Harbour hydrodynamic model originally set up by the Northern Territory Government was further refined for East Arm using the most up to date bathymetry available. This included the recent bathymetric surveys provided by Inpex and additional surveys carried out by the Australian Institute of Marine Science. Hydrodynamic simulations were run for a lunar tide cycle (29 days) which comprises 2 sets of spring and neap tides. The simulations were done for the case where the sandbar exists and the case where the sandbar had been removed. The differences in the magnitude of tidal currents were compared and the results show that the currents in East Arm are little affected by the removal of the sandbar.

A fine sediment transport model was run for two months, being the period required to remove the sand bar, and then for a subsequent month to predict the final dispersion of fine sediments. The model predicts that even with a 10% leakage of sediment from the dredge head that fine sediment concentrations will not exceed 2 mg/L above ambient conditions for the duration of dredging. Fine sediment concentrations decline rapidly after the cessation of dredging back to ambient conditions. The model further predicts that the maximum deposition of fine sediment does not exceed 50 micrograms (0.05 millimetres) during dredging and is further reduced in the month after dredging ceases.

A long term sand transport model predicts that the area where the sandbar exists is a natural deposition area and is due to the large eddy circulation that exists in that area. The model predicts that sand will deposit in the area at a rate of 0.1 – 0.2 metres per year not including the effects of cyclone or storm surges. This suggests that the formation of the sandbar occurs over a multi decadal timeframe.
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Background

The Northern Territory Government Department of Planning and Infrastructure has an intention to fill an area called Pond F at the port of Darwin using sand sourced from a sand bar which is situated south of Old Man Rock. The intended dredging operation will remove material from the Sand Bar which currently comprises approximately “1.4 million m$^3$ of sand with little or no fines” (GHD 2007, Darwin Project Estimates for Darwin Port Corporation, unpublished report to DPI December (p.15)). The sand is intended to be dredged through a submarine dredge pipeline towards the Port facility. The location of the sandbar and the proposed pipeline route is shown in figure 1.

![Figure 1 Location and plan for dredging of the east arm sandbar (provided by DPI).](image)

Field and modelling studies have been undertaken to assist with the management of the project and address issues that may be of concern. These issues represent processes that are unknown and potential impacts from the dredging operations. Unknowns and potential impacts at this time include:

1. Hydrodynamic changes within East Arm of Darwin Harbour as a result of removing a large portion of the sandbar
2. Sediment leaving dredge area due to disturbance of the dredge action
3. Longer term sediment transport pathways and origins of sediment.

Part 1 of this report deals with the hydrodynamic sediment transport aspects. Part 2 reports on the benthic habitat mapping.
1. Hydrodynamics

The existing Darwin Harbour hydrodynamic and sediment transport model was used in this investigation. The model has been used on many projects within Darwin Harbour and was developed by the Northern Territory Government to assist with an understanding of dynamic physical processes within the harbour to evaluate potential impacts and design of developments.

The existing model was further refined in the East Arm area to utilise recent bathymetric surveys. Extensive fine scale surveys were carried out in 2008 for the Inpex LNG shipping requirements and the extent of this survey is shown in figure 2. The Inpex survey did not cover the entire sandbar region and additional transects were surveyed over the sandbar as part of this project. The additional detail added to the East Arm area ensures that the representation of tidal current and direction is adequate for this study. The model has been well calibrated and tested over many years by using Acoustic Doppler Current Profiler (ADCP) tidal current mapping techniques.

The hydrodynamic model was forced by applying a tidal condition at the ocean boundary. These tides were based on the tides recorded at the Fort Hill Wharf tide recorder. The relationship between the tides recorded at Fort Hill Wharf and the ocean boundary are well known as several oceanographic moorings have been deployed in this region (Williams 2006). The model was run for a period of one month to capture the spring neap tidal sequence with the maximum spring tide range being 7 metres.

Current vectors for spring tides are shown in figures 3 – 6.
The sandbar was removed from the model to a depth of 7 metres below low water Chart Datum and the model was rerun for the same period. It is difficult to appreciate the subtle differences in velocity from a vector plot so time series plots of the difference in current speeds at selected locations (figure 6) are shown in figures 8–12. The results show there are no significant differences in current speed from removing the sand bar. Much of the sandbar is underwater and the deepening of the area has made only subtle differences to the tidal current magnitudes.
Figure 5 Spring flood tide with sandbar dredged

Figure 6 Spring ebb tide with sandbar dredged
The times series plots represent difference in current speed which has been calculated as the current with sandbar minus the current with sand bar removed. A negative value shows that the currents have increased with the removal of the sandbar and a positive value shows that the currents have increased.
Figure 9 difference in tidal current magnitude for location 2

Figure 10 difference in tidal current magnitude for location 3
Figure 11 difference in tidal current magnitude for location 4

Figure 12 difference in tidal current magnitude for location 5

Modelling of the tidal currents before and after the removal of the sandbar shows a maximum difference in current speed of approximately 0.060 metres/second at the location where the sandbar is presently the shallowest (figure 8). The velocity differences diminish further way from the sandbar. At the East Arm wharf face the differences are only a few millimetres per second (figure 10).

The sandbar occupies a small area in comparison to the width of the estuary and the majority of the sandbar is several metres under water at low tide. Consequently removal of 300,000 m$^3$ of the sand bar has a negligible effect on tidal current
magnitudes and would not effect navigation in the area. Bed shear stresses in the area will be unaffected so the area will not experience any increase or decrease in erosion or deposition than that which has occurred in the past under the same conditions.

2. Sediment Transport from dredging

It is proposed to remove a large volume of sand from the sandbar by the use of a cutter suction dredge. The material will be piped to pond F within the East Arm wharf complex. As the disposal area is contained within bund walls there is no concern regarding leakage of fine sediment material from this area. During dredging of the Waterfront project around 600,000 m³ of fine mud was dredged and piped to pond K within the wharf complex without any leakage from the pond so the techniques exist to fully contain the sediment. The only concern is from potential leakage around the cutter suction head of the dredge.

The recent dredges that have been used in Darwin Harbour for the waterfront project and the Cullen Bay dredging have had the capacity to dredge material at a rate of 2000 m³ / hour. The ratio of water to sediment is about 90:10. For the case of the East Arm Sandbar this results in a sand dredging rate of 200 m³ / hour. Fine sediment content is approximately 10% (Acer Forester 1998) which gives a dredge rate of 20 m³ / hour for fine sediment. The moisture content of the fine sediment is approximately 50% so the equivalent dry weight of sediment is 10 m³ / hour. If we assume a leakage around the cutter suction dredge of 10%, which is considered high and therefore conservative, the amount of fine sediment disposed into the water during dredging is around 1 m³ / hour. A rate of 0.5 kg / second has been used in the modelling and has been applied continuously. This adds another level of conservatism to the model as continuous operation doesn’t occur as the dredge has to frequently move location and shutdown for service checks. For modelling purposes a volume of 300,000 m³ removed at an effective sand dredge rate of 200 m³ / hour would take in the order of 1500 hours or 62.5 days if operated continuously. The model has been run for 60 days with a continuous sediment input of 0.5 kg / second and then run for a further 30 days with no sediment input to simulate the rate of dispersion throughout the area.

Sediment plumes generated by the model are shown in figures 13 –17.

Selected locations for time series analyses of sediment concentration and deposition are shown in figure 18.
Figure 13 Sediment plume at flood tide one week after commencement of dredging

Figure 14 Sediment plume at ebb tide one week after commencement of dredging
Figure 15 Sediment plume at spring tide one month after commencement of dredging

Figure 16 Sediment plume at ebb tide one month after commencement of dredging
Figure 17 Sediment plume at ebb tide 2 months and 1 week after commencement of dredging

Figure 18 locations of time series plots of fine sediment concentration and deposition
Figure 19: Fine sediment concentrations at position 1

Figure 20: Fine sediment concentrations at position 2
Figure 21 fine sediment concentrations at position 3

Figure 22 fine sediment concentrations at position 4
Figure 23 fine sediment concentrations at position 5

Figure 24 fine sediment concentrations at position 6
The maximum concentration predicted by the modelling is 2.7 mg/L above ambient conditions at position 1 (figure 19) and these levels are only reached for short periods of time. Average concentrations at the dredge site are around 1.5 mg/L above ambient (figure 19). The peak concentration occurs at the cutter suction dredge head and the concentrations fall away from the dredge location to half these values at the other plotted locations. These values are low compared to the average background concentrations that occur in this part of Darwin Harbour. These minor elevations in concentrations above ambient conditions should not present a problem to benthic habitats due to decreased light or smothering (see Smit, part 2 of this report). At the cessation of dredging the concentrations fall back to ambient levels over the following month.

The field of influence of dredge plumes can be far reaching and the final location and thickness of deposition of fine sediment is as important as the concentration values in the water column.

A contour of deposition thickness at the end of dredging is shown in figure 26. Time series of deposition thickness (as shown in figure 18) for the selected locations is shown in figures 27 – 33.
Figure 26 deposition measured in microns after 3 months

Figure 27 deposition times series at location 1
Figure 28 deposition times series at location 2

Figure 29 deposition times series at location 3
Figure 30 deposition times series at location 4

Figure 31 deposition times series at location 5
The maximum thickness of deposition is modelled to be 45 microns occurring at location 5 (figure 31). After the cessation of dredging most of the deposited fine sediments have not been able to consolidate and are removed over the next month so that over a large area the final deposition thickness is less than 0.5 microns. The modelling was based on a bed shear stress for deposition of 0.06 N/m² and a bed shear stress for erosion of 0.08 N/m². These values have been used in previous model runs of dredging in Darwin Harbour with success and partially verified with field measurements. These measurements are continuing as the derivation of bed shear
stress for differing sediment types is crucial for the accurate modelling of the fate and transport pathways of sediments. The modelling results indicate that dredging of the sand bar is not considered to have any impact on tidal currents. The modelling results also indicate that dispersion of fine sediment from the dredging exercise will have minimal impacts on the surrounding area. Impacts could be lessened further by deploying a screen around the cutter suction head of the dredge. These screens are sometimes referred to as buckets and are a steel casing that fits around the cutter suction head and limits the amount of leakage from the site.

3. Longer Term Sediment Transport

The long term transport of sediment in Darwin harbour is dependant on many parameters including:

- Tidal current strength and duration of both flood and ebb tides
- The frequency and duration of waves of different wave period classes generated by seasonal winds and storm surges including cyclones
- The quantity and type of sediment entering the harbour from river inflows and from the ocean
- The distribution of sediment sizes and types throughout the harbour
- The thickness and compaction (often termed bulk density) of bed sediments
- The bed shear strength (related to tidal current strength, depth of water and the roughness of the bottom) for erosion and deposition of sediments
- The rate at which different types of sediment fall through the water column when suspended.
- The interaction of sediment classes with each other and organic matter

Most of these parameters are not known for sediments in Darwin Harbour. To assist with the evaluation of sediment pathways in the harbour a longer term sediment model was set up. The model used the same bathymetry as for the hydrodynamic and dredging simulations but had the known sandbars removed. The harbour was given a constant thickness of 0.5 metres of fine sand with a grain size of 0.2 mm. This grain size was selected as representing the median grain size of sand in the harbour. The model was given an initial water column concentration of 0.2 mg/L. A constant sediment inflow of 0.2 mg/L was applied at the ocean boundary. The model was run for a period of one year with a typical flood and sediment concentration of 2 mg/L applied at the Elizabeth and Blackmore Rivers. The river flow inputs were maintained for a 4 month period and the model was continued for a further 8 months with no river input. This then represented both a wet and dry season. The RMA11 model was used to simulate the movement of sand using the sediment transport algorithms developed by Van Rijn and implemented in the model by King (2008). The model is capable of simulating up to 5 sediment size classes but due to the lack of knowledge of sand classes and their dynamics in Darwin Harbour only one class has been simulated. The model was used to provide a qualitative assessment of transport pathways and deposition areas and not as a definitive quantitative assessment. The model was driven by tidal currents and river inflows only. As wave data for Darwin has never been measured waves have not been included in the
simulation. However waves would play a very important role in accelerating sediment transport especially in the shallower areas.

In addition to the modelling, sand samples have been taken at several locations distributed throughout the harbour. The will be analysed for mineralogical signatures. The mineralogy is determined by X-ray diffraction from an external laboratory (CSIRO Land and Water Adelaide) and the results were not ready at the time of writing this report. The results will be provided as an additional report.

The result of the sand transport is shown in figures 34 – 36. Little to no erosion or deposition is indicated by green dots, erosion by blue dots and deposition by brown dots.

![Figure 34 Sand deposition areas in East Arm. Blue dots represent areas of erosion, green dots represent areas where there has been no change, brown dots represent areas of deposition](image-url)
The model has predicted that deposition occurs at known sand bar locations. These include the East Arm sandbar (figure 34) and the Fannie Bay sandbar (figure 35). Additionally, the model has predicted deposition in Middle Arm (figure 36). Middle Arm has several extensive sand bars. The origin of the middle arm sand bars are most likely from the Blackmore River. This is evident when viewing the sandbars as the sand grain size increases in coarseness in an upstream direction. The sands are fine near Wickham Point and Channel Island and coarsen to include fine gravels by the area near the middle arm boat ramp. It is likely then that a large proportion of the siliceous sands found in the East Arm sandbar originate in Middle Arm. As the sand migrate down the estuary and enters the main harbour the flood tide dominant
currents then transport the sand into East Arm. Calcareous sands most likely have a more tortuous path. Some of the calcareous sand may originate in the mangrove areas from shell production but many of these would be buried in the fine mud. During storm surges some of this shell material may be resuspended and moved out into the channels where it can be transported. There are many shell ridges behind the mangrove zones and the majority of shell material is most likely deposited in these areas as the result of storm surge and then not available for further transport by tidal currents and waves. Calcareous sand originating from the ocean boundary of Darwin Harbour would be transported by tidal currents and waves with the sand remaining in the strongest currents until such time as they reach areas of strong recirculation. Two areas of this type are found at the edge of the main channel near Fannie Bay and Emery Point and in East Arm. These large areas of recirculation are well defined by the model. Both the Fannie Bay and East Arm sandbars have properties similar to the formation of sand levees on river banks. The currents transport the sand and the sand disperses laterally and is deposited in the areas of weaker currents. The circulation zones for East Arm are shown in figures 37 - 41.

Flood tides entering East Arm flow in a south east direction past east arm wharf onto the sandbar and then turn toward the east (figure 37). As the tide slows toward slack tide an anti clockwise circulation sets up behind East Arm wharf. Prior to the construction of the wharf the setup was behind South and North Shell Islands and the shoal between them. This area is where the East Arm expands from a constriction between South Shell Island and Wickham Point – Walker Shoal to a wide expanse through to Hudson Creek (figure 38). The dissipation of momentum forms the eddy. This large eddy circulation builds in strength and size and forms a sizeable deposition zone for sediments transported by the flood tide. The centre of the eddy circulation moves southward (figure 39). At flood slack tide and the beginning of the ebb tide the centre of circulation is on the sandbar (figure 40). As the ebb tide builds the outgoing current has a westerly direction. Sediments that were deposited to the north and north east of the sandbar are worked back toward the sandbar (figure 41). While waves have a significant role in reworking sediments and developing undulating bed forms on the sandbar the long axis of the bar is in the direction of the currents.

This process is not changed by the current proposal to dredge the East Arm sandbar. The longer term sediment modelling indicates that the rate of deposition in the sandbar area is around 0.1 – 0.2 metres per year under forcing from tidal currents only. At this rate it would have taken many decades for the sandbar to have formed into its present configuration. After dredging it is estimated that it may take up to several decades for the sandbar to reform to the same depth. This estimate does not include the influence of cyclonic storm surges. The rate to reform may be much quicker depending on the intensity and frequency of storm surges.
Figure 37 Spring flood tide 1

Figure 38 Spring flood tide 2
Figure 39 Spring flood tide 3

Figure 40 Spring ebb tide 1
The volume of the sandbar estimated in the unpublished GHD report of 2007 is 1.4 million cubic metres. The volume of the sandbar calculated from combining the late 2008 surveys by Inpex and the 2009 surveys by AIMS is 1.6 million cubic metres. If the surface area of the sandbar remained basically unchanged at 680,000 square metres then this represents a total average change in depth of 0.30 metres or 0.15 metres per year which agrees with the modelling. The change in depth has been calculated using datasets only 2 years apart so some caution needs to be used when comparing to model results but they do give a useful indication and is the only data available.

Table 1 shows a relationship between the level in chart datum and the calculated volume of sand contained in the sandbar

<table>
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<th>Level (chart datum)</th>
<th>Volume (cubic metres)</th>
</tr>
</thead>
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</tr>
<tr>
<td>-6</td>
<td>1,112,000</td>
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<td>28,000</td>
</tr>
<tr>
<td>0</td>
<td>7,700</td>
</tr>
</tbody>
</table>
Representative cross sections of the sandbar (figure 42) are shown in figure 43. The cross sections are plotted from the northern side of the sandbar to the southern side.

Figure 42 location of cross section plots of the East Arm sandbar
Figure 43 Cross section plots of sandbar in East Arm. The assumed base of the sandbar is indicated by the dashed line.

Conclusions

The Northern Territory Government is proposing to dredge a large volume of sand from the sandbar in East Arm to be used as construction material for the expansion of the wharf infrastructure. The existing hydrodynamic model of Darwin Harbour was refined using the latest bathymetric information for East Arm. The model was run for a one lunar month tide cycle. The model was run for a case with the present East Arm sandbar and a case with sandbar removed. The difference in tidal current magnitude was calculated. The differences in tidal current magnitude are small with maximum differences occurring in the shallowest areas of the sandbar of up to 0.060 m/s. Further away from the
sandbar the differences in the navigable deeper channels are in the order of millimetres per second. The removal of the proposed quantity of sand will not have a noticeable effect on tidal current magnitudes.

The model was also used to evaluate sediment disturbance and distribution due to dredging. The predicted disturbance was minor with maximum sediment concentrations less than 3 mg/L above ambient levels. These values are considered conservative. The slightly elevated concentrations dissipate rapidly after the cessation of dredging. The levels of increased sediment concentration could be further reduced with use of a shroud or bucket around dredge head.

Deposition of fine sediments was predicted to be less than 45 microns. These sediment deposits are predicted to be short lived as there is no time for the small volumes of sediment to consolidate before being further distributed by the spring tides. Overall deposition thickness throughout East Arm is predicted to be less than 1 micron.

Longer term modelling suggests sediment pathways for siliceous sand may be from the Middle Arm. Calcareous sands may be derived mainly from oceanic sources with some minor contribution from local sources. The model predicted deposition at known sandbar locations indicating that the model is reliably predicting sediment transport by tidal currents.

Deposition rates at the sandbar are slow and may be in the order of 0.1 – 0.2 metres per year. This rate will depend on the intensity and frequency of storm surges. As there is little information of the distribution of sediment classes, their physical and chemical interactions, throughout the harbour only one sand class was modelled representing the median sand size. Cyclonic storm surges were not modelled as there is no information on the bed shear stresses generated by these surges. It is estimated that reformation of the sandbar after dredging could take several decades depending on the intensity and frequency of storm surges. These modelled rates agree with depths of deposition derived from surveys taken over the past two years.

Sediment modelling can be improved with better mapping of sediment distribution and field studies to define bed shear stresses under both tidal currents and waves.

References

