Appendix 10 – Review of “Bleaching patterns across the Pilbara in early 2008” by Dr Andrew H Baird, James Cook University.

Our Reference: DRIMS # 4496551
Your Reference:

20 October 2008

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Dear Neville

DEMG RECOMMENDATION REGARDING THE REVIEW BY DR A.BAIRD OF "BLEACHING PATTERNS ACROSS THE PILBARA IN EARLY 2008"

Dredging was undertaken during the summer of 2008 in Mermaid Sound as part of the Woodside Energy Ltd (Woodside) PLUTO LNG Project. Ministerial Conditions for the dredging required Woodside to undertake a substantial programme of coral health monitoring to assess any possible effects in the area of turbidity generated by dredging. Coral health monitoring showed significant mortality of coral had occurred at a number impact sites during this time. Detailed analysis of conditions prevailing in Mermaid Sound in summer 2008 clearly showed water temperatures higher than "normal" and in those cases where net mortality was measured, it was considered that this coral mortality was related to thermal bleaching due to high water temperatures, and not due to dredging related activities.

To investigate this matter further, Woodside contracted Dr Andrew Baird (James Cook University, Townsville) to undertake a detailed review of all coral health information collected by Woodside and others in the region during the summer of 2008, and *inter alia* to advise of the likelihood of thermal bleaching being a major cause of coral mortality during that period. The Terms of Reference provided to Dr Baird have been attached for reference.

The report was finalised in August 2008 and circulated to the PLUTO LNG Dredge Environmental Management Group (DEMG) and then discussed at the DEMG meeting on 10 October 2008. The DEMG would like to provide the DEC and Woodside with its following overall Comments and Recommendations on the Baird report and its conclusions:

1. The DEMG found the report prepared by Dr Baird met all of the Terms of Reference and presented a valuable summary of the Dampier coral bleaching observations for the summer of 2008. The Baird report provides a well

reasoned summary of the significance of the 2008 event of elevated water temperatures in both a wider regional context and within broader scientific understanding of coral bleaching events generally.

2. The DEMG accepts the major finding of the report that the coral bleaching observed throughout the Dampier Archipelago in the first half of 2008 was part of a more widespread pattern of bleaching along the Pilbara coast during the same period.

3. The DEMG supports the view taken by Woodside and its advisors that the bleaching impacts on corals observed during the PLUTO LNG coral health monitoring programme are consistent with thermal stress and that by and large the responses of the corals appear to have been typical of other warm water stress events elsewhere. Consequently the DEMG supports the interpretation that the Level 2 and Level 3 exceedances observed during summer 2008 were probably due to thermal bleaching and not due to dredging or dredging related activities. The DEMG also considers the mortality reported at inner impact site ANGI resulting in the statistically observed Level 3 exceedance in September 2008 to be a result of the loss of coral due to the summer thermal bleaching event.

4. The DEMG would endorse initiatives by the proponent to revise its coral health monitoring program in light of the reports findings. This is essential to provide a suitable base for the monitoring of coral health during the proposed Stage 2 dredging. This revision requires the inclusion of a number of new coral specimens at each of the sampling sites.

5. The DEMG is not assured that any additional data analysis would yield further options for better management of Stage 2 dredging, but it could be helpful in improving understanding of broader coral ecological issues in the region

The DEMG would also like to take the opportunity of providing the following broad comment on the issue of coral mortality and thermal bleaching.

The ability to isolate thermal stress effects in corals at a variety of spatial scales appears to very important. The DEMG notes that an increase in the frequency of higher maxima of annual sea surface temperature in Dampier is likely in the future, in agreement with a broadly observed trend of warming sea surface temperatures on both the northwest and northeast coasts of Australia. Nonetheless, in warmer than usual seasons, the extent and severity of elevations in water temperatures in the Dampier Archipelago will be driven to a large degree by local weather conditions and small scale heating as a result of a low level of water movement or exchange. The current water quality monitoring data, combined with a better understanding of fine scale water mixing at numerous locations, could in the future allow the development of a thermal risk map model for corals in the Archipelago that would enhance the understanding of likely future coral bleaching patterns

We trust these comments and recommendations will be of value in the monitoring and auditing of coral health patterns during the proposed Stage 2 dredging as well as for similar dredging operations in the north west of Western Australia.

Yours faithfully

Des Lord
CHAIR PLUTO LNG DEMG

CC- Department of Environment and Conservation – Ian Munro
Attachment 1- Andrew Baird Review Terms of Reference

Review of
"Bleaching patterns across the Pilbara in early 2008"

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SUMMARY

This purpose of this review was to determine whether the patterns of bleaching and recovery in coral assemblages in Mermaid Sound following high sea surface temperatures (SST) in March 2008 were consistent with patterns observed in other regions of the world, and also to determine whether suspended sediment levels (SSL) associated with dredging for the Pluto project influenced patterns of mortality and recovery. This document reviews the data presented in the MScience report "Bleaching patterns across the Pilbara in early 2008" and compared these data with mass bleaching events in the literature. The duration of the bleaching (most colonies had recovered or died within 8-12 weeks) was comparable with, if not shorter than, other thermally induced mass bleaching events in similar coral assemblages and the overall value of gross mortality (14 %) was low in comparison to most recent mass bleaching events. Furthermore, there is no strong evidence for SSL adding to the severity of bleaching and mortality, nor impeding recovery. Some Impact sites (sites identified by mathematical models to be at risk of high SSL from the dredging) had higher levels of mortality than expected based on the extent of bleaching, however, these sites also experienced higher maximum SST during the thermal anomaly and were often dominated by taxa susceptible to bleaching, such as acroporids. More detailed analyses of these data could quantify the relative contribution of high SST, SSL and taxonomic differences among assemblages to spatial patterns in mortality and recovery.

Specific points from the Terms of References

1. The data collected were adequate to address the specific question as to whether or not the severity of bleaching is consistent with thermal impact as the sole driver of mortality and patterns of recovery.

2. The severity of bleaching observed is consistent with a thermal impact as the sole driving factor.

3. The timing and duration of recovery was similar to, if not shorter, than other similar reef areas affected by thermal bleaching.

4. The pattern of recovery and the extent of mortality was within limits expected for these coral assemblages based on the severity of the thermal shock.

5. Further data analysis could quantify the relative contribution of temperature, suspended sediment levels and taxonomic differences among assemblages to spatial patterns in mortality and recovery.

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INTRODUCTION

In January 2008 a large area of the Pilbara coast experienced historically high sea surface temperature (SST) leading to coral bleaching from Cape Preston to Port Hedland. The bleaching within Mermaid Sound was extensive and concurrent with dredging associated with the Pluto LNG Development. The purpose of this review was to determine whether the patterns of bleaching and recovery in coral assemblages in Mermaid Sound were consistent with patterns observed in other regions of the world, and further to determine whether dredging may have influenced patterns of bleaching, mortality and recovery.

Reef corals form obligate symbiotic associations with dinoflagellates commonly known as zooxanthellae. These symbiotic algae provide for up to 90 % of the energy requirements of the coral host (Bythell 1988). Under stress, such as high sea water temperature, this assocation can break down with consequent loss of the pigmented algal symbionts. This process is known as coral bleaching. Consequently, when the density of zooxanthellae is reduced following bleaching the coral loses an important source of nutrition. If the loss of symbionts is very high, or prolonged, the coral will starve, unless it can supplement its nutritional needs from other sources, such as ingesting sediment or feeding on the plankton (Grottoli et al. 2006).

Current theories to explain thermal bleaching suggest that heat makes light toxic. At high temperatures even normal light levels overload the photosynthetic apparatus of the zooxanthellae (Jones et al. 1998) resulting in the production of reactive oxygen species which damage animal tissue (Lesser 1997). Consequently, the effects of heat can be ameliorated by reducing light levels. In this context it can be understood that high sediment loads are not necessarily a source of stress for corals, particular with respect to thermal bleaching (Anthony 2006). Increased sediment loads will increase turbidity, reducing the amount of light reaching colonies and therefore raising the temperature threshold at which cellular damage will begin.

In addition, sediment may be a source of nutrition for some species (Anthony 2000), and therefore bleached corals with access to sediments may be able to make up for the lose of energy caused by bleaching. Indeed, the most recent experimental investigation of the synergy between bleaching and sediment stress indicates that sediment may actually ameliorate the effects of thermal stress by reducing light stress and providing a source of nutrition (Anthony et al. 2007). However, the effect of sediment will also depend on the duration of exposure. If corals have been exposed to high sediment for an extended period energy expended in maintaining colony surfaces free from sediment may have reduced coral energy stores. Coral condition is one of the best predictors of how a given colony will respond to bleaching (Fitt et al. 2000, Anthony et al. 2007).

REVIEW

1. Review the data collected by MScience on

a. Water temperature;
b. Bleaching status of corals;
c. Transition of bleached corals to recovery or death;
d. Taxonomy of bleached and unbleached corals.

Data on water temperature, bleaching status, transitions and taxonomy appears sound and adequate to address the specific question as to whether or not the severity of bleaching is consistent with thermal impact as the sole driver of mortality and patterns of recovery. There were a few occasions where data is missing, in particular, the collection of suspended sediment levels (SSL) was prevented on some peak occasions and there are a few gaps in the temperature records. Such gaps are almost unavoidable, in particular during major climatic fluctuation, such as cyclones. In addition, the peak in the proportion of colonies bleached was almost certainly missed at those sites not surveyed in mid February (survey 7) when bleaching peaked at most of those sites sampled on this occasion. However, it is unlikely this affected the results, because most high effect sites (i.e. those sites where mortality was higher than predicted from the extent of bleaching), such as NELS, GIDI, ANG3, also had high levels of bleaching (Fig. 8). The one exception to this was SWIT where the lack of a mid-Feb sample meant that the extent of bleaching was almost certainly underestimated. Consequently, the higher than expected mortality at SWIT is almost certainly caused by the underestimate of bleaching severity, rather than higher SST or SSL. While it is impossible to asses the taxonomic accuracy of the data without accessing the images, I have frequently worked with MScience staff in the field and am confident in their taxonomic skills.

In order to compare the thermal anomaly among sites, it is also essential to have historical records of SST. Many indices are available with which to compare thermal stress, including degree heating days (Berkelmans 2002) or heating rate (Maynard et al. 2008). These indices require an estimate of the bleaching threshold for each site, which is estimated from historical satellite derived SST data. This data would allow for spatial variation in the bleaching threshold to be determined and the difference in the thermal anomaly among sites to be quantified and compared. These data would have been very useful for determining the extent to which high effect sites also experienced a higher thermal anomaly (see Recommendations for further data analysis).

2. The severity of bleaching

Comment on whether the severity of bleaching observed is consistent with a thermal impact as the sole driving factor.

The spatial and temporal patterns in the severity of bleaching are consistent with a thermal impact as the primary factor. Bleaching at Zone C sites (Fig. 6) peaked slightly later than at Zone B (Fig. 5) which is consistent with a later rise in SST temperature in Zone C compared with Zone B (Fig. 16). Sites with high levels of bleaching were generally those that also experienced higher maximum SST, such as ANG2 (Fig. 18). The patterns of susceptibility to bleaching among the 6 taxa examined (Fig. 10 & 11) are consistent with patterns from other thermally induced mass bleaching events (Loya et al. 2001, McClanahan et al. 2004): acroporids were the taxa most susceptible to bleaching with very little mortality recorded in the remaining taxa. While it is not clear how high SSL would alter these patterns of susceptibility, the most likely outcome would be a greater than expected mortality of taxa susceptible to sediment stress. The overall mean proportion of tissue bleached peaked at 18 % in early March (Fig. 4), which is comparable with other thermally induced mass bleaching events in similar coral assemblages, such as inshore reefs in the central Great Barrier Reef (Jones et al. 1997, Marshall and Baird 2000, Jones 2008). Considerable spatial variation in the proportion of tissue bleached was evident, ranging from less than 10 % at LEGD (Fig. 7) to 40 % at GIDI (Fig. 6), however, these patterns are consistent with other reports of mass bleaching following thermal stress (Berkelmans and Oliver 1999, Berkelmans et al. 2004) and are most likely caused by small scale spatial variation in the magnitude of the thermal anomaly or historical difference in the temperature regime among sites.

However, it is also clear that some high effect sites (i.e. those sites where rates of gross mortality where higher than expected from the extent of bleaching) are those predicted by mathematical modelling to be at risk from dredging i.e. Impact sites (Fig. 8) for example, NELS, GIDI and ANG3. These sites, with the exception of NELS, also ranked high in terms of the empirical estimates of suspended sediment levels, in particular, during peak periods of SSL associated with Cyclone Nicholas (Fig. 21 & Fig. 23). Further analysis is required to determine the extent to which each of these factors affected the rates of bleaching (see Recommendations for further data analysis).

3. Timing of recovery

Comment on whether the timing of recovery is consistent with that seen in areas where there have not been secondary impacts, or whether there is evidence that recovery may have been delayed due to other factors.

Patterns of bleaching and mortality from thermal stress can be influenced by many features of the thermal anomaly including how quickly temperatures rise, how high above historical averages they reach and the duration of the event (Jeff Maynard pers comm.). Consequently, it is difficult to compare events without quantifying these parameters. While these data are available to quantify the thermal anomaly in Mermaid Sound in 2008 they have yet to be evaluated (see Recommendations for further data analysis). However, the timing of recovery from bleaching in Mermaid Sound is comparable (Jones 2008), or even more rapid (Baird and Marshall 2002) than other recent thermal bleaching events. Bleaching was first recorded on 17 Feb 2008 and 12 weeks later only 2 % of colonies remained bleached (Fig 4). In contrast, corals of some taxa, in particular faviids and *Porites* stayed bleached for between 20 and 28 weeks following mass bleaching at Orpheus Island in the Central GBR in early 1998 (Baird and Marshall 2002) and a recovery period in the order of months is typical of other corals taxa following thermal stress (Fitt et al. 1993, Diaz-Pulido and McCook 2002, McClanahan et al. 2005). Consequently, there is no strong evidence for dredging impeding recovery from bleaching in Mermaid Sound in 2008.

Comparisons with Cape Lambert 2008

Bleaching patterns in 2008 at Cape Lambert are comparable to those in Mermaid Sound. Gross mortality at Cape Lambert sites ranged from 1.1 % to 12.1 % (Table 4). Just as in Mermaid Sound, bleaching severity was higher on inshore sites, and outer sites did not begin to bleach until a month after inshore sites. While there is some suggestion that references sites suffered less mortality per unit bleaching than impact sites (Fig 29) the long intervals between surveys (meaning peak bleaching values were probably missed), the low number of impact and references sites, the lack of temperature data at the site level and the lack of any examination of the taxonomic differences in site assemblages means that it is not possible to determine what caused the differences in mortality among sites.

Mass Bleaching in Mermaid Sound 2005

The mass bleaching in Mermaid Sound in 2005 provides an interesting comparison to that in 2008. The proportion of colonies bleached in surveys in March and April 2005 (ranging from 50 to 90 %) was significantly higher on average than in 2008 (overall mean of 18 %, Fig 4). However, rates of mortality in 2005 were lower (< 10 %) than in 2008 (ranging from 2 to 30 %). My personal observations in Mermaid sound in October 2006 suggest that rates of mortality, presumably from the bleaching in 2005, in some taxa at some sites were almost certainly higher than 10 %. Nonetheless, the 2005 event may well be an excellent reference against which to compare the effect of temperature in the absence of dredging in Mermaid Sound.

4. Pattern of recovery and mortality

Comment on whether the pattern of recovery/mortality is within limits which might be expected for these coral communities based on the severity of the thermal shock alone, or if some secondary influence is likely to have elevated the mortality rate.

These data suggest patterns of bleaching, mortality and recovery/mortality are comparable with other mass bleaching events, although a preliminary comparison with the 2005 event in Mermaid Sound (see above) suggests mortality in 2008 was higher than in 2005. However, in the absence of further detailed analysis, in particular quantifying the degree and nature of the thermal anomaly at each site it is not possible to determine to what extent these patterns were influence by dredging. Another important caveat includes the fact that the full extent of mortality caused by bleaching may not be apparent at the time of the last reported census in May 2008. For example, following mass bleaching on the GBR in 1998 some colonies took up to 8 months to die, and some colonies died so after recovering normal pigmentation (Baird and Marshall 2002). Similarly, colonies of some species, such as *Cyphastrea*, die following thermal stress even though they do not bleach (McClanahan 2004).

Consequently, to fully evaluate the mortality from the bleaching event it will be necessary to survey the assemblages again at some later stage.

Analysis of additional data on mortality

Spatial variation in gross mortality among taxa

Here, I briefly address patterns highlighted in additional data provided on request by MScience. In particular, the plots of gross mortality by site for each taxa (Fig. 1) suggest there may be higher mortality than expected at some Impact sites. Table 1 lists the sites where gross mortality following the bleaching event was higher than the average for the taxa as a whole. Importantly, all of these sites, with the exception of WINI, are Impact sites. It is also clear from Fig. 1 that the acroporids were the only taxa that suffered significant mortality over a large scale. This suggests that the thermal anomaly was not that great and therefore only susceptible taxa were affected. Alternatively, acroporids may be particularly susceptible to synergistic effects between heat and SSL. In addition, there was little correlation among taxa in terms of mortality at the site level i.e. there are few sites with consistently high mortality in more than one taxa, the few exceptions being: GIDI where “other”, acroporids and faviids all suffered high gross mortality; NELS and SUP2 where both Porites and acroporid suffered high gross mortality and CRTS where other and acroporid suffered high gross mortality. This suggests a complex interplay of factors is responsible for the patterns of mortality, rather than a single factor, such as temperature or SSL, except perhaps at GIDI.

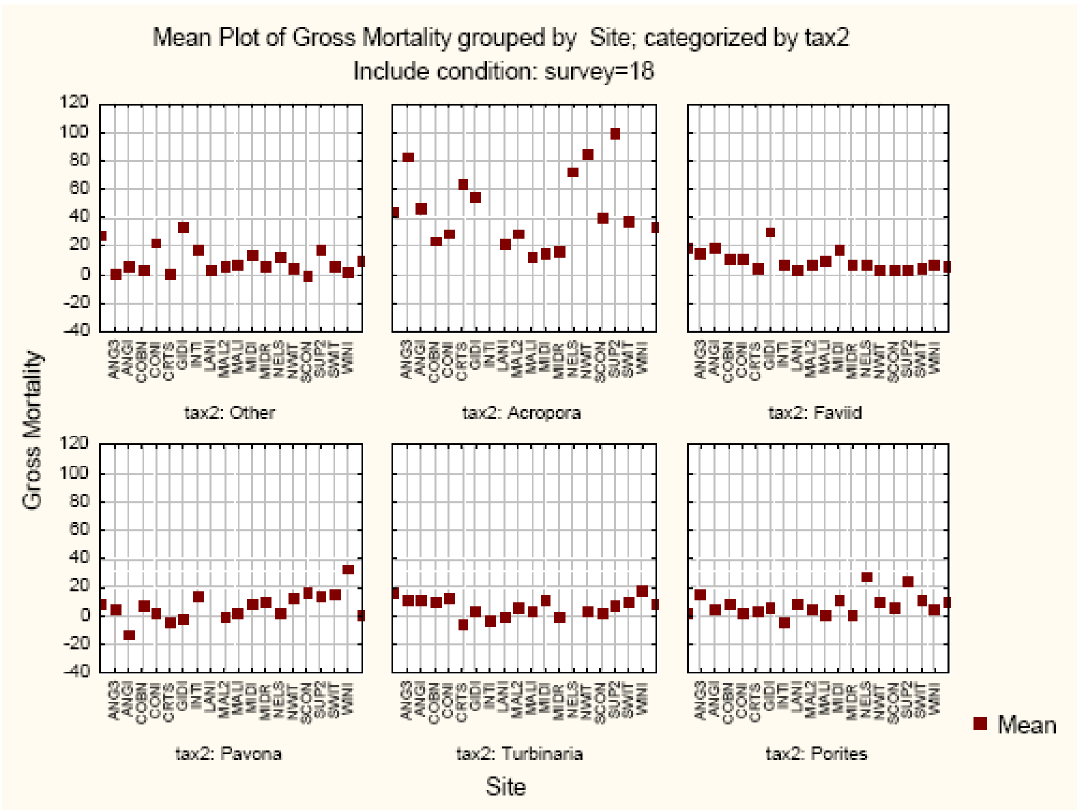

Fig 1. Gross mortality by taxa by site

Table 1. Sites with higher than average rates of gross mortality for each of the 6 taxa.

Taxa	Percent mortality cut off (%)	Sites where gross mortality higher than cut off
Other	20	ANG3, CRTS, GIDI,
Acropora	40	ANG1, CRTS, GIDI, NELS, NWIT, SUP2
Faviid	20	GIDI
Pavona	20	WINI
Turbinaria	none	NONE
Porites	20	NELS, SUP2

5. Further data analysis: suggestions

Spatial and temporal patterns of bleaching and mortality as a function of SSL and temperature

As discussed above, these data allow for a more detailed investigation of the relative contribution of thermal stress and sediment to patterns of mortality and recovery. At present, it is not possible to determine whether the higher mortality at some sites is caused by higher temperatures or higher SSL. By quantifying both these factors and using multiple regression it will be possible to explore the proportion of variation in mortality attributable to each of these factors. The first step would be to remove the confounding effect of differences in assemblage structure among sites by performing the analyses outlined below separately for each of the 6 main taxa (*Acropora*, Faviidae, *Porites*, *Pavona*, *Turbinaria*, Others). Secondly, an estimate of cumulative sediment stress is required for each site. The simplest estimate would be the sum of the daily means in SSL for each site. Finally, an estimate of cumulative thermal stress is required. There are a number of potential estimates in use including degree heating days (Berkelmans 2002) or heating rate (Maynard et al. 2008). These indices require an estimate of the bleaching threshold for each site, which is estimated from historical satellite derived SST data. This data is available commercially, at the scale of less than 2 km, which would allow for spatial variation in the bleaching threshold within Mermaid Sound to be determined. Such variation is common over these small scales (Marshall and Baird 2000) and for the cumulative estimates to be accurate these differences should be accounted for. These variables could then be regressed against gross mortality and the relative contribution of thermal stress and sediment stress quantified.

Did dredging affect morality or recovery?

While the severity of bleaching/mortality will be influenced by the duration and magnitude of thermal stress, recovery will not. Rather, it will be related to the extent of bleaching within colonies and events that occur after bleaching, eg SSL, chance encounters with zooxanthellae etc. Consequently, to explore recovery colonies of each taxa should be classified into moderately and severely bleached and the duration of bleaching (the time from the first symptoms of stress eg > 10 % bleached until the disappearance of symptoms < 10 % bleached) compared as a function of SSL and thermal stress.

In addition, coral condition at the time of the thermal anomaly may have been influenced by SSL in the months before the event (this could be a positive influence for heterotrophic species) and if these data are available (i.e. SSL in the months preceding bleaching), it would be possible test whether or not sediment levels in the months leading up to bleaching were a good predictor of mortality (controlling for differences in thermal anomaly among sites).

Comparisons with previous bleaching events:

Perhaps the best control for the effect of dredging on spatial patterns of mortality is data from the last bleaching event in Mermaid Sound in 2005. An expected relationship among temperature and bleaching mortality in the absence of dredging could be constructed from the 2005 event and deviations from this expected pattern in the presence of dredging could be explored using data from the 2008 event.

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Appendix 11 – Marine Quarantine Management - Previously Submitted Compliance Reports.

A total of 5 dredging related vessels and their associated equipment have been assessed to date prior to use on the Pluto Project. A register of previous compliance reporting correspondence that documents the assessment and clearance process for these vessels has been collated below.

Subject	*Vessel Name*	*Reference Correspondence*		
		To	*From*	*Date(s) and/or WBPL Reference Number(s)*
Phase 1 Dredging Scope				
Submission of Cornelius Zanen Field Assessment Report	Cornelius Zanen (Trailer Suction Hopper Dredge)	DoF	Woodside	13/11/2007
Submission of Cornelius Zanen Field Assessment Report	Cornelius Zanen (Trailer Suction Hopper Dredge)	DEC	Woodside	14/11/2007
Advice in accordance with Ministerial Conditions 8-7 and 8-4	Cornelius Zanen (Trailer Suction Hopper Dredge)	DEC	DoF	19/11/2007
Submission of Cornelius Zanen Arrival Inspection Report	Cornelius Zanen (Trailer Suction Hopper Dredge)	DEC and DoF	Woodside	20/11/2007
Submission of Phoenix Field Assessment Report	Phoenix (Cutter Suction Dredge)	DoF	Woodside	20/12/2007
Submission of Phoenix Arrival Inspection Report	Phoenix (Cutter Suction Dredge)	DoF	Woodside	24/12/2007
Advice in accordance with Ministerial Conditions 8-7 and 8-4	Phoenix (Cutter Suction Dredge)	DEC	DoF	24/12/2007
Vessel departure dates and destination advice.	Cornelis Zanen (Trailer Suction Hopper Dredge) and Phoenix (Cutter Suction Dredge)	DoF	Woodside	PLU/GOV/00224; 17/04/2008
Submission of Hippopotes pre-arrival Vessel Risk Assessment Score Sheet (VRASS).	Hippopotes (Backhoe Dredge)	DoF and DEC	Woodside	21/02/2008
Submission of Murray River pre-arrival VRASS.	Murray River (Split Hopper Barge)	DoF and DEC	Woodside	22/02/2008
Submission of Yarra River (Split Hopper Barge) pre-arrival VRASS.	Yarra River (Split Hopper Barge)	DoF and DEC	Woodside	21/02/2008
Advice in accordance with Ministerial Conditions 8-7 and 8-4	Hippopotes, Murray River, and Yarra River	DEC	DoF	22/02/2008
Submission of Yarra River Field Assessment Report	Yarra River (Split Hopper Barge)	DoF	Woodside	26/02/2008
Submission of Yarra River Arrival Inspection Report	Yarra River (Split Hopper Barge)	DoF	Woodside	20/03/2008
Vessel departure dates and destination.	Hippopotes (Backhoe Dredge)	DoF	Woodside	PLU/GOV/00277; 13/08/2008
Phase 2 Dredging Scope				
Notification of Hippopotes arrival within Mermaid Sound	Hippopotes (Backhoe Dredge)	DoF	Woodside	22/09/2008
Notification of Yarra River barge arrival within Mermaid Sound	Yarra River (Split Hopper Barge)	DoF	Woodside	25/09/2008
Submission of Yarra River barge arrival Inspection Report	Hippopotes (Backhoe Dredge)	DoF	Woodside	3/10/2008
Submission of Hippopotes Arrival Inspection Report	Yarra River (Split Hopper Barge)	DoF	Woodside	15/10/2008