7 Marine Impacts and Management

7 MARINE IMPACTS AND MANAGEMENT

7.1 Introduction

This chapter of the draft environmental impact statement (Draft EIS) for INPEX's Ichthys Gas Field Development Project (the Project) describes the potential impacts to the marine environment that will be associated with the offshore and nearshore development areas of the Project. These areas are described briefly below, and in more detail in Chapter 3 *Existing natural, social and economic environment*.

The offshore development area includes the Ichthys gas and condensate field (Ichthys Field) in the Browse Basin off the coast of north-western Australia and the gas export pipeline route from the field to the mouth of Darwin Harbour. Components of the Project that will be developed in this area include subsea production wells and flowlines, the central processing facility (CPF), the floating production, storage and offtake (FPSO) facility and the major portion (some 852 km) of the gas export pipeline. Details of the offshore infrastructure and activities are summarised as follows:

- the drilling of production wells using a mobile offshore drilling unit (MODU) and support vessels
- the installation of approximately 50 subsea wells and flowlines to carry the natural gas and other reservoir fluids from the wells to the CPF
- the installation and commissioning of the CPF, FPSO and gas export pipeline
- the export of condensate from the FPSO to offtake tankers
- the ongoing operation of the CPF, FPSO and gas export pipeline
- decommissioning.

The nearshore development area includes the gas export pipeline route from the mouth of Darwin Harbour to Middle Arm Peninsula together with the coastal areas around Blaydin Point and Middle Arm Peninsula, ending at the low-water mark. The infrastructure to be constructed in this area includes the nearshore section of the gas export pipeline with a shore crossing on the west side of Middle Arm Peninsula south of Wickham Point, a product loading jetty with a marine outfall, a module offloading facility, and a shipping and navigation channel. The activities associated with the nearshore infrastructure can be summarised as follows:

- the construction of the nearshore section of the gas export pipeline, including trenching, rock armouring and the installation of the pipeline shore crossing
- the construction of a jetty and module offloading facility, with associated dredging for shipping and navigation channels
- the operation of the jetty for hydrocarbon export and the operation of the module offloading facility
- the operation of the marine outfall on the jetty
- the decommissioning process.

The environmental impact assessment provided in this chapter includes discussion of potential impacts in a regional context. This includes potential impacts to "matters of national environmental significance" as defined in the *Environment Protection and Biodiversity Conservation Act 1999* (Cwlth) (EPBC Act). Matters of national environmental significance relevant to the offshore and nearshore development areas include the following:

- listed threatened species and ecological communities
- migratory species protected under international agreements
- the Commonwealth marine environment.

In light of these potential impacts, management controls are described that will be implemented by INPEX to mitigate possible negative effects from Project activities.

In order to determine the resulting "residual risk" after management controls are applied, an assessment of the risks of the various potential impacts was undertaken according to the methods presented in Chapter 6 *Risk assessment methodology*. Summary tables of the offshore and nearshore activities, potential environmental impacts, management controls and mitigating factors, and resulting residual risk (consequence, likelihood and risk rating) are provided throughout this chapter.

The risk assessment was undertaken with consideration of sensitive environmental receptors, which include the marine benthic biota and macrofauna in the vicinity of the offshore and nearshore development areas. Because of the proximity of the nearshore development area to the cities of Darwin and Palmerston, the local community is also regarded as a key sensitive receptor in some cases. Other impacts to the community associated with activities such as recreational or commercial fishing are described in Chapter 10 *Socio-economic impacts and management*.

Management controls will be implemented to ensure that all significant potential environmental impacts associated with the Project are avoided or minimised. A number of monitoring mechanisms are also proposed that will allow INPEX to gauge the effectiveness of management controls.

A comprehensive and auditable environmental management system based on the principles of the International Organization for Standardization's ISO 14000 environmental management series of standards will be implemented to provide a systematic and structured approach to environmental management. The system proposed is described in Chapter 11 *Environmental management program*.

For some specific offshore activities, additional environmental management plans will be required under the Offshore Petroleum and Greenhouse Gas Storage (Environment) Regulations 2009 (Cwlth) (OPGGS(Environment) Regulations)[1]. These will include plans for pipeline installation, drilling, construction and operation of the CPF and FPSO, and an oil-spill contingency plan.

7.2 Offshore impacts and management

7.2.1 Alteration of habitat

Seabed disturbance

The seabed in the offshore development area will be altered through direct disturbance by drilling and anchoring, the installation of subsea equipment, pipelay and potentially by pre- or post-pipelay trenching in some areas along the gas export pipeline route. Drilling will also result in some indirect impacts, for example through the settling of drill cuttings on the seabed and the discharge of drilling fluids. These are discussed separately in Section 7.2.2 *Drilling discharges*.

While the production wells are being drilled, the MODU will be held in place by anchors. During this time, physical disturbance to the seabed will be associated with the laying and retrieval of anchor chains. As the anchors are carried out to position by the support vessel there may be some dragging of the anchor chain across the seabed. Once in place, the anchor chains are likely to remain relatively stationary, except at the "touch-down" point where the chain will move up and down depending on the state of the sea. The exact anchoring configuration that will be used will be dependent on the type of MODU selected and is therefore not yet known. A MODU typically has 8 to 12 anchors.

The CPF and FPSO will be held in place by anchors for the life of the Project. As for the MODU, these anchor chains will cause some disturbance to the seabed during installation and then may move up and down at the touch-down point. In the longer term these anchors and chains will become artificial habitat for benthic biota (discussed further below).

The layout of the field infrastructure has not yet been finalised. However, it is considered appropriate to use the layout presented in Chapter 4 *Project description* to calculate the area of seabed affected because of the following considerations:

- Any changes to the layout would be relatively minor in nature.
- The changes would not result in any significant change to the area of seabed affected.
- The benthic community in the field is widely distributed with no apparent changes in density or structure (see Appendix 4 to this Draft EIS).

The area that will be disturbed by the subsea production equipment and by the moorings of the MODU, CPF and FPSO has been estimated to be approximately 74 ha, as described in Table 7-1.

Laying and retrieving the anchor chains for the MODU, CPF and FPSO is likely to result in some temporary physical disturbance to the seabed, though this will be localised. This disturbance will likely be confined to a corridor approximately 3–5 m wide for each anchor chain. The anchor and anchor chain scars are expected to refill rapidly and the biological communities associated with these sediments are expected to recover quickly from the disturbance.

Similarly, an anchored lay barge will be used to construct infield flowlines, which will disturb the seabed for around 500 m on each side of the alignment. These anchor and chain scars will only be temporary and benthic communities will recover rapidly.

Long-term physical change of the seabed at the field will include that associated with moorings, subsea trees, flowlines, manifolds and other subsea production equipment.

The seabed to be modified by infield infrastructure has been characterised as rippled sands with regular low sand waves, flat bare sand with shell fragments and clay–silt sand (see Chapter 3). Water depths throughout the Ichthys Field vary between 235 m and 275 m. The area supports very few visible organisms and has mobile sediments that do not favour the development of a diverse epibenthic community. These sparse, low-diversity benthic infauna communities are well represented in the region (see Appendix 4), and the area to be disturbed represents only 0.09% of the area of the Ichthys Field (0.02% of the WA-37-R retention lease area). The environmental consequences of seabed disturbance in the offshore development area are predicted to be negligible.

1 The Offshore Petroleum and Greenhouse Gas Storage (Environment) Regulations 2009 (Cwlth) (OPGGS(Environment) Regulations) replaced the Petroleum (Submerged Lands) (Management of Environment) Regulations 1999 (Cwlth) (P(SL) (MoE) Regulations) on 17 December 2009.

Table 7-1: Area of seabed at the Ichthys Field subject to direct physical disturbance

Infrastructure	Number	Area per unit (m^2)	Area (m^2)
MODU anchors	8	10	80
CPF anchors	32	70	560
FPSO anchors	20	70	1 400
CPF riser bases	15	70	980
Export gas riser base	1	525	525
Riser support structure foundations	1	2 800	2 800
FPSO riser bases	10	70	700
Drill centre	14	29 826	417 564
Subsea gas export pipeline end termination	1	45	45
Infield production flowlines (metres)	246 000	0.5	123 000
Infield MEG* and service flowlines (metres)	129 000	0.2	25 800
Infield flowline terminations	72	30	2 160
Transfer lines (metres)	35 000	0.4	14 000
Rock dump anchor berm	20	4 400	88 000
Rock dump trigger berm	40	800	32 000
Umbilicals (metres)	133 000	0.2	26 600
Subsea umbilical termination assemblies and umbilical distribution assemblies	40	15	600
Total area (m^2)	**n.a.**	**n.a.**	**736 814**
Total area (ha)	**n.a.**	**n.a.**	**73.68**

* MEG = monoethylene glycol.

n.a. = not applicable.

Construction of the gas export pipeline will create a long linear disturbance corridor. In deep offshore areas of the route, the gas export pipeline will generally be placed directly on to the seafloor, with minimal disturbance on either side. At the eastern end of the route towards Darwin Harbour, the corridor is likely to vary in width depending on the substrate and the types of preparation activities required to construct a suitable surface for pipe-laying, such as sand-wave pre-sweeping, pre- or post-lay trenching, and rock dumping. Minimal alteration of the seabed is preferred for pipeline construction from both an engineering and environmental perspective—that is, the preferred pipeline route will avoid rocky areas and reefs wherever possible because of the difficulties of pipelay operations in these areas.

Geophysical surveys have indicated that the greater part of the pipeline route (>98%) consists of featureless, unconsolidated clay or silty sands, with rare areas of rock outcrops and subcrops as described in Chapter 3. Targeted drop-camera surveys at 18 sites along the pipeline alignment recorded low-diversity benthic communities of flat bare sand with shell fragments or clay or silt sand at 10 of the sites. Rocky outcrops identified at the remaining sites hosted benthic animals that are common throughout the region, including soft corals, gorgonians (sea fans) and sponges (see Appendix 4). Disturbance of the relatively narrow pipeline corridor through these benthic communities can be considered of low consequence in the context of the vast areas of similar habitat throughout the region.

The gas export pipeline will be laid using a pipelay barge kept in position using either dynamic positioning systems or an anchor system, depending on the depth of water, the seabed conditions and vessel availability. Anchored construction barges typically have at least 8 large drag anchors. In total, the width of the disturbance corridor during the construction of the gas export pipeline could be up to 1000 m, that is, 500 m on either side of the alignment. The anchors of the pipelay barge, if used, would disturb some areas of seabed, particularly through the lateral movement of the anchor lines as the barge moves forward. Limestone pavement or isolated reefs along the pipeline route would be particularly susceptible to anchor damage, while in areas of bare sand or silty seafloor, anchor-chain scars would be naturally infilled and benthic communities would recover swiftly. Similar recovery was recorded in Mermaid Sound, Western Australia, after pipeline installation and rock-dumping by Woodside; seabed disturbance was recorded up to 500 m on either side of the alignment and evidence of rapid recolonisation and rehabilitation of the soft-sediment benthic habitats was observed within one year of the construction project. Hard corals damaged by anchor-chain drag were expected to recover within a few years (Woodside 1997).

The primary means of maintaining the stability of the gas export pipeline on the offshore seabed will be by concrete weight coating, but trenching and rock armouring may be applied where extra stability is needed. This would result in disturbance of more benthic habitat and would generate turbidity and sedimentation in the area in the short term. However, the sparse benthic communities along the greater part of the route would be expected to recover rapidly and rock armouring would create new habitat that could be colonised by benthic species (as described below).

Indirect effects are considered unlikely, given the small zone of disturbance relative to the extent of similar habitats adjacent to the pipeline corridor. The area to be disturbed by the offshore pipeline represents a very small fraction of the total habitat area and disturbance is likely to be localised.

Artificial habitat

The presence of Project infrastructure in the offshore development area provides hard substrate for the settlement of marine organisms. Colonisation of the structures over time leads to the development of a fouling community similar to that found on subsea shipwrecks. The presence of these structures and the associated fouling community also offers predator and prey refuges and visual cues for aggregation (Gallaway et al. 1981).

Investigation of the fouling communities on platforms on the North West Shelf has shown that complex ecosystems develop on the structures within two years of being set in place. Depending on water depth, these communities are primarily dominated by sponges, bryozoans, ascidians (sea squirts), crustaceans (primarily barnacles) and brittlestars. The rate of development of the fouling community for deep-water seabed structures is likely to be somewhat slower because of the lower temperatures and reduced light availability at depth. These differences are illustrated in the fouling abundance on settlement plates set in different water depths near the Titanichthys exploration well at the Ichthys Field, shown in figures 7-1 and 7-2 (RPS 2007). The depths in the figure captions are measured as "below mean sea level" (BMSL).

Source: RPS 2007.

Figure 7-1: Settlement plates from approximately 10 m BMSL at the Ichthys Field after 6 months

Source: RPS 2007.

Figure 7-2: Settlement plates from 2 m above the seabed, at approximately 248 m BMSL, at the Ichthys Field after 6 months

Once present in the field, the CPF, FPSO and supporting infrastructure will provide near-surface artificial hard substrate for colonisation by invertebrates and algae. This will provide a food source for other organisms and will encourage aggregation of fish around these facilities. While increased fish numbers could provide food for seabirds, there are very few seabird migratory paths crossing the North West Shelf region where the Ichthys Field is located. Anecdotal evidence suggests that existing offshore oil & gas facilities in north-western Australia are rarely visited by seabirds, with the exception of seagulls in some cases.

The seabed infrastructure, such as the wellheads, flowlines and gas export pipeline, will also provide new hard substrate habitat for benthic communities and is likely to result in a local increase in species abundance and biodiversity (Hixon & Beets 1993; Pollard & Matthews 1985). However, factors such as water depth, low temperature and ocean currents will decrease the potential for establishment of algae and invertebrates on the hard substrates and it is estimated that growth on the seabed infrastructure at the Ichthys Field would be only 15 mm thick after 25 years (RPS 2007). This represents a very minor change in the benthic habitat, particularly in the context of the Browse Basin region.

It is likely that the gas export pipeline will provide artificial hard substrate for colonisation by invertebrates and seaweeds in shallower waters at the eastern end of the route, and particularly in sections where rock armouring is applied. This benthic community will also attract mobile animals such as fish and squid. The artificial seabed habitat will support increased biological productivity and diversity compared with the broad areas of mainly featureless seabed surrounding the pipeline route. However, this effect will be highly localised in the context of the offshore marine environment and the impact of this change is considered minor in consequence. During the operational phase of the Project, further disturbance of the seabed along the pipeline corridor is not envisaged unless periodic inspections reveal the need for additional stabilisation for particular sections of the pipeline.

Some subsea infrastructure (e.g. mooring suction piles, infield flowlines and subsea flowlines) may remain in place following decommissioning, and the associated habitat would be left intact for the longer term. Where infrastructure is removed at decommissioning (e.g. anchor chains, risers, wellheads and subsea manifolds), it is expected that the epibenthic biota will soon return to its original abundance and composition.

Management of marine habitat

The use of a semi-submersible MODU during drilling activities will restrict the area of direct seabed disturbance during drilling to the well, the anchor points and the chains to the touch-down point.

Flowlines will be laid directly on to the seabed without trenching. The gas export pipeline will be installed with concrete weight coating, which will reduce the need for rock dumping or trenching in deep offshore waters and minimise disturbance of the seabed.

Surface structures such as the CPF and FPSO are likely to be treated with antifouling paints to limit growth of fouling communities and to maintain the operability of the infrastructure. Antifouling paints will be selected in accordance with regulatory requirements, which include the prohibition of paints based on tributyltin (TBT) compounds (see Section 7.2.3 *Liquid discharges*).

A Provisional Decommissioning Management Plan has been compiled (attached as Annexe 5 to Chapter 11), which outlines the processes to be undertaken to identify appropriate measures for the closure of the offshore facilities at the end of the Project's life, as well as management of the associated environmental risks. This plan will guide the development of more detailed plans at later stages of the Project, and includes the following prescriptions:

- Consideration of decommissioning feasibility will be incorporated into the initial design of each facility.
- The CPF and FPSO will be removed from the infield location at the end of the useful life of the field.
- The gas export pipeline will be flushed of all hydrocarbons, filled with sea water and left in place after decommissioning.
- Options for decommissioning the other subsea facilities (e.g. mooring suction piles and infield flowlines) will be investigated in advance of decommissioning, with consideration of the associated environmental impacts.
- Offshore decommissioning will also be subject to assessment under relevant legislation and international conventions and treaties, including the following:
  - the *Offshore Petroleum and Greenhouse Gas Storage Act 2006* (Cwlth), the EPBC Act and the *Environment Protection (Sea Dumping) Act 1981* (Cwlth)
  - the United Nations Convention on the Law of the Sea (UNCLOS)
  - the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto (MARPOL 73/78) (IMO 1978).

Residual risk

A summary of the potential impacts, proposed management controls, mitigating factors and residual risk for offshore marine habitats is presented in Table 7-2. Impacts to offshore marine habitat are considered to present a "low" to "medium" risk and it is likely that any effects on the environment will be localised and small in scale.

Table 7-2: Summary of impact assessment and residual risk for alteration of habitat (offshore)

Aspect	Activity	Potential impacts	Management controls and mitigating factors	Residual risk*		
				C†	L‡	RR§
Seabed disturbance	Installation, operation and decommissioning of offshore infrastructure.	Removal or disturbance of seabed sediments.	Seabed habitat at the Ichthys Field consists of unconsolidated sands with low biodiversity and is similar to wide surrounding areas. The disturbance area is a very small portion of the total field area. Flowlines will be laid directly on the seabed, not trenched. Provisional Decommissioning Management Plan.	F (B3)	6	Low
Seabed disturbance	Gas export pipeline construction and operation.	Disturbance of a variety of seabed types along the pipeline route.	The gas export pipeline to be installed with concrete weight coating, to minimise the need for trenching or rock armouring. The gas export pipeline route avoids sensitive benthic habitats. The seabed habitat at the Ichthys Field consists of unconsolidated sands with low biodiversity and is similar to wide surrounding areas.	E (B3)	6	Medium
Artificial habitat	Long-term operation of the CPF, FPSO and other surface and subsea facilities in the offshore marine environment.	Subsea and surface structures provide new habitat for marine fouling communities. Benthic community composition is altered. Biological productivity and diversity is increased.	The affected area is a very small portion of the total field area. Any antifouling paints used on surface or subsurface structures will be selected in accordance with regulatory-authority requirements. The CPF and FPSO will be removed from the infield location at decommissioning. Provisional Decommissioning Management Plan.	F (B3)	6	Low

* See Chapter 6 *Risk assessment methodology* for an explanation of the residual risk categories, codes, etc.

† C = consequence.

‡ L = likelihood.

§ RR = risk rating.

7.2.2 Drilling discharges

Seabed drilling activities will be carried out during the construction and operations phases at the offshore development area. Up to 50 subsea production wells will be drilled. These activities will generate drill cuttings that will be discharged to the marine environment. The potential effects of these discharges are described below.

Drill cuttings

Drill cuttings are inert pieces of rock, gravel and sand removed from the subsea well during the drilling process. They are composed of calcarenite, shale and sandstone. Cuttings are likely to range in size from very fine to very coarse particles, with a mean diameter of 10 mm.

Studies carried out in the Gulf of Mexico found that sediments less than 500 m from drilling locations were enhanced with coarse-grained materials predominantly derived from drill cuttings (Boehm et al. 2001). This change may be temporary as sediment redistributes and disperses over time. Where this occurs, the type and abundance of the animal species in the sediment will also change over time as those unsuited to the new characteristics are replaced by those that are suited. Field studies suggest that infauna community composition may be altered within approximately 100 m of a production platform following drilling activity (Hart, Shaul & Vittor 1989).

Smothering of an area of the seabed by drill cuttings can cause anoxic conditions to develop in the sediments over time. Encapsulated organic material that is present in the surface sediments at the time of smothering, or that is introduced with the cuttings (e.g. in drilling muds) (described below), will be biodegraded initially by organisms using the oxygen associated with the original surface sediments and deposited cuttings. Once this store of oxygen is depleted, the sediments are anoxic and biodegradation will occur more slowly by micro-organisms using electron acceptors other than oxygen (Brock & Madigan 1991). In circumstances where the drill cuttings have associated oil, either as a coating from synthetic-based muds (SBMs) (described below) or from oily sands removed from the reservoir, field studies have shown that this oil persists for long periods of time before it is fully biodegraded (Schaanning 1996). The observed persistence is considered to be primarily attributable to the reduced rates of biodegradation that occur in anoxic conditions of cuttings piles below the first few centimetres (Neff, McKelvie & Ayers 2000).

Dispersion of cuttings across the seafloor will be influenced by the prevailing currents and vertical settling forces, and a small proportion of cuttings (particularly fine material) could travel several kilometres from the drilling point.

At the Ichthys Field, the "Scientific and Environmental ROV Partnership using Existing iNdustrial Technology" (SERPENT) project recorded the changes in benthic habitat caused by drill spoil cover, using remotely operated vehicle (ROV) transects around an exploration drilling centre (SERPENT 2008). These surveys recorded "high" drill-spoil coverage within 20–35 m of the drilling point, causing complete coverage of the benthos with no evidence of bioturbation by benthic infauna. "Moderate" drill spoil cover extended out to 50–70 m from the drilling centre, with benthic infauna having re-established burrows in the drill spoil material. "Low" drill spoil coverage, where burrows made by benthic infauna were maintained under a light dusting of material, extended to the 80-m radius, which was the limit of the ROV survey area.

The drill spoil area recorded in ROV surveys was elongated along the north-west – south-east axis because of tidal currents. Overall, the extent of moderate-to-high coverage by drill cuttings at the single drilling centre was estimated at 0.7 ha (SERPENT 2008). Extrapolated across the entire 50-well drilling program, this would represent a total disturbance area at the Ichthys Field of 35 ha—equivalent to 0.0004% of the field area.

Any smothering effects on the sparse benthic communities in the offshore development area would be highly localised. As the seabed sediments in the Ichthys Field are uniform and widespread throughout the North West Shelf and Oceanic Shoals bioregions, the consequences of changes to these communities in the vicinity of the drilling locations can be considered to be low.

Discharged drill cuttings will create a temporary turbid plume. However, the seabed in the Ichthys Field is below the photic zone and benthic communities will be largely unaffected by increased turbidity. The nearest sensitive benthic communities are located at Browse Island and Echuca Shoal, respectively 33 km and 60 km from drilling locations—sufficiently distant to be outside the range of turbid plumes.

Drilling muds

Water-based muds (WBMs) can be used for the top-hole sections of the subsea wells, while SBMs are required for the lower-hole sections. Rock types change between the upper and lower portions of drill holes—SBMs are better suited to drilling in lower rock formations, which can swell when WBMs are used. portion of the top-hole sections will be drilled without a riser, with WBM being released at the seabed. Depending upon the final well design, a riserless mud return system may be used for recovery of WBM deeper in the top-hole section; alternatively returns may be achieved using a conventional riser.
It is anticipated that as much as 30% of the WBM from some top-hole sections could be lost over the shakers during high rates of penetration drilling. A conventional riser will be used to achieve a closed mud system when drilling the deeper lower-hole sections with SBM. Both WBM and SBM will be recovered and reused in subsequent wells as far as is practicable. However, as drill cuttings will be discharged overboard, some of the drilling muds attached to the drill cuttings will also be discharged to the marine environment.

The main concerns associated with the discharge of drilling muds to the marine environment are as follows:

- The muds may be toxic to marine biota.
- The muds and cuttings may cause increased turbidity.
- The muds and cuttings may alter sediment characteristics.

Water-based muds

The WBMs contain water as the base fluid along with a variety of special-purpose additives. A number of reviews have been carried out to identify common drilling-mud additives, application concentrations and toxicities. Table 7-3 contains the results of one such review presented by Swan, Neff and Young (1994). As shown, the wide range of drilling-fluid additives were all contained at extremely low concentrations relative to ecotoxicity levels for the mysid shrimp *Americamysis bahia* (formerly known as *Mysidopsis bahia*), the standard organism used in such toxicity tests. Therefore WBMs can be considered to be inert in terms of their toxicity and do not pose a risk to the marine environment at the offshore development area.

Table 7-3: Common drilling fluid additives, application concentrations and reported toxicities for the mysid shrimp *Americamysis bahia*

Product	Concentration range of application (ppb*)	96-hour LC_{50}† range (ppm‡)
Weighting agents		
Barite	0–631	>1 000 000
Haematite	0–500	>1 000 000
Calcium carbonate	10–81	>1 000 000
Viscosifiers		
Bentonite	12.5–30	>1 000 000
Extended bentonite	0–15	>1 000 000
Attapulgite	0–30	>1 000 000
Bacterially produced polymers	2	757 000
Polymers	1–2.5	78 000 – >1 000 000
Bentonite extender and flocculant	0.1–1.0	>1 000 000
Selective flocculant	0.1	>1 000 000
Thinners/deflocculants		
Sodium tetraphosphate	0–0.25	>1 000 000
Sodium acid pyrophosphate	0–0.5	>1 000 000
Quebracho compound	5	952 000
Sulfomethylated tannin	2–4	339 000 – >1 000 000
Synthetic polymers	1–4	74 000 – >1 000 000
Chrome lignosulfonate	3–23	500 000 – >1 000 000
Chrome-free lignosulfonate	4–20	310 000 – >1 000 000
Modified chrome lignite	25	201 000
Modified melanin	10	356 000
Modified calcium lignosulfonate	4	>1 000 000
Filtration control agents		
Preserved starch	0–6	472 000 – >1 000 000
Sodium carboxymethyl cellulose	0–2	>1 000 000
Polyanionic cellulose	0.5–3.0	>600 000 – >1 000 000
Sodium polyacrylate	1.5–3.0	1 000 000
Organic polymers	3–10	305 000 – >1 000 000
Processed lignite	3	>1 000 000
Causticised lignite	3–10	>1 000 000
Potassium lignite	6	>1 000 000
Pre-gelatinised starch	6–8	>1 000 000
Lubricants		
Specially prepared blend of organics	2–6	52 000 – >1 000 000
Blend of organic esters	2.0–17.5	104 000–494 000
Fatty-acid formulations	2.0–6.6	35 000 – >1 000 000
Graphite	0–6	865 000
Water-insoluble thermoplastic beads	10	>1 000 000
Shale control		
Water-dispersable asphalts	6–8	>1 000 000
Sulfonated asphaltic residuum	4–7	50 000 – >1 000 000
Aluminium compounds	5	>1 000 000

Table 7-3: Common drilling fluid additives, application concentrations and reported toxicities for the mysid shrimp *Americamysis bahia* (continued)

Product	Concentration range of application (ppb*)	96-hour LC_{50}† range (ppm‡)
Polymers	0.15–25.0	78 000 – >1 000 000
Detergents and emulsifiers		
Detergent modified fatty acids	4–8	238 000–302 000
Non-ionic surfactant	0.3	162 000 – >1 000 000
Defoamers and deflocculants		
Alcohol-based liquid defoamers	0.2–1.5	39 000 – >1 000 000
Surface-active dispersable liquid defoamers	0.15–0.7	82 000 – >1 000 000
Liquid surface-active agent tributylphosphate	0.15–3.0	51 000
Aluminium stearate	0.3	>1 000 000
Corrosion inhibitors		
Aluminium bisulfite solution	0.48	750 000
Filming amine oil	2	780 000
Modified organic inhibitor	0.5	130 000
Zinc compounds	6–7	31 000–78 000
Polyacrylate scale inhibitor	2	773 000
Bactericide		
Biocide	0.5	450 000

Source: Swan, Neff and Young 1994.

* ppb = parts per billion.

† The notation LC_{50} stands for “lethal concentration 50%”. It is the concentration of a chemical in air or water that will kill 50% of a group of a specific test animal species exposed to it in a given time, for example 24 hours, 96 hours, etc. The LC_{50} is a measure of the short-term poisoning potential of a substance.

‡ ppm = parts per million.

Release of WBMs from the MODU will result in a discharge plume. Field observations have found that the plume from drilling mud discharge is visible in the upper parts of the water column for up to 1 km from the discharge point during and for a short time (*c*.24 hours) after discharge. In 1985 the US Environmental Protection Agency (US EPA) compiled data from numerous studies on the growth and dilution of drilling-mud discharge plumes. The concentrations of drilling mud in the surface waters at set distances from the point of discharge were measured at several sites. The results indicated that the mud had been diluted by approximately one million times by the time it reached a distance of 1 km from the discharge point (US EPA 1985).

Turbidity is likely to increase in the Project’s offshore development area as a result of drilling-mud discharge plumes. However, this will be a short-term effect and any reductions in productivity (e.g. plankton growth) in the water column will be very localised in the context of the surrounding marine environment.

Synthetic-based muds

SBMs are composed of a base oil (such as an olefin, synthetic paraffin or ester) together with calcium chloride brine and treatment chemicals. The SBMs used in the offshore development area will be recovered in order to minimise release to the marine environment. However, small quantities will adhere to drill cuttings disposed of to sea. A number of researchers have assessed the toxicity of hydrocarbons from organic-phase drilling fluids in the water column. The acute toxicities of several base chemicals and their derivatives were presented in a literature review commissioned by the Minerals Management Service of the US Department of the Interior, which indicated that these compounds are generally toxic at high concentrations only, as shown in Table 7-4 (Neff, McKelvie & Ayers 2000).

Table 7-4: Acute toxicity to the mysid shrimp *Americamysis bahia* of several organic-phase base chemicals and their derivatives

Base chemical type	Chemical	96-hour LC_{50}* (mg/L)
Poly-a-olefins	Polypropene (MW 170)†	10 800
	Polypropene (MW 198)	30 000
	Decene dimer (MW 290)	574 330
	Polypropene (MW 310)	914 650
	Polybutene (MW 320)	>1 000 000
	Polypropene (MW 400)	>1 000 000
Internal olefins	C_{14}–C_{16} IO‡	<30 000
	C_{15}–C_{18} IO	119 658
	C_{16}–C_{18} IO	321 000
Ether	Dibutyl ether	>10 000
	Dihexyl ether	61 659
	Dioctyl ether	156 880
Esters	Methyl laurate	<10 000
	Isopropyl palmitate	271 701
	Isopropyl oleate	52 319
	C_{10}–C_{14} alcohols	<10 000
	C_{16} alcohol	30 158

Source: Neff, McKelvie and Ayers 2000.

* The notation LC_{50} stands for "lethal concentration 50%". It is the concentration of a chemical in air or water that will kill 50% of a group of a specific test animal species exposed to it in a given time, for example 24 hours, 96 hours, etc. The LC_{50} is a measure of the short-term poisoning potential of a substance.

† MW = molecular weight.

‡ IO = internal olefin.

SBMs are relatively non-toxic and readily biodegradable, and are considered to be an environmentally effective solution compared with traditional mud systems based on diesel and mineral oil. Using the toxicity ratings outlined by Cobby and Craddock (1999), most formulations range from "almost non-toxic" to "non-toxic".

Field studies of the environmental effects of ester-based drilling muds discharged on drill cuttings have shown that esters rapidly disappear from the sediments (Daan et al. 1996; Terrens, Gwyther & Keough 1998). In both studies, the authors have attributed this to rapid biodegradation and sediment relocation. Significant benthic fauna recovery has been recorded within 12 months of cessation of an ester-based mud drilling program in the North Sea (Daan et al. 1996).

Studies by the American Chemistry Council (ACC) indicate that both olefin and paraffin SBMs are non-toxic to water-dwelling organisms, and that olefin products have significantly less toxicity (4–20 times) than paraffin to sediment-dwelling organisms.

Both olefin and paraffin SBMs biodegrade in aerobic conditions (i.e. in the presence of oxygen), and in anaerobic conditions (i.e. in the absence of oxygen) olefin-based SBMs biodegrade much more extensively (>50%) than paraffin SBMs. Drilling locations in the Gulf of Mexico where olefin SBMs were used showed no significant effects on sediment quality and biological communities, and impacts were limited to the vicinity of the discharge (<250 m). Where impacts were observed, progress toward physical, chemical, and biological recovery appeared to occur within a year. The medium-term effects of paraffin SBMs were less conclusive—paraffin removal and rapid recovery were often attributed to sediment dispersion mechanisms and paraffin distributions tended to be very uneven (ACC 2006).

The effective dispersion of drill cuttings by the strong current regime in the Ichthys Field will enable aerobic breakdown of any SBMs adhering to the cuttings. Therefore the discharge of low levels of these muds is not expected to pose a risk of toxicity or contribute to anoxic conditions in marine sediments in the offshore development area.

Management of drilling discharges

A Provisional Liquid Discharges, Surface Water Runoff and Drainage Management Plan has been compiled for the Project (attached as Annexe 10 to Chapter 11). This will guide the development of more detailed plans during the construction and operations phases. The plan includes management controls for drilling discharges as follows:

- Procedural controls for preventing the accidental release of SBMs will be developed as part of a separate assessment under the OPGGS(Environment) Regulations.
- WBMs will be used instead of SBMs in the upper-hole sections of production wells.
- SBMs will be recovered after use and returned onshore for reuse or disposal.
- The concentration of SBMs on drill cuttings discharged to sea will be restricted to 10% by dry weight or less in accordance with Western Australian Government guidelines (DoIR 2006). An internal target of 5% or less of SBM on drill cuttings released to sea will be set.
- Use of cuttings driers or other options will be investigated to reduce SBMs on drill cuttings.

In addition, an environmental management plan will be developed for offshore drilling as required under the OPGGS(Environment) Regulations.

Residual risk

A summary of the potential impacts, management controls and residual risk for drilling discharges is presented in Table 7-5. After implementation of these controls, impacts from drilling discharges are considered to present risk levels of “low” to “medium” and it is likely that any effects on the marine environment will be localised and short-term.

Table 7-5: Summary of impact assessment and residual risk for drilling discharges (offshore)

Aspect	Activity	Potential impacts	Management controls and mitigating factors	Residual risk*		
				C†	L‡	RR§
Drill cuttings	Construction of offshore subsea wells.	Water quality decreased through increase in turbidity. Temporary disturbance to marine biota.	The strong ocean currents and deep water in the offshore development area will lead to rapid dispersion of turbid plumes. Drilling Environmental Management Plan as required under the OPGGS(Environment) Regulations.	F (E1)	6	Low
		Alteration of sediment characteristics.	The strong ocean currents and deep water in the offshore development area will spread cuttings piles in thin layers across the seabed. The benthic communities present are widespread and extensive in comparison with the disturbance area. Drilling Environmental Management Plan as required under the OPGGS(Environment) Regulations.	E (B3)	6	Medium
Drilling mud discharge	Discharge of WBMs to sea.	Toxicity to marine biota. Increased turbidity.	The strong ocean currents and deep water in the offshore development area will lead to rapid dispersion of cuttings and turbid plumes. Drilling Environmental Management Plan as required under the OPGGS(Environment) Regulations.	F (E1)	6	Low

Table 7-5: Summary of impact assessment and residual risk for drilling discharges (offshore) (continued)

Aspect	Activity	Potential impacts	Management controls and mitigating factors	Residual risk*		
				C†	L‡	RR§
Drilling-mud discharge	Discharge of SBMs adhering to drill cuttings.	Toxicity to marine biota. Alteration of sediment characteristics, including depletion of oxygen in surface sediments. Increased turbidity.	The strong ocean currents and deep water in the offshore development area will lead to rapid dispersion of cuttings and turbid plumes. Use WBMs in upper-hole sections instead of SBMs. Recover SBMs after drilling and reuse or dispose of onshore. The percentage by dry weight of SBMs released on drill cuttings will be restricted to 10%, with an internal target of 5% or less. Provisional Liquid Discharges, Surface Water Runoff and Drainage Management Plan. Drilling Environmental Management Plan as required under the OPGGS(Environment) Regulations.	E (B3)	6	Medium

* See Chapter 6 *Risk assessment methodology* for an explanation of the residual risk categories, codes, etc.

† C = consequence.

‡ L = likelihood.

§ RR = risk rating.

7.2.3 Liquid discharges

A variety of routine liquid wastes will be generated at the offshore development area during all stages of the Project as described in Chapter 5 *Emissions, discharges and wastes*. This section discusses the potential environmental impacts of these discharges in the context of the offshore marine environment.

Subsea control fluid

During operations, a water-based subsea control fluid will be used to control subsea tree valves remotely from the CPF. This will be likely to operate on an open-loop system, with small amounts of control fluid discharged from the wellhead valves on the seabed when they are operated. Typically, volumes of approximately 20 L of control fluid will be discharged from main valves at the base of risers and manifolds, on around two occasions per year. Smaller valves on subsea "Christmas" trees (at the wellheads) will be operated around five times per year, releasing around 4 L of control fluid each time.

Open-loop subsea control systems are an industry standard. The main properties required of a control fluid are low viscosity, low compressibility, corrosion protection, resistance to microbiological attack, compatibility with sea water, and biodegradability. The majority of subsea control fluids are based on fresh water with additives such as monoethylene glycol (MEG) (typically about 40%), lubricants, corrosion inhibitors, biocides and surfactants.

Subsea control fluids have been tested under the OSPAR Commission's Harmonised Offshore Chemical Notification Format (HOCNF). The testing includes an assessment of the potential of each component of a product to bioaccumulate and biodegrade in the environment, as well as the performance of three out of four possible toxicity tests that are chosen in accordance with the expected fate of the materials. Based on the results of these tests, the UK HOCNF classification for various water-based subsea control fluids is "Group E", representing the group of least environmental concern. Under this classification, up to 1000 t (approximately 1 000 000 L) of a substance may be released per annum from a single facility without prior notification to government bodies.

Given the low volumes discharged during each event, the potential impacts of this discharge are expected to be very localised, with a low impact on the marine environment. The release of subsea control fluids associated with the Project will not cause any significant impacts to listed species, migratory species or the surrounding marine environment.

Management for subsea control fluid

A Provisional Liquid Discharges, Surface Water Runoff and Drainage Management Plan has been compiled for the Project (attached as Annexe 10 to Chapter 11), which will guide the development of more detailed plans during the construction and operations phases. This plan includes the following management controls for subsea control fluids:

Table 7-6: Summary of impact assessment and residual risk for subsea control fluids

Aspect	Activity	Potential impacts	Management controls and mitigating factors	Residual risk*		
				C†	L‡	RR§
Release of subsea control fluids	Control of subsea tree valves.	Toxicity to marine biota.	Design of equipment to reduce volume of fluid released. Selection of water-soluble, low-toxicity control fluid. Provisional Liquid Discharges, Surface Water Runoff and Drainage Management Plan.	F (E1)	6	Low

* See Chapter 6 *Risk assessment methodology* for an explanation of the residual risk categories, codes, etc.

† C = consequence.

‡ L = likelihood.

§ RR = risk rating.

- Wellhead valves will be designed to minimise the volumes of subsea control fluids released.
- Water-soluble, low-toxicity hydraulic fluids will be selected to control open-loop subsea control valves.

Residual risk

A summary of the potential impacts, management controls and residual risk for subsea control fluids is presented in Table 7-6. After implementation of these controls, impacts from subsea control fluids are considered to present a "low" risk and any effects on the marine environment will be on a minor scale and highly localised.

Hydrotest water

Pressure-testing will be undertaken to determine the integrity of all facilities, including the FPSO and CPF, the gas export pipeline and the flowlines prior to commissioning. Pressure-testing is achieved by filling the lines with water, pressurising the water and monitoring for any change in pressure over time. This process is normally referred to as "hydrotesting". This is an important measure for avoiding or minimising the risk of accidental hydrocarbon leaks and is mandatory under Australian design codes.

In addition to water (either fresh water or sea water, but predominantly sea water), the hydrotest fluid normally contains a dye to aid in the detection of leaks, a biocide, an oxygen scavenger to prevent oxygen pitting of the steel, scale inhibitor and corrosion inhibitor. Fluorescein dye and a combined biocide and oxygen scavenger chemical containing acetic acid (5 to 10%), ammonium bisulfate (oxygen scavenger, 10 to 20%) and polyhexamethylene biguanide hydrochloride (PMBH, corrosion inhibitor and biocide, 10 to 20%) in fresh, brackish or sea water is a commonly used formulation for hydrotest water. It is also possible that MEG will be introduced during the dewatering and drying stage at the end of pipeline precommissioning to effectively remove water from the pipeline; the ecotoxicity of MEG is discussed below under *Produced water*.

The biocide PMBH is widely used in a variety of industries and by the general public as an alternative to chlorine for sterilising swimming pools. If fully diluted in the line, the maximum concentration of PMBH would be approximately 1000 mg/L. The reported toxicity of PMBH ranges from 0.65 to 0.9 mg/L (96-hour LC_{50} for bluegill sunfish) to 44 mg/L (96-hour LC_{50} for brown shrimp). Therefore, if discharged at sea the hydrotest fluid would need to be diluted more than 1000 times within a 96-hour period to avoid the potential for acute toxicity impacts. Given the deep waters and strong currents in the Project's offshore development area, dispersion of hydrotest water from the pipeline is expected to be rapid.

Hydrotesting for the topsides in the CPF and FPSO will be carried out at the shipyards where they are assembled. Some infield hydrotesting may be required for connection points and for the transfer line between these facilities, and this water would be discharged overboard at the sea surface. Hydrotest water from subsea flowlines and wells will be recovered through the production process and discharged at the sea surface from the CPF.

During precommissioning, the gas export pipeline will be flooded with approximately 1 GL of filtered and chemically treated sea water sourced from Darwin Harbour. The pipeline will then be hydrotested twice, using approximately 10 ML of treated water each time. At the end of each hydrotest operation, this treated water will be discharged from the offshore facilities to return the pipeline to ambient pressure. In the highly unlikely event of mechanical failure or a cyclone passing during the hydrotest operation, this water may need to be discharged from the onshore facility into Darwin Harbour. This scenario is discussed in the nearshore liquid discharges section (Section 7.3.4).

On completion of the hydrotesting, the pipeline will be dewatered and then dried and purged using nitrogen. During dewatering, the 1 GL of treated water in the pipeline will be discharged at the offshore facility.

It is expected that upon discharge of the hydrotest water, a plume of water similar in density to sea water will disperse through the water column. Given the strong current regime in the area and the considerable water depths, the hydrotest fluid is likely to disperse rapidly, minimising the potential for longer-term exposure effects. Any toxicity effects from the discharged pollutants would only impact on marine biota that happened to travel in the discharge plume for an extended period.

Management of hydrotest water

It is important to note that hydrotesting of flowlines is an important measure for avoiding and minimising risk associated with potential accidental releases of hydrocarbons and that it is mandatory under Australian design codes. The process for hydrotesting will be developed in more detail as the design of the offshore facilities progresses. Full details of the chemicals to be used, the concentrations, the quantities of water, the disposal method and their fate will be included in a Hydrotest Management Plan, subject to acceptance by Western Australia's Department of Mines and Petroleum acting on behalf of the Commonwealth Government.

A Provisional Liquid Discharges, Surface Water Runoff and Drainage Management Plan has been compiled for the Project (attached as Annexe 10 to Chapter 11). It will guide the development of more detailed plans during the construction and commissioning phases. This plan includes the following management controls for hydrotest water:

- Chemicals used in hydrotesting will be selected with consideration for their potential ecotoxicity.
- Modules will be precommissioned off site, if practicable, to minimise the discharge of hydrotest water to the marine environment.
- During dewatering of the gas export pipeline, treated water (approximately 1 GL) will be discharged at the offshore facility.
- Hydrodynamic modelling of hydrotest water plumes from the gas export pipeline will be undertaken prior to the commissioning phase in order to predict the dispersion of pollutants into the offshore marine environment.

Residual risk

A summary of the potential impacts, management controls, mitigating factors and residual risk for hydrotest water is presented in Table 7-7. Impacts from hydrotest water are considered to present a "low" risk as they are likely to be short-term and minor in scale.

Produced water

"Produced water" is water extracted from the gas reservoirs and separated from the hydrocarbon gases and liquids through a series of processes. Chemicals are added to the water from the gas reservoirs through the extraction and production process for purposes

Table 7-7: Summary of impact assessment and residual risk for hydrotest water (offshore)

Aspect	Activity	Potential impacts	Management controls and mitigating factors	Residual risk*		
				C†	L‡	RR§
Hydrotest water discharge	Commissioning of offshore gas production infrastructure.	Reduction in water quality because of dissolved chemical additives. Toxicity to marine biota.	Strong current regime and deep water in the offshore marine environment. Select hydrotest chemicals with consideration of their ecotoxicity potential. Precommission modules off site, if practicable. Hydrotest Management Plan (to be developed). Provisional Liquid Discharges, Surface Water Runoff and Drainage Management Plan.	F (E1)	6	Low

* See Chapter 6 *Risk assessment methodology* for an explanation of the residual risk categories, codes, etc.

† C = consequence.

‡ L = likelihood.

§ RR = risk rating.

such as controlling emulsion, inhibiting scale and hydrate formation, reducing corrosion and preventing the growth of bacteria. These production chemicals are soluble in produced water to varying extents. Other dissolved compounds in the produced water originate from the geological formation, such as organic acids, water-soluble hydrocarbons and salts, and some finely dispersed oils.

The characteristics of the produced water generated at the offshore development area are described in Chapter 5. For the Ichthys Project, produced water (including the dissolved fractions of production chemicals) will be discharged from the FPSO directly to the marine environment. In accordance with the requirements of the OPGGS(Environment) Regulations, the concentration of petroleum hydrocarbon in produced water discharged to sea will not be greater than an average of 30 mg/L (30 ppm) over any period of 24 hours.

Components of produced water

Metals

The metals associated with produced water are usually present as dissolved mineral salts. Because the reservoir water has been depleted of oxygen (through microbiological activity in the reservoir over millions of years), the metal ions are typically in lower oxidation states when discharged to the ocean as a component of the produced water.

Once discharged to sea the metal ions react with the oxygen in the surrounding sea water to form oxides. The metal oxides may then combine with anions such as sulfides, carbonates and chlorides and form insoluble precipitate. Precipitation as metal hydroxides or sulfides is the principal fate of heavy metals discharged with produced waters in the marine environment (E&P Forum 1994). Metals present in marine sediments as hydroxides or sulfides are not generally available for biological uptake (Jenne & Luoma 1977) and hence would not have any significant environmental impact.

Production chemicals

Production chemicals that may be discharged along with the produced water include the following types:

- hydrate inhibitors (most likely MEG)
- corrosion inhibitors
- scale inhibitors
- biocides.

The hydrate inhibitor MEG will be added in large volumes to the production process but will, in the main, be retained and recycled at the FPSO. Varying amounts of MEG will be discharged in the produced water directly to the marine environment. Worldwide, MEG is used as a chemical intermediate in the manufacture of polyesters or fibres, films and bottles, as well as for antifreeze in engine coolants or as a de-icer on airport runways and planes—runoff from these is the principal contributor of MEG to the environment (IPCS 2000).

MEG is miscible with water, does not volatilise nor undergo photodegradation, and is not adsorbed on to soil particles. Studies on a green alga (*Chlorella fusca*), a freshwater crayfish (*Procambarus* sp.) and a golden orfe carp (*Leuciscus idus melanotus*) revealed low potential for bioaccumulation of MEG in the marine environment (IPCS 2000).

MEG biodegrades readily when released to the environment, in both aerobic and anaerobic conditions, and several strains of micro-organisms capable of utilising ethylene glycol as a carbon source have been identified. Evans and David (1974) studied the biodegradation of ethylene glycol in four samples of river water under controlled laboratory conditions. The samples were dosed with 0, 2, or 10 mg of ethylene glycol per litre and incubated at either 20 °C or 8 °C. At 20 °C, primary biodegradation was complete within 3 days in all 4 samples, while at 8 °C, it was complete after 14 days and degradation rates were further reduced at 4 °C. Price, Waggy and Conway (1974) assessed the biodegradation of ethylene glycol in both fresh and salt water over a 20-day incubation period. Concentrations of up to 10 mg ethylene glycol per litre were used. In fresh water, 34% degradation was observed after 5 days, rising to 86% after 10 days and 100% after 20 days. Degradation was less in salt water—20% after 5 days and 77% after 20 days (IPCS 2000).

It is considered that MEG poses a negligible risk of ecotoxicity, as lethal effects on exposed organisms can only be caused by very high concentrations in sea water. Ecotoxicity values for the effect of MEG on a number of aquatic organisms are provided in Table 7-8; the high LC_{50} values indicate low toxicity.

In summary, given that produced water is rapidly dispersed by ambient currents, MEG would not be expected to have toxic effects on the marine environment.

Table 7-8: Ecotoxicity of monoethylene glycol (MEG) (as ethylene glycol)

Species	Life-cycle stage	Exposure (hours)	LC_{50}* (ppm)	Source
Goldfish (*Carassius auratus*)	Adult	24	5000	A
Goldfish (*Carassius auratus*)	–	72	34 250	B
Bluegill (*Lepomis macrochirus*)	Juvenile	96	27 540	A
Bluegill (*Lepomis macrochirus*)	–	–	27 540	C
Bluegill (*Lepomis macrochirus*)	–	96	34 250	B
Rainbow trout (*Oncorhynchus mykiss*)	Fry	96	60 829	A
Rainbow trout (*Oncorhynchus mykiss*)	–	–	18 000–46 000	C
Trout	–	96	41 000	B
Fathead minnow (*Pimephales promelas*)	Subadult	96	57 000	A
Water flea (*Daphnia magna*)	–	24	10 000	A
Water flea	–	48	46 300	B
Water flea (*Ceriodaphnia dubia*)	–	–	10 000–25 800	C
Brine shrimp (*Artemia salina*)	2nd–3rd instar larvae	24	180 624	A
Crayfish (*Procambarus* sp.)	Adult	96	91 430	A
Common shrimp (*Crangon crangon*)	Adult	48	100 000	A

Sources: A) PAN Pesticide Database 2010; B) ScienceLab.com, Inc. 2008; C) Old World Industries I 2003.

* The notation LC_{50} stands for "lethal concentration 50%". It is the concentration of a chemical in air or water that will kill 50% of a group of a specific test animal species exposed to it in a given time, for example 24 hours, 96 hours, etc. The LC_{50} is a measure of the short-term poisoning potential of a substance.

Other production chemicals (e.g. corrosion inhibitors, scale inhibitors and biocides) can be toxic to marine biota but will be discharged at much lower concentrations than MEG. The environmental effects of these components of produced water depend upon dosage concentrations and the sensitivity of the plant or animal receptors. Discharge modelling presented later in this section suggests that any chemicals contained in the production water at the offshore development area will be rapidly diluted and will not reach sensitive receptors.

Toxicity of produced water

The fundamental principle of toxicity is that the negative response increases as the dose increases. This is generally represented by a dose below which no response is observed (the "threshold"), to a dose causing a 100% response. It is important to note the difference between "dose" and "exposure":

- Dose is the amount that is known to enter the organism or to interact with a membrane of an organism (e.g. a fish gill) for a given exposure. The dose is specifically associated with the toxic response.
- Exposure is the amount or concentration of an agent in the ambient environment in which the organism resides. Simply being in the environment does not necessarily mean that the agent is absorbed by the organism at a dose, or for a duration of time, sufficient to reach a target site and exert a toxic effect.

"Acute" toxicity is a poisonous effect experienced by an organism, produced from a single or short dose (24 to 96 hours). Acute toxicity can result in severe biological harm or death, but survival through an episode of acute toxicity usually does not cause lasting effects. "Chronic" toxicity is the result of long-term exposure to a toxin in small repeated doses, for which symptoms may not appear for a long time and may last indefinitely.

Acute toxicities for produced-water discharges reported for various oilfields around the world have been reviewed and are summarised in Table 7-9. Note that these discharges are likely to contain a mixture of hydrocarbons, production chemicals and formation water in varying concentrations, depending on the oilfield and production systems employed. The lowest reported LC_{50} acute toxicity (i.e. the most toxic response) occurred at 8000 ppm (equivalent to dilution of 125 times), while the highest (least toxic) occurred at more than 900 000 ppm (equivalent to a dilution of 1.11 times). The mean reported measure of acute toxicity was 230 000 ppm (equivalent to a dilution of 4.35 times). For the purposes of determining potential impacts from produced water at the Ichthys Field, the highest dilution rate of 1:125 may be applied as an acute toxicity threshold.

Table 7-9: Reported produced-water acute toxicity concentrations

Group	Species	LC_{50}*, EC_{50}† toxicity range (ppm)	Reference
Algae	*Skeletonema costatum*	10 000–350 000; 50 000–680 000	Flynn, Butler and Vance 1996; Brendehaug et al. 1992
	Isochrysis sp. (Tahitian strain)	470 000	P. Farrell pers. comm. 2007
Echinoderms	*Strongylocentrotus purpuratus*	180 000–286 000	Schiff et al. 1992
Polychaetes	*Neanthes arenaceodentata*	180 000–290 000	Schiff et al. 1992
Molluscs	*Donax faba*	10 000–150 000	Din and Abu 1992
	Haliotis rufescens (larvae)	>900 000	Raimondi and Schmitt 1992
	Haliotis rufescens (settlement)	120 000	Raimondi and Schmitt 1992
	Crassostrea gigas	50 000	Somerville et al. 1987
Coelenterates	*Campanularia flexuosa*	50 000	Somerville et al. 1987
	Acropora millepora (fertilisation)	>900 000	Negri and Heyward 2000
	Acropora millepora (settlement)	80 000	Negri and Heyward 2000
Crustaceans	*Artemia salina*	160 000–180 000	Somerville et al. 1987
	Crangon crangon	20 000	Somerville et al. 1987
	Penaeus monodon	240 000	P. Farrell pers. comm. 2004
	Farfantepenaeus aztecus (larval)	8000–10 000	Rose and Ward 1981
	Farfantepenaeus aztecus (juvenile)	60 000–180 000	Rose and Ward 1981
	Litopenaeus setiferus (juvenile)	60 000–130 000	Zein-Eldin and Keney 1979
	Litopenaeus setiferus (adult)	40 000–90 000	Zein-Eldin and Keney 1979
	Balanus tintinnabulum	83 000	E&P Forum 1994
Copepods and amphipods	*Acartia tonsa*	20 000–250 000; 100 000	Flynn, Butler and Vance 1996; Somerville et al. 1987
	Tisbe battagliai	30 000–300 000	Somerville et al. 1987
	Gladioferens imparipes	310 000	P. Farrell pers. comm. 2004
	Calanus finmarchicus	100 000	Somerville et al. 1987
Fish	*Oncorhynchus mykiss*	100 000	Somerville et al. 1987
	Hypleurochilus geminatus	270 000; 160 000–410 000	Jackson et al. 1989; Rose and Ward 1981
	Cyprinodon variegatus	50 000–280 000; 70 000–340 000; 40 000–280 000	Moffitt et al. 1992; St. Pé 1990; Andreasen and Spears 1983
	Fundulus heteroclitus	>230 000	Black et al. 1994
	Lagodon rhomboides	500 000	Black et al. 1994
	Micropogonias undulatus	350 000	Black et al. 1994
	Mugil curema	500 000	Black et al. 1994
	Gasterosteus aculeatus	>750 000	Black et al. 1994

* The notation LC_{50} stands for “lethal concentration 50%”. It is the concentration of a chemical in air or water that will kill 50% of a group of a specific test animal species exposed to it in a given time, for example 24 hours, 96 hours, etc. The LC_{50} is a measure of the short-term poisoning potential of a substance.

† The notation EC_{50} stands for “effect concentration 50%”. It is the concentration of a substance that results in 50% less growth, fecundity, germination, etc., in a population. In ecology it is used as a measure of a substance’s ecotoxicity but, unlike the LC_{50} which measures lethality, the EC_{50} value measures sublethality—it demonstrates the adverse effects of a substance on a test organism such as changes in its behaviour or physiology.

The toxicity of the Ichthys condensate on marine biota has also been assessed by Geotechnical Services (2007a). These tests indicate that a dilution rate of 1:158 (equivalent to 0.127 mg/L hydrocarbons) produced no observable acute toxicity effects in fish larvae, the most sensitive of the marine biota included in the study. As hydrocarbons from the offshore facilities represent a portion of the solutes discharged to the marine environment, this dilution rate can be applied as a very conservative acute toxicity threshold for produced water.

There are relatively few studies that consider the chronic toxic effects of produced water. Black et al. (1994) cite an earlier study (Girling 1989) in which adverse chronic-toxicity effects were observed for the copepod *Acartia tonsa* at concentrations equivalent to between 0.5% and 7% produced water. A study of the chronic toxicity of produced water to species of sea urchin, mussel, shrimp and kelp by Cherr, Higashi and Shenker (1993) found adverse toxic effects occurring after exposure to 2–3% produced-water concentrations. Sublethal toxic effects of produced water, including damage to gill lamellae and impairment of iono-regulatory processes, have also been detected in fish continuously exposed for a period of 6 weeks to concentrations as low as 0.1–1.0% produced water (Stephens et al. 2000).

Mesocosm studies, which more closely approximate "real world" conditions, have demonstrated marked reduction in copepod populations after chronic exposure to concentrations equivalent to about 0.02–0.05% produced water (Davies et al. 1981).

Combining these estimates of chronic-toxicity threshold provides a range of 0.02–7% of produced water (equivalent to a dilution of 5000 to 14 times) over a period of weeks to months as the dosage required to elicit a chronic-toxicity response. The most conservative of these dilution rates (1:5000, equivalent to 0.004 mg/L hydrocarbons) can be used as a chronic-toxicity threshold level for produced-water dispersion from the Project's offshore development area, described in the following subsection.

Dispersion of produced water

In order to predict the dispersion of produced water in the offshore development area, hydrodynamic modelling was undertaken by Asia-Pacific Applied Science Associates (APASA). Three modelling methods were integrated to simulate this dispersion: an oceanic hydrodynamic model (HYDROMAP) for current data, a near-field discharge model (UM3), and a far-field advection and dispersion model (MUDMAP). The results of the study are summarised below, while the complete technical report is provided in Appendix 6 to this Draft EIS. Further detail on the development and validation of the oceanic hydrodynamic model is provided in Appendix 5.

For the purposes of modelling, discharge rates and characteristics were estimated based on preliminary knowledge of the gas reservoirs in the Ichthys Field. The Brewster reservoir contains significantly lower volumes of formation water than the Plover reservoir and will therefore generate produced water at lower flow rates and salinity levels (see Chapter 5). Two scenarios were modelled under both summer and winter weather conditions to better understand the dispersion of produced water throughout the life of the Project:

Scenario 1 Representing the maximum flow rate of produced water from the Brewster reservoir and none from the Plover reservoir. This would occur in Year 17.

Scenario 2 Representing the maximum overall flow rate, involving declining volumes from Brewster and peak flow rates from Plover. This would occur in Year 28.

The assumed characteristics of the produced water for each scenario are summarised in Table 7-10. An initial dispersed hydrocarbon concentration of 20 mg/L was assumed for both scenarios.

Table 7-10: Summary characteristics of produced water discharged at the Ichthys Project's offshore development area

Input	Scenario 1 (Year 17)	Scenario 2 (Year 28)
Flow rate	2000 m^3/d	5000 m^3/d
Composition	0% formation water 100% condensed water	50% formation water 50% condensed water
Temperature	50 °C	50 °C
Salinity	1 ppt	12 ppt

Produced water mixes into the marine environment in two distinct zones:

- Near-field: This is defined by the area where the levels of mixing and dilution are controlled by the plume's initial jet momentum and buoyancy flux, resulting from differences in the a density of the discharged water and the surrounding sea water. When the plume encounters a boundary such as the water surface, seabed or a density stratification layer, the near-field mixing is complete.
- Far-field: This is outside the near-field zone, where the discharge plume is transported and mixed by the ambient currents (APASA 2009a).

At the Project's offshore development area, produced water will be discharged continuously from the hull of the FPSO, 15 m below the sea surface. Near-field modelling indicated that the produced-water plume would initially plunge downward, creating a turbulent mixing zone approximately 1 m below the discharge pipe. Once the initial jet momentum ceased, the plume would remain sufficiently buoyant to rise to the surface and to continue to mix with ambient waters, though at a slower rate. As a result of mixing during the initial plunge and buoyant rise, the salinity and temperature of the discharge plume are predicted to reach background levels over a short distance (*c*.10 m), irrespective of flow rates and ambient current conditions (APASA 2009a).

Dilution levels achieved for the produced-water plume under both discharge scenarios, in both seasons, are summarised in Table 7-11. As near-field mixing does not consistently dilute the produced-water plume to low-toxicity threshold levels (i.e. it does not achieve a dilution rate of 1:158), far-field modelling is required to assess the extent and shape of the mixing zone in the offshore marine environment.

Table 7-11: Summary of dilution rates achieved by near-field mixing, within a 5-m horizontal distance of the release site

Scenario, season	Dilution rate achieved*
Scenario 1, summer	>1:120
Scenario 2, summer	>1:55
Scenario 1, winter	>1:114
Scenario 2, winter	>1:54

Source: APASA 2009a.

* Dilution rate achieved 95% of the time (95% confidence limit).

Far-field dispersion modelling indicated that the produced-water plume would remain in the surface layer (in the top 2 m), and would be transported by near-surface currents. The plume would oscillate and change direction with each flood and ebb tide, to the north-west and south-east respectively. As a result of this change in directions and current velocities, concentrations in the plume would be variable over time. Patches of higher concentrations (lower dilution rates) tend to build up at the turn of the tide, or in weaker currents. These higher-concentration patches would move as a unified group as the current speeds increased again (APASA 2009a).

Scenario 2 (maximum flow rate) is predicted to cause a much larger mixing area than Scenario 1, prior to reaching the threshold dilution rate for acute toxicity of 1:158 (see Figure 7-3). This mixing zone covers 0.0058 km^2 during summer conditions and 0.0061 km^2 during winter, and is reached within 60 m of the release site in both seasons. The 1:158 dilution threshold is reached within 10 m of the release site for Scenario 1 (low flow rate) in both seasons (APASA 2009a).

The conservative chronic-toxicity dilution rate (1:5000) is reached within 1.1 km of the release point for Scenario 1 and 3.6 km for Scenario 2. This relates to a mixing zone of 6.6 km^2 for Scenario 1 and 9.3 km^2 for Scenario 2 (APASA 2009a). Chronic-toxicity effects would only be caused to marine biota that are continuously exposed to this discharge plume in the surface water layers over time periods of weeks or months. As this area of effect remains within the open ocean surrounding the offshore facilities and is distant from Browse Island, there is no potential for impacts to sensitive shallow-water marine habitats.

Management of produced water

A Provisional Liquid Discharges, Surface Water Runoff and Drainage Management Plan has been compiled for the Project (attached as Annexe 10 to Chapter 11), which will guide the development of a series of more detailed plans during the construction and operations phases. Key inclusions in this plan include the following:

- Oil-in-water concentrations will meet the regulatory requirement under Regulation 29 of the OPGGS(Environment) Regulations of being not greater than an average of 30 mg/L over any period of 24 hours. The oil-in-water concentration of produced water discharged at the offshore development area will be measured continuously by an online analyser to ensure compliance with this regulatory criterion.
- Process chemicals will be selected with consideration of their potential ecotoxicity.

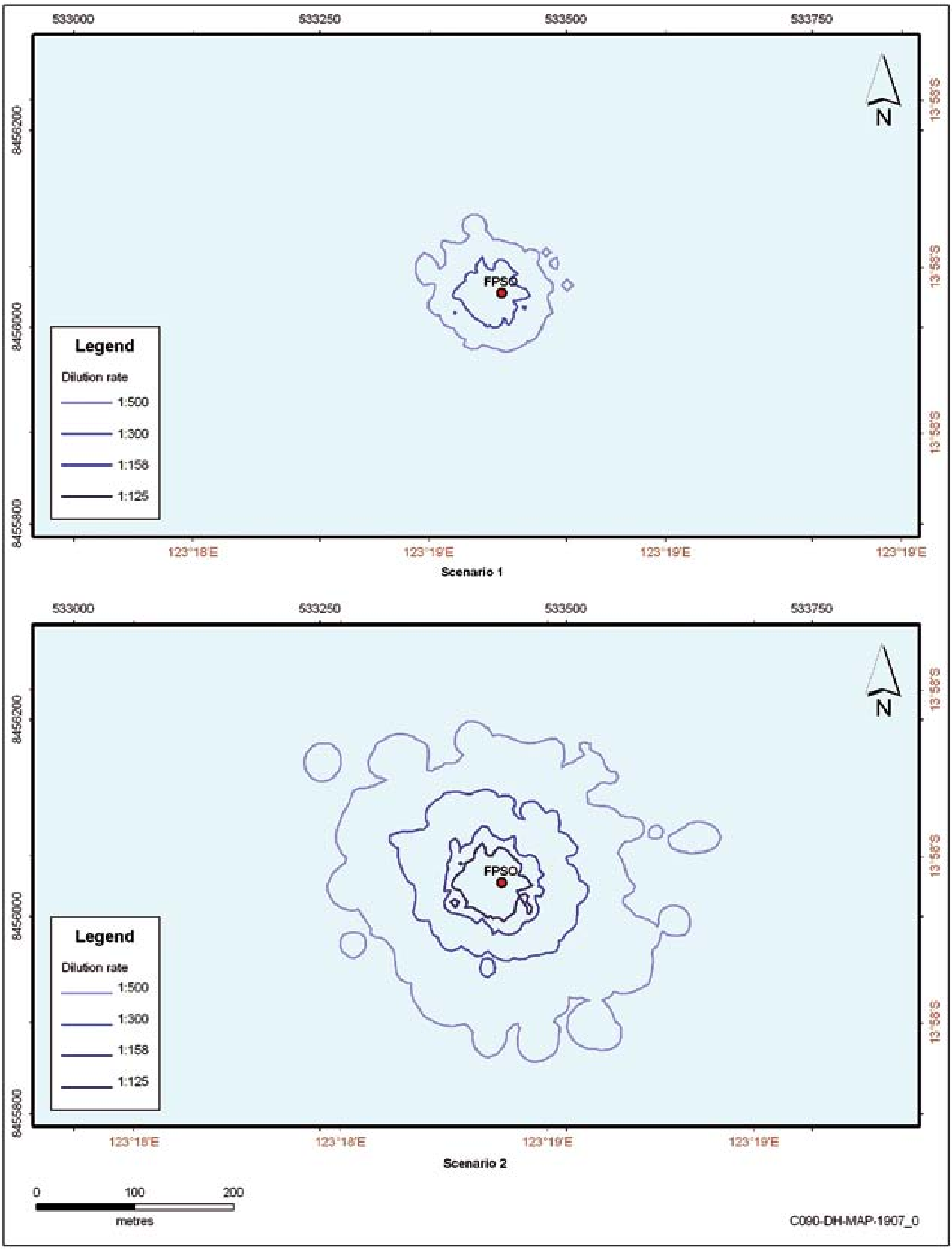

Figure 7-3: Predicted extent of produced-water mixing zones for scenarios 1 (top) and 2 (bottom) under combined summer and winter current conditions

Residual risk

A summary of the potential impacts, management controls, and residual risk for produced water is presented in Table 7-12. After implementation of these controls, impacts from produced water are considered to present a "medium" risk, as effects on the marine environment will be localised and discharges of pollutants are as low as reasonably practicable.

Table 7-12: Summary of impact assessment and residual risk for produced water (offshore)

Aspect	Activity	Potential impacts	Management controls and mitigating factors	Residual risk*		
				C†	L‡	RR§
Produced-water discharge	Routine operation of offshore gas production infrastructure.	Reduction in water quality because of elevated concentrations of dispersed oil, metals and production chemicals. Toxicity to marine biota.	The strong current regime and deep water in the offshore marine environment will disperse the discharge plume rapidly. The concentrations of oil-in-water will be ≤30 mg/L (24-hour average) and will be monitored constantly to ensure compliance. Provisional Liquid Discharges, Surface Water Runoff and Drainage Management Plan.	E (E1)	6	Medium

* See Chapter 6 *Risk assessment methodology* for an explanation of the residual risk categories, codes, etc.

† C = consequence.

‡ L = likelihood.

§ RR = risk rating.

Other wastewater discharge

Cooling water, desalination brine, and sewage and grey water will be routinely discharged from vessels and facilities to the marine environment in the offshore development area during all stages of the Project.

Large volumes of sea water used for cooling the gas-processing facilities will be discharged back to the marine environment at an elevated temperature (45–50 °C). Elevated seawater temperatures are known to cause alteration of the physiological (especially enzyme-mediated) processes of exposed biota (Wolanski 1994). These alterations may cause a variety of effects ranging from behavioural responses (including attraction and avoidance behaviour) to minor stress and potential mortality in cases of prolonged exposure. Around the offshore Project facilities, it is expected that an area of less than 0.1 ha around the discharge outfall will experience water temperatures more than 2 °C above ambient conditions for 50% or more of the time. This effect is considered very localised in the context of the offshore marine environment.

The effects of sewage discharged to the ocean have been relatively well studied (for example by Gray et al. 1992 and Weis, Weis & Greenberg 1989) and toxic effects generally only occur where high volumes are discharged into a small and poorly mixed waterbody. The small volumes of treated sewage and grey water discharged at the offshore development area are unlikely to cause toxic effects, especially considering the rapid dilution provided by the deep water and ocean currents in the area.

Sewage and grey water will also be discharged from pipeline construction vessels, except within 3 nautical miles of land, in accordance with Annex 4 of MARPOL 73/78 (IMO 1978). The volumes of sewage and grey water from these vessels will be relatively low and are expected to be fully biodegradable.

Discharges will be transient because of the constant movement of vessels along the pipeline route, reducing the impact to the marine environment to a very low level.

Desalination brine will be discharged from the CPF and FPSO, although in relatively low volumes with only very localised effects on water quality. The saline brine would be discharged at a rate of approximately 100 m^3/d from each facility and would be expected to rapidly disperse into the surrounding waters.

For all these discharged wastewater streams, the biota that could be exposed for long periods would be limited to fouling species (e.g. barnacles) in the immediate vicinity of outfall points. Planktonic species drifting with the discharge water as it disperses may also be affected, although for short periods. In the context of the offshore marine environment, however, wastewater discharges from the offshore development area will result in localised, low-scale changes in water quality.

Deck drainage discharges and management of accidental hydrocarbon spills on board the facilities are described in Section 7.2.4.

Management of wastewater

A Provisional Liquid Discharges, Surface Water Runoff and Drainage Management Plan has been compiled for the Project (attached as Annexe 10 to Chapter 11), which will guide the development of a series of more detailed plans during the construction and operations phases. Key inclusions in this plan include the following:

- Sewage wastes from the CPF and FPSO will be macerated to particles and scraps with diameters less than 25 mm prior to discharge, in accordance with Clause 222 of the Petroleum (Submerged Lands) Acts Schedule (DITR 2005).

The discharge will take place through submerged caissons.

- Construction vessels, supply vessels and the MODU will adhere to the following as permitted by the *Protection of the Sea (Prevention of Pollution from Ships) Act* (Cwlth) and the *Marine Pollution Act* (NT).
  - Sewage will not be discharged within 3 nautical miles of land.
  - Only treated sewage (with particles <25 mm in diameter) will be discharged between 3 and 12 nautical miles of land.
  - Untreated sewage may be discharged beyond 12 nautical miles of land.

Residual risk

A summary of the potential impacts, management controls and risks in relation to wastewater discharges are listed in Table 7-13. After implementation of these controls, impacts from wastewater discharges are considered to present a "low" risk, as the effects on the marine environment will be localised and discharges of pollutants are as low as reasonably practicable.

Ballast water

The ballast water contained in the MODU, CPF, FPSO and various vessels involved in construction and operations at the offshore development area will be fully segregated from fuel and product tanks in accordance with MARPOL 73/78 (IMO 1978) to remove the risk of contamination by hydrocarbons or chemicals. Therefore differences in chemical water quality between the ballast water taken on at the point of origin and the waters of the offshore development area are expected only to relate to salinity, turbidity or temperature and would be very minor in scale. Marine biota may also be transferred in ballast water to the offshore development area; the risks of transferring marine pests this way are discussed in Section 7.2.8 *Marine pests*.

Table 7-13: Summary of impact assessment and residual risk for wastewater discharges (offshore)

Aspect	Activity	Potential impacts	Management controls and mitigating factors	Residual risk*		
				C†	L‡	RR§
Sewage and grey water discharge	Routine operation of offshore vessels and facilities.	Alteration of marine environment including nutrient enrichment and toxicity.	The strong ocean currents and deep water will result in rapid dispersion in the offshore development area. Comminuted sewage (<25 mm) will be discharged from the CPF and FPSO through submerged caissons. Sewage and grey water will be treated and disposed of in accordance with *Protection of the Sea (Prevention of Pollution from Ships) Act 1983* (Cwlth) and the *Marine Pollution Act* (NT). No discharge from vessels will be made within 3 nautical miles of land. Only treated waste (macerated to <25 mm) will be discharged between 3 and 12 nautical miles from land, and untreated waste may be discharged beyond 12 nautical miles. Provisional Liquid Discharges, Surface Water Runoff and Drainage Management Plan.	F (E1)	6	Low
Cooling water discharge	Routine operation of offshore facilities.	Alteration of marine environment through increase in water temperature.	The strong ocean currents and deep water will result in rapid dispersion in the offshore development area. No specific management proposed as this is considered a negligible risk to the marine environment.	F (E1)	6	Low

* See Chapter 6 *Risk assessment methodology* for an explanation of the residual risk categories, codes, etc.

† C = consequence.

‡ L = likelihood.

§ RR = risk rating.

Ballast water discharged from the vessels and facilities at the offshore development area will disperse rapidly into the surrounding marine environment and will have little effect on water quality and marine biota in the area.

Management of ballast water

Vetting procedures for condensate tankers will be developed and implemented to ensure that ballast-water tanks are segregated from fuel and product tanks.

Residual risk

A summary of the potential impacts, management controls, and residual risk for ballast water is presented in Table 7-14. After implementation of these controls, impacts from ballast water are considered to present a "low" risk, with localised and low-scale effects on the surrounding marine environment.

Antifouling leachate

Antifouling paints commonly used on commercial vessels are formulations containing copper and "booster biocides" such as Irgarol 1051 (a triazine, $C_{11}H_{19}N_5S$), diuron, and zinc pyrithione. Booster biocides are designed to leach slowly from the paint to prevent fouling build-up. Table 7-15 presents the concentration of the most common antifouling additives, the rates at which they are expected to leach from the paints, and the reported range of their toxicities to algae and fish.

Copper is an essential nutrient for aquatic organisms but can also be toxic at elevated concentrations. Speciation plays a critical role in determining if copper is biologically available, toxic, or unavailable. In natural waters, copper and other trace metals will be complexed to both organic and inorganic ligands (Eriksen, Nowak & van Dam 2001) and therefore concentrations of free copper ion, the most biologically available form, within metres of the subsurface facilities are likely to be far less than the concentration at which toxic effects could occur.

Diuron and Irgarol 1051 are both herbicides that are highly toxic to phytoplankton and other aquatic plants and moderately toxic to animals. Both herbicides will decay in the presence of light; for diuron this occurs within a matter of days (Spectrum Laboratories 2004) while Irgarol 1051 has a much slower decay rate of about 80% after 15 weeks (Okamura et al. 2002). The concentrations of diuron and Irgarol 1051 likely to occur in surrounding waters as a consequence of leaching from antifouling paints are far less than the concentrations at which toxicity effects would occur.

Table 7-14: Summary of impact assessment and residual risk for ballast water (offshore)

Aspect	Activity	Potential impacts	Management controls and mitigating factors	Residual risk*		
				C†	L‡	RR§
Discharge of ballast water	Routine operations of offshore vessels and facilities.	Contamination of the marine environment by hydrocarbons.	Implementation of vetting procedures for condensate tankers, ensuring that ballast-water tanks are segregated from fuel and product tanks.	F (E1)	1	Low

* See Chapter 6 *Risk assessment methodology* for an explanation of the residual risk categories, codes, etc.
† C = consequence.
‡ L = likelihood.
§ RR = risk rating.

Table 7-15: Concentrations of active antifouling components in paints and their rate of leaching and toxicity to algae and fish

Additive	Minimum concentration (% w/w*)	Rate of leaching (µg/cm²·d⁻¹)	Toxicity to algae (µg/L)	Toxicity to fish (µg/L)
Copper oxide	10–50	1–101	1–8000 (Cu^{2+})	10–10 200 (Cu^{2+})
Copper thiocyanate	5–25	1–101	1–8000 (Cu^{2+})	10–10 200 (Cu^{2+})
Diuron	1–10	0.1–2.5	5–120†	8500–25 000
Irgarol 1051	0.1–5.0	2–16	1.4–2.4	400–2900
Zinc pyrithione	2	2.3–18‡	28‡	5–9§, 0.3–400‡

Source: Plymouth Marine Laboratory 2000.
* percentage weight for weight.
† US EPA 2010.
‡ DEFRA 2003.
§ Goka 1999; Okamura et al. 2002.

Both Irgarol 1051 and diuron will adsorb to suspended solids and have the potential to be sedimented. Once in sediments, the decay rates of both chemicals proceed at much slower rates, even under aerobic conditions (Okamura et al. 2000). There is therefore potential for these chemicals to be deposited on the seabed where they would remain in the sediments for months before degradation through chemical and biological mechanisms. However the quantity of diuron or Irgarol 1051 from antifouling leachate being sedimented would be extremely low and the rate of degradation, although low, would exceed the rate of sedimentation and thereby prevent concentrations from reaching levels sufficient to cause detectable environmental effects.

Zinc pyrithione is an effective microbicide widely used in antifungal and antibacterial formulations, including shampoos. It degrades rapidly in the water column by both abiotic and biotic pathways with a reported half-life in sea water of less than four minutes (DEFRA 2003). The products of pyrithione degradation are orders of magnitude less toxic than the parent compound (Turley et al. 2000).

In accordance with the requirements of the International Convention on the Control of Harmful Anti-fouling Systems on Ships (IMO 2001) and the *Protection of the Sea (Harmful Anti-fouling Systems) Act 2006* (Cwlth), no antifouling paints containing TBT compounds will be applied to vessels or equipment in the offshore development area.

The impact of antifouling leachate associated with Project vessels or equipment is predicted to be highly localised and negligible in the overall context of the offshore marine environment.

Management of antifouling leachate

Antifouling paints or methods with the least potential for environmental harm will be selected for use on subsea infrastructure, subject to meeting operational requirements.

Antifouling paints containing TBT compounds will not be used on any Project vessel, the pipelay barge or on any equipment in conformity with the requirements of the International Maritime Organization (IMO) and Australian law.

Residual risk

A summary of the potential impacts, management controls, and residual risk for antifouling leachate is presented in Table 7-16. After implementation of these controls, impacts from antifouling leachate are considered to present a “low” risk, with localised and low-scale effects on the surrounding marine environment.

7.2.4 Accidental hydrocarbon spills

Hydrocarbon characterisation

Hydrocarbons in oil and gas fields usually comprise hundreds of chemical substances. The relative balance of the constituent substances influences both the chemical and physical properties of the mixture, which in turn affect the potential for environmental impact on marine biota (Connell 1995).

The main physical properties that affect the behaviour of oil spilled at sea are its specific gravity in relation to water, its viscosity, its pour point and its volatility. Diesel fuel, for example, has a specific gravity of 0.84–0.88 and low viscosity and is therefore categorised as a light persistent oil.

Table 7-16: Summary of impact assessment and residual risk for antifouling leachate (offshore)

Aspect	Activity	Potential impacts	Management controls and mitigating factors	Residual risk*		
				C†	L‡	RR§
Antifouling leachate	Routine operation of support vessels, pipelay barge and subsea structures.	Toxic effects on marine biota from leached copper and biocide chemicals.	Leachates will be diluted rapidly in the strong-current, deep-water offshore environment. Antifouling paints or methods with the least potential for environmental harm will be used on subsea infrastructure, subject to operational requirements. Antifouling paints containing TBT compounds will not be used on any Project vessels or equipment.	F (B3)	6	Low

* See Chapter 6 *Risk assessment methodology* for an explanation of the residual risk categories, codes, etc.

† C = consequence.

‡ L = likelihood.

§ RR = risk rating.

Bunker fuel oils are often a mix of heavy residual fuel oils and marine diesel, with pour points in the range of 15–24 °C making them very viscous or even solid if released to sea.

When an oil spill occurs at sea, the compositions of hydrocarbon mixtures alter as the different chemicals undergo physical and chemical changes known as "weathering". Although the individual processes that bring about these changes act simultaneously, their relative importance during the lifetime of an oil slick varies as described below:

- *Spreading* is one of the most significant processes during the early stages of a spill. The main driving force behind the initial spreading process is the size of the spill. A large instantaneous spill will therefore spread more rapidly than a slow discharge of the same volume. Gravity-assisted spreading is quickly replaced by surface-tension effects. During these early stages the oil spreads as a coherent slick and the rate is influenced by the viscosity of the oil. Low-viscosity oils, such as condensate, spread quickly. Spreading is rarely uniform and there can be large variations in oil thickness in a slick.
- *Evaporation* occurs when the oil comes into contact with air and the more volatile compounds vaporise into the atmosphere. The initial spreading rate of the oil affects this process since the larger the surface area, the faster the light components will evaporate. Rough seas, high wind speeds and warm temperatures will also increase the rate of evaporation. Spills of condensate and refined products such as kerosene and gasoline may evaporate completely within a few hours and light crudes can lose up to 40% during the first day. In contrast, heavy crudes and fuel oils undergo little, if any, evaporation. Any residue of oil remaining after evaporation will have an increased density and viscosity, which affects further weathering processes and the choice of clean-up techniques.
- *Dispersion* is the break-up of the oil slick into droplets with a range of sizes through the action of waves and turbulence at the sea surface. Some droplets remain in suspension while the larger ones rise back to the surface, behind the advancing slick, where they may either coalesce with other droplets to re-form a slick or spread out in a very thin film. Droplets small enough to remain in suspension become mixed into the water column and the increased surface area presented by this dispersed oil can promote the rate of assimilation by other processes such as biodegradation and sedimentation.
- *Emulsification* is the absorption of water by the oil, forming a water-in-oil emulsion. Emulsions are often extremely viscous and, as a result, the other processes that would cause the oil to dissipate are retarded. In moderate to rough sea conditions, most oils rapidly form emulsions, the stability of which is dependent on the concentration of asphaltenes.
- *Dissolution* is the complete integration of oil into the water column. The solubility of hydrocarbons depends on their molecular structure and mass; as a general rule, solubility in water decreases as mass increases. The heavy components of crude oil are virtually insoluble in sea water whereas lighter compounds, particularly aromatic hydrocarbons such as benzene and toluene, are slightly soluble. However these compounds are also the most volatile and so are lost very rapidly by evaporation, typically 10 to 100 times faster than by dissolution. Concentrations of dissolved hydrocarbons thus rarely exceed one part per million and dissolution does not make a significant contribution to the removal of oil from the sea surface.
- *Oxidation* is a reaction with oxygen either to disassemble into soluble products or to form persistent tars. Many of these oxidation reactions are promoted by sunlight, and although they occur throughout the lifetime of a slick, the effect on the overall dissipation is minor in relation to other weathering processes. Under intense sunlight thin films break down at rates of no more than 0.1% per day. The final products of oil oxidation (hydroperoxides, phenols, carboxyl acids, ketones, aldehydes and others) are usually more soluble in water.
- *Biodegradation* is the degradation of hydrocarbons by marine micro-organisms. Sea water contains a range of bacteria, moulds and yeasts that can utilise oil as a source of carbon and energy. Such organisms are distributed widely throughout the world's oceans. There are about 100 species of bacteria and fungus capable of using oil products for their growth. The main factors affecting the rate of biodegradation are temperature and the availability of oxygen and nutrients, principally compounds of nitrogen and phosphorus. Each type of micro-organism tends to degrade a specific group of hydrocarbons and while a range of bacteria are capable of degrading most of the wide variety of compounds in crude oil, some components are resistant to attack.

Although spilt oil is eventually weathered and assimilated by the marine environment, the time involved depends upon variables such as the amount of oil spilled, its initial physical and chemical characteristics, the prevailing climatic and sea conditions, and whether the oil remains at sea or is washed ashore.

Properties of Ichthys Field condensate

Condensates can be dispersed into the water column, but are generally rapidly lost from the sea surface by evaporative weathering. The speed and extent of weathering in sea water is influenced by salinity, wind and wave energy, air and water temperature as well as condensate composition. In order to predict the fate of condensate released during an accidental spill at the offshore development area, weathering processes were simulated by APASA (2009b) using numerical modelling. The full technical report is provided in Appendix 7 to this Draft EIS.

Ichthys Field condensate is a light oil (API[2] gravity 58.7; density 744 kg/m³) with a low viscosity of 0.754 cP[3] and a relatively low proportion of aromatic hydrocarbons (3.1%). Simulations of oil spills at the water surface indicate that a high proportion of the oil (70–80%) would evaporate within the first day of release. Evaporation would then slow, leaving a non-volatile residual (*c*.15%) that would resist evaporation (Figure 7-4).

For pressurised releases at the seabed, the condensate would be atomised into droplets of variable size by the gas escaping under pressure from the offshore infrastructure. Smaller droplets would rise more slowly than larger droplets and hence the supply of condensate to the surface would be extended, increasing the duration of the weathering period. Simulations of a subsea condensate release at the Ichthys Field show that a relatively high proportion of the mass

2 American Petroleum Institute (API) gravity is a measure of how heavy or light a petroleum liquid is in comparison with water.

3 The centipoise (cP) is a unit of dynamic viscosity in the centimetre-gram-second system. It is equal to 1 millipascal second (mPa·s) in the International System of Units (SI).

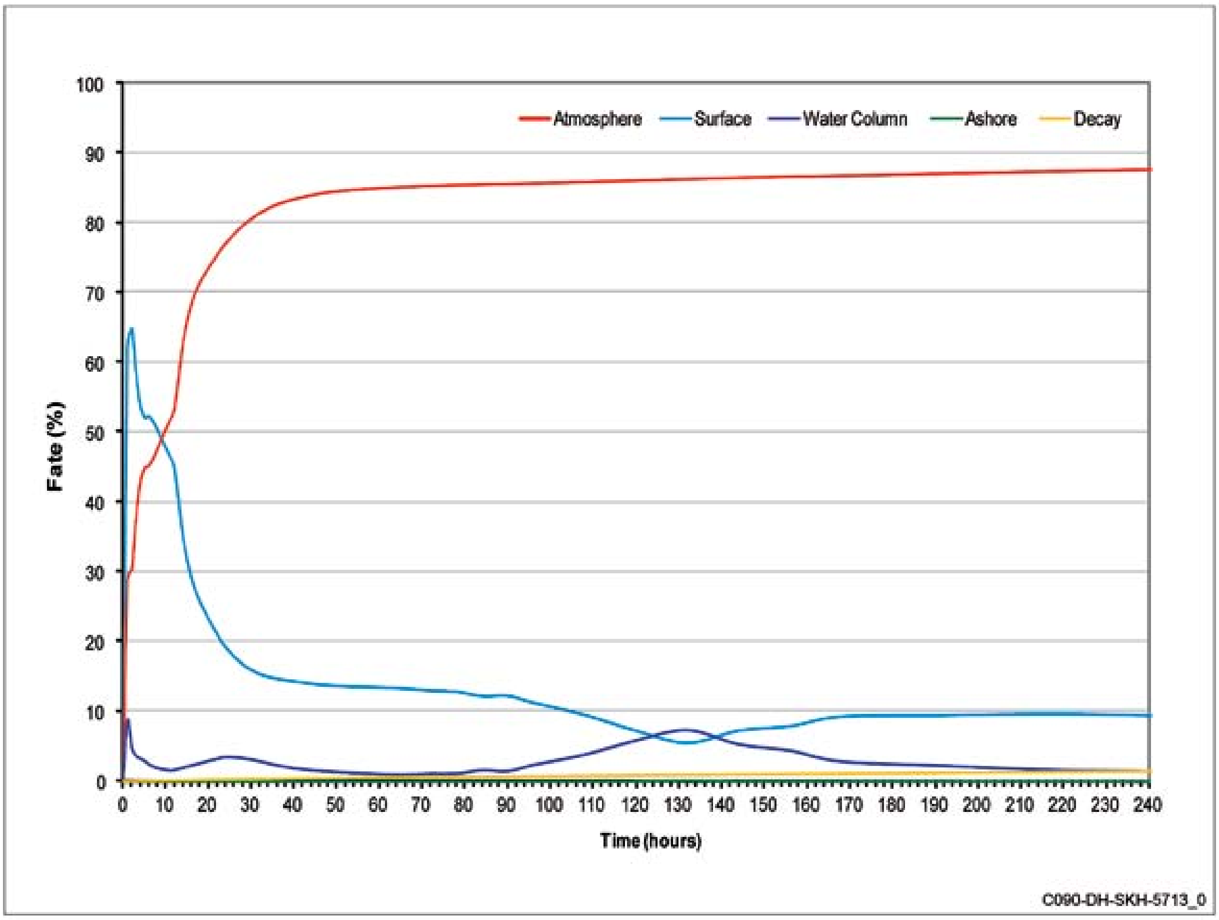

Figure 7-4: Predicted weathering and fates of a surface condensate release from the Ichthys Field

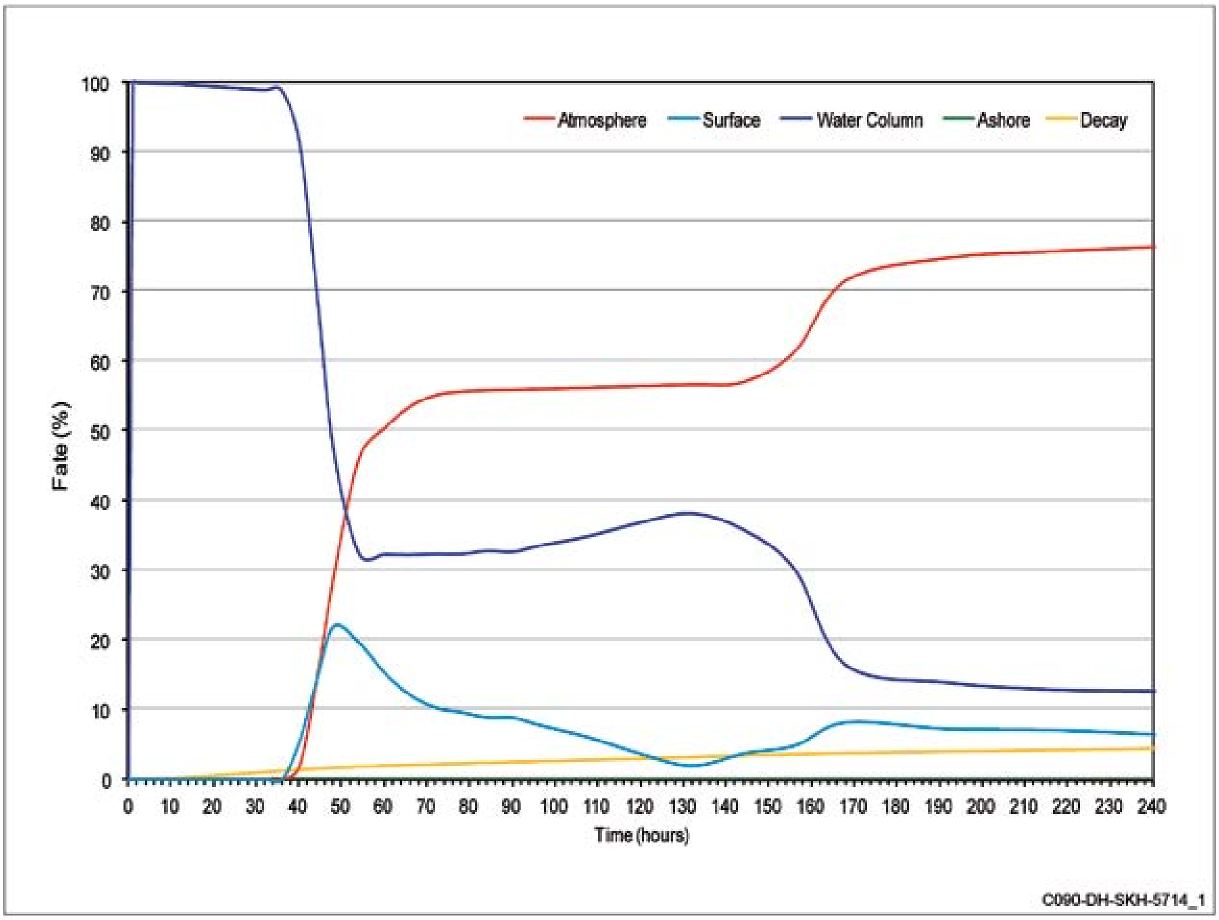

Figure 7-5: Predicted weathering and fates of a subsea condensate release from the Ichthys Field

remained entrained for up to 4 days and that the volatile components took up to 7 days to evaporate (Figure 7-5). About 40% of the mass was predicted to remain in the water column as fine droplets after this period.

Properties of diesel

Diesel fuels can be dispersed into the water column but, like condensates, are rapidly lost from the sea surface in most conditions prior to dispersion. For the purposes of predictive modelling of the weathering processes, diesel oil was characterised using the formulation of a commercial fuel and at a similar temperature to ambient conditions at the Browse Basin. This formulation has an initial API gravity of 37.6 (829.1 kg/m^3) and a viscosity of 4 cP (APASA 2009b).

Diesel is a mixture of volatile and semi-persistent hydrocarbons, with approximately 60–75% by mass predicted to evaporate over the first day or two depending upon the prevailing weather conditions. The remainder would not readily evaporate and the heavier components would tend to entrain as oil droplets into the upper water column in the presence of waves. This oil is not dissolved and can refloat to the surface if wave energies abate, and could be transported by near-surface currents (APASA 2009b).

Likelihood of spill occurrence

Accurate predictions of the source and frequency of hydrocarbon releases from oil and gas operations can be problematic. The usual method of predicting the frequency of an event occurring (known in oil-spill planning as the "primary risk") is to consider the historical rate of occurrence worldwide and then extrapolate a similar rate into the future. The majority of these data sources are based on incident history for North Sea and European operations, where there are a number of large facilities and supporting infrastructure (e.g. pipelines and support vessels). This creates more chances for accidents involving third-party vessels (e.g. vessel collisions or anchor damage to pipelines and flowlines). The Australian offshore oil & gas industry has a relatively good performance record, and often operates in remote areas that are distant from heavy shipping traffic. Extrapolating historical data from the North Sea or Europe to predict the likelihood of spills from offshore Australian operations is therefore likely to provide particularly conservative estimates for some types of incidents (ERS 2009).

The infrastructure and activities to be undertaken in the offshore development area present a range of scenarios where a loss of containment of hydrocarbons could occur. An assessment of the likelihood of oil spills occurring was undertaken by Environmental Risk Solutions Pty Ltd (ERS) using frequency data for previous similar incidents that have occurred in the oil & gas industry worldwide.

The likelihood of a spill occurring is expressed on an annual basis—that is, the number of times per year that an incident of that type could occur. This generally results in very small numbers (e.g. 1×10^{-4}), and the order of magnitude is considered the most important component. That is, events with a likelihood of 1×10^{-2} would be considered “likely” to occur, particularly for a project several decades in duration. Events with a likelihood of 1×10^{-7} are considered to have a very remote chance of occurring, even during the life of a long project.

Nine potential spill scenarios were identified for the offshore development area; these are described in Table 7-17, along with the calculated likelihood of these events occurring. The volumes and durations of these spills are indicative only, and are considered reasonable estimates of the types of accidental spills that could occur, given the management controls that will be in place for the Project. All scenarios are relatively fixed in their location (e.g. a subsea flowline rupture can only occur within the Ichthys Field), with the exception of a refuelling spill during construction of the gas pipeline. While a spill at an indicative location has been modelled (*c*.300 km west of Darwin), a spill of this nature could occur at any position along the offshore pipeline route. Accordingly oil spill contingency planning will account for the potential for refuelling spills along the entire length of the pipeline route. Of the scenarios considered, there are four with likelihoods greater than 1×10^{-2}, relating to refuelling of vessels with diesel fuel or loading condensate into export tanker vessels. The least likely spill scenarios are subsea well failures and ruptures of transfer lines or flowlines between the offshore facilities.

The subsea well failure scenarios (7 and 8) represent accidental spill events similar to the uncontrolled well failure that occurred in August 2009 at the Montara field in the Timor Sea. As shown in Table 7-17, the likelihood of this type of event occurring is very low. Extensive management controls apply to drilling and control of subsea wells, as described below under *Prevention and management of accidental hydrocarbon spills*.

Predictive spill modelling

In order to predict whether hydrocarbons released during the potential spill scenarios could reach sensitive environmental receptors around the offshore development area, spill-trajectory modelling was undertaken by APASA (see Appendix 7). Trajectory modelling was based on current data generated by the oceanic circulation model HYDROMAP, which simulates the influence of astronomical tides, wind stress and bottom friction on ocean currents. Further detail on the development and validation of the oceanic hydrodynamic model is provided in Appendix 5.

Numerical spill simulations were carried out using a three-dimensional model known as the Spill Impact Mapping and Assessment Program (SIMAP), which accounts for weathering processes such as evaporation and spreading, as well as for seasonal climate effects. Simulations were developed for wet-season (October–February), dry-season (May–July), and transitional (March–April and August–September) conditions.

The prevailing winds during the wet and dry seasons influence the direction of spill movement. Westerly winds during the wet season push spills to the east, towards the Kimberley coast, while the dry season is characterised by easterly winds that push spills west to the open ocean and in the direction of Scott Reef and Seringapatam Reef.

Because of the strong influence of offshore winds, simulated spill trajectories were found to be highly variable. For that reason, 200 simulations were completed per season and scenario combination (i.e. 600 per scenario and 4200 in total) for the assessment. Model outputs therefore do not show the area affected by one individual spill, but show the combination of these multiple spill simulations.

The extent of offshore spills was assessed down to a threshold level of 1 g/m^2 (1 µm thickness), which corresponds with a dull yellow film or sheen on the water surface. Summaries of the modelled outcomes for surface slicks are presented in figures 7-6 to 7-12 for each of the spill scenarios in Table 7-17. These outcomes assume that no management controls (i.e. spill responses) are applied and therefore present the worst-case scenarios for hydrocarbon spread into the marine environment.

The movement of entrained oil and dissolved aromatics from subsea spills have also been modelled as part of this study. In general, plumes were predicted to reduce in concentration to less than 1 ppb within 15 km of the release point. These plumes would not reach the islands or reefs in the vicinity of the offshore development area. Full results are provided in Appendix 7.

Table 7-17: Potential hydrocarbon spills in the offshore development area and the likelihood of their occurrence

Scenario number	Description	Location	Scenario	Likelihood* (per annum)
1	Subsea flowline rupture	Ichthys Field near CPF	A flowline rupture occurs on the seabed (up to 250 m depth) between a cluster of wells and the CPF, between isolation valves. This releases pressurised gas and 100 m^3 of atomised condensate over a one-hour period.	4.9×10^{-5}
2	CPF diesel fuel leak	CPF	Either a CPF diesel storage tank overflows to sea or a diesel supply ship accident occurs. This releases 50 m^3 of diesel to the sea surface instantaneously.	4.9×10^{-2}
3	CPF–FPSO condensate transfer line rupture	Midway between CPF and FPSO	A rupture occurs in the condensate transfer line from the CPF to the FPSO. This transfer line contains condensate, water, MEG, and gas. In the worst case, a full-bore rupture of a 12-inch internal diameter transfer line up to 10 km long would release 730 m^3 of condensate at the seabed somewhere between the CPF and FPSO location, at a depth of up to 250 m and for a duration of 12 hours.	1.5×10^{-4}
4	Ship collision at FPSO	FPSO	An offtake tanker or other large ship collides with the FPSO. This releases 1000 m^3 of condensate to the sea surface at the FPSO location over 12 hours. The 1000 m^3 represents the partial loss of a single cargo storage tank from an export ship or the FPSO as a result of the collision.	3.0×10^{-4}
5	FPSO condensate hose rupture	FPSO	A loading hose ruptures or a hose coupling fails when the FPSO is loading condensate into an offtake tanker. This releases 30 m^3 of condensate to the sea surface instantaneously.	4.9×10^{-2}
6	Refuelling spill during construction	Ichthys Field near CPF	A spill occurs during the refuelling of a construction barge near the CPF and FPSO locations. This releases 2.5 m^3 of diesel to the sea surface instantaneously.	4.9×10^{-2}
6a	Refuelling spill during construction (pipeline)	Along gas export pipeline route, *c.*300 km west of Darwin	A spill occurs during the refuelling of a pipeline construction barge in the Timor Sea *c.*300 km west of Darwin. This releases 2.5 m^3 of diesel to the sea surface instantaneously.	4.9×10^{-2}
7	Subsea well failure during development drilling	Ichthys Field	Control of a subsea well is lost during the initial drilling operation inside the retention lease at the Ichthys Field. This causes an uncontrolled release of gas and condensate at the seabed at a flow rate in the order of 4000 barrels of condensate per day.	9.2×10^{-5} per well drilled
8	Subsea well failure during production	Ichthys Field	Control of a subsea well is lost during the production phase inside the retention lease at the Ichthys Field. This causes an uncontrolled release of gas and condensate at the seabed at a flow rate in the order of 4000 barrels of condensate per day.	5.0×10^{-6}

Note: The scenario numbers here are continued in Table 7-35, which contains the primary risk assessment for the nearshore development area.

* Primary risk (ERS 2009).

Spill modelling has not been included for the longer-term subsea well failure scenarios because of their very low likelihood of occurrence (Table 7-17). If a subsea well failure were to occur, spill-trajectory modelling would be undertaken at that time for current weather conditions and spill flow rates, to guide response efforts as part of the Project's oil-spill contingency plan.

Scenario 1—Subsea flowline rupture

Simulations of this scenario indicated that the condensate would rise towards the surface over time. The larger droplets would surface relatively quickly (less than 1 hour), generating thin slicks and sheens close to the release location, while the smaller droplets would rise to the surface more slowly and would drift with the prevailing currents.

During wet-season conditions, slicks would drift east and there is a slight chance (<10% probability) that surface oil could reach the waters around Browse Island and even some areas of the Kimberley coast (Figure 7-6). The probability of shoreline exposure above the 1 g/m^2 threshold level is 9%, with a maximum of 3 m^3 of oil (3% of the initial spill volume) predicted to reach the shore.

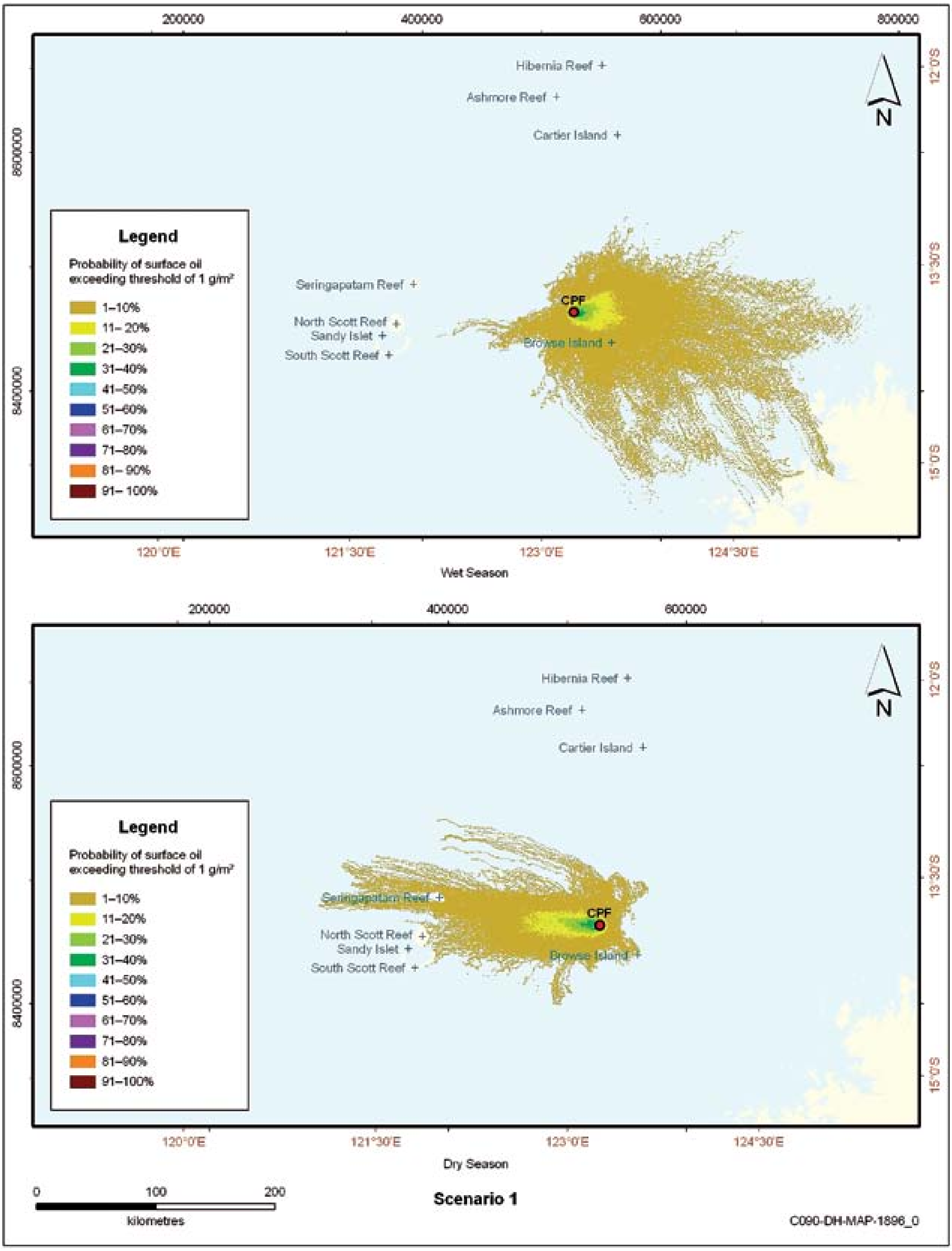

Figure 7-6: Scenario 1—subsea flowline rupture: simulated oil-spill trajectories for 100 m³ of condensate

During the dry season slicks would drift west towards Seringapatam Reef and North Scott Reef. However, because of the distance to these reefs (*c.*130 km) and the highly evaporative nature of the condensate, only a small percentage (≤1% or 1 m³) of the spill volume is expected to arrive at shore, with a 6% probability. Spills would take around 145 hours to reach any shoreline under these conditions (APASA 2009b).

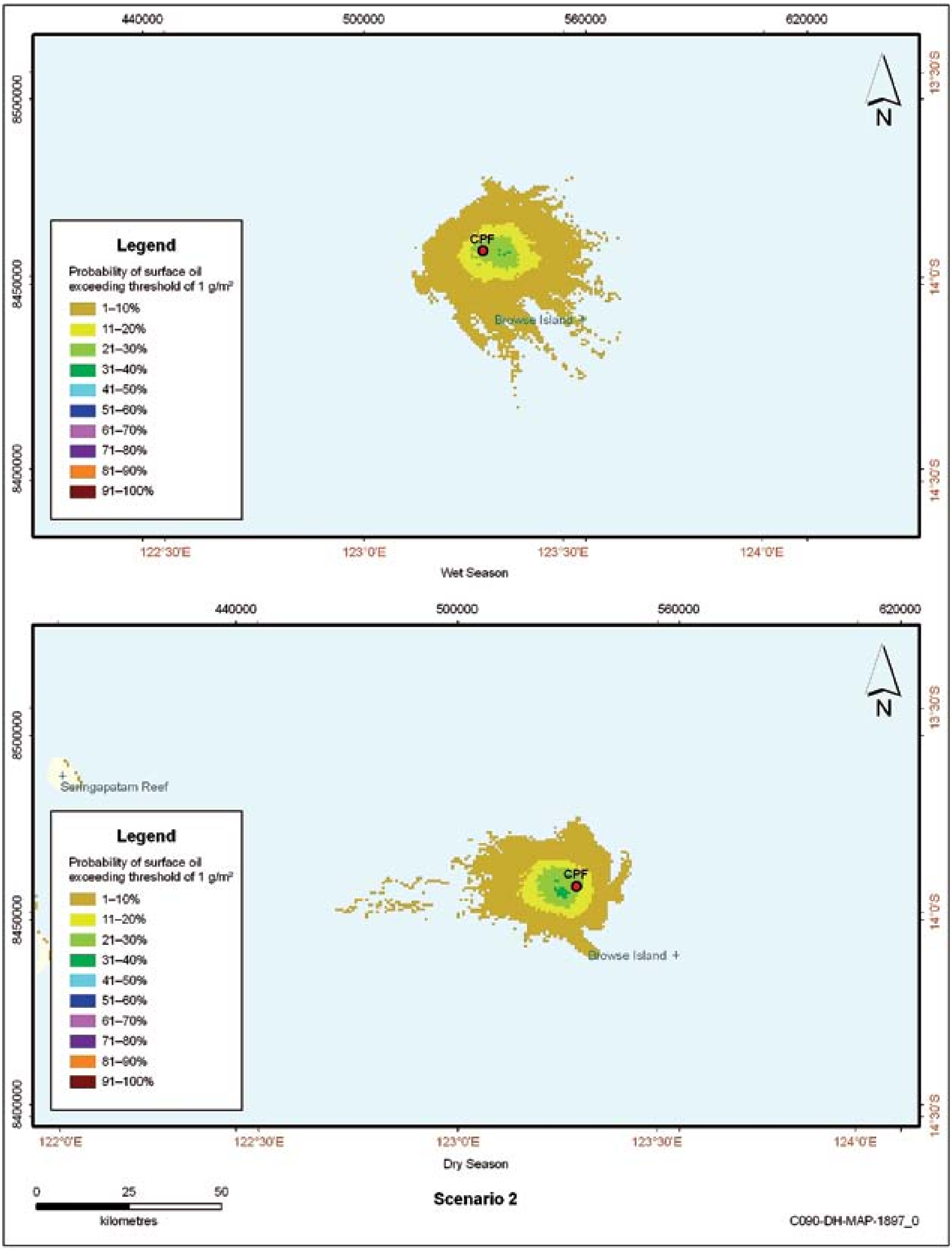

Figure 7-7: Scenario 2—CPF diesel fuel leak: simulated oil-spill trajectories for 50 m³ of diesel

Scenario 2—CPF diesel fuel leak

Spills for this scenario would travel relatively short distances, with very little probability (<1%) of exposure to shorelines at Browse Island during any season. Wet- and dry-season simulations of this scenario are presented in Figure 7-7 (APASA 2009b). The long distance to shorelines is a mitigating factor that reduces the potential environmental impacts of this spill scenario.

Scenario 3—CPF–FPSO condensate transfer line rupture

Simulations of this scenario indicate that some condensate would surface rapidly (seconds to minutes) through entrainment by the rapidly rising gas bubbles. A larger proportion would form a subsurface plume of entrained droplets that would migrate with the prevailing currents while continuing to surface. The condensate would undergo rapid loss of its most volatile compounds over the first 3–4 hours of surfacing. Evaporation rates would then decrease over the next 20 hours as the condensate weathers to leave less volatile components (APASA 2009b).

In wet-season conditions surface slicks would drift eastward, with the potential for low concentrations of weathered condensate to reach Browse Island or the mainland (Figure 7-8). The highest load of residual condensate predicted for the shoreline of Browse Island was 2.5% of the original spill volume (18 m^3).

Browse Island is not predicted to be exposed to this spill in dry-season conditions, with surface slicks consistently predicted to drift towards the west (Figure 7-8). The Scott Reef group could be exposed at some point (22% probability), with first shoreline exposure within 127 hours of the initial release. The highest expected load received at a shoreline is estimated to be 2.8% (20 m^3) of the initial spill volume (APASA 2009b).

Scenario 4—Ship collision at FPSO

This surface condensate spill will initially form a slick that will spread under the influence of gravity and surface tension as well as of prevailing currents and wind. Evaporation of volatile components would be the primary weathering process in this scenario because of the large surface area exposed to air.

Wind conditions sufficiently strong to generate breaking waves would increase the proportion of the condensate that would entrain over time. Entrained oil will resurface when weather conditions and seas return to a calm state. The spill model accounted for these processes in calculating the fate of slicks under varying conditions.

During wet-season conditions the surface slick caused by the spill would spread mainly eastwards (Figure 7-9), with a 31.5% probability of condensate reaching some point of the shoreline on Browse Island after 16 hours. There is also a chance (2% probability) of exposure of mainland shores under these conditions. The maximum predicted volume of oil arriving at shore is 5.7% of the initial spill volume, or 57 m^3 (APASA 2009b).

In dry-season conditions, the spill would move to the west (Figure 7-9) with a 38% probability of shoreline exposure at some point on Scott Reef or Seringapatam Reef after 112 hours. A maximum of 8% of the initial spill volume (80 m^3) could reach shores under these conditions (APASA 2009b).

Scenario 5—FPSO condensate hose rupture

This type of spill would remain in a localised area, with surface slicks decreasing to below the threshold concentration within 30 km of the FPSO because of a combination of spreading, evaporation and entrainment (APASA 2009b). Exposure of shorelines at nearby islands and reefs is not expected. The predicted movement of this spill in wet- and dry-season conditions is presented in Figure 7-10.

Scenario 6—Refuelling spill during construction (at the Ichthys Field)

This spill involves a relatively small volume of diesel fuel (2.5 m^3) and is expected to form a localised slick that would not cause exposure to islands and reefs in the area. The predicted movement of this spill in wet- and dry-season conditions is presented in Figure 7-11. There may be patches of diesel visible at the surface within 15 km of the release site because of the relatively high evaporation and spreading rates for diesel oil in combination with the wind and current conditions. The spill would disperse to a silvery sheen within one or two days (APASA 2009b).

Scenario 6a—Refuelling spill during construction (along the pipeline route)

In similar fashion to Scenario 6, this spill involves a relatively small volume of diesel fuel (2.5 m^3) and would form only a localised surface slick. This would spread and evaporate very quickly upon release and would rapidly diminish below threshold limits. The predicted movement of this spill in wet- and dry-season conditions is presented in Figure 7-12. No exposure to surface oil would be expected within a 5-km radius of the release site (APASA 2009b). Shorelines and submerged reefs along the greater part of the pipeline route would remain unaffected by this type of spill from construction vessels.

Likelihood of spills affecting shorelines

The likelihood of a hydrocarbon spill reaching a particular area of environmental concern, such as a sensitive shoreline habitat is known as the "secondary risk". This is derived by multiplying the likelihood of the spill occurring (the primary risk) by the probability of the spill moving towards sensitive areas, as shown by spill-trajectory modelling.

Large hydrocarbon spills from the offshore development area (i.e. scenarios 1, 3 and 4, as well as longer-term well-failure scenarios 7 and 8) are predicted to reach some point on the shorelines of Browse Island, Seringapatam Reef, Scott Reef and the Western Australian Kimberley coast. Spills from Scenario 2 are predicted to have a very low probability of reaching Browse Island during the wet season only. Spills from refuelling along the greater part of the pipeline route (e.g. Scenario 6a) will not affect shorelines.

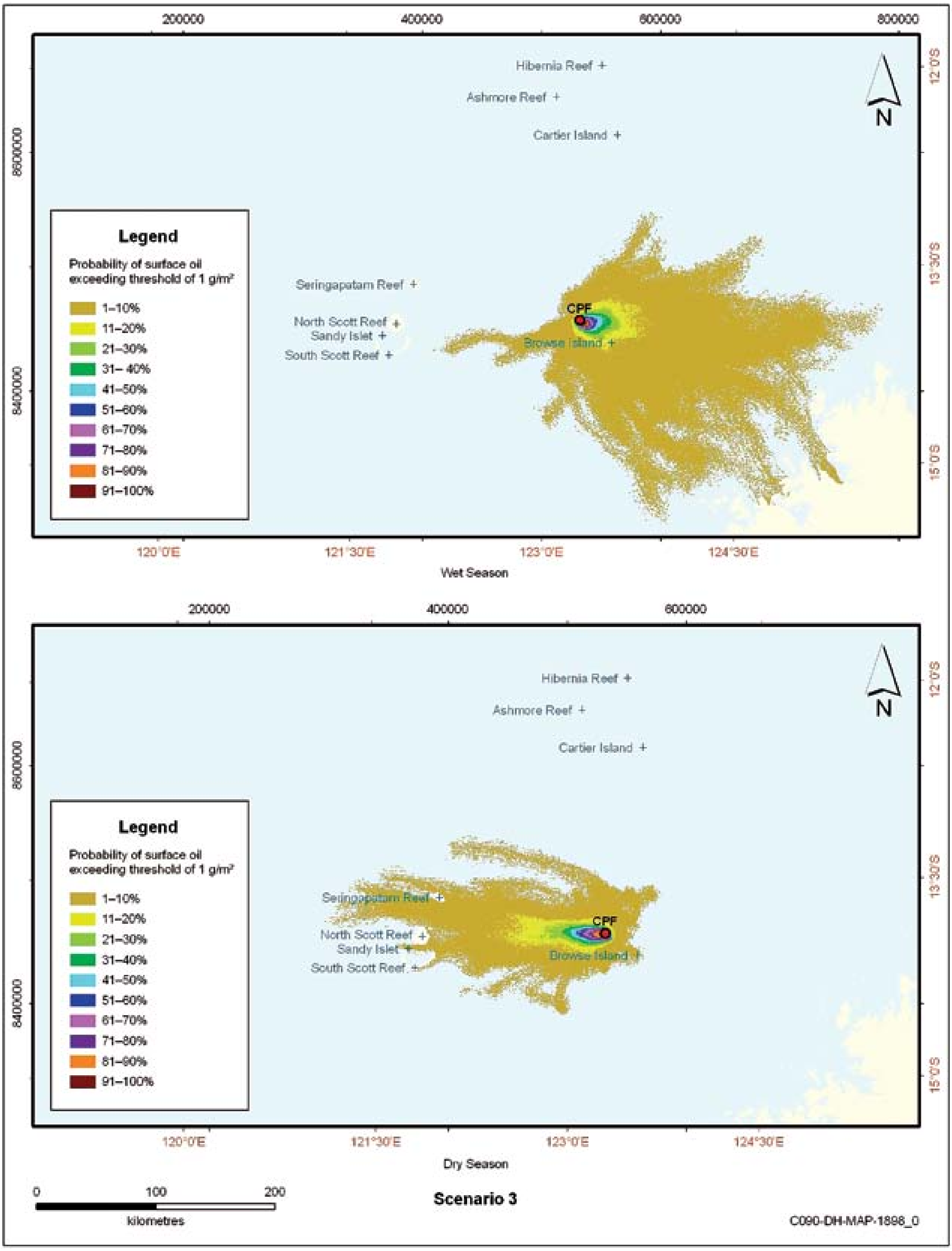

Figure 7-8: Scenario 3: CPF–FPSO condensate transfer line rupture—simulated oil-spill trajectories for 730 m³ of condensate

The remaining smaller-spill scenarios (5 and 6) are not predicted to reach any shoreline at all.

The secondary risks of impacts to sensitive marine habitats as a result of spills from the offshore development area are provided in Table 7-18.

These levels of risk (or "frequency" of an oil pollution event occurring) are considered to be very low and would be further reduced by the spill prevention and response controls to be implemented at the offshore development area.

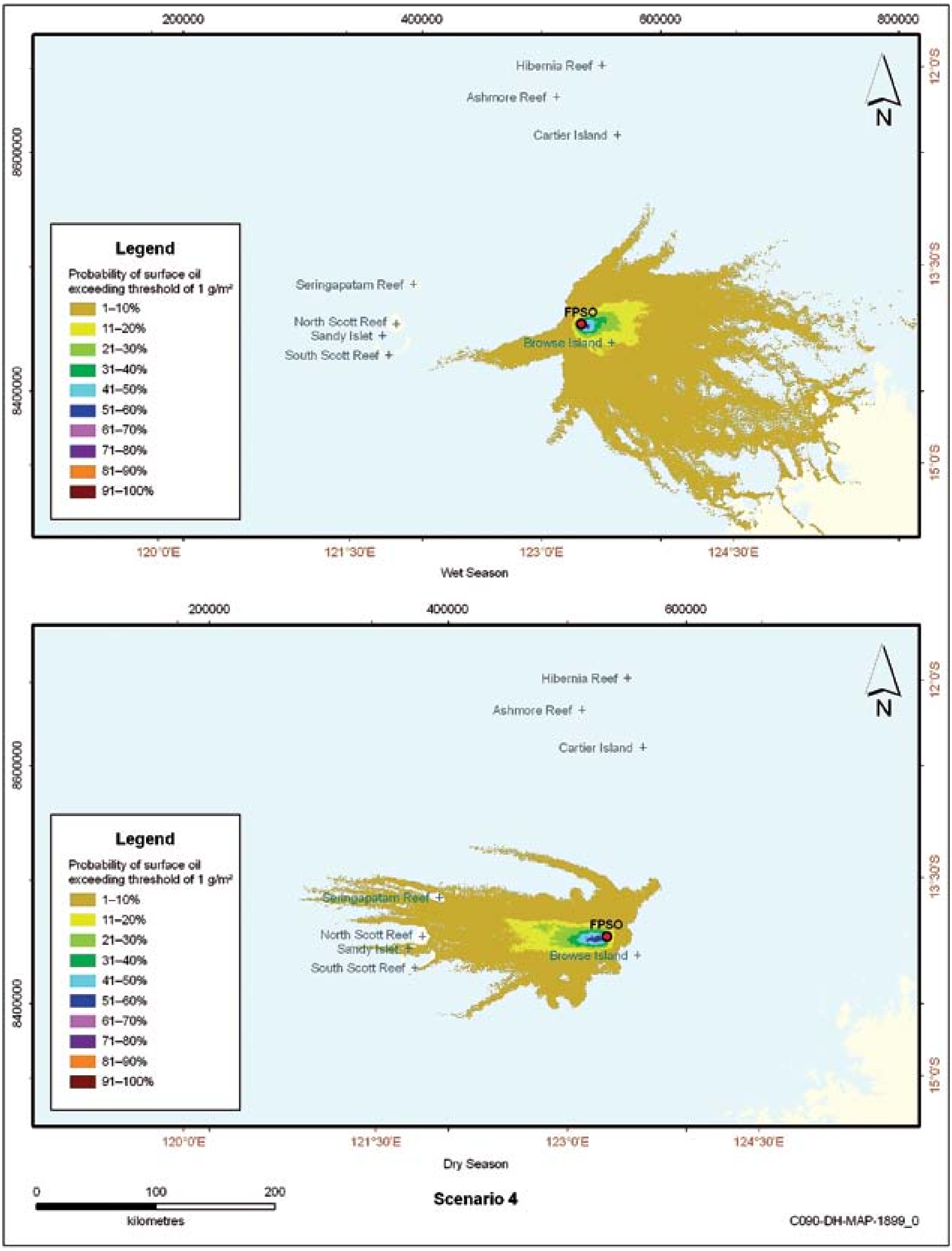

Figure 7-9: Scenario 4: ship collision at FPSO—simulated oil-spill trajectories for 1000 m³ of condensate

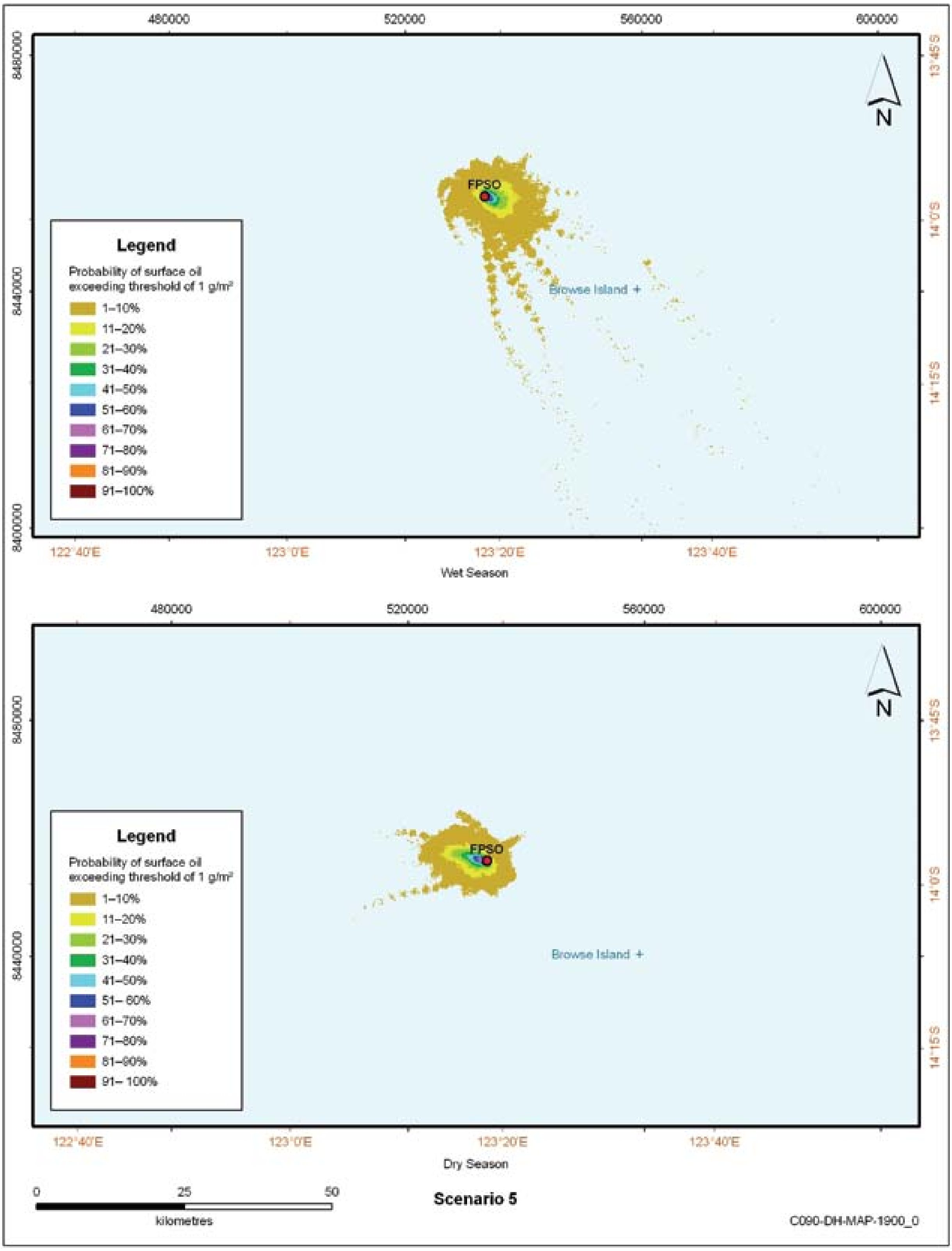

Figure 7-10: Scenario 5: FPSO condensate hose rupture—simulated oil-spill trajectories for 30 m³ of condensate

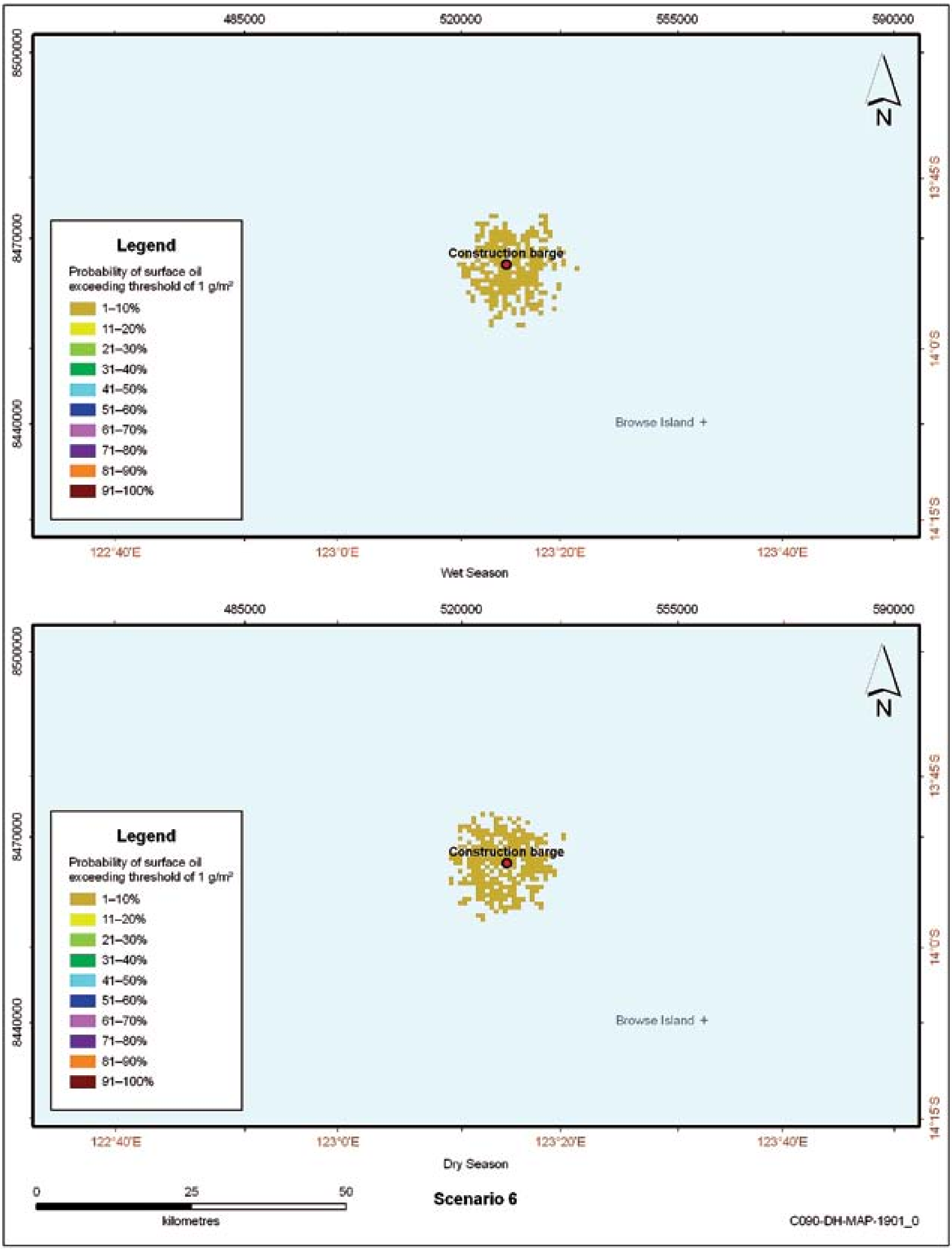

Figure 7-11: Scenario 6: refuelling spill during construction at the Ichthys Field—simulated oil-spill trajectories for 2.5 m³ of diesel

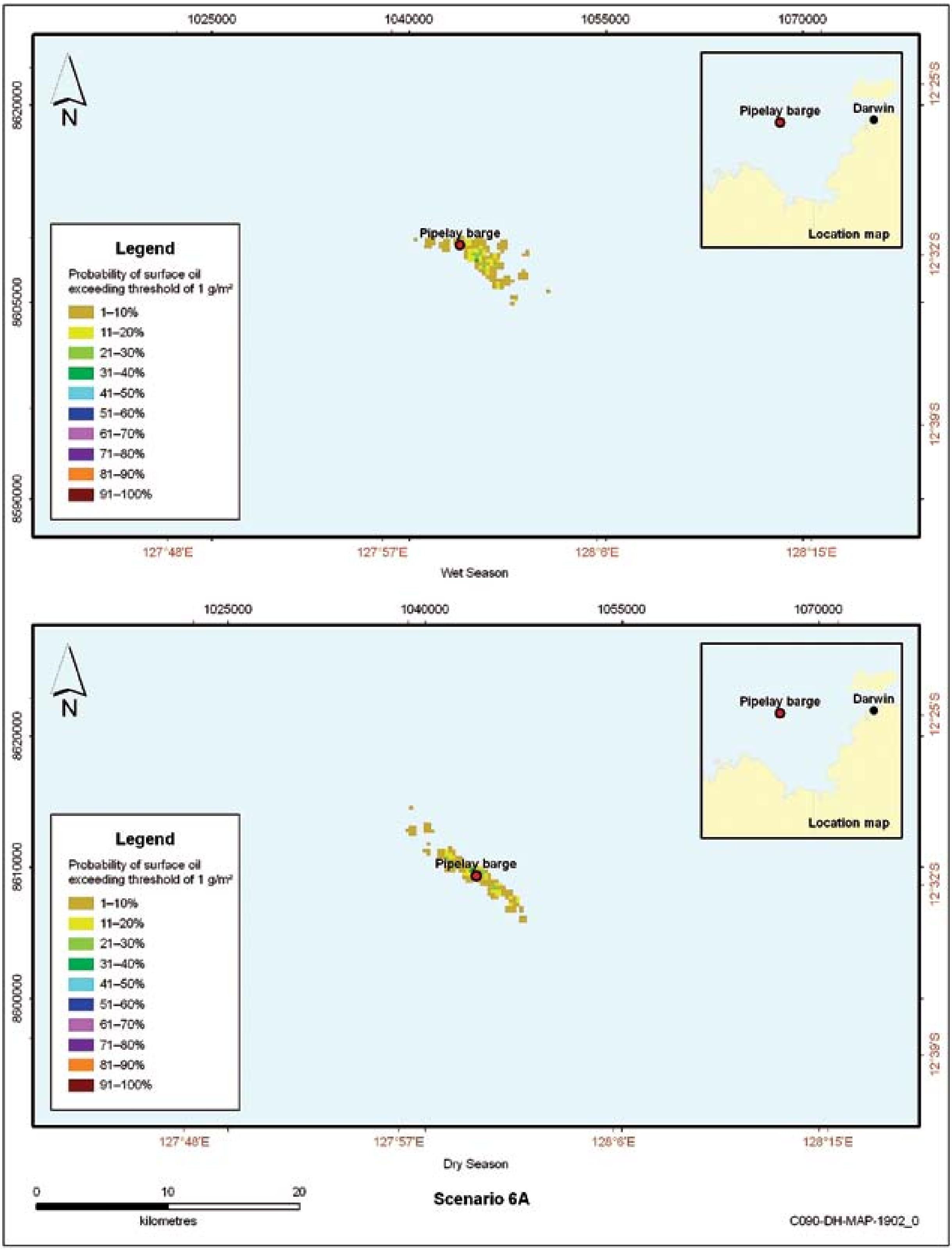

Figure 7-12: Scenario 6a: refuelling spill during construction along the pipeline route—simulated oil-spill trajectories for 2.5 m³ of diesel

Table 7-18: Likelihood of hydrocarbon spills from the offshore development area reaching sensitive shorelines

Scenario	Name	Primary risk (per year)	Secondary risk (per year)	
			Wet season	Dry season
1	Subsea flowline rupture	4.9×10^{-5}	1.84×10^{-6}	4.90×10^{-7}
2	CPF diesel fuel leak	4.9×10^{-2}	4.9×10^{-4}	None
3	CPF–FPSO condensate transfer line rupture	1.5×10^{-4}	2.57×10^{-5}	5.79×10^{-6}
4	Ship collision at FPSO	3.0×10^{-4}	4.50×10^{-5}	1.90×10^{-5}
5	FPSO condensate hose rupture	4.9×10^{-2}	None	None
6	Refuelling spill during construction (field)	4.9×10^{-2}	None	None
6a	Refuelling spill during construction (pipeline)	4.9×10^{-2}	None	None
7	Subsea well failure during development drilling	9.2×10^{-5} per well drilled	9.2×10^{-5} per well drilled	1.8×10^{-5} per well drilled
8	Subsea well failure during production	5.0×10^{-6}	5.0×10^{-6}	1.0×10^{-6}

Deck drainage

Discharges of deck drainage, both directly overboard and from oily-water separators, are likely to contain low volumes of contaminants that will disperse quickly into the marine environment without having toxic effects on the local marine biota. In the context of the offshore marine environment at the Ichthys Field and along the pipeline route, this liquid discharge is considered to pose negligible potential impact, particularly given the strong current regimes and water depths in the area.

Potential impacts of hydrocarbon spills

Research undertaken to evaluate the effect of oil on marine biota can be broadly separated into three main types:

- controlled laboratory studies to determine the acute, and less commonly the chronic, toxicity of specific hydrocarbon compounds (this type of study is by far the most common)
- controlled experiments that have been carried out in field or artificial field situations to study the effect on aspects of the marine environment
- opportunistic studies of accidental oil spills.

In addition to these relatively established fields of study there are also emerging fields of study into the potential endocrine disruptor effects of hydrocarbons and the development of biophysical models to predict impacts across a range of trophic levels (e.g. Gin et al. 2001). As yet there are very few data from which conclusions can be drawn regarding hydrocarbons as endocrine disruptor chemicals in the marine environment.

Several researchers have put forward models that integrate physico-chemical processes with biological uptake mechanisms to predict impacts on the marine environment (Volkman et al. 1994). These models, however, were considered to be of limited assistance to this risk assessment because they are either restricted to predicting the effect on a single key organism group, usually fisheries-biased, or they are still in their formative stages. Consequently biophysical models have not been used in this risk assessment.

Sources of effect

Hydrocarbons spilled to the marine environment have the potential to cause significant threats to marine life. Direct mortality can occur through toxic effects, physical coating and even asphyxiation. Sublethal effects can occur through the disruption of physiological or behavioural processes. Community-level changes can occur through mechanisms such as changes to habitat characteristics or the alteration of species interactions. Each of these sources of effect is summarised briefly in the following sections and considered in the assessment of impact to the identified sensitive community types.

Descriptions of toxicity refer to the inherent potential of a material to cause adverse effects in a living organism. The two basic types of toxicity are acute and chronic. Acute responses have a sudden onset after or during relatively high exposure that is often of short duration (typically 4–7 days). The end point can be lethal or non-lethal. A chronic response, involving end points that are realised over periods of several weeks to years, may be caused by relatively low exposures occurring over a long time. A chronic toxic response is usually characterised by slow toxic progress and long continuance.

As described in Section 7.2.3 *Liquid discharges*, it is important to distinguish between the "exposure" and the "dose" of a toxic substance received by an organism. Exposure relates to the amount or concentration of the substance in the surrounding environment, while the dose is the actual amount of the toxic substance that enters the organism and is specifically associated with the toxic response.

A very large number of studies have been published describing the toxicities of crude oils and hydrocarbon compounds. The common theme in the findings of these is that the observed toxicity of crude and refined oils is primarily attributable to volatile and water-soluble aromatic hydrocarbons (benzenes, naphthalenes and phenanthrenes) and the polycyclic aromatic hydrocarbons of higher molecular weight.

The most toxic components in oil, although having the highest solubility in water, tend to be those that are lost most rapidly through evaporation when oil is spilled. Because of this, lethal concentrations of toxic components leading to large-scale mortalities of marine life are relatively rare, localised, and short-lived, and only likely to be associated with spills of light refined products or fresh crude. At particular risk are animals and plants living in areas of poor water exchange or where special conditions, such as the incorporation of fresh oil into stable sediments, cause high concentrations of the toxic components to persist for a longer period than normal.

The sublethal effects of hydrocarbons in impairing the ability of individual marine organisms to reproduce, grow, feed or perform other functions have been demonstrated experimentally by numerous controlled laboratory studies and a smaller number of controlled field studies. The interpretation of these laboratory results is somewhat problematic because of the difficulties associated with relating what effect the loss of a small portion of embryos and larvae would have on a species' population. Long-term mesocosm[4] experiments, which more closely approximate "real world" conditions, have demonstrated marked reduction in copepod populations after chronic exposure to concentrations as low as 15 µg/L oil in water. Oviatt et al. (1982) found that No. 2 fuel oil had a significant effect on phytoplankton and zooplankton community structure at concentrations as low as 100 µg/L. More recent studies investigating developmental effects have demonstrated adverse toxic effects on salmon and herring embryos and larvae from chronic exposure to concentrations of oil in water of 1 µg/L (Carls, Rice & Hose 1999).

The toxicity of the condensate solution to the bioluminescent marine bacterium *Vibrio fischeri* was assessed using a Microtox® assay, which determines the concentration of weathered condensate required to affect 50% of the bacteria population.

4 A "mesocosm" in this context is an enclosed experimental ecosystem in which the fate and effects of oil on individual organisms or populations can be studied and evaluated.

Microtox® is a standardised toxicity test system used as a primary screening test for toxicants over time. As shown in Table 7-19, condensate from the Ichthys Field can be considered moderately toxic to the bacterium during the first 24 hours of a spill to the marine environment and decreases to non-toxic during the second day and onwards (Geotechnical Services 2007b).

Table 7-19: Microtoxicity ratings obtained from weathering tests on Ichthys Field condensate using the bacterium *Vibrio fischeri*

Time (hours)	EC_{50}* (%)	Microtoxicity rating
1	43.3	Moderately toxic
2	73.5	Non-toxic
4	65.9	Non-toxic
8	58.7	Moderately toxic
24	51.3	Moderately toxic
48	63.9	Non-toxic
72	>100	Non-toxic
96	>100	Non-toxic

Source: Geotechnical Services 2007b.

* The notation EC_{50} stands for "effect concentration 50%". It is the concentration of a substance that results in 50% less growth, fecundity, germination, etc., in a population. In ecology it is used as a measure of a substance's ecotoxicity but, unlike the LC_{50} which measures lethality, the EC_{50} value measures sublethality—it demonstrates the adverse effects of a substance on a test organism such as changes in its behaviour or physiology. In the case of *Vibrio fischeri* the EC_{50} is measured as the concentration producing a 50% reduction in bioluminescence. The concentration is measured as a percentage of the water fraction.

In addition, the toxicity to marine biota of 1-hour and 24-hour weathered samples of Ichthys condensate have been assessed for five marine species: (larval) pink snapper (*Pagrus auratus*), rock oyster (*Saccostrea commercialis*), brown kelp (*Ecklonia radiata*), phytoplankton (*Isochrysis galbana*), and the marine bacterium *Vibrio fischeri* that is used in the Microtox® screening test. As shown in Table 7-20, pink snapper are relatively sensitive to the weathered condensate, tolerating only low concentrations in surrounding waters (e.g. 5.7% after 24 hours of weathering). The brown kelp was able to tolerate the condensate, with no observable effects, in both the 1-hour and 24-hour weathered solutions.

Toxicity testing undertaken by various organisations has identified diesel as being toxic to a variety of marine species. The typical range of reported toxic concentrations (LC_{50}, EC_{50} and IC_{50}[5]) varies from

5 The notation IC_{50} stands for "inhibition concentration 50%". The IC_{50} value is the concentration of a substance that causes an inhibition of growth of 50% in a population of a target species when compared with controls.

Table 7-20: Ecotoxicity of the water-accommodated fraction for 1-hour and 24-hour weathered Ichthys condensate

Test	Weathered	EC_{50}* (%)	EC_{10}† (%)	LOEC‡ (%)	NOEC§ (%)
Microtox screening test (*Vibrio fischeri*)	1 hour	31.5	0.5	6.25	<6.25
	24 hour	38.2	0.9	6.25	<6.25
Phytoplankton (*Isochrysis galbana*)	1 hour	>83.3	>83.3	>83.3	>83.3
	24 hour	>83.3	34.4	41.7	20.8
Brown kelp (*Ecklonia radiata*)	1 hour	>100	>100	>100	100
	24 hour	>100	>100	>100	100
Rock oyster (*Saccostrea commercialis*)#	1 hour	32.0	24.3	50	25
	24 hour	33.8	26.7	50	25
Pink snapper (*Pagrus auratus*) (larval)	1 hour	14.7	10.1	1.25	0.63
	24 hour	5.6	3.9	5	2.5

Source: Geotechnical Services 2007a.

Note: All concentrations are presented as a percentage of the water fraction.

* EC_{50} (%) = "effect concentration 50%"—the concentration that causes a 50% reduction in growth, fecundity or germination (not lethality) in the test population.

† EC_{10} (%) = "effect concentration 10%"—the concentration that causes a 10% reduction in growth, fecundity or germination (not lethality) in the test population.

‡ LOEC (%) = "lowest-observable-effect concentration"—the lowest concentration that causes an observable effect in the test population.

§ NOEC (%) = "no-observable-effect concentration"—the highest concentration at which there is no observable effect in the test population.

\# Also known as *Saccostrea glomerata*.

approximately 3 to 80 mg/L. Diesel fuel appears to retain its toxicity during weathering because of the slow loss of light ends. In addition, the additives used to improve certain properties of diesel (e.g. ignition quality and cold flow improvers) contribute to its toxicity.

Effects on marine biota

Plankton

As a consequence of their presence close to the water surface, plankton may be exposed to spilt oil, especially in high-energy seas where the vertical dispersion of oil through the water column would be enhanced. Usually the eggs, larval and juvenile stages of plankton are more susceptible to oil pollution than the adults (Harrison 1999). Measures of the toxicity of the water-accommodated fraction of Ichthys condensate to phytoplankton indicate that the range for inhibiting 50% of the population is in the order of 6.5–65.0 g/L.

Plankton reproduce rapidly and natural populations would be widely dispersed throughout the offshore marine environment. Therefore accidental spills of hydrocarbons in the offshore development area are likely to have only temporary and minor effects on plankton populations.

Cetaceans

Cetaceans would be exposed to spilt oil when they surface to breathe, which may cause damage to their respiratory and nervous systems. Oil could also be ingested by cetaceans with potentially toxic effects. However, short-term inhalation of petroleum vapours at concentrations similar to those found in oceanic oil spills may not be necessarily detrimental. Cetaceans are not vulnerable to the physical effects of oiling as oils tend not to stick to their skin or affect insulation.

Blue whales and humpback whales (baleen whales) that may filter-feed near the surface would be more likely to ingest oil than gulp feeders or toothed whales and dolphins. While humpback whales have been observed feeding in the offshore development area on two occasions (see Chapter 3), the area is not considered a frequently used or critical feeding ground for this species. Vessel-based surveys of the Browse Basin area by the Centre for Whale Research (Western Australia) Inc. between June and November 2008 recorded low numbers of whales in a broad survey area, with average densities of 0.00013 large cetaceans per square kilometre. Dolphins were sighted more frequently, but still at low densities of 0.026 small cetaceans per square kilometre (Jenner, Jenner & Pirzl 2009). At these sparse distribution levels, any accidental spills from the offshore development area would not cause significant impacts to regional cetacean populations.

Experiments on bottlenose dolphins found that this species was able to detect and actively avoid a surface slick after a few brief contacts and that there were no observed adverse effects of the brief contacts with the slick (Smith, Geraci & St. Aubin 1983). It is not known if other marine mammals are able to similarly detect and avoid oil slicks. It has been observed in some oil-spill incidents that dolphins have detected oil and avoided it, but at other times have not done so and have been exposed to floating oil (Geraci & St. Aubin 1990). The strong attraction to specific areas for breeding or feeding may override any tendency for cetaceans to avoid the noxious presence of oil.

Turtles and sea snakes

There is little documented evidence of the effect of oil on turtles; they are, however considered to be vulnerable to oil spills at all stages of life. Should turtles make contact with a spill the impact is likely to include oiling of the body as well as irritations caused by contact with eyes, nasal and other body cavities and possibly ingestion or inhalation of toxic vapours. The effects of weathered oil on adult turtles include increased white blood cell count, sloughing of skin (particularly around the neck and flippers) and improper salt-gland function (Lutcavage et al. 1997).

Green turtles inhabit nearshore waters at Browse Island, Seringapatam Reef and Scott Reef, and the Kimberley coast. They nest from December to March, with peak hatchling emergence occurring during March. Flatback turtles also nest in Kimberley coastal areas, with peak nesting between November and February (see Appendix 4). Five of the eight oil-spill scenarios at the offshore development area could result in surface slicks and shoreline exposure in these areas. Of these, the ship-collision scenario (4) and the longer-term well failure scenarios (7 and 8) could cause substantial volumes of oil to reach shoreline habitats. In the highly unlikely event that these situations should occur, turtles in the local area might be affected by hydrocarbon toxicity, particularly if the spill were to coincide with the nesting season and hatchling emergence.

Seasnakes are known to occur in the offshore development area, but no information is available regarding the susceptibility or sensitivity of seasnakes to oil spills. They surface to breathe and would therefore be vulnerable to exposure to spilt oil.

Vessel-based surveys by the Centre for Whale Research recorded turtles and seasnakes in offshore waters in the Browse Basin very infrequently, that is, only 8 turtles and 21 seasnakes over a total survey area of 8126 km^2 (Jenner, Jenner & Pirzl 2009).

Fish

The impacts of exposure to hydrocarbons differ among the various life stages of fish (Volkman et al. 1994). The toxicity of dissolved hydrocarbons and dispersed oil to fish species has been the subject of a large number of laboratory studies. Generally, concentrations in the range of 0.1–0.4 µg/L have been shown to cause fish deaths in laboratory experiments (96-hour LC_{50}) for periods of continuous exposure, while a range of sublethal responses have been shown at concentrations down to about 0.01 µg/L.

Fish mortalities, however, are rarely observed to occur as a result of oil spills, especially in open waters. This has generally been attributed to the possibility that pelagic fish are able to detect and avoid waters underneath oil spills by swimming away from the affected area (Volkman et al. 1994). Where fish mortalities have been recorded as a result of these spills (for example from the groundings of the oil tanker *Amoco Cadiz* in Brittany in 1978 and the oil barge *Florida* in Massachusetts in1969) they have occurred in sheltered bays with limited water exchange, which is quite a different situation from the marine environment in the Ichthys Project's offshore development area.

Seabirds

The effects of oil spills on seabirds vary depending on the nature of the spill, the bird species and climatic conditions. Bird feathers trap a layer of air both within the feathers and between the feathers and skin, which acts to insulate the bird's body. The feathers maintain their shape by interlocking barbules that help to shed water in droplets. Oil contamination of bird plumage removes these water-repellent properties and results in the loss of thermal insulation. Birds then suffer the effects of chilling and hypothermia (which can lead to death) or may even suffer reduced buoyancy and drown (Volkman et al. 1994).

Ingestion of hydrocarbons, which may occur during feather-preening or by eating contaminated food or swallowing sea water, can cause toxic effects in seabirds or contribute to the development of abnormalities or decreased production and viability of eggs. Small quantities of fresh oil applied to the surface of eggs can kill the embryo and such deposits can be transferred by the parent bird (Volkman et al. 1994).

The offshore development area supports a low abundance of seabirds. A vessel-based survey of the Browse Basin by the Centre for Whale Research in 2008 recorded an average of 0.31 seabirds per square kilometre, with a tendency to record sightings closer to islands, for example Browse Island and Scott Reef. Browse Island, Seringapatam Reef and Scott Reef are not recognised as important habitat for seabirds, and spills that affect these areas are unlikely to result in a significant impact on seabird populations. However, Ashmore Reef and Cartier Island, as well as Roebuck Bay on the Kimberley coast, do support regionally significant populations of migratory birds and nesting seabirds. Oil-spill modelling for the scenarios described earlier in this section do not predict that hydrocarbons would reach Ashmore Reef or Cartier Island. Some of the larger-volume spills could reach the Kimberley coast in low concentrations during wet-season conditions, which corresponds with the period when migratory birds are present in the region. In these events, the volumes of oil reaching nearshore areas would be very low and would not be expected to cause widespread injury to birds.

Benthic communities

The intertidal benthic communities nearest to the Ichthys Field are located at Browse Island, approximately 33 km to the south-east. Similar communities also occur at Seringapatam Reef and Scott Reef which lie approximately 140 km to the west. Of the eight potential spill scenarios, six are predicted to result in shoreline exposure at Browse Island, although most have low secondary risk (see Table 7-18) and low concentrations because of long weathering and evaporation times. The benthic fauna of these areas is common throughout the region, although it is noted that Scott Reef harbours high coral-reef biodiversity (Done et al. 1994).

Most of the shorelines at these islands and reefs would be considered exposed and high-energy, contributing to a rapid recovery from any oil contamination event. Coral larvae, however, would be sensitive to hydrocarbon toxicity and if a large oil-spill event coincided with coral spawning, longer-term effects on coral recruitment might result. Done et al. (1994) suggest that Scott Reef forms a “stepping stone” for the dispersal of coral species from the Indonesian Arc to Rowley Shoals further south along the north-west continental shelf. Damage to coral larvae at Scott Reef could therefore impact coral recruitment over great distances. However, the extent to which the ecosystem at Rowley Shoals depends on replenishment from Scott Reef is not well known and the two areas may be primarily self-sufficient and self-seeding (Done et al. 1994).

Prevention and management of accidental hydrocarbon spills

Management of hydrocarbon spill risks in the offshore development area will be focused on preventing loss of containment through the following:

- providing facility integrity through initial design and shutdown systems
- preparing and implementing procedures for commissioning and operations (including cyclone procedures)
- ongoing maintenance, such as integrity testing of equipment and regular inspection of subsea equipment.

The *Offshore Petroleum and Greenhouse Gas Storage Act 2006* (Cwlth) requires that an accepted emergency response plan, which will include an oil-spill contingency plan (OSCP), must be in place before any offshore petroleum activities may commence. INPEX has already developed an OSCP that has been approved by Western Australia’s Department of Mines and Petroleum to support exploration activities in the Ichthys Field. This OSCP aligns with the requirements and functions of state, territory and Commonwealth response plans[6]. The OSCP will be revised prior to the commencement of construction and submitted to the relevant authorities for approval; it will be periodically reviewed and updated through subsequent phases of the Project.

The OSCP for the Project will include the following:

- emergency procedures for notification and immediate response in the event of a spill
- definitions of the roles and responsibilities of personnel in the event of a spill response
- a description of procedures to deal with an oil spill
- a description of the external resources available for use in combating an oil spill and how these resources are to be coordinated
- a description of procedures for environmental monitoring in the event of a spill.

In addition, a well control manual will be maintained, providing guidance on the response required in the unlikely event of a subsea well failure.

Other industry-standard provisions will be implemented at the offshore development area in order to prevent a spill occurring. These will be incorporated into plans and procedures that are yet to be developed. The following design features and management measures and controls will be employed:

- Each component of the offshore development area, including the gas export pipeline, will be designed to meet the oceanic, climate and seismic conditions of the area.
- Industry-standard drilling practices and equipment will be used to drill the production wells at the Ichthys Field
  - Blow-out preventers (BOPs) will be in place for each well, capable of withstanding pressures higher than those likely to be encountered. A BOP is a large valve located at the subsea wellhead, which can be closed if overpressure

6 Western Australia: *Western Australian marine oil pollution emergency management plan*, administered by the State Marine Pollution Committee.

Northern Territory: *Northern Territory oil spill contingency plan*, administered by the Northern Territory (National Plan) Marine Pollution Management Committee.

Commonwealth: *National plan to combat pollution of the sea by oil and other noxious and hazardous substances*, administered by the Australian Maritime Safety Authority.

from an underground zone causes formation fluids such as oil or natural gas to enter the well bore and threaten the rig. By closing this valve (usually operated remotely by hydraulic actuators), the drilling crew can prevent explosive pressure release and thus regain control of the downhole pressure.
    - A measurement-while-drilling system will be used to measure well paths, true vertical depth, bottom-hole location and orientation of directional drilling systems, and to transmit information to the surface for real-time pore-pressure monitoring. (Note that INPEX has already successfully completed drilling for eight exploration wells in the Ichthys Field; these have provided valuable information on the reservoir pressures. Management plans for drilling and operations will be developed, which will include precautions against a range of accidental-spill scenarios.)
- Industry-standard subsea equipment such as wellheads and flowlines will be employed, together with industry-standard moorings for the CPF and FPSO. Subsea equipment will be reviewed for potential snagging and dropped object damage and appropriate measures will be taken.
- Stability and protection of the gas export pipeline will be achieved by the most appropriate construction techniques, such as the addition of concrete coating, burial of the pipeline below the seabed and, where necessary, the placement of rock berms or armouring over the pipeline.
- Hydrostatic testing of the gas export pipeline will be undertaken prior to the introduction of hydrocarbons to ensure that there are no leaks in the pipeline.
- A precautionary zone will be implemented for the gas export pipeline, in consultation with the regulatory authorities, and will be identified on navigation charts.
- Periodic internal inspections of the gas export pipeline will be undertaken to assess its integrity.
- Trading tankers will be subject to vetting procedures to ensure that vessels are acceptable for loading.
- Loading operations will be monitored by a terminal representative on board the condensate tanker.
- All valves and transfer lines will be checked for integrity before use and loading operations will be continuously monitored.
- A collision detection system will be in place for the CPF and FPSO.
- Stocks of absorbent material and appropriate spill-response equipment will be located on site. The offshore support vessels will also have oil-spill response capability. Regular emergency-response exercises will be carried out.
- INPEX will have the capability to initiate real-time oil-spill fate and trajectory modelling so that a spill can be monitored and responses optimised.

In the event of a spill of light oils at the offshore development area, the likely management response will be to monitor the spill and allow it to weather naturally. Dispersants may be applied, in consultation with relevant authorities, if the spill threatens sensitive environmental receptors. The potential for effective use of offshore containment and recovery equipment will be evaluated during detailed oil-spill contingency planning processes.

A number of management controls will be implemented to avoid or reduce the risk of spills during refuelling at sea. These are as follows:

- The CPF and FPSO design will include, for example, level devices and the careful location of overflows from tanks and drainage systems.
- The FPSO will be double-sided.
- There will be visual monitoring of hoses, couplings and the sea surface during refuelling operations.
- There will be a maintenance and inspection program for the offtake loading hoses.
- Radio contact between the support vessel and the rig will be maintained and collision prevention procedures will be put in place.
- Dry-break couplings and breakaway couplings will be used where available and practicable.

In the case of small-scale oil spills on deck, areas on the MODU, CPF and FPSO where spills are more likely to occur will have containment facilities (i.e. bunding) to prevent contamination of deck washdown and stormwater runoff. Treated deck drainage will be discharged according to the following regulations:

- Oil-in-water concentrations discharged from the CPF and FPSO (fixed facilities) will be limited to not greater than an average of 30 mg/L over any period of 24 hours in accordance with Regulation 29 of the Offshore Petroleum and Greenhouse Gas Storage (Environment) Regulations 2009 (Cwlth).
- Oil-in-water concentrations in bilge discharges from vessels will not exceed 15 mg/L in accordance with MARPOL 73/78 Annex I (IMO 1978) and the Marine Pollution Regulations (NT).

Residual risk

A summary of the potential impacts, management controls, and residual risk for accidental hydrocarbon spills is presented in Table 7-21. The "likelihood" ratings shown are derived from the quantitative assessments of primary and secondary risk presented above, and do not account for spill-response procedures, which would reduce the extent of spills. These risk ratings are therefore considered to be conservative and could be reduced further in the event of an actual spill. The risks of harm to the offshore marine environment are considered to be "medium" or "low".

Table 7-21: Summary of impact assessment and residual risk for accidental hydrocarbon spills (offshore)

Aspect	Activity	Potential impacts	Management controls and mitigating factors	Residual risk*		
				C†	L‡	RR§
Accidental hydrocarbon spills	Scenario 1: Subsea flowline rupture at the Ichthys Field near CPF.	Exposure of large area of offshore waters to surface oil.	Facility integrity will be provided through initial design and shutdown systems. Industry standard equipment and procedures will be employed. Ongoing maintenance such as integrity testing and regular inspections will be carried out. Reviews of subsea equipment for snagging and dropped object damage. Spill-response equipment and procedures. Oil Spill Contingency Plan.	C (E1)	1	Medium
		Exposure of shorelines at Browse Island, Seringapatam Reef and Scott Reef to surface oil. Reduced growth of benthic communities.		D (B2)	1	Low
Accidental hydrocarbon spills	Scenario 2: CPF diesel fuel leak.	Exposure of moderate area of offshore waters to surface oil.	Facility integrity will be provided through initial design and shutdown systems. Ongoing maintenance such as integrity testing and regular inspections will be carried out. Spill-response equipment and procedures. Oil Spill Contingency Plan.	E (E1)	4	Medium
		Exposure of shorelines at Browse Island to surface oil. Reduced growth of benthic communities.		D (B2)	2	Medium
Accidental hydrocarbon spills	Scenario 3: CPF–FPSO transfer line rupture.	Exposure of large area of offshore waters to surface oil.	Facility integrity will be provided through initial design and shutdown systems. Industry standard equipment and procedures will be employed. Ongoing maintenance such as integrity testing and regular inspections will be carried out. Spill-response equipment and procedures. Oil Spill Contingency Plan.	C (E1)	2	Medium
		Low-level exposure of Browse Island, Seringapatam Reef and Scott Reef to surface oil. Reduced growth of benthic communities.		D (B2)	1	Low
Accidental hydrocarbon spills	Scenario 4: Ship collision at FPSO.	Exposure of large area of offshore waters to surface oil.	Radio contact between vessel and FPSO. Collision prevention procedures. Double-sided FPSO design. Spill-response equipment and procedures. Oil Spill Contingency Plan.	C (E1)	2	Medium
		Low-level exposure of Browse Island, Seringapatam Reef and Scott Reef to surface oil. Reduced growth of benthic communities.		D (B2)	1	Low

Table 7-21: Summary of impact assessment and residual risk for accidental hydrocarbon spills (offshore) (continued)

Aspect	Activity	Potential impacts	Management controls and mitigating factors	Residual risk*		
				C†	L‡	RR§
Accidental hydrocarbon spills	Scenario 5: FPSO condensate hose rupture.	Exposure of small to moderate areas of offshore waters to surface oil.	Maintenance and inspection program for condensate loading hose. Monitoring of loading operations by terminal representative on board the condensate tanker. All valves and transfer lines checked before use. Spill-response equipment and procedures. Oil Spill Contingency Plan.	F (B3)	4	Low
Accidental hydrocarbon spills	Scenario 6: Refuelling spill during construction at the Ichthys Field near the CPF.	Exposure of small areas of offshore waters to surface oil.	Visual monitoring of hoses, couplings and the sea surface during refuelling. Use of dry-break or breakaway couplings where practicable. Radio contact between vessels during refuelling. Spill-response equipment and procedures. Oil Spill Contingency Plan.	F (B3)	4	Low
Accidental hydrocarbon spills	Scenario 6a: Refuelling spill during construction along gas export pipeline route, *c.*300 km west of Darwin.	Exposure of small areas of offshore waters to surface oil.	Visual monitoring of hoses, couplings and the sea surface during refuelling. Use of dry-break or breakaway couplings where practicable. Radio contact between vessels during refuelling. Spill-response equipment and procedures. Oil Spill Contingency Plan.	F (B3)	4	Low
Accidental hydrocarbon spills	Scenario 7: Subsea well failure during development drilling.	Exposure of large areas of offshore waters to surface and entrained oil.	The installation of blow-out preventers on all subsea wells. Use of measurement-while-drilling techniques. Well control manual. Oil Spill Contingency Plan.	C (E1)	2	Medium
		Shoreline exposure at Browse Island, Seringapatam Reef and Scott Reef. Toxic effects on marine animals.		D (B2)	2	Medium
Accidental hydrocarbon spills	Scenario 8: Subsea well failure during production.	Exposure of large areas of offshore waters to surface and entrained oil.	The installation of blow-out preventers on all subsea wells. Well control manual. Oil Spill Contingency Plan.	C (E1)	1	Medium
		Shoreline exposure at Browse Island, Seringapatam Reef and Scott Reef. Toxic effects on marine animals.		D (B2)	1	Low

Table 7-21: Summary of impact assessment and residual risk for accidental hydrocarbon spills (offshore) (continued)

Aspect	Activity	Potential impacts	Management controls and mitigating factors	Residual risk*		
				C†	L‡	RR§
Deck drainage and stormwater runoff	Routine washdown of decks during operations and stormwater runoff.	Reduction in water quality caused by small quantities of oil, grease and detergents. Toxicity impacts to marine biota.	Containment of areas where small spills are more likely, and treatment of contaminated deck drainage prior to discharge. Oil-in-water concentrations will meet regulatory-authority requirements: • not greater than an average of 30 mg/L over any period of 24 hours from the FPSO and CPF • not more than 15 mg/L for the MODU and other vessels according to MARPOL 73/78 Annex I (IMO 1978) and the Marine Pollution Regulations (NT). Spill-response equipment and procedures. Provisional Liquid Discharges, Surface Water Runoff and Drainage Management Plan.	F (E1)	6	Low

* See Chapter 6 *Risk assessment methodology* for an explanation of the residual risk categories, codes, etc.

† C = consequence.

‡ L = likelihood.

§ RR = risk rating.

7.2.5 Waste

A variety of solid wastes will be produced at the offshore facilities during all phases of the Project. These are outlined in Chapter 5, and discussed in detail in this section. (Note that drill cuttings are discussed in Section 7.2.2.)

Scale

Low specific-activity scale may be present in waste generated during well-intervention work, surface equipment operation or maintenance and decommissioning. This scale may contain naturally occurring radioactive materials (NORMs).

Under certain conditions (high salinity, together with the presence of sulfates and/or carbonates together with calcium, barium and strontium) solid minerals (scales) will precipitate from produced water. The most common scales consist of barium sulfate ($BaSO_4$), strontium sulfate ($SrSO_4$) or calcium carbonate ($CaCO_3$). The most common places for scale to form are where there is a significant pressure drop or temperature change, or where two streams of different chemistry mix (e.g. one high in barium and low in sulfates, and the other low in barium and high in sulfates). Scale can precipitate in an oil production well, in associated subsea flowlines, in surface pipework, or in processing facilities.

When scale precipitates from produced water, the radium in the water will sometimes be concentrated into the solid scale at concentrations much higher than originally present in the water. However, as noted in the *Guidelines for naturally occurring radioactive materials* published by the Australian Petroleum Production & Exploration Association (APPEA 2002), uranium and thorium radionuclides are substantially less soluble in formation water than radium and NORM scale consequently contains practically no uranium or thorium.

As part of the field development planning for the Project, the potential for scale formation was assessed; this included the potential for individual wells to scale and also the scaling tendency of combinations of water from the various fields. The results indicated the possibility of scale deposition down-hole and in the processing system.

Scale inhibitor is likely to be used down-hole and throughout the production process to minimise the potential for the formation of scale. Further work may be required in this area during the next phases of the development. A detailed plan will be prepared for regulatory approval if disposal of removed scale is required.

The APPEA guidelines detail issues associated with NORMs, specifically focusing on the potential environmental effects of NORM disposal options. These include well injection or discharge of ground material into the sea for dilution and dispersion.

General non-hazardous wastes

General non-hazardous wastes that will be generated in the offshore development area include domestic and packaging wastes, cleaned oil drums, and construction materials such as plastics and metal. These non-hazardous wastes will not be dumped in the offshore marine environment but will be removed to the mainland for onshore disposal at an approved facility. This waste stream is therefore not expected to have an impact on the marine environment.

Food scraps generated on vessels and facilities in the offshore development area will mainly be discharged to the sea and are expected to be rapidly diluted, dispersed and assimilated. No measurable impact to surrounding water quality, outside a very small localised mixing zone, is expected because of the low volumes of discharge in an open ocean environment.

Some fish and oceanic seabirds may be attracted to the Project facilities and vessels by the discharge of food scraps. This attraction may be either direct, in response to increased food availability, or secondary as a result of prey species being attracted to the facilities. However the waste volumes discharged will be small and food scraps from the FPSO, CPF and MODU will be macerated, so the potential for impact is very slight.

Hazardous wastes

Hazardous wastes that will be generated at the offshore development area include excess or spent chemicals, SBMs and well completion fluids. These hazardous wastes will not be discharged to the offshore marine environment but will be removed to the mainland for onshore disposal at an approved facility. This waste stream is therefore not expected to have an impact on the marine environment.

Management of waste

A Provisional Waste Management Plan has been compiled for the Project (attached as Annexe 16 to Chapter 11), which will guide the development of a series of more detailed plans during the construction and operations phases. Key inclusions in this plan are as follows:

- Where practicable, the generation of sands and sludge will be avoided or minimised at source. The amount of sands and sludge disposed of overboard will be kept to a minimum and will only be so disposed of with the approval of the relevant regulatory authorities.
- Process equipment will be designed to restrict the potential for scale formation and scale-inhibition chemicals will be used if required.
- If scale is found to contain NORMs, a procedure will be developed for their storage and handling. NORM disposal will be determined on a case-by-case basis and will be discussed with the relevant regulatory authorities. The selected disposal method will minimise the potential for environmental impact.
- All solid wastes (with the exception of food scraps) from offshore vessels will be returned to the mainland for onshore disposal. These include:
  - plastics
  - floating dunnage, lining and packaging materials
  - paper, rags, glass, metal bottles, crockery, and similar refuse.
- Hazardous wastes will be retained on board vessels and offshore facilities and in due course transported to the mainland for disposal.
- For vessels, in accordance with the *Protection of the Sea (Prevention of Pollution from Ships) Act* 1983 (Cwlth), food scraps generated more than 12 nautical miles from shore (e.g. at the offshore development area) may be disposed of to sea untreated. Within 3–12 nautical miles of land (e.g. at some points along the pipeline route), food scraps will be ground to diameters of <25 mm before being disposed of overboard. Within 3 nautical miles of land, food scraps will not be disposed of overboard, but will be retained and disposed of onshore.
- For the CPF and FPSO, food scraps generated in the offshore development area will be ground to <25 mm diameter prior to discharge, in accordance with Clause 222 of the Petroleum (Submerged Lands) Acts Schedule (DITR 2005).
- Sufficient space will be provided on the FPSO and CPF to allow for the segregation and storage of wastes.
- Waste will be stored in the designated waste stations and appropriately segregated into hazardous waste and non-hazardous waste, and, where possible, into recyclable or reusable hazardous waste and recyclable or reusable non-hazardous waste. In the event of the discovery of any unidentified wastes, these will be treated as hazardous waste and stored accordingly.
- Chemicals and hazardous substances used during all phases of the Project will be selected and managed to minimise the potential adverse environmental impact associated with their disposal.
- Only approved and licensed waste contractors will be employed for waste disposal.
- Waste minimisation will be included in the tendering and contracting process.

Residual risk

A summary of the potential impacts, management controls, and residual risk for solid wastes is presented in Table 7-22. After implementation of these controls, impacts to the offshore marine environment are considered to present a “low” risk.

Table 7-22: Summary of impact assessment and residual risk for solid wastes (offshore)

Aspect	Activity	Potential impacts	Management controls and mitigating factors	Residual risk*		
				C†	L‡	RR§
Generation of scale with NORMs	Well-intervention work and surface equipment operation, maintenance and decommissioning.	Toxicity effects on marine biota as well as health risks to operators.	Process equipment will be designed to restrict the potential for scale formation and scale inhibition chemicals will be used if required. Should scale be found to contain NORMs, the disposal method will minimise the potential for environmental harm and will be selected in consultation with the regulatory authorities.	F (B3)	4	Low
Non-hazardous waste	Generation of non-hazardous waste through routine offshore operations.	Pollution of the marine environment, if disposed of overboard.	Non-hazardous wastes to be retained on board vessels, and transported to onshore facilities for disposal. Provisional Waste Management Plans.	F (B3)	4	Low
Food scraps	Routine operation of offshore vessels.	Alteration of marine environment including nutrient enrichment.	Low volume of waste, in strong current and deep-water marine environment. Dispose of to sea according to MARPOL 73/78 Annex V, Regulation 3(1b and 1c) (IMO 1978): • untreated if to be disposed of beyond 12 nautical miles of land • macerated to <25 mm if to be disposed of between 3 and 12 nautical miles from land Food scraps will be retained on board and disposed of onshore if generated within 3 nautical miles of land. Provisional Waste Management Plans.	F (E1)	6	Low
Hazardous wastes	Generation of hazardous waste through routine offshore operations.	Pollution of the marine environment, if disposed of overboard.	Chemicals and hazardous substances used will be selected to minimise adverse impacts associated with their disposal. Hazardous wastes to be retained on board vessels and offshore facilities until they can be transported to onshore facilities for disposal. Provisional Waste Management Plans.	F (B3)	3	Low

* See Chapter 6 *Risk assessment methodology* for an explanation of the residual risk categories, codes, etc.

† C = consequence.

‡ L = likelihood.

§ RR = risk rating.

7.2.6 Underwater noise emissions

The following discussion on the nature and potential impacts of underwater noise in the offshore development area is derived from a detailed literature review by URS Australia Pty Ltd, which is provided in full in Appendix 15 to this Draft EIS.

Underwater noise in the offshore environment

Sound behaves differently in water from in air, and underwater noise requires different methods of measurement and assessment from airborne noise. The scientific concepts behind underwater noise and its measurement are described below.

Sound

Sound is generated by the vibration of an object and is a form of wave energy that can travel through any elastic material or medium such as air, water or rock. Sound travels by vibrating the medium through which it is propagated. The medium's vibration (oscillation) is the back-and-forth motion of its molecules parallel to the sound's direction of travel, thereby causing a corresponding increase, then decrease, in pressure: this is measured as barometric pressure for sound in air, and hydrostatic pressure for sound in water.

The intensity or loudness of a sound is not expressed in terms of absolute pressure but in relative terms, by a logarithmic scale of decibels (dB). The pitch of a sound is related to the frequency with which the particles or molecules are oscillating, from low-frequency rumbles to high-frequency screeches and whistles, and is measured in hertz (Hz). Most sounds are complex broadband composites that have their power distributed over a spectrum of frequencies. Low-frequency sounds (<1 kHz) are least absorbed by sea water and therefore are the dominant component of ambient background noise in the marine environment.

Ambient noise refers to the overall background noise from both natural and human sources, where the contribution of a specific source is often not readily identifiable. Ambient noise levels are time-weighted averages, and include peak-level spikes or "transients" that are well above the average sound-pressure level. Where ambient noise occurs, the apparent level of individual received sounds drops, owing to the increased average background pressure from the combination of all sounds.

Broadband ambient noise levels in the open ocean range from 45–60 dB in quiet regions (with light shipping and calm seas), to 80–100 dB for more typical conditions (regular shipping and moderate sea states), and over 120 dB during periods of high winds, rain or biological choruses (Urick 1983).

Ambient noise in the 20–500 Hz (low-frequency) range is frequently dominated by distant shipping, particularly in regions of heavy traffic. Vocalisations of the great whales also contribute to this low-frequency band, with the duration and frequency of these choruses increasing in breeding, migrating and feeding areas (Croll et al. 2001; McCauley & Cato 2003). Around 300–400 Hz (in the low-frequency range) the level of weather-related sounds exceeds that of shipping noise. Wind, wave conditions and nearby rainfall dominate the 500–50 000 Hz range (low- to high-frequency range).

The main anthropogenic sources of noise in the marine environment are trading, working and recreational vessels; dredging activities; drilling and piledriving programs; the use of explosives; commercial sonar (depth sounders, fish finders and acoustic deterrents); geophysical sonar; and noise from low-flying aircraft and helicopters.

The characteristics of some common natural and anthropogenic sources of underwater noise are listed in Table 7-23.

Table 7-23: Examples of natural and anthropogenic underwater noise sources in the offshore marine environment

Source	Periodicity	Typical frequency range (Hz)	Indicative source level (dB)
Tectonic earthquakes, tremors, eruptions	Sudden irregular transients (2–20 minutes)	Low (10–100)	220–250
Lightning	Sudden short pulse	Broadband	*c*.260
Whale breaching and fluke slapping	Sudden pulse	Broadband	170–190
Baleen whale "songs"	Variable continuous or transients	Low to medium with harmonics	170–195
Delphinid whistles and squeals	Transients	High to very high (>10 kHz)	180–195
Sperm whale clicks, codas and creaks	Transients	High	180–235
Toothed whale echolocation sonar	Pulses or click bursts	High to very high (>10 kHz)	190–232
Sea ice noises	Variable transients	Broadband	120–190
Rough weather and rain	Irregular continuous	Broadband	80–120
Tide turbulence and sediment saltation	Regular continuous	Broadband	80–120
Fish choruses	Regular continuous	Low and medium-high tonals	80–120
Snapping shrimps	Regular continuous, with morning and evening peaks	Low to medium	80–120
Large tankers and bulk carriers	Variable continuous or transient	Low (10–30 Hz)	180–186
Rig supply tenders	Variable continuous or transient	Broadband	177
Powerboats with 80-hp outboard motors	Variable continuous or transient	Broadband up to several kHz	156–175
Zodiac inflatable boats with 25-hp outboard motors	Variable continuous or transient	Broadband up to several kHz	152
Drilling	Regular continuous	Medium-high (10–4000 Hz)	154–170
Seismic survey	Short pulses	Low to high (0–1000 Hz)	200–232
Cutter-suction dredgers	Regular continuous	Low (100 Hz tonal)	*c*.180
Piledriving	Short pulses	Low to high (0–1000 Hz)	180–215

Source: University of Rhode Island 2009; NOAA 2002; Cato 2000; Simon et al. 2003.

Hearing

The ability of animals and humans to hear a sound is related to both the amplitude of the received pressure waves and their frequency. "Noise" is any audible sound, that is, its frequencies lie within, or at least overlap, the sonic (or "hearing") range of humans or other animals.

The hearing process in both air and water depends on:

- the characteristics of the sound produced by its source
- the auditory properties of the receiver
- the amount and type of ambient noise.

While humans are unable to hear ultrasonic (>20 kHz) sounds, these are audible to dogs, bats, some seals, toothed whales and dolphins. Infrasonic (<20 Hz) sounds (too low-pitched for humans to hear) are known to be detectable by some land animals (e.g. elephants) as well as by manatees and probably by some of the larger baleen whales (see Appendix 15).

Detection of a sound by a distant marine animal also depends on the animal's sensitivity to the frequency peaks in the arriving sound, and the strength of these peaks relative to the local ambient noise (i.e. the degree of masking, by other sounds in the local environment). Whether or not a detectable sound becomes consciously noticed by an animal and elicits a response depends on the degree of processing (decoding) and interpretation applied by the auditory brain stem, and the nature of the signal (i.e. whether it conveys meaning).

It is acknowledged that available data on the effects of noise on marine mammals are variable in quantity and quality, and in many cases data gaps have severely restricted the development of scientifically based noise exposure criteria to manage risks to marine animals. Controlled experiments in laboratory settings have greatly expanded current understanding of marine mammal hearing and there is a reasonable understanding for representative species of odontocetes (dolphins and other toothed species of cetacean) and sirenians (e.g. dugongs) (see Appendix 15).

Furthermore, there are many more published accounts of behavioural responses of marine mammals to noise (Southall et al. 2007), although these generally do not provide a link to specific exposure conditions resulting in particular actions or behaviour. It is important to understand that behavioural responses are strongly affected by the context of the exposure as well as the animal's experience, degree of habituation, motivation and condition and the ambient noise characteristics and habitat setting (see Appendix 15).

Sound propagation and attenuation

The levels of noise received by marine animals are also dependent on the way noise is propagated through the water, and the degree of attenuation. Underwater sound propagation is a complex phenomenon influenced by a variety of factors which, depending on their context, may be of minor or major importance. The primary variables are:

- the frequency of the sound and its absorption losses. Absorption of sound by water is negligible at relatively low frequencies (up to 1 kHz), but increases with increasing frequency and is strongest for frequencies above a few kilohertz
- the sound velocity profile throughout the water column. For a specified frequency, the vertical sound–velocity structure determines how a travelling sound wave refracts or bends as it travels horizontally, which defines interactions with the seafloor and the sea surface
- the bathymetry along the sound wave's direction of travel
- the nature of the seabed. Depending on the make-up of the seabed substrate, sound energy may be absorbed and scattered, reflect off the seabed, penetrate the seafloor, or travel though the seabed to be reflected or refracted back into the water column
- the nature of the sea surface, which can also scatter, reflect or refract sound energy.

Sound propagates more efficiently than light through water. The efficiency of sound propagation allows marine mammals to use sound as a primary method of communication and to sense the presence and location of objects (Richardson et al. 1995).

In extreme conditions noise can theoretically cause injury to marine animals, but this would only happen with an exceptionally loud source and when the organism is within no more than a few metres of the source. It is more likely (but by no means certain) that noise could induce behavioural effects. This may include interference with an animal's ability to detect calls from conspecifics, echolocation pulses or other natural sounds. Another potential effect is the influence that these man-made sounds could have on behaviour. Behavioural effects could range from brief interruptions of resting, feeding or social behaviour, to short- or long-term displacement from important foraging, shelter or mating habitats (Richardson et al. 1995), or migration pathways.

Noise emissions from the Project

Underwater noise will be emitted from the offshore development area during the construction and operations phases of the Project. Underwater noise sources will include vessels, drilling, vertical seismic profiling (VSP), pipelay activities and operation of the offshore facilities. Background noise in the offshore development area was found to be around 90 dB re 1 µPa in low sea state conditions, with vessel and other anthropogenic noise sources occasionally increasing background noise levels above 100 dB re 1 µPa (McCauley 2009) (see Chapter 3).

In order to predict the propagation of underwater noise from the offshore development area, acoustic modelling was undertaken by SVT Engineering Consultants (SVT). The Monterey–Miami Parabolic Equation (MMPE) model was applied, using bathymetric data, geoacoustic parameters of the seabed (e.g. compressional sound speed, sound attenuation, and sediment density) and oceanographic parameters as inputs to the model.

The three most significant noise sources at the offshore development area are considered to be condensate tankers, support vessels and the MODU. The assumed characteristics of these noise sources are presented in Table 7-24. The offshore production facilities (the CPF and FPSO) are non-propelled vessels, whose main underwater noise emissions will be associated with pumps and machinery and will be relatively quiet compared with vessel propellers. The main processing equipment located above water will not be audible to any significant extent in the marine environment.

Table 7-24: Modelled characteristics of offshore noise sources

Source	Frequency range (Hz)	Source depth (m)	Source level (dB re 1 μPa²/Hz at 1 m)
Condensate tanker	30–500	10	185
Support vessel	500–5000	10	182
MODU	500	10	182

These sources are low- to mid-frequency and would be generated as continuous noises, not pulses. Southall et al. (2007) suggest that a permanent threshold shift (PTS; irreversible hearing loss as a result of exposure to intense impulse or continuous sound) in whales and dolphins is caused by sound-pressure levels of 230 dB re 1 μPa, well above the levels generated by the offshore vessels at the Ichthys Field.

Southall et al. (2007) also report that there are no published criteria for temporary threshold shift (TTS; temporary loss of hearing sensitivity) in cetaceans as a result of constant, non-pulsing noise sources. In addition, it is not currently possible to derive explicit criteria for behavioural disturbance, because of the large variations that exist between groups, species and individuals of the receiving marine animals.

However, most research indicates no, or very limited, responses in baleen whales and dolphins to noises at a received level range of 90–120 dB re 1 μPa and an increasing probability of avoidance and other behavioural effects, albeit generally minor, at a range of 120–160 dB re 1 μPa (Southall et al. 2007) (see Appendix 15 for discussion). Therefore, 120 dB re 1 μPa can be applied as a “threshold” criterion to underwater noise modelling at the offshore development area, to derive a zone that marine mammals may avoid because of Project activities.

McCauley et al. (2000) report that noise levels of 175 dB re 1 μPa cause avoidance behaviour in green turtles (see Appendix 15). Therefore 120 dB re 1 μPa also provides a highly conservative threshold level for impacts to turtles in the offshore development area.

A selection of contour plots are presented in figures 7-13 to 7-16, illustrating the extent of noise propagation from vessels and drilling activities at the Ichthys Field down to the 100 dB re 1 μPa level. The horizontal plots are presented at a depth of 60 m, which is two-thirds the depth of the isothermal layer and is therefore expected to be the depth of maximum acoustic penetration (SVT 2009).

Vessel traffic

Low-frequency noise generated by condensate tankers at the Ichthys Field is predicted to abate to 120 dB re 1 μPa within about 8 km of the source location (Figure 7-13). The area receiving 130–140 dB re 1 μPa is very small, less than 1 km in radius (SVT 2009). This low-frequency noise is within the hearing range of baleen whales (e.g. pygmy blue whales, humpback whales) and turtles, but is below the range of audibility for dolphins (see Appendix 15).

Medium-frequency noise generated by support vessels at the Ichthys Field is predicted to propagate further than that produced by condensate tankers. The 120 dB re 1 μPa threshold level is generally reached at a distance of around 3.5 km from the source, but extends up to 7 km at some points (Figure 7-14). The area receiving 130–140 dB re 1 μPa is less than 1 km in radius (SVT 2009). This type of noise is within the hearing range of baleen whales, turtles and dolphins (see Appendix 15).

The noise characteristics and propagation presented above is considered representative of the variety of vessels to be used at the offshore development area during the construction and operation phases of the Project. These will include rig tenders, module transfer barges, pipelay barges, heavy-lift crane barges, pipe supply vessels, and smaller, faster-moving support and survey vessels.

Ship numbers have been increasing in the Browse Basin over recent years, largely because of the supply vessels supporting the oil & gas industry (Broome Port Authority 2007). Therefore, although this area may be considered isolated with low vessel traffic, more recent development and activities occasionally increase ambient noise levels around the Project area by up to 10 dB re 1 μPa, to 100 dB re 1 μPa (McCauley 2009). These levels of ambient noise are not expected to cause avoidance behaviour in cetaceans (Southall et al. 2007).

Drilling

Low-frequency noise generated by the MODU while drilling production wells at the Ichthys Field is predicted to abate to the 120 dB re 1 μPa threshold level within around 6 km, but may extend up to 10 km at some points (Figure 7-15). The area receiving 130 dB re 1 μPa is very small, less than 1 km in radius (SVT 2009). This low-frequency noise is within the hearing range of baleen whales and turtles, but is below the range of audibility for dolphins (see Appendix 15).

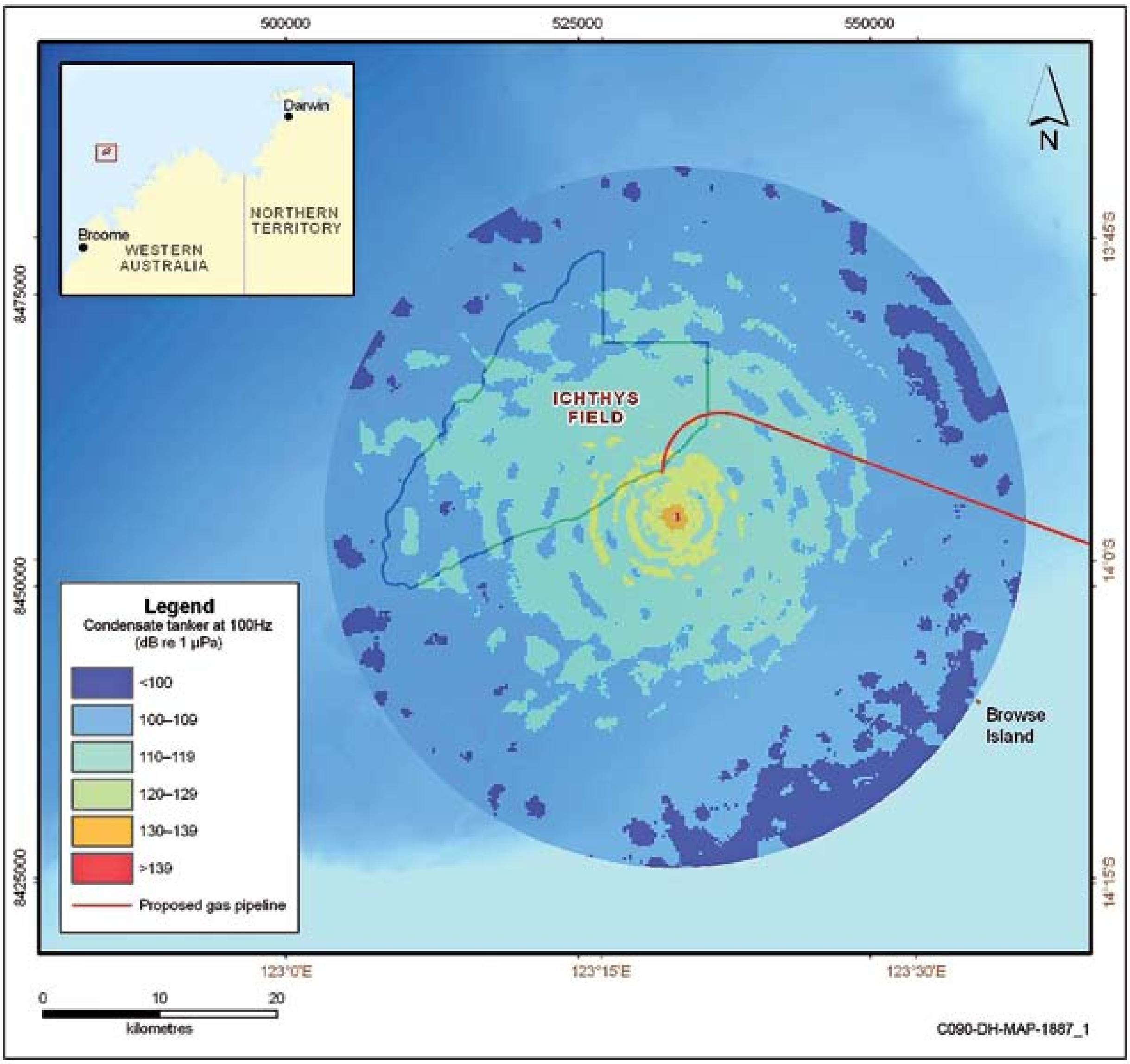

Figure 7-13: Underwater noise produced by a condensate tanker: 100-Hz contours at a depth of 60 m

Combined noise sources

During the early stages of the Project, there may be occasions where noise is generated by all three of the noise sources simultaneously. At these times, low-frequency noise may extend at the 120 dB re 1 μPa threshold level across a total horizontal distance of up to 30 km (Figure 7-16). Areas receiving 130 dB re 1 μPa or more would remain within around 2 km of each noise source (SVT 2009). As mentioned above, noise at this frequency range is within the hearing range of baleen whales and turtles, but is below the range of audibility for dolphins (see Appendix 15).

Vertical seismic profiling

VSP activities will generate low-frequency (200 Hz) pulsed noise at sound-pressure levels of around 190 dB re 1 μPa. These activities will be undertaken over short periods (8–12 hours) during the construction and early operational phases of the Project. VSP produces significantly less energy than large-scale offshore three-dimensional seismic surveys.

Southall et al. (2007) provide a criterion of 230 dB re 1 μPa as the threshold at which pulsed noise could cause injury in cetaceans. Therefore VSP in the offshore development area is unlikely to cause injury to baleen whales and dolphins that may be in the vicinity, although the noise levels of around 190 dB re 1 μPa can be expected to cause avoidance behaviour.

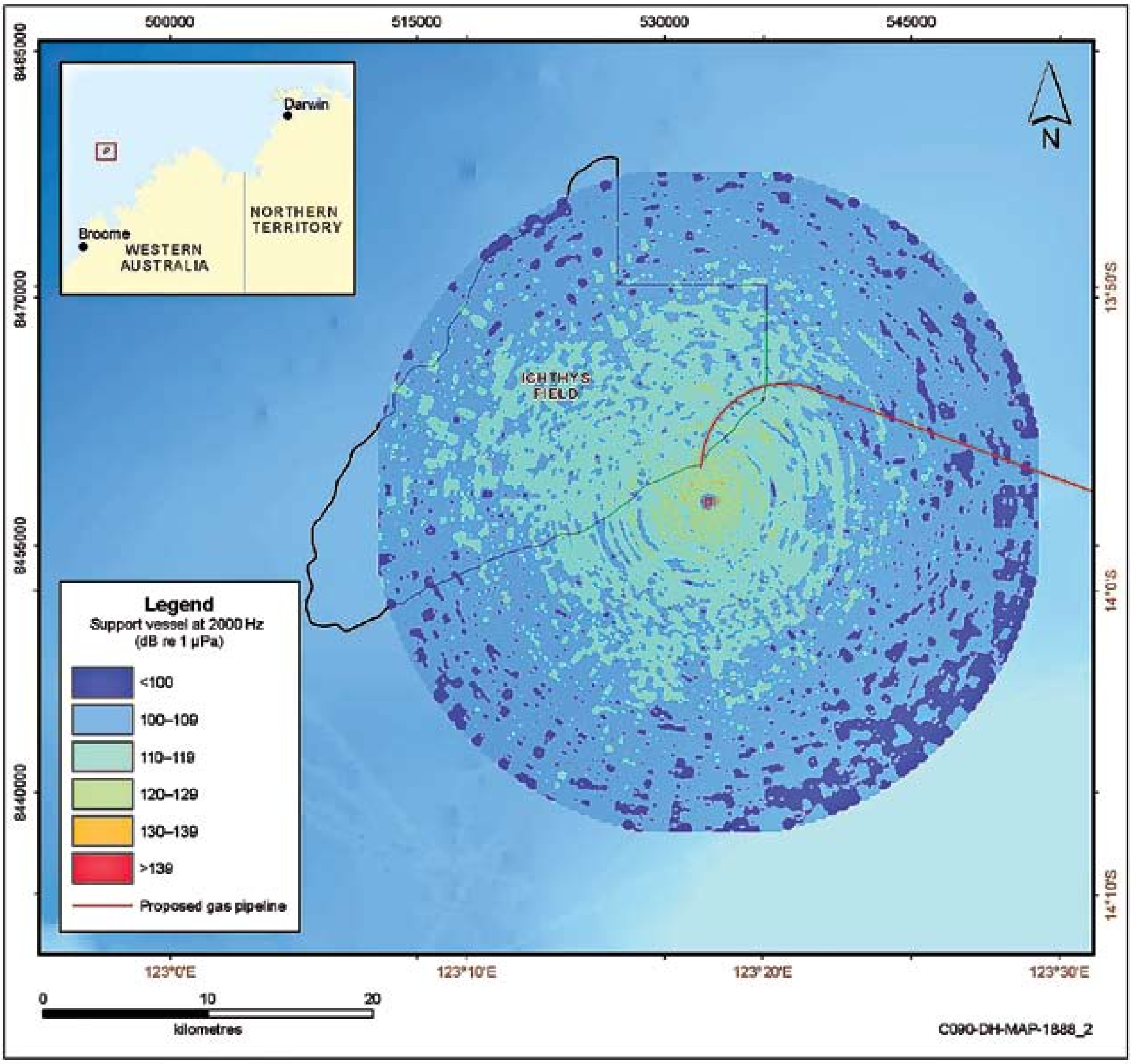

Figure 7-14: Underwater noise produced by a support vessel: 2000-Hz contours at a depth of 60 m

Attenuation of sound levels from VSP activities can be estimated using the empirical formula for practical spreading[7], as presented in Table 7-25. As shown, sound energy levels will drop rapidly with increasing distance from the VSP operation, and within 100 m will have reduced to 160 dB re 1 µPa. This sound level is within the range expected to cause minor avoidance behavioural effects in cetaceans (Southall et al. 2007).

Table 7-25: Attenuation of sound energy from vertical seismic profiling

Drop in sound intensity (dB re 1 µPa)	Received sound level (dB re 1 µPa)	Approximate distance from source (m)
10	180	4.5
20	170	22
30	160	100
40	150	464
50	140	2000

7 In deep water (e.g. 3–4 km depth), sound energy spreads outwards with negligible refraction or reflection from the seafloor or surface; in these circumstances, the spherical spreading law applies: *Transmission loss = 20 log (range).*

In shallow water (e.g. <500 m depth), the transmission of sound energy is reduced by refraction and reflection from the seafloor and surface. Under these conditions, the cylindrical spreading law can be used to estimate transmission loss: *Transmission loss = 10 log (range).*

Since sound energy is not perfectly contained by reflection and refraction, however, the true extent of spreading is often somewhere between the predictions given by spherical and cylindrical spreading. Thus, the practical spreading equation represents an intermediate condition between spherical and cylindrical spreading: *Transmission loss = 15 log (range).* This has been applied in Table 7-25.

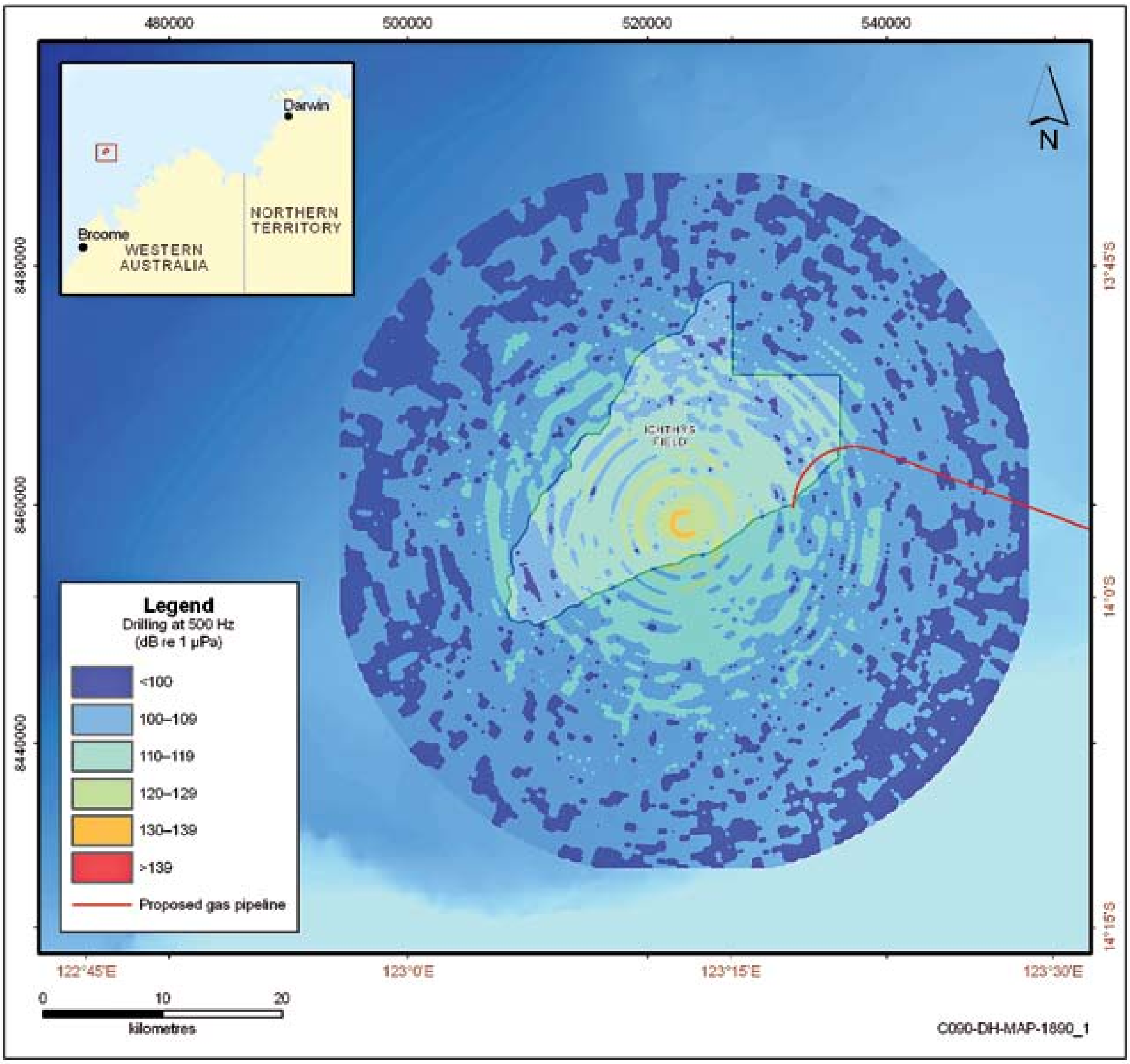

Figure 7-15: Underwater noise produced by drilling: 500-Hz contours at a depth of 60 m

Gas export pipeline

Construction of the gas export pipeline in the offshore area is unlikely to generate significant sound levels. Vessels, particularly any dynamic-positioning vessels, are likely to produce the most intense noise associated with the pipeline construction activities, and may also be used for periodic inspection and maintenance of the pipeline during operations. Any trenching or rock-dumping activities would generate only minor noise levels.

Operation of the pipeline is unlikely to generate noise of any ecological significance. Any noise that is generated would be minimal and inconsequential in comparison with ambient noise levels in the surrounding marine environment.

Potential impacts to marine animals

Baleen whales

Most of the available information on noise from vessel traffic is related to baleen whales as their optimal hearing frequency range generally coincides with the noise generated by vessels. Various researchers have suggested that low-frequency noises generated by vessel traffic may mask vocalisations by baleen whales, limiting their ability to communicate over long distances (see Appendix 15). However, vessel traffic associated with the Project is relatively small in scale and will not contribute significantly to ambient noise in the Ichthys Field or along the pipeline route.

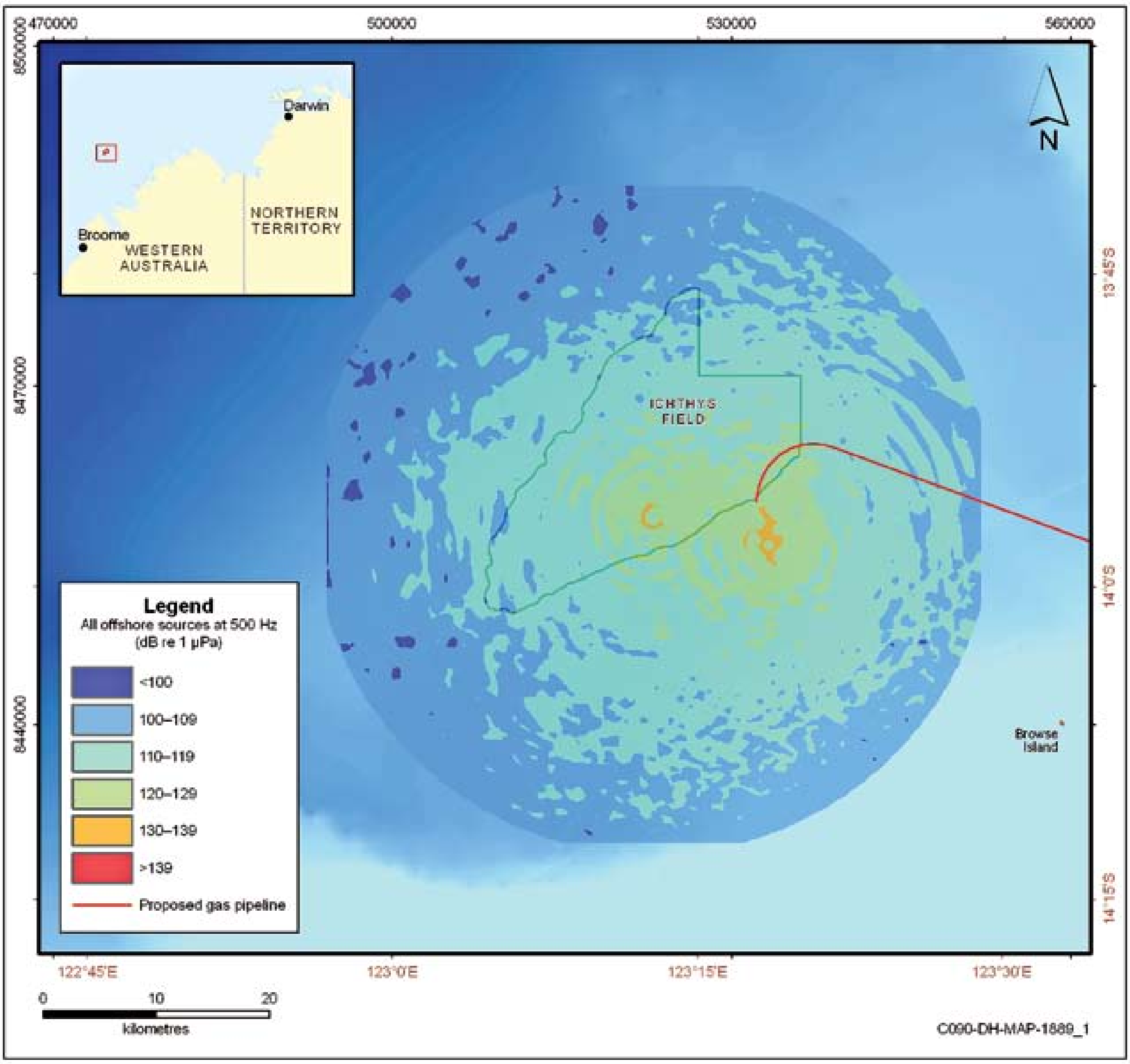

Figure 7-16: Underwater noise produced by all offshore sources combined: 500-Hz contours at a depth of 60 m

McCauley et al. (2000) observed that migrating humpback whales tended to avoid operating seismic sources when the received sound levels were greater than 157–164 dB re 1 µPa. As shown in Table 7-25, sound energy levels from VSP activities are likely to drop below this disturbance level (to 150 dB re 1 µPa) at distances of 464 m from the source. Given the extensive areas of open ocean surrounding the Ichthys Field, the area within which noise levels would disturb humpback whales is very small and is easily avoidable. VSP activities in the offshore development area will occur on a short-term basis and are unlikely to cause significant disturbance to migrating whales that pass through the area.

The offshore development area is not a critical breeding, feeding or aggregation area for baleen whales. It is noted that there is a significant humpback whale breeding area centred around Camden Sound on the Kimberley coast, 190 km south-east of the Ichthys Field (Jenner, Jenner & McCabe 2001) and that pygmy blue whale migration routes may occur in deep offshore waters to the west of the Ichthys Field (McCauley 2009).

Baleen whales are presumed to have a higher hearing sensitivity at low frequencies and therefore there is the potential for drilling noises to affect these species. However, potential effects are likely to be associated only with avoidance behaviour.

Toothed whales and dolphins

Toothed whales and dolphins have reduced hearing sensitivity in low-frequency (<1 kHz) ranges (Richardson et al. 1995), which generally correspond with the noise generated by vessels and drilling activities in the Project's offshore development area. Some species of dolphins are known to bow-ride on the wake of vessels, apparently unconcerned by shipping noise. Therefore, while toothed whales and dolphins are known to occur in the offshore development area, significant negative impacts to these species are not anticipated as a result of noise emissions from the Project.

Turtles

Information is lacking regarding potential impacts on turtles from noise associated with vessel traffic and drilling activities, although their reported auditory sensitivity range of 400–1000 Hz does correspond with the low-frequency noise generated by these sources. Sea turtles have been known to exhibit startle responses to sudden noises, including those generated by air guns used for VSP (McCauley et al. 2000).

The offshore development area does not contain critical breeding or nesting habitat for sea turtles. Turtle nesting is known to occur at Browse Island, which is 33 km south-east of the nearest drilling centre. Noise propagation modelling indicates that the offshore activities at the Ichthys Field will not be audible above background noise levels in the vicinity of Browse Island (SVT 2009).

A small number of turtles also nest at Cox Peninsula, around 2 km from the pipeline route. Pipelay activities in this area during construction will occur over a short period, passing this area of the coast within around one week. Any potential impacts to nesting activities will therefore be minor in scale.

Fish

The variation among fishes in respect to sensitivity to sound is immense. Observations of fish aggregating next to operating industrial infrastructure (such as oil and gas production platforms, wharves and shiploaders) suggests that at least some species are able to become habituated to some noise.

The hearing sensitivity of sharks is within the 20–800 Hz low-frequency range and coincides with the noise to be produced from offshore vessel, drilling and VSP activities.

Studies have shown that fish avoid approaching vessels when the radiated noise levels exceed their threshold of hearing by 30 dB or more, with this avoidance behaviour usually expressed by swimming down or horizontally away from the vessel path.

These effects have been found to be temporary: for example schooling patterns resume shortly after the noise source has passed by.

Temporary threshold shifts in particular fish species have been known to occur after exposure to airgun shots such as those used during VSP (McCauley et al. 2000). Given the extensive areas of open ocean surrounding the Ichthys Field, it is anticipated that pelagic fish could rapidly escape any area in which noise levels caused discomfort or annoyance.

Although various fish species occur in the offshore development area, no critical habitat or aggregation areas have been identified.

Management of noise

A Provisional Cetacean Management Plan has been compiled (attached as Annexe 4 to Chapter 11), which will guide the development of a series of more detailed plans to minimise the impacts of underwater noise on cetaceans during the various Project phases. Key inclusions in this plan include the following:

- the implementation of observation zones around VSP activities such as:
  - visual observation before start-up, whereby an "observation zone" with a horizontal radius of 3 km is deemed to be clear of whales for 30 minutes before VSP is permitted to commence
  - a "soft-start" procedure, where the VSP acoustic source commences at the lowest power setting, with a gradual increase in power over a 20-minute period
  - continuous monitoring of the "observation zone" to identify any approaching whales during VSP activities
  - shutdown of VSP activities if a whale is sighted within 500 m
  - following a whale sighting, recommencement of VSP activities after 30 minutes, and using the soft-start procedure.
- the implementation of vessel–cetacean interaction procedures, including not intentionally approaching within 50 m of a dolphin, or within 100 m of a large cetacean, and attempting not to approach cetaceans from head-on.

Residual risk

A summary of the potential impacts, mitigating factors and residual risk for underwater noise emissions is presented in Table 7-26. The residual risks of harm to marine animals are considered to be "low", as noise emissions to the offshore marine environment will be localised and many will be short-term and transitory in nature.

Table 7-26: Summary of impact assessment and residual risk for underwater noise

Aspect	Activity	Potential impacts	Management controls and mitigating factors	Residual risk*		
				C†	L‡	RR§
Underwater noise	Noise generation during construction: • VSP • drilling • supply vessels • pipelay barge • installation of field infrastructure (heavy-lift vessels, anchor handlings, tugs, etc.).	Avoidance by marine animals of the immediate area around vessels and facilities.	The offshore development area is distant from critical breeding and feeding grounds for marine mammals and turtles. Construction noise will be generated on an intermittent basis only. Procedures put in place for cetacean observation and exclusion during VSP operations. Provisional Cetacean Management Plan.	F (B1)	6	Low
Underwater noise	Noise generation during operations: • FPSO • CPF • supply vessels.	Avoidance by marine animals of the immediate area around vessels and facilities.	The offshore development area is distant from critical breeding and feeding grounds for marine mammals and turtles. Provisional Cetacean Management Plan.	F (B1)	6	Low

* See Chapter 6 *Risk assessment methodology* for an explanation of the residual risk categories, codes, etc.

† C = consequence.

‡ L = likelihood.

§ RR = risk rating.

7.2.7 Light emissions

Low-intensity light spill will be generated from the offshore facilities such as the CPF, FPSO, MODU and service vessels as a consequence of providing safe illumination of work and accommodation areas during the construction and operation phases.

It has been suggested that light may disorient cetaceans (Pidcock, Burton & Lunney 2003), but there is in fact no evidence to suggest that artificial light sources adversely affect the migratory, feeding or breeding behaviours of these marine mammals. As cetaceans predominantly utilise their acoustic senses to monitor their environment, light is not considered to be a significant factor in cetacean behaviour or survival. It is therefore unlikely that light spillage from the MODU, installation vessels, CPF or FPSO would cause any detectable response from cetaceans.

Lights have been reported to disorientate marine turtles, particularly hatchlings and female adults returning to the sea from nesting areas on the shore (Pendoley 2005). Once in the water, turtle hatchlings are believed to use the shore wave action as a directional cue to make their way offshore, rather than any light sources (see Appendix 4). Because of the distance of the Ichthys Field from land, it is not expected that light spill from offshore infrastructure will cause disorientation to hatchlings or adult female turtles. The closest turtle habitat is Browse Island, about 33 km away from the offshore facilities. This area is used by green turtles as a nesting area and is listed as a C-class reserve for this reason (see Chapter 3).

During construction of the gas export pipeline, the pipelay barge and support vessels are likely to pass approximately 2 km off Mandorah on the Cox Peninsula, at the entrance to Darwin Harbour. As described in Chapter 3, this area also provides minor flatback turtle nesting habitat. If construction activities correspond with the nesting season, there is a slight chance that hatchlings could be attracted towards the construction vessels. This effect would last for only two to three days while the vessels pass through the area, and the likelihood of a turtle hatchling actually reaching the vessels over 2 km is low. This short-term light spill is therefore not expected to affect the survival of turtle hatchlings from the Cox Peninsula. The significant turtle nesting beaches of the Anson–Beagle Bioregion (namely North Peron Island, Five Mile Beach, Bare Sand Island, Quail Island and Indian Island) are located distant (>40 km) from the pipeline route and well outside the influence of lighting impacts from pipelay vessels.

Light spill from the offshore facilities is unlikely to attract significant numbers of migratory birds or seabirds as the offshore development area is located distant from key aggregation areas in the region, such as Ashmore Reef, Roebuck Bay and Eighty Mile Beach (see Chapter 3). Studies in the North Sea indicate that migratory birds are attracted to lights on offshore platforms when travelling within a radius of 5 km from the light source. Outside this zone their migratory paths are unaffected (Shell 2009). Discussions with current industry personnel in the Browse Basin and North West Shelf suggest that existing offshore oil & gas facilities in the region do not encourage seabird or migratory bird aggregations.

Plankton levels are known to increase around offshore infrastructure, attracted by artificial lighting overnight. This food source encourages fish to aggregate around the submerged infrastructure, where biofouling communities also provide a food source. These effects of increased productivity will be highly localised in the context of the offshore marine environment and of minor consequence to the marine ecosystem.

Residual risk and management

Lighting from the offshore development area is not considered to pose a threat to the surrounding marine environment. There are no sensitive light receptors (e.g. turtle nesting beaches) in close proximity to the infrastructure and localised effects on marine biota are consequently considered to be minor.

Lighting design and operation on the offshore facilities, the pipelay barge and support vessels will meet personnel safety requirements. The safe working levels will be determined as part of a "safety case" assessment under the *Offshore Petroleum and Greenhouse Gas Storage Act 2006* (Cwlth).

7.2.8 Marine pests

Marine pests are introduced marine species that have been moved by human activity from their natural environment to an area where they can multiply and threaten biodiversity, fisheries and other commercial or recreational interests. The marine species recognised as representing an elevated pest risk to Australia are typically coastal or shallow-water species.

Predicting the ability of a marine organism to become a "pest" in a new environment can be difficult, as the interaction of species (both native and exotic) in an ecosystem is complex. A marine species may be introduced into one area with no apparent effects, but may become invasive or hostile to native species in another location. Generally speaking, an exotic marine organism has the potential to survive, establish and spread in environments that are similar to the conditions that prevail in its ecosystem of origin—for example in temperature, salinity, water depth, distance to land and seasonality.

The incidence of new marine pest introductions in Australia has increased in recent times. It is possible that such observations are an artefact of the increased number of studies and greater awareness of the problem, but it is generally considered that potential sources of introduction are increasing and that the rate of marine species introduction is actually rising. Commercial and recreational vessels are suggested as the major sources of accidental, anthropogenic marine pest introductions, as marine pests can be spread by "hitchhiking" on vessels travelling between different areas (Marshall, Cribb & Thompson 2003).

The two most important sources of marine pests in commercial vessels are ballast water and hull biofouling, as described in the following section.

Ballast water

Large ocean-going vessels use sea water as ballast to control trim, list, draught, stability or stresses of the vessel while at sea. Ballast water may be loaded at the point of origin and discharged at the vessel's destination, providing a vector for transporting marine organisms from one region to another. It is estimated that thousands of marine species, from plankton and algae to invertebrates and fish, are transported around the world in ballast water (Goggin 2004).

The risk of introducing a marine pest into a new environment in ballast water largely depends on the species' ability to survive for long periods in the ballast tanks. Several algal or protozoan genera, including some chlorophytes and dinoflagellates, produce spores that are capable of "resting" for long periods and are able to endure relatively long voyages. Many species of crustacean larvae are also able to survive transport in ballast water. The transit time between Australian and Asian ports is relatively short (often less than 20 days), which increases the risk of marine pest introduction through this mechanism by vessels associated with the offshore development area.

In general terms, the greatest risk posed by ballast water exists when the location of ballast-water uptake is similar in environmental and habitat conditions to the location of the ballast-water discharge, for example where both the point of origin and point of discharge are tropical environments, with similar water depth and ecology. These situations provide a greater chance for any species transferred between regions to survive and establish as a "pest". Exchanging ballast water in the open ocean while a vessel is en route is commonly undertaken to reduce the risk of transporting marine pests in ballast water from one port to another.

Coastal and shallow-water habitats are considered vulnerable to marine pest introductions as the marine species recognised as representing an elevated pest risk to Australia are typically coastal or shallow-water species. Ballast water discharged from the pipelay barge and support vessels in shallow waters (<50 m depth) in the Timor Sea, Beagle Gulf and close to the mouth of Darwin Harbour could present a marine pest risk if the water originates from a similar tropical, shallow-water environment. However, this region is sufficiently distant from land to reduce the risk of marine pest introduction to a low level.

The environment in the offshore development area is likely to be vastly different from that in coastal ports, both in Australia and overseas. Therefore, any ballast water discharged by vessels at the Ichthys Field during the operations phase of the Project is unlikely to introduce a marine pest that could establish successfully.

Biofouling

Biofouling is the growth of marine organisms, such as barnacles and algae, on immersed surfaces of vessels and structures. On commercial vessels, biofouling typically occurs on the hull and underwater fittings and voids, internal bilge spaces, cable lockers, anchors and mooring tackle, free flood spaces, wet compartments, and internal seawater systems. Other submerged and floating equipment such as buoys and floating platforms associated with construction and operation of the field will also be susceptible to biofouling. All vessels are vulnerable to biofouling, with the extent and diversity of organisms influenced by a vessel's design, operations and maintenance. Commercial vessels are often treated with antifouling paints to prevent the establishment and growth of fouling communities (see Section 7.2.3 *Liquid discharges*).

Large slow-moving vessels, such as pipelay barges, are considered to pose heightened marine pest risks because of the inherent biofouling vulnerabilities of their design, with a large number and variety of niche spaces on the submerged surfaces of these vessels. The slow vessel speed characteristic of pipe-laying operations also increases biofouling levels, as organisms are better able to establish and survive on vessel surfaces while passing water speeds are low.

Prior to undertaking pipelay construction activities for the Ichthys Project, it is possible that at least some of the pipelay vessels engaged will have travelled recently through ports in South-East Asia (e.g. Singapore) where the tropical climate is similar to that of the Beagle Gulf and Darwin Harbour. This increases the chance of survival for any exotic marine species accidentally transferred. High-risk marine pest species such as the black-striped mussel (*Mytilopsis sallei*) and the Asian green mussel (*Perna viridis*) currently exist in these South-East Asian waters and not in Australia (URS 2009).

Near-surface infrastructure such as the FPSO, CPF and supporting infrastructure provide potential hard substrate habitat for marine pests, which could originate from the port or yard where the infrastructure was first constructed or could be introduced by vessels travelling to the offshore development area (e.g. from an international port). While this hard substrate habitat is very isolated in the offshore development area, transport of a marine pest species from the offshore development area back to a coastal port (e.g. in Australia or another country) could represent an opportunity for establishment or spread of the pest species into the environment on a broader scale. Marine pests could also be transferred to a coastal port if an item of offshore infrastructure were to be brought in from the field for repairs, refurbishment or maintenance.

Management of marine pests

A Provisional Quarantine Management Plan has been compiled for the Project (attached as Annexe 13 to Chapter 11), which will guide the development of a series of more detailed plans during the construction and operations phases. This plan has been developed with consideration of the likely requirements of the relevant regulatory authorities, including the Australian Quarantine and Inspection Service (AQIS), the Northern Territory's Department of Regional Development, Primary Industry, Fisheries and Resources (DRDPIFR)[8], the Darwin Port Corporation (DPC), and Western Australia's Department of Fisheries. Key elements of this plan include the following:

- INPEX will ensure that vessels engaged in the Project comply with the biofouling requirements of the regulatory authorities.
- Vessels engaged in Project work will be subjected to a biofouling risk assessment, which may result in hull inspections and cleaning.
- Relevant Project vessels will be required to maintain satisfactory records of antifoulant coatings, hull-cleaning and ballast-water exchange.
- Marine fouling inspections (using ROVs) will also be used for opportunistic marine-pest monitoring on offshore structures.

8 The Northern Territory's Department of Regional Development, Primary Industry, Fisheries and Resources (DRDPIFR) became the Department of Resources (DoR) in December 2009.

Residual risk

A summary of the potential impacts, management controls, and residual risk for marine pests in the offshore development area is presented in Table 7-27. After implementation of these controls, impacts to the offshore marine environment are considered to present a "low" to "medium" risk and this is considered as low as reasonably practicable.

7.2.9 Marine megafauna

The vessels travelling to and from the offshore development area throughout the life of the Project expose large marine animals to a slight chance of injury through collisions.

Humpback whales are the most common whale species observed in the North West Shelf Bioregion. According to Jensen and Silber (2004), humpback whales are the second most often reported cetacean species struck by vessels. Whether this is because of their relative abundance compared with other great whales or to the particular susceptibility of the species is not known. Previous research has also indicated that several great whale species, including humpback, blue and fin whales, are less responsive to approaching vessels when they are feeding. The incidence of vessel strikes on cetaceans in Australian waters and the circumstances in which they take place is not well documented.

The vessels engaged in construction activities in the offshore development area, such as module transfer barges and pipelay barges, will typically be large and slow, moving with speeds of 0.5–3 knots. Construction of the pipeline will likely progress at a rate of 2–4 km per day. Given that construction will be undertaken by groups of vessels, and that noise would be generated by these, it is probable that whales and other marine megafauna would be deterred from approaching and that vessel collisions would be highly unlikely.

Smaller, faster-moving support vessels, such as anchor-handling tugs, pipe-supply vessels and survey vessels, will transit in and out of the offshore development area during construction at average speeds of 12–14 knots and maximum speeds of up to 20 knots. Tanker vessels engaged in product export during the operations phase would reach speeds of 15–19 knots in open seas. In the open ocean environment a vessel collision with a cetacean would be extremely rare; however, at these travelling speeds such a collision could cause injury or even death to the animal. Noise from vessels would generally alert marine animals to move away, although smaller cetaceans (e.g. dolphins) are known to bow-ride with vessels of all sizes.

Helicopters will be used frequently to transfer personnel to the offshore development area, and may take off from or land close to the sea surface.

Table 7-27: Summary of impact assessment and residual risk for marine pests (offshore)

Aspect	Activity	Potential impacts	Management controls and mitigating factors	Residual risk*		
				C†	L‡	RR§
Marine pests	Operation of vessels between the offshore development area and Australian or overseas ports.	Alteration of marine ecology in biofouling communities on submerged structures at the offshore development area.	Carry out biofouling risk assessment for all vessels. Vessel compliance with regulatory-authority guidelines for biofouling. Opportunistic monitoring of submerged surfaces using ROVs. Provisional Quarantine Management Plan.	E (B3)	2	Low
Marine pests	Use of pipelay barge and support vessels in coastal areas near Darwin.	Invasion of native marine ecosystems by pests, threatening native marine plants and animals and impacting upon maritime-based industries.	Biofouling risk assessment for all vessels. Vessel compliance with regulatory-authority guidelines for biofouling. Provisional Quarantine Management Plan.	C (B3)	2	Medium

* See Chapter 6 *Risk assessment methodology* for an explanation of the residual risk categories, codes, etc.

† C = consequence.

‡ L = likelihood.

§ RR = risk rating.

Helicopters could disturb cetaceans through generation of noise, although on a very localised and infrequent basis.

The offshore development area is small relative to the expansive open ocean surrounding it, and the risk of displacement of cetaceans by construction and operational activities is very low. There are no recognised cetacean feeding or breeding grounds in the offshore development area.

The potential for impacts to third-party shipping, navigation and commercial fishing is discussed in Chapter 10.

Management of marine megafauna

A Provisional Cetacean Management Plan has been compiled (attached as Annexe 4 to Chapter 11), which will guide the development of a series of more detailed plans during the construction and operations phases of the Project. This plan is consistent with the Australian National Guidelines for Whale and Dolphin Watching 2005, administered by the Commonwealth's Department of the Environment, Water, Heritage and the Arts (DEWHA), the Northern Territory's Department of Natural Resources, Environment, the Arts and Sport (NRETAS) and Western Australia's Department of Environment and Conservation (DEC). Key inclusions in this plan are as follows:

- Vessel interactions with cetaceans will be avoided by
  - aiming to maintain a distance of 100 m from a large cetacean or 50 m from a dolphin
  - operating at a no-wash speed when within 100–300 m of a large cetacean or when within 50–150 m of a dolphin
  - not actively encouraging bow-riding by cetaceans by driving towards pods of animals; however should any cetacean(s) commence bow-riding with a vessel, the vessel master will not change course or speed suddenly.
- Helicopters in the vicinity of a cetacean will (except in take-off, landing or emergency situations)
  - not fly lower than 500 m within a 500-m radius of a cetacean, or hover over this zone
  - avoid approaching a whale or dolphin from head-on
  - avoid flying directly over, or allowing the shadow of the helicopter to pass directly over a cetacean.

Residual risk

A summary of the potential impacts, management controls, and residual risk for marine megafauna in the offshore development area is presented in Table 7-28. After implementation of these controls, potential impacts are considered to present a "low" risk, as any interactions with cetaceans will be rare and very localised.

7.3 Nearshore marine impacts and management

The nearshore development area includes a corridor for the gas export pipeline extending from the mouth of Darwin Harbour through the centre of the Harbour to the pipeline shore crossing area south of Wickham Point on Middle Arm Peninsula. The gas export pipeline route for the Ichthys Project runs parallel to the existing Bayu–Undan Gas Pipeline, which feeds ConocoPhillips' Darwin Liquefied Natural Gas (LNG) plant.

Table 7-28: Summary of impact assessment and residual risk for marine megafauna (offshore)

Aspect	Activity	Potential impacts	Management controls and mitigating factors	Residual risk*		
				C†	L‡	RR§
Marine megafauna	Use of operation and construction vessels in the offshore development area.	Physical injury to large marine animals from collision with vessel.	The offshore development area is outside the key breeding and feeding areas for humpback whales. Construction vessels travel at low speeds. General noise and activity would deter marine animals from entering the area. Procedures for avoiding interaction between vessels and helicopters, with cetaceans. Provisional Cetacean Management Plan.	E (B1)	2	Low

* See Chapter 6 *Risk assessment methodology* for an explanation of the residual risk categories, codes, etc.

† C = consequence.

‡ L = likelihood.

§ RR = risk rating.

7 Marine Impacts and Management

The nearshore development area also includes the marine environment around Blaydin Point. This area is located on the southern banks of East Arm downstream of the Elizabeth River. In addition, for the purposes of this Draft EIS, an offshore site 20 km north of Darwin Harbour is considered to be part of the nearshore development area, as it will be used as a disposal ground for dredge spoil from nearshore construction activities.

7.3.1 Alteration of habitat

Seabed and shoreline disturbance

The construction of Project facilities in the nearshore development area will disturb areas of seabed in Darwin Harbour and parts of the shoreline of Blaydin Point and Middle Arm Peninsula through the following activities:

- dredging and rock armouring for the gas export pipeline through Darwin Harbour
- dredging and blasting for the shipping channel, turning basin, approach area, and berthing area in East Arm to the north and west of Blaydin Point
- using anchors and chains for construction and support vessels
- dredging and trenching for the gas export pipeline shore crossing south of Wickham Point
- constructing the jetty and associated earthworks on the northern side of Blaydin Point
- constructing the module offloading facility and earthworks (with associated dredging) on the eastern side of Blaydin Point.

These activities will cause localised direct damage to soft bottom benthos or rock pavement communities, with biota re-establishing when the substrates have returned to a suitably stable condition. This may be, for example, when sediments deposited on rock pavement areas have been removed by tidal currents. The time frame for recolonisation will depend upon the time taken for the substrate to return to a stable condition and on the motility and reproductive modes of the colonising biota (Guerra-García, Corzo & García-Gómez 2003; Zarillo et al. 2008). An area of hard substrate to be removed at Walker Shoal by drilling and blasting for the shipping channel, represents only a small portion of the hard substrate occurring elsewhere in the Harbour.

The abundance of benthic fauna generally recovers faster than the species diversity. The diversity of recolonising communities will initially be low, with assemblages being dominated by a small number of opportunistic species (WBM Oceanics Australia 2002). Disturbed areas are likely to be recolonised rapidly (days to weeks) by motile animals, while animals with larval phases will only re-establish after the first reproductive event following the period of disturbance. In some habitats, there may need to be a succession of recolonisation events (over perhaps several years) before the community returns to its pre-disturbance composition.

Soft-bottom and subtidal rock pavement communities occur throughout Darwin Harbour (see Appendix 8 to this Draft EIS). The area of these habitats within the disturbance footprint for the nearshore development area is minor in comparison with the areas of similar habitat occurring elsewhere in the Harbour. The viability of these communities in the long term is not considered to be threatened by the seabed disturbance caused by the Project.

Artificial habitat

The presence of the jetty, the gas export pipeline and the module offloading facility in the nearshore marine environment will provide hard substrate for the settlement of marine organisms. Colonisation of the structures over time will lead to the development of a fouling community and will provide prey refuges and visual cues for marine animals such as fish and reptiles.

The gas export pipeline through the Harbour is likely to support a similar marine assemblage to the existing Bayu–Undan Gas Pipeline (see Chapter 3), with a high coverage of animal and plant life such as soft corals, gorgonians, hydroids and algae and moderately abundant fish life (see Appendix 8). This artificial increase in hard-substrate habitat may be viewed as a positive impact by some stakeholders, particularly recreational fishermen.

Overall, the new hard substrates provided by nearshore infrastructure are likely to increase biodiversity and productivity in those areas of the Harbour, similar to the effects of the existing Bayu–Undan Gas Pipeline. If infrastructure is removed at decommissioning, it is expected that the abundance of epifauna will return to its original state.

Changes to hydrodynamics

The potential changes to local hydrodynamic processes such as circulation, inundation and wave propagation as a result of dredging and nearshore construction were investigated in a comparative modelling study by APASA (2010a). The modelling was undertaken using validated hydrodynamic and wave models (BFHYDRO and SWAN respectively, as described in Appendix 5) to represent existing conditions, and modified versions of these models that represented post-construction conditions by incorporating the proposed dredging areas. The full report from this study is provided in Appendix 11 of this Draft EIS.

Investigation of the effects of wind and river flow in East Arm demonstrated that hydrodynamic processes are dominated by tidal forcing. Seasonal and inter-annual variations are therefore relatively small and useful comparisons of changes to hydrodynamics are possible using short-term simulations of 30-day periods. The simulations also included no riverine discharge or land runoff, representing "dry flow" conditions, which are the worst-case scenario for the net migration of waters from the upper reaches of East Arm (see Appendix 11).

Four key parameters were investigated, all of which indicated that the impacts of the dredging program would be minor in scale. The parameters investigated are as follows:

- flushing of East Arm—flushing rates were predicted to decrease by 3–7% in East Arm as a result of dredging. This change can be attributed to a minor decrease in current speeds over the dredging area, which will marginally slow the penetration of water from the main body of Darwin Harbour. The scale of this effect is considered to be minor, and is not expected to cause a significant change in water quality or in retention times for water-borne pollutants.
- changes in current patterns—currents were predicted to decrease by 40–45% on a localised basis over the deeper parts of the dredging area (the turning basin and berthing area), because of the larger cross-section that would be available for movement of the tidal flows. Slight decreases in current speeds were also predicted more widely in East Arm, at lower magnitudes with increasing distance from the edge of the dredging area.
- wave energy—waves in East Arm are usually locally generated by wind, with small wave heights in the order of a few tens of centimetres. Predicted changes to wave heights as a result of dredging were very small (<50 mm) throughout East Arm and should not result in significant changes to wave-generated sediment movement.
- seabed sheer stress—because the current speed in the deeper parts of the dredging area is reduced, seabed sheer stress was also predicted to decrease, resulting in minor increases in sedimentation in the dredged areas (see Appendix 11).

On the scale of East Arm, the overall effects of dredging on the hydrodynamics of the area are considered minor and are not expected to cause significant changes to inundation of intertidal mangrove areas or natural sedimentation and erosion patterns (see Appendix 11). The potential impacts of sedimentation and turbidity on marine habitats are discussed in Section 7.3.2 *Dredging*.

Management of marine habitat

A Provisional Dredging and Dredge Spoil Disposal Management Plan has been compiled (attached as Annexe 6 to Chapter 11), which will guide the development of a series of more detailed plans during the construction and operations phases of the Project. Key inclusions in this plan are as follows:

- Dredging vessels will be equipped with appropriate global positioning system (GPS) equipment and other navigational aids to ensure that dredging will occur only in the specified dredge footprint.
- Anchoring plans and procedures for construction vessels involved in dredging and pipelay will be developed (in consultation with the DPC) to avoid sensitive seabed habitats.

No specific measures are proposed to reduce the artificial habitat provided by the gas export pipeline, the module offloading facility, the product loading jetty and the associated maritime infrastructure in the nearshore development area, as the increase in hard substrate area is not considered to represent an adverse impact upon the nearshore marine environment. Consideration will be given to relocating rock removed from Walker Shoal within the Harbour.

The separate issue of marine pest introduction and establishment on coastal infrastructure is discussed in Section 7.3.9 *Marine pests*.

Residual risk

A summary of the potential impacts, management controls, and residual risk for nearshore marine habitat is presented in Table 7-29. After implementation of these controls, impacts to marine habitats are considered to present a "medium" to "low" risk and are as low as reasonably practicable.

Table 7-29: Summary of impact assessment and residual risk for marine habitat (nearshore)

Aspect	Activity	Potential impacts	Management controls and mitigating factors	Residual risk*		
				C†	L‡	RR§
Seabed disturbance	Dredging and blasting for construction of access to jetty and module offloading facility.	Removal of soft-bottom biota and habitat. Removal of some areas of hard substrate. Provision of new artificial hard substrate habitat.	Soft-bottom habitat is widespread in Darwin Harbour. The disturbance footprint will be minimised where possible within the constraints of infrastructure engineering and operability. Dredging vessels will be equipped with navigational aids to ensure that dredging occurs within the specified dredge footprint. A soft-bottom benthos monitoring program will be put in place. Provisional Dredging and Dredge Spoil Disposal Management Plan. Provisional Piledriving and Blasting Management Plan.	E (B3)	6	Medium
Seabed disturbance	Dredging, trenching and pipelay at pipeline shore crossing.	Removal of soft-bottom biota and habitat. Provision of new artificial hard substrate habitat.	The disturbance footprint will be minimised where possible within the constraints of infrastructure engineering and operability. Anchoring plans and procedures for pipelay construction vessels will be developed to avoid sensitive seabed habitats. Dredging vessels will be equipped with navigational aids to ensure that dredging occurs within the specified dredge footprint. Provisional Dredging and Dredge Spoil Disposal Management Plan.	F (B3)	6	Low
Seabed disturbance	Trenching and rock dumping for construction of gas export pipeline.	Removal of soft-bottom biota and habitat. Provision of new artificial hard substrate habitat.	The disturbance footprint will be minimised where possible within the constraints of infrastructure engineering and operability. Dredging vessels will be equipped with navigational aids to ensure that dredging occurs within the specified footprint. An increase in hard-substrate biota and attraction of fish may benefit recreational fishing resources.	E (B3)	6	Medium
Hydrodynamics	Development of nearshore infrastructure and dredging area.	Reduced flushing of East Arm. Local changes to sedimentation and hydrodynamic processes affecting benthic habitats.	Dredging channel aligned with normal current directions in East Arm. Modelling indicates localised changes to currents and sedimentation only, with minimal impact on flushing processes and waves.	E (B3)	5	Medium

* See Chapter 6 *Risk assessment methodology* for an explanation of the residual risk categories, codes, etc.

† C = consequence.

‡ L = likelihood.

§ RR = risk rating.

7.3.2 Dredging

An extensive dredging program will be required to accommodate the construction of the shipping channel, approach area, turning basin, berthing area, module offloading facility, gas export pipeline and pipeline shore crossing in the nearshore development area, as described in Chapter 4. Disturbance of this volume of seabed sediments will cause sediment transport and deposition to adjacent parts of Darwin Harbour as well as increased turbidity in the water column over a period of time.

Maintenance dredging is expected to be required at approximately 10-year intervals during the operations phase. This would require the removal of relatively small quantities of dredged material, which would cause similar environmental effects but on a significantly lower scale.

In addition, without adequate management controls, land-clearing and excavation activities in the onshore development area could indirectly impact the marine environment through soil erosion and surface runoff. The impacts of this sedimentation are similar to those caused by dredging activities but are likely to occur on a much more localised scale. Terrestrial runoff from exposed coastal soils may also be a source of acid leachate. The marine impacts of this potential decrease in water quality are also discussed in this section.

Predictive modelling

The extent and intensity of sedimentation and turbidity impacts caused by dredging are dependent on a complex variety of factors including tidal currents and seabed morphology. In order to predict the effects of the preliminary dredging program on the nearshore marine environment, HR Wallingford (HRW) was engaged to undertake sediment fate modelling (HRW 2010; see Appendix 13 of this Draft EIS for the full report).

The model was based on a two-dimensional hydrodynamic model of Darwin Harbour, using a repeating spring–neap cycle of tides representative of the wet or dry seasons and a time series of wind data from which to generate wind waves. Flow conditions in the area were predicted using the TELEMAC-2D hydrodynamic solver, which is used to model various phenomena such as tidal flows in estuaries, coastal flows, storm surges, and floods in rivers, and is considered state-of-the-art software. The flow model was set up and validated against a selection of available in situ measurements, including logged current measurements from acoustic Doppler current profilers (ADCPs). Friction forces associated with mangrove roots in coastal areas of the Harbour were integrated into the model using coefficients derived from existing literature. Further details on the development and validation of the hydrodynamic model are provided in Appendix 12 of this Draft EIS.

Sediment plume dispersion was modelled using the SANDFLOW dynamic, non-cohesive sediment transport model developed by HRW. Results of the geotechnical and geophysical investigations of the proposed dredging areas were used as inputs to the model, as the density, consolidation and particle sizes of the substrates influence the behaviour of dredged material in the water column and its settlement on the seafloor.

The predictive modelling presented in this Draft EIS has accommodated uncertainties in source data and information by incorporating conservative assumptions at each stage of the modelling process. For example, assumptions relating to the volume of fine material to be dredged incorporated a conservative estimate, that is the highest proportion of fine fractions, into the predictive model. This approach has therefore delivered conservative modelling outcomes which provide a sound level of confidence on which to base environmental impact and management decisions.

The preliminary dredging program in East Arm was divided into ten phases, including a final 6-month post-dredging period. The nearshore pipeline dredging was also modelled as a discrete activity. Each phase was modelled separately and then added to the others to simulate the combined effect of the full dredging program. A detailed description of the proposed dredging program is provided in Chapter 4. In summary, dredging activity increases steadily over the first six phases, and Phase 6 is considered the “peak” of the program, with several vessels working simultaneously in the berthing area and turning basin. Dredging activity decreases considerably in phases 7 to 9.

The sediment fate model was not designed to provide predictions on near-field effects, which occur close to the dredging vessels. Rather, the model was designed to predict suspended-sediment concentrations and sedimentation in the mid- and far-field ranges, which represent the zones within one or more tidal excursions from the dredging operations. This was considered appropriate for the nearshore development area, as the key environmental receptors of interest (e.g. mangroves and key coral sites) in East Arm and Darwin Harbour are outside the immediate dredging footprint (see Appendix 13).

The main mechanism affecting the marine environment is the release of fine sediment particles (silts and clays) by dredging, as these can remain suspended in the water column under moderate to high current speeds and cause turbid plumes; they can be resuspended by successive tidal currents to travel long distances before settling. The cutter-suction dredger (CSD) is expected to release large volumes of fine materials when compared with a backhoe dredger (BHD) or trailing suction hopper dredger (TSHD). The fine materials released throughout the preliminary dredging

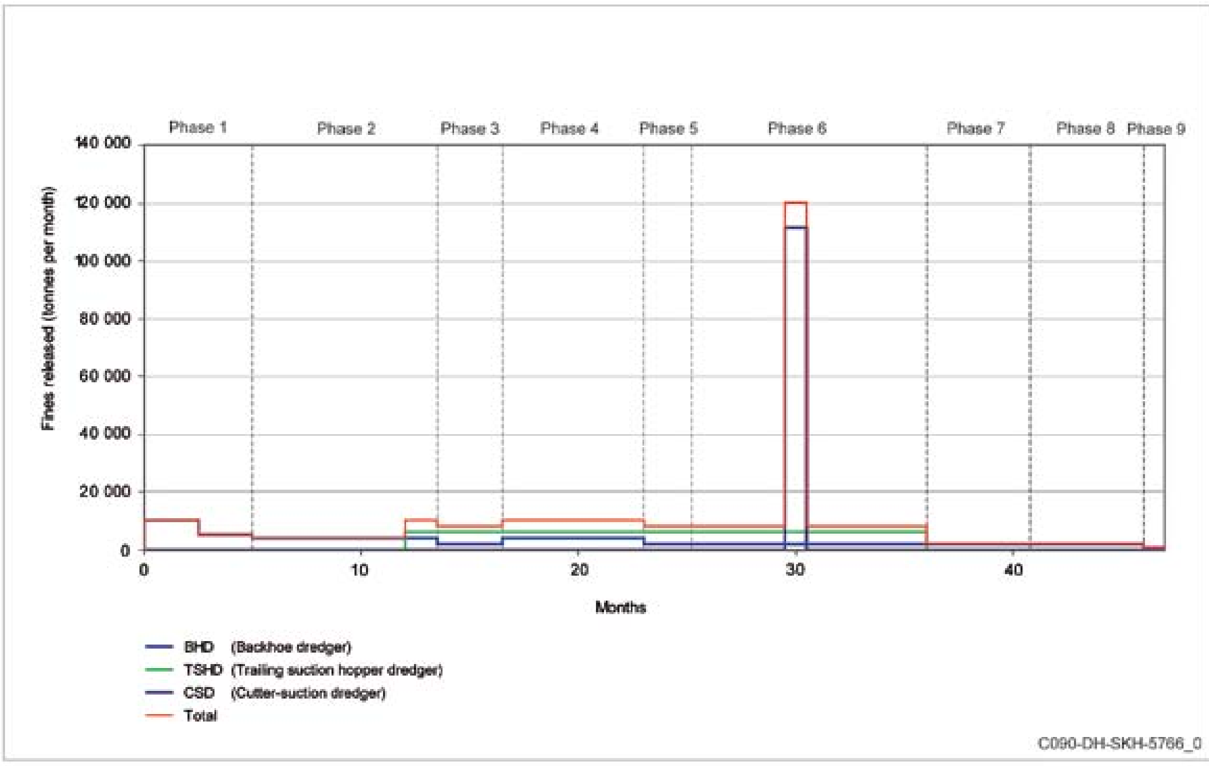

Figure 7-17: Predicted quantities of fine materials released during the dredging program in Darwin Harbour

program are shown in Figure 7-17; the large spike in fines release occurs in Phase 6 when a CSD is required to remove hard substrates from the berthing area. During all other phases of the dredging program, relatively low volumes of fines are released to the nearshore marine environment.

Three mechanisms of potential indirect environmental impacts from the dredging campaign were considered in the modelling study:

- suspended-sediment plumes, caused by the release of fine sediment particles into the water column by dredging, with later resuspension by tidal currents. Elevated suspended-sediment concentrations may lead to impacts upon biota such as corals that are sensitive to reductions in incident light, as well as smothering or damaging filter-feeders like sponges and bryozoans
- shoreline sedimentation, where fine sediments are transported by repeated settlement and resuspension into shallow coastal areas. Build-up of sediment can smother mangrove flora and invertebrate animals
- sand transport, where coarse sediments are shifted across the seabed. Sand build-up could smother benthic organisms such as corals or other invertebrates.

The impacts of sediment build-up on maritime infrastructure and heritage sites around Darwin Harbour are discussed in Chapter 10.

Suspended-sediment concentrations

Predicted suspended-sediment concentrations generated around East Arm at different stages of the dredging program are shown in figures 7-18 to 7-20. These plots represent instantaneous “snapshots” of the plumes predicted during dredging at peak periods during the tidal cycle when water velocity is at its highest. These are shown for both the ebb and flood flows of spring- and neap-tide conditions. Additional plots showing median and 95th percentile suspended-sediment concentrations during each phase are provided in Appendix 13.

The predicted suspended-sediment concentrations generated by dredging activities are provided down to a minimum of 3 mg/L above background, as anything below this concentration is not expected to have significant effects on marine biota and habitats and will rarely be visible in the naturally turbid waters of Darwin Harbour. The predicted concentrations are additional to background concentrations, which range from 1.5 to 83 mg/L in East Arm, with a mean of 15 mg/L (see Appendix 9 of this Draft EIS). As mentioned above, the model does not predict the high concentrations generated very close to the dredging vessels, which may reach levels in the hundreds or even thousands of milligrams per litre.

For all phases of the dredging program, the plumes generated during spring-tide conditions are much larger, and often reach higher concentrations, than those generated during neap tides. This is because spring tides involve greater variations in water levels, with higher current speeds and more extensive flows, than neap tides. The plumes presented for Phase 4 (Figure 7-18) can be considered representative of the spatial extent and suspended-sediment concentrations generated throughout the first two years of dredging (phases 1 to 5). These plumes are confined to East Arm and can reach up to 20 mg/L, with some smaller secondary plumes of higher concentrations developing in shallow intertidal areas (see Appendix 13).

The most intense turbid plumes are predicted for a 6-week period during Phase 6, when the CSD is operating on hard seabed material (Figure 7-19). During ebb-tide conditions at spring tides, these plumes could extend out of East Arm into the main body of Darwin Harbour, past Darwin's central business district. During flood-tide conditions at spring tides, these plumes would reach into Frances Bay, the Elizabeth River, Hudson Creek and other tributaries of East Arm, at concentrations up to 50 mg/L. During neap-tide conditions, however, the suspended sediments generated by this intensive dredging activity remain very localised around the dredging area (see Appendix 13).

The plumes presented for Phase 8 (Figure 7-20) are representative of phases 7 to 10, which include low-intensity dredging activity during the final year of the program and a 6-month period after the program is completed. Beyond the immediate vicinity of the dredgers, almost no suspended sediments above the minimum 3-mg/L level are predicted in East Arm. Some small low-concentration plumes could form in shallow intertidal areas during a spring tide as a result of resuspension (see Appendix 13).

Water-quality objectives for Darwin Harbour set by NRETAS include a long-term suspended-sediment concentration target during dry-season conditions of 10 mg/L (NRETAS 2009). This level is occasionally exceeded under natural conditions as shown in the nearshore water-quality study (see Appendix 9). Generally, dredging will generate suspended sediments above 10 mg/L only in close proximity to the dredging vessels. Under some tidal conditions, however, suspended-sediment plumes of this concentration or higher may be transported up to 10 km from the dredging area (Figure 7-19). Most of the suspended sediments caused by dredging will remain within upper-estuary waters in East Arm and will rarely reach the main body of the Harbour. Suspended-sediment concentrations are predicted to return to background levels throughout the greater part of East Arm during phases 7 to 10 of the dredging program (see Appendix 13).

Dredging for the nearshore pipeline will generate turbid plumes mainly at the shore-crossing area; dredging through the main body of the Harbour will involve low volumes of seabed material and localised short-term increases in suspended sediments only. The pipeline shore crossing is situated in an area of fine sediments across the intertidal and subtidal mudbank and will take around 5 weeks to complete. Median suspended-sediment concentrations generated during this time are predicted to be very low, below 3 mg/L. High concentrations are predicted for a short period during the approach to the second series of spring tides because of the accumulation of fine material on the seabed near the dredge during the previous neap tide. Once the tidal flows obtain sufficient energy, this material would be resuspended and generate a plume. A "snapshot" of this short-term effect is shown in Figure 7-21.

A time series of suspended-sediment concentrations for the entire dredging program at the protected Channel Island coral community is presented in Figure 7-22. Dredging at the pipeline shore crossing occurs at the start of the program (within the period Day 0 – Day 50), and generates peak concentrations of up to 18 mg/L over the coral community. The cyclical peaks in concentrations correspond to spring-tide periods. During neap-tide periods, concentrations fall as the sediments settle from the water column. There are also variations in concentrations within each day, with periods of slack water between ebb and flood tides.

Throughout the four-year dredging program, suspended-sediment concentrations of 10 mg/L above background levels at the Channel Island coral community are predicted to be extremely rare (occurring less than 0.01% of the time) (see Appendix 13).

The sediment fate model also predicts the suspended-sediment concentrations generated at other areas where corals are known to occur in East Arm (Table 7-30). Corals at South Shell Island and north-east Wickham Point will be situated closest to the dredging activities and will receive some exposure to plumes, although still at relatively low concentrations; concentrations above 20 mg/L occur less than 1% of the time at both sites. Corals at Weed Reef are predicted to be exposed to low concentration plumes (5 mg/L) only rarely (less than 0.01% of the time).

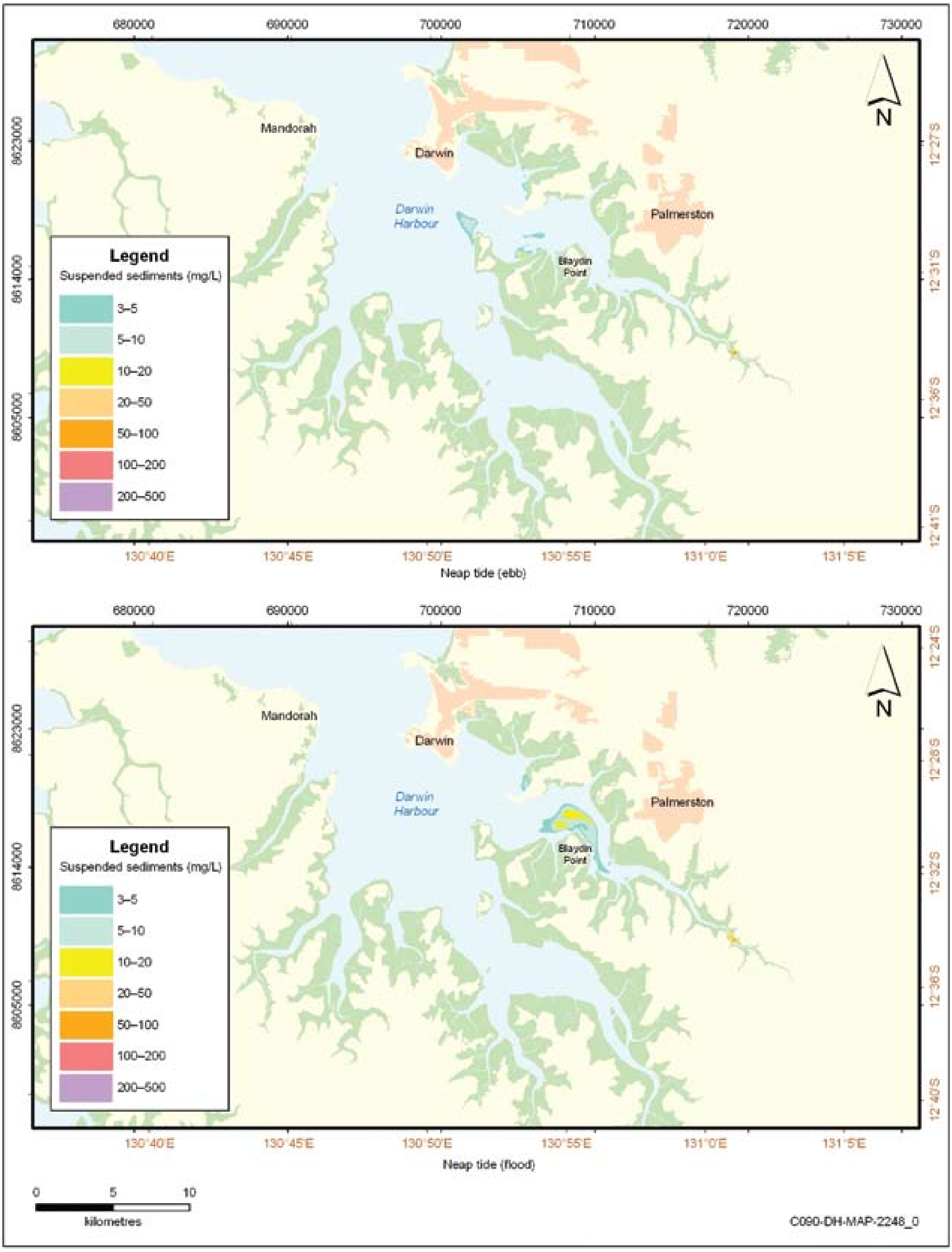

Figure 7-18 (a): Predicted instantaneous suspended-sediment concentrations during a typical tidal cycle in Phase 4 of the dredging program (duration 6.5 months)

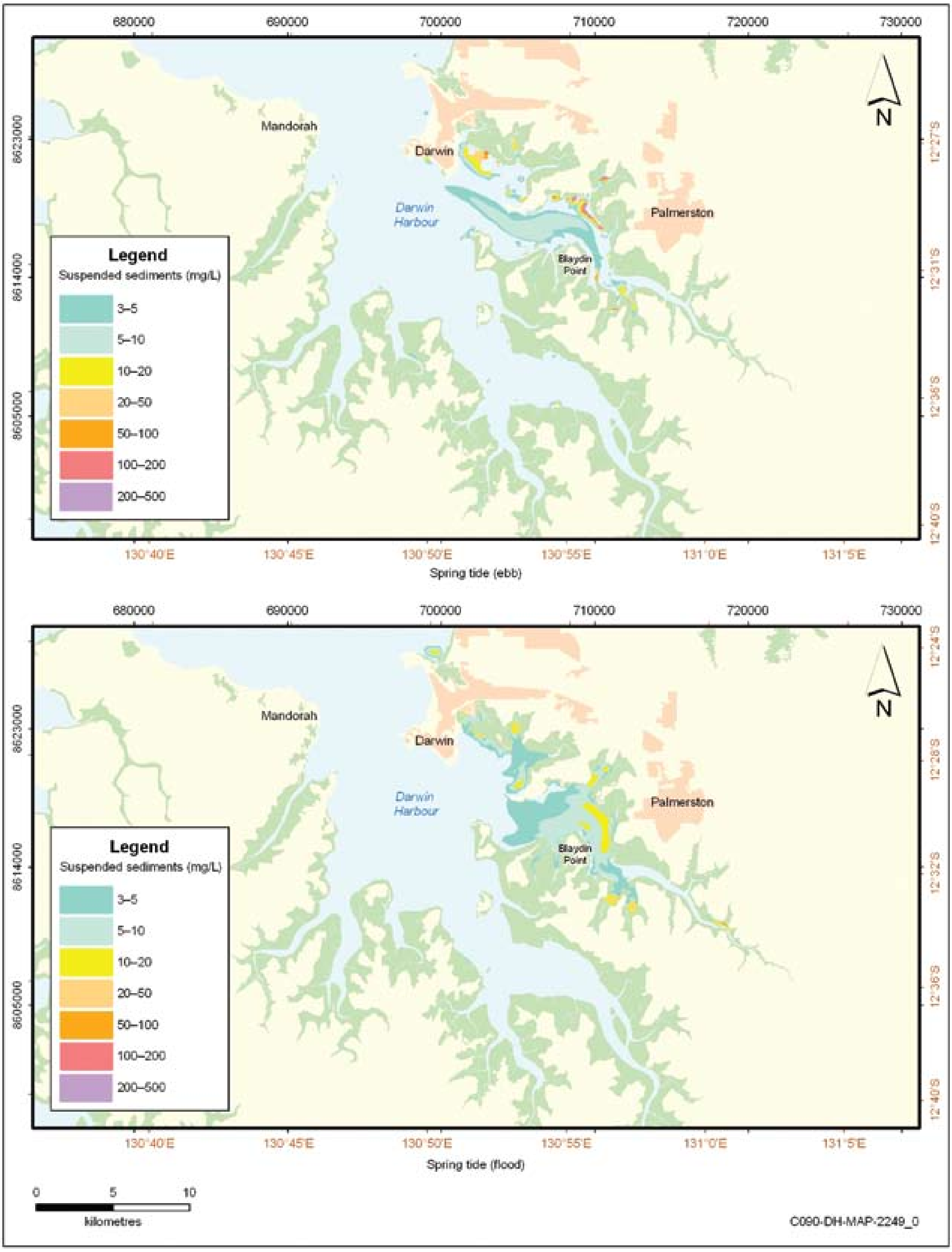

Figure 7-18 (b): Predicted instantaneous suspended-sediment concentrations during a typical tidal cycle in Phase 4 of the dredging program (duration 6.5 months)

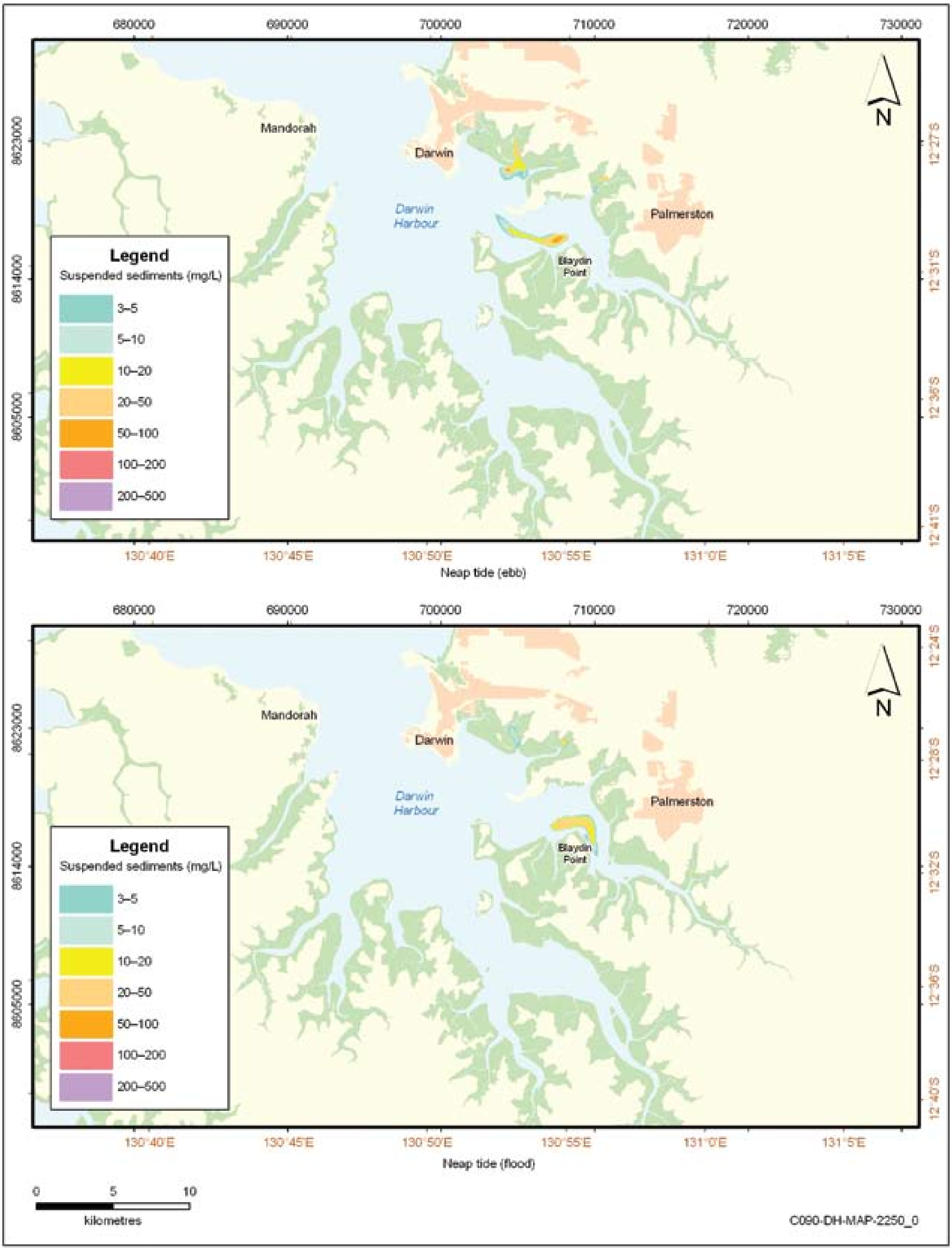

Figure 7-19 (a): Predicted instantaneous suspended-sediment concentrations during a tidal cycle at peak dredging in Phase 6 when the CSD is operating (duration 1.5 months)

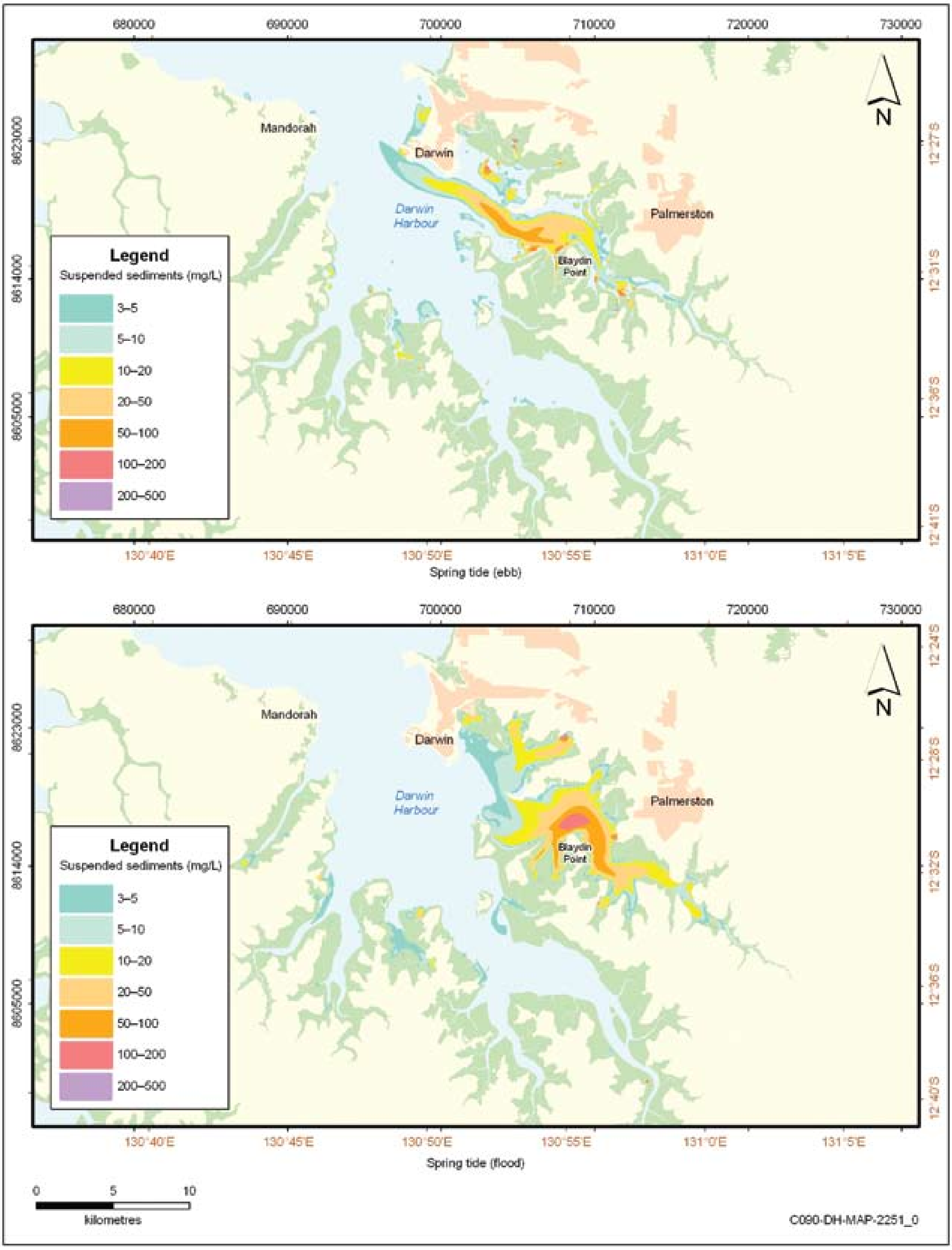

Figure 7-19 (b): Predicted instantaneous suspended-sediment concentrations during a tidal cycle at peak dredging in Phase 6 when the CSD is operating (duration 1.5 months)

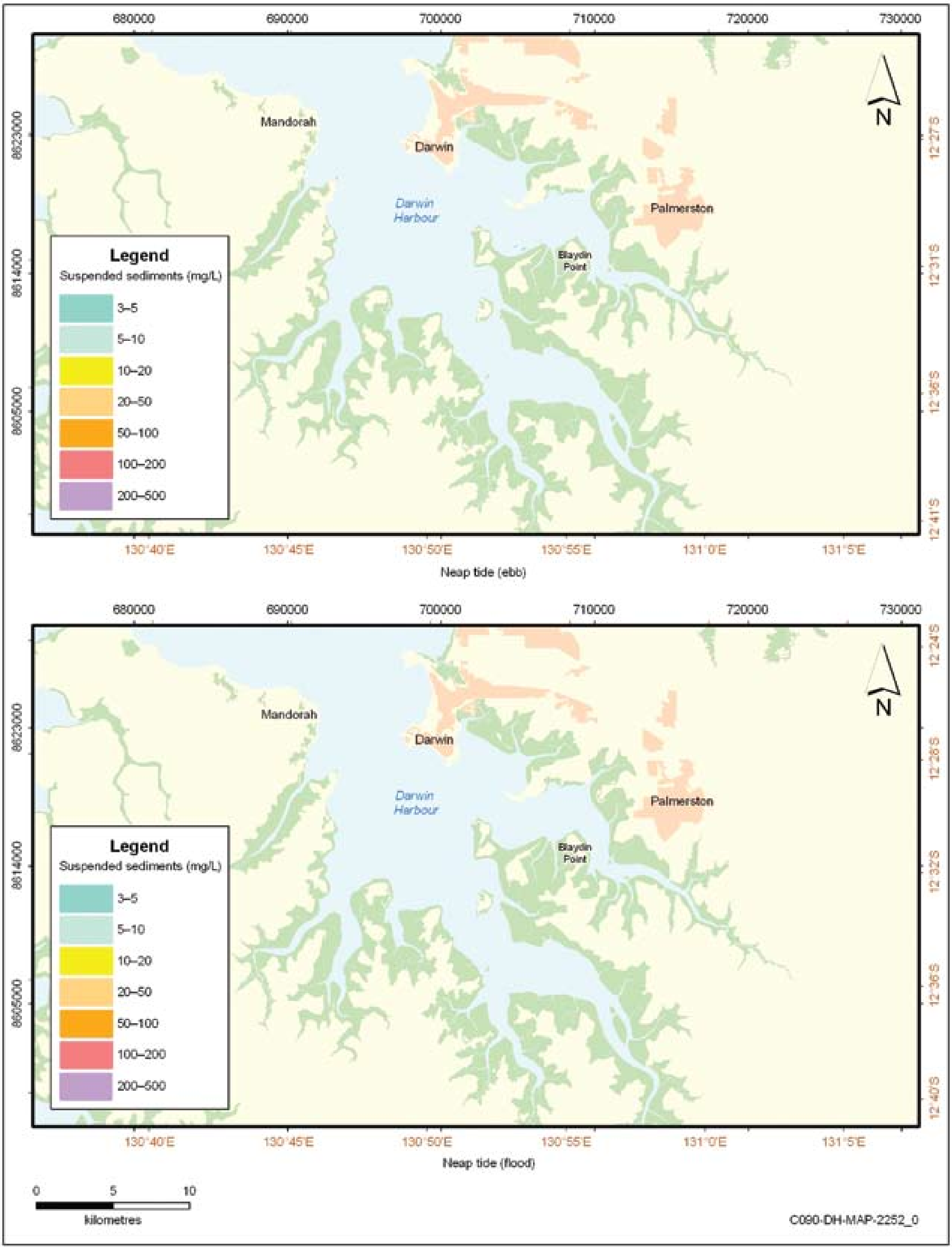

Figure 7-20 (a): Predicted instantaneous suspended-sediment concentrations during a typical tidal cycle in Phase 8 of the dredging program (duration 4.5 months)

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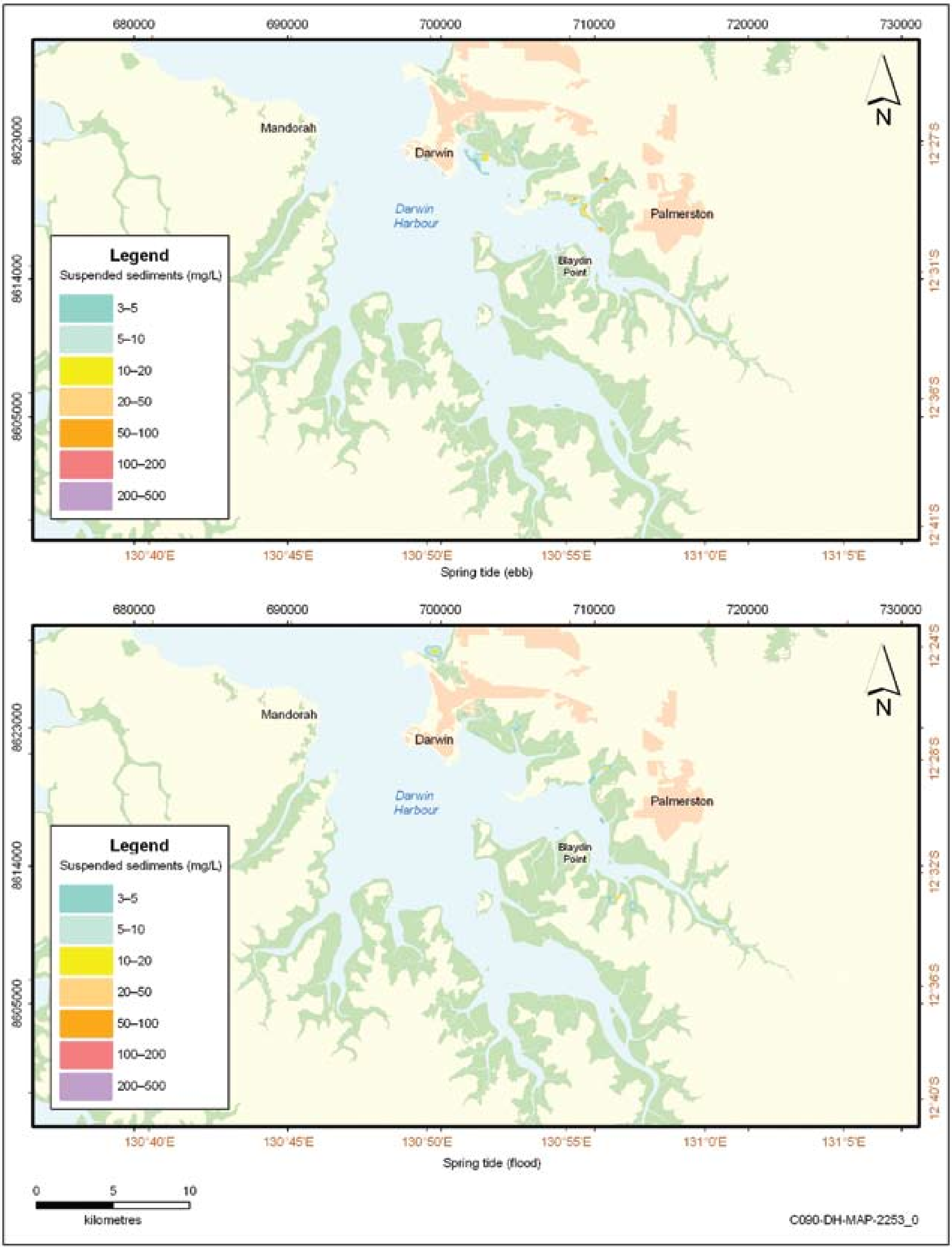

Figure 7-20 (b): Predicted instantaneous suspended-sediment concentrations during a typical tidal cycle in Phase 8 of the dredging program (duration 4.5 months)

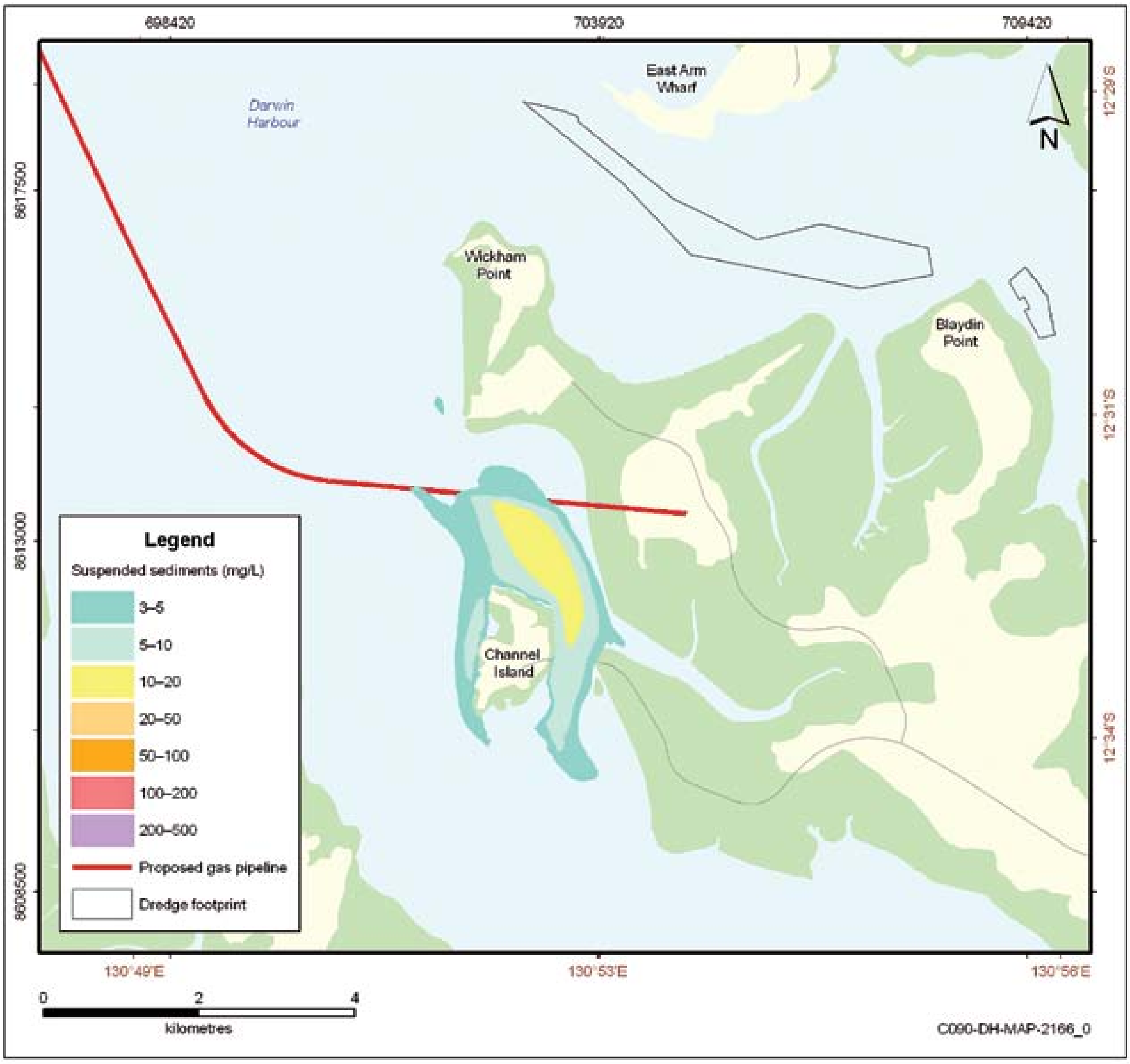

Figure 7-21: Predicted instantaneous suspended-sediment concentrations during dredging for the pipeline shore crossing during the approach to spring tide

Table 7-30: Predicted suspended-sediment concentrations at East Arm coral sites during the dredging program

Suspended-sediment concentrations (mg/L above background)	Percentage of time during which concentrations will be exceeded during the dredging program (%)		
	South Shell Island	North-east Wickham Point	Weed Reef
5	2.33	1.11	<0.01
10	1.09	0.55	0.00
20	0.50	0.16	0.00
50	0.04	0.01	0.00
100	<0.01	<0.01	0.00

Source: HRW 2010.

Shoreline sedimentation

Around the dredging area, ongoing resuspension of fine sediments is predicted to result in the gradual shunting of these materials into shallow areas, where current speeds are slow. Mangrove roots, trunks and leaves have been shown to exert high drag forces on current flows, resulting in sluggish water flow that induces settlement and trapping of suspended sediments in the mangrove fringe. Dredging for the approach area and turning basin is predicted to cause patches of sedimentation in intertidal areas throughout East Arm (Figure 7-23). These are known to be natural depositional areas (DHAC 2006) as described in Chapter 3. This sedimentation would increase gradually until the end of the peak dredging period in Phase 6 (three years into the four-year program).

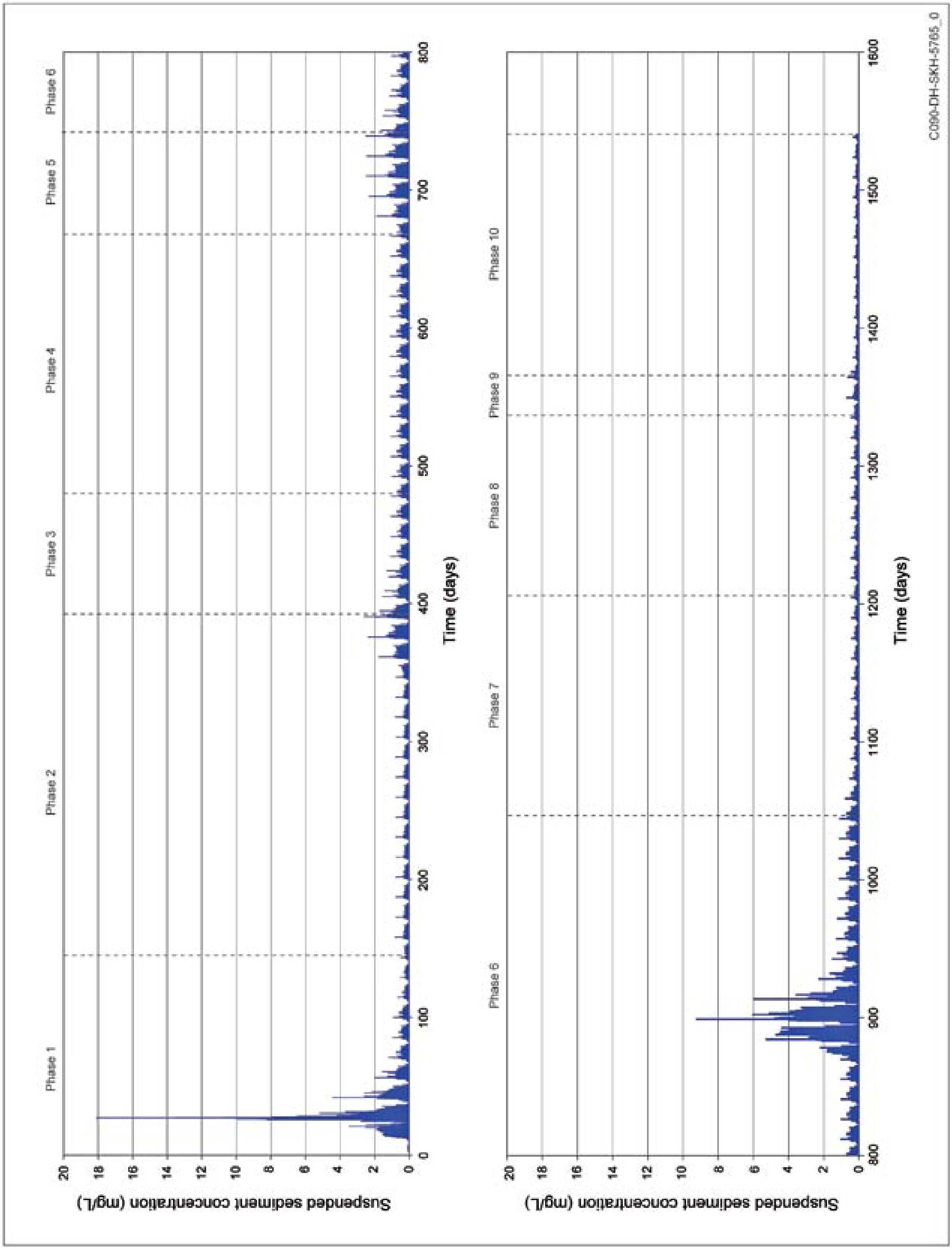

Figure 7-22: Time series of predicted suspended-sediment concentrations at the Channel Island coral community

From Phase 7 onwards, the lower levels of dredging activity result in no net increases in sediment deposition in mangrove areas. Some minor erosion of these accumulated sediments occurs during this time. Net sedimentation patterns at the end of Phase 10 (6 months after dredging) indicate that deposits of fine sediments would still be present in intertidal areas (see Appendix 13). In the long term, tidal currents may erode some of this material while some may be incorporated into the intertidal sediment profile.

Sediment accumulation as a result of pipeline dredging is low and is only predicted to occur in the immediate vicinity of the pipeline shore crossing (see Appendix 13).

Throughout East Arm, the intertidal mangrove zone varies in width and can extend up to 400 m horizontally from the mean low-water level (see the mangrove mapping provided in Chapter 3). Sediments are generally predicted to accumulate along the seaward edge of this zone, but the model also shows some accumulation higher in the profile. Overall, 30 ha of mangrove vegetation is predicted to accumulate more than 50 mm of sediment, and 2 ha of this is predicted to receive more than 100 mm (see Appendix 13).

Sediment accumulation on the subtidal seabed in Darwin Harbour is predicted to occur mainly within the dredging footprint, with little build-up for seabed features such as rock pavement. Sediment accumulation is influenced by the tidal pattern: neap tides allow sediment to settle to the seabed, while spring tides remobilise the sediment into the water column.

Sediment accumulation at coral sites around the Harbour is predicted to be negligible, with less than 1.0 mm of sediment deposition at the South Shell Island, north-east Wickham Point, Weed Reef and Channel Island communities during peak dredging (see Appendix 13).

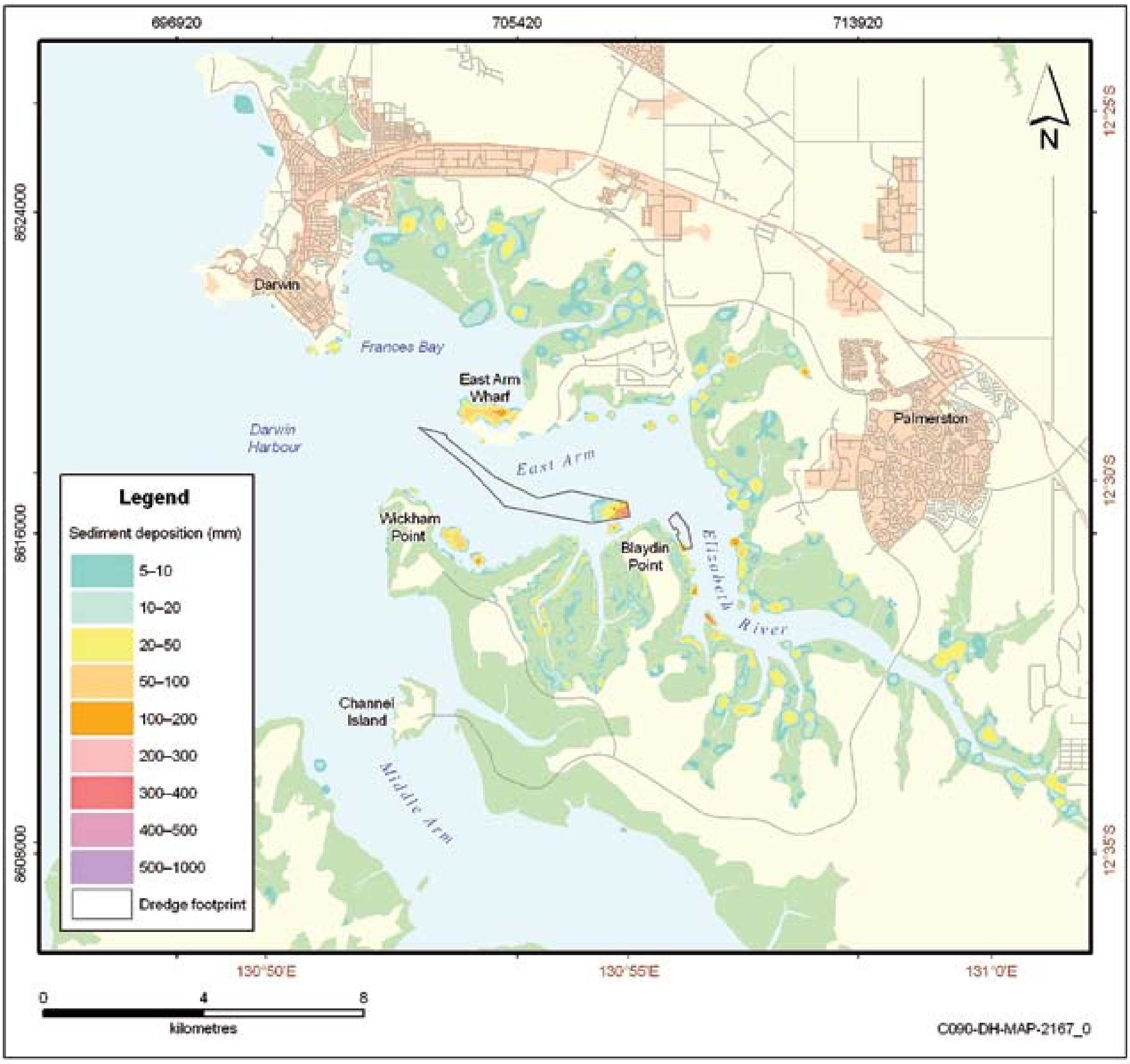

Figure 7-23: Predicted shoreline sediment accumulation at the end of peak dredging in Phase 6

Sand transport

The amount of sand released into East Arm from the dredging program is predicted to be small, in the order of 0.4 Mt, because no overflow from the TSHD is planned. Consequently, the quantities of sands migrating away from the dredging area are also predicted to be small (see Appendix 13).

Modelling of sand transport throughout East Arm indicates that the seabed is mobile under existing conditions, with a net flood-dominant transport pattern into East Arm. During and after dredging, there is predicted to be little change to the magnitude and direction of tidal currents and sand transport patterns in the western portion of the dredging area (the shipping channel). However, some sandy material could migrate from the eastern end of the dredging area (turning basin and berthing area) towards the north-east in the early stages of the dredging program. This pattern would be consistent with the alignment and migration of well-formed sand waves that already occur in this part of East Arm (Smit 2009). The total accretion outside the dredging footprint is estimated to be a few centimetres in depth (see Appendix 13).

At the end of dredging, the deepened areas in the turning basin and berthing area are predicted to cause currents to slow appreciably. Sand transport at the base of this pocket would decrease as a result and this part of the dredged area is predicted to form a trap for sandy material (see Appendix 13).

Impacts on marine habitats

Mangroves

Key adaptations of mangrove plant species to the intertidal environment are specialised aerial-root systems that allow root respiration in anaerobic, waterlogged soils. These occur in the form of cable roots and pneumatophores (vertical roots) in the genera *Sonneratia* and *Avicennia*, and in the form of prop or stilt roots, or buttressed trunks, in the genera *Rhizophora*, *Camptostemon* and *Ceriops*.

Mangroves are known to promote sedimentation in the intertidal zone, as their stems and roots can significantly reduce the velocity of tidal water through a combination of friction acting on water movement and sediment flocculation. Natural sediment accretion rates at a variety of sites worldwide were reported by Ellison (1998) at generally less than 5 mm/a, but reached up to 10 mm/a. These levels were apparently tolerable, causing no negative effects on plant growth.

Excess input of sediment to mangrove communities can cause tree stress owing to smothering and burial of root systems. Impacts can range from reduced vigour to death, depending on the amount and type of sedimentation and the mangrove species involved. A review of sediment burial of mangroves in Australia and internationally (Ellison 1998) describes mangrove degradation or death from sediment deposition depths of between 50 and 2000 mm. The response of different mangrove species to root burial does not appear to be standardised and is likely to be a function of root architecture, tidal range, sediment composition and grain size. In the Australian examples, deaths of *Avicennia marina* were caused by sedimentation depths of 120–500 mm, and deaths of *Rhizophora* spp. were linked to sediment depths of 500–700 mm (Ellison 1998).

Similar differences in species tolerance to sedimentation were observed at a cyclone-affected site north of Exmouth, Western Australia, and this was attributed to the specialised root architecture of each species (Biota 2005). The pneumatophores of *A. marina* were largely, but not completely, buried by the sediment deposited in the mangrove zone, causing widespread tree deaths. However, the more elevated and exposed “stilt” root system of *Rhizophora stylosa* remained above the new sediment level and the trees displayed minimal signs of stress. The lenticels (gas-exchange pores) on *R. stylosa* roots were typically more than 100 mm above the normal sediment height, providing a level of tolerance to changes in sediment levels (Biota 2005).

Sonneratia alba woodland dominates the seaward margin of the mangrove zone throughout East Arm (see the mangrove mapping by Brocklehurst and Edmeades (1996), provided in Chapter 3). Behind the *S. alba* zone in East Arm, the most frequently occurring assemblages include the following:

- *Rhizophora stylosa* closed forest
- *Rhizophora stylosa – Camptostemon schultzii* closed forest
- low open woodland, consisting of scattered *Sonneratia alba*, *Rhizophora stylosa* and *Avicennia marina*
- *Ceriops tagal – Avicennia marina* low closed forest
- *Ceriops tagal* low closed forest.

Of these mangrove communities, the *Ceriops tagal – Avicennia marina* low closed forest assemblage is likely to be the most sensitive to sedimentation, because of the dependence of *A. marina* on fine pneumatophores that would potentially be coated or buried by sediment.

While Ellison (1998) noted that there are insufficient data available to establish specific tolerances, on the basis of existing literature it is considered that sedimentation levels of up to 50 mm would be generally tolerable by the mangrove communities throughout East Arm, regardless of the species affected. Above this level of sedimentation, *S. alba* and *A. marina* would be most at risk of decreased growth or death. At sedimentation levels above 100 mm, tree deaths in *S. alba* and *A. marina* are considered likely. *Rhizophora* trees can be expected to tolerate higher levels of accretion, up to 200 mm.

It is also noted that many of the sediment burial events described by Ellison (1998) resulted from instances of rapid sediment deposition (e.g. from floods, cyclones or short-term human disturbance) that occurred over a few days or weeks. Therefore these threshold levels may be very conservative when applied to the sedimentation levels predicted in East Arm mangroves over four years of dredging.

As described earlier in this section, modelling predicts that around 2 ha of mangroves will be affected by sedimentation of 100 mm or more over the first three years of the dredging program, which equates to roughly 35 mm per year. In addition, there are some 28 ha predicted to receive net sedimentations of between 50 and 100 mm, or 17–35 mm per year. It is possible that the more sensitive mangrove species (e.g. *Sonneratia*, *Ceriops* and *Avicennia*) could be at risk of reduced plant growth or even localised death, at net deposition rates between 50 mm and 100 mm, and that some tree deaths are likely at net sedimentation rates of >100 mm. Given that 20 450 ha of mangrove vegetation occurs around the inner shores of Darwin Harbour (see Chapter 3), the relative scale of this potential loss as a result of sedimentation is very low, representing between 0.01% and 0.15% of the total area respectively for the 50-mm and 100-mm deposition thresholds.

Biota (2005) suggests that mangroves are well equipped to regenerate from disturbances such as sedimentation. The intertidal zone in Darwin Harbour is an inherently dynamic environment and the large tidal range, along with extreme events such as cyclones, causes natural sediment movement. In the Exmouth example, evidence of mangrove recovery was recorded in surveys five years after the cyclone damage occurred. Seedling recruitment of *Avicennia marina* was reported to be widespread and locally abundant at this stage (Biota 2005).

Invertebrate animals associated with the mangrove root zone can also be affected by increased sedimentation. Invertebrates are an important component of the intertidal ecosystem as they contribute to carbon- and nutrient-cycling and support animals at higher trophic levels. In addition, burrowing by intertidal invertebrates locally aerates the soil and creates conduits for water and nutrient exchange in the mangrove muds (OzCoasts 2010).

According to Norkko et al. (2002), sediment deposition affects mangrove invertebrates in a number of ways:

- by physically smothering the sediment surface, causing anoxia
- by changing the sediment grain size, affecting rates of invertebrate movement and sediment biogeochemistry
- by enhancing turbidity, with implications for suspension feeder and primary productivity
- by changing the sediment food quality.

In Darwin Harbour, seaward assemblages support the highest diversity and abundance of the invertebrate fauna of the mangrove zones, with peak species richness in the dry season, particularly for polychaete worms. Wet-season monsoon conditions generate wave action, typically leading to erosion of surface sediments in the seaward mangroves and subsequently lowering the abundance of invertebrate animals (Metcalfe 2007).

Polychaete diversity and density is particularly affected by sediment properties such as grain size and silt content. An increase in fine sediment deposition in the seaward mangrove zone may facilitate an increase in deposit-feeding polychaetes, which consume detritus in marine sediments.

Bivalve (mollusc) species are filter-feeders and strain suspended matter and food particles from the water column. Bivalves are found across all mangrove assemblages, but in greatest abundance on the seaward edge. These species would be disadvantaged by sedimentation and may decrease in abundance and diversity as a result (Norkko et al. 2002).

Metcalfe (2007) recorded clear differences in invertebrate species composition between landward and seaward mangrove assemblages. Changes in sediment levels and microtopography could result in a shift of species composition for species such as gastropods (snails) and crustaceans (crabs). For crab species, the size of sediment is strongly correlated with foraging and feeding mechanisms for digestion. Sediment accumulation could displace some crab species but could provide a suitable environment for others.

In terms of grain size and chemical qualities, the composition of sediments accumulating in the intertidal zone will be similar to the existing sediments in those areas. Any invertebrate fauna communities displaced by sedimentation from dredging activity will be able to recolonise the areas.

Hard-coral communities

Sedimentation and turbidity are major causes of degradation of scleractinian corals (Cortés & Risk 1985; Hodgson 1990; Pastorok & Bilyard 1985; Rogers 1983). Sediment affects coral by smothering when the particles settle out, by reducing light availability through turbidity and potentially reducing coral photosynthesis and growth (GBRMPA undated). Excessive sedimentation and turbidity can alter both biological and physical processes, may reduce growth and calcification rates and, if persistent, will cause coral bleaching and death (Rogers 1983; Torres & Morelock 2002; Wesseling et al. 1999). Sediments deposited on coral tissues can cause necrosis through smothering or bacterial infection, and suspended sediments can abrade polyps (Hodgson 1990; Rogers 1983; Wesseling et al. 1999).

Hard corals can rid themselves of sediments by exuding mucous secretions that slough off in tidal currents and return the sediments to the water column. However, this process is metabolically expensive and cannot be sustained in the long term or at high sedimentation levels.

Where mass mortality of corals occurs, the coral reef may not recover, particularly if the subsequent recruitment of corals is also affected. Species composition in these areas can shift to a community dominated by macroalgae.

Offshore coral reef communities are generally regarded as being adapted to low-turbidity and low-nutrient conditions. In contrast, nearshore and coastal communities have evolved in relatively turbid environments where suspended sediment and turbidity are primarily influenced by local wind and wave regimes (GBRMPA undated). However, the extent and severity of impacts in nearshore areas are highly variable and depend on a range of factors including the coral species affected, sediment concentration, grain size, water depth and water temperature (Rogers 1990).

Coral assemblages can persist in areas subject to periods of high natural turbidity and sedimentation (e.g. during cyclones and river floods). These events expose corals to high concentrations of suspended solids and high sedimentation rates for short periods of time. Generally, the species composition of coral communities in areas regularly exposed to these perturbations is different from the composition of clear-water communities. Taxa resilient to turbidity and sedimentation dominate in these areas and the coral assemblage can survive the short-term impacts from these stressors. Erftemeijer and Reigl (2008), for example, in a review of 53 studies exploring differences in sensitivity of corals to sedimentation and turbidity from dredging, suggested that minimum light requirements of corals can be as low as <1% of surface irradiance and that their tolerance to suspended-sediment concentrations can be up to 165 mg/L in marginal nearshore reefs. Maximum tolerable sedimentation rates of >300 $mg/cm^2 \cdot d^{-1}$ were found and the duration that corals could survive high sedimentation rates was found to be more than 14 days for very tolerant species (Erftemeijer & Riegl 2008).

Dredging in the nearshore development area will generate plumes of turbid water that will periodically impinge upon adjacent hard-coral communities, such as those at South Shell Island and off the north-east coast of Wickham Point. The extent of adverse impacts upon these communities will depend upon how close the corals are to their limits of tolerance of sedimentation and to their critical light limits, but given the naturally turbid estuarine environment in Darwin Harbour, it is likely that these species are adapted to periods of low light levels.

The predicted depths of accumulated sediment on coral sites adjacent to the dredging area are negligible (<1 mm), as tidal currents are predicted to resuspend any fine sediments that fall on these areas during periods of slack water. However, it is noted that the model does not account for the small lumps and crevices that form the outer surfaces of corals, and that some fine sediments may be trapped within these that cannot be removed by ambient currents. While some coral polyps may be able to remove this sediment by secretion of mucus, there may be small patches or parts of individual corals that suffer some reduced growth or death as a result of sedimentation.

The coral species that occur in East Arm also exist elsewhere in Darwin Harbour (see Appendix 8) and it is considered that there is good potential for the recovery over time of any areas affected by the dredging program as natural recruitment will gradually rejuvenate the communities.

The Channel Island coral community will be exposed to pulses of decreased light availability during dredging at the pipeline shore crossing. These pulses of turbid water will coincide with peaks in natural background turbidity levels (i.e. under spring-tide conditions). There will also be periods during neap tides where higher incident light levels will be available to light-sensitive biota (such as hard corals), allowing photosynthetic activity to return to natural levels. The levels of suspended sediments predicted for the Channel Island coral community are not expected to result in decreased growth or coral mortality as they are relatively low and short in duration. The area will be subject to monitoring and management controls (described below) given its status as a protected natural heritage area. In the unlikely event of impacts to the coral community as a result of dredging, it is considered that any decline in coral abundance will be reversible over time as natural recruitment replenishes the community.

Other benthic communities

Removal of soft- and hard-bottom benthic communities by dredging activities (i.e. direct impacts) are discussed in Section 7.3.1 *Alteration of habitat*. The potential for indirect impacts from turbid plumes and sand transport upon these communities is as follows:

- Soft-coral and sponge (filter-feeder) assemblages could be smothered, resulting in mortality, where relatively high rates of sedimentation occur, such as in areas of subtidal pavement or rock near the dredging area in East Arm. If the accumulated sediment is subsequently removed by natural processes, the re-exposed hard substrate is likely to be recolonised by similar soft-coral and sponge assemblages. While the sediments remain in place, they are likely to be colonised by soft bottom communities typical of those existing across broad areas of the Harbour seafloor. The low levels of sedimentation predicted for South Shell Island and north-east Wickham Point (<1 mm) are unlikely to smother filter-feeders.
- Impacts upon soft-coral and sponge assemblages will also occur where suspended-sediment loads increase to the level that clogging of their respiratory and feeding structures occurs. At sublethal levels of increased turbidity, these filter-feeding communities may benefit from the release of organic matter from the sediments by the dredging works.
- Smothering of soft-bottom communities in East Arm, which have been shown to consist predominantly of amphipods, polychaetes and bivalves (see Appendix 8), could occur in areas close to the dredging footprint. While immobile animals may be smothered by incoming sediments, some infauna may be able to tolerate thin layers of deposition. WBM Oceanics Australia (2002) cites a Florida-based study that provides several examples of polychaete and bivalve species that were able to reach the surface following burial by 210 mm of sediment, and notes that some species are able to move horizontally to escape. This corresponds with observations by Smit (2009) of polychaetes on the lee side (the most mobile part) of sand waves in East Arm. Smit hypothesised that these worms would have to grow outwards to compensate for the continuous accretion of mobile sediments, or that they may be opportunistic users of this habitat and have a high turnover.
- Benthic communities downstream from the dredging area may benefit from an increase in the availability of food resources transported in turbid plumes. A monitoring program after dredging in Moreton Bay, Queensland, recorded higher abundances and diversity of benthic organisms than normal for that area, at sites 1.5–2.0 km downstream of the dredging operation (WBM Oceanics Australia 2002).

As the soft-coral, sponge and soft-sediment communities of the nearshore development area are well represented elsewhere in the Harbour, the chance of the dredging program having significant impacts upon the ecology of these marine communities on a Harbour-wide scale is considered very low. Localised losses near the dredging area are expected to recover through recruitment from unaffected communities nearby.

Marine mammals

The most commonly recorded cetacean species in Darwin Harbour are the coastal dolphins—the Australian snubfin, the Indo-Pacific humpback and the Indo-Pacific bottlenose (as described in Chapter 3).

Various studies suggest that dolphins can forage for prey successfully in turbid waters. Although they are known to have well-developed vision, which assists in predator avoidance and social interaction, as their eyes do not point forward their use of vision in pursuit of prey may be limited and they may rather detect their prey using echolocation (Mustoe 2006). In his report, Mustoe notes that dolphins are commonly observed in turbid water where vision would not be of any significant benefit; for example, feeding by stirring up mud to find bottom-dwelling fish and crustaceans, and feeding in plumes created by vessels, where they may be exploiting demersal fish species that are exposed by propeller wash.

Similarly, Australian snubfin dolphins have often been observed foraging in turbid, shallow areas around river mouths, and Indo-Pacific humpback dolphins are found in slightly deeper waters, including dredged channels (Parra 2006). Turbid plumes that occur in East Arm as a result of dredging may be utilised similarly by dolphins for foraging.

The known foraging habitats of snubfin and Indo-Pacific humpback dolphins are in coastal and estuarine waters less than 20 m deep, close to river mouths and creeks, with foraging undertaken in mangrove communities, seagrass beds and sandy-bottom environments through to open coastal waters with rock and/or coral reefs (DEWHA 2010), as described in Chapter 3. These diverse marine environments, with the exception of seagrass beds, occur widely throughout Darwin Harbour and regionally. The river mouth, sandy-bottom substrate and mangrove areas affected by dredging in East Arm represent only a small portion of this available habitat.

Dugong foraging habitats in Darwin Harbour such as rocky reefs at Weed Reef and Channel Island are not expected to be impacted by turbid plumes from dredging. Dugongs may avoid Channel Island during the period of dredging activity at the pipeline shore crossing because of the turbid plumes, noise and general vessel movements in the area; however, this period of disturbance will last for a relatively short 5-week period.

Fish

The fish stocks in East Arm represent a food-chain link between benthic communities and carnivorous marine animals (e.g. dolphins), as well as an important resource for recreational fishing and tourism. Fish, including recreationally important species such as barramundi, mangrove jack, jewfish and bream, may be attracted into the areas disturbed by dredging to feed upon invertebrates liberated from the seafloor sediments or upon the smaller fish attracted to the disturbance. Dolphins may also feed upon fish attracted to the vicinity of the dredges. The carnivorous fish species and dolphins that feed in the upper reaches of Darwin Harbour are likely to be adapted to detecting prey in turbid water. Most fish have a lateral-line system that detects vibrations and assists them to locate prey and to avoid predators (Allsop et al. 2003).

The effects of the dredging operation upon some fish species may therefore be an increase in feeding activity and, potentially, an increase in predation. There may also be some mortality of fish because of physical clogging of their gills by turbid plumes. These types of injuries, however, are caused by very high suspended-sediment concentrations, for example 4000 mg/L as reported by Jenkins and McKinnon (2006). These concentrations are expected to be very rare during Project dredging, even adjacent to the dredging equipment.

Fish eggs and larvae are more vulnerable to suspended sediments than older life stages. Jenkins and McKinnon (2006) reported that levels of suspended sediments greater than 500 mg/L are likely to produce a measurable impact upon larvae of most fish species, and that levels of 100 mg/L will affect the larvae of some species if exposed for periods greater than 96 hours. Levels of 100 mg/L are also likely to affect the larvae of a number of marine invertebrate species (e.g. abalone, sea urchins and bivalves). The sensitivity to suspended sediments of larvae in species local to Darwin Harbour has not been researched. However, based on this assumed "threshold" concentration of 100 mg/L, suspended-sediment levels that could damage fish eggs and larvae could only occur in close proximity to the dredger.

As noted in Chapter 3, Darwin Harbour contains very little suitable spawning habitat for barramundi. It is considered unlikely that dredging activities will disrupt any migration pathways of fish out of Elizabeth River as the turbid plumes will not form a barrier across East Arm. The habitats available to fish in East Arm are similar to those that occur throughout the Harbour.

Marine reptiles

Marine turtles may utilise a wide range of habitats throughout Darwin Harbour for foraging. The potential habitat for green, hawksbill and flatback turtles is presented in maps in Chapter 3. Flatback turtles in particular are known to feed in turbid, shallow waters (DEWHA 2010) and are unlikely to be affected by plumes from dredging. Green turtles and hawksbill turtles, which feed on rocky reefs, sponge and soft-coral areas, and mangroves, may avoid turbid plumes but will be able to utilise unaffected adjacent habitats.

Seasnakes and crocodiles are likely to be accustomed to turbid conditions as they regularly frequent shallow coastal areas and mangroves. They are not expected to be impacted by plumes from the dredging program.

The risk of entrainment of turtles in dredging equipment is discussed in Section 7.3.10 *Marine megafauna*.

Acid sulfate leachate

Some soils and sediments at the pipeline shore crossing, along the onshore pipeline route, and in the ground flare and module offloading facility construction areas are potentially acid-generating if exposed to air (see sections 3.3.5 and 3.4.4 of Chapter 3 *Existing natural, social and economic environment* and Section 8.2.2 of Chapter 8 *Terrestrial impacts and management*). Sulfuric acid leachate can decrease the pH of surrounding waters and can mobilise metals in the disturbed sediments, increasing their availability to enter the food chain.

Fish deaths caused by water acidity are the most obvious and localised impacts of acid sulfate leachates in the marine environment. Chronic effects such as reduced hatching and decline in growth rates could impact marine biota on a wider scale. Acid water also affects the health of fish and other aquatic life through damage to the skin and gills—skin damage increases the susceptibility of fish to fungal infections, while both gill and skin damage reduce the ability of fish to take in oxygen or regulate their intake of salts and water (Sammut et al. 1995). In extreme cases, marine water acidity could cause damage to shellfish and corals as the acid conditions dissolve bicarbonate-based shell material.

The potential for acute impacts upon the nearshore marine environment from leachates will be limited to those periods when the cut surfaces of acid-generating soils are exposed to the air. A natural mitigating factor is the regular tidal inundation of most areas that are prone to acid generation; the lower oxygen environment underwater will suppress further leachate formation and the water will dilute and at least partially neutralise any acid generated.

Chronic impacts from leachates could only arise if acid-generating soil surfaces remained in an oxygenated environment, where ongoing leaching of metals from the sediments could occur. However, the metal loads released would decrease over time as metal concentrations in the sediments declined. Further, the large tidal exchanges occurring across the intertidal areas would lead to rapid dilution of any metals leached from the sediments.

Mangrove muds are naturally acidic as a result of the high levels of organic matter and the waterlogged conditions. Sedimentation of the shoreline by fine materials released during dredging is not expected to generate additional acidification that could affect plants and animals in the mangrove community. Testing of the subsurface marine sediments in the dredging area does indicate that many areas contain potential acid sulfate soil (see Chapter 3). However, when released into the water column, these fine sediments will be mixed with sea water and are expected to be neutralised by dissolved carbonates. Upon their arrival at the intertidal zone, fine sediments from dredging will be similar in composition to the normal marine sediments deposited in the mangroves and are not expected to represent an additional acid sulfate or heavy-metal contamination risk.

As described in Chapter 8, acid sulfate soils will be the subject of a dedicated management plan and monitoring program.

Management of dredging

A Provisional Dredging and Dredge Spoil Disposal Management Plan has been compiled for the Project (attached as Annexe 6 to Chapter 11), which will guide the development of a series of more detailed plans during the construction and operations phases. Key inclusions in this plan are discussed below.

Mangroves

An intertidal sedimentation monitoring program will be developed to assess the effects of sediment accretion on mangrove communities within selected areas of East Arm. The monitoring program will include:

- a baseline assessment of mangrove health and sediment levels at key potential impact sites and suitable reference sites
- quarterly rapid-assessment surveys of mangrove health at the monitoring sites to detect short-term and localised changes in tree condition and canopy cover. Sediment depths will also be measured, using a surveying method appropriate to the small-scale changes (i.e. centimetres) that may occur.

If mangrove tree deaths result because of sedimentation from the dredging program (and are not attributable to natural causes or activities external to the Project), rehabilitation of the affected areas will be undertaken after the completion of dredging activities through a combination of natural recruitment, facilitated natural recruitment and active planting.

East Arm

- A coral monitoring program will be developed to investigate the degree of resilience of corals in East Arm to exposure to sedimentation and elevated turbidity. Monitoring sites at South Shell Island and north-east Wickham Point that were established for previous dredging activities at East Arm Wharf (GHD Pty Ltd 2002) will be used. Video transects and photographic records of the coral communities at these sites will be established prior to the commencement of dredging, with monitoring carried out during dredging and after dredging. Any changes in coral cover or health will be assessed against turbidity data collected adjacent to the sites. As in the earlier East Arm Wharf dredge monitoring programs, coral communities at Weed Reef and Channel Island will be used as reference sites. During the construction of the pipeline shore approach and crossing, only Weed Reef will be suitable as a reference site because of the proximity of the construction activities to Channel Island. During the preparation of the pipeline route, when the dredger will be operating in the vicinity of Weed Reef, only Channel Island will be suitable as a reference site.

- A soft-bottom benthos monitoring program will be developed, with pre- and post-dredge sampling of these benthic communities to identify any changes occurring as a result of the dredging program. Monitoring sites are likely to include the embayment to the east of Wickham Point, as well as suitable reference areas.
- A marine sediments and bio-indicators monitoring program will be developed to assess any increase in bioavailable heavy metals as a result of excavation of acid sulfate soils during the construction phase.

Pipeline shore crossing

A reactive coral monitoring program will be developed to actively manage the dredging, trenching and excavation works at the pipeline shore crossing in order to protect the nearby Channel Island coral community. The program will be similar to those implemented for other developments in Darwin Harbour (e.g. the construction of East Arm Wharf and the installation of the Bayu–Undan Gas Pipeline), and will guide the implementation of management controls during dredging. The monitoring program will comprise the following:

- A 12-month baseline assessment of turbidity levels will be undertaken at the Channel Island coral community and at the reference location at Weed Reef.
- Trigger levels will be developed for turbidity at the Channel Island coral community. As turbidity in Darwin Harbour varies markedly with tidal cycle (neap vs spring tides) and season (wet vs dry season), a matrix of trigger levels may be required.
- A baseline assessment of representative colonies of the coral genera *Herpolitha*, *Mycedium* and *Turbinaria* will be undertaken at both Channel Island and Weed Reef.
- Aerial observations will be made at the commencement of dredging at the pipeline shore crossing to ascertain the potential for surface plumes to impinge upon the Channel Island coral community. These will be undertaken during spring tides when the distance travelled by the plumes will be maximised, and during neap tides when the density of the plumes will be greatest because of the slower tidal currents.
- Turbidity logging will be carried out during dredging at the pipeline shore crossing to ascertain whether near-bottom plumes (not detectable from the air) are reaching the Channel Island coral community.
- If turbidity trigger levels at the Channel Island coral community are exceeded, coral monitoring will be undertaken to determine whether significant coral mortality has occurred at Channel Island compared with the Weed Reef reference site. ("Significant coral mortality" is defined as a percentage of coral mortality relative to the baseline condition of corals at the site. This will be assessed using methods adopted for recent dredge monitoring programs in north-west Western Australia (EPA 2007)).
- If significant coral mortality is recorded along with high turbidity levels, management controls, such as temporary suspension of dredging activities during certain phases of the tidal cycle, will be implemented.
- In the event of significant coral mortality, follow-up monitoring of the Channel Island coral community will also be undertaken after the dredging program is completed. The frequency and duration of post-dredging monitoring would depend on the degree of mortality recorded and will be carried out in consultation with NRETAS.

Residual risk

A summary of the potential impacts, management controls, and residual risk for the turbidity and sedimentation effects of dredging is presented in Table 7-31. After implementation of these controls, impacts to marine habitats are considered to present a "low" to "medium" risk.

Table 7-31: Summary of impact assessment and residual risk for dredging (nearshore)

Aspect	Activity	Potential impacts	Management controls and mitigating factors	Residual risk*		
				C†	L‡	RR§
Turbid plumes	Dredging for construction of jetty, module offloading facility and pipeline.	Sedimentation and turbidity impacts to coral communities in the vicinity, leading to reduced growth or death.	Corals found in East Arm occur at other sites throughout Darwin Harbour. Tidal currents assist in removing sediment from coral surfaces. Provisional Dredging and Dredge Spoil Disposal Management Plan.	E (B3)	4	Medium
		Sedimentation and turbidity impacts to soft-coral and sponge communities.	Soft-coral and sponge communities in East Arm occur at other sites throughout Darwin Harbour. Tidal currents assist in removing sediment from soft-coral and sponge surfaces.	E (B3)	5	Medium
		Sedimentation and turbidity impacts to fish eggs and larvae.	Turbid plumes decrease to relatively low levels at mid- and far-field distances. Mangrove habitats utilised for fish breeding are extensive and widespread throughout Darwin Harbour.	E (B3)	5	Medium
		Reduction in available habitat and food resources for coastal dolphins.	No significant breeding or foraging areas for these species are known in the nearshore area. Dolphins may benefit from foraging opportunities around plumes. Other similar habitat within and near Darwin Harbour will remain unaffected by turbid plumes.	E (B1)	4	Medium
		Reduction in available habitat and food resources for marine turtles.	No significant breeding or foraging areas for these species are known in the nearshore area. Other similar habitat within and near Darwin Harbour will remain unaffected by turbid plumes.	E (B1)	4	Medium
		Reduction in available habitat and food resources for dugongs.	Key dugong habitats at Channel Island and Weed Reef are not predicted to be affected by plumes. No significant seagrass habitat exists in the nearshore area. Macroalgal communities occur throughout Darwin Harbour and most will not be affected by turbid plumes.	E (B1)	3	Medium
	Dredging for pipeline shore crossing.	Sedimentation and turbidity impacts to protected Channel Island coral community, leading to reduced growth or death of benthic biota.	The dredging program in the vicinity of Channel Island is brief in duration. The corals are likely to be adapted to a high-turbidity environment. Reactive coral monitoring program. Provisional Dredging and Dredge Spoil Disposal Management Plan.	E (B3)	3	Medium

Table 7-31: Summary of impact assessment and residual risk for dredging (nearshore) (continued)

Aspect	Activity	Potential impacts	Management controls and mitigating factors	Residual risk*		
				C†	L‡	RR§
Sand transport	Dredging for construction of jetty, module offloading facility and pipeline.	Smothering of soft-sediment biota in East Arm.	Sand transport already occurs under existing current flows. The benthic biota are sparse and likely to be adapted to sand movement. Soft-sediment biota are well represented throughout the Harbour.	F	5	Low
Coastal sedimentation	Dredging for construction of access to jetty and module offloading facility.	Sedimentation of mangroves around East Arm, causing reduced plant growth or death. Localised deaths or reduced growth of invertebrate animal communities.	If mangrove tree deaths result because of sedimentation from the dredging program (and are not attributable to natural causes or activities external to the Project), rehabilitation of the affected areas will be undertaken after the completion of dredging activities through a combination of natural recruitment, facilitated natural recruitment and active planting. The mangrove zone is likely to receive regular influxes of sediment and the invertebrate fauna is likely to be tolerant or to recover quickly. Intertidal sedimentation monitoring program. Provisional Dredging and Dredge Spoil Disposal Management Plan.	E (B2)	4	Medium
Acid sulfate soils	Excavation of mangrove mud for construction of pipeline shore crossing and module offloading facility.	Acid sulfate soil leaching, reducing marine water quality. Reduced health of intertidal marine animals as a result of acid or toxic metal levels in local waters.	Daily tidal movements will dilute nearshore waters and flush leachates from the local area. Excavation volumes will be minimised where possible. Marine sediments and bio-indicators monitoring program. Provisional Acid Sulfate Soils Management Plan.	E (E1)	3	Medium

* See Chapter 6 *Risk assessment methodology* for an explanation of the residual risk categories, codes, etc.

† C = consequence.

‡ L = likelihood.

§ RR = risk rating.

7.3.3 Dredge spoil disposal

The large volume of spoil to be dredged in the nearshore development area will be disposed of at an offshore site to the north of Darwin Harbour around 12 km north-west of Lee Point, as described in Chapter 4. Some of the spoil deposited in this area will be transported by the prevailing currents and will cause turbid plumes in surrounding waters.

Chemical properties of dredge spoil

The qualities of sediments in the nearshore development area were characterised through 151 surface samples and 18 subsurface samples as described in Chapter 3. Typically, surface sediments of fine to coarse sands and gravel-sized particles were recorded in the main shipping channel and turning-basin area, with higher proportions of fine particles in areas close to shore at the areas proposed for the pipeline shore crossing and the module offloading facility. Subsurface sediments were found to include phyllite and sandstone bedrock, as well as some silts and clays.

Sediment quality was assessed through laboratory testing, with metal and contaminant levels compared against the National Ocean Disposal Guidelines for Dredged Material (NODGDM)[9] (the full results are provided in Appendix 9). Metals concentrations were consistently low with the exception of arsenic, which is commonly recorded at elevated levels in the Darwin region and is likely to be an indication of local geology rather than the result of anthropogenic contamination. Laboratory testing using acid digests showed that arsenic in dredged material is unlikely to be toxic in the marine environment, as only very small proportions dissolved into a bioavailable form. Other contaminants such as tributyltin were not recorded above the minimum limits of laboratory testing and petroleum hydrocarbons were below the limits for the majority of sites. The recorded concentrations of tributyltin and petroleum hydrocarbons do not pose a contamination risk when disposed of in dredge spoil (see Appendix 9).

Acid sulfate soil risks were identified in over one-third of the sediment quality samples, which indicates the potential to generate sulfuric acid when the dredged sediments are exposed to oxygen (air) (see Appendix 9). Any acid-generating material deposited underwater at the offshore spoil disposal ground will be exposed to air for only a brief period, during transit from the dredging area in the hopper vessel. Hopper loads will contain a considerable amount of water, minimising the exposure of dredged material to air. Sea water is naturally alkaline and has a moderate acid-buffering capacity because it contains dissolved carbonate and bicarbonate ions. Underwater disposal is an accepted treatment method for acid sulfate soil because of its negligible potential for adversely impacting upon the marine environment through acidification or release of metals.

Dispersion of dredge spoil

As described in Chapter 4, the offshore disposal site was selected in consultation with NRETAS, the DPC, the Marine Safety Branch of the Department of Planning and Infrastructure (DPI)[10], local shipping companies and the Amateur Fishermen's Association of the Northern Territory (AFANT). Local shipping companies identified the route from Howard Passage to Darwin Harbour as an important navigation channel, where disposal of solid material could pose a hazard to the under-keel clearance of ships if not appropriately managed. AFANT identified a need to protect recreational and commercial fishing areas such as Charles Point Patches and the Lee Point artificial reefs from sedimentation impacts caused by the dredge spoil disposal activities. The main concern of NRETAS was to avoid sediment deposition on Darwin's northern beaches and adjoining seagrass zones, while the DPC wanted to be sure that sediments would not return to the Harbour to infill dredged shipping channels.

Site selection

In order to select a suitable disposal site, short-term predictive modelling of sediment dispersion was completed by APASA for a total of nine potential sites (Figure 7-24) (APASA 2010b; see Appendix 14 of this Draft EIS for the full report). A boundary-fitted hydrodynamic (BFHYDRO) model was developed for Darwin Harbour and its surrounds to simulate tidal flows, current velocities, salinity and temperature distributions. Spoil disposal by a hopper vessel was simulated at each of the test areas using the SSFATE sediment fate model (see Appendix 5 for a description of the models).

Simulations involved discharges of 5000 m^3 of spoil at regular 3-hour intervals over approximately 26 days. Modelling focused on the fate of sediments immediately after the main spoil mass had struck the seabed and caused the billowing of finer sediments back into the water column. To account for seasonal effects, simulations were repeated using wind, tide and current data samples from representative wet- and dry-season periods (see Appendix 14).

Simulations of the currents affecting Beagle Gulf and the entrance to Darwin Harbour indicated that the continental shelf bathymetry produces marked steering effects on the tidal currents. Tidal currents offshore from the headlands of Darwin Harbour flow roughly east at flood tide and west at ebb tide. The main drainage channel into the Harbour trends north-west and flooding tides are steered and accelerated along the axis of this entrance channel. Ebbing tides display the reverse trend, diverging and slowing with distance offshore along the channel. Therefore the speed and direction of tidal currents vary throughout the area, which would influence the patterns of transport of sediments suspended by disposal or subsequently resuspended by currents and waves (see Appendix 14).

Shear stress at the seabed is predicted to be highest in shallow areas near the Harbour entrance channel and to decrease with increasing depth. Wave action and swells influence seabed shear stress, reducing the stability of sediments in shallower waters. The rate of remobilisation was predicted to reduce markedly in water depths greater than 12 m (see Appendix 14).

9 It is noted that the National Ocean Disposal Guidelines for Dredged Material (NODGDM) were formally replaced by the National Assessment Guidelines for Dredging 2009 (NAGD) in May 2009, although the two sets of guidelines are very similar. The marine sediments study was completed in 2008 and referenced the NODGDM.

10 The Northern Territory's Department of Planning and Infrastructure was restructured in December 2009. The Marine Safety Branch is now part of the Department of Lands and Planning.

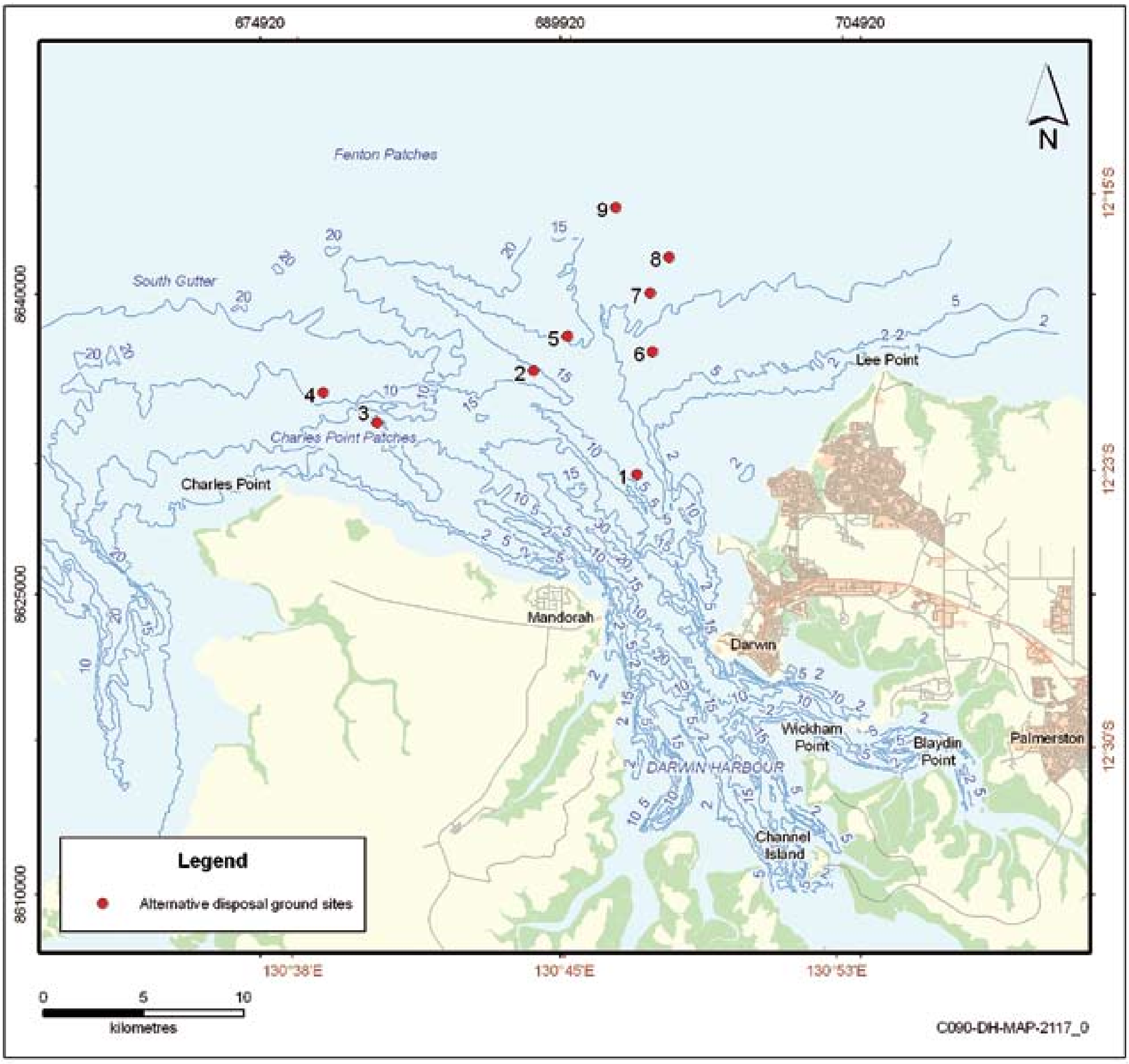

Figure 7-24: Sites outside Darwin Harbour which were considered for offshore spoil disposal

Three example simulations are presented in figures 7-25 to 7-27, showing the highest predicted deposition rates (mm/h) around each disposal site as a result of spoil disposal. Note that the outer contours represent the full field of effect over the duration of the simulation and the internal details highlight the worst expected sedimentation rate for each location. Maximum deposition values occur at different times at each location and sediments redistribute over time within the field of effect; for this reason the results should not be interpreted as cumulative loads (see Appendix 14).

Site 1 is positioned in a water depth of 12 m in the main tidal channel leading into Darwin Harbour. Plumes of fine sediments generated by spoil disposal at this site were predicted to drift up to 15 km, with low-level deposition at Darwin's northern beaches, Fannie Bay and on the shore adjacent to Darwin's central business district. Site 3 is located in a water depth of 10 m north of Charles Point Patches, where the tidal currents draw plumes of fine sediments towards the Harbour entrance. Relatively high sedimentation rates (>10 mm/h) were also predicted at Charles Point Patches when disposal at this site coincided with ebbing tides. Site 9 was positioned in the deepest water (at a depth of 15 m), it was considered optimal for spoil disposal as fine sediments drifted north-east and west with the tides without impinging upon Darwin Harbour or inshore habitats (see Appendix 14).

Site 9, while showing good potential for dispersal of dredge spoil in the long term, was found to be located close to a shipping route for vessels travelling between north-eastern Australia and Darwin Harbour.

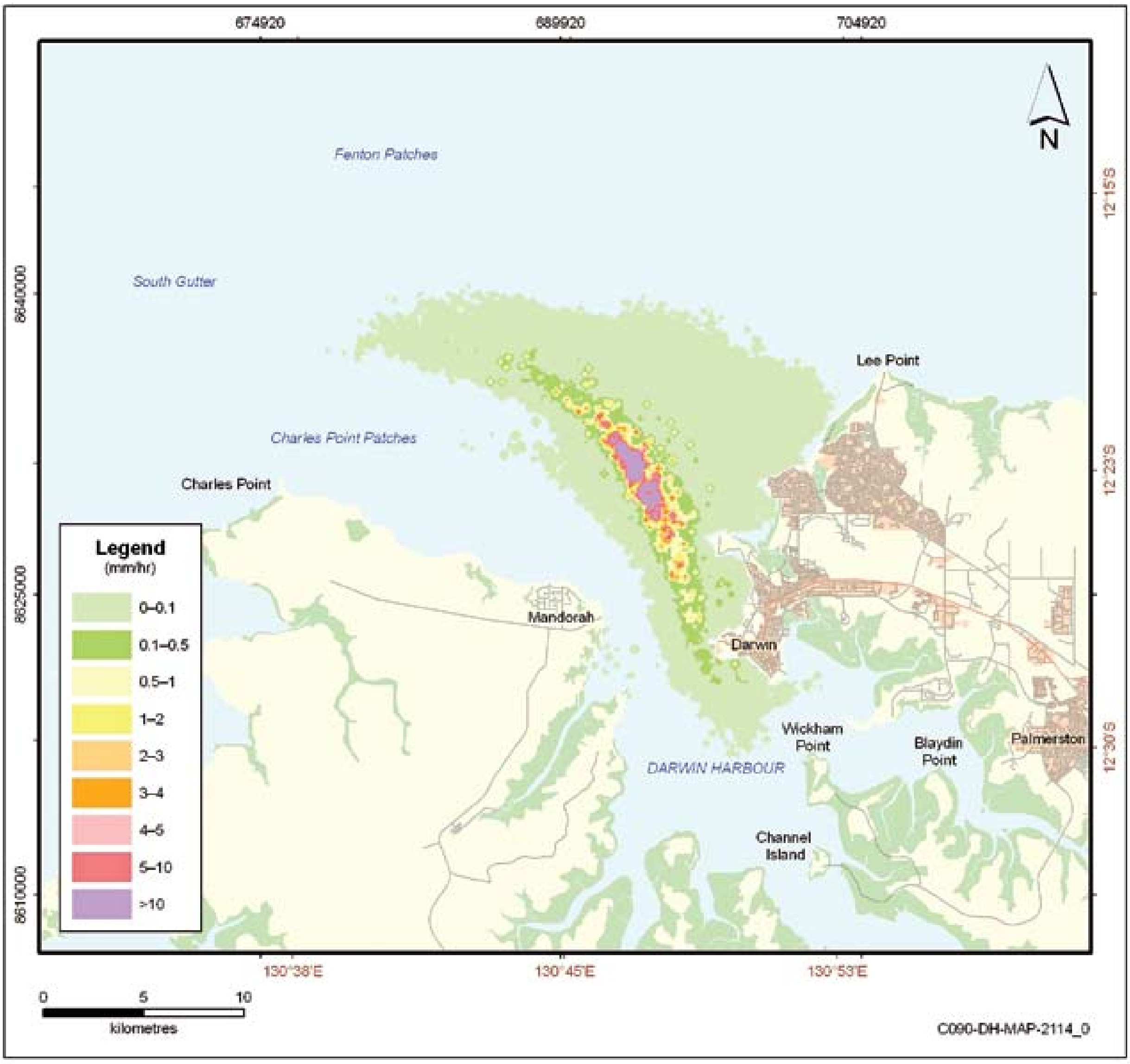

Figure 7-25: Site 1: predicted maximum hourly sediment deposition rate

In order to avoid reducing the under-keel clearance for commercial ships passing near the spoil deposits, which could affect ship handling and safe navigation, Site 9 was shifted slightly north-east to deeper water and lengthened to align with the main tidal axis. This tenth site was finally selected as the offshore spoil disposal ground.

Predictive modelling of spoil disposal

Predictive modelling of sediment dispersal at the selected offshore spoil disposal site for the preliminary dredging program was carried out by HRW, using the TELEMAC-2D flow model and the SANDFLOW sediment transport model (HRW 2010; see Appendix 13 for the full report). Similarly to the nearshore dredge modelling (see Section 7.3.2), the study provided insight into three mechanisms of environmental impact:

- suspended-sediment plumes
- shoreline sedimentation
- sand transport.

The effects of offshore spoil disposal on shipping navigation are described in Chapter 10.

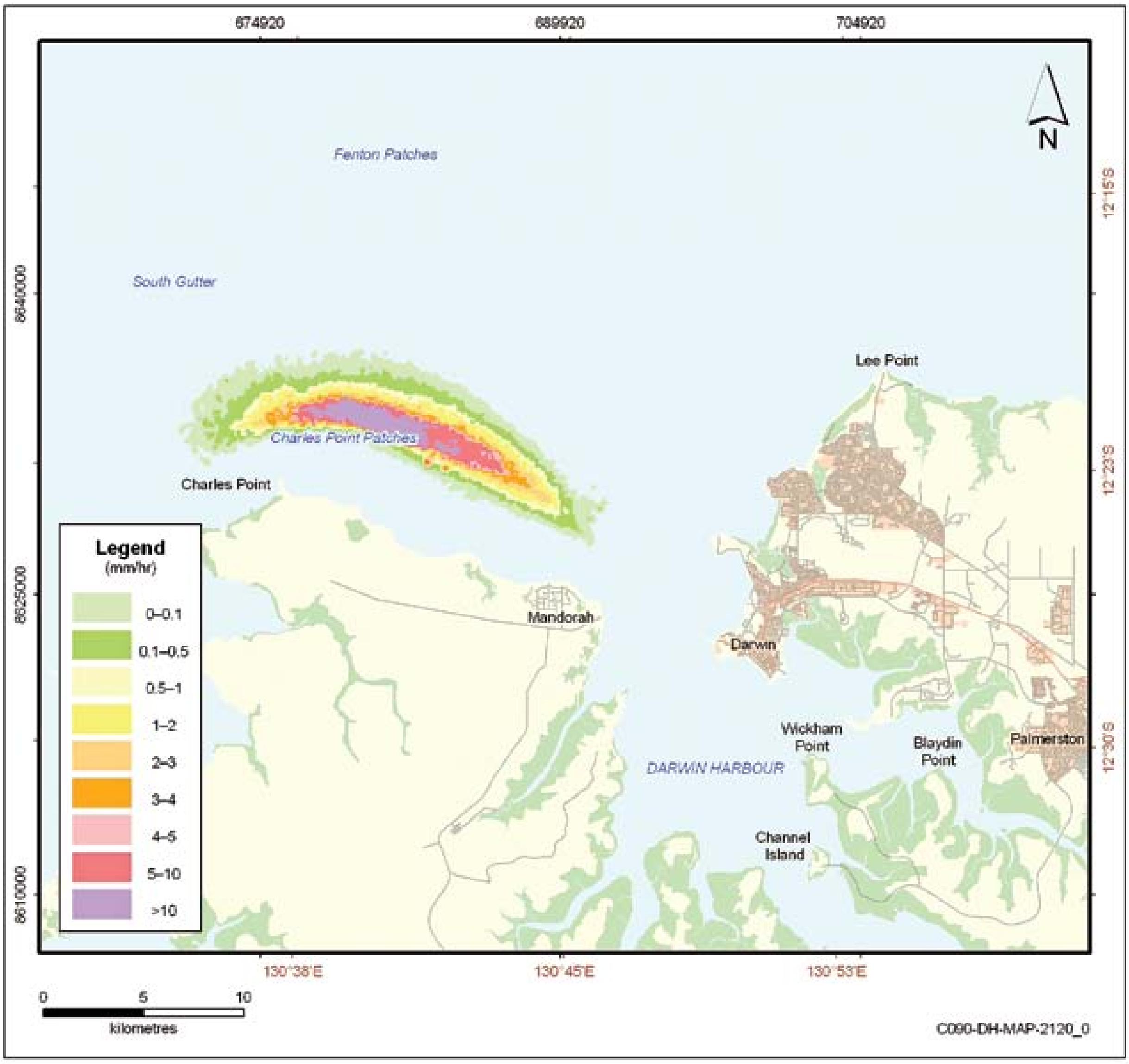

Figure 7-26: Site 3: predicted maximum hourly sediment deposition rate

Suspended-sediment plumes

Fine-grained materials will be transported mainly to the north-east of the spoil disposal ground by tidal currents. These plumes would travel close to the seabed and will rarely be visible from the ocean surface. The largest plumes will be generated during Phase 5 of the dredging program. The median size of these suspended-sediment plumes is shown in Figure 7-28; the plumes are predicted to be smaller than these half of the time, such as during neap tides, and larger half of the time, during spring tides. The predicted median suspended-sediment concentrations are low, with a maximum of 5 mg/L generated in offshore waters to the east of the spoil ground (see Appendix 13).

To understand the increased transport of sediments during spring-tide conditions, the 95th percentile suspended-sediment plume is shown in Figure 7-29. This represents the peak of spoil disposal activities. The 95th percentile concentrations represent the maximum size that plumes could reach during the majority of the worst-case conditions. These plumes are predicted to be much more extensive, reaching coastal waters from Lee Point through to Shoal Bay, Gunn Point and around the Vernon Islands at concentrations of 5–10 mg/L. Some higher concentrations, in the 10–20 mg/L range, could occur in some areas, including the Howard River. During other phases of the spoil disposal program the spatial extent of the plume is predicted to be significantly smaller and peak concentrations in the Howard River are lower, in the 5–10 mg/L range (see Appendix 13).

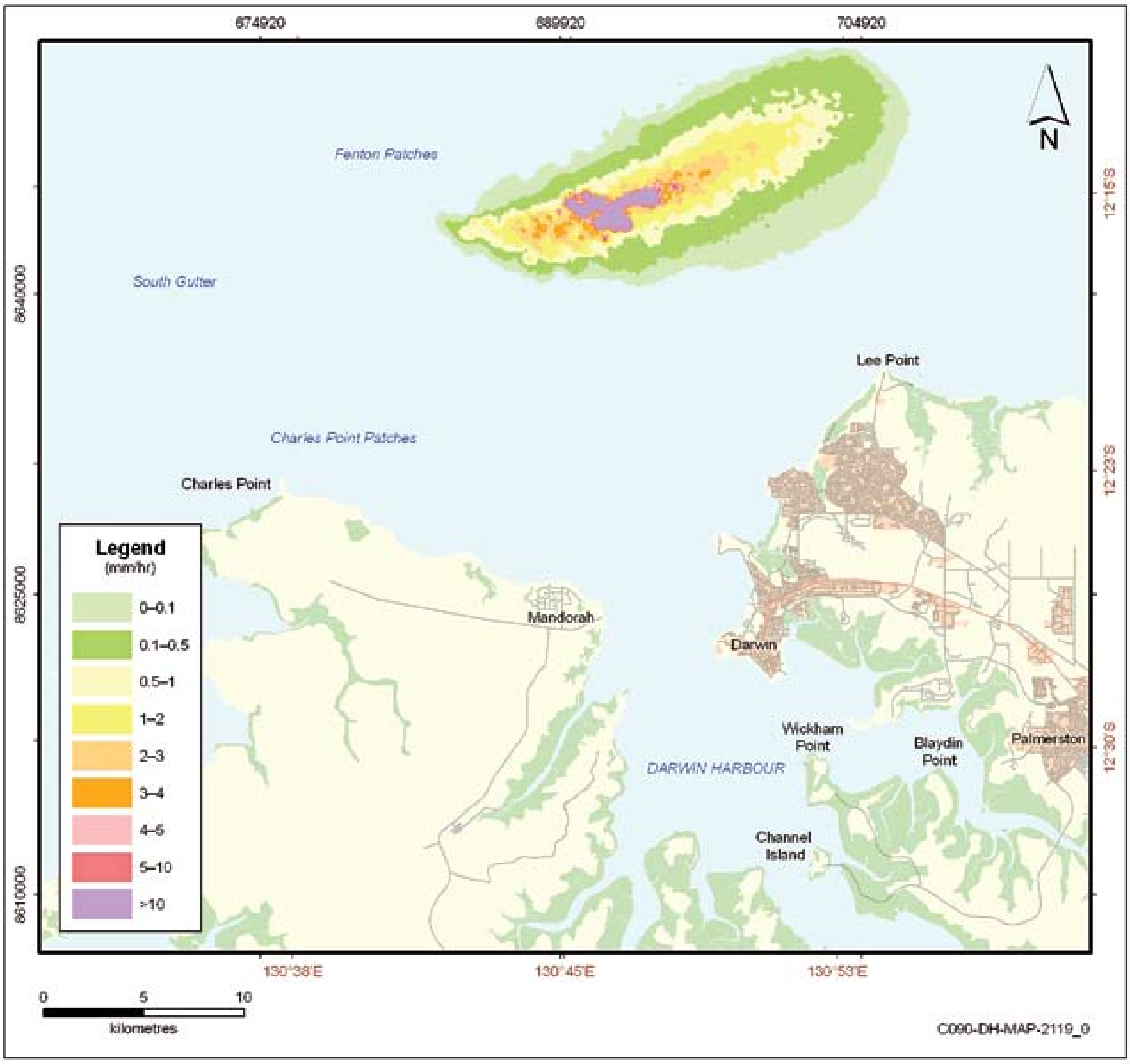

Figure 7-27: Site 9: predicted maximum hourly sediment deposition rate

The Howard River system and Gunn Point would both receive turbid plumes during multiple phases of the dredging and disposal program. Time-series graphs for indicative points reveal maximum levels of 12 mg/L at Howard River and 7 mg/L at Gunn Point during spring tides, dropping to near background levels during neap tide conditions (see Appendix 13). Overall, these peaks exist for relatively short periods of time; suspended-sediment concentrations exceed 5 mg/L above background levels for less than 1% of the entire dredging program at both Howard River and Gunn Point (see Appendix 13).

Shoreline sedimentation

Resuspension of fine sediments from the offshore spoil disposal ground by tidal currents is predicted to result in some sediment accumulation in coastal areas. Similar to the effects within Darwin Harbour, this sedimentation is predicted to peak at the end of Phase 6 (three years into the four-year dredging program) (Figure 7-30). After this time the accumulated sediment stabilises, with some minor erosion, as the contributions from dredge spoil disposal activities reduce. At the end of Phase 10, six months after dredging, deposits of fine sediments are still predicted to persist in coastal areas (see Appendix 13). While some of these sediments may erode away, others are likely to become incorporated into the intertidal sediment profile.

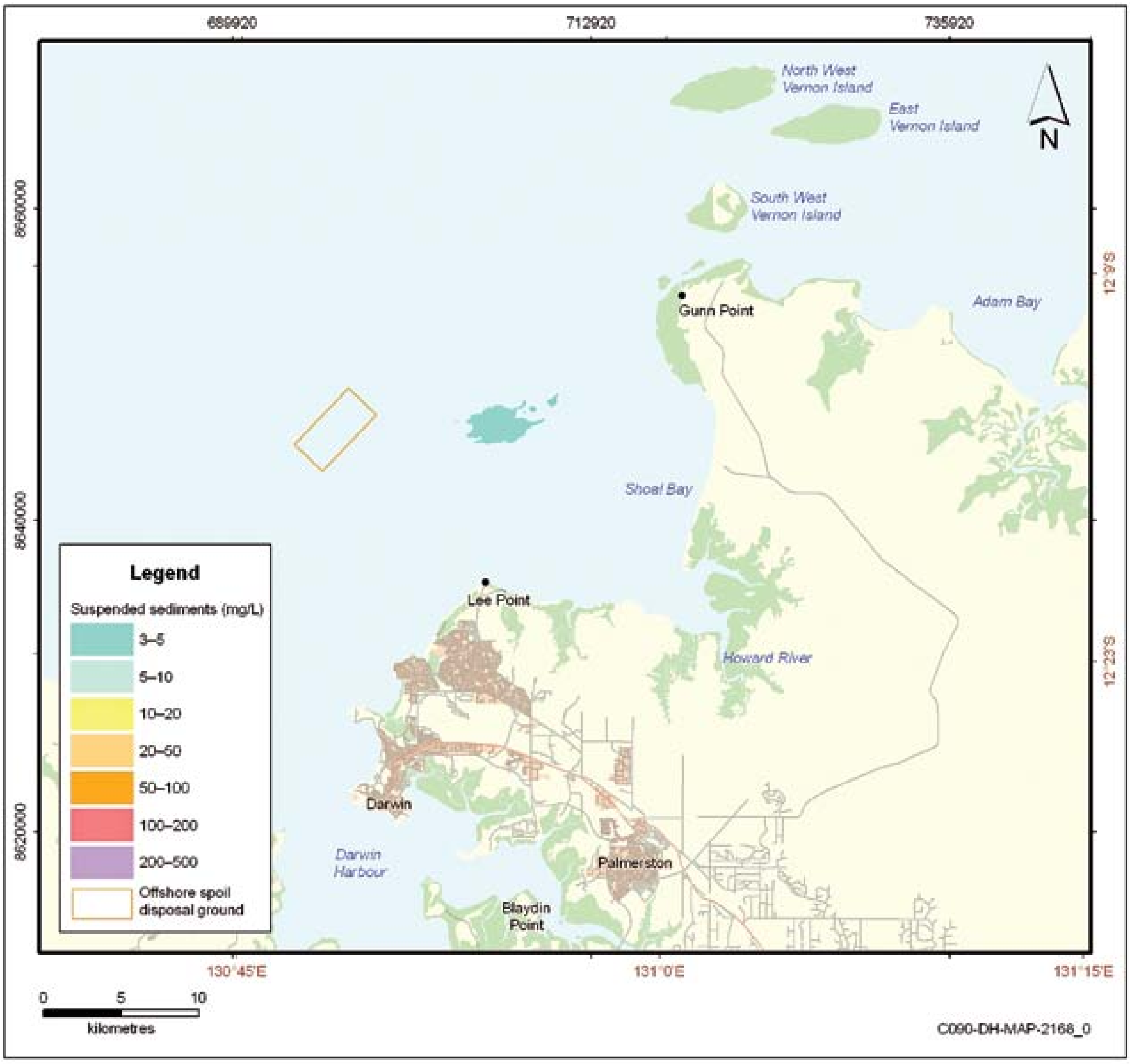

Figure 7-28: Predicted median suspended-sediment concentrations during Phase 5 of the dredging program

Sediment build-up is predicted to occur mainly between Lee Point and the Howard River, and in Shoal Bay, as well as east of Glyde Point in Adam Bay at the mouth of the Adelaide River. Sedimentation rates for most of these areas are in the order of 5–20 mm over the three-year time period; equivalent to 3–7 mm of sediment per year. The model does not represent the effects of freshwater outflow from the Howard and Adelaide rivers, which may also influence the pattern and levels of accretion in these areas (see Appendix 13).

Sand transport

Modelling of sand transport indicates that the seabed surrounding the spoil disposal ground is potentially mobile. Strong sand transport pathways were identified under flood-tide currents, in a south-westerly direction towards Darwin Harbour. This movement is neutralised and reversed when wave energy increases, as the sands are able to move north-east with the weaker, but longer, ebb tide. This situation occurs when wave heights are around one metre or higher, which would occur more frequently in the wet season but also occasionally during the dry season (see Appendix 13).

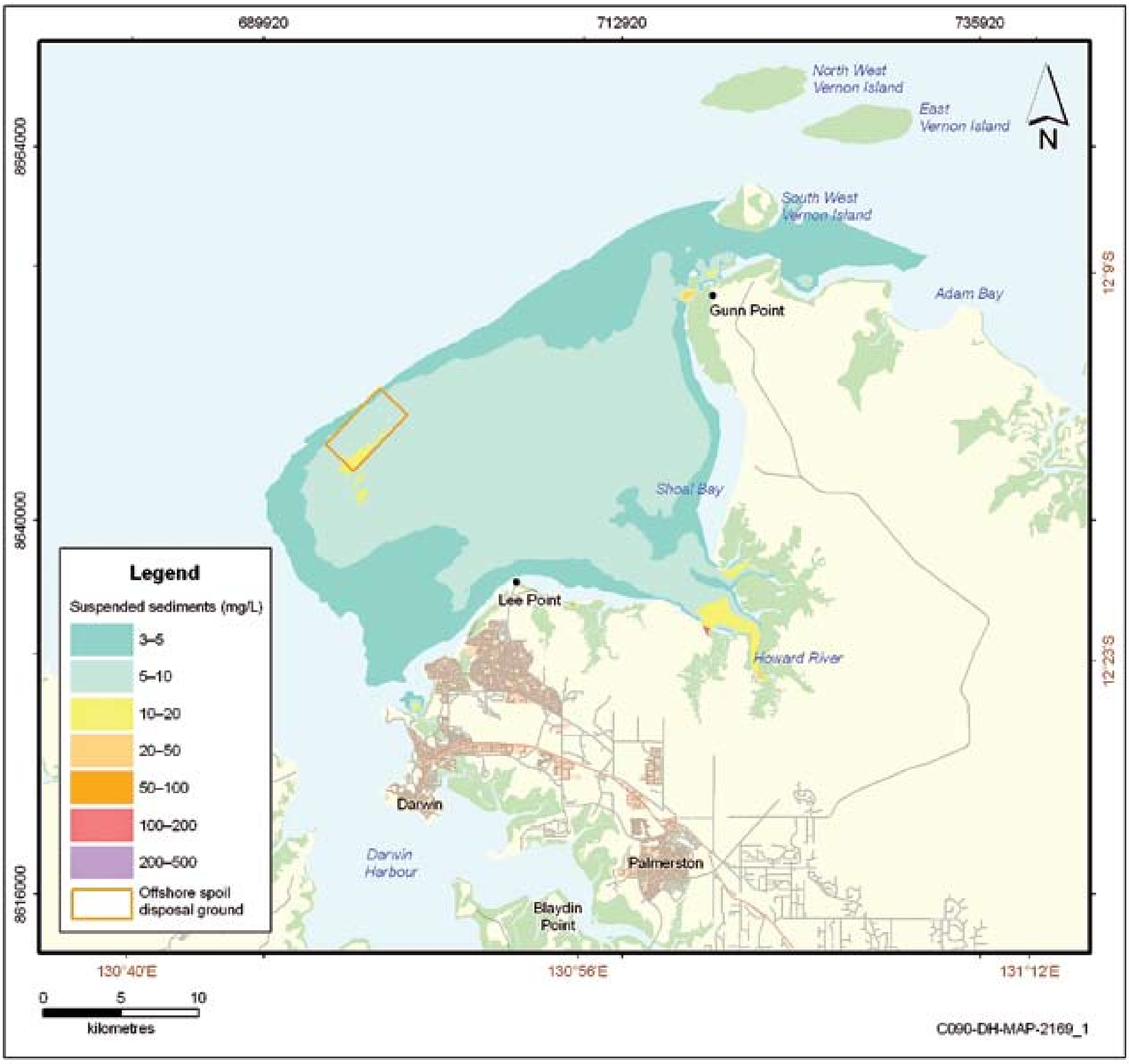

Figure 7-29: Predicted 95th percentile suspended-sediment concentrations during Phase 5 of the dredging program

The material to be disposed of at the offshore spoil disposal ground is broadly similar in texture to the silty sand that is currently found on the seabed at the site, according to a drop-camera survey (see Appendix 8). In the long term, a large proportion of the sand-sized sediments at the spoil disposal ground can be expected to migrate and mix with the surrounding seabed sediments. Some of this spoil will move towards the entrance of Darwin Harbour, which modelling shows is an active zone of erosion and deposition (see Appendix 13). This is consistent with the presence of sandbanks and subtidal bars that have been observed near the mouth of the Harbour and which are caused by natural seabed movement. Any material from the offshore spoil disposal ground that moves towards Darwin Harbour represents a very small fraction of the mobile sediments naturally transported across the seabed in this region.

Impacts to benthic habitats

Offshore

A sidescan sonar survey of the spoil ground, conducted in February 2009 (EGS 2009), showed a gently sloping seafloor composed of soft sediments, with no hard substrate. Seafloor sediments at and around the offshore disposal site are predominantly medium-to-coarse carbonate sands (Smit, Billyard & Ferns 2000). The disposal of dredge spoil on to these sediments is unlikely to markedly change the particle size distribution overall as the finer fractions of dredge spoil will drift with the tidal currents to be deposited in a thin layer across a wide area.

Upon release at the disposal site, dredge material will descend rapidly to the seabed and will smother any sparse benthic communities that may be present.

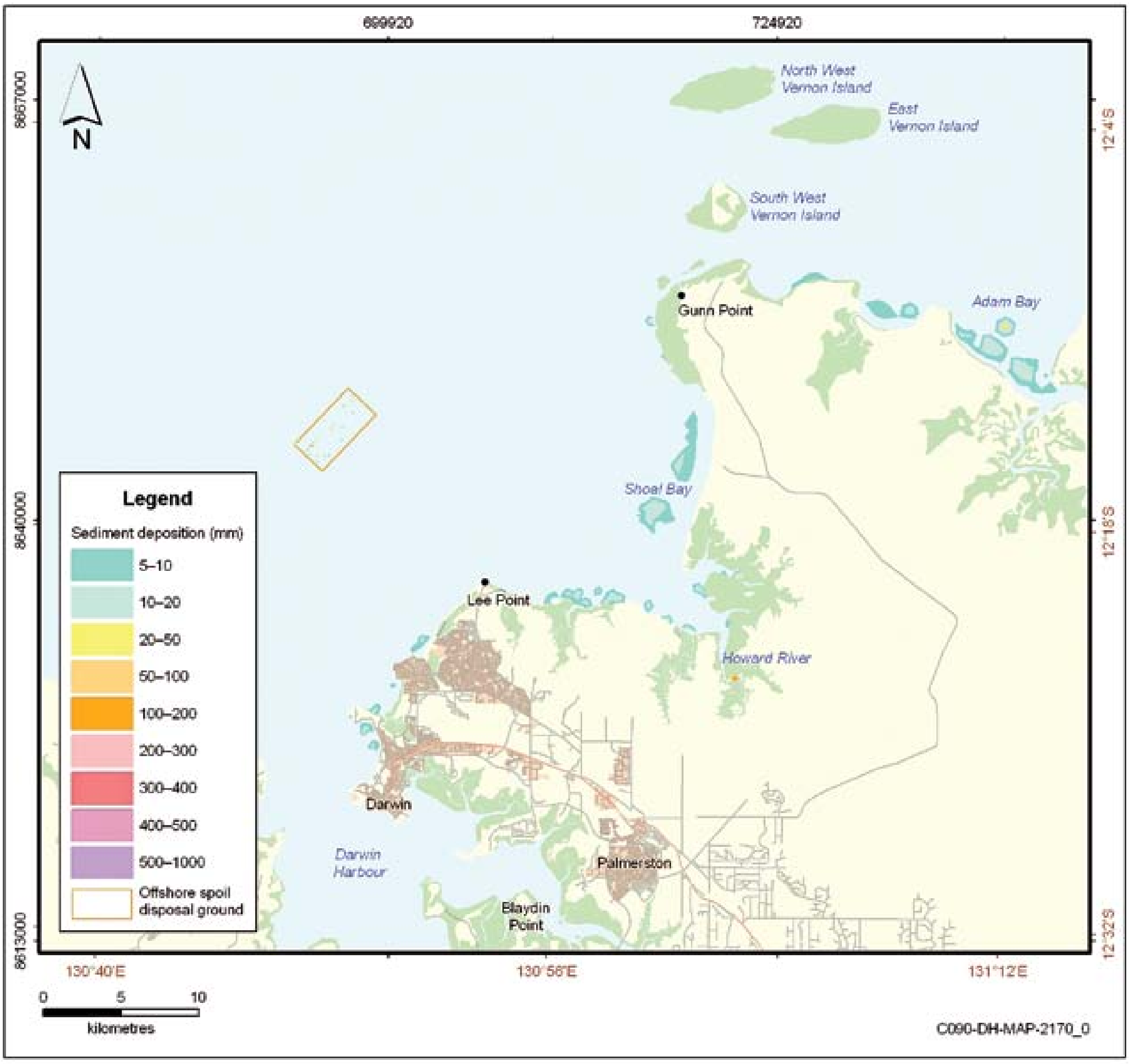

Figure 7-30: Predicted coastal sediment accumulation at the end of Phase 6 of the dredging program

Water currents will disperse the dredge material across the seabed over time, spreading it in increasingly thin layers. As the dredging campaign progresses, the seabed in the spoil ground will develop a hummocky appearance, with mounds of spoil material in various stages of dispersion.

Dredge material disposal will cause some mortality of the burrowing soft-bottom benthic biota present at the disposal site (e.g. polychaete worms and bivalve molluscs). However, sampling by Smit, Billyard and Ferns (2000) showed that the benthic communities in the vicinity of the spoil ground were also characterised by motile crustaceans (small, shrimplike amphipods and crabs) that may survive inundation by dredge material through digging their way back to the surface layer of the seabed. In the longer term, the marine sediments at the disposal area will be recolonised by benthic animal communities similar to those presently established there.

Rocks incorporated in the dredged material are likely to remain in the close vicinity of the disposal site. These rocks could provide a stable substrate upon which sessile animals such as sponges, soft corals, ascidians and bryozoans (and associated motile animals such as feather stars) could become established, representing a diversification of habitat types and biodiversity in the disposal area. Depending on the extent of this effect, fish could also be attracted to the area to forage for food. These changes, however, would be localised in the disposal area and are highly unlikely to be of regional significance.

Coastal areas

Gunn Point and Vernon Islands

Low-concentration turbid plumes travelling towards the Vernon Islands and Adam Bay will mix within the naturally turbid waters of the area. Strong ocean currents are common at this point in the coastline as the narrow channels between Melville Island, the Vernon Islands and the mainland restrict flows between Beagle Gulf and Van Diemen Gulf.

Previous marine habitat surveys in and around South Channel, between Gunn Point and South West Vernon Island, recorded waters of consistently high turbidity, with a rocky, gravelly seabed devoid of sediment deposition (I. Baxter, marine scientist, URS, pers. comm. February 2010; Smit, Billyard & Ferns 2000). Marine communities regularly consisted of filter-feeders such as soft corals, sponges, gorgonians and ascidians (I. Baxter, pers. comm. February 2010; GHD Pty Ltd, pers. comm. March 2010).

Hard corals were recorded on the seaward slopes of reef pavements around Gunn Point and South West Vernon Island. Many of the coral species were typical of turbid reefs, for example *Turbinaria* spp., *Mycedium* spp. and *Goniopora* spp. Large coral colonies were rare and deep loose coral rubble was recorded, indicative of frequent disturbances from storm waves. In general, the corals observed were in healthy condition. Mucus production and sloughing of fine sediments by corals, particularly in *Porites* and *Turbinaria*, was observed at several sites (GHD Pty Ltd, pers. comm. March 2010). Periodic peaks in suspended sediment as a result of spoil disposal are not expected to significantly damage these reef-slope coral communities as they are adapted to similar conditions.

More sheltered hard corals occur on Gunn Reef in the Blue Holes, two steep-sided channels in the reef pavement of around 200 m width and 20 m depth. They contain relatively clear water and support a diverse cover of hard corals at depths down to 2 m. Turtles and fish have been observed in high numbers in the holes. During ebb tide, when turbid waters move west through South Channel, water drains from the holes towards the channel, preventing suspended sediments from entering. During flood tides, the holes are filled from the western side of Gunn Reef (I. Baxter, pers. comm. February 2010). These incoming flows could be affected by low-concentration turbid plumes from spoil disposal during spring-tide periods (up to 4–7 mg/L as shown in Figure 7-29). Under these periodic conditions, the coral communities in the Blue Holes could be exposed to reduced light and low levels of sediment deposition. As spring-tide conditions are short in duration (1–3 days) and are interspersed with longer clear-water periods (11–13 days), these light sedimentation episodes are unlikely to cause significant reductions in coral health. The nature of the Blue Holes as deep channels in the reef flat suggests that they are not natural depositional areas for suspended sediments.

Large intertidal reef flats occur around all three of the Vernon Islands and at Gunn Point. Surveys of these areas recorded algal turf throughout the intertidal pavements (I. Baxter, pers. comm. February 2010; Whiting 2004). Patches of macroalgae in this area typically consisted of species of *Padina* and *Sargassum*, though *Laurencia* and *Udotea* were also common (I. Baxter, pers. comm. February 2010). These habitats are known to support relatively high numbers of dugongs, in the context of the Anson–Beagle Bioregion (Whiting 2004). The algal communities around Gunn Point and South West Vernon Island are predicted to receive turbid plumes from spoil disposal during spring tides, while those at North West Vernon and East Vernon islands are outside the predicted extent of the plumes. Many species of macroalgae can tolerate periodic short periods of low light conditions without reductions in productivity. However, given that plumes from spoil disposal may be reaching this area for up to two years, some species may show reduced growth.

A study on the biological effects of a dispersed sediment plume on temperate macroalgae found that many taxa are able to adjust their photosynthetic apparatus to make best use of variable light reaching the individual, maximising their photosynthetic rates. However, lower light conditions were generally associated with a drop in net 24-hour productivity (Turner 2004). Algal communities in Darwin Harbour show regular seasonal variations in productivity, with high biomass levels during the dry season and low levels in the wet season (Whiting 2004). This corresponds with light availability, which is reduced during the wet season as a consequence of the higher levels of suspended sediments from terrestrial runoff and the reduced sunlight on cloudy days. The algal communities at Gunn Point are expected to have a similar capacity to recover rapidly after a period of low light conditions. In addition, dugongs would have access to unaffected algal habitats at North West Vernon and East Vernon islands throughout the spoil disposal period.

Adam Bay

Further east into Adam Bay, previous surveys recorded coastal areas with more obvious deposition patterns of sediment veneer overlying subtidal pavements, and mudflats occurring in the bays. Seagrasses and hard corals were rarely recorded, and it was concluded that natural turbidity levels prevented their growth (I. Baxter, pers. comm. February 2010; Smit, Billyard & Ferns 2000).

Modelling predicts some low-level sedimentation of these coastal areas as a result of the Project's spoil disposal program. This material will blend with naturally deposited sediments and the rates of sedimentation across the four-year dredging program (net 10–20 mm and 2.5–5 mm/a) can be considered insignificant. Other sources of coastal sedimentation in this region include the breakdown of rocks along shorelines, terrestrial sediments washed from floodplains, and the breakdown of shells and corals.

Shoal Bay and Howard River

Further south, modelling also predicts some development of turbid plumes and low-level sedimentation around Hope Inlet and the Howard River, which are situated in the Shoal Bay conservation area (Harrison et al. 2010). This river system is believed to be a nursery area for barramundi, whose juveniles grow in extensive wetlands of grasses and sedges that are flooded during the wet season. These wetlands are very productive and also provide important habitat for the early stages of other fish species and for prawns. Juvenile barramundi, 100–250 mm in length, move into nearby rivers towards the end of the wet season and generally migrate upstream to permanent fresh water for three to four years. When they reach maturity they move downstream to marine waters. The barramundi stock of Darwin Harbour is believed to use the Shoal Bay wetlands as nursery habitat (R. Griffin, marine biologist, pers. comm. February 2010).

Suspended-sediment plumes with concentrations of 3–20 mg/L are predicted in the Howard River during spring-tide conditions, which could occur for two or three days each fortnight during each phase of the dredging program (see Appendix 13). These suspended-sediment concentrations are additional to background levels. Jenkins and McKinnon (2006) estimate that suspended-sediment concentrations greater than 500 mg/L would produce a measurable impact upon larvae of most fish species, while levels of 100 mg/L would affect larvae of some species if exposed for periods greater than 96 hours. Based on these "threshold" levels, it is unlikely that plumes from offshore spoil disposal would increase suspended sediments in the Howard River to an extent sufficient to cause damage to fish larvae.

The extensive tidal flats and freshwater wetlands of Shoal Bay are important feeding and roosting areas for migratory shorebirds such as great knots in their non-breeding season. It is also a regionally important area for waterbirds such as radjah shelducks, magpie geese and brolgas (Harrison et al. 2010).

The water in this system, particularly during the wet season, is expected to be naturally turbid because of the suspension of marine sediments by tidal currents and the influx of terrestrial sediments in freshwater runoff and stream flow. Extensive mudflats and sandflats are a common feature of Shoal Bay (Harrison et al. 2010), indicating a natural depositional environment. Suspended sediments from the Project's spoil ground with concentrations of up to 20 mg/L and the deposition of less than 10 mm of sediments per year in the lower reaches of the Howard River do not pose a threat to the barramundi breeding cycle or the use of the area by waterbirds and shorebirds.

Lee Point

Seagrass beds are known to occur in coastal waters off Casuarina Beach between Lee Point and Rapid Creek, up to around 2.5 km offshore (N. Smit, Marine Biodiversity Group, NRETAS, pers. comm. July 2009). This area is predicted to receive turbid plumes with concentration levels of 3–10 mg/L only during spring tides in Phase 5 of the dredging program (Figure 7-29) and not during the other phases (see Appendix 13). These brief exposures to low light conditions are unlikely to significantly affect seagrass growth. No sediment accumulation is predicted over these seagrass beds, although some deposition (5–10 mm) is predicted for the southern end of Casuarina Beach near the mouth of Rapid Creek (Figure 7-30).

Management of dredge spoil disposal

As described in Section 7.3.1 above, a Provisional Dredging and Dredge Spoil Disposal Management Plan has been compiled (attached as Annexe 6 to Chapter 11), which will guide the development of a series of more detailed plans during the construction phase of the Project. Key management controls include the following:

- A bathymetric survey of the disposal area and immediate surrounds will be undertaken prior to the commencement of the dredging campaign, to inform the planning of the disposal operations and to establish baseline conditions.
- Periodically during the dredging campaign, further bathymetric surveys will be undertaken to assess the distribution of dredge spoil in the disposal area and to ascertain whether the heavier sediment fractions are migrating beyond the boundary.
- Periodic bathymetric surveys will also enable the management of disposal activities in such a way that shoal areas do not develop, with deeper areas selected preferentially for dumping the spoil.
- On completion of the dredging campaign, a bathymetric survey of the entire disposal area and its immediate surrounds will be undertaken to confirm final depths.
- A soft-bottom benthos monitoring program will be developed with pre- and post-spoil disposal sampling of these benthic communities to identify any changes occurring as a result of the disposal program.

Table 7-32: Summary of impact assessment and residual risk for dredge spoil disposal

Aspect	Activity	Potential impacts	Management controls and mitigating factors	Residual risk*		
				C†	L‡	RR§
Seabed disturbance	Offshore dredge spoil disposal.	Smothering of benthic communities inside disposal area, and then outside the area as sediments disperse. Alteration of seabed sediments.	Sediment types and benthic communities are common throughout the region. Hydrodynamic modelling was used to select the disposal area in order to minimise remobilisation of sediments into sensitive locations. Soft-bottom benthos monitoring program. Provisional Dredging and Dredge Spoil Disposal Management Plan.	E (B3)	6	Medium
Coastal sedimentation	Offshore dredge spoil disposal.	Low-level deposition of sediments on to coastal subtidal and intertidal marine habitats, causing smothering and reduced growth of benthic biota.	Affected areas are naturally depositional environments, where marine communities are adapted to sedimentation. There are few seagrasses and hard corals in the affected areas. Macroalgae are more tolerant of sedimentation.	E (B3)	6	Medium
Turbid plumes	Offshore dredge spoil disposal.	Low light conditions over coastal benthic biota, causing reduced growth and primary production.	The plumes are transported to coastal areas on spring tides only. The tidal cycle results in clear water conditions between turbid spring tides. There are few seagrasses and hard corals in affected areas. Macroalgae are more tolerant of variable light conditions.	E (B3)	4	Medium

* See Chapter 6 *Risk assessment methodology* for an explanation of the residual risk categories, codes, etc.

† C = consequence.

‡ L = likelihood.

§ RR = risk rating.

The potential for interaction between dredge spoil disposal vessels and marine megafauna will be managed through the Provisional Cetacean Management Plan developed for the Project, as described in Section 7.3.10 *Marine megafauna*.

Residual risk

A summary of the potential impacts, management controls, and residual risk for dredge spoil disposal is presented in Table 7-32. After implementation of these controls, impacts to marine habitats are considered to present a "medium" risk.

7.3.4 Liquid discharges

A variety of routine liquid wastes will be generated at the onshore and nearshore development areas during all stages of the Project as described in Chapter 5. This section discusses the potential environmental impacts of these discharges in the context of the nearshore marine environment.

Routine discharges

Wastewater from the operation of the gas-processing facilities (including process water, contaminated surface runoff, demineralisation reject water, sewage and grey water) will be treated, commingled and discharged to the nearshore marine environment at a combined outfall on the product loading jetty. Some of these wastewater streams will be continuous (e.g. demineralisation reject water) while others will vary in volume and solute concentrations (e.g. process water and plant drainage). Volumes of potentially contaminated runoff from process areas will also vary markedly between seasons, with large increases in runoff during wet-season rains.

Predictive modelling has been used to optimise the design of the outfall diffuser at the jetty, providing the maximum possible near-field dilution for the wastewater. This process involved comparing a range of port diameters, spacings and port openings under varied current conditions. The selected diffuser configuration is based on 4 ports, each with a diameter of 100 mm and at a spacing of 5 m (see Appendix 10 to this Draft EIS for details).

During construction, prior to completion of the jetty outfall, treated sewage and grey water from the onshore development area will be discharged to East Arm at a location selected for high current flows and rapid dispersion.

Toxicity of wastewater

The pollutants of most concern in wastewater from the onshore development area are petroleum hydrocarbons, which reach the wastewater stream when collected in surface runoff following accidental spills, tank drainings and washdown of equipment. Other production chemicals may also reach the wastewater stream intermittently, at varying concentrations.

As described in Section 7.2.3 *Liquid discharges*, acute toxicity is a short-term and severe poisonous effect, while chronic toxicity causes long-term health effects as a result of repeated doses at lower concentrations. At present, Australian water-quality guidelines do not provide acute or chronic-toxicity threshold criteria for total petroleum hydrocarbons (TPHs). To assess the potential impacts of the Project's wastewater discharges, a conservative chronic-toxicity threshold of 0.007 mg/L TPH has been applied. This criterion was derived by Tsvetnenko (1998), who compiled a range of reported toxicity levels for various marine species and applied statistical analysis according to methods developed by the US Environmental Protection Agency. The petroleum hydrocarbons were considered to be active toxicants only in dissolved form and, because of the lack of species-specific ecotoxicology studies (particularly for tropical Australian species), an acute–chronic ratio of 25 was assumed. For these reasons, the 0.007 mg/L threshold is considered conservative (Tsvetnenko 1998).

Other pollutants in the discharged wastewater will include nutrients and faecal coliforms (from sewage), which at high concentrations might lead to eutrophication of the nearshore marine environment and even algal blooms. It is also noted that the water-quality objectives developed for Darwin Harbour (NRETAS 2009) place particular emphasis on maintaining sustainable levels of nutrients in Harbour waters. Treatment processes applied prior to discharge of sewage wastewater from the Project will result in very low levels of nutrients being released to the Harbour, and exceedances of the levels given in the water-quality objectives are not expected outside the immediate mixing zone.

Dispersion of wastewater

In order to predict the dispersion of wastewater in the nearshore development area, hydrodynamic modelling was undertaken by APASA (2009c). Three modelling methods were integrated to simulate this dispersion: a validated estuarine and coastal hydrodynamic model (BFHYDRO) for current data, a near-field discharge model (UM3) and a far-field advection and dispersion model (MUDMAP). The results of the study are summarised below, while the complete technical report is provided in Appendix 10. Further detail on the development and validation of the hydrodynamic model is provided in Appendix 5.

For the purposes of modelling, discharge rates and characteristics were derived based on preliminary estimates of the treated effluent and stormwater to be generated at the onshore development area (see Chapter 5). Two scenarios were modelled, representing the wet and dry seasons, to provide a better understanding of dispersion during varying rainfall conditions.

Characteristics of the wastewater streams that were used to inform the dispersion model are summarised in Table 7-33. These are influenced by increased surface runoff from wet-season rains, leading to higher wastewater release rates and TPH concentrations and lower salinity during the wet season.

Table 7-33: Assumed characteristics of the wastewater stream from the combined outfall

Characteristic	Dry season	Wet season
Wastewater flow rate (continuous)	18 m^3/h	160 m^3/h
Salinity of wastewater (ambient surface-water salinity)	0.325 ppt (35.3 ppt)	0.02 ppt (32.7 ppt)
Temperature of wastewater (ambient surface-water temperature)	26 °C (24.8 °C)	35 °C (32.7 °C)
Total petroleum hydrocarbon concentration	0.2 mg/L	10 mg/L

Dilution factors required to reach the chronic-toxicity threshold concentration of 0.007 mg/L TPH (assuming a background concentration of 0 mg/L and not accounting for natural decay) are 1:29 and 1:1428 for the dry-season and wet-season scenarios respectively.

At the nearshore development area, wastewater will be discharged from a diffuser outfall at the jetty, approximately 1 m above the seabed (*c*.14 m below Lowest Astronomical Tide (LAT)). Near-field modelling indicates that the plume is initially driven by its own momentum horizontally from the outlet. As the plume velocity decreases (<1 m from the orifice), the buoyancy of the plume will cause it to rise rapidly towards the water surface, causing turbulence and entraining water. Upon reaching the surface, the plume is predicted to remain at the sea surface and disperse with the prevailing currents. During dry-season conditions, near-field mixing provides a dilution ratio of at least 1:334 within 4 m of the outlet, well below the required threshold dilution ratio for chronic toxicity (1:29) (APASA 2009c).

During wet-season conditions, dilutions of 1:76 to 1:227 are predicted within 11 m of the outlet, depending on ambient current speeds. This rate of dilution is insufficient to avoid chronic toxicity and therefore far-field modelling was conducted to predict the extent and shape of the wet-season mixing zone (APASA 2009c).

The far-field dispersion model indicated that the wastewater plume would remain in the surface layer (the top 2 m), where the near-surface currents would affect its overall transport. The plume was predicted to oscillate with the flood and ebb tides, and patches of higher concentrations tended to build up at the turn of the tide. These patches moved as a cohesive unit as the current speeds increased again. These higher-concentration patches tended to stay within the wider plume, sometimes combining when current reversals caused patches to move back and build up (APASA 2009c).

On average, the TPH concentrations are predicted to form an elliptical shape in an east–west direction, in line with the major tidal axis (Figure 7-31). At a 95% confidence level, the wastewater is diluted to below 0.007 mg/L TPH within 330 m of the outfall during the wet season, which is at least 440 m from the nearest shoreline. At a 50% confidence level, the mixing zone is much smaller, reaching the dilution threshold within 86 m of the outfall (APASA 2009c).

Mixing zones for wastewater from the discharge outfall are considered small and are indicative of rapid dilution of the pollutants into nearshore waters. The periods of exposure to hydrocarbons would be very short for most pelagic biota and as the mixing zone is distant from sensitive benthic communities (e.g. the corals at Channel Island or Weed Reef), there is no potential for contamination of these areas.

Treated sewage and grey water discharged during both the construction and operations phases will contain elevated concentrations of nutrients compared with background levels, but the nutrients would assimilate rapidly into the nearshore marine environment without toxic effects.

Hydrotest

Hydrotesting of the onshore facilities will occur during the commissioning phase and wastewater produced by this activity will be discharged separately from other routine wastewater. Chemical additives and their concentrations have not yet been finalised for hydrotest water.

Chemicals such as biocides and corrosion inhibitors are the key potentially toxic components of process and hydrotest water. When discharged to the marine environment, they may have toxic effects on marine biota that exist close to the discharge point. However, these effects will be mitigated by the rapid dispersion of pollutants with tidal currents.

If fresh water is used for hydrotesting, its discharge into Darwin Harbour in large volumes may represent a marked change to water-quality conditions in the marine environment, particularly in the dry season when Harbour waters are at their highest salinity levels. However, tidal mixing in the nearshore area is high in all seasonal conditions and this freshwater input is not expected to cause significant impacts to marine biota beyond the immediate vicinity of the outfall.

Vessels

Vessels involved in nearshore construction activities and in ongoing product export from the onshore processing plant will produce wastewater streams including ballast water, sewage and grey water.

Sewage and grey water from ships will not be discharged into Darwin Harbour waters. The *Marine Pollution Act* (NT) and Marine Pollution Regulations (NT) prohibit sewage and grey water discharge from vessels within 3 nautical miles of the coast (this includes the whole of Darwin Harbour).

All vessels will have ballast-water tanks fully segregated from fuel tanks to minimise the risk of hydrocarbon contamination of the ballast water. The ballast water in vessels arriving at the nearshore development area is likely to originate from the open ocean in accordance with management strategies to minimise the risk of transferring marine pests (see Section 7.3.9).

Antifouling compounds will leach from the coatings of vessels in Darwin Harbour, but given the very low concentrations generated, coupled with the effects of dilution caused by tidal currents, there is again a negligible risk of pollution impacts to the marine environment.

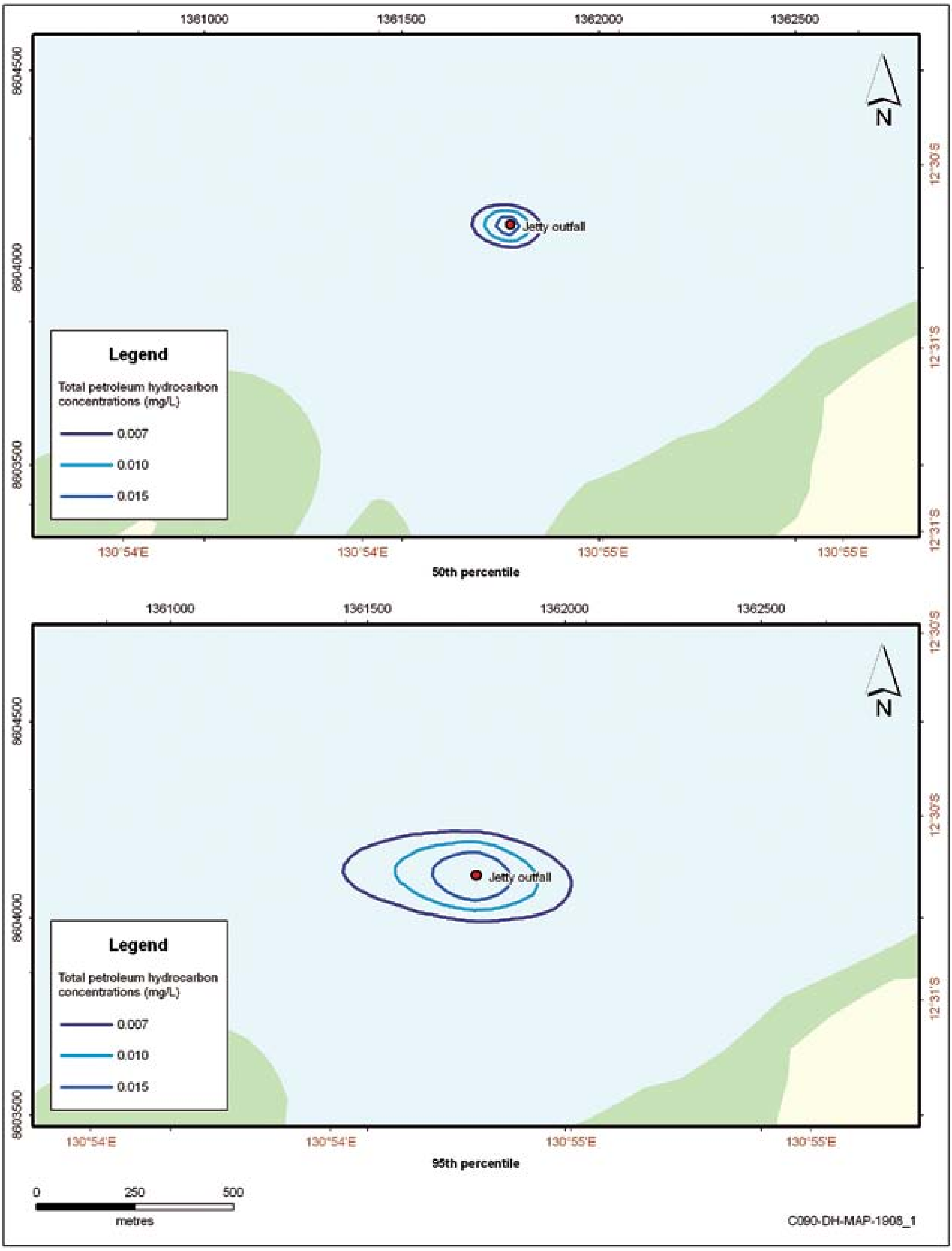

Figure 7-31: Predicted extent of wastewater mixing zones at the product loading jetty outfall during wet-season conditions

Management of wastewater

A Provisional Liquid Discharges, Surface Water Runoff and Drainage Management Plan has been compiled (attached as Annexe 10 to Chapter 11), which will guide the development of a series of more detailed plans during the construction and operations phases of the Project. Key inclusions in this plan are as follows:

- Drainage at the onshore development area will be designed to isolate areas that could be exposed to hydrocarbon contamination (as described in Chapter 5). Wastewater from these areas will be directed to an oily-water treatment system.
- The wastewater outfall diffuser will be designed to optimise near-field dispersion of the discharged wastewater.
- Wastewater streams will be sampled at appropriate frequencies and selected water-quality parameters will be documented.
- Maintenance practices during the operations phase (e.g. drainage of tanks and equipment of hydrocarbons) will avoid discharge of hydrocarbons to the oily-water treatment system.
- An on-site treatment facility will be used to treat sewage from the onshore development area to produce high-quality wastewater during the operations phase.
- A waste discharge licence will be sought for the onshore processing plant from NRETAS under the *Water Act* (NT). Discharge limits set by this licence will be met through a monitoring and verification program, developed as part of the environmental management program for the Project.
- Hydrotest management plans and supporting documents will be developed for approval under the relevant legislation prior to precommissioning.
- Production and hydrotest chemicals will be selected with consideration of their ecotoxicity.
- Where practicable, process modules will be precommissioned off site at the module yards.
- Where practicable, hydrotest water will be reused by onshore facilities (e.g. hydrocarbon storage tanks).
- No sewage or grey water from ships will be discharged into Darwin Harbour, in accordance with the Marine Pollution Regulations (NT).
- Antifouling paints on vessels and equipment will not contain TBT compounds, as required by IMO regulations.
- A Darwin Harbour water quality monitoring program will be developed to assess any impacts of the Project on water quality in the nearshore development area during the operations phase.
- Validation of wastewater dispersion modelling for the jetty outfall will be undertaken.

Waters from hydrotesting and dewatering of the gas export pipeline will be discharged offshore, at the Ichthys Field. In the highly unlikely event that hydrotest depressurisation cannot be undertaken offshore (e.g. because of a cyclone or mechanical failure) it may be necessary to discharge approximately 10 ML of hydrotest water into Darwin Harbour.

Under these circumstances, an additional assessment (e.g. chemical screening and selection) will be undertaken to minimise impacts on the nearshore marine environment. These measures will be outlined in a hydrotest management plan to be developed prior to precommissioning and approval will be sought under the *Water Act* (NT) as required.

Residual risk

A summary of the potential impacts, management controls, and residual risk for liquid discharges is presented in Table 7-33. After implementation of these controls, potential impacts from liquid discharges are considered to present a “low” to “medium” risk, as changes in water quality in the marine environment will generally be localised and short-term.

7.3.5 Accidental hydrocarbon spills

Hydrocarbon characterisation

Weathering processes that affect spilt hydrocarbons in the marine environment are described in detail in Section 7.2.4 *Accidental hydrocarbon spills*.

The processes that would influence hydrocarbon weathering in the nearshore development area differ from those in the offshore area because of different local climatic and sea conditions and the shorter distance to shore. Predicted weathering and fates for potential condensate and diesel spills from the nearshore development area are described in this subsection. These were derived through numerical modelling of oil-spill scenarios by APASA (APASA 2009b, provided as Appendix 7).

Properties of nearshore condensate

Condensate received at the onshore processing plant would have marginally lower density (API gravity 75.7; density 682.9 kg/m^3) and viscosity (0.296 cP) but a higher aromatic content (6.4%) than the offshore condensate (described in Section 7.2.4). The condensate would be highly volatile, with complete evaporation occurring within 6 hours if spilled at the sea surface (Figure 7-32) (APASA 2009b).

Table 7-34: Summary of impact assessment and residual risk for liquid discharges (nearshore)

Aspect	Activity	Potential impacts	Management controls and mitigating factors	Residual risk*		
				C†	L‡	RR§
Wastewater discharge	Routine operation of onshore processing plant.	Alteration of marine environment through nutrient enrichment, toxic discharges, etc.	A waste discharge licence will be sought for the onshore processing plant from NRETAS under the *Water Act* (NT). Drainage systems will isolate potentially contaminated areas and wastewater will be treated through separate drainage systems prior to discharge. A chemical selection process will be developed and will include consideration of the potential for ecotoxicity. Monitoring and verification will be carried out to ensure that discharge limits are maintained. Provisional Liquid Discharges, Surface Water Runoff and Drainage Management Plan.	E (E1)	6	Medium
Wastewater discharge	Hydrotesting of onshore processing plant.	Localised reduction in water quality. Toxic effects on marine biota.	A waste discharge licence will be sought for the onshore processing plant from NRETAS under the *Water Act* (NT). A chemical selection process will be developed and will include consideration of the potential for ecotoxicity. Module systems will be precommissioned off site if practicable. Hydrotest management plans. Provisional Liquid Discharges, Surface Water Runoff and Drainage Management Plan.	F (E1)	6	Low
Wastewater discharge	Operation of vessels in the nearshore development area during construction and operations.	Alteration of the marine environment including nutrient enrichment and toxicity.	Discharge of wastewater in accordance with DPC regulations. Provisional Liquid Discharges, Surface Water Runoff and Drainage Management Plan.	F (E1)	6	Low

* See Chapter 6 *Risk assessment methodology* for an explanation of the residual risk categories, codes, etc.

† C = consequence.

‡ L = likelihood.

§ RR = risk rating.

Likelihood of spill occurrence

The infrastructure and activities to be undertaken in the nearshore development area present a range of scenarios where a loss of containment of hydrocarbons could occur. An assessment of the likelihood of oil spills occurring was undertaken by ERS, using frequency data for previous similar incidents that have occurred in the oil & gas industry worldwide. In oil-spill planning this likelihood is known as the “primary risk” of a spill event.

The likelihood of a spill occurring is expressed on an annual basis—that is, the number of times per year that an incident of that type could occur. This generally results in very small numbers (e.g. 1×10^{-4}), and the order of magnitude is considered the most important component. That is, events with a likelihood of 1×10^{-2} would be considered “likely” to occur at some point, particularly for a project with a life of several decades. Events with a likelihood of 1×10^{-7} have a very remote chance of occurring, even during the life of a long project.

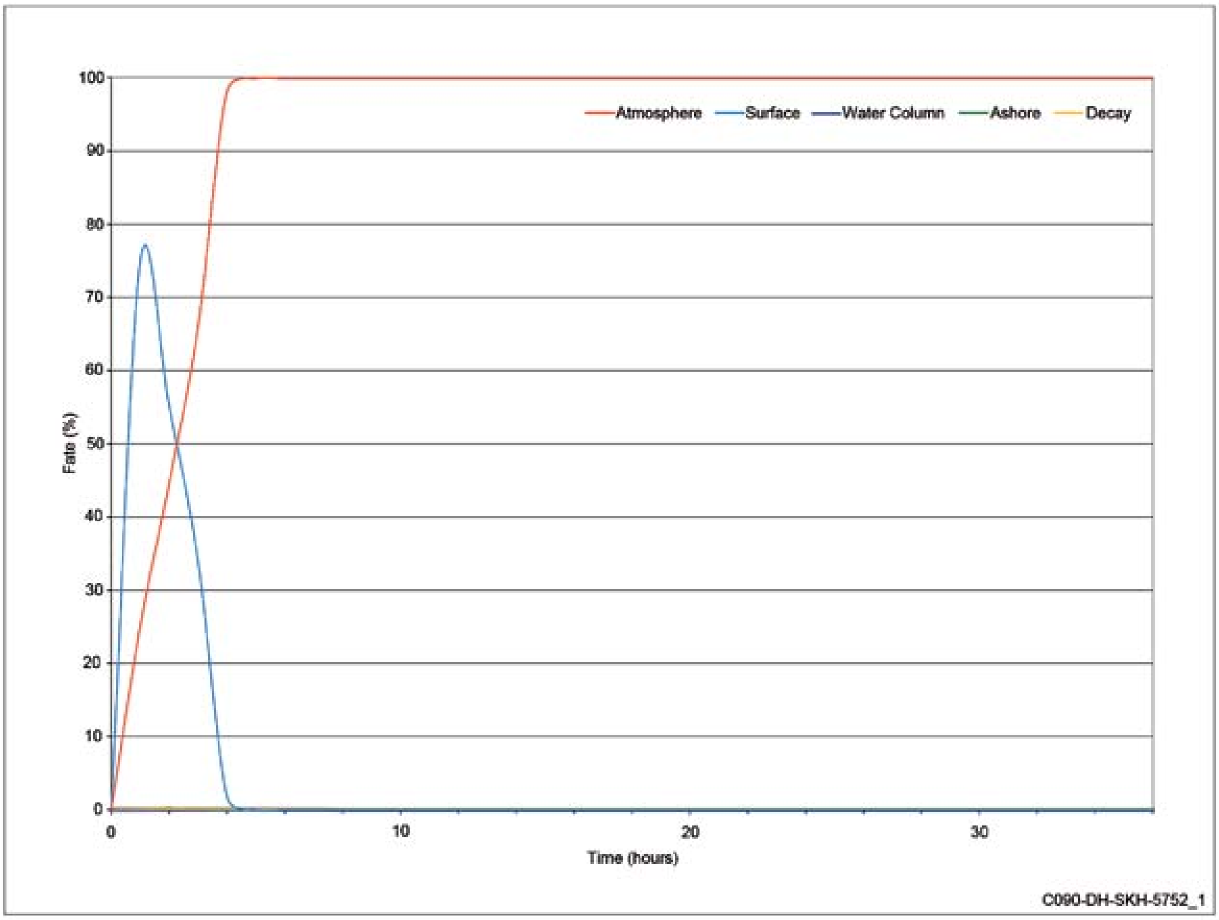

Figure 7-32: Predicted weathering and fates of a surface condensate release from the nearshore development area

Four potential spill scenarios were identified for the nearshore development area. They are described in Table 7-35, along with the calculated likelihood of these events occurring. The volumes and durations of the spills are indicative only and are considered reasonable estimates of the types of accidental spills that could occur given the management controls that will be in place for the Project. Of the scenarios considered, the refuelling spill of low volumes of diesel is the most likely. Refuelling of vessels at East Arm will occur many times during the construction and operations phases of the Project. The diesel transfer hose and its associated couplings are considered to be the most likely source of leaks from this activity (ERS 2009).

Rupture of the gas export pipeline in Darwin Harbour is the least likely loss-of-containment scenario. An incident of this nature could be caused by anchor damage from large vessels using the Harbour, such as large cargo ships or naval vessels. Rupture of the gas export pipeline at a centralised point in Darwin Harbour has been modelled; however anchor damage could be incurred at any position along the pipeline where water depths allow large vessels access. Accordingly, oil-spill contingency planning will account for the potential for a pipeline rupture (or leak) along the entire length of the pipeline route. To control an accidental event such as this, a loss of pressure in the pipeline would be detected and valves at either end of the gas export pipeline would quickly close. This system would operate automatically and the time frame to closing down the pipeline would be less than 10 minutes. Ensuring that these types of response controls are integrated into the design of the pipeline is part of the safety case to be developed for the Project under the *Energy Pipelines Act* (NT) and the *Offshore Petroleum and Greenhouse Gas Storage Act 2006* (Cwlth).

Table 7-35: Potential hydrocarbon spills in the nearshore development area and the likelihood of their occurrence

Scenario number*	Description	Location	Scenario	Likelihood† (per annum)
9	Gas export pipeline rupture	Darwin Harbour	A gas export pipeline full-bore rupture occurs in Darwin Harbour. This releases highly pressurised gas, LPGs and condensate at the seabed at a depth of around 15 m. About 5% of the condensate remains in the water column. The rest of the condensate and all of the LPGs and gas evaporate. Over 3 hours, 50 m^3 of condensate is released.	2.7×10^{-6}
10	Gas export pipeline leak	Darwin Harbour	A gas export pipeline leak from a nominal 25-mm hole occurs in Darwin Harbour. This releases highly pressurised gas, LPGs and condensate at the seabed at a depth of around 15 m but at a much lower rate than the full-bore rupture of Scenario 9. About 25% of the condensate remains in the water column. The rest of the condensate and all of the LPGs and gas evaporate. Over 24 hours, 1 m^3 of condensate is released.	1.1×10^{-5}
11	Leak of condensate loading line or a coupling failure at the jetty	Blaydin Point	A condensate loading line leaks or a coupling fails at the jetty. A 30-second leak occurs before flow across the jetty to the condensate offtake tanker can be stopped. This releases 25 m^3 of condensate to the sea surface at the loading berth.	3.5×10^{-3}
12	Refuelling spill at East Arm Wharf	East Arm Wharf	A refuelling spill occurs at a berth at East Arm Wharf. A fuel-hose rupture or other leak results in an instantaneous spill of 0.2 m^3 of diesel on to the sea surface during refuelling.	4.9×10^{-2}

* The scenario numbers are continued here from Table 7-17, which contains the primary risk assessment for the offshore development area.

† Primary risk (ERS 2009).

Spills of liquefied petroleum gases (LPGs) and LNG during loading at the jetty are not considered to pose a risk of slicks in the marine environment, as these substances are highly volatile and would evaporate very quickly. Spills of LPGs and LNG have therefore not been included in the primary risk assessment.

Predictive spill modelling

In order to predict whether hydrocarbons released during the potential spill scenarios could reach sensitive environmental receptors around the nearshore development area, spill-trajectory modelling was undertaken by APASA (see Appendix 7 for the full APASA report). Trajectory modelling was based on a boundary-fitted hydrodynamic (BFHYDRO) model developed for Darwin Harbour. This model simulated tidal elevations, current velocities, salinity and temperature distributions within the Harbour and its approaches. Further detail on the development and validation of the hydrodynamic model is provided in Appendix 5.

Numerical spill simulations were carried out using the three-dimensional model SIMAP, which accounts for weathering processes such as evaporation and spreading as well as seasonal climate effects. Simulations were developed for wet-season (October–February), dry-season (May–July) and transitional (March–April; August–September) conditions.

Simulations of spills in the nearshore development area indicated that the movement of any hydrocarbon slicks would be strongly affected by local tidal currents. Complicating these drift patterns, prevailing winds will act to spread slicks and generate a net drift over longer durations than one tidal cycle. Seasonal wind patterns are predicted to generate an increased probability of exposure to eastern shorelines during the wet season and to western shorelines during the dry season (APASA 2009b).

A total of 100 single random trajectories was simulated, per season and scenario combination (i.e. 300 per scenario and 1200 in total), for the assessment. Model outputs therefore do not show the area affected by one individual spill, but show the combination of these multiple spill simulations.

The extent of nearshore spills was assessed down to a threshold level of 1 g/m^2 (1 µm thickness), which corresponds with a yellowish-brown sheen on the water surface.

Summaries of the modelled outcomes of the spill scenarios presented in Table 7-35 are presented below. These outcomes assume that no management controls (i.e. spill responses) are applied and therefore present the worst-case scenarios for hydrocarbon spread into the marine environment.

Scenario 9—Gas export pipeline rupture

Under all seasonal conditions, the movement of the surface slick resulting from this spill is predicted to be tidally dominated. The major portion of the slick would remain in the central corridor of the Harbour, reaching upstream as far as Channel Island and downstream to the entrance to the Harbour between Mandorah and Fannie Bay (Figure 7-33).

Shoreline exposure is not predicted to occur above the threshold level (1 g/m^2) for this spill. Entrained oil is expected to occur in close proximity (<1 km) to the release site because of the initial subsurface release. Once it surfaces, condensate is unlikely to be entrained in the water again because of the relatively calm conditions inside the Harbour (APASA 2009b).

Scenario 10—Gas export pipeline leak

Movement of the slick created by this relatively small spill would be minimal and very low surface-water exposure probabilities were predicted in spill modelling (Figure 7-34). Because of the slow release rate and high volatility of the condensate, there is negligible risk of exposure to shoreline areas (APASA 2009b).

Scenario 11—Condensate loading line leak or coupling failure at jetty

Processed condensate is predicted to evaporate rapidly. However, because of the magnitude of the tidal currents in East Arm, a proportion of the condensate slick generated by this scenario is predicted to drift throughout East Arm before evaporating and could potentially expose some areas of shoreline to risk. The main area of surface-water exposure during all seasons was predicted to be within one tidal migration (about 6 hours of travel) along the tidal axis (Figure 7-35). Seasonal winds also influenced the predicted extent of surface slicks, with a <10% chance of migration west out of East Arm during wet-season conditions (APASA 2009b).

Slicks could arrive on the shore of Blaydin Point and the western headland of Lightning Creek on a flood tide as quickly as within one hour of the spill occurring. However, the maximum probability of exposure of any shoreline is fairly low, at 23%, because of the high volatility and rapid weathering of the processed condensate. The maximum volume of condensate predicted to reach the shoreline would be 4.2–5.8 m^3 (17–23% of the spill volume) (APASA 2009b).

Scenario 12—Refuelling spill at East Arm Wharf

Slicks caused by this diesel spill would generally move along an east–west axis as a result of tidal movements, and would remain within East Arm under all seasonal conditions (Figure 7-36).

As diesel is less volatile than condensate, the slick would undergo weathering processes more slowly and would persist longer in the marine environment, with a consequent potential for shoreline exposure. The spill would likely cause shoreline exposure next to East Arm Wharf (a 67–79% probability) within an hour of the spill event. Shorelines to the east and south of East Arm may also be exposed at discontinuous points, although with a much lower probability (<10%). The maximum volume of diesel predicted to reach the shoreline is relatively high, at 140–164 L (70–82% of the initial spill volume) (APASA 2009b).

Likelihood of spills affecting shorelines

The secondary risk of hydrocarbon spills occurring and then reaching sensitive shorelines in Darwin Harbour is derived by multiplying the primary risk from Table 7-36 by the probability of shoreline exposure from spill-trajectory modelling.

As discussed above, spills from the gas export pipeline in the main body of the Harbour (scenarios 9 and 10) are not predicted to affect shorelines. Spills of condensate or diesel in East Arm are more likely to reach shorelines, transported by regular tidal movements and to a lesser degree by seasonal winds.

The calculated secondary risk for nearshore spills is provided in Table 7-36. These levels of risk (or "frequency" of an oil pollution event occurring) are considered low, and would be further reduced by the spill prevention and response controls to be implemented in the nearshore development area.

Potential environmental impacts of spills

The potential impacts of hydrocarbon spills are described in Section 7.2.4, including the mechanisms by which hydrocarbons can be toxic or harmful, the ecotoxicity of the condensate from the Ichthys Field, and the potential effects of oil spills on various groups of marine biota including cetaceans, turtles, seabirds, fish, local benthic communities and plankton. The nearshore development area contains additional marine biota that could be affected by an accidental oil spill.

Benthic biota

Oil spills can be readily dispersed and incorporated into shallow, sedimentary environments by wind, waves and tides. In general, short-term effects on intertidal benthic communities are characterised by losses of sensitive species, dominance of tolerant species and early colonisation by opportunists, depending on the intensity of the oil pollution. The rate of recovery is influenced by the characteristics of the shoreline: exposed rocky-shore communities appear to recover more quickly, for example within two years, than sheltered low-energy coastlines, which can take five to eight years to recover (Volkman et al. 1994).

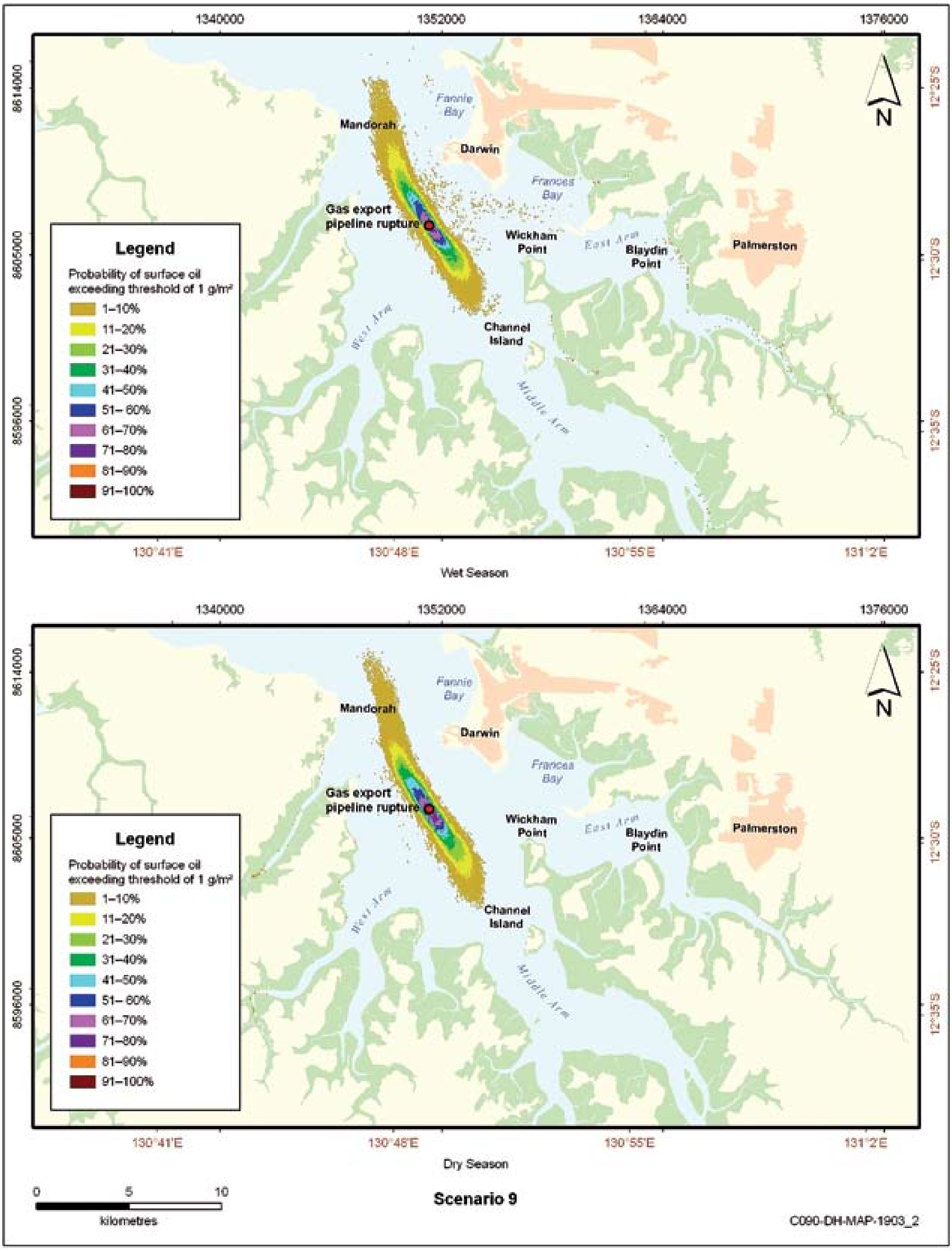

Figure 7-33: Scenario 9—gas export pipeline rupture: simulated oil-spill trajectories for 50 m^3 of condensate

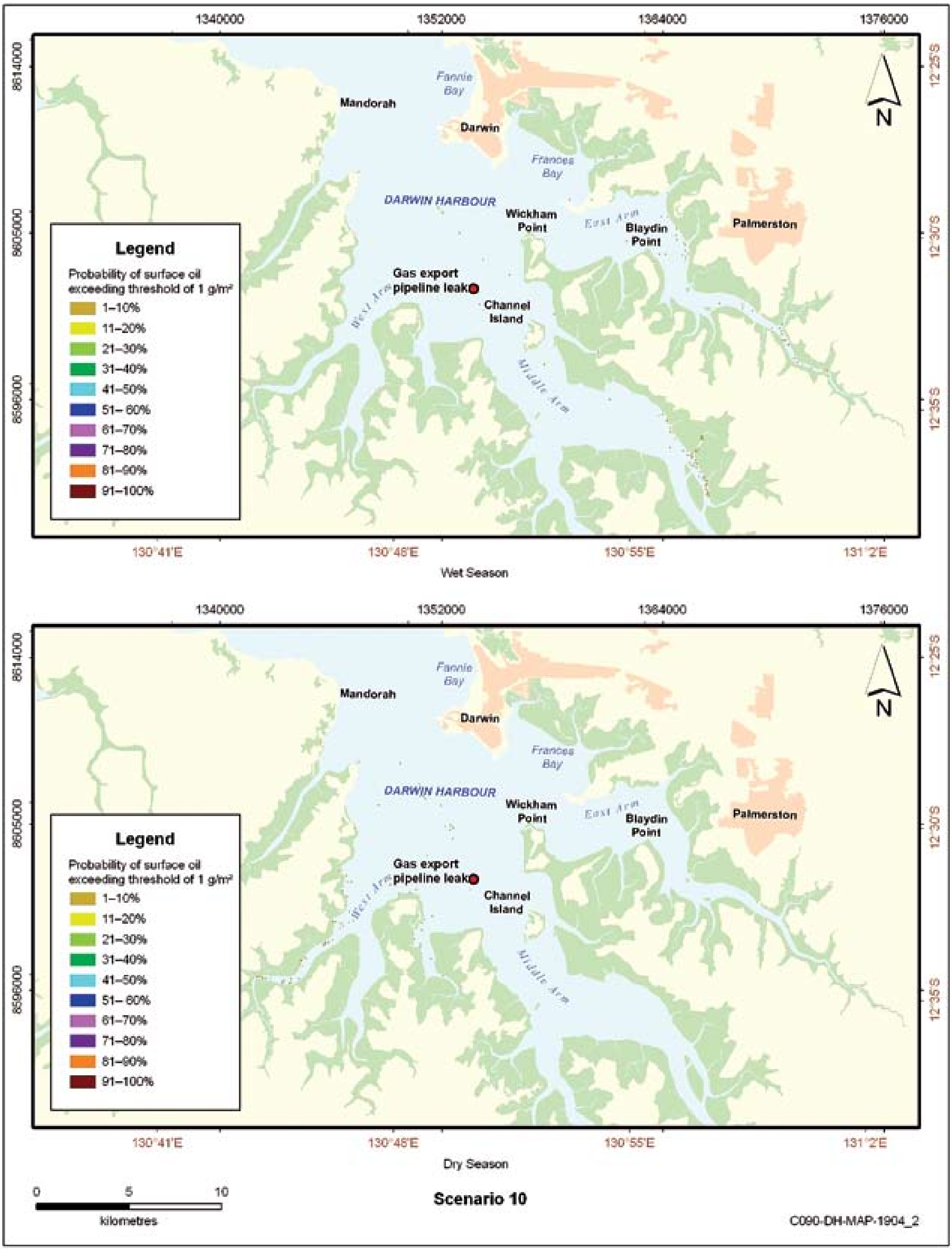

Figure 7-34: Scenario 10—gas export pipeline leak: simulated oil-spill trajectories for 1 m³ of condensate

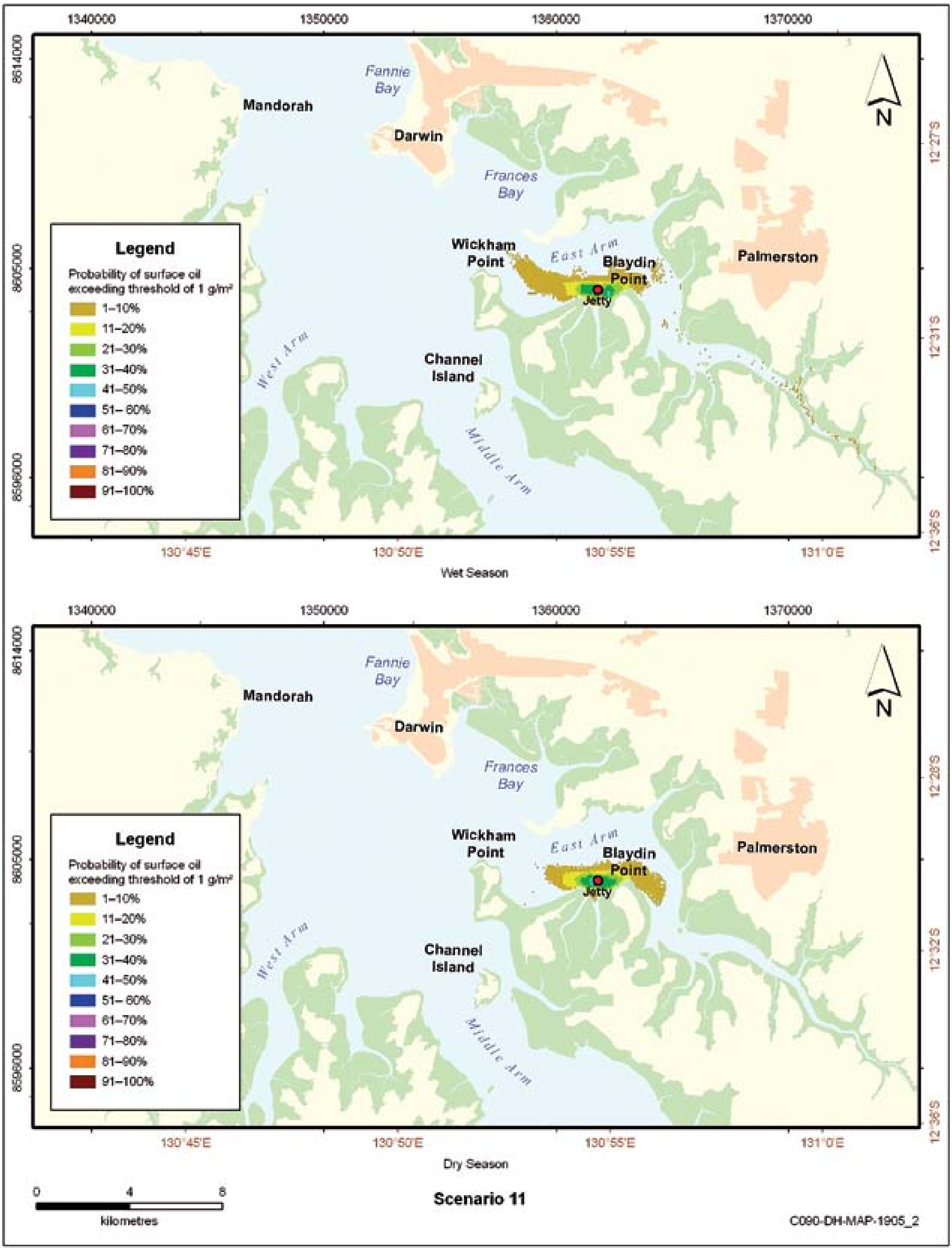

Figure 7-35: Scenario 11—condensate loading line leak or coupling failure: simulated oil-spill trajectories for 25 m^3 of condensate

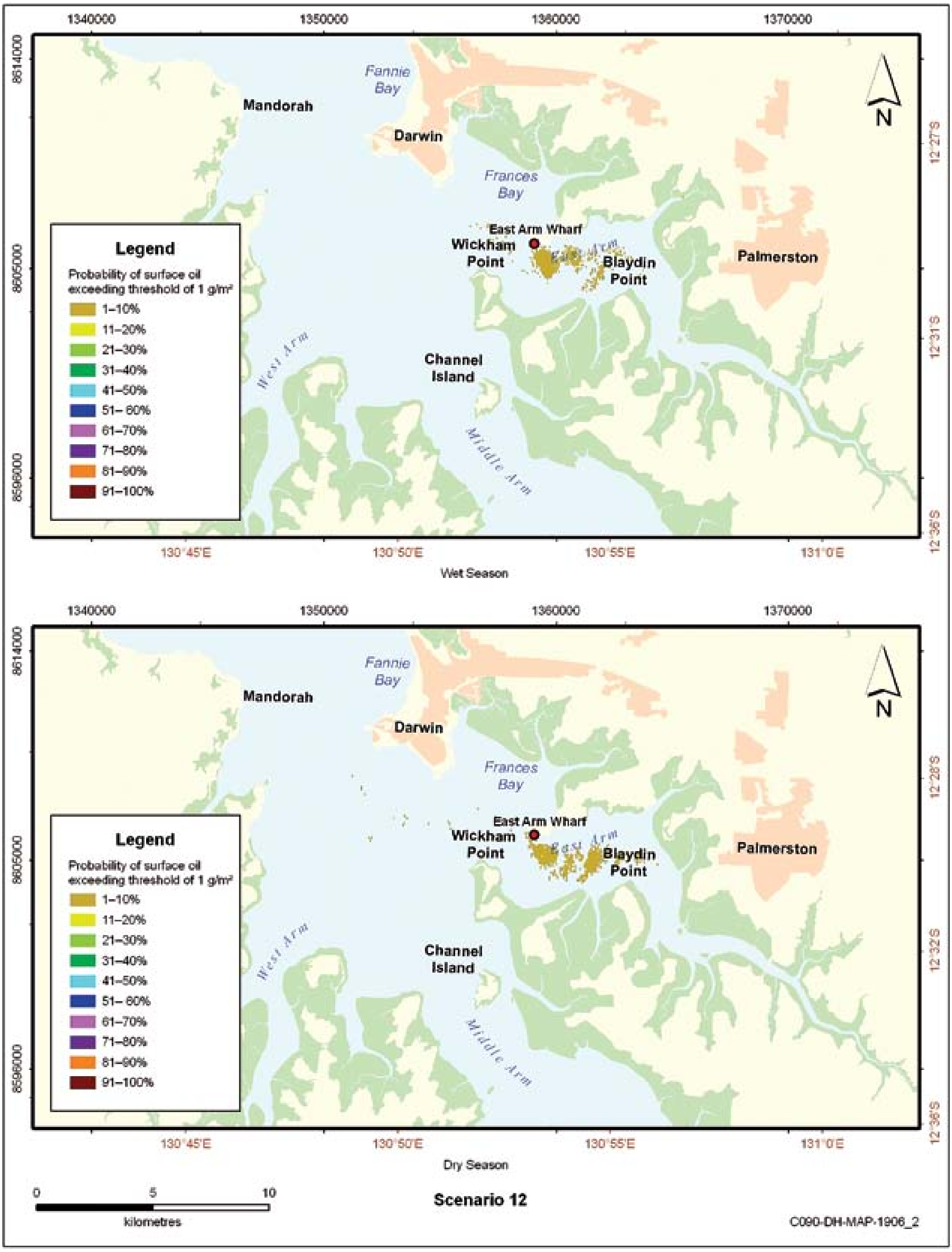

Figure 7-36: Scenario 12—refuelling spill at East Arm Wharf: simulated oil-spill trajectories for 0.2 m³ of diesel

7 Marine Impacts and Management

Table 7-36: Likelihood of hydrocarbon spills from the offshore development area reaching sensitive shorelines

Scenario	Name	Primary risk (per year)	Secondary risk (per year)	
			Wet season	Dry season
9	Gas export pipeline rupture	2.7×10^{-6}	None	None
10	Gas export pipeline leak	1.1×10^{-5}	None	None
11	Leak of condensate loading line or a coupling failure at the jetty	3.5×10^{-3}	6.9×10^{-4}	4.0×10^{-4}
12	Refuelling spill at East Arm Wharf	4.9×10^{-2}	2.0×10^{-2}	1.1×10^{-2}

Corals

Areas of hard and soft corals in East Arm occur at South Shell Island, Old Man Rock and north-east Wickham Point. These communities are exposed to the water surface at low tide and therefore could be affected by a hydrocarbon spill during certain conditions. Similarly, the Weed Reef coral community is exposed at low tide and may be at slight risk from a gas export pipeline rupture, depending on the exact location of the spill. The Channel Island coral community in Middle Arm would not be affected by the modelled spill scenarios; however a pipeline rupture or leak at a location closer to Channel Island has the potential to affect these coral communities.

Corals occupy intertidal and subtidal zones and oil-exposure effects will vary depending on the extent of physical contact, the depth of immersion, tidal movements, currents, wind and waves. Oil that is immersed, solubilised and dispersed in water has a much greater effect on corals than oil floating at the surface (Volkman et al. 1994).

Corals that are exposed to or above the water surface are more vulnerable to the effects of oil that those in submerged areas. Tissue death can occur where oil adheres to corals, although sensitivities vary among different species. In an example from Panama, oil exposure caused severe damage to intertidal biota at the seaward side of reefs and flats where oil had accumulated at low tide. Seaward populations of common sessile animals such as zoanthids, hydrocorals and scleractinian corals were severely reduced. Previously abundant populations of sea urchins, snails and stomatopods (mantis shrimps) on the reef flats also showed reductions (Volkman et al. 1994).

Extensive mortality of subtidal corals (e.g. of scleractinian genera) has been observed on oiled reefs, particularly at depths of 3 m or less. Extensive sublethal effects have also been recorded, including bleaching, production of mucus and dead areas of coral tissues, which may influence the long-term survival of coral populations even more than the initial individual mortalities (Volkman et al. 1994).

Soft-bottom communities

The response of benthic invertebrates to oil spills varies widely between species. Some burrowing invertebrates such as polychaetes and copepods are relatively tolerant and elements of the infauna contribute to bioturbation and degradation of the oil in sediments. Conversely, however, burrowing bivalves are susceptible to bioaccumulation and oiling effects (Volkman et al. 1994).

Oil contamination in subtidal soft-bottom sediment communities can cause very high or even total mortality of benthic fauna, including burrowing filter-feeders, echinoderms, molluscs, amphipods and prawns. Recolonisation of the denuded oiled sediment commences with opportunistic polychaetes, followed by a succession of animals in a series of fluctuations until stability is reached. Amphipods are particularly sensitive to oil contamination and take a number of years to return (Volkman et al. 1994).

Intertidal and subtidal soft-sediment communities occur throughout East Arm. They could be affected by spill Scenario 12 and by Scenario 11 to a lesser degree.

Mangroves

Mangrove vegetation occurs throughout Darwin Harbour in the intertidal zone. Mangroves are known to be particularly susceptible to pollution from hydrocarbon spills and tree deaths have been recorded in a number of such spills internationally. Contact with mangrove roots is particularly critical, as coating and trapping of oil among the partially submerged pneumatophores affects normal respiratory and osmoregulatory functions (Volkman et al. 1994).

The impact of hydrocarbon spills on mangroves can be divided into two phases: the short-term mortality phase because of coating with fresh condensate and the longer-term effects of the weathered hydrocarbons becoming incorporated into sediments, which inhibits the growth of seedlings and larger plants (Volkman et al. 1994).

Shoreline exposure is predicted to occur in East Arm for spill scenarios 11 and 12. For Scenario 11, the mangrove fringe at the north of Blaydin Point is the most likely area of impact. Scenario 12 could expose shoreline mangroves at various points in the east and south of East Arm depending on the weather and tidal conditions at the time of the spill (APASA 2009b).

Prevention and management of accidental hydrocarbon spills

An OSCP and emergency response plan will be developed for the Project in accordance with the *Offshore Petroleum and Greenhouse Gas Storage Act 2006* (Cwlth) (as described in Section 7.2.4 *Accidental hydrocarbon spills*). The OSCP will provide details of organisational responsibilities, actions and procedures, reporting requirements and the resources available to ensure effective and timely management of an oil spill. It will, for example, make provision for appropriate spill-response equipment to be located at the nearshore facilities, for support vessels used in the nearshore area also to have oil-spill response capability, and for regular emergency response exercises to be carried out.

As part of its OSCP, INPEX will have the capability to initiate real-time oil-spill fate and trajectory modelling, so that spills can be monitored and responses optimised.

Other industry-standard provisions will be implemented at the nearshore development area in order to prevent a spill occurring. These will include the following:

- Each component of the nearshore development area, including the gas export pipeline, will be designed to meet the oceanic, climatic and seismic conditions of the area.
- Sections of the pipeline in Darwin Harbour will be laid in a trench and impact protection (rock dumping) will be placed over the trench to mitigate risks from anchor damage and ship grounding. The extent of this will be dependent on the outcomes of the final quantitative risk assessment.
- The jetty structure is being designed according to Australian Standard *AS 4997:2005, Guidelines for the design of maritime structures*, taking cyclones into account; the loading arms, for example, will be designed to allow them to be tied down should a cyclone threaten Darwin.
- A 200-m precautionary zone will be implemented around the gas export pipeline prohibiting anchoring by vessels in accordance with Section 66(5) of the *Energy Pipelines Act* (NT).
- Periodic internal inspections of the gas export pipeline will be undertaken to assess its integrity.
- Condensate tankers will be subject to vetting procedures. Product loading operations will be monitored by a terminal representative on board the export tanker.
- Approach speeds to the berth will be monitored by a speed-of-approach laser system, with the data transmitted to the vessel pilot.
- All shipping movements in Darwin Harbour will be controlled by a vessel traffic system operated by the DPC.
- Visual monitoring of hoses, couplings and the sea surface will be undertaken during refuelling of vessels. Dry-break couplings and breakaway couplings or similar technology will be used where available and practicable.
- A maintenance and inspection program will be in place for product loading arms.
- An emergency shutdown interface will be in place between vessels and the onshore processing plant.
- During product loading, radio contact will be maintained between the support vessel and the jetty, and collision prevention procedures will be implemented.

In the event of a spill of light oils at the nearshore development area, the likely management response will be to deploy spill containment and clean-up equipment such as booms. If the spill threatens sensitive environmental receptors, dispersants may be added in consultation with the relevant authorities.

Residual risk

A summary of the potential impacts, management controls, and residual risk for the identified nearshore hydrocarbon spill scenarios is presented in Table 7-37. The “likelihood” ratings shown are derived from the quantitative assessments of primary and secondary risk presented above, and do not account for spill-response procedures which would reduce the frequency and extent of spills. Therefore, these risk ratings are conservative and could be reduced further in the event of an actual spill. The risks of harm to the nearshore marine environment are considered to be “medium” or “low”.

7.3.6 Waste

Solid wastes will not be discharged to the nearshore marine environment from vessels or infrastructure associated with the Project. Non-hazardous wastes generated in the nearshore development area (e.g. domestic and packaging wastes, clean oil drums, construction materials such as plastics and metal) as well as hazardous wastes (e.g. spent engine oils, batteries and paints) will be removed to the mainland for onshore disposal at an approved facility.

Table 7-37: Summary of impact assessment and residual risk for accidental hydrocarbon spills (nearshore)

Aspect	Activity	Potential impacts	Management controls and mitigating factors	Residual risk*		
				C†	L‡	RR§
Accidental hydrocarbon spills	Scenario 9: Gas export pipeline rupture in Darwin Harbour.	Exposure of moderate areas of nearshore waters to surface oil.	The gas export pipeline is designed to meet the conditions of the area. Trenching and rock dumping over sections of the gas export pipeline in Darwin Harbour for protection and stability. Precautionary zones put in place to prohibit anchoring in the vicinity. Spill-response equipment and procedures. Oil Spill Contingency Plan.	D (E1)	1	Low
Accidental hydrocarbon spills	Scenario 10: Gas export pipeline leak in Darwin Harbour.	Exposure of small areas of nearshore waters to surface oil.	The gas export pipeline is designed to meet the conditions of the area. Trenching and rock dumping over sections of the gas export pipeline in Darwin Harbour for protection and stability. Precautionary zones put in place to prohibit anchoring in the vicinity. Spill-response equipment and procedures. Oil Spill Contingency Plan.	E (E1)	1	Low
Accidental hydrocarbon spills	Scenario 11: Leak of condensate loading line or a coupling failure at jetty at Blaydin Point.	Exposure of moderate areas of nearshore waters to surface oil.	Emergency shutdown interface put in place between the vessel and the plant. Maintenance and inspection program for product loading arms. Spill-response equipment and procedures. Oil Spill Contingency Plan.	D (E1)	3	Medium
		Localised areas of mangroves, intertidal communities and possibly corals exposed to oil, leading to reduced growth or death.		E (B2)	2	Low
Accidental hydrocarbon spills	Scenario 12: Refuelling spill at East Arm Wharf.	Exposure of moderate areas of nearshore waters to surface oil.	Visual monitoring of hoses, couplings and the sea surface during refuelling of vessels. Continuous radio contact between the vessel and the wharf. Use of dry-break couplings and breakaway couplings where practicable. Spill-response equipment and procedures. Oil Spill Contingency Plan.	F (B2)	4	Low
		Localised areas of mangroves, intertidal communities and possibly corals exposed to oil, leading to reduced growth or death.		E (B2)	4	Medium

* See Chapter 6 *Risk assessment methodology* for an explanation of the residual risk categories, codes, etc.

† C = consequence.

‡ L = likelihood.

§ RR = risk rating.

Similarly, food scraps generated by vessels in the nearshore development area will be contained on board and later transported to an onshore disposal facility in accordance with the Marine Pollution Regulations (NT). Under this legislation, food scraps may not be disposed of overboard within 3 nautical miles of land. This exclusion zone includes all of Darwin Harbour and extends out past the Tiwi Islands (Melville Island and Bathurst Island); it encompasses the whole of the nearshore development area.

Management of waste

A Provisional Waste Management Plan has been compiled (attached as Annexe 16 to Chapter 11), which will guide the development of a series of more detailed plans during the construction and operations phases of the Project. Key inclusions in this plan include the following:

- All hazardous and non-hazardous solid wastes generated in the nearshore development area, including food scraps, will be retained on board vessels and transported to onshore facilities for disposal.
- Chemicals and hazardous substances used during all phases of the Project will be selected and managed to minimise the potential adverse environmental impact associated with their transport, transfer, storage, use and disposal.
- Only approved and licensed waste contractors will be employed for waste disposal.
- Waste minimisation will be included in the tendering and contracting process.

Residual risk

A summary of the potential impacts, management controls, and residual risk for solid waste is presented in Table 7-38. After implementation of these controls, potential impacts from solid wastes are considered to present a “low” risk, as wastes will be not be disposed of into the marine environment.

7.3.7 Underwater noise and blast emissions

The following discussion on the nature and potential impacts of underwater noise and blasts in the nearshore development area is derived from a detailed literature review by URS, which is provided in Appendix 15. Airborne noise emissions from the Project, and their potential impacts, are discussed in Chapter 10.

Underwater noise in the nearshore environment

Background information on noise sources in the marine environment and the propagation of sound through water to receptors such as marine animals are described in detail in Section 7.2.6 *Underwater noise emissions*. In contrast to deep offshore waters,

Table 7-38: Summary of impact assessment and residual risk for solid wastes (nearshore)

Aspect	Activity	Potential impacts	Management controls and mitigating factors	Residual risk*		
				C†	L‡	RR§
Discharge of food scraps	Routine operation of nearshore vessels.	Alteration of marine environment including nutrient enrichment.	Food scraps will be retained on board all vessels in the nearshore development area for later transport to an onshore facility for disposal. Provisional Waste Management Plan.	F (E1)	6	Low
Non-hazardous waste	Routine operation of vessels during nearshore construction and ongoing product export.	Pollution of the marine environment if disposed of overboard.	All wastes will be disposed of to onshore facilities. Waste minimisation will be included in the tendering and contracting process. Provisional Waste Management Plan.	F (B3)	4	Low
Hazardous wastes	Generation of hazardous waste through routine nearshore operations.	Pollution of the marine environment if disposed of overboard.	All wastes will be disposed of to onshore facilities. Non-hazardous chemicals will be preferentially used where practicable and cost-effective. Waste minimisation will be included in the tendering and contracting process. Provisional Waste Management Plan.	F (B3)	3	Low

* See Chapter 6 *Risk assessment methodology* for an explanation of the residual risk categories, codes, etc.

† C = consequence.

‡ L = likelihood.

§ RR = risk rating.

ambient noise levels and frequencies across shelfal and nearshore waters are far more variable with changes in season, location and time of day. While the key sources of underwater noise remain shipping and local weather conditions such as wind, rain and sea state, the contributions from marine biota as well as various fishing, boating and industrial noises in ports and harbours become significant, and change regularly with time and place (Cato 2000; Urick 1983).

The type, intensity and propagation of sources contributing to ambient noise in coastal waters are also more spatially variable as a consequence of finer-scale changes in seafloor topography and seafloor substrate. Noise levels increase where more reflective rocky substrates are prevalent and decrease where thick absorptive layers of fine sediments and mud occur.

Turbulence and seafloor saltation noise induced by strong tidal streams can also become locally dominant, particularly in coastal parts of northern Australia with large tidal ranges (such as Darwin Harbour). For example, ambient noise in embayments in the Kimberley that contain coarse gravelly sediments can exceed 110–120 dB on a diurnal basis, particularly during spring ebb and flood tides (Curt Jenner, Research Biologist, Centre for Whale Research, Fremantle, Western Australia, unpublished data).

Ambient noise monitoring carried out to characterise the existing acoustic conditions in Darwin Harbour is presented in Chapter 3.

Noise emissions from the Project

Underwater noise will be emitted from the nearshore development area during the construction and operations phases of the Project, through activities such as piledriving and drill-and-blast operations, dredging, rock dumping, dredge spoil disposal and general vessel movements. Darwin Harbour already contains an operational port that generates underwater noise from a variety of pre-existing Harbour operations, many of which were constructed and currently operate using activities similar to those proposed for the Project's nearshore development area. The key Project activities that are likely to produce noise emissions significantly different (or louder) than current port activities are piledriving and drill-and-blast operations.

Underwater noise propagation modelling is not considered appropriate for the nearshore development area as predictions would be confounded by a large number of variables in this environment.

These are as follows:

- shallow water
- the variable depth of water because of the large tidal range
- naturally occurring underwater noise caused by the flow of large volumes of water during tidal movements
- the variation in bottom type, affecting the reflection or absorption of noise
- the variation in salinity, particularly between Middle Arm and East Arm and the main body of the Harbour
- the proximity and volume of existing anthropogenic noises
- local weather conditions (e.g. thunderstorms) that can also produce underwater noise.

Each of these factors adds a degree of uncertainty to predictions of underwater noise. A predictive model would need to make generalisations and assume homogeneous states, although they may not exist. However, the potential impacts of noise from key Project activities in the nearshore development area can be assessed through available literature and experience and an understanding of the key receptors in the nearshore environment as outlined below.

Piledriving

Piledriving will be undertaken periodically during the construction phase to install steel piles for the jetty and the module offloading facility. During these construction activities, actual piledriving would be undertaken for 30–40% of an operational shift, with general vessel movement and preparation occurring at other times. While under way, piledriving would generate persistent underwater noise "pulses", with a source level of up to 200 dB re 1 µPa. Noise levels will vary depending on the substrate and the piledriving method used, with the impact piling technique likely to generate the loudest noise.

Piledriving will be a significant source of noise in the nearshore marine environment. The repetitive and pulsed nature of this activity will generate noise with the potential to startle marine animals and lead to avoidance of the affected area. Any effects arising from piledriving would be more acute during the initial start-up phase. Pulsed noise can cause temporary threshold shift (loss of hearing) in marine mammals at levels of 200 dB re 1 µPa and above (see Appendix 15). Given that this level is equivalent to the noise source level for piledriving, such effects on dolphins or dugongs in Darwin Harbour could only be expected in the immediate vicinity of the activity. This noise would be attenuated considerably within tens of metres because of the East Arm's inherently poor acoustic propagation conditions caused by the shallow water, highly variable bathymetry, variable salinity and bottom type, and the expected high ambient noise levels. Even without allowing for losses because of scattering and absorption, noise from a 200-dB source would drop to a level of about 170 dB at a distance of 100 m and to 150 dB at around 2000 m[11].

It is not currently possible to derive criteria for pulsed noise that could cause behavioural disturbance in marine mammals (Southall et al. 2007). This conclusion is based on the large degree of variability in responses between groups, species and individuals. Ambient noise levels of 150–170 dB are already generated in East Arm by existing marine activities (see Chapter 3) without apparent effects on local animal populations.

Drill and blasting

Blasting in the nearshore development area may be required where rock is encountered that cannot be removed by dredging, such as at the entrance to the shipping channel at Walker Shoal. Blasting will be undertaken using the "confined" blasting (drill-and-blast) method, which involves drilling small holes in the rock with charges placed and connected in the holes for subsequent surface firing.

In comparison with surface blasting methods, confined blasting generates reduced effects on the marine environment. This is primarily because surface blasting requires a larger charge to break up rock material (generally three times larger than for confined blasting), as the explosive energy is dispersed throughout the water column rather than being directed at the rock (Ecos 1996).

The impact of a set of underwater blasts can also be reduced by implementing micro-delays between explosions, through connected fuses. The detonation event therefore comprises a chain of individual subordinate detonations. These produce irregular and less pronounced peak pressure levels than would occur if all the explosives were detonated simultaneously, or if a single aggregate charge of the same net explosive content was detonated (see Appendix 15). For the nearshore development area, it is proposed to use around six 50-kg charges set on micro-delays (as described in Chapter 5), producing lower peak pressure levels than would result from a single 300-kg blast.

For blasting generally, the risk of mortality is confined to an area in close proximity to the point of detonation, with a surrounding wider area where injury is possible.

11 According to practical spreading laws: *Transmission loss = 15 log (range).*

Beyond the immediate vicinity of detonation there is a wider area where minor injury, in the form of permanent threshold shift, is also possible. The greatest likely effect from the use of explosives, however, is as a result of noise disturbance, rather than blast or impulse. The zone of influence of noise-related potential impacts as a result of underwater detonations is substantially larger than that for lethality or injury, but still relatively confined.

Management controls such as the establishment of protection zones around the detonation site before and during blasting activities can protect marine animals in the area, and will be implemented for the Project. The Canadian Department of Fisheries has developed a method to calculate zones of impact for marine mammals and fish (as described in Ecos 1996), with consideration of the size of the charge, the depth of detonation and the depth of the surrounding water. According to this method, the charges proposed for the nearshore development area (with a 300-kg total charge detonated at the seabed in a water depth of 15 m) produce the zones of impact presented in tables 7-39 and 7-40 for marine mammals and fish respectively. This indicates that marine mammals more than 1250 m from the source, and 10-kg fish more than 660 m away, would not receive blast-related injuries. As described above, using multiple smaller charges set on micro-delays would reduce overall peak pressure levels, so the zones of impact presented in the tables below are conservative.

Table 7-39: Zones of impact for a diving marine mammal from a 300-kg confined blast

Distance (m)	Potential impact
473	No mortality, but a high incidence of moderately severe blast injuries, including eardrum rupture.
519	High incidence of slight blast injuries, including eardrum rupture.
854	Low incidence of trivial blast injuries, but no eardrum ruptures.
1248	Safe level and no injuries.

Source: Yelverton et al. 1973, not seen, cited in Ecos 1996.

Table 7-40: Zones of impact for a 10-kg fish from a 300-kg confined blast

Distance (m)	Potential impact
263	50% mortality
342	1% mortality
657	No injuries

Source: Yelverton et al. 1973, not seen, cited in Ecos 1996.

Marine mammals, reptiles (crocodiles and turtles) and humans (scuba-divers etc.) can all be affected by underwater blasts because of the large air-filled cavities in their lungs, and would all require a similar-sized zone of protection from blasting impacts.

Small "scare" charges prior to blasting operations are used in some settings to help reduce startle responses from the main blast and to encourage any animals in the vicinity to leave the blast area. However, toothed whales and dolphins have been found to be attracted to the location of blast detonations (Richardson et al. 1995), possibly to investigate the noise or in search of dead, injured or disoriented fish as prey. Owing to the presence of coastal dolphins in Darwin Harbour, scare charges are not considered an appropriate management control for use in the nearshore development area.

Alternative techniques to drilling and blasting are being investigated for the removal of the hard rock material within the shipping channel. At this stage, however, it is not possible to confirm whether there are any viable alternatives.

Dredging

Dredging is likely to be the most persistent source of underwater noise in the nearshore development area, as it will be generated consistently through the construction phase for up to four years. Source levels from dredgers are relatively modest, at around 160–170 dB re 1 µPa, and generate low-frequency noise. This type of noise is not expected to affect marine animals negatively to any significant extent, but it may cause some species to avoid the area.

Rock dumping and dredge spoil disposal

Rock dumping and dredge spoil disposal activities will be intermittent throughout the construction phase of the Project. Noise generated by rock dumping is likely to be broadband low frequency at modest source levels. Spoil disposal is not expected to generate noise to any appreciable extent, apart from the noise generated by the vessels carrying out the activity.

Vessel movement

Noise will be generated by vessels on a variable basis during the construction phase of the Project, depending on dredging and maritime construction activities. During operations, the Project will require around 200 tanker vessels per year to load product at Blaydin Point. Ships generate broadband noise from their propellers, motors, auxiliary machinery, gearboxes and shafts, together with their hull wake and turbulence. Noise generated by merchant ships is typically in the 20–500 Hz frequency range, which contributes to ambient low-frequency noise levels, particularly in regions with heavy ship traffic.

The sound levels produced by individual ships depend on their size, the number of propellers, the number and type of propeller blades, blade biofouling and maintenance conditions. In general, larger ships generate louder source levels (see Appendix 15).

Vessel propellers can also produce "cavitation" noise, where the propeller blades form gas-filled cavities in the very low pressure water generated on their forward faces. Intense broadband sound is created when these bubbles subsequently collapse, either in a turbulent stream or against the surface of the propeller. Cavitation noise can occur in the region of 500–3000 Hz, depending on the size of the vessel (see Appendix 15).

This type of noise can be generated by tanker vessels with constant-pitch propellers, but only when travelling at relatively high speeds (typically above 7–14 knots). Tanker movement through Darwin Harbour will be conducted at low speeds, and is not likely to generate cavitation noise. Vessels equipped with variable-pitch propellers and/or thrusters, such as tugs, supply tenders and dynamically positioned vessels (e.g. pipelay barges), could produce cavitation noise more frequently and will operate in the nearshore development area during the construction phase. While this noise would be generated intermittently, it is likely to be audible to marine animals such as dolphins and may cause them to avoid the area.

It is noted that pleasure craft and other small vessels fitted with outboard motors use high-speed propellers that generate cavitation noise in the spectrum 1–15 kHz and at relatively loud source levels (150–180 dB re 1 µPa). These types of vessels are commonly used throughout Darwin Harbour and generate noise that would be audible to dolphins.

Potential impacts to marine animals

As described in Section 7.2.6 *Underwater noise emissions*, the available data on the effects of noise on marine animals are variable in quantity and quality, and data gaps often restrict the development of scientifically based noise exposure criteria for mitigating risks to marine animals. Behavioural responses are strongly affected by the context of the exposure as well as the animals' experience, degree of habituation, motivation and condition and the ambient noise characteristics and habitat setting (see Appendix 15). Therefore, while the following assessment of potential impacts to marine animals in the nearshore development area is based on the best available information, it is subject to some uncertainties because of the paucity of research.

Cetaceans

The most commonly recorded cetacean species in Darwin Harbour are three coastal dolphins—the Australian snubfin, the Indo-Pacific humpback and the Indo-Pacific bottlenose (Palmer 2008).

Confined blasting has the potential to disturb, injure or even kill dolphins. Management controls such as protection zones will therefore be implemented, as described below, to reduce the risk of physical injury to dolphins through marine blasting.

Noise from piledriving and blasting activities will mainly be generated at frequencies below the optimal hearing range of dolphins (Richardson et al. 1995). However, the Australian snubfin dolphin does use some whistles in the 1–8 kHz range during foraging and socialising behaviours (Van Parijs, Parra & Corkeron 2000). While some of the higher-frequency components of piledriving noise will be audible to these dolphins, the modulation and tonal characteristics of this noise would be different from dolphin vocalisations, and would be highly unlikely to interrupt communication between individuals.

Mustoe (2008) cites a study in Victoria Harbour in Hong Kong where Indo-Pacific humpback dolphins showed behavioural responses to percussive piledriving. Dolphins were sighted within 300–500 m of the operation and showed increased swim speeds during piledriving, which were construed by researchers as positive avoidance behaviour. Similarly, dolphins in Darwin Harbour may avoid areas close to piledriving and blasting activities, where a noise threshold for discomfort or annoyance is reached.

Generally, loud sounds that are sudden are more likely to elicit a response than those that build up slowly (Mustoe 2008). For this reason, soft-start procedures will be used during piledriving to reduce startle responses.

If a sound is not associated with additional harmful effects, it seems less likely to be avoided and habituation is possible. Structured, repeated sounds may have in-built redundancy, allowing animals to ignore them (Mustoe 2008). Given that nearshore piledriving activities will last for many months, some habituation in local dolphins may become apparent. Frequent breaks in piledriving activities will also allow dolphins to move through the area relatively freely. The potential for any impact would be further reduced because of the many noise-attenuating features of the marine environment in the area.

The majority of noise frequencies generated by dredging, shipping and piledriving activities will be below the optimum hearing ranges for dolphins. In contrast, small vessels operating in Darwin Harbour (such as recreational boats) generate noise of much higher frequency which is audible to dolphins. Therefore impacts to dolphins as a result of noise from the Project are expected to be low.

Dugongs

Noise from the nearshore development area is likely to have similar effects on dugongs as on dolphins. Dugongs are likely to avoid areas where piledriving and blasting activities occur and physical injuries from underwater noise are not expected. Dugongs utilising the rock platforms around Channel Island or Weed Reef for foraging may be discouraged from the area while dredging activities for the gas export pipeline are under way, but these activities would be completed within a few weeks.

Marine reptiles

The low-frequency noise generated by blasting, piledriving and dredging activities will be audible to turtles, which hear in the 400–1000 Hz range. Sudden noises are known to elicit startle responses from turtles. They would also be at risk of injury from blasting activities in similar fashion to marine mammals. Although turtles are known to frequent Darwin Harbour, no significant nesting, breeding or foraging habitats have been identified in the nearshore development area.

Crocodiles are also likely to be able to hear the low-frequency noise generated by nearshore construction activities and would be at risk of injury when in close proximity to a blasting site.

Fish

The upper reaches of creeks represent breeding habitat for some of the fish species inhabiting Darwin Harbour. These areas present very poor sound propagation conditions because of the shallow water depth and soft substrate and most of the noise from nearshore construction activities is expected to attenuate before reaching these areas.

Marine blasting will result in some fish kills within the immediate blast zone. Piledriving activities may also cause some acute damage and mortality to fish at very close ranges. For pelagic fish, however, the most likely behavioural response during piledriving would be avoidance of the area.

Sharks and their relatives such as the freshwater sawfish (*Pristis microdon*) may be less susceptible to blast and impulse effects than are many fish, because of their lack of a swim bladder, their physical size and their general morphology.

Cumulative impacts

Noise generated by the Project will add to the existing periodic and transitory sounds contributing to ambient underwater noise in Darwin Harbour. The Port of Darwin already receives a wide variety of vessels. Around 1600 trading vessels and 5600 non-trading vessels visited the Harbour in 2008–09 and this number is forecast to increase. Other existing sources of underwater noise include biological sources (e.g. snapping shrimp) and weather (e.g. heavy rain, lightning storms), as described in Chapter 3.

Over the long-term operational phase of the Project, tanker vessel movements would represent an increase of 3% in vessel traffic (based on 2008–09 levels), and over time would account for less as shipping activity in the Port of Darwin continues to expand. The impacts of this increase in ambient noise levels are difficult to assess in terms of their significance to marine animals. However, disruptions to breeding, foraging or migration patterns in animal species as a result of existing noise sources in Darwin Harbour have not been recorded; this may be the result of a lack of research or may be evidence of a lack of impact. Given that no regionally significant habitat occurs in the nearshore development area, the potential for underwater noise to result in cumulative negative impacts to populations of marine animals is considered to be low.

Management of noise and blast emissions

A Provisional Piledriving and Blasting Management Plan has been compiled for the Project (attached as Annexe 12 to Chapter 11), which will guide the development of a series of more detailed plans during the construction and operations phases.

Key components of this plan that relate to management of marine blasting include the following:

- A permit-to-work (or similar) system will be implemented to ensure that areas where blasting and piledriving activities are occurring, or will occur, are clearly identified and that management measures are in place prior to work commencing.
- Only the minimum required charge will be used for nearshore blasting operations.
- Confined blasting methods will be used, with micro-delays between charges to reduce peak pressure levels of each blast in the surrounding waters.
- Fauna protection zones will be developed for nearshore blasting. The extent of these zones will be determined when detailed geotechnical investigations have been completed and further information from drill-and-blast contractors becomes available.
- Trained marine fauna observers will survey the fauna protection zones prior to the commencement of blasting. Blasting activities will be suspended if marine megafauna (e.g. cetaceans, dugongs, turtles and crocodiles) are observed to enter the fauna protection zone. Detonations will only occur if the fauna protection zone is observed to be free of marine megafauna for a period of at least 20 minutes.
- For effective surveillance, blasting will only be conducted in daylight conditions and with benign sea conditions so that observers are better able to sight any marine megafauna within the fauna protection zone.
- The potential to use passive or active acoustic monitoring to identify submerged marine animals in the fauna protection zone will be evaluated. If practicable, these methods are likely to be used to complement the precautionary marine animal observations prior to the commencement of blasting activities.
- Should fish be killed as a result of blasting activities and float to the surface, they will be retrieved in order to minimise the possibility of scavenging seabirds and other predators being injured by subsequent blasts.
- A permit to conduct marine blasting will be sought from the Department of Resources (DoR) as required under Section 16 of the *Fisheries Act* (NT).

Management controls that relate to piledriving include the following:

- An observation zone with a radius of 100 m will be implemented at the commencement of piledriving activities. This area will need to be confirmed clear of cetaceans, dugongs, turtles and crocodiles for 10 minutes prior to commencement.
- Piledriving will commence with a soft-start procedure, in which activities are gradually scaled up over a 5-minute period. This will provide an opportunity for any sensitive marine animals to leave the area before being exposed to the full intensity of underwater noise.
- Piledriving activities are planned to be undertaken during daylight hours only. Night-time piledriving would only be required if Project construction activities were to fall significantly behind schedule.

Noise impacts to the community and management controls are discussed in Chapter 10.

Residual risk

A summary of the potential impacts, management controls and mitigating factors, and residual risk for underwater noise and blasting is presented in Table 7-41. After implementation of controls, potential impacts from noise and blasting are considered to present a "low" to "medium" risk.

Table 7-41: Summary of impact assessment and residual risk of underwater noise

Aspect	Activity	Potential impacts	Management controls and mitigating factors	Residual risk*		
				C†	L‡	RR§
Underwater noise	Piledriving during jetty and module offloading facility construction.	Avoidance of the area by fish, and potentially a small number of injuries in close proximity to the piledriving activity.	Soft-start procedures will be used to reduce startle responses. Piledriving activities will only be carried out during daylight hours unless construction activities fall significantly behind schedule. Provisional Piledriving and Blasting Management Plan.	F (B3)	3	Low
Underwater noise	Piledriving during jetty and module offloading facility construction.	Avoidance of the area by marine megafauna, including threatened species.	No significant breeding, foraging or aggregation areas for threatened species are known to exist in the nearshore development area. An observation zone will be put in place to ensure that large animals are clear of the area prior to the commencement of piledriving. Soft-start procedures will be used to reduce startle responses. Piledriving activities will only be carried out during daylight hours unless construction activities fall significantly behind schedule. Provisional Piledriving and Blasting Management Plan.	F (B1)	6	Low
Underwater noise	Rock dumping and offshore spoil disposal.	Avoidance of the area by marine megafauna and fish, including threatened species.	No significant breeding, foraging or aggregation areas for threatened species are known to exist in the nearshore development area. Noise source levels from these activities are relatively low.	F (B1)	6	Low
Underwater noise	Dredging during construction of the nearshore development area.	Avoidance of the area by fish and marine megafauna, including significant species.	Predominantly low-frequency broadband noise. No significant breeding, foraging or aggregation areas for threatened species are known to exist in the nearshore development area. The greater part of Darwin Harbour will remain unaffected by changes in underwater noise levels.	F (B1)	6	Low
Underwater noise	Use of explosives on hard rock at Walker Shoal during construction.	Localised injuries or deaths to fish. Avoidance of the area by fish.	Confined blasting methods with micro-delays between blasts will be used to reduce peak pressures and the radius of impact zones. Use the minimum required charge for blasting. Provisional Piledriving and Blasting Management Plan.	E (B3)	6	Medium
Underwater noise	Use of explosives on hard rock at Walker Shoal during construction.	Localised injuries or deaths to marine megafauna, including significant species.	No significant breeding, foraging or aggregation areas for threatened species are known to exist in the nearshore development area. Confined blasting methods with micro-delays between blasts, to reduce peak pressures and radius of impact zones. Use the minimum required charge for blasting. Fauna protection zones, with blasting activities suspended if marine megafauna are observed inside the zones. Blasting during daylight and benign sea conditions only. Provisional Piledriving and Blasting Management Plan.	D (B1)	2	Medium

Table 7-41: Summary of impact assessment and residual risk of underwater noise (continued)

Aspect	Activity	Potential impacts	Management controls and mitigating factors	Residual risk*		
				C†	L‡	RR§
Underwater noise	General shipping and vessel movements	Displacement of fish and marine megafauna from the vicinity of vessels.	The nearshore area is located close to an existing port. Marine megafauna may be accustomed to vessel traffic. No significant breeding, foraging or aggregation areas for threatened species in the nearshore development area. Provisional Cetacean Management Plan.	F (B1)	6	Low

* See Chapter 6 *Risk assessment methodology* for an explanation of the residual risk categories, codes, etc.

† C = consequence.

‡ L = likelihood.

§ RR = risk rating.

7.3.8 Light emissions

Lighting systems on the onshore and nearshore infrastructure and berthed vessels will generate light emissions to the marine environment at Blaydin Point and its surrounds. Currently, artificial light sources exist at East Arm Wharf and the Darwin LNG plant at Wickham Point (4 km and 5 km from Blaydin Point respectively), as well as lighting of lower intensity from residential and urban areas throughout the northern and eastern shore areas of Darwin Harbour.

Marine turtles are known to be sensitive to artificial lighting sources during nesting and hatching (Pendoley 2005). However, the mangroves and mudflats throughout the shoreline of Darwin Harbour do not provide suitable beach habitat for turtle nesting. The closest turtle nesting beaches to the nearshore development area are at Mandorah (more than 20 km from Blaydin Point) and at Casuarina Beach, north of Darwin Harbour, where existing car-park lighting and street lighting spills on to the beach in some areas. This area is 20 km north of Blaydin Point and faces out to Beagle Bay; light spill from the nearshore development area will not be detectable at Casuarina Beach. Both beaches support only low-density turtle nesting.

Artificial light is not considered likely to have negative effects on foraging turtles, dolphins or dugongs (Mustoe 2008). There is no evidence that dugongs and dolphins in Darwin Harbour are adversely affected by the light regimes of other developments along the Harbour foreshore. Likewise, seasnakes in Darwin Harbour are not noticeably attracted to lights on jetties and wharfs and informal surveys of mangrove snakes suggest no apparent effects of foreshore development on snake numbers (Dr Michael Guinea, marine biologist, Charles Darwin University, pers. comm. August 2008).

Residual risk and management

Lighting from the nearshore development area is not considered to pose a threat to the surrounding marine environment. There are no sensitive light receptors (e.g. turtle nesting beaches) in close proximity to the proposed Project infrastructure and, in consequence, any localised effects on marine biota are considered to be minor.

Lighting design and operation for the nearshore facilities will meet personnel safety requirements.

During the operations phase, berthing and departure of tanker vessels and support vessels will be carried out mainly during daytime but occasionally at night. All vessels will be operated (and lit) according to safety requirements and in consultation with the DPC.

7.3.9 Marine pests

As described in Section 7.2.8, marine pest risks associated with the Project need to be considered closely and the appropriate management strategies defined. Of all the marine-based activities associated with the Project, the nearshore activities, particularly during the construction phase, represent the greatest risk of marine pest introduction. Marine pest risks are generally heightened in areas where water is shallow (less than 50 m deep) and close to the coastline, or near shoals and reefs, as the marine species recognised as representing an elevated pest risk to Australia are typically coastal or shallow-water species. This risk is exacerbated by the fact that coastal areas also have many features considered vulnerable to the impacts of marine pest invasions, such as coastal maritime infrastructure and aquaculture facilities.

The major mechanisms for marine pest transfer are ballast-water discharge and biofouling; an introduction to these is provided in Section 7.2.8, while the particular issues relevant to the nearshore infrastructure and Project activities are discussed below.

Biofouling

The vessels involved in nearshore construction activities, such as the barges used for module transport and pipelay and the dredgers and their supporting vessels, pose particular marine-pest risks. These vessels are generally large and slow-moving, increasing the opportunity for marine organisms to establish and grow on submerged surfaces. Dredgers and other specialist construction vessels are likely to have complex equipment and underwater surfaces, providing a variety of biofouling niches and making cleaning and inspection difficult. Some of these vessels, such as jack-up barges and dredging barges, will also be in direct contact with the Harbour floor, increasing the potential to transfer marine pests to seabed habitats.

Before construction activities commence in Darwin Harbour, it is also possible that at least some of the vessels engaged on the Project will have travelled recently through ports in South-East Asia (e.g. Singapore), where the tropical climate is similar to that of the nearshore development area. This will further increase the risk of the successful establishment of any marine pests accidentally transferred. Marine pest species such as the black striped mussel (*Mytilopsis sallei*) and Asian green mussel (*Perna viridis*) occur in South-East Asian waters (URS 2009).

The operations phase of the Project also poses a marine pest risk, although on a smaller scale. Tankers entering Darwin Harbour from international ports represent relatively low inherent risks as they are streamlined ships that present fewer opportunities for the growth of biofouling organisms. Marine pest risks for these tankers are principally related to the discharge of ballast water, which will require quarantine management.

Ballast water

Vessels engaged in construction activities will generally (although not universally) carry some ballast water, but the frequency and volume of ballast-water discharges from these vessels will be relatively modest. Ballast water in tanker vessels originating from ports in temperate waters (e.g. from Japan) is unlikely to contain marine species that could survive and become established in the tropical waters of Darwin Harbour during the operations phase. Therefore marine pest risks to the nearshore development area from ballast water do exist, but to a lesser extent than the risks posed by biofouling.

All ships in Australian coastal waters discharging ballast water which has been sourced from outside Australia are required to conform to AQIS's ballast-water requirements. In general terms, the discharge of international ballast water is prohibited unless the vessel has performed an open-ocean exchange of this water, and the exchange complies with AQIS's requirements for such exchange.

Management of marine pest risk

A Provisional Quarantine Management Plan has been compiled for the Project (attached as Annexe 13 to Chapter 11), with consideration of the requirements of the relevant regulatory agencies (which are likely to include AQIS, the DoR and the DPC). It will guide the development of a series of more detailed plans during the construction and operations phases. Key inclusions in the plan include the following:

- Discharge of ballast water into Darwin Harbour will be carried out in accordance with AQIS requirements.
- INPEX will ensure that vessels engaged in the Project comply with the biofouling requirements of the regulatory authorities.
- Vessels engaged in Project work will be subjected to a biofouling risk assessment which may result in cleaning or hull inspections.
- Relevant Project vessels will be required to maintain satisfactory records of antifoulant coatings, hull-cleaning and the exchange of ballast water.

A marine pests monitoring program will be developed for Darwin Harbour in conjunction with the relevant regulatory authorities, including NRETAS and the DoR. It is anticipated that the monitoring program methodology will be consistent with the monitoring framework developed by the National Introduced Marine Pests Coordination Group (NIMPCG). The monitoring plan will likely include the following:

- the identification of specific development areas for invasive species monitoring
- the scheduling of periodic monitoring to search for marine pests
- the assessment of any apparent impacts of any marine pests (if identified) and their association with Project activities
- the implementation of programs for the control and/or eradication of marine pests where they have been identified, in consultation with relevant regulatory agencies and the Commonwealth's Consultative Committee on Introduced Marine Pest Emergencies.

Table 7-42: Summary of potential impacts, management controls and risk for marine pests (nearshore)

Aspect	Activity	Potential impacts	Management controls and mitigating factors	Residual risk*		
				C†	L‡	RR§
Marine pests	Hull biofouling during the construction phase (e.g. on pipelay barge, dredging barge) and operations.	Invasion of native marine ecosystems by pests, threatening native marine plant and animal life and impacting maritime industries.	Biofouling risk assessment in place for all vessels. Ensuring vessel compliance with regulatory-authority guidelines for biofouling. Marine pest monitoring program. Provisional Quarantine Management Plan.	C (B3)	2	Medium
Marine pests	The discharge of ballast water during construction and operations.	Invasion of native marine ecosystems by pests, threatening native marine plant and animal life and impacting maritime industries.	Discharge of ballast water into Darwin Harbour will be carried out in accordance with AQIS requirements. Marine pest monitoring program. Provisional Quarantine Management Plan.	C (B3)	2	Medium
Marine pests	The transfer of exotic marine pests to coastal ports because of infection of vessels at the offshore development area.	Invasion of native marine ecosystems by pests, threatening native marine plants and animals and impacting maritime industries.	Biofouling risk assessment in place for all vessels. Ensuring vessel compliance with regulatory-authority guidelines for biofouling. Undertaking opportunistic ROV inspection of submerged infrastructure surfaces at offshore facilities. Provisional Quarantine Management Plan.	C (B3)	2	Medium

* See Chapter 6 *Risk assessment methodology* for an explanation of the residual risk categories, codes, etc.

† C = consequence.

‡ L = likelihood.

§ RR = risk rating.

Residual risk

A summary of the potential impacts, management controls, and residual risk for marine pests is presented in Table 7-42. After implementation of these controls, potential impacts from marine pests are considered to present a "medium" risk.

7.3.10 Marine megafauna

Marine animals that regularly swim at the water surface, such as dugongs and turtles, could interact with vessels operating in the nearshore development area during the construction phase. On very rare occasions, a marine mammal or turtle could suffer injury from a vessel collision. Large construction vessels (e.g. dredging barges, dump barges, pipelay barges and heavy-lift module transporters) are slow-moving (typically around 0.5–3 knots) and afford marine animals the opportunity to take action to avoid them. Smaller, fast-moving tender and crew-transfer vessels, which may travel at speeds of up to 20 knots, could be more hazardous to marine animals. It is noted that regular marine traffic already uses Darwin Harbour and that the construction phase will introduce an increase to these existing levels.

Product tankers operating during the operations phase will rarely exceed speeds of 10 knots in Darwin Harbour and will move slower in East Arm on their approach to Blaydin Point, with tugs in attendance. Again, marine animals will have ample opportunity to take action to avoid approaching vessels. Marine animals would also be expected to be attuned to the large slow-moving vessels which presently frequent the Harbour, especially in the vicinity of East Arm Wharf and Hudson Creek.

Trailing suction hopper dredgers (TSHDs) can occasionally injure or kill marine turtles near the seabed by accidentally sucking them into the equipment. Cutter-suction and backhoe dredgers cannot do this as they lack trailing suction dragheads (Dickerson et al. 2004). Suction into the draghead would affect the water column close to the equipment, out to a radius of around one metre. Efficient operation of the equipment can also reduce the risk of turtle entrainment, including ensuring that the suction surface is buried in the sediment while dredging and that the pumps to the TSHD are turned off when the draghead is lifted off the seabed.

It is presumed that sawfish could also be entrained in dredging equipment as they inhabit muddy seabeds. Incidents of injury or death to these animals are expected to be very rare during nearshore dredging activities as vessel noise and turbid plumes would discourage turtles and sawfish from remaining near the dredging equipment.

As described in Chapter 3, listed threatened species of marine animals do occur in the Harbour but no critical breeding or foraging areas have been identified for these in or around the nearshore development area. The potential for injury or death by vessel collisions or entrainment is very slight and would affect individuals without impacts to the broader populations of these species.

Other impacts to marine animals from noise and shockwaves as a result of piledriving and blasting activities are discussed in detail in Section 7.3.7.

Management of marine megafauna

A Provisional Cetacean Management Plan has been compiled for the Project (attached as Annexe 4 to Chapter 11), which will guide the development of a series of more detailed plans during the construction and operations phases. Key inclusions in this plan include the following:

- Vessel interactions with cetaceans in the nearshore development area will be avoided by:
  - aiming to maintain a 100-m distance from a large cetacean or a 50-m distance from a dolphin
  - operating at a "no-wash speed" when within 100–300 m of a large cetacean or 50–150 m of a dolphin
  - not actively encouraging bow-riding by cetaceans. However, should any cetacean(s) commence bow-riding, the vessel master will not change course or speed suddenly.

A Provisional Dredging and Dredge Spoil Disposal Management Plan has also been developed for the Project (Annexe 6 to Chapter 11). As part of this plan, practical options for reducing the risks of marine animal entrainment in TSHDs will be explored in consultation with the dredging contractor. These will be incorporated as management controls into the final dredging management plan. Options could include installing deflectors on dragheads and using turtle "tickler" chains on the trailing arms.

The potential impacts of underwater noise and blasting on marine megafauna are discussed in Section 7.3.7 *Underwater noise and blast emissions* and are managed through the Provisional Piledriving and Blasting Management Plan.

Residual risk

A summary of the potential impacts, management controls, and residual risk for marine megafauna is presented in Table 7-43. After implementation of these controls, potential impacts to marine megafauna as a result of Project activities in the nearshore development area are considered to present a "low" risk and would only affect individual animals on a localised scale.

7.4 Conclusion

7.4.1 Outcome of risk assessment

Offshore

Activities in the offshore development area that have the potential to impact on the environment include the installation of facilities, routine discharges and emissions (e.g. produced water, drilling muds and noise), and accidental events such as spills of condensate or diesel. Baseline surveys and modelling informed an assessment of the potential environmental impacts of these activities.

The risk assessment process, taking into account management controls and mitigating factors, identified 13 "medium" and 26 "low" residual risk potential environmental impacts associated with the offshore development area. These risk ratings are considered to be acceptably low, mitigating risks to sensitive habitats and significant or migratory species.

"Matters of national environmental significance" (as defined in the EPBC Act) associated with the offshore development area include the Commonwealth marine environment and some threatened and migratory animal species that could occur in the area, including whales and other cetaceans, turtles, sharks and seahorses. Surveys at the Ichthys Field recorded only a low number of whales and the area is not considered significant for whale breeding or feeding. Development of the offshore facilities and the gas export pipeline would affect a very small proportion of the extensive and relatively uniform marine habitats in the region, and would not reduce the available habitat for significant species. No threatened ecological communities have been identified in or near the offshore development area.

The most significant ecological habitat in the vicinity of the offshore development area is Browse Island, which is located approximately 33 km from the offshore facilities. The island is used for nesting by

Table 7-43: Summary of impact assessment and residual risk for marine megafauna (nearshore)

Aspect	Activity	Potential impacts	Management controls and mitigating factors	Residual risk*		
				C†	L‡	RR§
Vessel movements	Operation of construction and support vessels in the nearshore development area during construction phase, and tanker vessels and support vessels during operations.	Vessel collision, causing injury or death to marine megafauna. Disturbance to feeding activities and displacement from normal habitat.	No critical breeding or foraging areas for cetaceans, dugongs or turtles are known to exist in the nearshore development area. Large numbers of vessels already use Darwin Harbour regularly. Procedures for avoiding interactions between vessels and cetaceans. Provisional Cetacean Management Plan.	E	2	Low
Dredging	Operation of trailing suction hopper dredger (TSHD) in the nearshore development area during construction.	Entrainment of marine turtles and sawfish, causing injury or death.	No critical breeding or foraging areas for turtles or sawfish are known to exist in the nearshore development area. Practical options for reducing the risks of marine fauna entrainment in TSHDs will be explored and incorporated into the final dredging management plan. Provisional Dredging and Dredge Spoil Disposal Management Plan.	E (B1)	3	Medium

* See Chapter 6 *Risk assessment methodology* for an explanation of the residual risk categories, codes, etc.

† C = consequence.

‡ L = likelihood.

§ RR = risk rating.

green turtles (*Chelonia mydas*), which are listed as "vulnerable" under the EPBC Act. The only potential impact to Browse Island associated with the Project is the risk of hydrocarbons reaching shore in the unlikely event of a major condensate spill. Other emissions and discharges from the Project, including light, noise, produced water and drilling muds, are expected to remain distant from the island.

Drill cuttings from the construction of subsea production wells will generate a turbid plume in offshore waters, which will be dispersed by the strong ocean currents and deep water. While WBMs will be discharged along with drill cuttings, SBMs will be recovered for recycling and reuse prior to eventual onshore disposal. The concentration of SBMs on drill cuttings discharged to sea will be restricted to 10% by dry weight or less in accordance with Western Australian Government guidelines (DoIR 2006). An internal target of 5% or less of SBM on drill cuttings released to sea will be set.

Produced-water volumes from the offshore facilities will vary throughout the life of the Project and will contain varying concentrations of production chemicals. A comparison of expected field dilution rates against typical produced-water ecotoxicity indicates that Ichthys Field discharge concentrations should dilute to below acute toxicity levels within 10–60 m and to below chronic-toxicity levels within 1.1–3.6 km of the release point.

A large volume of water (1 GL) with low concentrations of dissolved chemicals will be discharged offshore after hydrotesting of the gas export pipeline. This "one-off" discharge is anticipated to rapidly disperse into the open ocean and will remain distant from habitats that would be sensitive to toxicity.

Discharges of drill cuttings, drilling muds, produced water and hydrotest water will comply with the requirements of offshore petroleum legislation. No wastes other than grey water, macerated sewage and food scraps will be discharged from the CPF and FPSO.

Ichthys Field condensate is a light oil with low viscosity and a relatively low proportion of aromatic hydrocarbons. In the unlikely event of accidental spills, any hydrocarbons at the water surface would undergo rapid weathering (evaporation of 70–80% of the spill volume) within the first day of release. Under certain wind conditions, however, trajectory modelling indicates that there is a chance that persistent hydrocarbons from large spills could reach points on the shorelines of Browse Island, Seringapatam Reef, Scott Reef and the Western Australian Kimberley coast. Spill scenarios of this scale include the rupturing of a subsea flowline, a CPF diesel fuel leak, the rupturing of a condensate transfer line, a ship colliding with the FPSO, or a subsea well failure. The likelihood of shoreline oil exposure from these scenarios ranges from 4.9×10^{-4} to 4.9×10^{-7} events per annum.

Because of the remote location of the Ichthys Field, emissions and discharges are very unlikely to combine with those from other facilities and contribute to cumulative impacts. The recently proposed Prelude field is located 15 km to the north of the Ichthys Field, while the fields of Jabiru, Challis and Montara are situated between 150 and 270 km to the north-east.

Nearshore

Activities in the nearshore development area that have the potential to impact on the environment include the construction of facilities and the associated dredging program, routine wastewater discharges, and accidental events such as hydrocarbon spills or the introduction of marine pests. Baseline surveys, modelling and comparison of the Project with similar past developments informed an assessment of the potential environmental impacts of these activities.

The residual risk assessment process, taking into account management controls and mitigating factors, identified 17 "medium" risk and 24 "low" risk potential environmental impacts associated with the nearshore development area. These risk ratings are considered acceptably low, mitigating the risks to sensitive habitats and significant or migratory species and minimising pollution and health impacts to the surrounding community.

"Matters of national environmental significance" associated with the nearshore development area are threatened and migratory animal species, including cetaceans, dugongs, birds, turtles, sharks and seahorses, and migratory birds that could occur in the area. While coastal dolphins, dugongs, marine turtles and sawfish are known to occur in Darwin Harbour, no significant breeding or feeding grounds have been identified for these species in or near the nearshore development area.

Dredging is required to provide a shipping channel and turning basin to provide tanker access to the product loading jetty, to provide access to the module offloading facility and to facilitate burial of the gas export pipeline. The dredging program proposed during the nearshore construction period will remove mainly soft-sediment benthic communities and some areas of rock pavement that support corals and algae. These marine communities are well represented elsewhere in the Harbour.

Dredging will generate turbid plumes that are mainly confined to East Arm. Turbid plumes will reduce the incident light levels reaching benthic biota, which could affect sensitive species such as corals and algae. However, predictive modelling shows that turbidity will be influenced by tidal currents and suspended-sediment levels in the water column in many places fall to close to background during neap tides as the sediments settle, before being resuspended by strong spring-tide movements. Hence, benthic biota will experience periods of turbidity close to background levels, throughout the dredging program and this is expected to mitigate long-term impacts upon these communities.

Turbid plumes can also release nutrients stored in marine sediments, providing a food source for fish and subsequently attracting predators such as marine mammals and reptiles. Conversely, marine megafauna may be deterred from the area because of the noise and movements of the various dredging and support vessels.

Predictive modelling of the proposed four-year dredging program indicates that some fine marine sediments will build up in shoreline areas around East Arm. Mangrove vegetation communities occur along these shorelines and some species rely on specialist root adaptations such as pneumatophores, stilt roots and buttress roots to facilitate gas exchange and respiration in anaerobic, waterlogged soils. Excess sedimentation on these structures could result in reduced mangrove tree health and even death. Around 2 ha of mangroves are predicted to receive more than 100 mm of sediment as a result of the dredging program which may cause tree deaths. An additional 28 ha of mangroves are predicted to receive between 50 mm and 100 mm of sediment which may cause reduced tree health or even localised deaths.

Sedimentation is not predicted to occur to any significant extent at coral communities in the Harbour as tidal currents would remove any settling particles relatively quickly.

Offshore disposal of dredge spoil will be carried out in an area of relatively featureless sandy seabed, with sparse benthic biota in water depths of 15–20 m. Turbid plumes generated by this spoil placement will be dispersed to the north-east and south-west by repeated tidal currents. On large spring tides, this could cause suspended-sediment concentrations of up to 7 mg/L around the Vernon Islands, and up to 12 mg/L in the Howard River in Shoal Bay. During neap tides, however, these concentrations would decrease to near-background levels. Hard corals and seagrass are rare in these areas and soft-coral and algal communities are expected to be able to withstand these periodic turbidity events without significant decreases in growth. Some low-level sedimentation of intertidal and subtidal areas could result within embayments in Shoal Bay and Adam Bay, which are naturally muddy depositional areas.

Marine blasting will be used to remove hard rock in the vicinity of Walker Shoal. This activity will generate underwater noise and blast impacts that could cause avoidance behaviour or injuries (or even death in the case of blasting) to marine megafauna in close proximity. Confined blasting methods will be used with micro-delays between blasts to reduce peak pressures and the radius of impact zones. Protection zones will be implemented for marine megafauna, with blasting activities suspended if animals are observed inside these zones. Passive and active acoustic monitoring techniques will be investigated and, if implemented, would complement vessel-based surveillance for fauna protection zones reducing risk even further. Some fish deaths are expected in close proximity to the blasting and these cannot be avoided. Marine blasting is only required during the construction phase and blasting activities will be localised.

Alternative techniques to drilling and blasting are being investigated for the removal of the hard rock material within the shipping channel. At this stage, however, it is not possible to confirm whether there are any viable alternatives.

Piledriving will be required for jetty construction. As with marine blasting, this will generate underwater noise and vibration that could cause avoidance behaviour or injuries to marine megafauna in the close vicinity. An observation zone and a soft-start procedure (in which activities are gradually scaled up over a five-minute period) will be implemented at the commencement of piledriving activities. As with marine blasting, the Project's piledriving activities are not expected to significantly disturb local populations of marine megafauna. Piledriving is only associated with the construction phase and the effects will be localised.

Predictive modelling indicates that treated wastewater discharges from the Project will dilute rapidly to below biological effect levels and that any hydrocarbons discharged from the onshore development area will degrade quickly under natural weathering processes. Similarly, freshwater discharges during hydrotesting are expected to mix quickly with nearshore marine waters without significant disturbance to biota. Other emissions, such as noise and light, will represent an incremental increase to the emissions already received by the nearshore marine environment and are not expected to significantly affect ecological processes in Darwin Harbour.

Spill-trajectory modelling indicates that accidental hydrocarbon spills during vessel refuelling or condensate loading could be transported to points on the shorelines of East Arm by tidal movements and seasonal winds. Mangroves are known to be particularly sensitive to contamination by hydrocarbons and could suffer reduced growth or death in the unlikely event of a spill. Spill prevention and response controls will decrease the likelihood of spills occurring and reaching the shore. Leaks or ruptures of the gas export pipeline are not predicted to cause shoreline exposure along the greater part of its length because of the volatility of the gas and condensate in the pipeline.

The use of large slow-moving vessels such as pipelay barges during the nearshore construction phase represents the main marine pest transfer risk for the Project, particularly where these vessels mobilise from overseas ports. Quarantine procedures will be implemented, in consultation with AQIS, to protect the marine habitats and the maritime infrastructure and industries in Darwin Harbour from marine pest introductions.

A range of monitoring programs are proposed, to measure potential effects on the receiving nearshore marine environment (see Chapter 11). These include the following:

- a Darwin Harbour water quality monitoring program, which will determine whether effluent discharges adversely impact water quality
- a marine sediments and bio-indicators monitoring program, which will identify changes in pH and heavy metal availability in marine sediments as a result of construction activities in acid sulfate soils, and the accumulation of metals and petroleum hydrocarbons in sediments and selected bio-indicators as a result of surface-water and groundwater flows
- a mangrove health monitoring program, which will assess any impacts to mangrove health around Blaydin Point and East Arm as a result of activities in the onshore development area
- coral monitoring programs, which will identify stress in corals at Channel Island during dredging (and trigger management responses if required) and which will document the dredging effects of increased turbidity and sedimentation on corals in East Arm
- a soft-bottom benthos monitoring program will be developed with pre- and post-dredging and spoil disposal sampling of these benthic communities to identify any changes occurring as a result of both the dredging and spoil disposal programs
- a marine pests monitoring program, to identify the presence of marine pests in a timely manner, consistent with the monitoring framework proposed by the Commonwealth Government's National Introduced Marine Pests Coordination Group.

It is considered that the level of management and risk reduction presented for the offshore and nearshore development areas represents a proactive and conservative approach to maintaining environmental values, while allowing progress for the Project in a sustainable fashion. The management controls to be implemented will be further developed in consultation with stakeholders and will continue to be updated throughout the various stages of the Project.

7.4.2 Environmental management plans

As described throughout this chapter, a suite of provisional management plans has been developed to outline the proposed management controls that reduce the potential for marine environmental impacts. These provisional plans will guide the development of more detailed plans as the Project progresses. The plans contain the objectives, targets, detailed actions and monitoring to be carried out to manage a variety of environmental aspects that include those listed below:

- acid sulfate soils
- cetaceans
- decommissioning
- dredging and dredge spoil disposal
- liquid discharges, surface water runoff and drainage
- piledriving and blasting
- quarantine
- waste.

For some specific offshore activities, additional environmental management plans will be required under the OPGGS(Environment) Regulations. These will include plans for pipeline installation, drilling, and construction and operation of the CPF and FPSO, as well as an oil-spill contingency plan. These plans are not provided in this Draft EIS as they will be assessed under a separate approvals process.

INPEX's Health, Safety and Environmental Management Process is described in Chapter 11 and the provisional management plans that have been developed for the Project are attached as annexes to Chapter 11.

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