11. FUEL SPILL RISK ASSESSMENT

11.1 Existing Conditions

11.1.1 The proposed fuel reception facility at Tuen Mun Area 38 is intended as a permanent replacement for the existing temporary facility at Sha Chau. At present, aviation fuel is imported to Hong Kong in ocean going tankers and stored at a depot in Tsing Yi. The fuel is subsequently reloaded into 5,000 dwt tankers for transport to Sha Chau. The throughput demand of the airport is currently 5.8 billion litres per annum representing approximately three trips a day to the AFRF at Sha Chau. The fuel is transferred from the AFRF to the airport by twin submarine pipelines. Aviation fuel has been transported to the airport by this combined method since 1998 and no spill incident has occurred in that time.

11.1.2 Construction of the PAFF will allow imported fuel to be stored directly for supply to the airport by pipeline eliminating the present double handling at Tsing Yi. In addition, the need for routine barge access to the AFRF in the sensitive waters of the Sha Chau and Lung Kwu Chau Marine Park will be eliminated.

11.1.3 Pollution of the sea by fuel spills is a concern due to the potential consequences on a local scale. However, it is important to recognise that major spillages resulting from the tankering and transport of fuel are infrequent and by no means the principal cause of marine pollution from oils (Clark, 1992). A breakdown of the estimated 2 - $3x10^6$ tonnes of oil entering the world's oceans is presented below in Table 11.1.

Table 11.1 Breakdown of Global Oil Losses to Marine Waters

Source	% of total contribution
Industrial and urban run-off	37
Marine shipping	33
Tanker accidents	12
Atmosphere	9
Natural sources	7
Exploration and production	2

Reference: ITOPF, 1987.

11.2 Key Issues

11.2.1 Aviation fuel has the potential to impact the marine environment if released in large quantities. A major spillage of aviation fuel could affect marine organisms, be harmful to sensitive marine and coastline habitats, adversely affect fisheries catches or their quality, temporality affect recreational or amenity areas such as beaches and other legitimate uses of marine water including abstraction.

11.2.2 Possible sources of a spill from the facility can be identified as losses from the tank farm (principally releases via the drainage system from equipment plus containment failures), the jetty (e.g. rupture of the loading arm or jetty equipment, damage to an approaching or berthed tanker) and the pipeline (e.g. offshore rupture).

11.2.3 Table 11.2 below summarises the identified key spill scenarios to the marine environment, with an indication of the amount of fuel to be released, as detailed in Section 10. These are representative frequencies and a variety of spill sizes could occur with varying frequencies.

Table 11.2 Summary of Fuel Spill Scenarios to Marine Waters

Spill Scenarios To Sea	**Frequency$^{(1)}$**
Tank Farm	
Spill from outlet (80 tonnes, 100m^3)	6×10^{-4} /yr
Spill from outlet (280 tonnes, 350 m^3)	4×10^{-5} /yr
Spill from outlet (600 tonnes, 750 m^3)	7×10^{-5} /yr
Spill resulting from overtopping bunds (2040 tonnes, 2550 m^3)	1×10^{-7} /yr
Jetty	
Release from striking/impact (all vessels all releases)	1.2×10^{-4} /yr
• Release from tank rupture (7% of dwt)	6.7×10^{-5} /yr
• Multiple tank rupture (100% of dwt)	2.3×10^{-6} /yr
• Tank rupture for largest vessel (5,600 tonnes, 7.000m^3)	1.4×10^{-5} /yr
• Multiple tank rupture for largest vessel (80,000 tonnes, 100,000m^3)	4.7×10^{-7} /yr
Loading arm rupture (175-583m^3 at 3500 m^3/hr)	3.4×10^{-5} /yr
Large equipment release on jetty (175-583m^3 at 3500 m^3/hr)	8.3×10^{-4} /yr
Release from jetty riser (175-583m^3 at 3500 m^3/hr)	9.2×10^{-5} /yr
Submarine pipeline to tank farm (225 – 551 tonnes, 281-689 m^3)	3.7×10^{-6} /yr
Marine Traffic (within 500m of jetty)	
Release from collision or grounding (all vessels, all releases)	2.3×10^{-5} /yr
• Release from tank rupture (7% of dwt)	1.3×10^{-5} /yr
• Multiple tank rupture (100% of dwt)	4.6×10^{-7} /yr
• Tank rupture for largest vessel (5,600 tonnes, 7,000m^3)	2.7×10^{-6} /yr
• Multiple tank rupture for largest vessel (80,000 tonnes, 100,000^3)	9.3×10^{-8} /yr
Pipeline	
Pipeline leakage (all leaks up to and including rupture)	6.8×10^{-6} /km/yr
Pipeline rupture (60 to 1,200 tonnes, 75m^3 to 1,500m^3)	1.9×10^{-6} /km/yr

Note (1): All frequencies are derived from the relevant sections in Section 10. For example, $9.3\text{x}10^{-8}$/yr has been calculated from Table 10.11 ($8.17\text{x } 10^{-5}$ x 0.015 x 0.02) + ($4.56 \text{ x } 10^{-4}$ x 0.0075 x 0.02)

11.2.4 All these facilities will be designed, constructed and operated in such a way as to ensure that the likelihood of failure is minimised as far as reasonably practicable. The likelihood of a major fuel spill from any of these circumstances is, therefore, small. The largest potential spill events from the operation of the PAFF are releases from tankers approaching the PAFF both due to grounding and collision. The most likely spill events come from the jetty operations, either due to general equipment failure or due to loading arm failure or striking/impact. Any spill to the sea from the tank farm is very unlikely due to the containment systems, except via the drainage system. The quantities expected to be released via the drainage system are generally less than those from marine incidents or incidents at the jetty. A release from the submarine pipeline to the AFRF is also possible, but at a very low frequency. The maximum release quantities are from marine transport incidents, including striking or impact at the jetty, and the most likely spills are from releases due to the jetty operations. The key scenario for assessment is therefore a release from a tanker at or near the jetty. The larger spills as a worse case have, therefore, been modelled as discussed in Section 11.3 below.

11.2.5 Notwithstanding the low likelihood of any environmental incident arising from a major spillage of fuel, some statistically quantifiable risk of failure will always remain and, therefore, it is essential to derive emergency contingency plans to effectively contain and clean up all accidental spillages quickly at short notice and to minimise the quantities of fuel reaching environmentally sensitive receivers. As such, it is necessary to identify possible sources and characterise conjectured spill incident scenarios and to understand the likely movement and dispersion of spilled fuel in the environment. This understanding will provide a solid basis for identifying suitable mitigation to ensure that the risks of losses and subsequent hazards to the environment are kept to a practical minimum and that the emergency contingency plans have full regard for the likely fate of any lost fuel to provide for effective remedial action to minimise impacts on sensitive environmental receivers.

11.2.6 A fuel slick on the sea surface will be subject to a number of degradation processes (see Farmer, 1997). These can be broadly categorised as follows:

- Spreading – fuel will rapidly spread on the sea surface in the immediate aftermath of a spill. Initial spreading is gravity driven away from the point of spillage such that thickness tends to decrease towards the edges where the slick is held by surface tension.

- Evaporation - lighter fuel fractions will quickly evaporate to the atmosphere. This process is enhanced in warmer weather and by wave and wind action. Previous studies in Hong Kong have identified that evaporation of heavy marine diesel oil considerably less volatile than aviation fuel is likely to be substantial in prevailing water temperatures of 23-24°C (Spooner, 1977). In a typical temperate climate most hydrocarbons with a boiling point below about 200°C will evaporate in less than 24 hours. Similarly evaporation of aviation fuel (boiling point 200 – 260°C) is likely to be fairly rapid.

- Dispersion - wave action will break up a slick and eventually cause it to form droplets. These may remain in suspension or fall to the sea floor. Fuel spills would be expected to remain cohesive until spreading depletes thickness to less than about 0.1 mm.

- Emulsification – fuel in the sea will gradually physically absorb water to form emulsions. The process is enhanced by the mixing action of wind at the fuel / water interface. As emulsification continues the fuel density will increase until it approaches that of the surrounding water.

- Dissolution - lighter fuel fractions may dissolve in water. However, in subtropical climes such as in Hong Kong the process of evaporation would dominate and dissolution is unlikely to be significant. Dissolved components of the spilled fuel will ultimately be absorbed in sediments or released to air by evaporation.

- Sedimentation – emulsified fuel will have an increasing tendency to sink to the seabed. Fuel in contact with particulate matter e.g., sand entrained by nearshore wave action, will also deposit on the sea floor.

11.2.7 The physical form of aviation fuel spilled to sea will obviously be transformed through the processes outlined above and it will ultimately be lost to the atmosphere or deposited to sinks on shore or on the seabed. A spillage of aviation fuel is likely to dissipate through the primary driving forces of evaporation, emulsification, sedimentation and biodegradation within a period of about 3 days (ERM, 1995).

11.2.8 By far the most serious environmental consequences of a major fuel spill would occur in the early stages when the fuel may form extensive slicks on the sea surface. Direct contact with the fuel may affect many types of marine organisms.

11.2.9 Dissolved fuel components may affect marine life especially sensitive life stages such as fish larvae, which could be affected by concentrations of the order of 50ug/l. However, widespread fish kills are not usually observed following oil spills. Fish would normally be expected to leave the affected area and return once the fuel has dissipated. Petroleum hydrocarbons either ingested and/or adsorbed from the water column will be fairly rapidly detoxified by fish (Whipple *et al.*, 1981) and crustaceans (Capuzzo and Lancaster, 1981) to non-toxic metabolites but low residual concentrations of hydrocarbons in the water or within the food chain can cause serious tainting of fish and shellfish flesh rendering them inedible or unfit for sale. Although it should be noted that slight tainting does not appear to be a problem to local consumers.

11.2.10 Sessile and immobile fauna such as bivalve molluscs are more susceptible to direct contact than free swimming species. Exposure to aviation fuel could potentially cause smothering and clogging of gill filaments. Molluscs are able to avoid polluted ambient conditions for long periods through closure of the shell. Nevertheless these species remain vulnerable on account of their limited ability to metabolise and excrete fuel compounds (owing to relatively inefficient enzyme systems involved in petroleum hydrocarbon metabolism; Moore *et al.*, 1987) and thus they may accumulate hydrocarbons from the water column to high concentrations (e.g., Goldberg *et al.*, 1978).

11.2.11 Marine mammals have the ability to detect hydrocarbon spills and can take evasive action although the available evidence is not conclusive. Studies on captive bottlenose dolphins (*Tursiops truncates*), a species that is related to, and shares many ecological characteristics with humpback dolphins, showed that the dolphins can detect and avoid crude oil and mineral oil slicks (Smith *et al.*, 1983; Geraci and St. Aubin, 1987). There is some data to suggest that dolphins cannot detect lightly coloured or refined oil products that disperse into thin films (Geraci *et al.*, 1983). However, field observations following incidents involving large crude oil tankers also suggested that the spills apparently did not cause significant damage to them. While comparable studies following losses of aviation fuel to the sea are not available, a similar behaviour pattern would be expected. Ritchie and O'Sullivan (1994) reported negligible effects on otters, seals and dolphins following the wreck of the crude oil tanker the *Braer* off the Shetland Isles, UK. A review of another incident involving a major crude oil spill from the *Sea Empress* off the coast of Wales, UK found that whilst some seals caught up in the spill were oiled there were no mammal deaths caused by the spill (SEEC 1996). After the 1989 *Exxon Valdez* oil spill in Prince William Sound, Alaska, most cetaceans observed during monitoring surveys appeared to be behaving normally, although one Dall's porpoise (*Phocoenoides dalli*) was seen covered in oil and appeared stressed, with laboured breathing. Its fate is unknown (Harvey and Dahlheim 1994). A more recent assessment of the effects of the oil spill of the *Erika*, off the French Atlantic coast, however, did not observe any measurable effect on dolphins or seals (Ridoux *et al*., 2004). It shall be noted that, however, all these spills were primarily related to heavy oils such as crude oil, occurred on open coasts or involved more oceanic species that have more wide-ranging movements than do Hong Kong humpback dolphins. Dolphins in coastal areas, and especially those that inhabit bays and estuaries, are potentially more vulnerable to oil spill effects than are more oceanic species (Geraci 1990; Wursig 1990).

11.2.12 The most detailed observations of dolphins' responses to oil spills, and those most pertinent to the Hong Kong situation, are those of Smultea and Wursig (1992,1995) after the *Mega Borg* oil spill in 1990 in nearshore waters off Galveston Bay, in the Gulf of Mexico. Bottlenose dolphins were observed for several days from aircraft in the area around the oil spill. Dolphins consistently detected and avoided mousse oil, although group structure appeared to break down as dolphins moved around it. Slick oil appeared to be detectable to dolphins, but they were observed to swim through it. Of more direct relevance to the PAFF study area, previous reviewers have concluded that it is unlikely that a population of dolphins would be disabled by a spill at sea. Dolphins directly observed from reconnaissance aircraft and surface vessels following two oil spills in Texas, USA were also seen to move under or around thick oil slicks (from ERM review, 1995).

11.2.13 Behavioural studies of local humpbacked dolphin suggest that the normal swimming speed of the dolphins is about 1-2 m/s although as high as 4-6 m/s has been reported. The mean diving time is about 29 seconds although as long as 270 seconds have been recorded (Jefferson, 2000). For this case, the initial spill radius is about 478m which would be formed in about 5-10 minutes (300-600 seconds) giving a spreading speed of about 0.8 – 1.6 m/s. It would, thus, appear that a dolphin could easily swim away from a spill without difficulty even if a spill did occur in its vicinity. Overall, it would appear that, there is evidence to suggest that dolphins are able to detect oil and outrun a spill without difficulties, although they may not necessary avoid them, especially light sheen. It must be noted also that the probability of a dolphin actually coming into a contact with a spill in the first instance (see Section 11.3.3.3) is very low, notwithstanding the fact that the spill will dissipate very rapidly (within a few hours at any one location and within a few days overall as discussed below) and the fact that the dolphins stay below water most of the time whereas aviation fuel being lighter than water would form a thin layer on the surface of the water before evaporating. As such, the likelihood of any actual exposure would be very small and of short duration.

11.2.14 Biomagnification of spilled hydrocarbons through the marine food chain is unlikely to be a particular concern for dolphins. The principal food species of Indo-Pacific Humpback dolphins are estuarine fish although squid and crustaceans (shrimp) may be occasionally preyed upon (Jefferson, 1998; 2000). Both fish and crustaceans are able to metabolise petroleum hydrocarbons (Capuzzo and Lancaster, 1981; Whipple *et al*., 1981; Brzorad and Burger, 1994) relatively efficiently although there may be some risk from species including molluscs (e.g. squid that may form part of the dolphins' diet) which may store hydrocarbon pollutants. In terms of the potential to affect the food chains and accumulation in dolphins, it should be noted that the vast majority of the spilled hydrocarbons (HCs) will be lost through evaporation and other weathering process in a very short time (i.e., 2-3 days even for the largest spill scenario) and the amount remaining in the marine environment will be extremely low thereafter. Thus, the remaining amount of HCs which would ultimately become bio-available will be very small. Furthermore, as fish and crustaceans have the capability to metabolise/detoxify/excrete the petroleum hydrocarbons, they generally do not magnify through the food chain (Capuzzon and Lancaster, 1981; Whipple *et al*., 1981; Brzorad and Burger, 1994). For example, during the 5 years EM&A programme for the contaminated mud disposal site at East of Sha Chau (Meinhardt under preparation) between 2001-2005, 2680 fisheries samples (including fish, prawn and shrimps, crabs and squids) were analysed for contaminants including PCBs and PAHs. The result indicated that PCBs and PAHs were below analytical detection limits and the average detection frequency was only 1.7% indicating these contaminants were generally not bio-accumulated.

11.2.15 Post-spill studies of the *Exxon Valdez* (see API 2001 and the references cited) oil spill in 1989 did not show any evidence of biomagnification. In addition, demersal fish species swim predominantly under the surface and are very unlikely to come into direct contact with oil should a spill occur (with the fuel floating on the surface once spilt and evaporating rapidly). The chance of contaminated fish being subsequently eaten by a dolphin is very minimal. Dolphins do not lick themselves to clean fur, as some other marine mammals do, and are thus not likely to ingest enough oil for acute effects. While long term impacts from ingestion of small amounts of oil over time are possible (Geraci and St. Aubin 1980), this would not be an issue in this case as any spilled jet fuel would not persist in the environment to cause any long term impacts. Based upon this and the very low probability of the spill occurring in the fist place, the likelihood of dolphins getting enough toxic chemicals into their systems through the food chain to do serious harm is small (Jefferson, pers comm.).

11.2.16 Furthermore, dolphins themselves are able to metabolise and excrete hydrocarbons and, thus, elevated accumulation within dolphin tissue is most unlikely. There is evidence to suggest both pinnipeds and cetaceans can metabolise petroleum hydrocarbons to polar metabolites because of the mixed-function oxidase system in their kidneys/ liver. Because polar metabolites are soluble, these can then be excreted (Haebler, 1994 and the references cited). Long-term exposure to organic contaminants (such as DDTs, PCBs, HCHs, and PAHs), however, can cause reproductive compromise in dolphins (Geraci and St. Aubin 1987), and studies in Hong Kong are beginning to show some evidence for this in the local population of humpback dolphins (Jefferson, 2005; Jefferson *et al*. in press). Cetaceans are known to have a very limited ability to metabolise organic contaminants, such as DDTs, PCBs, etc., and these substances appear to bioaccumulate in their tissues (Jefferson *et al*. in press). Although oil typically contains highly toxic polycyclic aromatic hydrocarbons (PAHs), which are a contaminant of concern for dolphins in Hong Kong (Clark 1998), jet fuel typically consists of light refined products and is relatively free from heavy PAHs and organochlorine compounds are not present in jet fuel. Hong Kong sediments have been found to contain significant quantities of PAHs and other petroleum hydrocarbons, which suggest that dolphins may be exposed to certain levels of these contaminants at low background levels (Zheng and Richardson

1999). Overall, marine mammals are considered to be at greater risk from organochlorine pesticides than from petroleum hyrdrocarbons (Hanson 1985).

11.2.17 Surface slicks resulting from a major spillage may seriously affect avian fauna. Contacted with fuel oil could cover and destroy the protective insulation and buoyancy function of bird feathers as well the ability of an affected bird to fly. Attempts to self clean by preening may result in direct ingestion of the fuel and its toxic constituents.

11.2.18 Fuel spills would also be a major concern where they could potentially impact on slow growing coral species. The destruction of coral stands could take years to recover.

11.2.19 Impacts on mangroves could also persist for many years if spilled fuel became entrained within the complex ecosystems in which any attempts at clean up are likely to be very problematic. Mangrove trees could defoliate on contact with fuel. Direct contact with an influx of fuel could be devastating for juvenile fish, molluscs and crustaceans and other fauna inhabiting the diverse mangrove habitat.

11.2.20 It should, however, be noted that crude oils and products differ widely in toxicity and environmental impacts. Crude oils is a natural mixture of hydrocarbons and other compounds which tends to be more persistent and could cause impacts both due to toxicity and physical effect such as smothering. Light oils, on the other hand, are highly volatile and non-persistent and, thus, are less environmental damaging. As the majority of the available data is associated with major crude oil spills, for the purposes of this assessment it is assumed that spilled aviation fuel would be similarly damaging although it should note that spills of light refined products (e.g., kerosene which is the major component of jet fuel) may evaporate completely within a few hours (ITOPF, 2002) and they would, thus, cause far less environmental damage compared to their heavier counterparts.

11.2.21 Aside from the direct environmental impacts discussed in the preceding section, major fuel spills could impact on beaches forcing their closure for expensive clean-up.

11.3 Prediction and Evaluation of Impacts

11.3.1 Assessment Approach

11.3.1.1 The likelihood and severity of potential impacts has been assessed by means of a conventional environmental risk analysis involving:

- identification of fuel spillage scenarios;
- impact assessment; and
- identification of mitigation measures.

Fuel Spillage Scenarios

11.3.1.2 Fuel spill scenarios have been identified in the Hazard to Life assessment (Section 10 refers) and as detailed above and summarised in Table 11.2, these comprise spills from four main elements of the PAFF system, namely, from marine transport, during jetty transfer, submarine pipeline and the tank farm storage. The causes of the spills considered include failure of the system and accident incidents.

11.3.1.3 In terms of likely movement, spilled fuel reaching the sea surface from either an incident at the seawall adjacent to the tank farm or in the vicinity of the jetty will behave in an approximately similar manner under any given set of tidal conditions and any given spill quantity. The dominant parameter will be the spill quantity and the key driving force will be the hydrodynamic currents, which will increase away from the shoreline towards the main Urmston Road channel. Under some circumstances, wind induced transport of the floating surface slick may also be important and wind effects are also discussed later. For conservative assessment purposes, a greater understanding of the likely area of spill spread can be gained by simulating an incident located on the seaward approach to the jetty. Thus, for the purposes of this assessment, this scenario with an incident point 500m from the jetty as the centre point of the release has been modelled.

11.3.1.4 As detailed in Table 11.2, the spill size in respect of the majority of the spill scenarios is small. However, the largest potential spill events from the operation of the PAFF are releases from tankers approaching the PAFF both due to grounding and collision. The rupture of one or all of the tanks of an 80,000dwt tanker would result in the largest pools of oil at sea. Dangerous Goods tankers generally have 12 to 18 individual tanks in them so as to balance the load to maintain stability of the vessel, with larger tankers usually having more tanks. As an example, the barges from Tsing Yi to Sha Chau all have 12 tanks. Assuming 14 tanks in an 80,000 dwt vessel, each tank would carry about 7% of the load. Thus, one spill scenario is that 100% of one tank's content would be instantaneously released, equivalent to 7% of a tanker's dwt or 5,600 tonnes of aviation fuel. For conservative assessment purposes the thickness of the pool formed is assumed to be small, in the region of 10mm in the first instance (see Appendix H2, Section 2.3 for further explanation of how this figure is derived), and based upon this, the resultant size of pool from the worst case spill would be in the region of 478m in radius.

11.3.1.5 However, as detailed in Section 10.1, as a result of the Court of Final Appeal quashing the Environmental Permit in its judgment of July 2006, the Hazard to Life Assessment included in the previous EIA report (July 2002) has been reviewed and updated taking into account the rulings of the Court of Final Appeal. As a result of the review, Section 10 also identified a further scenario which could affect the marine environment, which involved the rupture of all tanks in the 80,000dwt tanker with the immediate release of the contents of one tank (5,600 tonnes) followed by the continuous release of the remaining 74,400 tonnes over a period of 3 days. Releases from multiple tanks will take place over some days and as such the release would not be considered as instantaneous. It should be noted, however, that the probability of such a spill is very small (9.3×10^{-8} /yr, Table 11.2) and, compared to other possible spill scenarios, is by far the least likely spill to occur.

11.3.1.6 Notwithstanding the above worst case scenarios, the proposed pipeline from the PAFF tank farm to the coupling point at the existing AFRF will stretch undersea for approximately 4.8km and a failure could be conjectured for any point along this length. Spills arising from pipeline failure and surfacing offshore may behave differently from spill sources on land or close to the PAFF jetty. In order to cover the range of impacts that could possibly arise should this very unlikely circumstance ever arise, two pipeline spill scenarios have also been modelled. These are leakage from a pipeline rupture approximately 1000m from the tank farm shoreline in the middle of the Urmston Road channel where the hydrodynamic currents are relatively strong and the strongest advection would be expected. Additionally, in view of the particular concerns relating to impacts near the existing AFRF within the Sha Chau and Lung Kwu Chau Marine Park, an additional simulation has been conducted at a release point at the marine park boundary approximately 400m from the existing AFRF.

11.3.1.7 The worst credible case pipeline spill would result from a full bore rupture of one of the pipelines. Aviation fuel from the submarine pipeline will initially be driven out of the release outlet opening by momentum as the fuel is pumped through. The fuel spillage can be rapidly detected, however, by the integral leak detection system via the detection of any pressure drop along the pipeline. On detection of the leak, pressure sensors will automatically trigger closure of two emergency shut down valves (located at PAFF and Sha Chau). These can also be operated manually from the PAFF control room. In addition, all the transfer pumps at PAFF will be immediately stopped and, thus, there will be no further transfer of aviation fuel through the submarine pipeline. This will be affected within a few minutes of a catastrophic pipeline failure. Subsequently, following relaxation of the pressure differential, fuel will escape more slowly through a buoyancy driven process as it is gradually displaced by seawater. Since the operational pressure of the submarine pipeline is around 12 bar, the spill from the pipeline will continue to occur for a little while until the pressure drops to around 2-3 bar, the same pressure as for the water at the seabed. At this point, the release will be resisted by the 2 bar head of pressure experienced at the seabed and when the pressure is in equilibrium, the spillage will stop. Consequently, 100% loss of the whole content inside the submarine pipeline will not occur. In practice this latter phase of the release could be effectively mitigated through implementation of an emergency contingency action plan to externally plug the point of rupture.

11.3.1.8 Similarly, vertical movement of the emergent fuel plume will initially be momentum driven close to the release outlet. This momentum will however be diminished by the pressure head experienced at the pipeline depth and the physical obstruction of rock armour protection such that the fuel is likely to seep through the seabed and percolate through the rock armour losing much of its momentum in the process. Thereafter, the plume rise will be mostly buoyancy driven. As the fuel rises it is likely to entrain water creating a water fuel emulsion, which will eventually reach the sea surface. This process coupled with weathering and tidal motions of the sea will mean that by the time the fuel reaches the sea surface, it will not remain as one large pool. Rather, the fuel would have broken up into a number of small emulsified pools thus facilitating its degradation. However, for the purposes of undertaking a conservative assessment, it has been assumed that a coherent surface patch will form.

11.3.1.9 Based upon the above, any rupture in the pipeline would cause a pressure drop and the integrated detection system would instigate an automatic shutdown of the fuel pumps. The pumping rate of the fuel within the pipeline is 1,500m^3/hour and, assuming a shut down response time of 180 seconds, a spill volume of 75m^3 or 60 tonnes would occur. For the conservative purposes of this assessment it is assumed that this volume will be released instantaneously and spread on the surface as a single coherent patch with a thickness of 10mm (see Appendix H2, Section 2.3). This corresponds to an initial patch of radius 49m. This spill scenario was selected for further modelling in order to assess the fate of the spilt fuel. Two spills from pipeline ruptures were considered: a pipeline rupture in the Urmston Road and a pipeline rupture on the boundary of the marine park.

11.3.1.10 Following the initial Hazard to Life Assessment (Chapter 10), a second pipe rupture scenario was assessed in which it was assumed that the automatic shutdown system would fail and that it would take up to 1 hour to stop the discharge of fuel to the sea. At the pumping rate of 1,500m^3/hour, 1,200 tonnes of fuel would be lost. Consequently, at the locations in the Urmston Road and at the boundary of the marine park at which the 60 tonne fuel loss was simulated, a second series of simulations has been undertaken for the loss of 1,200 tonnes at a uniform rate over a period of 1 hour. In the simulations of the 60 tonne spill, the fuel was assumed to form a patch of 49m in radius. If the 1,200 tonne spill was also instantaneous then a pool of about 291m radius would be formed. However, as noted above, the simulations of the 1,200 tonne spill occur over a period of 1 hour and as such the small plume that would form would depend on the tidal current speed at the time of the spill. For example, a loss rate of 1,500m^3/hour is equivalent to a loss rate of 0.42m^3/s and, if the tidal currents are 1m/s and assuming an initial plume thickness of 10mm, the initial plume would be approximately 42m in width and 300m in length.

11.3.1.11 The six scenarios identified above and selected for further assessment using computer models represent conjectured events likely to result in:

1. the largest credible instantaneous spill to sea (5,600 tonnes) 500m from the jetty
2. the largest credible instantaneous spill to sea 500m from the jetty (as Scenario 1) but with the subsequent continuous release of the remaining 74,400 tonnes over the following period of 3 days;
3. an instantaneous spill of 60 tonnes from a pipe rupture into the main Urmston Road marine channel where the hydrodynamic currents and thus spill spread is expected to be greatest;

3a a spill of 1,200 tonnes over a period of 1 hour from a pipe rupture in the main Urmston Road marine channel at the same location as was used in Scenario 3;

4. an instantaneous spill of 60 tonnes from a pipe rupture immediately on the boundary of the Marine Park; and

4a a spill of 1,200 tonnes over a period of 1 hour from a pipe rupture immediately on the boundary of the Marine Park at the same location as was used for Scenario 4.

11.3.1.12 These six main scenarios were considered adequate to characterise and allow an assessment of the full range of spill impacts that may arise in the operational phase of the facility.

11.3.1.13 While all six main scenarios above took account of different prevailing wind conditions during the wet and dry seasons, as described in more detail below, it was considered necessary to undertake a sensitivity test for a range of wind conditions. As such, in addition to the four main scenarios detailed above, when assessing Scenario 2, additional simulations were also carried out to assess the sensitivity of the fate of any fuel spill from a point 500m from the jetty under a range of different wind conditions. These additional simulations applied the computer model in a stochastic manner. It is important to note that such stochastic modelling does not depend on the magnitude of the spill but generates a risk map showing only the relative probability of the fuel spill affecting locations (not the amount of fuel) within the modelled area under a range of possible wind conditions.

11.3.1.14 These additional stochastic simulations should be regarded as sensitivity tests which provide additional information on the areas most likely to be impacted from a spill 500m from the jetty (as considered in Scenarios 1 and 2) under the range of wind conditions which might be encountered in each of the wet and dry seasons. The expected magnitudes of the impacts from the fuel spill scenarios are estimated from the results of the simulations of Scenarios 1 and 2.

Computer Models

11.3.1.15 Scenarios 1, 3 and 4 above were simulated first using the Delft Hydraulics hydrodynamic and particle tracking models to gain an understanding of the movement and range of conjectured fuel spills from the operation of the fuel receiving facility and the supply pipeline to the airport. The particle tracking model, PART, included a linear decay parameter to simulate the evaporation and emulsification of the spilt fuel. Scenarios 2, 3a and 4a were simulated using a different version of the particle tracking model which includes specific oil spill processes covering spreading under gravity, wind induced drift, evaporation, emulsification, density changes with emulsification, weathering, entrainment of oil in the receiving waters and trapping of oil on the coastline. Full details of the PART-Oil model, and details of previous applications are given in Appendix J2.

11.3.1.16 It is important to bear in mind that the modelling assessment is based on a multiplicity of conservative parameter inputs to identify the extreme range of plume movement that might be credibly predicted. The output is intended to facilitate implementation of an effective emergency contingency plan to ensure best practical protection of any sensitive receivers that might be considered at risk, notwithstanding the very low likelihood of such an event ever occurring in practice.

11.3.1.17 Delft Hydraulics have established well calibrated three-dimensional hydrodynamic and water quality models of the Pearl Estuary and the whole of Hong Kong Territorial waters. These models have been calibrated and validated using a number of historical data sets. The latest model is referred to as the Update model and it could be applied directly in the present assessment of the fuel pipeline. However, the model grid resolution in the area of interest is considered to be too coarse and therefore another existing higher resolution model of tidal flows covering the Western Harbour and North West New Territories, referred to as the Western Harbour Model, has been applied. The Western Harbour Model of tidal flows extracts boundary conditions from the Update model and has also been fully validated by Delft Hydraulics for EPD. The areas covered by both the Update Model and the Western Harbour Model are shown in Figure 6.10. Details of the Western Harbour Model's mesh are presented in Figure 6.11.

11.3.1.18 As in previous studies of potential aviation fuel spills in Hong Kong e.g. the EIA for the existing AFRF at Sha Chau (ERM, 1995), the Delft3D random walk particle tracking model was used initially to simulate the fuel release. The three-dimensional particle tracking model, PART, forms part of the Delft3D suite of models and it takes hydrodynamic input from the Delft3D Western Harbour model of tidal flows which has already been calibrated. As described above, following completion of the initial simulations (Scenarios 1, 3 and 4 above), a more sophisticated version of PART, PART-Oil, became available and was used to simulate Scenario 2 and to carry out sensitivity tests with respect to the influence a range of wind conditions might have on the fate of a spill from a point 500m from the jetty.

Key Modelling Assumptions

11.3.1.19 The fuel spills are simulated as buoyant particles. Based on the volume of fuel spilled, the extent of the initial patch has been calculated on the basis of the assumption that the fuel will spread under hydrostatic forces as a circular patch until it reaches a thickness of 10mm. It is also assumed that, for instantaneous spills, this spreading occurs over a timescale, which is short compared, to any significant transport by tidal currents and the initial patch is circular. For continuous spills into moving water, if the spill duration is significant with respect to the distance the receiving waters might move during the spill, relatively narrow plumes will be generated and the initial plume width has been estimated based on the representative tidal currents, the rate of fuel loss and assuming a fuel layer 10mm thick.

11.3.1.20 As a result of evaporation and emulsification, it was assumed in Scenarios 1, 3 and 4 which employed the PART model that, as in earlier studies, the fuel would decay linearly to disappearance after 4 days (ERM, 1995). This decay rate was selected to be lower than might actually be found in practice and so does not overestimate fuel losses. In the later simulation of Scenario 2, the PART-Oil model was applied which modelled these processes explicitly and did not require any assumptions on a linear decay rate.

Scenarios Simulated

Offloading Jetty – Scenario 1

11.3.1.21 A major spill from a ruptured tanker has been simulated at a point 500m seaward from the offloading jetty within the main approach channel (see Figure 11.1). The initial radius of the patch is taken to be 478m based on an assumed loss of 5,600 tonnes of fuel.

Offloading Jetty – Scenario 2

11.3.1.22 Scenario 2 was based on Scenario 1 with the instantaneous spill of 5,600 tonnes 500m from the jetty but followed by the continuous spillage of the remaining 74,400 tonnes from the 80,000 tonne load over a period of 3 days immediately following the initial instantaneous spill fuel. The application of 3 days for the loss of the remaining fuel is considered conservative and more details on the determination of this time period are provided in Section 10. It should, also be noted, however, that of all spill events to sea which have been considered (Table 11.2), this is the least likely event which might be expected to occur.

Pipe Route – Scenarios 3, 3a, 4 & 4a

11.3.1.23 Leakages at two points along the pipe route were also simulated. For the instantaneous spills of 60 tonnes (Scenarios 3 and 4), the centre point of the surface patches were simulated in the middle of the Urmston Road Channel approximately 1000m from the Tuen Mun area coastline and at the point where the pipeline crosses the marine park boundary approximately 400m from the existing AFRF at Sha Chau (see Figure 11.1). In each case, it was assumed that $75m^3$ or 60 tonnes of fuel are lost forming a patch of 49m initial radius. For the larger spills of 1,200 tonnes (Scenarios 3a and 4a), the spill locations were at the same positions used for Scenarios 3 and 4 and it was assumed that the fuel would be lost at a uniform rate of a period of 1 hour. For these continuous releases, a small plume would be generated where the initial plume width would depend on the tidal current speeds at the time of the release.

Tidal Conditions Simulated

11.3.1.24 Based on the previous studies, it is not expected that any significant coherent fuel patch will survive for longer than 60 to 72 hours (ERM 1995). Nevertheless the simulations were run for periods of at least 4 days. In order to cover the possible range of tidal conditions under which a fuel spill might occur, in each of the wet and dry seasons, the same fuel spills were simulated over a 4-day period of spring (large amplitude) tides and again over a 4-day period of neap (small amplitude) tides. For Scenarios 1, 3, 3a, 4 and 4a, the same releases were also simulated to begin at high water, low water, mid-flood tide and mid-ebb tide to cover the possible range of transport routes which might occur.

Meteorological Conditions Simulated

11.3.1.25 When the model of tidal flows was calibrated, different wind conditions in the form of wind fields equivalent to the prevailing winds of 5m/s from the North East in the dry season and 5m/s from the South West in the wet season were applied. The main impacts from these winds on the main tidal flow patterns were expected to be small but were included for completeness and the simulated tidal flows were used as the basic hydraulic input for the simulations. The more sophisticated PART-Oil model, however, applied to simulate Scenario 2, 3a and 4a, has the capability to include the separate wind induced surface drift of a thin floating oil slick due to the prevailing winds in each season and the loss of fuel at the coastline should the plume approach the shore.

11.3.1.26 When carrying out the simulations of Scenario 2, the PART-Oil model was also applied in a stochastic manner in which a further range of wind conditions were applied in a single simulation in order to look at the sensitivity of the fuel spill dispersion to different wind conditions. The purpose of this sensitivity test was to obtain a risk map showing the potential for the fuel plume to impact on different areas in the receiving waters depending on the frequency of occurrence of different wind conditions.

11.3.1.27 For the stochastic simulations, wind records were obtained from the Hong Kong Observatory for wind stations located at Chek Lap Kok International Airport, Sha Chau, Tuen Mun and Tai Mo To covering a period of 9 years from October 1997 to the most recent data available (31 October 2006). The wind data was examined and, for each station, where some data values were missing due to recording failure or instrument, malfunction, good data was substituted from a neighbouring station for the same period. From the resulting data sets, 500 wind series of 15 day duration were selected at random from the 9 year period covered by the data (a 15-day duration had to be selected to be consistent with the period covered by the tidal flow simulations although the fuel spill only spanned a shorter period within the 15-day tidal cycle). In the model, each selected 15-day wind record was associated with its own set of particles and the wind drift generated by each of the 500 different wind conditions could be simulated simultaneously and independently.

11.3.1.28 When the model is applied in a stochastic manner, only the spill location is important and the magnitude of the spill is not used. When applied in this way, the model results are presented in the form of a risk map showing the relative probability that any area might be impacted by a spill from the spill site and in the form of a map showing the minimum time of travel from the spill site to any point within the modelled area affected by the spill. The magnitude of any impact (e.g. thickness of the floating fuel layer) at any location must then be inferred from the simulations of Scenarios 1 and 2.

11.3.2 Results of Assessment

11.3.2.1 The above scenarios have been modelled and the relevant plots provided in Appendix J1, together with a summary of the findings below. Surface flow velocity vector plots are also provided in Appendix J1. A brief summary of the simulated conditions and the result plots is presented at the beginning of Appendix J1.

Scenario 1 - Spill at Offloading Jetty

11.3.2.2 The worst case fuel spill scenario initially simulated was the tanker rupture at the jetty spilling some 5600 tonnes of fuel instantaneously (Scenario 1). The spill from this scenario spreads to the mouth of Deep Bay and in a south easterly direction towards Green Island, depending upon the season, tidal range and time of spill within the tidal cycle. In all cases the spill dissipates rapidly and disappears within 2 days.

Dry Season

11.3.2.3 During the dry season, releases at spring tide higher high water flow towards Ma Wan and Tsing Yi, reaching the west coast of Ma Wan, and the Ma Wan Fish Culture Zone, after some 7 hours (Appendix J1, Figs 1-1 to 1-4). The coastline of the north eastern tip of Lantau Island and Rambler Channel would also be affected in the short term. Ma Wan and the coastline along Castle Peak Road is also affected during spring tide mid-ebb releases (Appendix J1, Figs 4-3 to 4-10).

11.3.2.4 For a neap (small amplitude) tide with spills at high water and mid-flood, the spill is not caught by the strong Urmston Road currents and instead moves southwards towards the airport platform and the North Lantau coast between Tung Chung and reaching partially as far as Sunny Bay (Appendix J1, Figs 5-5 to 5-13 and Figs 7-5 to 7-12). The key sensitive receivers in this case include the seagrasses and mangroves at Tai Ho Wan. However, seagrasses and mangroves in Tung Chung Bay should not be affected and the cooling water intakes at the airport and Tung Chung should be submerged below the level of the spill.

11.3.2.5 Spring tide lower low water and mid-flood (large amplitude tide) releases oscillate between the Brothers, Neilingding Island and the west side of Sha Chau (Appendix J1, Figs 2-1 to 2-16 and Figs 3-1 to 3-15). Initially the plume is swept up the coastline between Castle Peak and Black Point towards Deep Bay but does not affect the coast at Lung Kwu Tan where horseshoe crab are known to breed, nor does the plume appreciably enter into Deep Bay. However, after some 10 or 11 hours after the spill, the Lung Kwu Chau and Sha Chau area is affected in the short term. This area is frequently used by the Indo-Pacific Humpback Dolphin and the dispersion of the plume could result in dolphins leaving the area until the spill has dissipated. Ma Wan is also affected by the release at mid-flood, as is some of the coastline and beaches along Castle Peak Road (Appendix J1, Figs 3-6 to 3-8).

11.3.2.6 A low water neap (small amplitude) tide release, however, does affect the coast at Lung Kwu Tan but the spill disappears from the area within a few hours (Appendix J1, Figs 6-4 to 6-5). The spill ultimately ends up along the North Lantau coast but dissipates within about 12 hours (Figs 6-8 to 6-16). Ma Wan and the fish culture zone are not affected.

Wet Season

11.3.2.7 During the wet season, the spills show similar patterns flowing eastwards along the coastline and towards Ma Wa and Tsing Yi. Releases at higher high and lower low water during spring tide in the wet season spread out thinly along the coastline on the east side of Castle Peak Bay and will potentially affect the gazetted beaches in this area (Appendix J1, Figs 9-1 to 9-11 and Figs 10-1 to 10-14). However, the effects are short lived with the spill virtually disappeared after 24 hours. Release at mid-flood during spring and neap tides spreads out rapidly to affect large areas between the Tuen Mun coast and the Brothers. The spill affects the North Lantau coast and Ma Wan in the short term (Appendix J1, Figs 11-4 to 11-10 and Figs 15-4 to 15-10). Neap (low amplitude) tides during lower low and mid-flood water also effect Lung Kwu Tan briefly (2-3 hours; Appendix J1, Figs 14-3 to 14-6 and Figs 15-1 to 15-4).

11.3.2.8 During a mid-ebb release, the spill follows the pattern of the high and low water spills and hugs the coastline from Castle Peak Bay to the Rambler Channel (Appendix J1, Figs 12-1 to 12-8 and Figs 16-1 to 16-7). However, part of the spill breaks off and a pool of fuel moves past Ma Wan and through the Kap Shui Mun channel, with the Ma Wan Fish Culture Zone being affected for only between 1-2 hours (Appendix J1, Figs 12-7 to 12-11 and Figs 16-7 to 16-11) . Again the spill disappears within about a day.

11.3.2.9 In summary, the worst case fuel spill has the potential to affect the coastline at Lung Kwu Tan which is a nursery for horseshoe crabs, the Ma Wan fish culture zone, the beaches along the Tuen Mun to Sham Tseng coastline, the mangroves and seagrasses at Tai Ho Wan on the north Lantau coastline and Lung Kwu Chau. As the spill is large and divides up into numerous patches as it disperses, there may be disturbance to fish and dolphins in the short term. Notwithstanding, however, it would take several hours for a spill to reach the ecologically important habitats and the majority of the fuel would have dissipated, leaving a very low hydrocarbon concentration by the time the spill reaches these habitats. Thus the impacts to fauna and flora of these habitats would be minimal. With the implementation of appropriate mitigation measures (described in Section 11.4), impacts to these sites could be avoided. Overall, impacts to the fauna are likely avoidable and the spill will disappear in a very short period of time.

Scenario 2 - Spill at Offloading Jetty

11.3.2.10 Scenario 2 was very similar to Scenario 1 in that it simulated an initial instantaneous spill of 5,600 tonnes 500m from the jetty but Scenario 2 also included the continuous release of the remaining 74,400 tonnes of fuel from the tanker over a period of 3 days. Scenario 2 is the least likely spill to occur by a large margin (Table 11.2) and the probability of this spill occurring is two orders of magnitude smaller than the instantaneous spill of 5,600 tonnes considered in Scenario 1. The initial instantaneous spill and the continuous spill over a period of 3 days simulated under Scenario 2 will be transported and dissipated more or less independently of each other. As a result, Scenario 2 does allow a re-evaluation of Scenario 1 (instantaneous spill only) using the more sophisticated PART-Oil model which includes a more realistic wind drift for the fuel spill being simulated in the model. In the discussion which follows, the results from the simulation of Scenario 1 are still presented but should be considered in the light of the findings from the more sophisticated simulation of Scenario 2.

11.3.2.11 While the total spillage of 74,400 tonnes of fuel is much larger than the 5,600 tonne spill considered in Scenario 1, the loss rate over 3 days is equivalent to a loss of 340m^3/hour and the initial width of the continuous plume at the spill site would be expected to be of the order of 70m for a mean tidal water speed of around 0.5m/s. The result of the continuous spill, therefore, while assessed to be a very unlikely event (Table 11.2), was expected to be a relatively narrow plume which would evaporate rapidly and disperse at low concentration.

11.3.2.12 The impact of the initial release of 5,600 tonnes 500m off the jetty had been simulated in Scenario 1 and the purpose of Scenario 2 was to assess the added impact of the continuous release of 74,400 tonnes of fuel over a period of 3 days after the initial spill. As described above, Scenario 2 was simulated using a more sophisticated model, PART-Oil, which simulated the main physical processes experienced by an oil spill rather than parameterising these processes as a linear decay. PART-Oil also allowed the effects of wind drift on the thin floating fuel slick to be simulated in more detail.

11.3.2.13 For the simulations of Scenario 2, it was decided that, based upon the results of Scenario 1, to simulate the initial release beginning at high water on neap and spring (small and large amplitude) tides in the wet and dry seasons because the plumes following a high water release in Scenario 1 appeared to have the greatest impact in the vicinity of the fish culture zone at Ma Wan, would impact the northeast coastline of Lantau Island and could be visible in the Western Harbour and Rambler Channel. As with the simulations of low water releases and mid-flood and mid-ebb releases, spills at high water also had the potential to impact on the beaches near Castle Peak and the coastline at Lung Kwu Chau. However, impacts at most sensitive receivers for all the release times simulated under Scenario 1 were relatively short lived (1-2 hours). For the assessment of the continuous release of 74,400 tonnes over a period of 3 days, the starting point within the tidal cycle was expected to be unimportant because the spill would continue throughout the full range of flood and ebb tidal flow conditions and it was concluded that an initial release beginning at high water for Scenario 2 would provide the additional information required with respect to the continuous spill of 74,400 tonnes over a 3 day period.

11.3.2.14 The results from the simulations of Scenario 2 are discussed below and presented in Appendix J1.

Dry Season

11.3.2.15 The plan contour plots in Appendix J1 show the initial instantaneous spill and the coherent plume generated by the continuous release. For the dry season spring tide, the initial patch of fuel generated by the instantaneous spillage of 5,600 tonnes of fuel can be seen clearly up to 25 hours after the initial spill where it has reached the entrance to Deep Bay. The plume from the continuous spill can also be identified easily. After 32 hours, the spill site is still discharging fuel and the resulting coherent plume can be seen but there is little obvious evidence remaining of the initial 5,600 tonne spill. The fuel patch from the initial spill and the plume from the continuous spill head in a southerly direction away from the spill site and appear to remain independent of each other. On the neap tide, the tidal excursion in the Urmston Road is smaller than on the spring tide and the initial spill and continuous plume do not reach Deep Bay. As was found in the spring tide simulation, the initial spill and the continuous plume both head in a southerly direction and sensitive receivers such as the Ma Wan fish farms were not predicted to be impacted by the spill to any significant extent ($<10^{-3}$kg/m^2).

11.3.2.16 The impact of the wind simulated in PART-Oil (5m/s from the North East) can be seen in that the simulated plume tends to migrate towards the south and west and, on both spring and neap tides, impinges on the northern and eastern shores of Chek Lap Kok Airport in around 16 hours of the initial spill taking place on the spring tide and after 26 hours on the neap tide. The northern shore of Lantau Island from Tung Chung to around Siu Ho Wan was also impacted after a period of around 22 to 30 hours after the initial spill. The plume would also impact on The Brothers and, to a lesser extent, Lung Kwu Chau and the coastline from Butterfly Beach past Castle Peak to Lung Kwu Upper and Nim Wan although impacts at these areas remote from the spill site are very small. Impacts along the coast to the West of Tuen Mun were not predicted to be significant.

11.3.2.17 At those sensitive receivers which might be impacted by the plume, impacts are generally of short duration (2-3 hours) although, for the continuous spill, the same sensitive receiver might be impacted more than once for similar periods of time on successive tides or on both the flood and ebb tides as the fuel spill is carried by the tidal currents.

Wet Season

11.3.2.18 In the wet season, a 5m/s wind from the South East was simulated in PART-Oil which has an obvious impact on the fuel spill in that much of it impinges quite rapidly on the Tuen Mun coastline from Castle Peak to Brothers Point and so the percentage of fuel remaining offshore as a floating plume is greatly reduced compared to the dry season simulation.

11.3.2.19 Following the wet season spill, Cafeteria Beach, Kadoorie Beach, Butterfly Beach, Shiu Wing Steel and the Cement Plant were predicted to be impacted by both the instantaneous spill and the continuous spill within 5-10 hours of the spill taking place although often at small concentrations ($<1kg/m^2$) and for short periods of time (1-5 hours). The instantaneous spill generally had a smaller impact at these sensitive receivers than the continuous spill. The continuous spill also tended to impact each sensitive receiver several times during the 3 day duration of the spill and, at Cafeteria and Kadoorie Beaches, at concentrations of up to $8kg/m^2$.

11.3.2.20 None of the spilt fuel was predicted to impinge on the Airport, the North Lantau Coastline, The Brothers, Ma Wan, Lung Kwu Chau and the Sha Chau Marine Park.

Stochastic Simulations of a Spill 500m Offshore from the Jetty

11.3.2.21 The simulations of the fuel spills described above for both Scenario 1 and 2 were for the prevailing wind condition which is the most predominant environment for the seasons and tides covered. The results of the simulation, thus, represent the most likely fate of the spilled fuel should a spill ever occur. The simulations were, however, deterministic in that all the principal dynamic processes which determine the fate of the fuel spill (namely the tidal flows and the wind fields) were specified and, for each simulation, there could only be one outcome. These models predicted the concentrations of fuel at any location within the model at any time within the period simulated for the specified tidal and wind conditions.

11.3.2.22 However, following the simulation of Scenario 2, the importance of wind drift on the fate of the fuel spill in each season was assessed by undertaking a sensitivity test and applying the PART-Oil model in a stochastic manner. When applied in a stochastic manner, the PART-Oil model is provided with historical data covering the full range of wind conditions which might be encountered in each season and the model generates a risk map showing the relative probability that any particular location within the water body or on the coastline might be impacted at any time within the simulation period as a result of the possible wind conditions which might apply. The model also calculates the shortest time of travel from the spill site to any point within the modelled area which might be impacted by the spill; the time of travel is important with respect to the thickness of the floating fuel and with respect to the development of a fuel response plan. Using this information, it is possible to assess how representative the results from the deterministic simulations are of the range of wind conditions which might be encountered in each season and allows an assessment to be made of any possible consequences of a spill taking place under different wind conditions compared to those employed in the deterministic simulations.

11.3.2.23 When applied in a stochastic manner, the location and duration of the spill must be specified similar to the deterministic simulation but, because the model is being used to predict the relative probability that fuel might reach any location within the modelled area, the magnitude of the spill is not relevant.

11.3.2.24 For the stochastic simulations, wind records were obtained from the Hong Kong Observatory for wind stations located at Chek Lap Kok International Airport, Sha Chau, Tuen Mun and Tai Mo To covering a period of 9 years from October 1997 to the most recent data available (31 October 2006). This wind data was first divided into two separate data sets for the wet season (May to September) and the dry season (October to April) and a large number of wind series (500 in each season) were obtained from these records by random sampling. These wind series contained the historical variation in wind strength and direction in each season and the results from the PART-Oil model should be representative of the relative probability that spilt fuel will be present in any area for the specified spill site.

11.3.2.25 From the previous simulations of Scenarios 1 and 2, it was noted that there were differences in the fate of the worst case fuel spill depending on the tidal conditions at the start of the spill. However, for the stochastic modelling, it was not thought that these differences would be large in the first few hours following any spill while the fuel would be at sufficient concentration (thickness) to be of environmental concern or risk to humans. For the stochastic modelling, therefore, it was decided to simulate a continuous spill from the location selected for Scenarios 1 and 2 (500m offshore of the jetty) over a complete neap tidal cycle which would eliminate the effect of spills occurring at different times within the tidal cycle.

Dry Season

11.3.2.26 In Appendix J1, Figures J.1 to J.3 present the results of the dry season stochastic simulation. Figure J.1 presents the relative probability that fuel will be present in a 500m by 500m area at some point within each 30 minute interval within the simulation period. It should be noted that the simulations was carried out for period of 7 days to ensure all fuel remaining within the model area was included but, as confirmed by the simulations above, little, if any fuel, was expected to remain after 2-3 days after the spill ceased. The probability that fuel will be found at the fuel spill site will not, therefore, be 1 because the fuel will be transported from the spill site relatively quickly by the tidal currents. (If the assessment period was only a few minutes rather than 7 days, the probability of finding fuel at the spill site would approach 1). The probabilities indicated in Figure J.1, therefore, are relative.

11.3.2.27 When comparing the relative probability (but not the magnitude of any impact) that each 500m stretch of coastline would be impacted by the fuel spill 500m offshore from the jetty under the range of possible wind conditions), it was noted that the fuel is most likely to come ashore close to the spill site (Castle Peak to Butterfly Beach) but also to affect the northern shoreline of the airport and a stretch of the North Lantau coastline from Tung Chung to Tai Ho.

11.3.2.28 Figure J.2 presents the expected time of travel from the spill site for fuel to reach the areas indicated. That is, if fuel from the spill is predicted to reach any location under some particular wind condition, the time of travel is the shortest time taken for the fuel to first reach that location. Reference should also be made to Figure J.1 to assess the relative probability that any fuel might reach a given location.

11.3.2.29 Figure J.3 presents the fuel budget showing the fate of the fuel over a period of 3 days. From Figure J.3, it can be seen that, after 24 hours, there is less than 5% of the total fuel spill remaining afloat. It should also be noted that, in Figure J.3, the fraction of the total fuel spill indicated as “Evaporated” only covers the mass of fuel evaporated from the floating plume. The fuel indicated as having “Beached” will also continue to evaporate and, as for the floating plume, little fuel is expected to remain on the shore after a period of around 24 hours.

Wet Season

11.3.2.30 Figures J.4 to J.6 present the results from the stochastic simulation of wet season conditions. From Figure J.6, it can be seen that the wet season fuel budget is similar to that predicted for the dry season with little fuel remaining afloat after 24 hours and, as noted for the dry season, little fuel is expected to remain onshore after a similar period of time. The evaporated fraction shown in Figure J.6 also only refers to evaporation from the floating plume and little fuel would remain onshore within 1-2 days of its arrival.

Stochastic Simulations – Discussion

11.3.2.31 The distribution of relative probabilities for the wet and dry seasons (Figures J.1 and J.4) show a distinct difference in the expected behaviour of the fuel spill between the seasons. During the dry season, it is more likely that the oil will end up to the south, south west and south east of the spill site. In the wet season, the fuel tends to take a more easterly route while following the coastline but with significant probabilities of some southerly drift from the spill site. In this respect, the results from the stochastic simulation on the whole reflect the main findings from the deterministic simulation of Scenario 2 for the dry season but, for the wet season, some differences between the stochastic and deterministic simulation of Scenario 2 can be seen and these are discussed further below.

11.3.2.32 The predicted travel times presented in Figures J.2 and J.5 appear to be generally shorter than predicted in the deterministic simulation of Scenario 2. The predicted times of travel from the stochastic simulations are the shortest times detected under the range of wind conditions considered and so it is to be expected that there will exist combinations of wind speeds and directions at times during the tidal cycle when the fuel spill could reach most locations faster than in the deterministic simulations carried out for Scenario 2. A shorter time of travel to any location may be indicative of a higher concentration than was predicted at the same location under the simulation of Scenario 2. However, the time of travel obtained from the stochastic application is the time taken for fuel to first appear at any location and it is also likely that this time of travel relates to the edge of the plume impinging on the location and where concentrations could be very low. Furthermore, under the condition when the plume arrives at a particular site faster than predicted in the deterministic simulation, the wind effect must be strong and thus evaporation of the spill could be accelerated and the amount of fuel reaching the site would not necessarily be significantly higher than as predicted in the deterministic simulation. For ease of reference, Table 11.3 Summarises the shortest times of travel to each sensitive receiver in each season.

Table 11.3 Summary of Minimum Times of Travel to Sensitive Receivers

Scenario 2 – Estimated Minimum Time of Travel (Hours)		
Sensitive Receivers at Potential Risk	**Wet Season**	**Dry Season**
Nim Wan	36	36
Lung Kwu Upper	20	18
Lung Kwu Lower	20	12
Castle Peak Power Station	<1	<1
Shui Wing Steel	<1	<1
Butterfly Beach	6-12	2-3
Castle Peak Beach	12	8
Kadoorie Beach	12	8
Cafeteria Beach	12	8
Ma Wan (Fish Culture Zone)	12	30
The Brothers	6	6
Tai Ho	16	8
Chek Lap Kok (Artificial Reefs)	20	5
Airport 2	20	6
Airport 1 (Sea Channel)	45	36
San Tau	24-36	<12
Sha Lo Wan	24-36	12-24
Sham Wat	48	20
East of Sha Chau	15	5
Sha Chau Marine Park (Artificial Reefs)	24	12-24
Lung Kwu Chau	24	18

11.3.2.33 In the dry season, the stochastic simulations indicated that the fuel is most likely to come ashore close to the spill site (Castle Peak to Butterfly Beach) but also to affect the northern shoreline of the airport and a stretch of the North Lantau coastline from Tung Chung to Tai Ho. Comparing with the results from the simulation of Scenario 2, it appears that the prevailing wind simulated in Scenario 2 may result in a more severe impact on the Airport shoreline and North Lantau coastline and a smaller impact on the shoreline around Castle Peak than might be expected under different wind conditions. Impacts on the coastline to the east of the spill site, on the north east shores of Lantau Island and at Ma Wan, however, were predicted in Scenario 2 to be to be small or negligible and this is also confirmed by the stochastic simulation of dry season conditions.

11.3.2.34 Comparing the results from the dry season simulation of deterministic Scenario 2 and the dry season stochastic simulation, it appears that the expected impacts from the fuel spill under prevailing dry season wind conditions (Scenario 2) are not significantly different to the most probable impacts likely to arise under a range of possible wind conditions which could be expected in the dry season. In particular, the probability of significant impacts occurring under different wind conditions at locations not predicted to be affected to the same extent under Scenario 2 are very small. For example, under Scenario 2, Ma Wan was not predicted to be impacted by the fuel spill and, from the stochastic simulations, it appears that Ma Wan is very unlikely to be impacted under any different wind conditions which might be expected in the dry season.

11.3.2.35 In the wet season, the simulation of deterministic Scenario 2 indicated that the fuel would be mainly confined to the Urmston Road and nearshore area from Castle Peak to Brothers Point with no significant southerly transport of the spill towards Chek Lap Kok or North Lantau. From the wet season stochastic simulation, Figure J.4, it appears that a more southerly drift of the spill under different wind conditions than was indicated by Scenario 2 is quite likely.

11.3.2.36 This higher relative probability of a more southerly drift of the spill under different wet season wind conditions may reflect the fact that the prevailing wind condition may not be as dominant or as well established in the wet season as in the dry season and that other wind conditions have larger relative probabilities of occurring. This could result in a higher relative probability that the spill may be transported in a more southerly direction than might be suggested by the simulation of the prevailing wind condition. However, it appears from the stochastic simulations that any more southerly transport of the spill in the wet season under different wind conditions would still not be as marked as in the dry season. The airport shoreline and North Lantau coastline would still be unlikely to be impacted to any significant degree (as predicted for Scenario 2) under different wet season wind conditions but the coastline from Castle Peak to Brothers Point might experience a smaller impact than predicted for Scenario 2.

11.3.2.37 Under non-prevailing but likely wet season wind conditions, it is likely that the net outcome would be that more of the fuel spill would remain offshore to the south of the spill site, where there are no specific sensitive receivers, without impinging on the shorelines of North Lantau and Chek Lap Kok and with more of the fuel being lost to evaporation at sea than predicted under Scenario 2. In this respect, the simulation of the wet season spill under Scenario 2 will not have underestimated potentially significant impacts along the shoreline bordering the Urmston Road.

11.3.2.38 In conclusion:

- From the stochastic simulations of dry season conditions, there do not appear to be any areas with significant relative probabilities of being impacted by the fuel spill which were not predicted to be impacted under the dry season simulation for Scenario 2. Considering the short term impacts (1-5 hours typically) from the fuel spill predicted under Scenario 2, there is no reason to believe that the dry season simulation of Scenario 2 will have omitted to identify any potentially more serious impacts which might arise under the range of expected wind conditions in the dry season; and

- The stochastic simulation of wet season conditions did indicate that, with respect to non-prevailing but still likely wind conditions in the wet season, the simulation of Scenario 2 may have overestimated the impacts of the spill on the New Territories coastline and underestimated the fuel losses through evaporation in the waters to the south of the spill site. In this respect, it is not thought that likely impacts on sensitive receivers or neighbouring coastlines which might arise under the range of expected wet season wind conditions will have been underestimated in the Simulation of Scenario 2 or that the simulation of Scenario 2 will have omitted to identify any potentially more serious impacts which might arise under the range of expected wind conditions in the wet season.

Scenarios 3 and 3a - Spill from Pipeline in Urmston Road

11.3.2.39 Scenarios 3 and 3a simulated the release of fuel as a result of a pipeline rupture in the Urmston Road where, in Scenario 3, the automatic shut-down system operated as designed with the instantaneous loss of only 60 tonnes of fuel, while in Scenario 3a, the automatic shutdown system was assumed to fail with fuel continuing to be pumped at a rate of 1,500m^3/hour for a period of 1 hour, equivalent to a loss of 1,200 tonnes of fuel. Due to the smaller amount of inventory, these potential releases are significantly smaller than the tanker rupture with only 60 or 1,200 tonnes being predicted to be released. Thus, the size of the resultant pool from the instantaneous loss (Scenario 3) (49m radius) or initial plume width for the continuous 1-hour release (Scenario 3a) (42m wide and 300m in length in tidal currents of 1m/s), are notably smaller than those generated by the spills from the tanker.

Dry Season

11.3.2.40 For Scenario 3, the releases during the dry season oscillate between Deep Bay and the tip of north east Lantau and the pool generally stays as one mass. The spill disappears within about 12 hours and, generally, does not affect any coastal areas with the exception of Lung Kwu Chau for a period of 1-2 hours during mid-flood releases, the north eastern tip of Lantau and Ma Wan during mid-ebb tides and would remain in the vicinity of the Sha Chau (marine park) for about 5 hours for a mid-flood release in dry season

11.3.2.41 For Scenario 3a, using the PART-Oil model with its more detailed simulation of surface wind drift than is simulated with the PART model used for Scenario 3, the small plume of fuel is transported in a more southerly direction than in Scenario 3 and approaches the Airport and North Lantau coastline both to the east and west of Chek Lap Kok International Airport depending on the time assumed for the start of the spill within the tidal cycle. The plume at times travelled to the west and south of Lantau Island but, in general, did not persist for more than 12-24 hours, although one simulation resulted in a plume persisting for up to 30 hours. Depending on the release time during the tidal cycle, the Lung Kwu Chau, Sha Chau and north Lantau shorelines could be impacted to some extent but for a short duration only.

Wet Season

11.3.2.42 For Scenario 3, the wet season releases tend to stay closer to the Tuen Mun coastline but do drift up into Lung Kwu Tan on occasions. At high water, the spill will reach the Castle Peak Bay and the beaches in this area and at mid-ebb, releases would migrate as far as the Rambler Channel and the beaches at Sham Tseng. As for the dry season the spill is short lived, dissipating in about 12 hours.

11.3.2.43 For Scenario 3a, with the larger fuel loss and more detailed simulation of surface wind drift, the spill for most release times within the tidal cycle impinged on the coastline in the vicinity of Tuen Mun with, in general, relatively small floating surface plumes at any given time. Depending on the release time during the tidal cycle, the plume was predicted to travel as far as Lung Kwu Lower and as far east as Ting Kau and the western entrance to the Rambler Channel. In general, however, the plume has dissipated within 12-24 hours.

Scenarios 4 and 4a - Spill from Pipeline at Marine Park Boundary

11.3.2.44 Fuel spill Scenarios 4 and 4a consider the effects of a fuel spill from the pipeline close to Sha Chau on the Marine Park boundary, 400m from the existing AFRF at Sha Chau. As with Scenarios 3 and 3a, the pipeline releases are small comprising some 60 or 1,200 tonnes of fuel and a small consolidated pool or short plume results.

Dry Season

11.3.2.45 For Scenario 4, a spill of 60 tonnes at this location during the dry season has the potential to affect three main areas, namely the north and western side of Lung Kwu Chau, Sha Chau and the natural coastline of north western Lantau, including Sham Wat and Kau San Tei. In all of these cases, the spill dissipates within a matter of hours.

11.3.2.46 For Scenario 4a with a spill of 1,200 tonnes, the plume is confined mainly to the waters south of Lung Kwu Chau and to the west of Chek Lap Kok Airport. The plume has the potential to impinge on the coastlines of Lung Kwu Chau, Sha Chau, Lantau Island to the west of Chek Lap Kok and Chek Lap Kok Airport seawalls. In all simulations, the plume dissipates within 12-24 hours.

Wet Season

11.3.2.47 For Scenario 4, the wet season spill disperses in different directions depending upon the tides. High water releases moving towards the Brothers and then on to the eastern tip of Lantau, accumulating briefly in Tso Wan. Low water spills do not reach the coast but oscillate between the airport platform and the Tuen Mun coastline. Mid-flood spill will affect Lung Kwu Tan for a period of 1-2 hours and releases at mid-ebb ultimately accumulate in Tai O where mangroves are present and would remain in the vicinity of Sha Chau (marine park) for about 3-4 hours for a mid-flood release in wet season The spill in this area is shown to disappear after about 12 hours.

11.3.2.48 For Scenario 4a with a spill of 1,200 tonnes, a spill commencing at high water on spring (large amplitude) tides could reach as far east as the Northern Rambler Channel. Depending of the time during the tidal cycle when the spill begins, the plume has the potential to impinge on the northern shore of the Chek Lap Kok Airport, the Brothers, Sha Chau and the coastline from Lung Kwu Lower to east of Ting Kau in the Rambler Channel. In all simulations, the plume generally dissipates within 12-24 hours or less in some cases.

11.3.3 Predicted Ecological Impacts from an Aviation Fuel Spill

11.3.3.1 There have been few studies into the ecological impacts from aviation fuel spills in Southeast Asian seas and available information is usually only available for crude oil spills. Ecological impacts are particularly evident in low-energy shallow coastal waters (i.e., those characterised by seagrass and mangrove habitats) that are known to require decades to return to their pre-spill condition whereas exposed hard substratum rocky-shores tend to recover from spills relatively quickly (months to a few years). An oil spill in Indonesian waters mostly affected mangroves in sheltered bays where recovery times were greater than 2.5 years and chronic discharges from a petrochemical plant led to reductions in intertidal invertebrates and tainting of fish in Jakarta Bay (GESAMP, 1993). The modelling has shown that the duration of impacts attributable to an aviation fuel spill are not expected to be persistent, however, soluble fuel fractions could affect marine organisms and deplete the oxygen content of seawater.

11.3.3.2 Diving and surface-dwelling seabirds and certain marine mammals (such as sea otters) are the most obvious victims of oil spills (GESAMP, 1993) although such incidents generally have negligible impacts on both fish and dolphin populations as these two groups are known to avoid direct contact (Clark, 1992). For the purposes of this assessment it is assumed that a surface slick of aviation fuel would impact similarly, although, it should be noted that because of the differences in the composition, crude oil is more persistent and potentially environmentally more damaging than the light refined products (e.g., jet fuel) which can evaporate and dissipate rapidly from the environment.

11.3.3.3 The Indo-Pacific Humpback dolphins in the study area comprise the Hong Kong/Pearl River Estuary population that are distributed over a wide spatial area (mostly comprising the area around the mouth of the Pearl River and Hong Kong's North-western waters). The NW Lantau area is the most dolphin abundant area within the plume influence area. As the humpback dolphin is the most important ecological sensitive receiver in the area, further assessment on the potential risk to them has been undertaken. Jefferson (2006) reports the average year-round density of dolphins in the NW Lantau is about 0.734 dolphins/ km^2 (i.e., 73.4 /100 km^2) with a seasonal high of 0.94 dolphins/km^2 (Autumn) and a seasonal low of 0.563 dolphins/km^2 (Spring). For the worst case, a density of 0.94 dolphins/km^2 (D) can be assumed for the purposes of assessment. As indicated in Table11.2, the outcome frequency of the largest possible spill of 80,000 tonnes from a vessel rupture (excluding the ignition probability) is 9.3×10^{-8} (P). For all sizes of vessels, the frequency would be 4.6×10^{-7} but the spill would be smaller. Based upon this and the initial approximate spill radius of about 478m, or 0.72 km^2 (A), the number of dolphins which may be affected (N) should such a spill occur can be estimated by the formula $N = P \times A \times D$, similar to the human risk assessment presented in Section 10. The calculation yields a value of 6.3×10^{-8} which equates to about 6.3 individuals in 100 million years. This demonstrates that it is extremely unlikely that a dolphin would be affected by an oil spill due to the PAFF.

11.3.3.4 Furthermore, the dolphin population is known to show marked shifts in the distribution in these waters (Jefferson, 2000). As such, it is most likely any dolphins inhabiting areas directly affected by an aviation fuel spill will disperse to areas away from the spill. Dolphins are relatively widely distributed across the whole Pearl River Estuary and north Lantau waters. Most dolphins have home ranges that extend outside the area predicted to be impacted by a spill at the PAFF. It is, however, noted that there are a few individuals that have small ranges of about 24 km^2 (Hung and Jefferson 2004). Some dolphins appear to use North Lantau as their entire home range and only seem to leave the area rarely, if at all (Hung and Jefferson 2004). Therefore, these individuals have slightly more potential to be affected. However, as the spill is relatively small (0.72 km^2) and evaporation of harmful fractions occurs rapidly, it is not expected that the increased risk would be significant. The modelling study revealed that any spill, if it occurred, will only last for a short period of time (a few days at most) affecting a limited area and the dolphins would still be able to make use of the non affected habitat in the North Lantau waters or in the wider Pearl River Estuary.

11.3.3.5 Even considering the worst-case Scenario 2 which led to wide spatial distribution of fuel, owing to the high mobility and wide range of the dolphin, significant impacts are not anticipated. For individual dolphins inadvertently present near a spill plume, there is also a potential risk of fire burn, direct skin contact and inhalation of toxic vapours. However, as discussed in Section 11.2 above, dolphins appear to have the ability to detect oil slicks, can swim away from a spreading plume without difficulty and can metabolise the petroleum carbon in case of accidental ingestion/absorption. The probability of the spilled fuel catching fire is extremely low and as noted in Section 10, for largest human fatality of 10.5 people, the lowest frequency is 1.96×10^{-10} (Table 10.15). The average number of people in the sea (on vessels) at any given time is 0.15/ha (see Section 10.3.3.23). The seasonal high dolphin population density of 0.94 dolphins/km^2 (or 0.0094 dolphin/ha), as discussed above, which is a factor of 1/16 compared to the density of people at sea. Thus, the number of fatalities of dolphin would be 0.65 compared to human fatality of 10.5. Furthermore, there does not appear to be any detail in the literature on dolphin reactions to a spill involving burning fuel but it is considered (Jefferson, pers comm.) that the dolphins would likely avoid the burning fuel as the aviation fuel on fire would be at the surface of the sea water. Thus, the fire risk should not be a concern.

11.3.3.6 As observed in the oil spill incidents (e.g., Smultea and Wursig, 1992; 1995; Geraci and St. Aubin, 1982), dolphins have been observed surfacing within the oil plume, and could, thus, be exposed to hydrocarbon vapours. While there have been no detailed studies testing the effects of breathing oil vapours on dolphins, it is likely that inhalation of toxic fractions can cause pneumonia (Hanson 1985), and can be life-threatening when there is long-term exposure (Geraci and St. Aubin 1980). However, studies on the inhalation of petroleum hydrocarbon vapours in laboratory animals and humans did not report any adverse effects on the respiratory system (Hartung, 1995 and the references cited). Whilst the toxic fractions could be at high levels for the first few hours after a major spill (until they have evaporated) (Geraci 1990), in practice, the oil fractions evaporate quickly enough that this is probably not a serious problem. As determined above, the probability of dolphins surfacing within the spill is extremely low and oil vapour inhalation would not be expected to be particularly harmful in the short-term (Jefferson, pers com.). There remains a concern that if the spill occurs in an area of high dolphin density, resident dolphins with small ranges could briefly be subjected to harmful vapours. Modelling studies, however, indicated that a plume will pass thorough the dolphin hot-spots rapidly and such duration of exposure would be unlikely to induce significant toxicological effects.

11.3.3.7 The epidermis of cetaceans is not fully keratinized on the surface (Geraci and St. Aubin 1987). Cetacean skin does not play much of a role in thermoregulation, but it does have important hydrodynamic properties, the functions of which may be compromised (at least temporarily) by long-term contact with toxic fractions of oil (Geraci and St. Aubin 1980, 1987). Oil contact is known to be capable of causing some (at least temporary) skin damage to dolphins (Geraci and St. Aubin 1987). All marine mammals would be expected to experience irritation and inflammation of eyes and sensitive mucous membranes upon oil contact, but the duration of exposure required for such effects is not well-known (Geraci and St. Aubin 1987). Experimental exposure of cetaceans including bottlenose dolphin (*Tursiops truncates*) and Risso’s dolphin (*Grampus griseus*) to crude oil and gasoline (for up to 75 minutes) showed that histological change varies with duration exposure and that the histological damage was reversible (Geraci and St.

Aubin, 1982, 1985). Thus, cetacean skin appears to be more resistant to toxic effects from petroleum hydrocarbons than that observed in other mammals (Haebler, 1994).

11.3.3.8 The highest potential for any impact to dolphins attributable to a fuel spill is most likely to be sub-lethal. Ingestion of heavily fuel-tainted fish may pose some risk (chronic exposure of certain PAHs can be carcinogenic in higher mammals) although as described above, these concentrations would likely be low and fuel components such as PAHs can be metabolised fairly rapidly by fish and also subsequently when tainted fish are ingested by dolphin. It is also noted that owing to the ephemeral nature of any spill and consequent short-term bioavailability of fuel for uptake by fish, any risks associated with ingestion of prey items tainted by fuel components are small and highly short-term (acute). Chronic exposures of fuel-tainted prey items are not anticipated and the sub-lethal risks attributable to consumption of oiled food items are, therefore, also insignificant.

11.3.3.9 In summary, dolphins are not as vulnerable to the detrimental effects of oil spills as are other marine mammal species (such as seals and sea otters, which depend on fur for thermoregulation), although coastal species (such as Hong Kong humpback dolphins) may still be susceptible to harm, especially in the unlikely event that the dolphin is present in the vicinity of a plume. Significant impacts on the population as whole are also not expected although individuals, especially those with a relatively small home range, could be subject to slightly higher potential impacts. However, as demonstrated above the likelihood that the spill would occur and that a dolphin would be directly affected by the spill is extremely small. Notwithstanding, it is proposed that the emergency response plan will specify that if a spill occurs, there would be some specific dolphin monitoring by dolphin experts. It would include both at-sea surveys and beach surveys to look for stranded animals and include the need to liaise with Ocean Park specialists to get their assistance in rehabilitation of any dolphins that might be affected by the spill. This is further discussed in Section 11.4 and Appendix J3.

11.3.3.10 Research into the impact of a major oil spill on marine ecological receivers and fisheries following a spill of 4000 tonnes of heavy marine diesel in Hong Kong (Ap Lei Chau) in 1973 showed that local fish species were able to metabolise the oil (ambient aromatic fraction concentration calculated at 45-60 $\mu g\ l^{-1}$; Spooner, 1977). Although mortality was evident in some fish held in cages (10% mortality was observed in the stock held in the fish cages at Sok Kwu Wan, Lamma Island within one month of the spill) that were unable to avoid the oil and highly territorial species (such as damsel fish and porcupine fish) were killed (Spooner, 1977), the catastrophic impacts recorded in the fish farming operation were short-lived and recovery was rapid (nine months), following dissipation of oil in the water column and restocking of fish in the cages (Spooner, 1977). Although short-term impacts to some fish have been reported in Hong Kong due to major spills of heavy oils, the lighter aviation fuel is predicted to dissipated very rapidly and disappear within 1-2 days (based upon the worst case Scenarios 1 and 2) and hence impacts to free swimming fish from an aviation fuel spill are predicted to be insignificant The modelling of Scenario 2 indicated that the fish culture zone at Ma Wan was unlikely to be affected by the worst case fuel spill but consideration should be given to protecting this resource in the event of a spill, subject to the location and size of the spill.

11.3.3.11 Filter-feeding invertebrates such as bivalves are known to accumulate high concentrations of petroleum hydrocarbons (Goldberg *et al.*, 1978) owing to relatively inefficient enzyme (mixed function oxygenase) detoxification. There are numerous molluscs in the study area (Section 7) and significant mortality of bivalves has been recorded previously in Hong Kong following a spill of 4000 tonnes of heavy marine diesel (Spooner, 1977). As discussed above in Section 11.2, contact with lighter aviation fuels is less likely to have an impact on filter-feeding fauna compared with heavy crude oils and molluscs can accumulate high concentrations of petroleum hydrocarbons without suffering mortality (although sublethal responses are still often evident). As detailed in Sections 11.3.2.17 and 11.3.2.19 above for the worst case spill considered, the plume will evaporate rapidly and only affect an area for between 1-5 hours depending upon the season. As such, owing to the transient nature of any fuel spill and the fact that fuel will float on the water surface after release and so will not come into direct contact with this species, impacts on molluscs are predicted to be insignificant in the longer-term.

11.3.3.12 It is noted that under certain circumstances, a spill may briefly reach Lung Kwu Tan. This area is also known as a nursery area for horseshoe crabs. Although it is difficult to predict the impacts of a fuel spill on horseshoe crabs as few data are available, as adult animals are highly mobile, a spill briefly (a matter of hours is predicted) reaching Lung Kwu Tan is not anticipated to represent a significant impact. A fuel spill may, however, impact less mobile juvenile stages that are unable to avoid spills effectively. Although impacts are predicted in the less mobile juvenile crabs, impacts to the overall population are not considered to be significant. Notwithstanding, it would be recommended to protect this area in the event of a spill.

11.3.3.13 Corals are not predicted to be greatly affected by a surface spill in the study area as the fuel would largely float and the depth of the water in the North-western waters is a sufficient buffer between the surface and sublittoral corals. A subsurface spill due to damage of the submarine pipeline could, however, lead to direct impacts on corals as oil spills are known induce both histopathological injury and mortality (Brown and Howard, 1985). Although major oil spills have been reported to cause substantial mortality in coral reef systems (GESAMP, 1993) it is notable that spill of 4000 tonnes of heavy marine diesel from Ap Lei Chau did not have any noticeable impacts on the coral reef fauna found subtidally at Lamma Island (Spooner, 1977). It would appear that intertidal corals are more vulnerable to oil than those found subtidally (GESAMP, 1993) presumably because oils are washed ashore and trapped in intertidal coral reefs. Oil pollution also appears to be most harmful to corals over prolonged (chronic) exposures (GESAMP, 1993). The few coral records from the study area indicate that the species present are mostly subtidal and a surface aviation fuel spill is not considered to pose a significant threat. Similarly, a subsurface spill through a burst pipe will be of short duration as the oil rises rapidly to the surface and the predicted impacts to corals are considered to be highly localised and overall impacts are insignificant.

11.3.3.14 Accidentally spilled fuels are known to be particularly damaging in low-energy shallow coastal waters that are often inhabited by important flora such as mangroves and seagrasses. There are no significant mangrove stands or seagrass communities in the immediate vicinity of the PAFF although important mangal is present at Tai Ho Wan, Tung Chung, San Tau and Sham Wat on the Northwest coast of Lantau (Tam and Wong, 2000). These areas have also been identified as horseshoe crab nursery grounds. The modelling results indicate that the stand at San Tau and Tung Chung Bay would not be affected by any spills. However, the stand at Tai Ho Wan, together with the stand in Tai O could be affected in the short term (less than a day) if a spill was to occur. Accumulated heavy oils in low-energy habitats such as mangrove stands are known to be persistent and have the potential for long-term impacts. As discussed above in Section 11.3.3.1 the modelling has shown that the duration of impacts attributable to an aviation fuel spill is not expected to be persistent and chronic (long-term) exposures appear to be more damaging to biological communities. Although short-term impacts attributable to a fuel spill to seagrass beds and mangroves are predicted, it is likely that they will not be of the magnitude observed through heavy oil exposures. There is not, therefore, expected to be any significant long-term damage in the biological communities present at Tai Ho Wan and Tai O due to a short-exposure to fuel as both exposure time and persistence are predicted to be acute only.

11.3.3.15 It should be noted that the risk from a fuel spill is low as accidents due to human error and pipeline failure at marine terminals represent one of the lowest sources of petroleum hydrocarbon inputs to the sea world-wide (see Table 11.1 above) and reflects the care taken to reduce accidents (Clark, 1992). However, notwithstanding the rapid disappearance of the fuel, contingencies to protect key coastline areas including the islands located within the Marine Park and marine resources will be needed to be included in the spill response plans.

11.4 Mitigation Measures

11.4.1 The mitigation measures identified here are also summarised in the Environmental Mitigation Implementation Schedule in Appendix B. All elements of the fuel handling, storage and transportation system will be designed to minimise the risk of failure and resultant leaks and spills to the lowest practicable level. Tanks in the tank farms will be constructed in a bunded area surrounding the tanks which will have an ultimate (2040) collection capacity of at least 150% of the volume of the largest tank in the bund to contain any fuel spills. Emergency shut down valves shall be installed within the wider site storm drainage system to provide for further emergency retention of spillages. Protection against leaks from the bottom of the tanks is achieved by the installation of an impermeable membrane in the tank foundation beneath the tank bottom. In respect of the pipeline, besides protection of the pipeline being covered with a protective rock armour layer, integrated methods of control will also be built into the design of the pipeline. A leak detection system will be installed to provide early detection of any leak and at the first sign of a pressure drop, would instigate an automatic shut-off system. Contingency plan procedures will require investigation and immediate action to stem the release, as described below.

11.4.2 All tankers approach the berth using a pilot and tug system to minimise the risk of grounding or striking the jetty. In addition, a workboat will be on standby at the jetty during tanker berthing to pull the containment boom into place around the vessel as well as to contain the actual spills. Skimmers will also be available for quick deployment in case of a spill.

11.4.3 While these methods will minimise the risk of a spill, minimise the amount of a spill and contain the spill if it did occur, it will also be necessary to define an emergency response plan and implement an operator-training programme to assure the quick response needed to further minimise the impact of any fuel leak, as described in Section 11.4.5 below.

11.4.4 The results of the spill modelling have shown that some key sensitive marine ecological receivers could be affected in the short term by a spill associated with the PAFF. As such it will be necessary to include contingencies to protect these resources in the spill response plan. The locations which should be protected by the rapid use of booms are as follows:

- Ma Wan fish culture zone;
- Lung Kwu Tan beach and horseshoe crab nursery area;
- Tai Ho Wan mangroves and seagrass stands and horseshoe crab nursery area;
- Tai O mangrove stand;
- gazetted beaches in Castle Peak Bay and along the coast to Sham Tseng;
- coastline of Lung Kwu Tan, Sha Chau and Tree Island;
- Sha Chau and Lung Kwu Chau Marine Park; and
- Tung Chung Bay/San Tau mangrove and seagrass stands and horseshoe crab nursery area.

11.4.5 The PAFF operator will maintain a readiness to react to any fuel spills in the Spill Response Plan procedure which will set out all necessary actions for preparedness, prevention and responses. The rationale for the spill response plan would be based around prevention and early detection and will be continuously developed before and after the commissioning of the PAFF. In particular, the spill response plan will define procedures to contain and clean up spills of various categories in order to reduce hazards to life and impacts to the environment. A Jetty Operation Manual will be prepared to specify the requirements for vessels to berth at the jetty including the compulsory use of pilots and tug boats. In addition, spill control equipment will be stored at the PAFF tank farm and the jetty and will include at least the following:

- sand bags;
- oil water separator;
- containment booms;
- oil skimmers with recovery containers;
- absorbent booms; and
- absorbent pads.

11.4.6 On the prevention side, the sub sea pipelines will be protected by impressed current cathodic protection system and monitoring by a leak detection system to prevent and manage the risk of fuel leakage. Routine inspections will be undertaken on a regularly basis (such as daily, weekly, monthly or quarterly basis) to ensure the proper functioning of the whole facility.

11.4.7 The key features which should be included in the spill response procedures are summarised below and an outline Fuel Spill Contingency Plan is provided in Appendix J3:

- organization of the spill response team and the responsibilities of each member.

- response procedures to be adopted in the case of a spill, including:
    - identification of the source of spill;
    - reporting to relevant Authorities;
    - containment of leaking fuel;
    - recovery and processing of free fuel;
    - clean up methodology; and
    - handling and disposal protocols; and
    - at sea surveys and beach surveys for dolphins to look for stranded animals and include the need to liaise with Ocean Park specialists to get their assistance in rehabilitation of any dolphins that might be affected by the spill.

- establishment of an emergency control centre on the PAFF site;

- establishment of effective communication emergency mechanisms and a 24-hour emergency contact list;

- training and competence level requirement of PAFF staff; suitable and regular spill response training to be provided to the operating personnel and regular spill response drills to be conducted to test and exercise the responses;

- provision and maintenance of spill equipment at the PAFF land site, on the PAFF jetty at the Sha Chau reception point and at the HKIA site;

- drills and exercise requirements; and

- follow-up procedures and post spill recordings.

11.4.8 In order to ensure the on-going adequacy of the fuel spill contingency plan and that it is being implemented as required, it is proposed that an Environmental Management System be set up for the operational phase of the project to allow regular audits of the systems/mitigation measures incorporated in the project and the fuel spill contingency plan.

11.4.9 In addition, the proper functioning and structural integrity of the PAFF facility will be important to ensuring leaks and spillages do not occur. Therefore, the requirements for regular and routine inspections and audits of the facility during its operational life to ensure the correct operation and integrity of the PAFF and instant readiness of all necessary systems to prevent or reduce the risk of any leaks or spillages will be addressed in detail in the operational manual, as was the case with the existing aviation fuel facilities at Sha Chau and airport. The whole PAFF facility, including the tank farm, jetty and pipelines will be subjected to at least two stringent inspections every year including one undertaken pursuant to the Joint Inspection Group (JIG) (an internationally recognised body formed by major oil companies, including, Chevron, ExxonMobil and Shell. The JIG Guidelines for Aviation Fuel Quality Control and Operating Procedures have been endorsed by The International Air Transport Association (IATA) as a standard) and another one undertaken by a technical advisor principally an oil major, e.g. Shell. With respect to the pipelines, the PAFF operator will inspect the whole sub sea pipelines every 5 to 10 years by using intelligent pigging to check the integrity and structure of the whole submarine pipeline. As a standard practice, the operator will also undertake a major HSE (Health, Safety and Environmental) audit every 3 years. With respect to the tanks, the structural integrity of the tanks will be subject to structural survey every year to comply with the statutory requirements. The sub sea pipelines are protected by impressed current cathodic protection system and monitored by a leak detection system. Relevant text on these audits is included in Section 15.

11.5 Residual Impacts

11.5.1 With the above recommended mitigation measures in place to prevent, contain and clean-up spills and leaks of fuel stored or conveyed to and from the site, potential environmental impacts on the environment, particularly water quality and marine ecology can be minimised. While the risk of spills cannot be completely prevented, the risks can be minimised and are well within acceptable bounds. The proposed mitigation measures keep impacts to a practical minimum such that no adverse residual impacts are predicted from spilled fuel.

11.6 Environmental Monitoring and Audit

11.6.1 Based upon the integrated mitigation measures and procedures which will be put in place to prevent, contain, clean-up and dispose of any spillage, significant environmental effects are highly unlikely to arise. The regular programme of inspections of the system during the operational stage will be specified in the emergency response plan. However, it is recommended that a design phase audit of the spill response plan is undertaken to check that it includes the necessary elements and of the design of the pipelines, tanks and jetty to ensure key spill detection and control elements are included. In addition, in order to ensure the on-going adequacy of the fuel spill contingency plan and that it is being implemented as required, it is proposed that an Environmental Management System be set up for the operational phase of the project to allow regular audits of the systems/mitigation measures incorporated in the project and the fuel spill contingency plan. Further details are provided in Section 15 of this report and in the EM&A Manual.

11.6.2 The following regular inspections and audits will also be undertaken during the operational phase of the facility:

- two inspections every year of the tank farm, jetty and pipelines including one undertaken pursuant to the Joint Inspection Group (JIG) explained above;
- inspection of the whole sub sea pipelines every 5 to 10 years;
- Health, Safety and Environmental audit of the facility once every 3 years; and
- inspection of the structural integrity of the tanks once per year.

11.6.3 In addition, it is recommended that the Franchisee undertake some routine monitoring of water quality in the vicinity of the PAFF site to check the effectiveness of the proposed precautionary measures implemented for on-site spill control. The details of the monitoring to be undertaken will be prepared by the Franchisee as part of the PAFF Operations Manual and the details will be agreed with the relevant authorities within 3 months of the commencement of operation of the PAFF. However, the monitoring should include but not be limited to the parameters of TPH and PAH and reference should be made to the existing monitoring programme undertaken for the fuel tank farm on the HKIA platform.

11.6.4 As much of the prevention for the risks to human life, leakages and spillages, on land and in the sea, are based upon the design and construction of PAFF following the latest technology, standards and guidelines. In order to ensure that the required design measures are taken into account during the planning and design for the future tank development, a review of the EIA report will be undertaken at the planning stage for the future expansion (around 2025 as required). The review is required only if the latest technology, standards and statutory requirements are deemed to have changed by that time.

11.7 References

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