APACHE ENERGY LIMITED

WONNICH GAS DEVELOPMENT

CONSULTATIVE ENVIRONMENTAL REVIEW

EPA ASSESSMENT 1040

ovember 1996

Wonnich Gas Development

Consultative Environmental Review

EPA Assessment Number 1040

Proponent:

Apache Northwest Pty Ltd
256 St Georges Terrace
Perth WA 6000

8 November 1996

WONNICH APPRAISAL DRILLING PROGRAMME

CONSULTATIVE ENVIRONMENTAL REVIEW

Invitation to comment

The Environmental Protection Authority (EPA) invites people to make a submission on this proposal.

Apache Energy Limited (the proponent) proposes to develop the Wonnich gas field from the Exploration Permit TP/8.

In accordance with the Environmental Protection Act, Apache Energy Limited has prepared a Consultative Environmental Review which describes the proposal and its likely effect on the environment.

The CER is available for public review for four (4) weeks from 9 November 1996 closing on 9 December 1996.

After receipt of submissions from the public and Government agencies, the EPA will prepare an assessment report with recommendations to the Government, taking into account issues raised in submissions.

Why write a submission?

A submission is a way to provide information, express your opinion and put forward your suggested course of action including alternative approaches.

It is useful if you can suggest ways to improve the proposal.

All submissions received by the EPA will be acknowledged. Submissions will be treated as public documents and may be quoted in full or in part unless specifically marked confidential.

Why not join a group?

If you prefer not to write your own comments, it may be worthwhile joining a group interested in making a submission on similar issues.

Joint submissions may help to reduce the work for an individual or group while increasing the pool of ideas and information.

If you form a small group (up to 10 people) you may wish to indicate the names of all participants.

If your group is larger, please indicate how many people your submission represents.

Developing a submission

You may agree or disagree with, or comment on general or specific issues discussed in the CER.

It helps if you give reasons for your conclusions, supported by relevant data.

You may make an important contribution by suggesting ways to make the proposal environmentally more acceptable.

When making comments on specific points in the CER:

- clearly state your point of view;
- indicate the source of your information or argument if this is applicable;
- suggest recommendations, safeguards or alternatives.

Points to keep in mind

By keeping the following points in mind, you will make it easier for your submission to be analysed;

- attempt to list points so that the issues raised are clear. A summary of your submission is helpful;

- refer each point to the appropriate section, chapter or recommendation in the CER;

- if you discuss sections of the CER, keep them distinct and separate, so there is no confusion about which section you are considering;

- attach any factual information you want to provide and give details of the source. Make sure your information is accurate.

Remember to include

- **Your name,**
- **address,**
- **date, and**
- **whether you want your submission to be confidential**

THE CLOSING DATE FOR SUBMISSIONS IS: 9 December 1996

Submissions should be addressed to:

The Environmental Protection Authority
'Westralia Square'
141 St. Georges Terrace
Perth W.A. 6000

Attention: Mr Tim Gentle (phone 09 222 7085)

sam:WONCER.DOC

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EXECUTIVE SUMMARY

- This document is a Consultative Environmental Review (CER) submitted by Apache Energy Limited and the Joint Venture Partners to seek environmental approval to develop the Wonnich gas field, located in Exploration Permit TP/8.
- The development proposal is to drill two wells from a single location located some 8 km west-southwest of Hermite Island, Montebello Islands. This is the site of the Wonnich-1 exploration well which was drilled in mid-1995. The development will consist of an unmanned, offshore production monopod tied back via a pipeline to existing processing facilities on Varanus Island.
- The gas development is scheduled to begin in April 1997 and will take about 15 months before commissioning of first gas. The proposed life of the project is 10-15 years.
- Petrofree™, a palm oil formulation based on non-aromatic esters will be used as the drilling fluid for the two wells.
- The major marine ecological habitats of the region include macroalgal beds, fringing and patch coral reefs, rocky shores, sandy beaches and mangals. These habitats support fauna of both commercial and conservation significance.
- Social, commercial and historical resources of the region include the towns of Onslow and Dampier, the Onslow Prawn Fisheries Grounds, a pearl fishery, three historic shipwrecks, historic nuclear testing sites and limited tourist activity adjacent to the Montebello Islands.
- Apache Energy has been involved in the exploration and production of oil and gas on and near the Lowendal Islands, located some 25 km to the south of the Montebello Islands, since 1983.
- The Wonnich gas development will have a negligible impact on the environment from routine operations as it will be a closed system with insignificant discharge of effluents into the marine environment. The primary impact factor will be from infrastructure installation causing a short term, localized disturbance.
- Drill cuttings will be disposed in the lost circulation zone of the formation and not into the marine environment, while drilling fluid will be collected for reuse.
- Negligible volumes of produced formation water will be generated and this will be treated through the existing facilities on Varanus Island.
- The overall probability of an incident occurring from the development which would result in a spill of condensate reaching the fringing reefs or shorelines of the Montebello Islands is very low. Safety and management plans will be developed which will further reduce the chances of an accident.
- Modeled trajectories indicate that the quantity of condensate which would reach the fringing reefs or shorelines from an accident, would be small due to the rapid evaporation rate of condensate. The projected travel times for contact indicate that the risk to a resource did not solely depend on the distance from a spill source as winds and currents were important influencing factors.
- Apache Energy will undertake the environmental strategies, guidelines and management commitments given in this CER for the Wonnich gas development and will fulfill those commitments to the satisfaction of the appropriate statutory authorities.

1. INTRODUCTION

1.1 Background

In 1994, Ampolex Limited (Ampolex), representing the Joint Venture Partners for Exploration Permit TP/8, sought approval to drill an exploration well at the Wonnich hydrocarbon prospect at a location some 25 km to the northwest of Varanus Island and 8 km to the south-west of Hermite Island, one the larger islands of the Montebello group of islands (Figure 1).

The level of assessment for the exploration well designated Wonnich-1 was set at a Consultative Environmental Review (CER), and the required report was submitted to the Environmental Protection Authority (EPA) in February 1995 (Ampolex Limited 1995).

The proposed drilling program was subsequently granted environmental approval, subject to conditions, by the Minister for the Environment in June 1995. Wonnich-1 was drilled by the jack-up drilling unit *Ron Tappmeyer* between 8 July and 13 August 1995.

Wonnich-1 was drilled without incident and resulted in a hydrocarbon discovery in the Flag Sandstone formation. Production testing assessed a 77 m column of gas-condensate reservoir fluid overlying an 8 m column of oil.

In December 1995, the Joint Venture Parners submitted an application for approval to drill two appraisal wells from a single location approximately 7 km west south-west of Hermite Island. This drilling program was set at the CER level of assessment and is presently undergoing final evaluation.

1.2 The Present Proposal

The Joint Venture Partners seek approval to develop the Wonnich gas field (Figure 2) using an offshore production monopod tied back to the existing processing facilities on Varanus Island (Figure 3). This will entail production drilling, and the installation of a monopod and pipeline.

Two wells will be drilled from a single surface location approximately 8 km west south-west of Hermite Island (Figure 4). The wells will be located immediately adjacent to the Wonnich-1 well. A biodegradable ester based drilling fluid, Petrofree™, will be used for the drilling program, with down hole disposal of drill cuttings for both wells.

The production facilities will include an unmanned monopod which will accommodate the well heads, testing equipment and emergency shut-down facilities. A pipeline will bring gas and associated condensate to Varanus Island for separation and processing. The proposed life of the project is 10-15 years.

1.3 Summary of Impacts

The primary impact producing factors associated with the Wonnich gas development are placement of the infrastructure, routine operations and accidental events. Operational impacts include drilling discharges to the marine environment, supply vessels, helicopters, and air and noise emissions.

The Wonnich gas development will result in negligible impact to the environment from infrastructure installation and routine operations. Installation will cause a short term localized impact, and there will be an insignificant quantity of effluents discharged from routine operations into the marine environment. Drilling fluid will be collected for reuse and the majority of drill cuttings will be discharged down the well annulus. No produced water will be generated. An environmental analysis of routine activities and their potential impacts has been carried out for each stage of the development.

A quantitative environmental risk assessment has been carried out to identify all potential sources of condensate spills, their probability of occurrence and their potential consequences on sensitive resources.

1.4 Legislative Requirements and the CER Process

Exploration and development of offshore petroleum resources in Western Australia is undertaken subject to a number of State and Commonwealth Government Acts. The principal State Act, the *Petroleum (Submerged Lands) Act* 1982, as amended, applies to projects located in State waters. State waters extend for a nominal distance of three nautical miles (5.5 km) offshore from the mainland but are extended to include the waters surrounding the islands under State jurisdiction, which include the Montebello Islands and consequently the Wonnich gas development site. The *Petroleum (Submerged Lands) Act* is administered by the Department of Minerals and Energy Western Australia (DME).

The review of the environmental impacts of developments in Western Australia, including petroleum exploration and development, is controlled by the *Environmental Protection Act* 1986. The EPA, acting under the provisions of the Act, has determined that the Wonnich gas development proposal should be formally assessed under Part IV of the Act and has set the level of assessment at a CER.

Guidelines for the preparation of this CER have been provided by the Department of Environmental Protection (DEP) and are set out in Appendix 1.

The EPA's stated objective of the environmental review process is to "... protect the environment, and environmental impact assessment is deliberately a public process in order to obtain broad ranging advice. The review requires the proponent to describe the proposal, receiving environment, potential environmental impacts, and the management of the issues arising from the environmental impacts, so that the environment is protected to an acceptable level."

This CER:

- describes the environmental setting in which the proposed development program will take place;
- presents an environmental analysis of production drilling and production activities and their potential effects;
- presents a quantitative risk assessment of the program; and
- details the management strategies to be adopted to minimize the actual and potential environmental effects arising from drilling and production activities.

This document has been prepared in accordance with the guidelines provided by the DEP to facilitate the environmental review process and document the issues raised. It will be reviewed by the EPA, DEP, Department of Conservation and Land Management (CALM), Department of Fisheries, Western Australian Museum (WAM), other agencies, community groups and individuals.

1.5 Justification of the Project

Petroleum exploration and production is the single most significant economic activity in Australia's marine environment. The gross production value from Australia's petroleum industry generated $8.6 billion in 1995-96. Of this $8.6 billion, $2.4 billion was paid to government in royalties, resource rents and income tax. In the period 1994/95, the value of Western Australian offshore production exceeded $2.5 billion, representing 32% of national production.

Oil and gas development on the North West Shelf of Australia is becoming increasingly important as the production from Bass Strait fields continues to decline. Both the Australian Commonwealth and Western Australian Governments recognize and support the need for Australia to at least maintain present levels of self sufficiency inoil and gas. The Western Australian Government regularly releases permit areas for tender to petroleum companies and consortiums to encourage onshore and offshore hydrocarbon exploration.

The Carnarvon Basin, within which the Montebello Islands are located, accounts for more than 99% of the State's gas and condensate production and 98% of the total oil production.

Natural gas is the most environmentally acceptable and efficient fuel for electricity generation. Coal-fired electricity generation is about 40% efficient while gas-fired generation is close to 50%. More importantly, to produce a unit of energy from natural gas, far less carbon dioxide is produced than from any other fossil fuel. Therefore, reducing coal based electricity generation with natural gas can make a significant contribution towards meeting any greenhouse commitments.

The proposal by the TP/8 Joint Venture Partners to develop the Wonnich gas field is an integral component of Australia's commitment to develop its oil and gas reserves. The project will benefit the community through capital expenditure, payment of royalties and employment.

1.6 Public Consultation

In keeping with Apache's policy of open communication with government and the community, all interested parties will be kept informed and up to date on the progress of the Wonnich gas development project, and all concerns will be addressed.

Copies of this CER will be forwarded to parties who have an interest in the project (Appendix 2). Further presentations will also be made to interested parties prior to the commencement of the project.

1.7 The Proponent

In December 1995, Apache Energy Limited (Apache) replaced Ampolex as the proponent for the Wonnich program. Apache will be managing the production drilling, and the installation and operation of the production facilities on behalf of the Joint Venture Partners.

The Joint Venture Partners in TP/8 are:

Ampolex (Western Australia)
Ampolex (Varanus) Pty Ltd
Apache Northwest Pty Ltd
Hardy Petroleum Ltd
Kufpec Australia Pty Ltd
Tap (Harriet) Pty Ltd
New World Oil and Developments Pty Ltd
Novus Harriet UK Limited

The address for Apache Northwest Pty Ltd (the proponent) is:

Apache Energy Limited
3rd Floor
256 St George's Terrace
PERTH WA 6000

Telephone number: (09) 422 7222
Contact person: (09) Dr Iva Stejskal

1.8 Acknowledgments

The Joint Venture Partners thank the following for the monitoring or scientific expertise they provided and which was incorporated into this report: LeProvost Dames & Moore (marine monitoring), the Australian Institute of Marine Science (coral biogeography), SpecTerra, CSIRO and the Department of Transport (remote sensing). Thanks are extended to the East Spar Alliance for the provision of the aerial photograph of the East Spar pipeline.

LOCALITY MAP

Figure 1

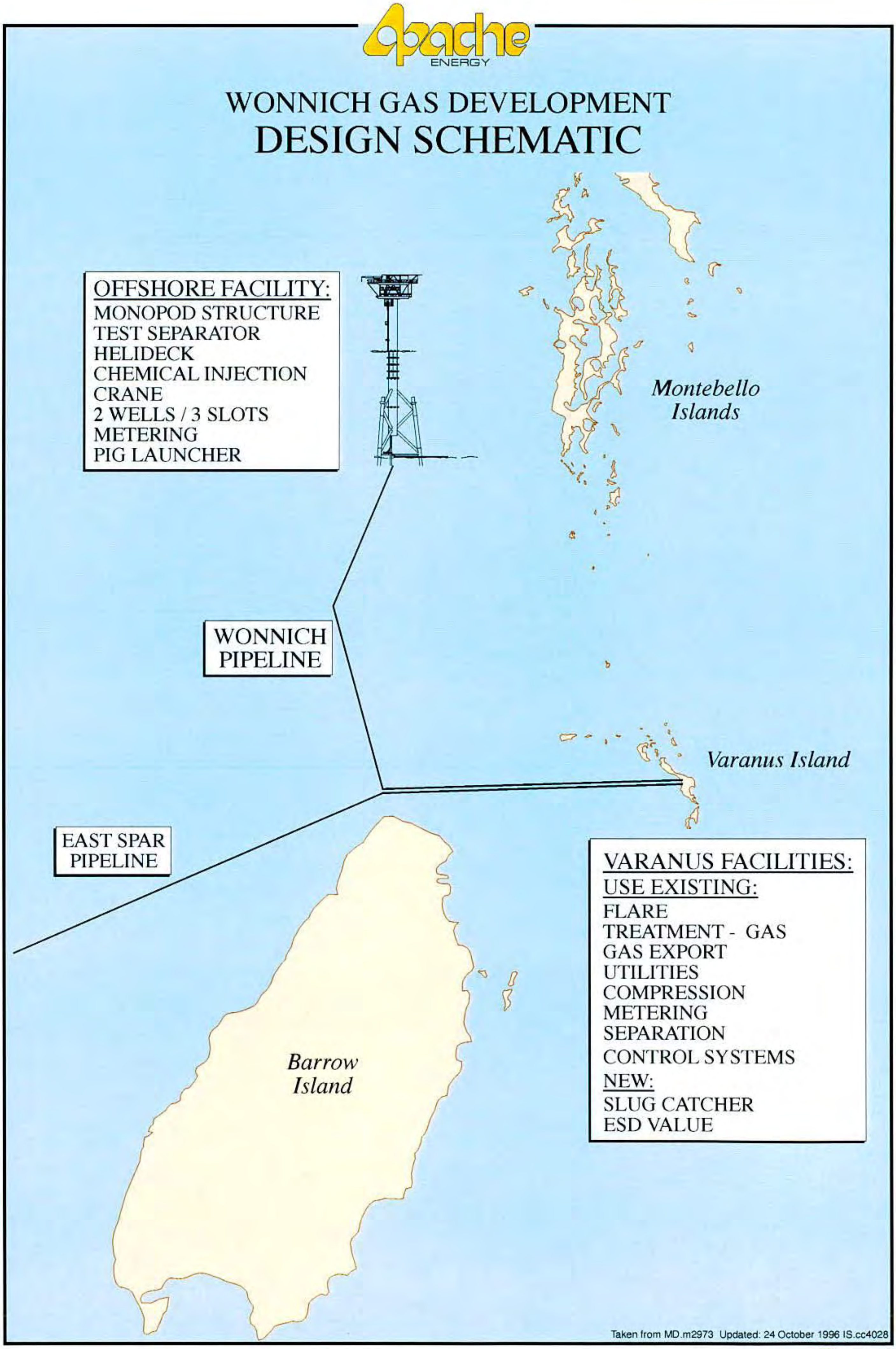

Apache ENERGY
WONNICH GAS DEVELOPMENT
DESIGN SCHEMATIC
OFFSHORE FACILITY:
MONOPOD STRUCTURE
TEST SEPARATOR
HELIDECK
CHEMICAL INJECTION
CRANE
2 WELLS / 3 SLOTS
METERING
PIG LAUNCHER
Montebello Islands
WONNICH PIPELINE
Varanus Island
EAST SPAR PIPELINE
VARANUS FACILITIES:
USE EXISTING:
FLARE
TREATMENT - GAS
GAS EXPORT
UTILITIES
COMPRESSION
METERING
SEPARATION
CONTROL SYSTEMS
NEW:
SLUG CATCHER
ESD VALUE
Barrow Island
Taken from MD.m2973 Updated: 24 October 1996 IS.cc4028

Figure 2

Apache ENERGY

VARANUS ISLAND FACILITIES

March 1996

Updated 9 September 1996 JAC.m3899(p2)

Figure 3

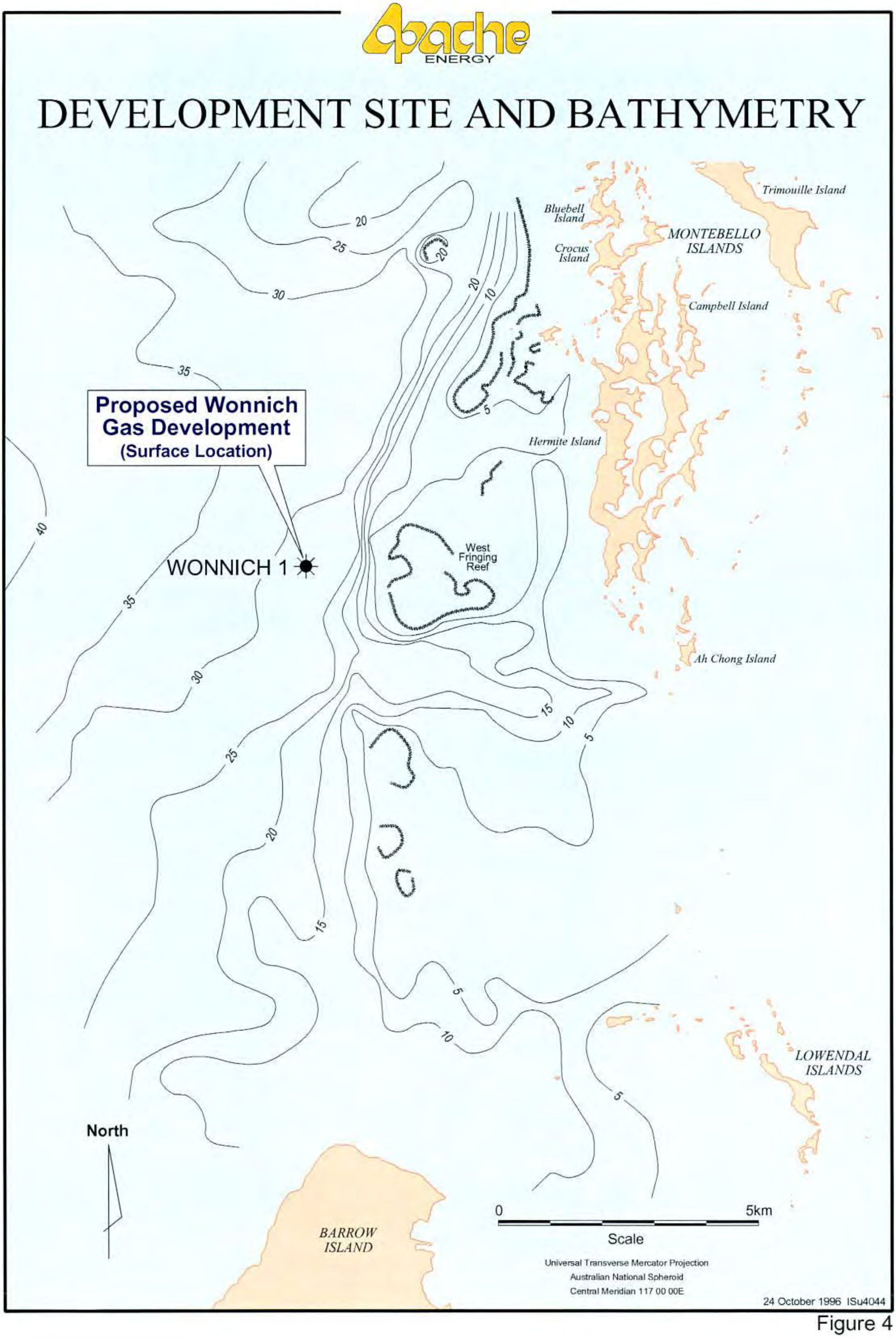

Apache
ENERGY
DEVELOPMENT SITE AND BATHYMETRY
Trimouille Island
Bluebell Island
Crocus Island
MONTEBELLO ISLANDS
Campbell Island
Hermite Island
Proposed Wonnich Gas Development
(Surface Location)
WONNICH 1
West Fringing Reef
Ah Chong Island
LOWENDAL ISLANDS
BARROW ISLAND
North
0
5km
Scale
Universal Transverse Mercator Projection
Australian National Spheroid
Central Meridian 117 00 00E
24 October 1996 ISu4044

Figure 4

2. PROJECT DESCRIPTION

2.1 History of Exploration and Development in the Montebello Region

The Montebello region is currently subject to various onshore and offshore petroleum production leases and exploration permits. The first exploration wells were drilled on Trimouille Island in 1967 by West Australian Petroleum Pty Limited (WAPET). WAPET has since produced in excess of 250 million barrels of oil from Barrow Island, some 25 km to the south of the Montebello Islands.

The first offshore exploration well drilled in waters adjacent to the Montebello Islands was in 1969 (Flag-1) followed by Tryal Rocks-1 and Campbell in 1979 (Figure 5). In license area TL/1, 5 & 6, and adjacent areas TP/8 and WA-192-P, which are geologically similar, there have been 48 wells drilled since 1982 without incident or significant oil spill.

Apache, its Joint Venture Participants and their predecessors, have been engaged in the exploration and production of oil and gas in license area TL/1, 5 & 6, which lies immediately to the south of TP/8, since 1983. The Harriet Field, located 8 km northeast of Varanus Island, was discovered in 1983 and brought into production in 1986. Light crude oil is produced from 14 wells tapped by three offshore platforms: Harriet Alpha, Bravo and Charlie. This oil is transported to Varanus Island via a subsea pipeline where it is stored in three 250,000 barrel tanks. The oil is transferred to tankers berthed at a deep water loading terminal and shipped to both Australian and overseas refineries as a source for petrol, diesel and aviation fuel.

Five relatively small gas fields were discovered between 1979 and 1995: Campbell, Bambra, Sinbad, Rosette and Alkimos. Production of gas from three of these fields was the basis of the Harriet Gas Gathering Project and allowed Apache to economically utilize gas which would otherwise have been flared.

Gas from the Campbell, Sinbad, Rosette and Alkimos fields, and associated gas from the Harriet oil field is processed in the Low Temperature Separation (LTS) Plant and is then transported via the Sales Gas pipeline to the mainland for domestic and industrial use.

Commencing in late 1996, gas and condensate from the East Spar field, located some 65 km to the west of Varanus Island will be processed at a dedicated plant located adjacent to Apache's facilities.

The production of oil and gas from the Harriet Joint Venture and East Spar Joint Venture is expected to continue into the next century.

2.2 Project Logistics

The proposed Wonnich gas development, located in TP/8, will encompass :

- installing an unmanned monopod;
- drilling two wells; and
- installing a pipeline to Varanus Island.

The installation of the prefabricated monopod at the Wonnich site will be the first stage in the development of the Wonnich Field. Once the monopod has been installed by the jack-up rig, the wells will be drilled through the allocated well slots. When drilling is complete and the wellheads have been positioned, the rig will jackdown and move away.

In conjunction with the construction of the monopod and drilling activities, the pipeline between the Wonnich gas field and Varanus Island will be installed on the seabed.

2.3 Location

The Wonnich gas development will be at a location immediately adjacent to Wonnich-1 and approximately 3 km from the southern sector of the Montebello fringing reef (Figure 4).

The seafloor at the proposed development site lies at a depth of 27 m and consists of limestone pavement that is either covered with sheets of mobile, coarse white calcareous sands, exposed, or thinly veneered and sparsely colonized with algae.

The nearest landfall to Wonnich is the rocky western shore of Hermite Island and lies approximately 5 km to the east of the fringing reef. There are two bays on the western side of the island, Wild Wave Lagoon and Turtle Lagoon, the latter supporting a small mangrove community which fringes the sheltered shoreline. The bays are located near to the northern end of the island, the closest, Wild Wave Lagoon, being about 12 km from the well site. The remainder of the shoreline is limestone cliffs.

2.4 Proposed Timetable

The gas development is scheduled to begin in April 1997. It is anticipated that the project will take 15 months between commencement of the project and commissioning of first gas.

2.5 Production Drilling

2.5.1 Program summary

The development drilling program details may be summarized as follows:

Surface hole location:	Latitude: 20° 30' 03.56" S Longitude: 115° 25' 39.93" E
Approximate water depth:	27 m
Number of wells:	Two, to be drilled from the same location
Well names:	To be advised
Types of wells:	Directional
Total vertical depth:	2300 - 2400 m
Approximate length of drilling period:	35 days
Type of drilling unit:	Jack-up rig *Maersk Victory*
Drilling fluid:	Petrofree™

2.5.2 Drilling logistics

The drilling rig to be used for the development program will be the self elevating, cantilever jack-up barge *Maersk Victory* (Figure 6). The barge is towed into position by one or two support vessels. When in position, the legs are jacked down to the seafloor and the barge raises itself approximately 15 m above the sea surface, supported by the legs which bear down on the sea floor.

The one or two support vessels which will tow and position the rig will also supply the rig with fresh water, food, fuel, bulk drilling fluid materials and drilling hardware. These vessels will operate between the rig and the Port of Dampier. Another vessel will stand by the rig to act as the oil spill response vessel providing a rapid response in the unlikely event of a spill of hydrocarbons.

The drilling rig and support vessel crews will be accommodated aboard their respective vessels. Crew changes will involve transfers by helicopters to and from Karratha Airport.

2.5.3 Drilling procedures

The proposed directional profiles for the wells are shown in Figure 7.

Generally, a 36 inch hole is first drilled with seawater (90%) and clay (10%) to a depth of about 25 m below the seabed and a 30 inch conductor casing is installed into the hole. The casing is cemented into position and a riser and diverter are attached to allow drilling fluid recirculation and well control. Drilling then continues in a 17½ inch hole with the next string of casing set at approximately 1,100 m.

Deeper hole drilling will utilize the ester-based drilling fluid Petrofree™. After cementing of this casing, a Blow-Out Preventer (BOP) will be installed and the casing tested. Drilling of the well then continues to total depth with casing strings of decreasing diameter being set and cemented to allow the control of formation pressure and well bore instability. After the cementing of each casing string, the casing and the BOP is pressure tested before drilling continues.

Formation pressures within the well bore and the volume of returned drilling fluid are continuously monitored. If a flowing formation is intercepted, the drilling fluid density is increased proportionately to provide primary well control. The BOP is used to seal the well in the rare event of a surface blowout.

At the completion of drilling each well, electric logging tools are run over the length of each well to evaluate the reservoir. The development well is then lined with production casing which is cemented into place. The well is completed by installing production tubulars and downhole isolation valves, and placing a Christmas tree of isolation valves atop the well head.

2.5.4 Safety precautions

Before drilling operations commence on each well, routine precautions will be undertaken by the drilling contractor to ensure the stability of the drilling rig and to minimize the risk of movement during storm conditions. Previous drilling at Wonnich-1 and monopod installation in the adjacent production license area have provided information on the nature and stability of the seabed and the underlying strata, particularly with respect to the expected depth of penetration by the rig legs. The positioning and jack-up operation will be closely supervised by the drilling supervisor, rig supervisor and vessel skippers.

During drilling, a 500 m radius temporary exclusion zone around the rig will be declared under legislation and gazetted accordingly. The few vessels that do operate in these waters will be informed on approach by radio about the exclusion zones applying around the rig.

The well will be designed and engineered to standards approved by DME to ensure that well pressures remain under control. Annular, ram and drill string BOPs will be used. A typical BOP stack design system would incorporate the following:

- double 'U' ram, 10,000 psi working pressure;
- single 'U' ram, 10,000 psi working pressure; and
- an annular preventer, 5,000 psi working pressure.

The BOP system will be able to contain pressure far in excess of pressures encountered at Wonnich-1 (3,308 psia) or generally found in the Carnarvon Basin.

Casing sizes and lengths and the intervals where the hole is cement-sealed around the casing will be selected to maximize well control. Experience gained from Wonnich-1 and the numerous wells previously drilled in the vicinity will facilitate well design. Well design is conservative to ensure a margin of safety to control any higher than expected pressures.

An Emergency Response Manual and an Oil Spill Contingency Plan, both detailing safety procedures in the event of an accident or emergency situation, will be submitted for approval to DME as required by legislation as part of the approval to drill the wells. Copies of the Emergency Response Manual and Oil Spill Contingency Plan are introduced in the Environmental and Safety induction process and are made available to crew members prior to the commencement of any work.

2.6 Production Facilities and Pipeline

The proposed Wonnich production platform will be of similar design to Apache's existing unmanned Sinbad structure (Figure 8). Details of this monopod are provided below as a guide.

The Wonnich platform will be located approximately 8 km to the west of Hermite Island. The monopod will be tied back to the existing facilities on Varanus Island, will be designed for automatic operation by telemetry from the island (Figure 2) and will be unmanned except during routine maintenance or well wireline work.

The sub-structure will be based upon a braced monopod design. The topside will have four decks: a cellar deck, mezzanine deck, production deck and helideck. The total height would be at about 29 m above mean sea level.

It is anticipated that two wells will be used for production, although the platform would have provision for up to five wells. Well conductors and risers will be routed within the main caisson and pass to the following topside process facilities:

- well head and christmas trees;
- flowlines and manifolds;
- test separator;
- export riser;

- Emergency Shut Down (ESD) valve;
- fire detection and shut down system; and
- pig launcher.

Other facilities on the monopod will include:

- thermo-electric generators and solar panels;
- crane and associated lay-down area;
- chemical injection drums/pumps; and
- personnel safety systems including life-rafts, life buoys, escape ladders etc.

Reservoir fluids can generally be divided into hydrocarbon and non-hydrocarbon fluids. Hydrocarbons fluids include dry gas, gas-condensate and black oil while non-hydrocarbon fluids encompass produced formation water.

A gas-condensate reservoir fluid is a hydrocarbon system that is totally gas in the reservoir. As the hydrocarbon travels from the reservoir to surface, it undergoes changes in pressure and temperature, with possible accompanying change in phase. Upon a decrease in pressure and temperature, the heavier hydrocarbons present in the reservoir condense at the surface to form a free liquid phase (condensate). The Wonnich field is primarily a gas-condensate reservoir which is why gas and associated condensate is produced.

The test separator on the monopod will allow individual metering of the gas and condensate components of the production fluids. Typical flow rates may be:

- gas, 20,000 standard m^3 per hour per well;
- condensate, less than 2 kL per hour per well.

All fluids will be co-mingled for export via a pipeline to Varanus Island for separation and processing (Figure 9). The gas will be compressed into the existing Low Temperature Separation (LTS) Plant on Varanus Island and incorporated into the Sales Gas pipeline to the mainland. The condensate will be stored within the bulk storage tanks located on Varanus Island for loading to tankers via an existing offshore loading facility.

Leak detection systems will be linked to ESD valves to automatically shut down the flow of gas and condensate. These systems are designed to instantaneously isolate any leakages either downhole, topside, or both.

The main chemicals stored on the monopod will be corrosion inhibitors. Typical storage volumes would be 600 L and this would be stored in a chemical bund draining to a sump via an underflow weir. This system prevents rainwater flushing spillages from the bund into the marine environment.

Typical manning of the platforms during normal operations is a two hour visit by a three person crew at a rate of three visits every two weeks (based on recent operating conditions at Apache's other monopods). During wireline work, a crew of up to six would be on board for a full shift every day of the work (typically 4-5 days). Transport of personnel and equipment to the rig will normally be by vessel, although helicopters may also be used. Regulatory navigation lights with low emission energy will be used and there will be no routine gas flare.

2.6.1 Installation sequence

The platform substructure is proposed to be installed utilizing a jack-up rig. The installation sequence will be:

- position the jack-up rig adjacent to the Wonnich-1 wellhead;
- transport substructure to site and offload from supply vessel or barge utilizing the jack-up rig;
- upend and position substructure;
- pile foundations into the seabed and grout into place;
- transport topside to site and offload from supply vessel or barge utilizing the jack-up rig;
- lift and weld topside to substructure; and
- complete installation of process facilities.

2.6.2 Safety precautions

A detailed Basis of Design (BOD) will be prepared for all facilities and will provide the operators requirements. The BOD will include:

- load criteria - i.e. dead loads, live loads, environmental loads;
- design codes;
- process and utility design criteria;
- operating requirements; and
- safety system requirements.

All documentation, including the BOD will be reviewed and approved by the DME prior to commencement of installation.

2.6.3 Process description

Only minor additions will be required to the existing process facilities on Varanus Island. The additional equipment which will be placed within the present facilities site include an ESD value, slugcatchers, pig receivers and tie-in facilities to the existing LTS plant.

TP/8 PERMIT AREAS AND WELL SITES

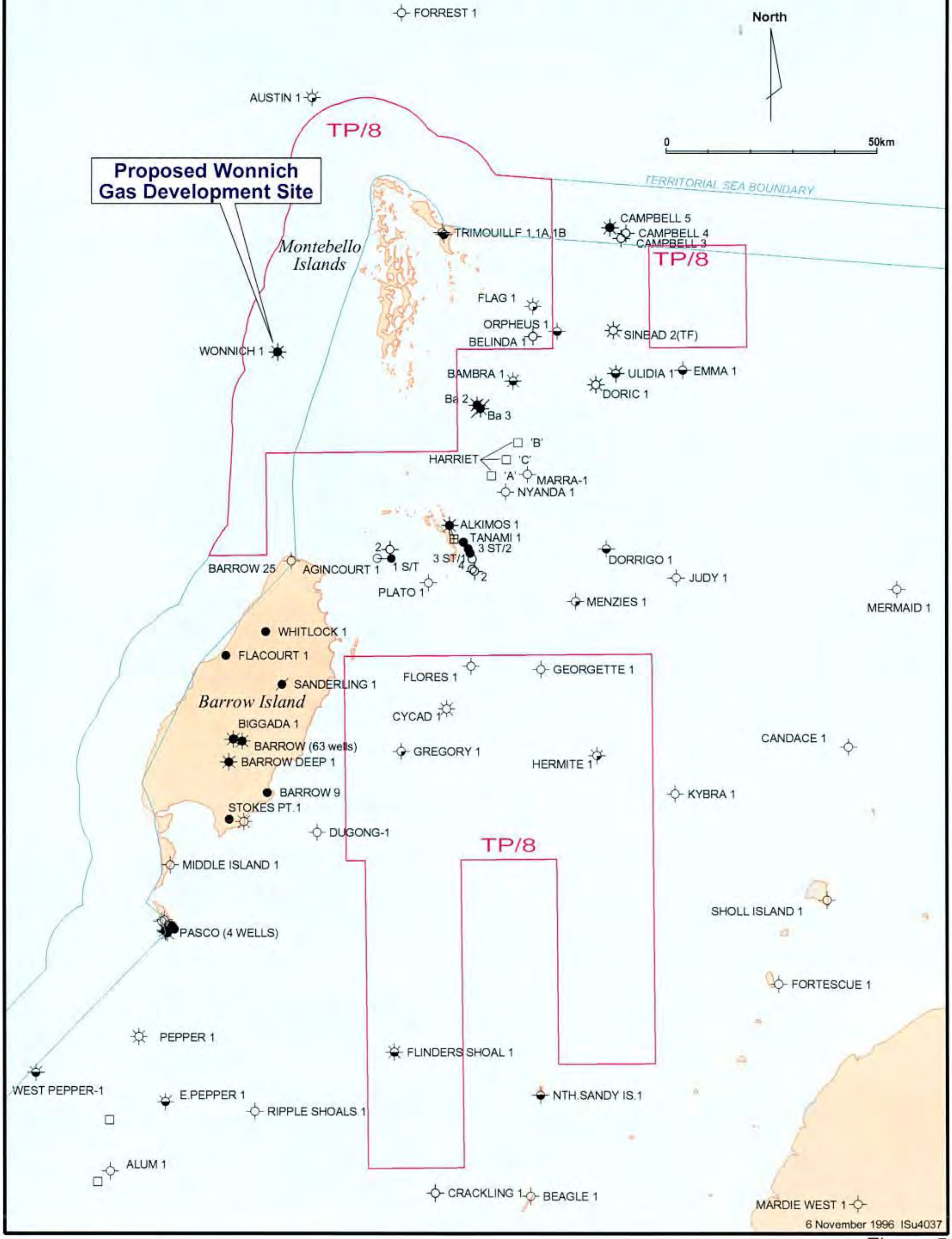
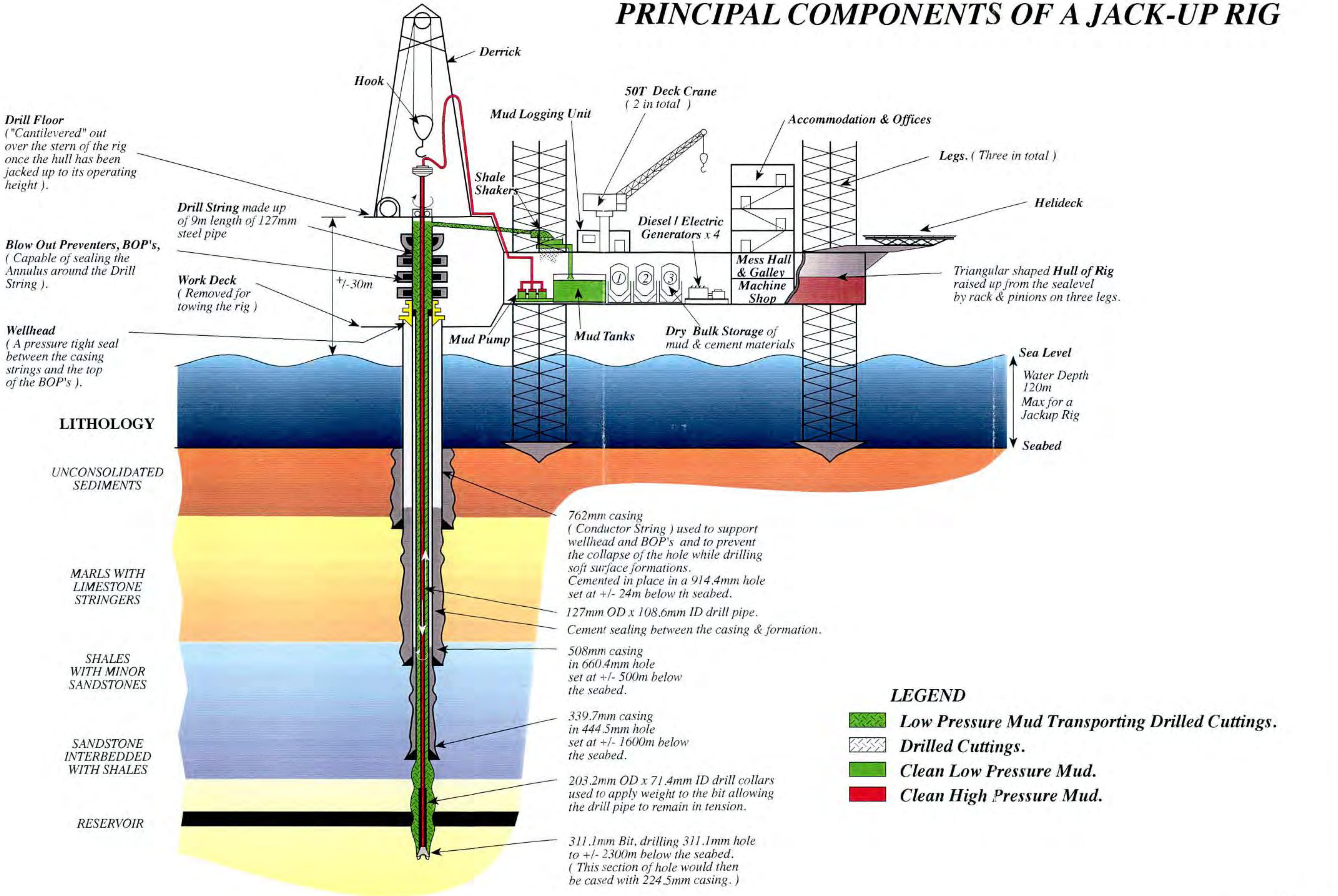


Figure 5

PRINCIPAL COMPONENTS OF A JACK-UP RIG



NOT TO SCALE

Date: 18 October 1996 IS.cc4030

Figure 6

Wonnich Gas Development

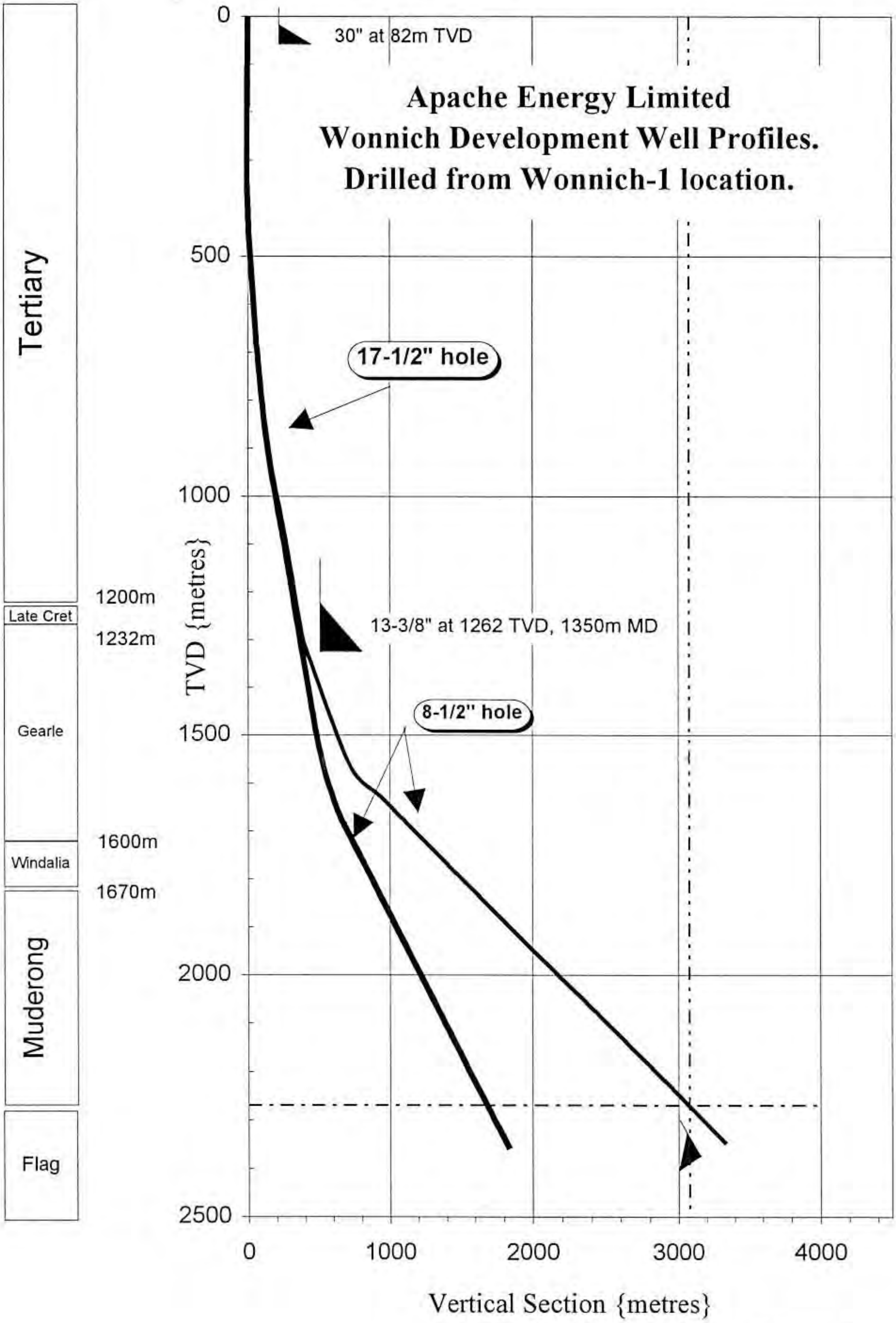
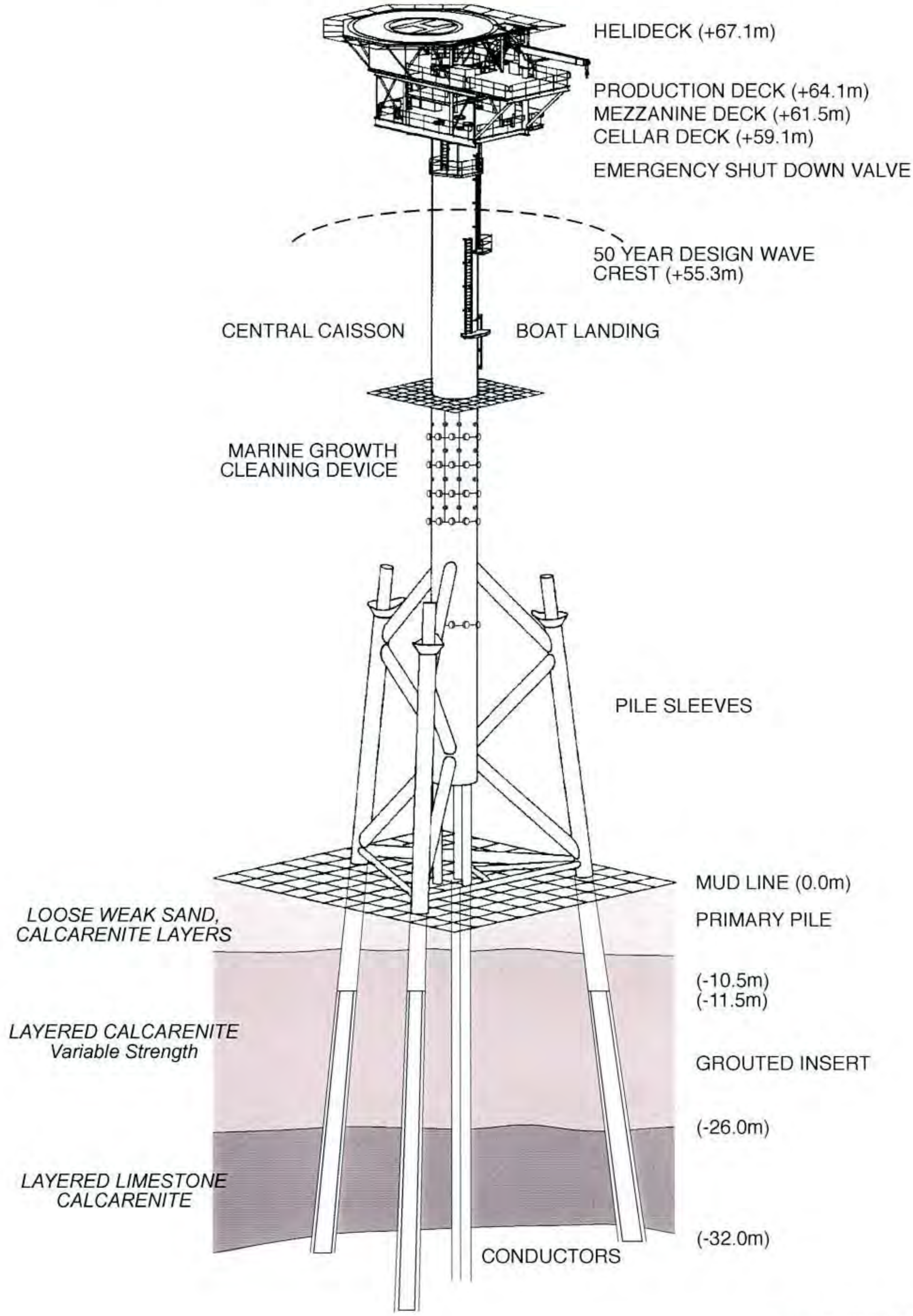


Figure 7

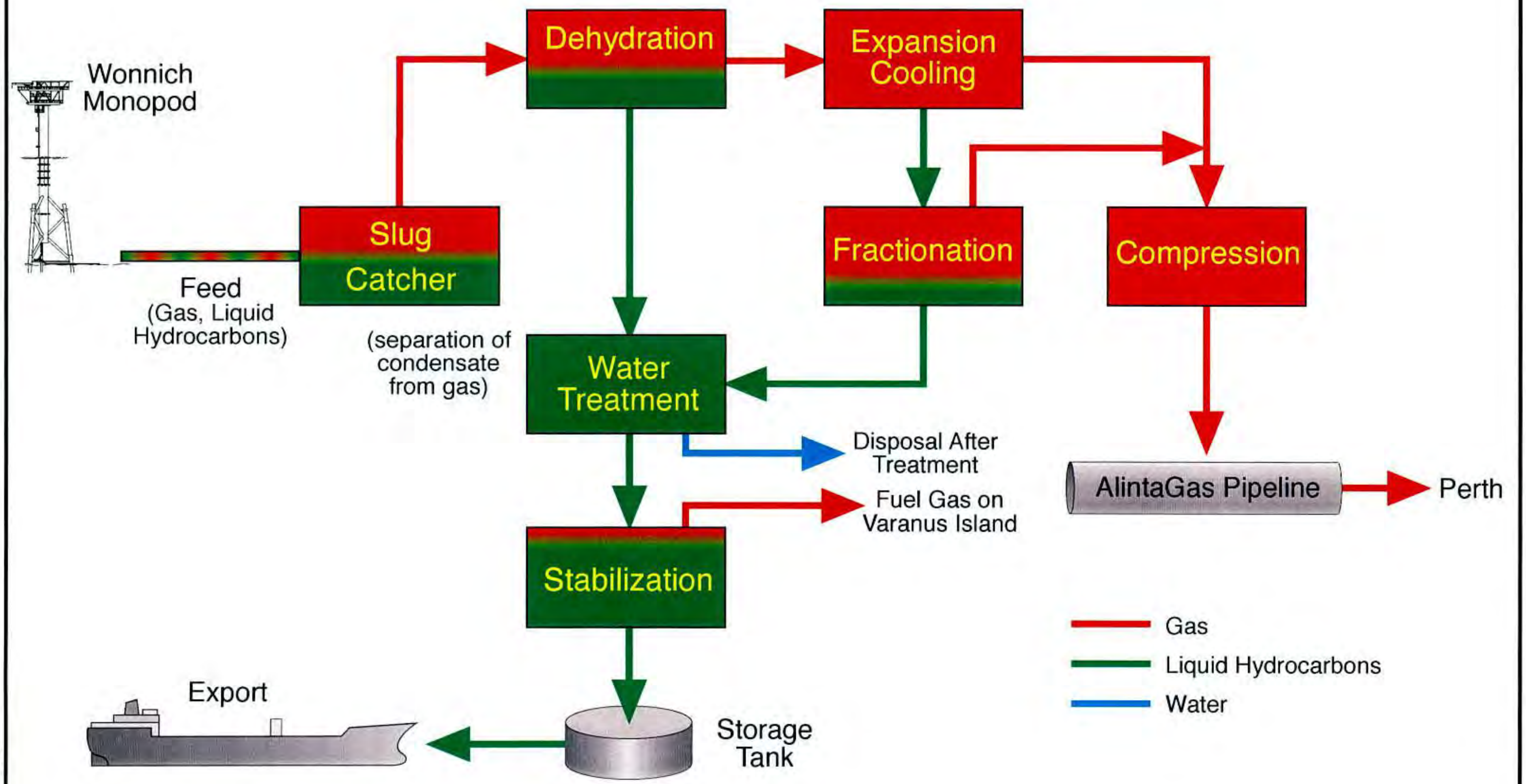
MONOPOD PRODUCTION PLATFORM SCHEMATIC



Updated 24 October 1996 IS.m399

Figure 8

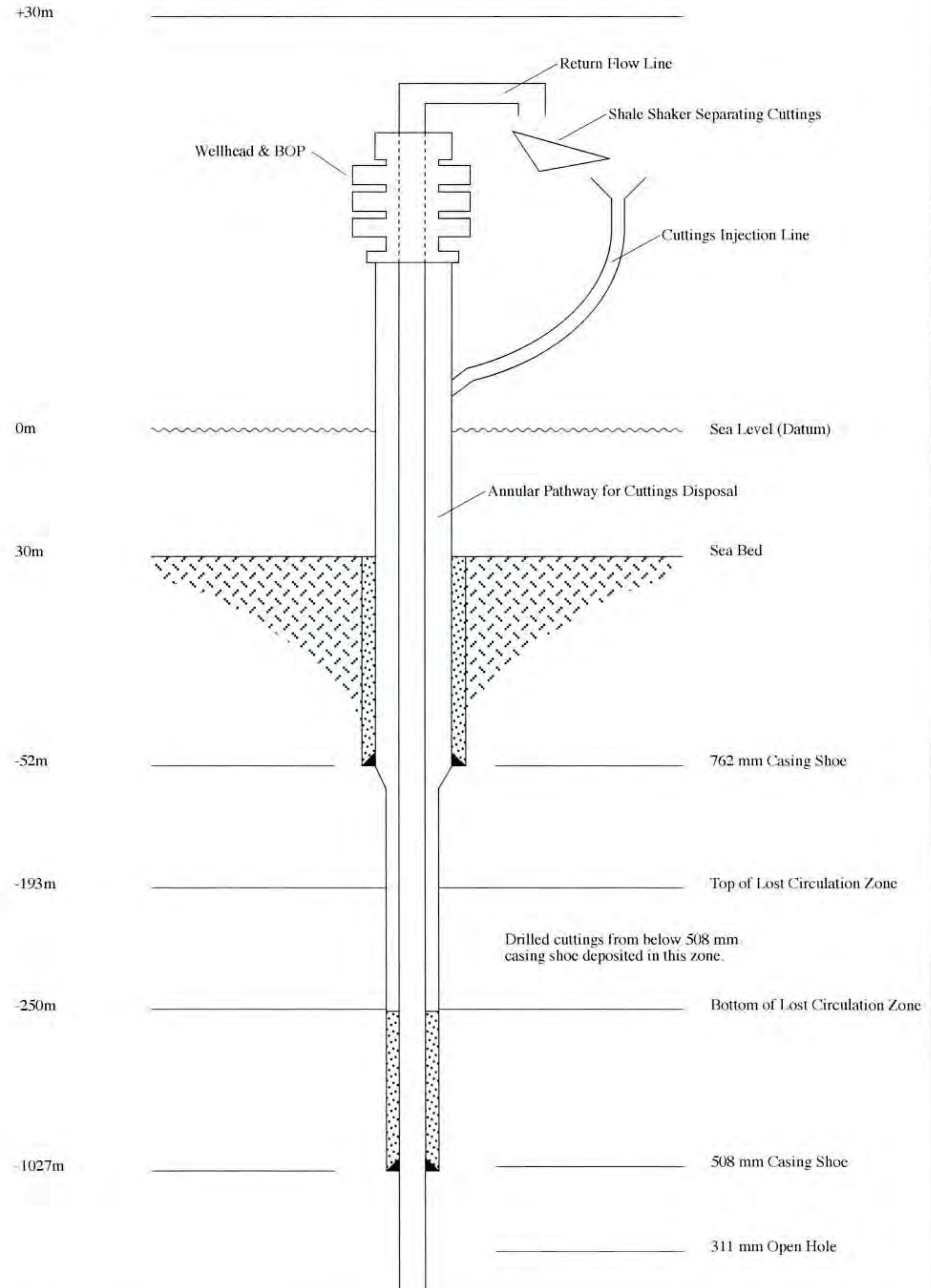
SIMPLIFIED SCHEME OF LOW TEMPERATURE SEPARATION PROCESS



Updated 24 October 1996 IS.m403

Figure 9

DISPOSAL OF CUTTINGS
TO THE WELL ANNULUS



Updated 24 October 1996 IS.m4031

Figure 10

3. ENVIRONMENTAL ANALYSIS OF ROUTINE OPERATIONS

A description of the natural, commercial, industrial and social resources of the area surrounding the Wonnich gas development site is given in Appendix 3.

This section of the report describes the types of routine activities associated with the drilling and production operations, their potential effects and the mitigating actions which will be put into place.

3.1 Production Drilling

Current plans for the development of the Wonnich gas field require the drilling of two production wells using the cantilever jack-up drilling unit *Maersk Victory*. An overview of the actual effects of routine activities and their proposed management is given in Table 1.

3.1.1 Physical activities

Rig positioning and anchoring

The two sources of physical impact associated with drilling operations are caused by the imprints on the seabed by (1) the legs of the drilling rig and (2) the anchor moorings for the support vessels.

The weight of a jack-up drilling rig results in the formation of a depression in the seafloor at each of the sites where the legs are positioned. The area and depth of the leg imprints into the seafloor will be dependent on the weight of the rig and the substrate type. From past experience, the area of each of the depressions at the Wonnich site will be approximately 175 m^2. Once the drilling rig is moved from site, the leg depressions will act as traps for marine detritus and sand. These depressions will eventually fill and therefore the effect is temporary as recolonization by benthic organisms will be rapid.

The support vessels will use normal anchors while on standby by the drilling rig. Anchoring will be confined to sandy bottoms and will not be allowed on coral reefs or in the vicinity of known shipwreck sites.

Artificial lights

Due to safety regulations, lights on the drilling rig must be kept alight 24 hours per day. These lights are an attractant to marine life and seabirds, and depending on the foraging range of the particular species may result in a short-term concentration of animals in the immediate vicinity of the rig.

Noise

Drilling activities, machinery, helicopters and boat engines will cause noise during the drilling operation. However, the impact of noise to resources such as birds will be minimal due to the distance of the Wonnich field from the adjacent islands.

Helicopters servicing the rig will be instructed to remain at least 1 km offshore from the islands as they fly to and from the rig to avoid disturbing adult or fledgling birds which may be present. No personnel will be allowed to land on any of the islands unless permission is given by the Department of Conservation and Land Management (CALM).

TABLE 1: Environmental Analysis of Impact
Production Drilling - Wonnich Gas Development

Description	Source	Quality/ Composition	Quantity	Treatment and/or Discharge Point	Predicted Environmental Effects	Mitigating Actions
Physical Activities						
Positioning of rig	Three legs of drilling unit.	Formation of three depressions into seabed.	175 m^2 each.		Will cause some disruption and suspension of bottom sediment. Legs will act as traps for detritus and sand. Will eventually fill with sand and become recolonized.	Minimal damage expected due to hard (limestone) seabed.
Anchoring	Rig and supply vessels.		Two anchors.		Anchoring will be confined to sandy bottom and will cause negligible disturbance.	Anchoring guidelines will be in place to ensure that no anchoring will occur on coral reefs or bommies.
Artificial lights	Lights on rig.	Fluorescent lights meeting safety standards.			Lights are an attractant to marine life and some birds. May result in a concentration of these animals over the short period of the drilling program.	Lights must be left on at all times due to safety regulations.
Noise	Helicopters, engines etc.		One flight per day three times a week.		Negligible. Helicopters land and take off routinely from Varanus Island.	Helicopter path is predominately over water.

Table 1 cont.

Description	Source	Quality/ Composition	Quantity	Treatment and/or Discharge Point	Predicted Environmental Effects	Mitigating Actions
Solid and Liquid Wastes						
Drill cuttings	Rock chips cut out of formation by drill bit.	Coarse to fine rock and sand chips.	200 m^3	First 20 m^3 will be deposited onto the seabed adjacent to the well. The cuttings from the remainder of the well will be discharged down the annulus into the lost circulation zone.	Local concentration of cuttings will result in the smothering of seabed flora and fauna. Extent of impact, given quantity of cuttings, should be no greater than 10m diameter around well. Recolonization will be rapid.	Cuttings from the 36" hole are discharged onto the seabed minimizing spreading and turbidity plume.
Drilling fluids	By-product of drilling operations.	Ester based fluid.	Zero to ocean.	Residual fluid will be discharged down annulus.	Negligible. Some residual fluid will be retained on the cuttings, but these will be discharged into the lost circulation zone.	Solids control equipment will be optimized to ensure maximum separation of fluid from cuttings and minimum loss of fluid. Equipment routinely checked to ensure no spillage.
Cooling water	Diesel fueled power generators.	Temperature slightly above ambient seawater (~3 °C).	200 m^3 per day.	Discharge above sea level.	Negligible. Water will be cooled and oxygenated upon discharge.	Water will be discharged at barge level (~15m above sea level) to facilitate cooling and oxygenation.

Table 1 cont.

Description	Source	Quality/ Composition	Quantity	Treatment and/or Discharge Point	Predicted Environmental Effects	Mitigating Actions
Oil contaminated drainage water	Deck drainage, drainage from machinery spaces.	Water containing hydrocarbons.	Variable.	Oily discharges collected via a closed drainage system, treated to statutory limits using separation equipment, treated water discharged to sea, oil recycled.	Negligible. Very low concentration of hydrocarbons which will evaporate and dissipate very rapidly.	Separation equipment has automatic shut down capability if oil content exceeds statutory limit.
Galley wastes	Kitchen wastes.	Putrescible wastes.	Variable.	Putrescibles are macerated to statutory size prior to discharge to sea.	Negligible. Rapid dilution will ensure that nutrification will not occur.	Separation of putrescible wastes from solids (i.e. tins cans) by using clearly marked bins in the galley.
Sewage, gray water	By-product of habitation (~70 people).	Will contain dishwashing detergent, soap.	6,000 L per day.	Treated via the sewage treatment plant and discharged above sea level.	Negligible. Detergents will break down rapidly and dilution will ensure nutrification will not occur.	Biodegradable soaps to be used on the rig. Sewage treatment plant to be maintained to ensure effective treatment.
Waste oil	Machinery.	Hydraulic and lubricating oils.	Variable.	Used oil contained in drums and returned to mainland for recycling.	None.	Drums containing oil will be stored within a bunded area on the rig until transport to the mainland for recycling.
Solid wastes	By-products of drilling activities.	Paper, wood, steel, plastic containers.	Variable.	Landfill or recycling.	Negligible.	Waste will be segregated on the rig into clearly marked skips for appropriate waste disposal method.

Table 1 cont.

Description	Source	Quality/ Composition	Quantity	Treatment and/or Discharge Point	Predicted Environmental Effects	Mitigating Actions
Pipe dope	Sealant, lubricant, cleaning of pipestring.	Heavy metals, grease.	50 L per well.	Retained on drill cuttings.	Negligible. Pipe dope is amalgamated with the drill fluid and cuttings which will be discharged down the annulus.	Use pipe dope which has lowest concentration of heavy metals and hydrocarbons, is biodegradable, but still meets safety and performance criteria.
Others						
Fishing	Workforce.			None.	Negligible.	No fishing is allowed from the drilling rig or supply vessels.
Atmospheric emissions	Fuel burning equipment.	Combustion products.	Variable, depending on fuel usage. On average, 10,000 L fuel used per day.	Atmosphere.	Negligible.	Engines will be tuned to run at the most efficient capacity to minimize volume of emissions.

3.1.2 Liquid and solid wastes

Drill cuttings

Drill cuttings are crushed rock particles generated by the drill bit and brought to the surface in the drilling fluid. These inert rock particles vary in size from silt to gravel.

During the drilling of the 36" hole, the drill cuttings will be deposited on the seabed adjacent to the well. The volume of cuttings will be about 20 m^3. No drilling fluid is used for this section: only seawater and clay are used.

In the section of the well between the base of the 36" hole and the bottom of the second hole section (up to 1,100 m deep), no drill cuttings are returned to the surface as the cuttings and fluid are lost in the porous formation (lost circulation zone).

The drill cuttings and fluid from the deeper sections of the wells, which are eventually brought to surface, are separated through the solids removal equipment on the rig. The treated cuttings will be reinjected down the annulus of the well and not discharged onto the seabed (Figure 10).

Drilling fluids

Drilling fluids perform a number of functions, including carrying cuttings to the surface, providing hydraulic power to the drill bit, exerting a hydrostatic head to prevent caving or sloughing of the formation, preventing flow of formation fluids into the borehole, and preventing kicks and blowouts (Hinwood *et al.* 1994).

To protect the environment and at the same time meet the technical requirements of the drilling program, Apache proposes to use Petrofree™, a palm oil formulation based on non-aromatic esters. It contains no toxic aromatic hydrocarbons, is biodegradable under both aerobic and anaerobic conditions, and does not bioaccumulate (Appendix 4). Drilling fluids based on esters are alternatives to water-based and oil-based drilling fluids. In situations where the geological formation can result in hole instability due to the angle of drilling, ester based drilling fluids are commonly used.

Drilling fluid will not be discharged into the marine environment during the development drilling program. Petrofree™ will be separated from the cuttings via the solids control equipment and returned to the manufacturer in Dampier for reuse. Only a minor amount of fluid will be retained on the drill cuttings and this will be discharged down the annulus of the well.

Cooling water

Seawater is used as a means of cooling machinery on the drilling rig. No chemical inhibitors or chemicals are added to the cooling water. The temperature of this water will be 1-3°C higher than the ambient seawater, but this is cooled and re-oxygenated as it falls from its discharge point at rig deck level (~ 15 m above sea level) into the ocean.

Deck drainage, waste oily water and waste oil

Deck drainage consists mainly of washwater from cleaning the decks and occasionally rainwater. It may contain small amounts of spilt oil, cleaning chemicals and paint chips.

Deck drains on the rig where machinery is present and where cleaning solvents will be used will be a closed unit. All runoff will be collected in a sump connected to an oily water separator. The water will be separated from the oil to levels meeting the Western Australian Government *Petroleum (Submerged Lands)* Act 1982 statutory guidelines: oil in water concentration will not exceed 50 mg/L at any one time or an average of 30 mg/L over any

24 hour period. Once separated, the oil will be transferred to drums and returned to shore for recycling. The treated water will be discharged to the ocean.

The oily water separator on the rig has an automatic alarm and shutdown system if the oil levels in the treated water are above 30 ppm.

Waste oil (e.g. lubricating oil) is generated by machinery. The used oil is collected, stored within designated bunded areas and transported to shore for recycling.

Domestic wastes

Sewage, gray water from showers and laundry, and food scraps constitute the domestic waste generated on the drilling rig. Seawater is used in the toilets and fresh water is used for the bathrooms and the galley.

Sewage is treated through a sewage treatment plant which utilizes aeration to enhance biological breakdown prior to discharge to the ocean. The treated sewage stream is discharged with the seawater cooling water which dilutes the treated sewage more than 100 times prior to reaching the ocean. Further dilution is achieved once this combined water disperses in the ocean.

Food wastes are macerated prior to being discharged overboard and all other kitchen wastes are bagged and disposed onshore at an appropriate landfill site. Kitchen, shower and laundry water are discharged directly overboard. Biodegradable soaps, cleaning and laundry powder are used.

Solid wastes

Solid wastes are generated during routine human and drilling activities. This waste includes paper, scrap steel, metal, packaging, etc.

All solid wastes are segregated into marked skips prior to disposal onshore at an appropriate site.

Drums and scrap metal are re-used or recycled, and non-reusable solids are disposed of onshore at an appropriate landfill site.

Pipe dope

Pipe dope is used as a sealant and lubricant between the drill pipe threaded connections. It consists generally of grease and may contain traces of heavy metals (e.g. zinc and lead) to provide the required lubricity. Approximately 25 L of pipe dope may be used during the drilling of a two-week well.

The pipe doping with the lowest concentration of heavy metals and hydrocarbons, but which will still meet safety and performance criteria, will be used. No pipe doping will be discharged into the seabed as it will become amalgamated with the drilling fluid and cuttings which will be reinjected into the annulus of the well.

3.1.3 Atmospheric emissions

Greenhouse gases, the principle being CO_2, will be generated during the drilling program by machinery and engines. To minimize the production of emissions, all engines will be tuned to maximum efficiency.

3.1.4 Summary of the effects of routine operations during drilling

The overall effects of the drilling program on the marine environment are expected to be minimal and confined to the immediate vicinity of the drilling rig.

The effects of drilling on the physical environment will be confined to the footprints left by the rig. This will be a temporary effect as the footprints will be recolonized rapidly with a similar range of organisms to those present before drilling.

The discharge of a small volume of drill cuttings will cause short-term, localized turbidity, and the burial of some biota. The high energy of the open ocean will disperse these materials quickly and recolonization will be rapid.

The nearest landfall is Hermite Island, located some 8 km to the east of the drilling location. Noise and light from the rig are not likely to impact any birds or marine fauna. Marine fauna, such as whales, dolphins and turtles may avoid the rig during the drilling operations, but otherwise will not be affected.

Domestic waste consisting of sewage, kitchen, shower and laundry water will be rapidly dispersed in the open ocean conditions and will not contribute to excess nutrient input or eutrophication.

The area in which the Wonnich drilling program is located is not used for commercial finfish purposes and consequently will not have any impact on these activities.

3.2 Production Facilities

The Wonnich gas development scenario will be virtually a closed system with negligible discharge of routine effluents into the marine environment: only very small quantities of treated sewage will be discharged and this may occur twice a month, depending on maintenance requirements. All other fluids will be separated and processed through the existing facilities on Varanus Island.

The environmental analysis of the impact of production activities on the environment is presented in Table 2.

3.2.1 Physical activities

Monopod positioning and installation

The primary physical impact will be from the positioning and installation of the monopod. This structure will be in place for the life of the project, thereby becoming a permanent feature of the area for the life of the project (10-15 years).

Installation of the monopod will result in the localized disturbance of the seabed sediments and associated seabed flora and fauna, and an increase in the turbidity of the surrounding water. However, the increase in turbidity will be short term lasting only during the installation phase which will take about two weeks. Disturbed sediments around the monopod will become rapidly stabilized and recolonized.

The monopod may become encrusted with marine organisms because it will form a hard substrate on a mobile, sandy seabed. This may be of beneficial use as it will provide an artificial reef for various types of marine life. Fish are attracted to these structures because they provide protection and access to food resources which would otherwise not be available (Kasprzak & Perret 1996; Black *et al.* 1994).

Some maintenance work involving the removal of encrusting organisms on a regular basis may be necessary to maintain the integrity of the structure.

Artificial lights

Only small navigation lights will be present on the monopod, and will be required to be kept on during the night.

TABLE 2: Environmental Analysis of Impact
Production Activities - Wonnich Gas Development

Description	Source	Quality/ Composition	Quantity	Treatment and/or Discharge Point	Predicted Environmental Effects	Mitigating Actions
Physical Activities						
Installation and positioning	Positioning and installation of monopod.	Burial of seabed flora and fauna. Loss of small area of seabed from base of monopod.			Installation may cause short term increased water turbidity. Structures will become permanent features over the life of the project. Installations will provide artificial reef for various types of marine life.	None required. Turbidity of water will be short-term and localized.
Artificial lights	Lights on monopod.	Red and green navigational lights.			Negligible.	Lights must be left on at all times due to safety regulations.
Anchoring	Supply vessels.		1-2 anchors.		Negligible as anchoring will be confined to sandy seabed.	Anchoring guidelines will be in place to ensure that no anchoring will occur on coral reefs or bommies.
Noise	Machinery, helicopters, vessels.	Low humming drone.			Behavioural responses resulting in the avoidance of the immediate area by some individuals.	None required as noise will not result in physical harm or mortality of animals.

Table 2 cont.

Description	Source	Quality/ Composition	Quantity	Treatment and/or Discharge Point	Predicted Environmental Effects	Mitigating Actions
Solid and Liquid Wastes						
Contaminated drainage water	Drainage from machinery spaces.	Water containing hydrocarbons.	Variable.	Oily discharges collected via a closed drainage system and purged into pipeline.	Negligible. No contaminated water should reach main deck areas.	Machineray areas bunded and closed areas.
Sewage	By-product of human activities.	Sewage.	Small.	Sewage collected in portable toilets. Taken to Varanus Island for treatment.	None as sewage will be collected in portable toilets and not discharged into the ocean at site.	Sewage treatment to be carried on using Varanus Island treatment plant.
Waste oil	Machinery.	Hydraulic and lubricating oils.	Variable.	Used oil contained in drums and returned to mainland for recycling.	None. All machinery located in bunded areas.	Drums containing oil will be stored within a bunded area on the rig until transport to the mainland for recycling.
Solid wastes	By-products of production activities.	Paper, wood, steel.	Variable.	Landfill or recycling.	Negligible.	Waste will be taken to Varanus Island and segregated for the appropriate waste disposal method.
Corrosion and scale inhibitors	Production facilities.	Primarily phosphorous and nitrogen based.	Unknown at this time.	Amalgamated as component of gas-condensate stream.	Negligible as it will be retained within a closed system.	Quantity of inhibitor used not to exceed the volume necessary to carry out the job.

Table 2 cont.

Description	Source	Quality/ Composition	Quantity	Treatment and/or Discharge Point	Predicted Environmental Effects	Mitigating Actions
Others						
Fishing	Workforce.			None.	Negligible.	No fishing is allowed from the drilling rig,, monopod or supply vessels.
Atmospheric emissions	Fuel burning equipment, flaring of gas, emergency venting.	Combustion products, mainly CO_2.		Atmosphere.	May contribute small amount to total greenhouse loading in atmosphere.	Engines will be tuned to run at the most efficient capacity to minimize volume of emissions.
Ozone depleting substances	Fire fighting system monopod.	Halons	Unknown at present as quantity dependent on type of system.	Atmosphere.	Contribution to ozone depleting substances load in atmosphere.	Regular inspections and tests for leaks. Used only in emergencies.
Decommission of platform	Removal of monopod at end of field life.	Monopod		Removal, resuse and recycle.	May diminish created habitat for marine organisms. Short term turbidity during removal of structure.	No explosives will be used for removal. Cutting will be made by mechanical means.

Noise

Machinery on the monopod, helicopters and supply vessels will cause noise. However, the impact of noise on resources such as marine mammals, turtles and birds will be minimal due to the distance of the Wonnich gas development from the adjacent islands and the monopod being unmanned. It is known that turtles and some marine mammals come close to production units for a short period of time and then move away.

Quarantine

No access will be allowed onto the Montebello Islands during the installation of the monopod unless permission is given by CALM. This is to prevent the introduction of non-native plants and animals to the islands.

3.2.2 Liquid and solid wastes

Produced water

An insignificant amount of produced formation water, the fossil water associated with hydrocarbon reservoirs, will be generated during the life of the Wonnich gas development. No significant, recordable produced water volumes are likely to occur until the last years of the production. Large quantities of formation water reduces the gas production rates from the wells making the project non-operational and uneconomic. This is because the wellhead pressure would decline to a point where flow into the pipeline would not be possible.

Deck drainage and waste oil

There will be zero discharge of any drainage into the marine environment from the monopod. All deck drainage, including drains in areas where machinery is present and where cleaning solvents are used, will lead to blind sump drains. The drainage material collected in these sumps is stored in a vessel and periodically purged into the pipeline. Separation of any liquid materials is carried out on Varanus Island.

The small amounts of waste oil generated by machinery will be collected, drummed and sent onshore for recycling.

Domestic wastes

Sewage will be collected in portable toilets and treated on Varanus Island. As this is an unmanned platform, minimal sewage and no gray water or food wastes will be generated.

Other liquid chemicals

Corrosion inhibitors may be used to prevent corrosion and build-up of microbial growth and aid leak detection. Any residual inhibitor will be incorporated into the gas and condensate stream.

Any other liquid chemicals and wastes stored on the monopod will be clearly marked, placed on pallets and within a bunded area.

Solid wastes

No routine solid wastes will be generated during the operation of the monopod. Waste materials such as paper and packaging materials produced during maintenance work will be bagged and taken back to Varanus Island for segregation and proper disposal.

3.2.3 Tanker traffic

There will not be an increase in the frequency of tanker activity into the Varanus Island offloading terminal as the small volumes of Wonnich condensate will only be replacing some of the declining Harriet oil field production.

3.2.4 Atmospheric emissions

There will be no flaring associated with the Wonnich gas development because all the gas will be processed for sales gas. Small quantities of Wonnich gas will be burned in thermo-electric generators located on the monopod and which are used to provide back-up power.

3.2.5 Decommissioning

Decommissioning is the process of planning, gaining approval and implementing the removal, disposal or re-use of an installation when it is no longer needed for its current purpose.

Under the Western Australia *Petroleum (Submerged Lands) Act* 1982 (Section 107), the licensee may be directed to do any of the following:

- remove all property brought into the lease area or make arrangements that are satisfactory to the Minister with respect to the property;
- plug or close off all wells;
- make provision for the conservation and protection of the natural resources; and
- make good any damage to the seabed or subsoil of the area.

Apache is committed to the restoration of property at the end of the Wonnich gas development. At the end of the field life, the wells will be plugged and the casing cut just below the level of the seabed. The topside section will be removed and taken away for recycling and disposal. The pipeline will be cleaned-out, opened at both ends to seawater and left *in situ* to disintegrate naturally.

Prior to decommissioning, Apache will consult with all relevant parties including DME, DEP, CALM, and fisheries and conservation groups.

3.2.6 Summary of routine impacts arising from production activities

The environmental impact from the installation of the monopod, and routine production of gas and condensate will be insignificant since it is virtually a closed system.

There will be a disturbance to benthic organisms due to the installation and placement of the Wonnich monopod. The sediment plumes and increased turbidity during the installation period will be localized and transitory. However, this will not cause any permanent degradation to water quality or the condition of the seabed and no permanent change in the population of any marine plant or animal is expected to result. Where exposed, the monopod will provide a hard, artificial substrate and reef for marine organisms.

The installation of the monopod will occur outside the annual coral spawning period, thereby eliminating any impacts to the coral gametes.

3.3 Pipeline Facilities

The Wonnich gas development will require the installation of a prefabricated pipeline between the monopod and Varanus Island. This pipeline will consist of a steel pipe up to 12" in diameter coated with corrosion protection coating and concrete as weighting.

An overview of the impacts from the pipeline route and installation is given in Table 3.

3.3.1 Physical activities

Pipeline route

Three routes for the Wonnich pipeline were investigated (Figure 11):

- The first route (Route 1) runs from Wonnich until reaching the existing East Spar pipeline at which point it turns eastwards and heads towards the Varanus Island in relatively shallow water. The length of the pipeline is approximately 33 km of which about 50 m is landline.
- Another route (Route 2) via the Bambra wellhead crosses a reef in an area of shallow water south of Ah Chong Island before turning south towards Varanus Island, where the pipeline would come ashore in the existing trench.
- The most direct route (Route 3) crosses areas of reef in very shallow water, coming onshore on the west side of Varanus Island.

In May 1996, Fugro Survey Pty Ltd carried out a geophysical pipeline survey to describe the major features of each route. Details of this survey are given in Appendix 5.

Route 1 was concluded to be the optimum route from the point of view of:

- ease of installation;
- ease of post installation stability;
- ease of inspection and maintenance; and
- least environmental impact.

Installation and stabilization

The offshore section of the pipeline will be laid by a conventional lay-barge. The final stabilization will consist of a combination of weight coating, burial and mechanical anchors.

The onshore section of the pipeline will parallel the East Spar pipeline route (Western Mining Corporation 1995) and will cut through a sand dune which was disturbed in 1996 for the installation of the East Spar pipeline (Figure 12). The land section will be pulled ashore through the re-excavated sand dune from the shallow water lay-barge located 300-500 m offshore from the island. Care will be taken to prevent damage to the existing pipeline.

The same procedures for cutting into the dune, reinstating and revegetating the dune as carried out for the East Spar pipeline will be used (WMC 1995) and Apache will keep in close consultation with CALM to ensure the correct procedures are followed. These procedures include:

- minimizing soil disturbance by development of a detailed method of excavation which will include using trench sheeting to stabilize the sides of the trench cut into the dune;
- stockpiling topsoil and rootstock;

TABLE 3: Environmental Analysis of Impact
Pipeline Facilities - Wonnich Gas Development

Description	Source	Quality/ Composition	Quantity	Treatment and/or Discharge Point	Predicted Environmental Effects	Mitigating Actions
Physical Activities						
Installation of pipeline	Positioning and installation of pipeline.	Loss of small area of seabed.	12" pipeline, 33 km in length.		Offshore: increased turbidity during installation but this will be transitory and localized, loss of small area of seabed, attractant to marine life. Onshore: disturbance to rehabilitated sand dune.	Offshore: work will not be carried out during coral spawning period. Onshore: detailed guidelines for trenching, stabilizing and revegetating the dune will be developed. Limited access to adjacent dunes.
Hydrotest fluid	Hydrostatic testing of pipeline to ensure integrity.	Seawater with anti-corrosion additive.	1000 m^3	Lined bund area on Varanus Island.	Negligible. Water collected within bund area will be left to evaporate. Bund is lined, so no penetration to groundwater.	Use least amount of anti-corrosion additive as possible to maintain integrity of pipeline.
Corrosion protection	Pipeline.	Chemical additive, sacrificial aluminium anodes.			Negligible as all additives will be incorporated into the gas-condensate product. Aluminium levels will not be above background seawater levels.	Use least amount of anti-corrosion additive as possible to maintain integrity of pipeline.

- limiting access to dunes adjacent to the trenched area;
- protecting areas which need to be traversed by using sleepers or similar system; and
- revegetating the area with the stockpiled material and seeding with plant seeds collected on Varanus Island.

The mangroves present on either side of the pipeline route will not be disturbed or removed. Timing will also be organized so that installation does not occur during the coral spawning times.

3.3.2 Chemical additives

Corrosion protection

The carbon dioxide content in Wonnich gas (4.05 mole percent) will create a mildly corrosive environment inside the pipe. The treatment method to control corrosion will involve continuous injection of inhibitor at the inlet of the pipeline.

In addition, the following steps will be taken:

- a baseline corrosion survey using instrumented tools will be performed during the commissioning stage of the pipeline. Subsequent surveys will be carried out at regular intervals. Consideration will also be given to utilizing a permanently installed corrosion monitoring system;
- corrosion probes will be installed at both inlet and outlet points of the pipeline and be monitored during routine maintenance activities;
- routine pigging will be performed to displace liquids accumulated in the low points in the pipeline and to evenly distribute inhibitor chemicals; and
- a small nominal corrosion allowance will be calculated to the design of the pipeline and applied.

Cathodic protection for the outside of the pipeline will be provided by special aluminium anodes placed approximately every 120 m along the pipeline. Regular pipeline inspections will be carried out using divers and Remotely Operated Vehicles (ROVs).

None of the chemical additives will be discharged into the marine environment as residual quantities will be incorporated into the gas and condensate product.

Hydrotest fluid

Hydrotest water will be injected into the pipeline for hydrostatic testing purposes prior to commissioning to ensure that the pipeline will meet pressure standards and that there are no leaks along the length of the pipeline. Hydrotest water consists mainly of seawater with an anti-corrosion additive. The total volume of fluid which will be used to test the pipeline will be about 1000 m^3 (1,000,000 L).

Upon completion of the tests, the water in the export line will be removed using compressed air driven equipment and discharged into the Varanus Island bund area where it will undergo evaporation.

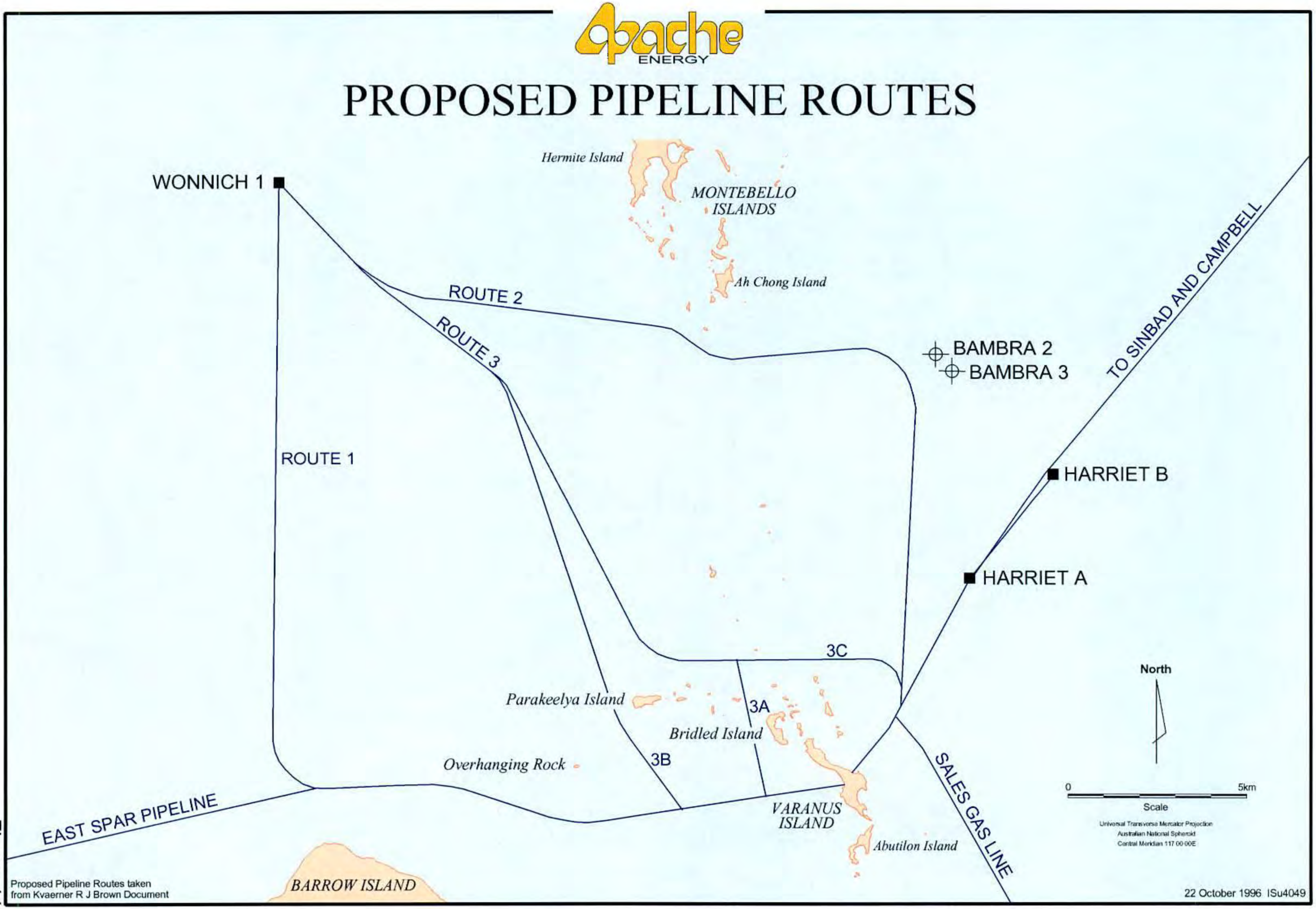
3.3.3 Quarantine

Quarantine procedures (Procedure EA-00-II-002) have been developed to ensure that non-native plants and animals are not introduced to Varanus Island during the installation of the land portion of the pipeline. These procedures are to be strictly followed prior to any equipment or machinery being brought onto the island.

3.3.4 Summary of environmental impact of the pipeline

No permanent impact to the terrestrial or marine flora and fauna is expected from the pipeline installation. The onshore section of the pipeline is to cross an area on Varanus Island where disturbance to the sand dunes has recently occurred. Once the pipeline is installed, the dune will be reinstated, stabilized and revegetated with indigenous plants. The mangroves on either side of the onshore section of the pipeline will not be disturbed and installation will be conducted outside the coral spawning season.

Neither hydrotest water nor chemical additives will be discharged into the marine environment: hydrotest water will undergo evaporation within the lined bund area on Varanus Island and residual chemical additives will be incorporated into the product stream.



ENERGY
PROPOSED PIPELINE ROUTES
Hermite Island
MONTEBELLO ISLANDS
Ah Chong Island
WONNICH 1
ROUTE 2
ROUTE 3
ROUTE 1
BAMBRA 2
BAMBRA 3
TO SINBAD AND CAMPBELL
HARRIET B
HARRIET A
3C
3A
3B
Parakeelya Island
Bridled Island
Overhanging Rock
VARANUS ISLAND
Abutilon Island
SALES GAS LINE
EAST SPAR PIPELINE
BARROW ISLAND
North
0
5km
Scale
Universal Transverse Mercator Projection
Australian National Spheroid
Central Meridian 117 00 00E
Proposed Pipeline Routes taken from Kvaerner R J Brown Document
22 October 1996 ISu4049

Figure 11

EAST SPAR PIPELINE CROSSING - VARANUS ISLAND

Figure 12

4. ENVIRONMENTAL RISK ASSESSMENT OF ACCIDENTAL SPILLS

Risk assessment is defined as the process of determining the frequency of occurrence of an event and the probable magnitude of adverse effects - economic, human safety and health, or ecological - over a specified period of time (Kolluru 1994).

The process of identifying the risks and likelihood of given events, and the magnitude of their effects consists of several interrelated steps including:

- risk identification: recognizing that hazards exist and identifying their characteristics;
- risk determination: determining the characteristics of risks either qualitatively or quantitatively. These may include frequency, magnitude, spatial scale, duration and intensity of adverse consequences; and
- risk control: setting up a management system with standards, procedures, guidelines, etc. to decrease or eliminate risk and to review performance.

Two sources of liquid waste which may enter the marine environment due to accidental discharge during Wonnich drilling and production activities are drilling fluid and condensate. The biodegradable, ester based drilling fluid Petrofree™ will be used for the Wonnich production drilling program (see Section 3.1.2).

Because condensate could cause the greatest impact on the marine and intertidal resources of the region, a quantitative environmental risk assessment was carried out on potential spills of condensate from the Wonnich production facilities.

Environmental risks associated with accidental hydrocarbon discharges from the Wonnich gas development were quantified by considering the best available estimates for two components of the risk: the historic frequency of accidental hydrocarbon discharges (as gas-condensate) and, the probability that such discharges will migrate to sensitive shallow water habitats. The potential for harmful effects of such contact is difficult to quantify reliably and must necessarily be considered in a qualitative sense.

4.1 An Overview of Sources of Spills From Oil and Gas Operations

4.1.1 Commonwealth of Australia offshore areas

In almost 30 years of operation, the oil and gas industry in Australia has drilled over 1,500 exploration and development wells and produced over 3,500 million barrels (556,500 million L) of oil. During this same period, the total amount of oil spilled to the marine environment from all offshore oil exploration and production activities has been estimated to be under 1,000 barrels (159,000 L), with the majority of these spills occurring during production activities (Volkman *et al.* 1994).

Six blowouts have occurred in Australia of which three occurred during exploration drilling. All six were gas blowouts and none resulted in an oil spill. There have been no blowouts in Australia since 1984, which is evidence of the technological and procedural improvements which have occurred over the last decade.

4.1.2 Western Australia offshore areas

A database containing spills to the marine environment greater than 80 L has been compiled by the Department of Minerals and Energy of Western Australia (DME) since July 1989. Oil, drilling fluid and chemical spills are recorded in this database.

Between July 1989 and March 1996, a total of 229 exploration, appraisal and development wells have been drilled in the State and Commonwealth waters of Western Australia. Since the inception of the database, there have been 59 oil spills, 13 drilling fluid spills and 3 chemical spills recorded for all oil and gas activities in Western Australia (Table 4).

No blowouts have occurred in Western Australian waters. Detailed knowledge of the characteristics of the Wonnich reservoir, including reservoir pressure, make the chances of a blowout very small (see Section 4.2.1).

Oil spills

A summary of the oil spill data, broken down into type of activity (seismic, drilling, production testing and production) is given in Table 5.

Taking into account all activities in both State and Commonwealth waters, the least number of oil spill incidents occurred during seismic and drilling activities (2 incidents each). The majority of oil spill incidents resulted from production operations.

Between July 1989 and March 1996, 229 wildcat, appraisal and production wells were drilled over 6,751 drilling days (Table 6). Within this time period, only two oil spills have occurred during drilling operations, one resulting in a spill of 1.89 barrels (293 L) and the other, one barrel (159 L). The causes for these incidents were, respectively, a collision between a supply vessel and drilling rig at night resulting in the rupture of the fuel tank on the vessel, and a hole in the fuel transfer hose between the support vessel and rig.

A total of 14 incidents were a result of production testing: two incidents within State waters and 12 incidents in Commonwealth waters. The majority of these incidents were from one operation and were due to insufficient combustion during production testing, resulting in the fallout of oil. The average volume of oil released into the marine environment during each of these incidents was about 6 barrels (930 L).

The main causes for the 41 oil spill incidents resulting from production operations were pipeline leakage due to corrosion and flowline disconnection on Floating Production and Storage Offloading (FPSOs) facilities.

Drilling fluid spills

All recorded spills of drilling fluid occurred during the drilling of development wells. A total of 13 spills were recorded in the DME database resulting in 922 barrels of fluid being discharged accidentally into the marine environment over a seven year period. The main causes for these spillages were overflow of the mud tanks and rain valve failure.

Chemical spills

Three chemical spills were recorded in the DME database. Approximately 19 barrels of glycol and inhibitor were discharged into the marine environment during production activities. These spills were attributed to failure of pumps and human error.

Table 4 : The number of oil, drilling fluid and chemical spills from oil and gas activities in Western Australia (State and Commonwealth waters).

Year	Oil spills		Drilling fluid spills		Chemical spills	
	Number of incidents	Volume spilt (bbls)	Number of incidents	Volume spilt (bbls)	Number of incidents	Volume spilt (bbls)
1989*	5	79	1	104	0	0
1990	12	94	2	16	0	0
1991	5	23	3	28	3	19
1992	5	32	0	0	0	0
1993	18	137	0	0	0	0
1994	7	225	2	504	0	0
1995	7	25	3	49	0	0
1996+	0	0	2	221	0	0
Total	59	614	13	922	3	19

* data from 1.8.89 to 31.12.89
\+ data from 1.1.96 to 31.3.96

Table 5 : The number and sizes of oil spills in Western Australian State and Commonwealth waters according to activity. All volumes are given in barrels.

	Number of incidents	Total volume spilt oil	Average volume of oil spilt incident	Minimum volume spilt	Maximum volume spilt
State and Commonwealth waters					
Seismic	2	13.1	6.6	0.6	12.5
Drilling	2	2.9	1.5	1	1.9
Production testing	14	93.4	6.7	1	30.0
Production	41	504.7	12.3	0.01	220
Total	59	614.1	10.4	0.01	1.9
State waters					
Seismic	0				
Drilling	1	1.9			
Production testing	2	7.4	3.7	0.4	4.0
Production	20	131.3	6.6	0.01	44.3
Total	23	140.6	10.8	0.01	4.0
Commonwealth waters					
Seismic	2	13.1	6.6	0.6	12.5
Drilling	1	1			
Production testing	12	85.9	7.2	1	30
Production	21	373.5	17.9	0.01	220
Total	36	473.5	13.1	1	12.5

Table 6: The number of oil spills which occurred in Western Australian waters during drilling operations, broken down to year and type of well drilled.

Year	Total number of wells drilled	Well type			Total number of drilling days	Minimum number of drilling days	Maximum number of drilling days	Number of incidents	Volume of spilt oil (bbls)
		Exploration	Appraisal	Development					
1989*	12	8			240	9	63	0	
			1		23	-	23	0	
				3	141	12	58	0	
1990	37	14			507	12	138	0	
			6		153	8	61	0	
				17	647	4	177	0	
1991	31	20			524	6	68	0	
			6		182	4	82	0	
				5	217	21	72	0	
1992	25	14			435	7	138	1	1.89
			8		311	7	142	0	
				3	33	7	16	0	
1993	38	20			532	6	117	0	
			6		108	2	47	0	
				12	308	10	93	0	
1994	40	9			168	6	45	0	
			16		303	6	63	0	
				15	652	7	134	0	
1995	38	20			644	5	139	1	1
			5		90	6	37	0	
				13	303	5	58	0	
1996+	8	3			78	4	23		
			4		81	19	39		
				1	71	-	71		

* Data from 1.7.89 to 31.12.89
+ Data from 1.1.96 to 31.3.96

4.1.3 Apache Energy's activities

Since the discovery of the Harriet oil field in November 1983, 48 wells have been drilled by Apache and its predecessors within licence area TL/1, 5 & 6 and in the adjacent areas TP/8 and WA-192-P over 1,348 drilling days (Table 7). A detailed list of all the wells is provided in Table 8.

Table 7: Summary of the number of wells drilled and tested by Apache in TL/1, 5 & 6, TP/8 and WA-192-P since 1983.

Number of wells drilled	Drill days	Number of incidents	Volume of oil spilt (bbls)	Number of wells tested
48	1348	1	1.89	23

In this time, one incident occurred during drilling: in 1992, approximately 1.9 barrels (302 L) of diesel fuel were spilled at the Ulidia exploration well site when a support vessel collided with the drilling rig and ruptured the vessel's fuel tank. No environmental impact from this spill was recorded.

No drilling fluid has been accidentally spilt during any of Apache's drilling operations.

Between July 1989 - March 1996, four incidents resulted in oil spillage into the marine environment from Apache's offshore operations. The causes for the spills were: disconnected hose pipe, valves inadvertently left open, drain overflow and overflow of a test separator. All four spillages were small (0.13 - 6 barrels) and did not cause any environmental impact. None of these spillages originated from the two gas-condensate platforms Sinbad and Campbell. Apache has not had any accidental spills of oil into the marine environment from any of its offshore operations since 1993.

4.2 Potential Sources and Sizes of Spills

The potential sources and sizes of liquid discharge from the drilling and production operations identified for the Wonnich gas development are summarized in Table 9.

4.2.1 Production drilling

The sources of potential spillage from production drilling are:

- leakage or spillage of diesel or lubricating oil from engines;
- leakage or spillage from the diesel transfer hose;
- leakage of chemicals from drums stored on the drilling rig;
- accidental discharge of drilling fluid from the shakers or transfer hoses;
- an accidental discharge of oil during production testing;
- rupture of a fuel tank; and
- and uncontrolled discharge at surface due to loss of control of a well.

The discharge of main concern is accidental spillage of oil and the potential sources which may give rise to the largest spills are discussed below.

Table 8: Wells drilled into the Flag Sandstone by Apache - 1983 to 1995. The Flag Sandstone is the only hydrocarbon bearing geolgical sequence in the Wonnich area.

	Drilled	Well Name	Well type	Drill Days	Tested	Test Type	Testing Hours	Production Since
1.	1994	Alkimos 1	Wildcat	14	N	Production	0	1994
2.	1995	Austin 1	Wildcat	42	Y	RFT	0	-
3.	1982	Bambra 1	Wildcat	96	Y	DST/RFT	7.35	-
4.	1983	Bambra 2	Appraisal	129	Y	DST/RFT	27.4	-
5.	1988	Bambra 3	Appraisal	15	Y	RFT	0	-
6.	1994	Belinda 1	Wildcat	6.6	N		0	-
7.	1986	Campbell 2	Production	30	Y	DST	25.4	1992
8.	1992	Campbell 3	Production	7	N		0	-
9.	1992	Campbell 4	Production	23	N		0	-
10.	1995	Campbell 5	Production	42	Y	RFT	0	1995
11.	1996	Doric 1	Wildcat	9	N		0	-
12.	1983	Emma 1	Wildcat	28	Y	DST/RFT	0.30 Failure	-
13.	1983	Flores 1	Wildcat	17	Y	RFT	0	-
14.	1983	Georgette 1	Wildcat	22	N		0	-
15.	1983	Harriet A1	Production	41	Y	DST/RFT	127.0	1984
16.	1983	Harriet A2	Production	70	N		0	-
17.	1984	Harriet A3	Production	60	Y	DST	21.0	1984
18.	1984	Harriet A4	Production	35	Y	RFT	0	1984
19.	1984	Harriet A5	Production	8	Y	DST	17.2	1984-1994
20.	1994	Harriet A5 S/T	Production	6	N		0	1994
21.	1984	Harriet A6	Production	21	Y	DST/RFT	15.15	1984-1995
22.	1990	Harriet A7	Production	11	N		0	1990
23.	1994	Harriet A8	Production	19	N		0	1994
24.	1994	Harriet A8H	Production	0	N		0	1994
25.	1994	Harriet A9	Production	9	N		0	1994
26.	1994	Harriet A9H	Production	0	N		0	1994
27.	1995	Harriet A10	Production	9	N		0	-
28.	1984	Harriet B1	Production	22	Y	DST/RFT	31.0	1984
29.	1985	Harriet B2	Production	44	Y	DST	22.5	1984
30.	1985	Harriet B3	Production	35	Y	DST/RFT	34.25	1984
31.	1990	Harriet B4	Production	10	N		0	1984
32.	1985	Harriet C1	Production	19	Y	RFT	0	1985
33.	1985	Harriet C2	Production	23	N	RFT aband.	0	1985
34.	1990	Harriet C3	Production	12	N		0	1990
35.	1992	Marra 1	Wildcat	14	N		0	-
36.	1985	Nyanda 1	Wildcat	24	N		0	-
37.	1986	Orpheus 1	Wildcat	27	Y	RFT	0	-
38.	1986	Plato 1	Wildcat	23	N		0	-
39.	1987	Rosette 1	Wildcat	123	Y	DST	90.0	1992
40.	1990	Sinbad 1	Wildcat	33	Y	DST	17.0	1992
41.	1992	Sinbad 2	Production	35	N	Production	0	1992
42.	1991	Tanami 1	Wildcat	31	Y	RFT	0	1991
43.	1991	Tanami 2	Appraisal	19	N		0	-
44.	1994	Tanami 3	Appraisal	33	N		0	-
45.	1994	Tanami 3 S/T	Production	0	N		0	-
46.	1994	Tanami 3 S/T2	Production	0	N		0	-
47.	1992	Ulidia 1	Wildcat	11	Y	RFT	0	-
48.	1995	Wonnich 1	Wildcat	40	Y	DST/RFT	60.41	-
				1347.6 days			20.6 days	

RFT: Repeat formation test
DST: Drill stem test

Table 9: Overview of potential sources, consequences and prevention of accidental fluid discharge into the marine environment.

Source of spill	**Potential maximum size**	**Potential effects**	**Preventative actions**
Leakage from engines or machinery	20L	Consists of engine oil or hydraulic fluid. Negligible impact. Small amounts of diesel would dissipate and evaporate very quickly.	Drip trays and sumps placed under all engines. Oil collected in deck sump, emptied on regular basis and treated via oily water separator.
Spillage of chemicals from drums	205 L	Minor as the main chemical would be light diesel oils which would evaporate quickly.	Drums are stored on pallets and in bunded areas away from open grates.
Spillage or leakage of cuttings from cuttings discharge system linking drilling rig to annulus	500 L	Negligible. Cutting and fluid would disperse quickly, with the heavier materials sinking to the bottom. Will contribute to short term turbidity.	Continuous monitoring of fluid volumes and regular visual inspections carried out. Low flow rate and facility for immediate shutdown will minimise volume released.
Leakage or spillage from diesel transfer hose during drilling period	2,000 L	Negligible as diesel would evaporate very quickly.	Detailed refueling procedures developed and followed. Refueling only during suitable weather and seastate conditions. Dry couplings installed on fuel hose.
Spillage or leakage of drilling fluid from transfer hose	2,000 L	Minor. Fluid would cause short term turbidity but would disperse rapidly. Smothering unlikely due to dispersion.	Only dry materials for water based fluid passed from support vessel to the rig. Fluid is mixed in bulk tanks located within the hull of the drilling rig.
Leakage or rupture of pipeline	3,000 - 61,000 L per day.	Gas release with condensate. Volume of condensate dependent on size and type of pipeline leakage or rupture. Condensate could impact on marine resources if wind and currents carry it towards the shallow marine areas adjacent to the mainland.	Pipeline designed to accepted standards. Pressure of fluids monitored continuously and linked with alarm and shutdown system. Corrosion inhibitors used to prevent against corrosion. Line to be stabilized by appropriate means (e.g. rock bolting, rock armory) to ensure that it won't shift in heavy seas or cyclones.

Table 9 cont.

Source of spill	Potential maximum size	Potential effects	Preventative actions
Rupture of drilling rig fuel tank due to impact	80,000 L	Some risk of fire. Could impact on marine resources if wind and currents carry it towards the shallow marine areas adjacent to the mainland.	Fuel tanks are located above the surface of the water and are contained within the hull of the rig. Chances of impact are slim as hull will be higher than vessel and tanks are protected by ballast tanks.
Rupture of support vessel fuel tank	80,000 L	Safety issue with potential fire or sinking of vessel. Could impact marine resources adjacent to mainland.	Work adjacent to rig or monopod only in suitable weather conditions. Work at night only in emergencies. Navigation lights on all night.
Wellhead blowout	19,000 L	Predominately gas with small volumes of associated condensate. Small quantities of condensate wil be retained on deck of monopod. Larger quantities may overflow into ocean.	Hydrocarbon detection systems and alarms. Automatic emergency shut-down systems and isolation valves. All pipework and wellheads designed tin accordance to accepted standards. Inhibitor used to prevent corrosion and maintain integrity of the pipework. Regular inspections and maintenance carried out.

Refueling

Spills of diesel fuel during refueling can be caused by hose breaks, coupling failures or tank overfilling, and generally involve volumes less than 2,000 L, with quantities minimized by prompt shutdown of pumps by automatic safety valves.

In order to minimize the risk of spillage, the following measures will be taken:

- the rig will be fully fueled before being brought on site in order to minimize the number of refueling operations required at the drill site;
- the transfer hoses will be fitted with 'dry' couplings;
- a vacuum breaking system will be in place to drain the fuel left in the hose after completing the transfer, back to the supply vessel tanks;
- drip trays will be provided beneath the refueling hose connections on the supply vessel and the rig;
- fuel transfer will be carried out in daylight hours;
- refueling will be permitted only at times when the prevailing currents are moving away from the adjacent reef system, in order to provide the maximum time for response in the event of an accidental spill;
- refueling will occur only at times when sea conditions are sufficiently calm for there to be minimal risk to the transfer lines;
- crew of both the rig and the workboat will stay in continuous contact during the whole of the operation via handheld radios and will actively monitor the operation for its entire duration; and
- suitable absorbent material will be held on the supply vessel and the rig to mop up any small spills.

Well control

Extensive training, procedures and equipment are in place to maintain well control and prevent blowouts. Blowouts would not only impact the environment, but could also result in loss of life and property.

During drilling, kicks can occur. A kick is defined as a flow of formation fluids or gas into the well bore. If the pressure within the formation being drilled is greater than the hydrostatic pressure of the drilling fluid acting on the well bore, an influx of formation fluids (oil, gas, water) into the well bore can occur. The severity of the kick will depend on the porosity and permeability of the formation (i.e. how it allows fluid to flow through it), and the difference between the formation pressure and drilling fluid pressure.

A blowout is an uncontrolled kick and can take place at the surface or underground between two separate permeable bodies of rocks (formations).

Kicks are prevented by maintaining the correct density of the drilling fluid down the well bore. This is achieved by adjusting the concentration of various components of the drilling fluid so that the fluid hydrostatic pressure is greater than the formation pressure.

There are a number of warning signs which indicate that a kick is taking place. These include an increase in drilling fluid flow rate, an increase in the drilling bit penetration rate (indicating a change in the type of rock being drilled) and the presence of gas bubbles in the returned drilling fluid. If one or more warning signs of a kick are observed, steps are taken to check for flow from the well and the well is immediately shut-in. The well can then be easily brought under control by adjusting the density and weight of the drilling fluid.

A production well drilling program has less risk of a blowout than an exploration program due to the knowledge of the geological conditions acquired from the exploration and appraisal wells. With respect to Wonnich this acquired knowledge includes the following:

- the "Flag Sandstone" is the only hydrocarbon bearing geological sequence in the Wonnich area (Figure 13). This Flag Sandstone is a well sorted, medium to coarse grained homogeneous sandstone with high porosity and permeability. The Wonnich reservoir is normally pressured; that is, the pressure in the reservoir is equal to the pressure applied by a column of water above it. This normal pressurization was confirmed by the Wonnich-1 discovery well. Reservoir pressure is known to be 3,286 pounds per square inch absolute (psia) (Figure 14). All other wells (drilled by Apache or other operators) which have penetrated the same geologic interval (the Flag Sandstone) have also been normally pressured.

- the distance to the top of the Wonnich reservoir and the geological formations are known across the reservoir as a result of the information provided by Wonnich-1, in addition to the data acquired during seismic surveys. This ensures that no unexpected reservoir fluids will be encountered at any stage during the wells.

Because the pressure within the reservoir, the fluid properties, and the depth to the reservoir are known, any wells drilled to intersect the reservoir can be easily controlled utilising properly weighted drilling fluids. This knowledge, along with use of up-to-date drilling equipment, and regulated "best practice" drilling practices, ensures that the risk of a blowout is very small.

The requirements associated with any drilling program include detailed procedures for all drilling activities, blowout prevention equipment maintenance, regular (minimum weekly) blowout prevention drills and table-top oil spill exercises.

The Wonnich gas development drilling program is regulated through the Department of Minerals and Energy of Western Australia (DME) with the *Petroleum (Submerged Lands) Act* 1967, as amended, and the Schedule - Specific Requirements as to Offshore Petroleum Exploration and Production 1990 being the relevant regulatory documents. In addition, Apache will utilise four main documents to manage the drilling process for the Wonnich wells. These are the Drilling Procedures Manual - Jackup Rigs, the Emergency Response Manual, the Oil Spill Contingency Plan, and the Wonnich Gas Development Drilling Program. These documents define the plans, procedures and contingency plans that are utilised throughout the drilling process.

Some of the procedures that Apache must adhere to during the drilling program which will reduce the risk of a blowout are:

- two or more barriers for the control of well bore pressure will be in place at all times during the drilling program. These include Blow Out Preventers (BOP) and maintaining the proper mud density.

- the BOP stack will be pressure tested prior to commencement of operations and on a routine basis (i.e. at least weekly) during the drilling program.

- all casing strings will be pressure tested to a pressure in excess of the reservoir pressure prior to drilling.

- provision of well reservoir characteristics to the drilling engineers so they can plan for the interception of hydrocarbons during drilling.

- mud logging techniques will be carried out to give a quantitative measure of the pressure contained in any formation drilled. Modifications to the drilling program, including changing the density of the drilling fluid, will be made where necessary.

- the drilling crew will be fully trained in emergency well control procedures. This will be achieved by implementing regular emergency practice drills during the drilling program. In addition, the senior members of each crew will be certified in well control techniques through accredited courses.

4.2.2 Production activities

Potential sources of hydrocarbon spillage resulting from production activities are:

- hydrocarbon releases from the process area during operation;
- wellhead blowouts;
- pipeline leakage or rupture; and
- ship collision.

4.3 Frequencies for Accidental Discharge of Condensate

Accident frequencies were calculated by risk engineers Stratex Worley Pty Ltd for specific scenarios that could result in the release of gas-condensate to the environment (Appendix 6). This assessment was based on the *Formal Safety Assessment* of a combined drilling and production program conducted for the Sinbad and Campbell gas producing monopods (Stratex Worley 1993), but incorporated more up-to-date failure rate data.

Accident rates were calculated for three sets of scenarios for potential condensate release.

Scenario set 1 – Hydrocarbon releases from the process area during operation

- large leak of unprocessed gas (> 25 mm perforation)
- small leak of condensate (≤ 25 mm perforation)
- large leak of condensate (> 25 mm perforation)

Scenario set 2 – Gas blowouts

- during drilling
- during completion
- during production
- during wireline operations

Scenario set 3 – Pipeline leakage or rupture

- corrosion pitting (5 mm perforation)
- small leak (20 mm perforation)
- large leak (80 mm perforation)
- total pipeline rupture (full bore = 250 mm perforation)

Accident rates for process leaks were calculated from the individual release frequencies of component parts of the processing system using the E&P forum *Hydrocarbon Leak and Ignition Database* (E&P Forum 1992). The frequency of gas blowouts was also calculated using this database. This database incorporates records up to 1992, mostly from the North Sea, Gulf of Mexico but also from Australia. Due to the far greater activity in the North Sea and Gulf of Mexico, this database is heavily dominated by the overseas data.

Pipeline and riser failure data were derived from a database containing mostly North Sea records (*Advanced Mechanics and Engineering* 1990), and covering 579 pipelines (100,000 km years of operation).

Caution must be used when extrapolating risk frequencies from historic data compiled overseas and applying them to current practices in Australia. By world standards, Australia has a very strict safety regime and this is reflected in the low number of spills which have occurred in Australian waters. In addition, many current practices have been put into place to prevent the re-occurrence of previous accidents. For these reasons, accident frequencies presented here are likely to be overestimates for the proposed activities.

In addition to the frequency rates, Stratex Worley provided estimates of the maximum quantity of condensate that may be spilt during each scenario. These quantities were based on the response times of automatic and manual Emergency Shut Down (ESD) systems that are in place on the Sinbad and Campbell platforms, with allowance for the inventory that would be lost from pipelines and containment vessels subsequent to shutdown. For example, gas detectors on the production platform would be connected directly to automatic ESD systems. These would be capable of rapidly (<15-20 seconds) closing off the supply of hydrocarbons, but containment vessels may continue to release hydrocarbons until pressure is equalized with the atmosphere.

All inventory releases are worst case in that all condensate in a perforated chamber (i.e. a section of the processing facilities or the export pipeline) will be released to the environment.

The accident frequency rates for the scenarios are given in Table 10.

4.4 Risk of Spills Reaching Sensitive Resources

4.4.1 Characteristics of oil

Fundamental to the determination of the consequences of spilt oil is an understanding of the behaviour and fate of oil. The nature and severity of environmental impacts from oil depends in part on the composition of the oil. The chemical and physical properties of spilled oil change with time. The rate of change depends both on the initial chemical composition of the oil and 'weathering' or aging. Generally, the longer the spilled oil is weathered, the fewer the ecological damaging constituents it will contain. Weathering tends to reduce the toxicity of spilled oil because the toxic components are lost through evaporation, dissolution or degradation from photo-oxidation and microbial activity.

The types of oil which may be spilt into the marine environment from the Wonnich drilling and production activities are:

- Wonnich condensate;
- diesel fuel; and
- crude oil or bunker oil.

Wonnich condensate

Wonnich condensate is a typical North West Shelf condensate. Sinbad condensate, which is similar, is a light hydrocarbon with an API° gravity of 56 and containing about 12% aromatics. It has a low pour point (<0 °C), high flash point (24 °C) and relatively high viscosity (0.8750 cst at 25 °C).

Table 10: Estimated accident frequencies and potential sizes of resulting condensate spills.

Scenario	Maximum volume condensate release (kg)	Frequency
Gas blowout		
1st year*	14,500	$4.47 \times 10^{-3}\ yr^{-1}$
Subsequent years *	14,500	$2.81 \times 10^{-3}\ yr^{-1}$
Process area leakage		
Large leak of unprocessed gas	150	$1.97 \times 10^{-3}\ yr^{-1}$
Small leak of condensate	1,430	$6.57 \times 10^{-3}\ yr^{-1}$
Large leak of condensate	2,835	$3.15 \times 10^{-4}\ yr^{-1}$
Pipeline leakage or rupture		
Corrosion pitting	3,828 per day	$3.74 \times 10^{-5}\ km^{-1}\ yr^{-1}$
Small perforation	46,788 per day	$3.73 \times 10^{-5}\ km^{-1}\ yr^{-1}$
Large perforation	12,435	$3.74 \times 10^{-5}\ km^{-1}\ yr^{-1}$
Total pipeline rupture	14,050	$2.49 \times 10^{-5}\ km^{-1}\ yr^{-1}$

*Blowout risk for first year includes the risks for drilling, completion and production. Risk for subsequent years includes the risks of two wireline workovers per year.

1 tonne = 1000 kg   1 tonne = 1298 L condensate

Spreading and evaporation of condensate is rapid (Table 11 and Figure 15) (Kagi *et al.* 1988). At a water temperature of 26 °C, approximately 70% of the total volume of condensate spilt will have evaporated within 60 minutes. About 15-20% of the total volume of condensate spilled will resist evaporation.

Table 11: Spreading rates of condensate on water. Values are spill diameter in metres.

Time Mins/Hrs	**4 Tonnes ($5.2\ m^3$)**	**20 Tonnes ($26\ m^3$)**	**100 Tonnes ($130\ m^3$)**	**200 Tonnes ($260\ m^3$)**	**500 Tonnes ($650\ m^3$)**
20 / 0.33	170	284	500	610	829
40/ 0.67	178	297	522	621	870
80/ 1.3	191	325	561	699	940
220/ 3.7	228	386	669	831	1130
520/ 8.7	281	479	824	1032	1400
1020/ 17.0	341	582	998	1254	1701
3020/ 50.3	478	817	1400	1760	2388

Other oils

Diesel fuel is a light petroleum product with an API° gravity ranging from 36-62. Diesel spreads rapidly after spillage to form a thin film which will evaporate quickly in tropical conditions (Table 12). It is estimated that after 10 hours, approximately 50% of the spilled oil will have evaporated, including 80% of the toxic light ends. In terms of spreading, a 2,000 L spill of diesel will spread to an area of diameter 200 m and a thickness of less than 0.2 mm within three hours (Table 13). Thinly spread oil photo-oxidizes quickly and is naturally dispersed by wind and wave action. This further breaks up the oil, enhancing biodegradation and weathering.

Table 12: The estimated spreading rates of diesel. Values are spill diameter in metres.

Time Mins/Hrs	**2 Tonnes ($2.38\ m^3$)**	**10 Tonnes ($11.9\ m^3$)**	**50 Tonnes ($59.5\ m^3$)**	**100 Tonnes ($119\ m^3$)**	**200 Tonnes ($238\ m^3$)**
10/ 0.17	74	128	220	282	245
20/ 0.33	94	161	274	345	435
40/ 0.67	118	202	245	435	549
60/ 1.0	137	232	396	498	631
100/ 1.7	161	275	470	588	741
200/ 3.3	204	346	592	764	933
500/ 8.3	274	470	804	1007	1270
1000/ 16.7	345	592	1020	1274	1607
2000/ 33.3	431	745	1272	1603	2023

Table 13: The evaporation rate of diesel.

TIME: Minutes	**20**	**60**	**120**	**360**	**600**	**1200**	**2400**
Hours	**0.3**	**1.0**	**2.0**	**6.0**	**10**	**20**	**40**
Approximate percentage of original oil remaining	97	88	79	60	48	35	27
Approximate percentage of naphthalene derivatives (C_{11}-C_{15}) range.	95	80	70	37	20	5	2

The spreading and evaporation of heavy fuel oils cannot be quantified in advance of a spill. However, fuel oils are likely to be less viscous and will spread and evaporate significantly slower than diesel. For a spread on an unrestricted area, it has been observed that about 90 percent of heavy crude oil will be contained in a central area of about 10 percent of the area bounded by the visible oil film.

4.4.2 Probability of reaching sensitive resources

Determination of spill trajectories

The projection of oil spill trajectories and the assessment of the risks to the resources adjacent to the Wonnich gas development site made use of Apache's OILMAP/OILTRAK oil spill prediction and management system (Appendix 7). This system uses a suite of computer models to predict the movement, weathering, dispersion and entrainment of specific oil types.

The consequence of a condensate spill will depend on how far and where the hydrocarbon travels before evaporating. Wonnich condensate is expected to have similar composition and properties to that produced at Sinbad and Campbell. Based on the physical properties of this condensate, the OILMAP computer model predicted relatively rapid evaporation rates under the expected conditions. The evaporation rate will increase with both the temperature and velocity of the wind.

The OILTRAK/OILMAP computer system was used to predict the risk that condensate spills might migrate to sensitive shallow water habitats. Field verifications around the Montebello Islands and other locations has demonstrated the reliability of this system (Appendix 7).

The OILTRAK/OILMAP computer system was used to conduct Monte Carlo simulations for each of the accident scenarios listed in Table 10. The Monte Carlo simulations involved generating multiple (50) simulated spill events and predicting the trajectory of each for four days. Each spill event was started at a randomly selected time relative to the tide and run under a randomly selected portion of an historic wind time series for Varanus Island. Based on the frequency with which condensate reached locations during the 50 spills, probability contours were generated for each accident scenario.

All scenarios were tested under the two major seasonal wind patterns experienced in the area: 'summer' winds which are experienced between October to March and 'winter' winds which are experienced between June to August. Other months have winds that are transitional between these patterns (Steedman Science & Engineering 1991). Assuming that the periods of transitional winds can be evenly divided between the two major seasons, 'summer' winds are experienced approximately 63% of the year, while 'winter' winds are experienced approximately 37% of the year.

The 'summer' wind time series (summer season) used for modeling was recorded in October -November 1995, while the 'winter' wind time series (winter season) was recorded in July-August 1995 (62 days in each case).

Probability of condensate reaching sensitive resources

The probability that condensate would reach reefs or shores due to each type of accident was subsequently calculated for each of the two seasons as:

Seasonal risk =

[probability of accident during the season] X [probability of contact during the season].

The probability of an accident during each season was calculated as a proportion of the annual rate given in Table 10 (summer: 63%; winter 37%). The overall annual risk was determined by summing the risk frequencies for each season. The lifetime risk was calculated for a production lifetime of 15 years (i.e. annual risk x 15 years). The results of the analyses are summarized in Tables 14 and 15.

The OILTRAK/OILMAP system provided estimates of the probability of condensate reaching particular locations for each accident scenario, as well as the minimum time before contact during any of the 50 spills modeled for each scenario. These probability contours are given in Figures 16 - 29. All estimates of risk for the transport of oil spills assume that no action has been taken to divert or collect any of the condensate that has been spilled. Table 16 summarises the probability that reef and shoreline locations would be reached by condensate, and the minimum time to contact required for each scenario.

Risk to the Montebello Islands

The risk analysis indicated that there is a low, overall risk of condensate reaching the fringing reefs and shorelines of the Montebello Islands from the proposed development. This overall low risk can be attributed to both the low historic frequency of accidental releases for the planned activities and to the generally low probability that resulting spills would reach the reefs or shores. While for some of the individual accident scenarios there was a high probability that fringing reefs or island shores may receive condensate, the overall risk of a spill occurring in the first instance is very low.

The probability of contact was predicted to be lowest for discrete spills that could be detected and isolated rapidly by the ESD systems to be included in the facilities. Spills from such accidents, although potentially large, were predicted to have less than a 5% chance of reaching the fringing reefs and shores of the Montebello Islands due to the high evaporation rate of the condensate, and the indirect route that spill trajectories would follow. For example, condensate was not predicted to reach fringing reefs and shores from large gas leaks (Figures 20 and 21), while condensate from gas blowouts had a small chance of reaching these areas (Figures 16 and 17).

Table 14: Risks from platform or well head leakages showing estimated accident frequencies, potential sizes of resulting condensate spills, and the overall annual probability that shores or fringing reefs would be reached by a condensate spill. The quantities of condensate released assume automatic detection and shutdown.

Accident	**Estimated condensate volume (L)**	**Summer**			**Winter**			**Annual**	**Lifetime**
Gas blowout		**Accident [1] frequency**	**Transport probability**	**Seasonal Risk**	**Accident [1] frequency**	**Transport probability**	**Seasonal Risk**	**Overall risk**	**Overall risk**
1st year	18,821	2.81×10^{-3}	2.0×10^{-2}	$\mathbf{5.6 \times 10^{-5}}$	1.65×10^{-3}	2.0×10^{-2}	$\mathbf{3.3 \times 10^{-5}}$	8.9×10^{-5}	**N/A**
Subsequent years	18,821	1.77×10^{-3}	2.0×10^{-2}	$\mathbf{3.5 \times 10^{-5}}$	1.03×10^{-3}	2.0×10^{-2}	$\mathbf{2.1 \times 10^{-5}}$	5.6×10^{-5}	$\mathbf{8.7 \times 10^{-4}}$
Process leak									
Unprocessed gas, large perforation (>25 mm)	216	1.24×10^{-3}	$<1.0 \times 10^{-2}$	$\mathbf{<1.2 \times 10^{-5}}$	7.30×10^{-4}	$<1.0 \times 10^{-2}$	$\mathbf{<7.3 \times 10^{-6}}$	$<1.9 \times 10^{-5}$	$\mathbf{<2.9 \times 10^{-4}}$
Condensate, small perforation (<25 mm)	1,856	4.14×10^{-3}	2.0×10^{-2}	$\mathbf{8.3 \times 10^{-5}}$	2.43×10^{-3}	2.0×10^{-2}	$\mathbf{4.9 \times 10^{-5}}$	1.3×10^{-4}	$\mathbf{1.9 \times 10^{-3}}$
Condensate; large perforation (>25 mm)	2,944	1.98×10^{-4}	4.0×10^{-2}	$\mathbf{7.8 \times 10^{-6}}$	1.16×10^{-4}	2.0×10^{-2}	$\mathbf{2.3 \times 10^{-6}}$	1.0×10^{-5}	$\mathbf{1.5 \times 10^{-4}}$

1 Assuming summers last 63% of year and winters last 37% of year. Calculated from the length of the summer and winter wind patterns and allocating transitional months equally to summer and winter.

Table 15: Risks from pipeline leakages showing estimated accident frequencies, potential sizes of resulting condensate spills, and the overall annual probability that shores or fringing reefs would be reached by a condensate spill. The quantities of condensate released assume automatic detection and shutdown unless otherwise indicated. Response time for small leaks remote from Varanus Island assumes detection by gas metering anomalies. Those for corrosion pitting, and small leaks near Varanus Island assume visual detection of the spill, based on the expected level of activity near the spill sites.

Accident	**Estimated condensate volume (L)**	**Summer**			**Winter**			**Annual**	**Lifetime**
Within 1st 1 km of export pipeline		**Accident frequency**	**Transport probability**	**Seasonal Risk**	**Accident [1] frequency**	**Transport probability**	**Seasonal Risk**	**Overall risk**	**Overall risk**
Corrosion pitting	19,470 over 10 days	2.36×10^{-5}	4.0×10^{-1}	**9.4×10^{-6}**	1.38×10^{-5}	1.6×10^{-1}	**2.6×10^{-6}**	**1.2×10^{-5}**	**1.8×10^{-4}**
Small perforation (20 mm)	121,532 over 2 days	2.35×10^{-5}	9.0×10^{-1}	**2.1×10^{-5}**	1.38×10^{-5}	4.0×10^{-1}	**2.2×10^{-6}**	**6.1×10^{-5}**	**9.1×10^{-4}**
Large perforation (80 mm)	15.,576	2.36×10^{-5}	4.0×10^{-2}	**9.4×10^{-7}**	1.38×10^{-5}	4.0×10^{-2}	**5.5×10^{-7}**	**1.5×10^{-6}**	**2.2×10^{-5}**
Full bore rupture (210 mm)	18,237	1.56×10^{-5}	4.0×10^{-2}	**6.2×10^{-7}**	0.92×10^{-5}	4.0×10^{-2}	**3.7×10^{-7}**	**9.9×10^{-7}**	**1.5×10^{-5}**
2-3 km west of Varanus Island									
Corrosion pitting	19,470 over 10 days	2.36×10^{-5}	1.4×10^{-2}	**3.3×10^{-7}**	1.38×10^{-5}	6.0×10^{-1}	**8.3×10^{-6}**	**8.6×10^{-6}**	**1.3×10^{-4}**
Small perforation	121,527 over 2 days	2.35×10^{-5}	7.0×10^{-1}	**1.6×10^{-5}**	1.38×10^{-5}	8.0×10^{-1}	**1.1×10^{-5}**	**2.7×10^{-6}**	**4.0×10^{-4}**
Large perforation	15.,576	2.36×10^{-5}	2.0×10^{-2}	**4.7×10^{-7}**	1.38×10^{-5}	6.0×10^{-2}	**8.3×10^{-7}**	**1.3×10^{-6}**	**2.5×10^{-5}**
Full bore rupture	18,237	1.56×10^{-5}	2.0×10^{-2}	**3.1×10^{-7}**	0.92×10^{-5}	1.4×10^{-1}	**1.3×10^{-7}**	**4.4×10^{-7}**	**6.6×10^{-6}**

Table 15 continued

Accident	Estimated condensate volume (L)	Summer			Winter			Annual	Lifetime
Within 500 m of Varanus Island									
Corrosion pitting	3,888 over 2 days	1.18×10^{-5}	1	**1.18×10^{-5}**	6.90×10^{-6}	5.0×10^{-1}	**3.5×10^{-6}**	**1.5×10^{-5}**	**2.2×10^{-4}**
Small perforation	2,196 over 2 hours	1.17×10^{-5}	9.0×10^{-1}	**1.05×10^{-5}**	6.90×10^{-6}	3.6×10^{-2}	**2.5×10^{-7}**	**1.1×10^{-5}**	**1.6×10^{-4}**
Large perforation	15.,576	1.18×10^{-5}	7.0×10^{-1}	**8.26×10^{-6}**	6.90×10^{-6}	3.6×10^{-2}	**2.5×10^{-7}**	**8.5×10^{-6}**	**1.3×10^{-4}**
Full bore rupture	18,237	7.8×10^{-6}	6.0×10^{-1}	**4.68×10^{-6}**	4.60×10^{-6}	3.5×10^{-2}	**1.6×10^{-7}**	**4.7×10^{-6}**	**7.0×10^{-5}**

Table 16: Risks to reefs and shorelines showing the probability that condensate would reach the locations and the minimum elapsed time required for specific accidents. Estimates are based on 50 spills modeled under randomly selected conditions of tidal state and historic winds recorded for the season.

Accident	Season	Location	Probability of contact	Minimum time before contact
Process leaks and blowouts at platform				
Gas blowout	Summer	West fringing reef	2%	3 hours
	Winter	West fringing reef	2%	4 hours
		Hermite Island	2%	10 hours
		Southern islands	2%	9 hours
Unprocessed gas - large perforation	Summer	No contact		
	Winter	No contact		
Condensate - small perforation	Summer	West fringing reef	2%	4 hours
	Winter	West fringing reef	2%	7 hours
Condensate - large perforation	Summer	West fringing reef	4%	3 hours
	Winter	West fringing reef	2%	5.5 hours
		Southern reef	1%	6 hours
		Hermite Island	2%	9.5 hours
		Southern islands	2%	9 hours
Pipeline leaks and ruptures at platform				
Corrosion pitting	Summer	West fringing reef	16%	3 hours
		Northern reef	6%	12 hours
		Hermite Island	4%	9 hours
		Southern islands	2%	9 hours
	Winter	West fringing reef	40%	4 hours
		Southern reef	30%	9 hours
		Hermite Island	10%	9 hours
		Southern islands	40%	9 hours
Small perforation	Summer	West fringing reef	90%	3.5 hours
		Northern Reef	70%	7 hours
		Southern Reef	30%	5 hours
		Crocus Island	6%	>12 hours
		Alpha Island	2%	>12 hours
		Primrose Island	2%	>12 hours
		Norwest Island	2%	>12 hours
		Hermite Island	15%	9 hours
		Southern islands	30%	9 hours
	Winter	West fringing reef	40%	5.5 hours
		Southern Reef	40%	5.5 hours
		Hermite Island	4%	>12 hours
		Southern islands	40%	9.5 hours
Large perforation	Summer	West fringing reef	4%	5.5 hours
		Hermite Island	2%	9 hours
		Southern islands	2%	9 hours
	Winter	West fringing reef	4%	9.5 hours
		Southern islands	2%	9 hours
Full bore rupture	Summer	West fringing reef	2%	3 hours
	Winter	West fringing reef	2%	4 hours
		Hermite Island	2%	10 hours
		Southern islands	2%	9 hours

Table 16 cont.

Accident	Season	Location	Probability of contact	Minimum time before contact
Pipeline leaks and ruptures 2-3 km west of Varanus Island				
Corrosion pitting	Summer	Bridled Island	14%	2 hours
		Varanus Island	4%	2 hours
	Winter	Bridled Island	60%	2 hours
		Varanus Island	20%	3 hours
		Parakeelya Island	10%	4 hours
		Barrow Island	2%	>12 hours
Small perforation	Summer	Varanus Island	40%	9.5 hours
		Bridled Island	70%	3 hours
	Winter	Bridled Island	80%	2 hours
		Varanus Island	20%	2 hours
		Barrow Island	20%	9 hours
Large perforation	Summer	Bridled Island	2%	2 hours
		Varanus Island	2%	3 hours
		Double Island	2%	3 hours
	Winter	Bridled Island	6%	3 hours
		Varanus Island	4%	3 hours
		Double Island	2%	>12 hours
Full bore rupture	Summer	Bridled Island	2%	3 hours
		Varanus Island	2%	3 hours
	Winter	Bridled Island	14%	3 hours
		Varanus Island	4%	3 hours
		Parakeelya Island	4%	12 hours

Table 16 cont.

Accident	Season	Location	Probability of contact	Minimum time before contact
Pipeline leaks and ruptures within 500 m west of Varanus Island				
Corrosion pitting	Summer	Bridled Island	100%	5 hours
		Varanus Island	8%	2 hours
		Parakeelya Island	6%	9 hours
	Winter	Bridled Island	30%	4 hours
		Varanus Island	50%	2 hours
		Parakeelya Island	30%	6 hours
		Barrow Island	20%	>12 hours
Small perforation	Summer	Bridled Island	90%	2 hours
		Varanus Island	10%	3 hours
	Winter	Bridled Island	20%	3 hours
		Varanus Island	36%	2 hours
		Barrow Island	8%	>12 hours
Large perforation	Summer	Bridled Island	21%	4 hours
		Varanus Island	70%	2 hours
		Parakeelya Island	8%	6 hours
		Barrow Island	4%	>12 hours
	Winter	Bridled Island	24%	4 hours
		Varanus Island	36%	2 hours
		Parakeelya Island	8%	6 hours
		Barrow Island	4%	12 hours
Full bore rupture	Summer	Bridled Island	12%	4 hours
		Varanus Island	60%	2 hours
		Parakeelya Island	6%	9 hours
	Winter	Bridled Island	25%	6 hours
		Varanus Island	35%	2 hours
		Parakeelya Island	5%	12 hours

Leaks due to small pipeline perforations near the platform, and which may continue for some time before they are detected and isolated, are predicted to have a higher probability of contacting reefs or shores (up to 90%; Figures 8 and 9). This is due to the continual input of condensate, which would be subject to varying wind and tide conditions, and would therefore have a greater potential of spread. Balancing this greater probability is the low quantities of condensate that would be on the water at any time or place. For example, for a continuous leak from a small perforation in the pipeline at 20 °C and with no wind, OILMAP predicted that 17% of the spilt condensate would remain on the water surface during the period of release. At 28 °C, with a steady 15 knot wind, the model predicted that only 5% would remain on the water surface during the period of release.

For most accident types, reefs and shorelines were generally predicted to have a similar probability of contact during summer and winter, although the shorelines affected sometimes differed (Table 16). This result was due to the contrasting influence of ambient temperatures and prevailing winds in each season. During winter, condensate evaporation was slowest. However, the prevailing wind tended to push oil to the southwest and away from the Montebello Islands. In contrast, the prevailing winds experienced in summer tended to drive oil to the northeast, and towards the fringing reefs and islands. However, the higher air and water temperatures expected in this season reduced the potential for condensate to spread to the northern reefs and shorelines for most scenarios.

Risk to the Lowendal Islands and Barrow Island

The risk assessment showed that, taking into account both the accident frequency and the probability or transport to shore, there was a relatively low overall risk that the Lowendal Islands or Barrow Island would receive condensate released from the pipeline (Table 15). The highest overall risk during the lifetime of the pipeline was predicted to be from chronic leaks, which might result from corrosion or fatigue, rather than from catastrophic pipeline failure. A rigorous programme of routine monitoring and preventative maintenance will mitigate such risks.

The shoreline locations which could potentially receive condensate varied with the spill location, the spill size, and the season, but usually included the west sides of Varanus Island and Bridled Island (Table 16). The probability of condensate spills contacting these locations increased with their proximity to the leak. Risks to these shores were also generally greater during summer, when prevailing winds are to the northeast. Barrow Island was generally considered to be at risk only during winter, and only after condensate had been on the water for 12 hours or longer and hence subject to considerable evaporation.

Although, under some accident scenarios, there was a relatively high probability that the island shores would receive condensate, the overall risk during the lifetime of the pipeline was still comparatively low, due to the low frequency of such accidents.

4.5 Consequences of an Oil Spill

The environmental effects of hydrocarbon spills will vary, amongst other things, on the toxicity of the oil, the concentration and nature of dissolved or dispersed hydrocarbons, the length of exposure to the hydrocarbons, and the sensitivity of individual marine species. In general, the greatest effects will be exerted on sensitive species that are found in shallow, sheltered waters where hydrocarbons may accumulate for an extended time. Subtidal habitats may be protected from hydrocarbons due to the overlying water column. Biota living in habitats exposed to strong currents and wave action may be relatively unaffected due to a short period of exposure to hydrocarbons. The environmental effects of hydrocarbons vary and can include:

- Mortality through direct smothering.
- Mortality through toxic effects.

- Physiological stress that does not lead to mortality
- Bioaccumulation of hydrocarbons for a period after the spill
- Physical or chemical alteration of habitats that may induce longer term changes in population or community structure.

It is important to place any such changes in context with the natural variation observed in natural marine communities. Such communities are highly dynamic, and change constantly due to natural fluctuations in physical and biological factors such as temperature, cyclone frequency, sand movement, predation, competition and recruitment success.

Marine habitats that have been altered by oil contamination will begin to recover as soon as the toxicity of the oil has degraded to a level that can be tolerated by resistant species. The time scales of recovery will vary from species to species, and with the severity of the initial disturbance, with observed periods ranging from a few days, to more than a decade for severely polluted locations (GESAMP 1993).

The chances of condensate reaching the sensitive resources adjacent to the Wonnich drilling and development location is considered to be low. However, the resources which are considered most at risk from a spill are listed below in order of protection priority:

- mangroves and associated tidal flats
- coral reefs (during low tide)
- seagrass beds (during low tide)
- beaches used by marine turtles and seabirds

The main commercial marine resource requiring protection in the area comprises pearl farm sites in the Montebello Islands and within the Dampier Archipelago.

Detailed information of the impact of oil on various resources is given in Appendix 8. An overview of the consequences is given in Table 17.

4.6 Oil Spill Response Actions and Strategies

Details of response actions and strategies to be taken in the event of an oil spill are detailed in Apache's Oil Spill Contingency Plan.

Should an oil spill occur, Apache would immediately take the following actions:

- follow procedures to protect human life and equipment. Implement procedures to reduce the risk of fire or explosion;
- cut off the supply of oil to the spillage;
- identify the extent of spillage and the weather/current conditions in the area;
- implement offshore and onshore actions for oil spill tracking, dispersion, containment, collection, treatment and clean-up, as appropriate;
- response actions will be coordinated in accordance with the three tiers of Oil Spill Control depending on the size of the spill, the proximity to environmentally sensitive areas and the resources available to control the spill. Response team members and responsibilities are set out in the Oil Spill Contingency Plan;
- if an oil slick is likely to reach a shoreline, advise fisheries and pearling companies, and wildlife agencies. Advise appropriate agencies to assume responsibility for wildlife rehabilitation activities; and
- monitor affected shoreline and intertidal zones to determine environmental effects of spill impact and clean up operations.

Response strategies to spillage include the following principal options:

- Take no action other than surveillance
- Combat the slick at sea
- Shoreline deflection and/or clean-up.

The implementation of a strategy or combination of strategies is dependent upon physical conditions prevalent at the time. The speed and direction of winds and currents, general sea conditions and the type of spill will determine which combination of options is suitable.

Given the location of the Wonnich field, the amount of time before any spill hits any land, and the characteristics of Wonnich condensate, the most effective response to a spill that is moving towards sensitive resources would be agitation by vessel propellers, containment and shoreline deflection, with the aim of extending the potential for evaporation. Spills that were moving away from shore areas would be continuously monitored while the oil degrades and disperses naturally. Response equipment and personnel would be placed on standby as a contingency.

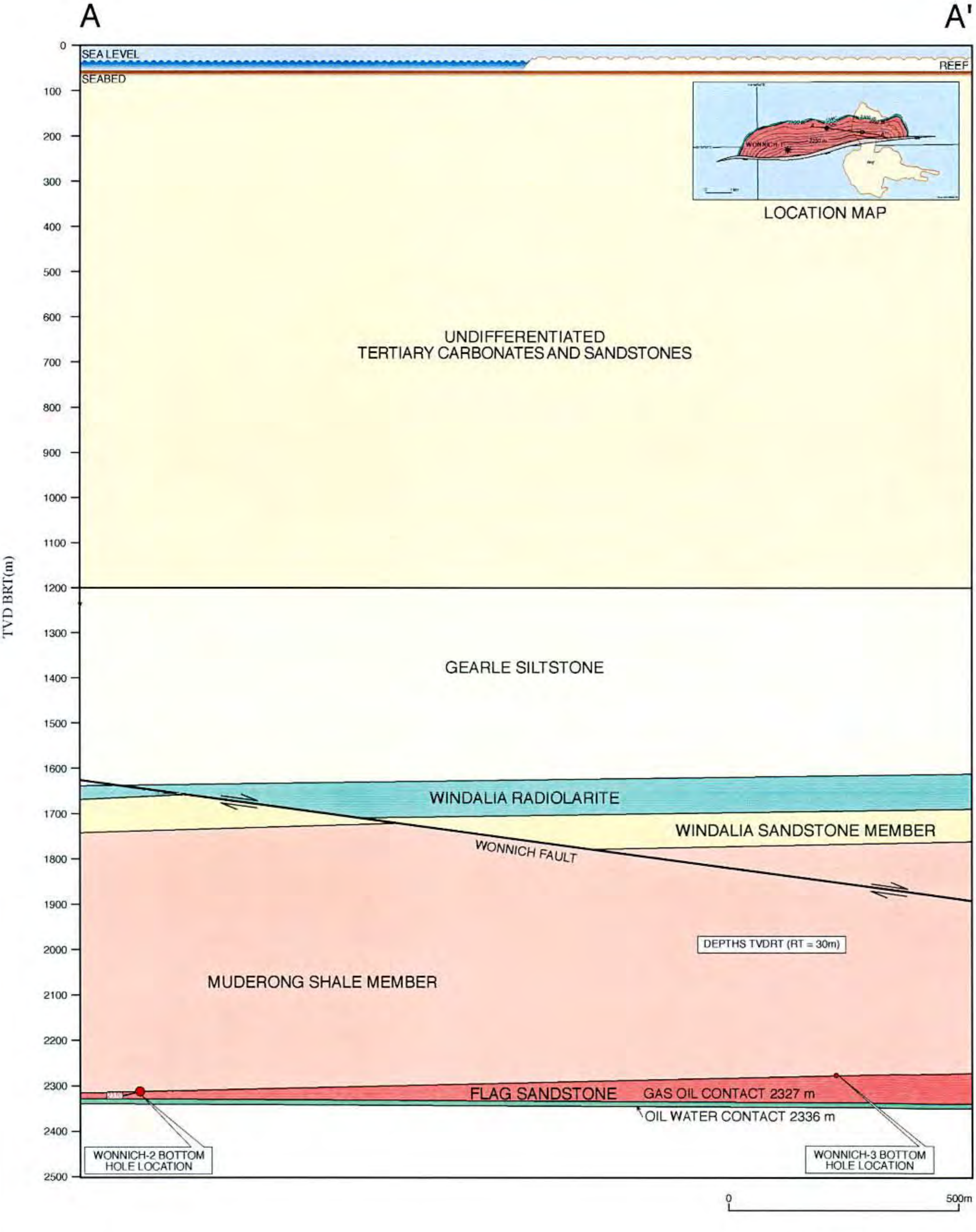
Table 17: Overview of the consequences of an oil spill on natural and social resources. A light crude oil is used as the source of impact.

Resource	Importance	Impact	Recovery time
Plankton	Component of marine food chain. Primary producers. Many marine species have larval form in plankton.	Major impact will be to plankton on surface of the water where oil is located. Plankton in water column may be affected as light crude is somewhat soluble.	Immediate Spatial movement and effective reproductive strategies will result in rapid recovery.
Subtidal seabed communities	Potentially high biological productivity. Feeding grounds for turtles, dugongs and fish.	Effect minimal except in shallower waters where oil may reach the seabed. Toxic components in oil may affect flora and fauna. Heavier oil may persist in sand sediment for period of time.	1 year. Rapid recovery due to spatial movement of animals and high reproductive capacity of colonizing species.
Rocky intertidal shores	Dominated by oysters and barnacles. Includes array of other fauna and flora. Rock platforms used by birds.	Damage by smothering or toxic effects. Oil may not adhere to rock for long period of time. Low potential for oil accumulation except in crevices and pools. Natural cleansing by waves reduces persistence of oil.	1-2 years.
Mud tidal flats	Supports mangrove communities. High productivity. Feeding grounds for wading birds.	Oil may not penetrate very deep due to fine sediment, but may accumulate at high tide level. Burrows of animals may act as pathways for oil, assisting penetration. Severe impact to fauna may lead to reduced food supply for wading birds.	2-10 years. Dependent on penetration of oil and tolerance of animals.
Sandy beaches	Turtle nesting grounds, associated fish species in shallow waters off sandy beaches.	Accumulated oil may affect nesting turtles or hatchlings on their way to the ocean. Some oil may penetrate into sand and persist for a period of time. Seepage of accumulated oil may impact fauna.	2-10 years. Dependent on penetration and accumulation of oil.
Algae and seagrass beds	Stabilize shoreline and seabed. Highly productive. Food source for turtles and dugongs. Nursery grounds for marine invertebrates. Provide shelter.	Algae is considered to be relatively resilient to oil. Intertidal seagrass beds most prone to damage. Tolerance to oil varies amongst species. Depressed growth rate, leaves turning brown, covering by algae are reported responses. Animals associated with seagrasses could be heavy impacted.	Algae: 1 year Seagrass: 1 year - decades

Table 17 cont.

Resource	Importance	Impact	Recovery time
Corals	Provide habitat for high density and diversity of animals. Nurseries for many fish. Important for tourism.	Minimal impact if coral remains submerged and oil is mixed in the water column. Localised tissue rupture, increased algae growth, excessive mucous production are potential responses. If coral dies, habitat composition may change to predominantly algae. Some corals long lived and slow growing. Recovery dependent on recruitment success.	1 year - decades
Mangroves	Highly productive. Source of food and shelter for wide diversity of organisms. Nursery grounds for some marine species. Stabilize shoreline.	Oil may persist for long time in sediment, especially where penetration has occurred (i.e. down animal burrows). Response range from defoliation, chlorosis and death of trees due to toxic impact. Infauna may be decimated by oil due to its toxicity.	Trees: 10-50 years Fauna: 2-5 years
Fin fish	Commercial and recreational value. Contribute to food chain.	Low risk of impact to adults in open water due to mobility. Toxic component may cause tainting or death to fish in sheltered waters. Larvae and eggs floating on surface prone to impact.	Years in enclosed waters.
Seabirds	Lovely to observe. Add to biodiversity of area.	Damage to plumage and ingestion .	Slow to medium recovery depending on reproductive potential.
Turtles	Add to conservation status and biodiversity to area. Food source to indigenous people.	May be prone to eye infections if contact made with oil. Mobile and can therefore avoid oil. Greatest impact will be to nesting turtles and hatchlings. May ingest oil while feeding.	Slow recovery.
Marine mammals	Add to conservation status and biodiversity of area.	Appear to be able to avoid oil. However, if come into contact, may suffer eye infections, skin irritations, inhalation of fumes, ingestion of oil. Dugongs may be affected if food source impacted.	Slow recovery.
Finfish	Economic value.	Oil which contacts finfish or invertebrate fisheries (crabs, crayfish, prawns) can cause direct mortality or sublethal effects that may inhibit growth and reproduction. Decimation of stocks may result in economic impact.	Slow to medium.
Tourism	Economic value.	Access to oiled beaches to be avoided, fishing may be restricted and some natural resources used for diving may be restricted for access.	Medium

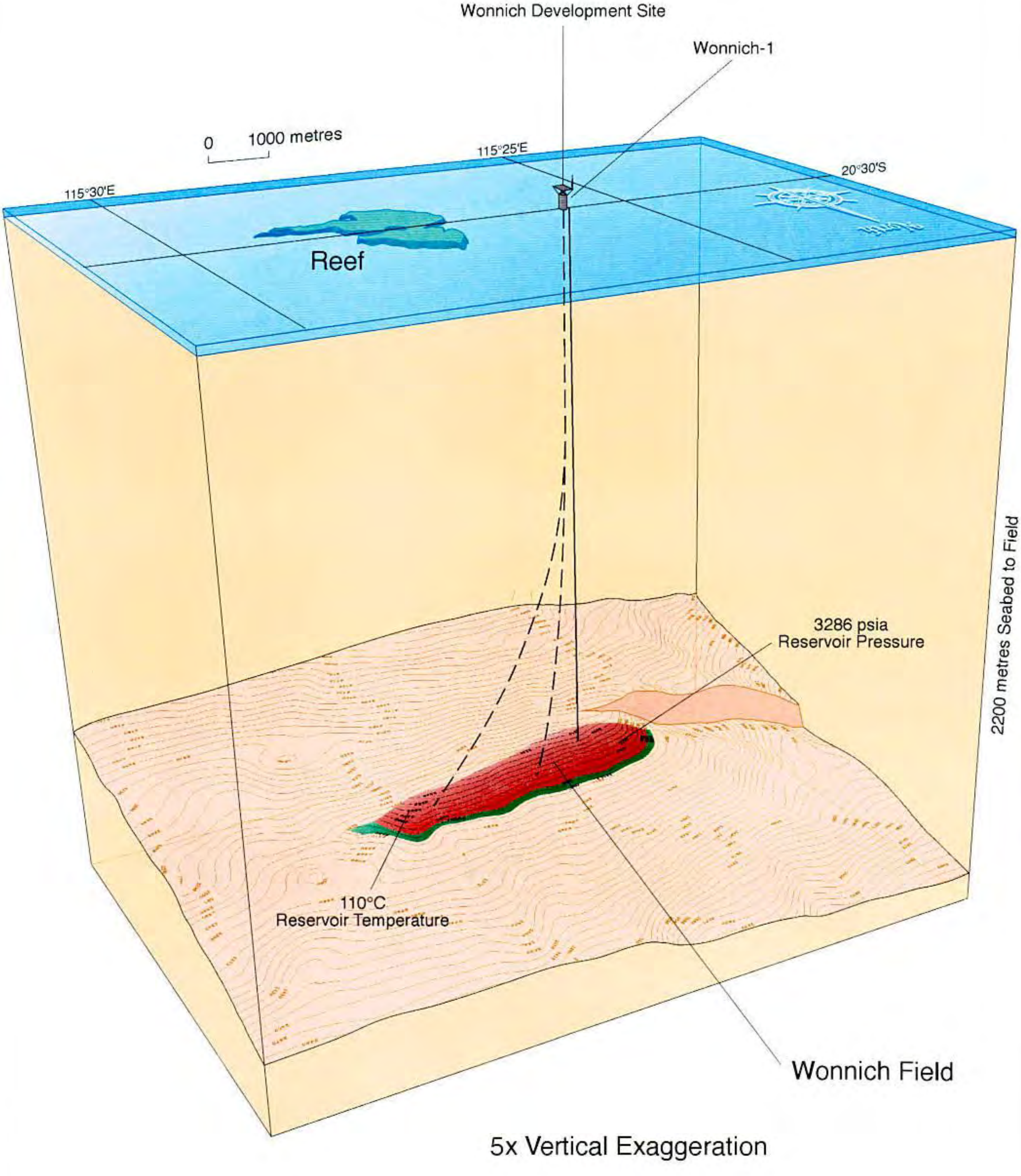
GEOLOGICAL CROSS SECTION THROUGH WONNICH WELL LOCATIONS



See also DG.m3468 6 November 1996 DG.m4110(P2)

Figure 13

PERSPECTIVE VIEW OF THE WONNICH FIELD LOOKING SOUTH-WEST

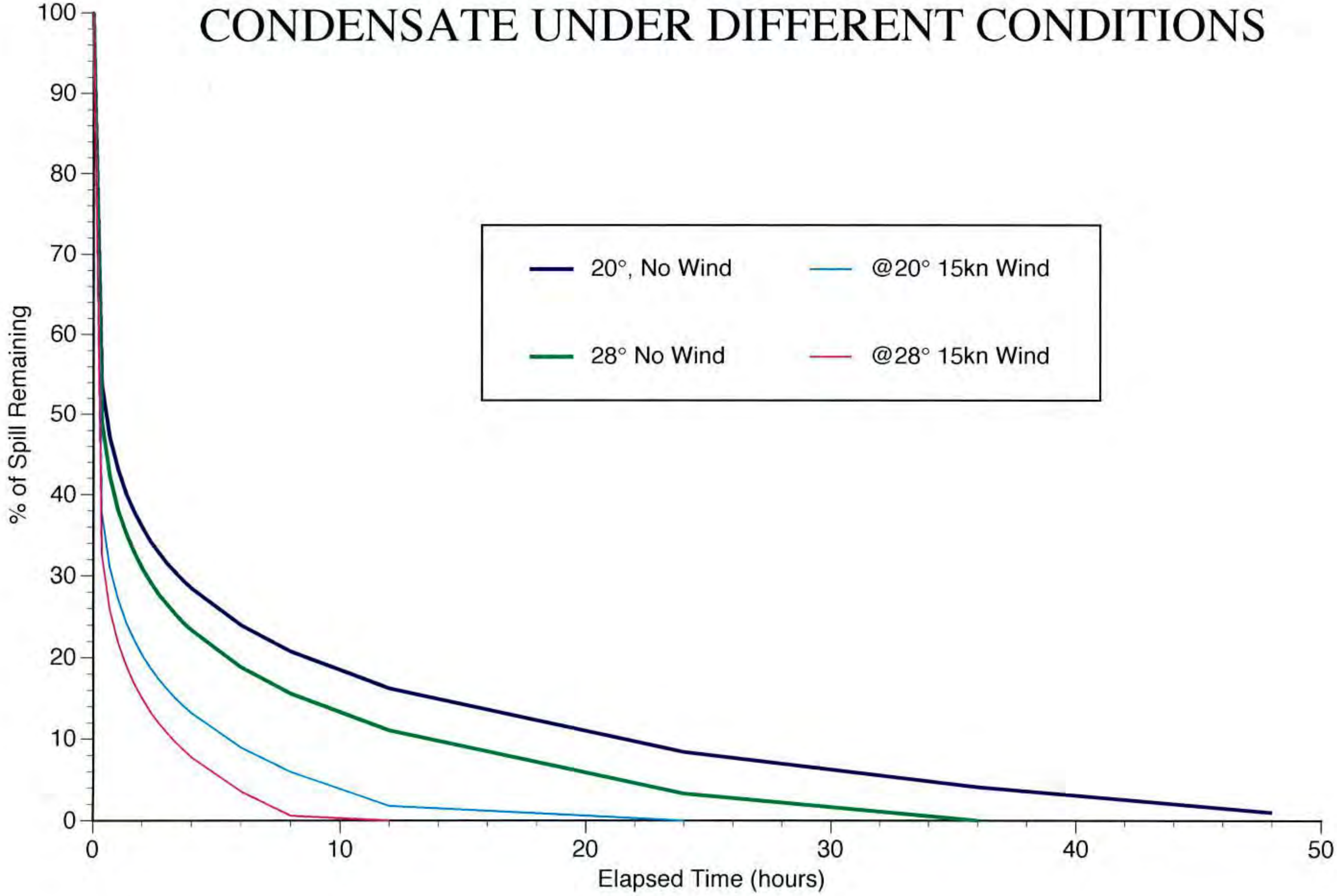


Taken from MDu3589 Dated: 24 October 1996 MD.m3588

Figure 14

Apache ENERGY

PREDICTED EVAPORATION RATES FOR CONDENSATE UNDER DIFFERENT CONDITIONS

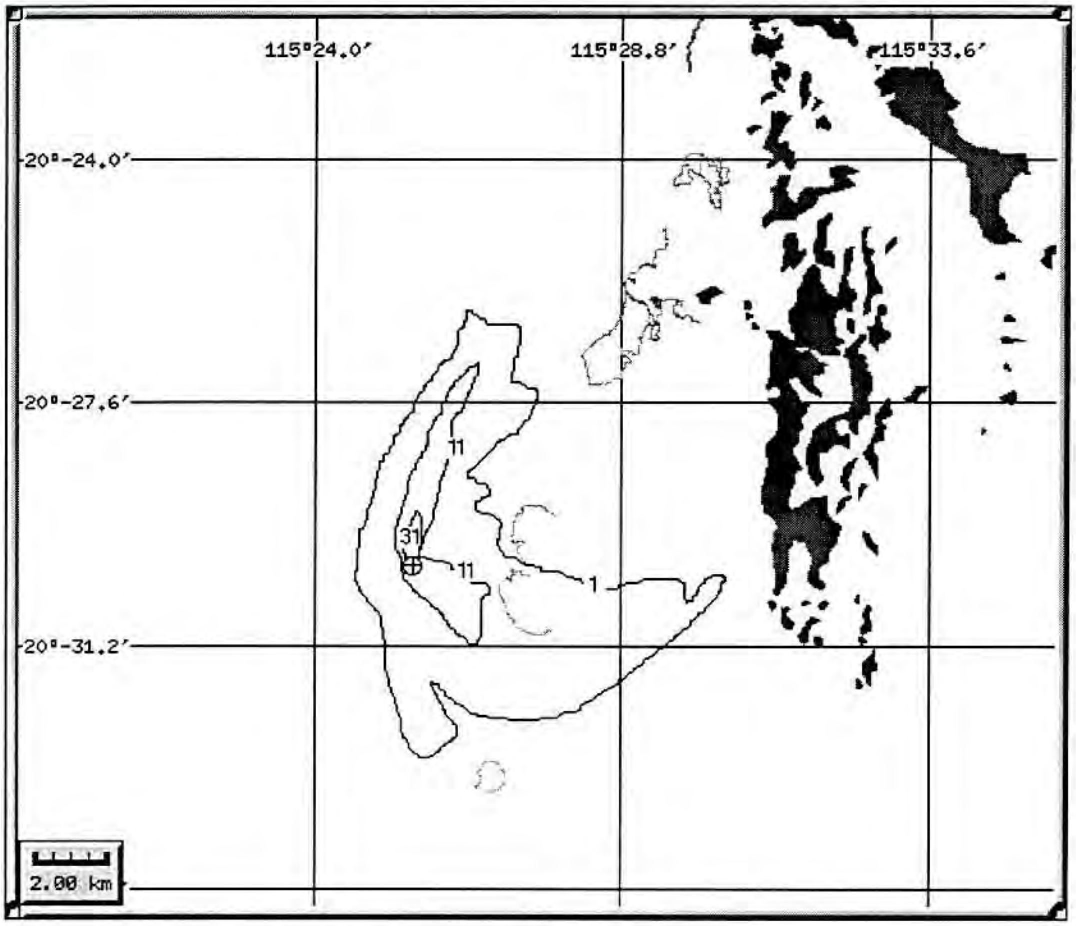


4 October 1996 SL.m3988

Figure 15

Figure 16
Scenario 1 : Gas blowout during summer

Gas blowout at the monopod location during the summer wind season (typically October to March, but also experienced during the transitional months of September and April-May). Emergency shut down is triggered by gas detection, isolating the release of gas in approximately 10 seconds. Estimated release of inventory as condensate at atmospheric pressure is 18,821 litres.



Probability contours showing the predicted risk (as %) of spills contacting particular locations.

Accident Scenario	Potential release (L)	Seasonal accident frequency*	Shallow sites contacted	Probability of contact	Overall risk to the site	Minimum time before contact
Gas blowout 1st year	18,821	2.81×10^{-3}	Western reef	2%	5.6×10^{-4}	3 hours
Gas blowout Subsequent years	18,821	1.77×10^{-3}	Western reef	2%	5.6×10^{-4}	3 hours

* Based on the summer lasting 63% of the year.

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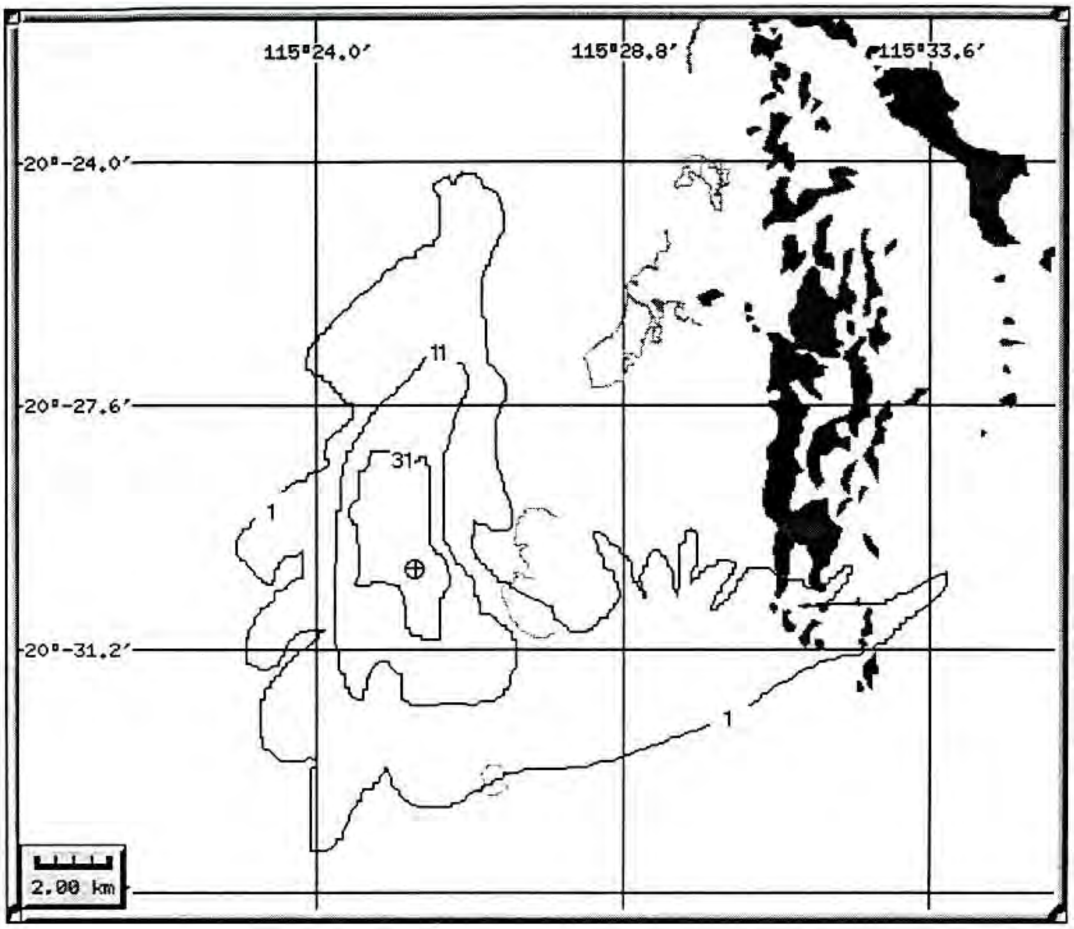
Figure 17
Scenario 2 : Gas blowout during winter

Gas blowout at the monopod location during the winter wind season (typically June to August, but also experienced during the transitional months of September and April-May). Emergency shut down is triggered by gas detection, isolating the release of gas in approximately 10 seconds. Estimated release of inventory as condensate at atmospheric pressure is 18,821 litres. Air and water temperatures at 20 °C.



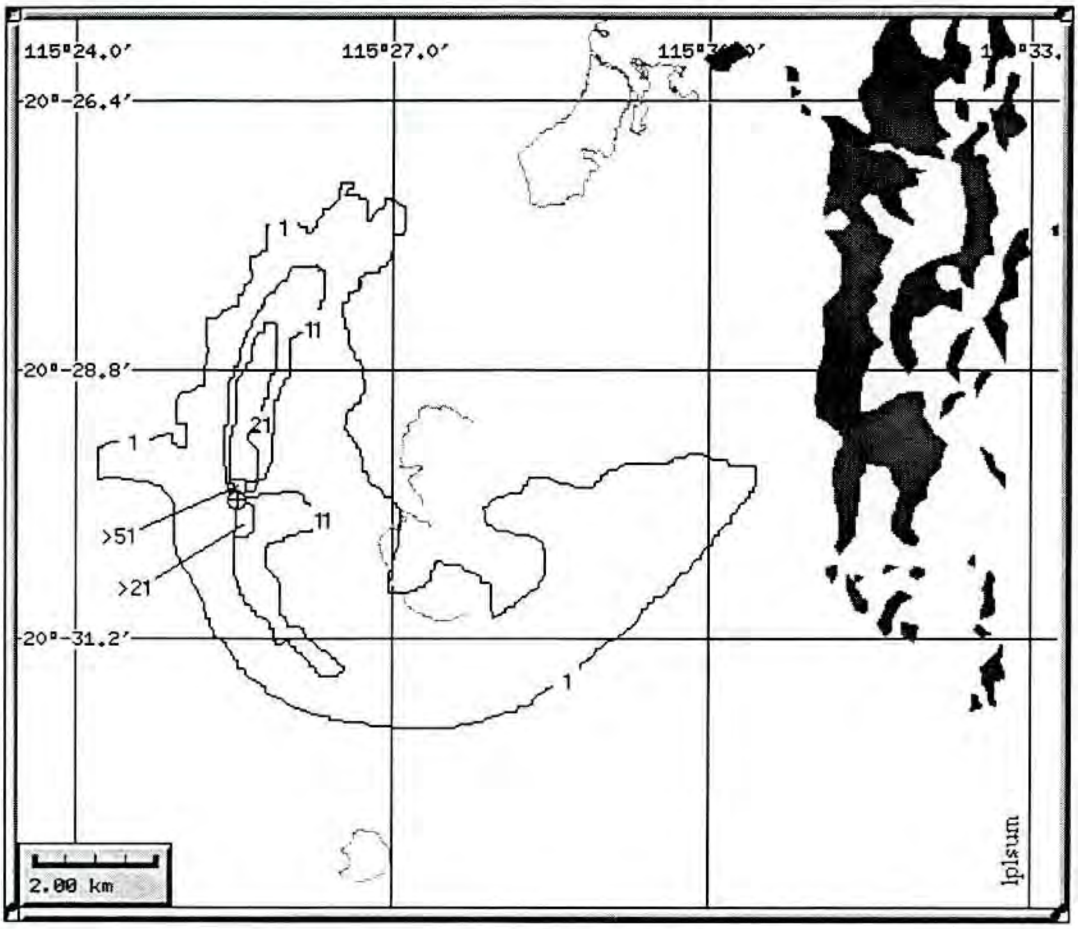
Probability contours showing the predicted risk (as %) of spills contacting particular locations.

Accident Scenario	Potential release (L)	Seasonal accident frequency*	Shallow sites contacted	Probability of contact	Overall risk to the site	Minimum time before contact
Gas blowout 1st year	18,821	2.81×10^{-3}	Western reef	2%	5.6×10^{-4}	4 hours
			Hermite Island	2%	5.6×10^{-4}	10 hours
			Southern islands	2%	5.6×10^{-4}	9 hours
Gas blowout Subsequent years	18,821	1.77×10^{-3}	Western reef	2%	3.5×10^{-4}	4 hours
			Hermite Island	2%	3.5×10^{-4}	10 hours
			Southern islands	2%	3.5×10^{-4}	9 hours

* Based on the winter lasting 37% of the year

Figure 18
Scenario 3 : Large condensate release from monopod during summer

Large perforation (>25 mm) in the condensate seperator facility on the monopod during the summer wind season. Emergency shut down is triggered by gas detection, isolating the release of gas in approximately 10 seconds. Estimated release of inventory as condensate at atmospheric pressure is 2,944 litres. Air and water temperatures are 28 °C.



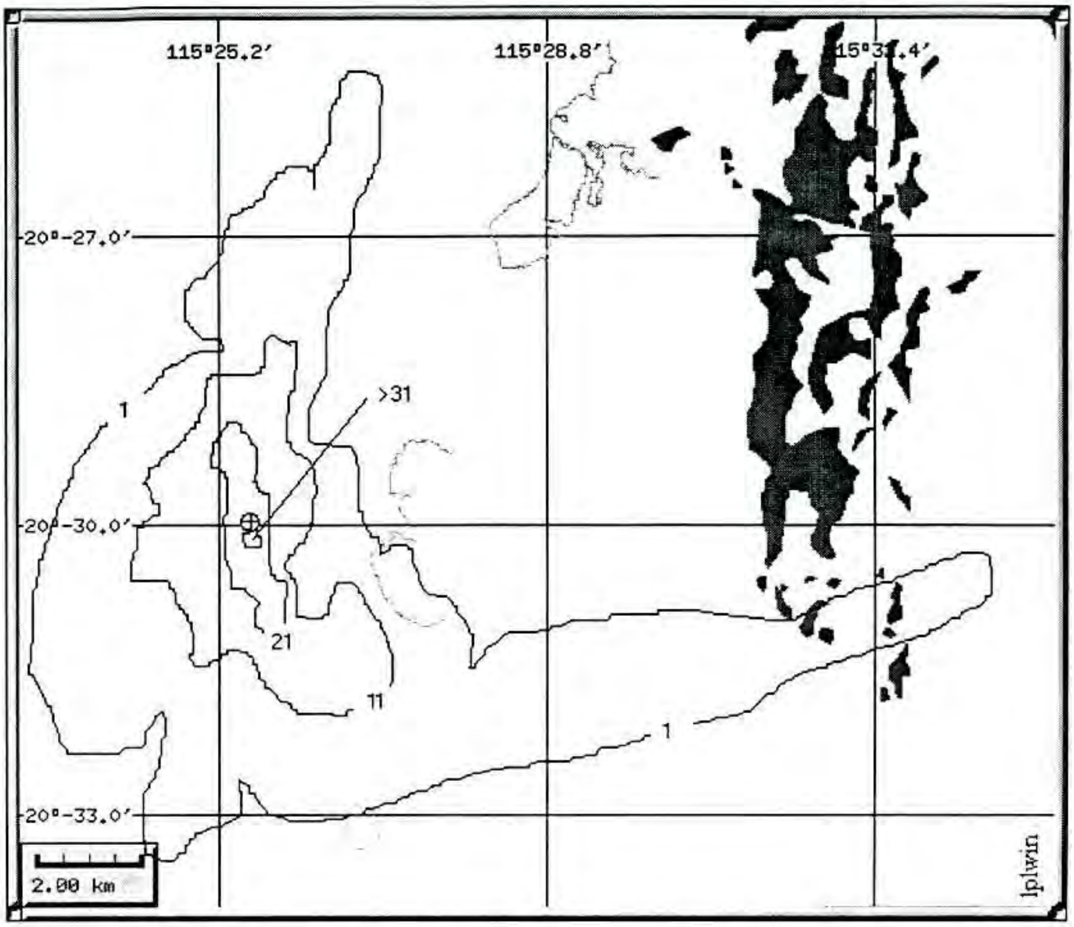
Probability contours showing the predicted risk (as %) of spills contacting particular locations.

Accident Scenario	Potential release (L)	Seasonal accident frequency*	Shallow sites contacted	Probability of contact	Overall risk to the site	Minimum time before contact
Large leak of condensate	2,944	1.98×10^{-4}	Western fringing Reef	4%	7.9×10^{-6}	3 hours

* Based on the summer lasting 63% of the year

Figure 19
Scenario 4 : Large condensate release from monopod during winter

Large perforation (>25 mm) in the condensate seperator facility on the platform during the winter wind season. Emergency shut down is triggered by gas detection, isolating the release of gas in approximately 10 seconds. Estimated release of inventory as condensate at atmospheric pressure is 2,944 ltres. Air and water temperatures are 20 °C.



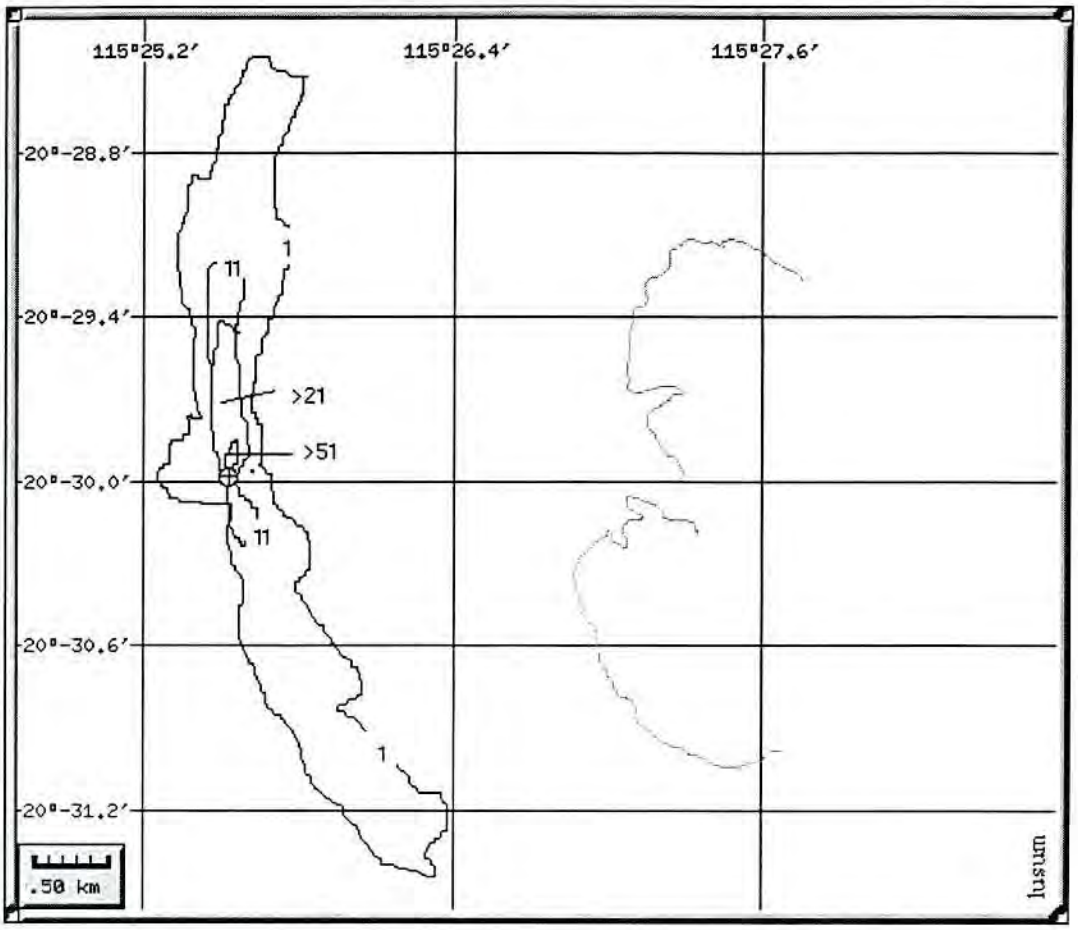
Probability contours showing the predicted risk (as %) of spills contacting particular locations.

Accident Scenario	Potential release (L)	Seasonal accident frequency*	Shallow sites contacted	Probability of contact	Overall risk to the site	Minimum time before contact
Large leak of condensate	2,944	1.16×10^{-4}	Western reef	2%	2.3×10^{-6}	5.5 hours
			Southern reef	1%	1.2×10^{-6}	6 hours
			Hermite Island	2%	2.3×10^{-6}	9.5 hours
			Southern islands	2%	2.3×10^{-6}	9 hours

* Based on the winter lasting 37% of the year

Figure 20
Scenario 5 : Large unprocessed gas release from monopod during summer

Large perforation (>25 mm) of unprocessed gas on the monopod during the summer wind season. Emergency shut down is triggered by gas detection, isolating the release of gas in approximately 10 seconds. Estimated release of inventory as condensate at atmospheric pressure is 216 litres. Air and water temperatures are 28 °C.



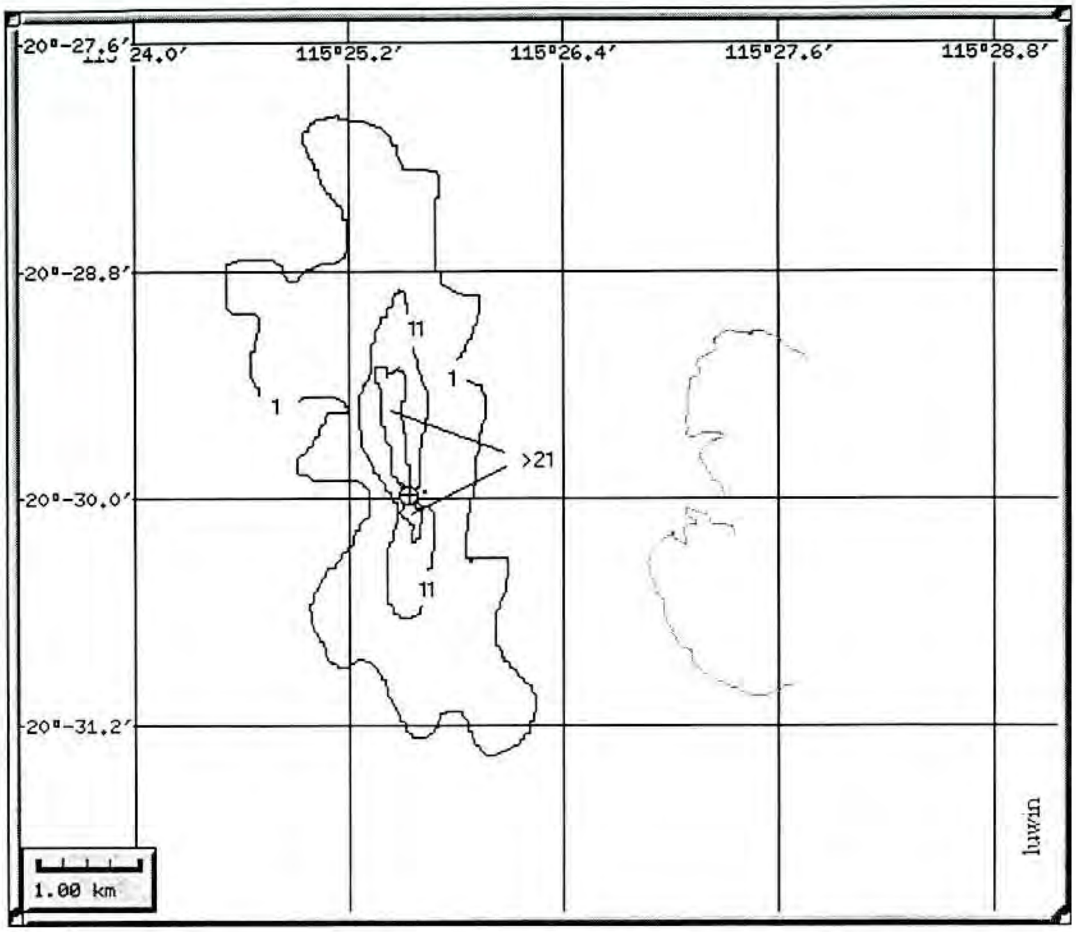
Probability contours showing the predicted risk (as %) of spills contacting particular locations.

Accident Scenario	Potential release (L)	Seasonal accident frequency*	Shallow sites contacted	Probability of contact	Overall risk to the site	Minimum time before contact
Large leak of unprocessed gas	216	1.24×10^{-3}	No contact	less than 1%	less than 1.2×10^{-5}	No contact

* Based on the summer lasting 63% of the year

Figure 21
Scenario 6 : Large unprocessed gas release from monopod during winter

Large perforation (>25 mm) of the unprocessed gas facilities on the platform during the winter wind season. Emergency shut down is triggered by gas detection, isolating the release of gas in approximately 10 seconds. Estimated release of inventory as condensate at atmospheric pressure is 216 litres. Air and water temperatures are 20 °C.



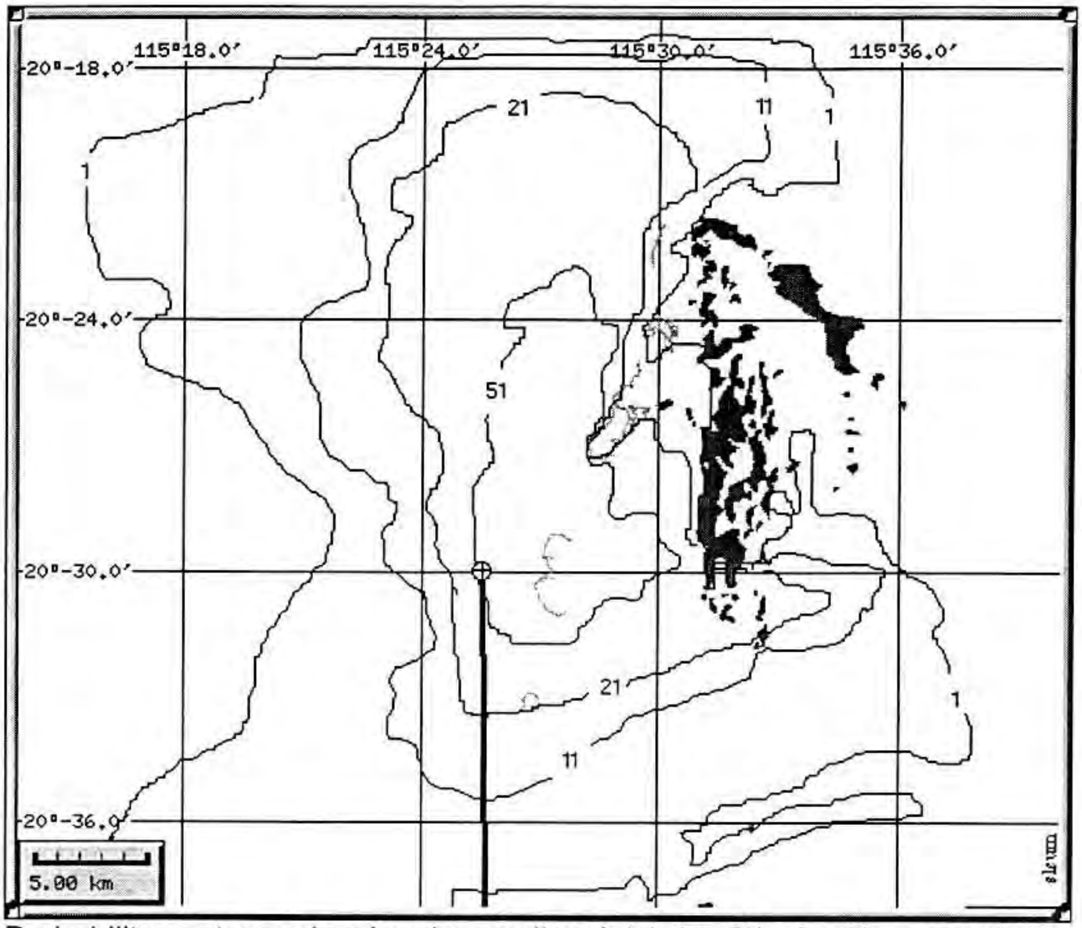
Probability contours showing the predicted risk (as %) of spills contacting particular locations.

Accident Scenario	Potential release (L)	Seasonal accident frequency*	Shallow sites contacted	Probability of contact	Overall risk to the site	Minimum time before contact
Large leak of unprocessed gas	216	1.24×10^{-3}	No contact	less tha 1%	less than 1.24×10^{-5}	No contact

* Based on the winter lasting 37% of the year

Figure 22
Scenario 7 : Small (20 mm) perforation in pipeline during summer

Small hole in the export pipeline near the platform location during the summer wind season. Detection is by metering anomalies at Varanus Island gas processing plant with isolation by telemetry. Flow time is 2 days. Estimated release of inventory as condensate at atmospheric pressure is 121,532 litres at 2,532 L hr^{-1}. Air and water temperatures are 28 °C.



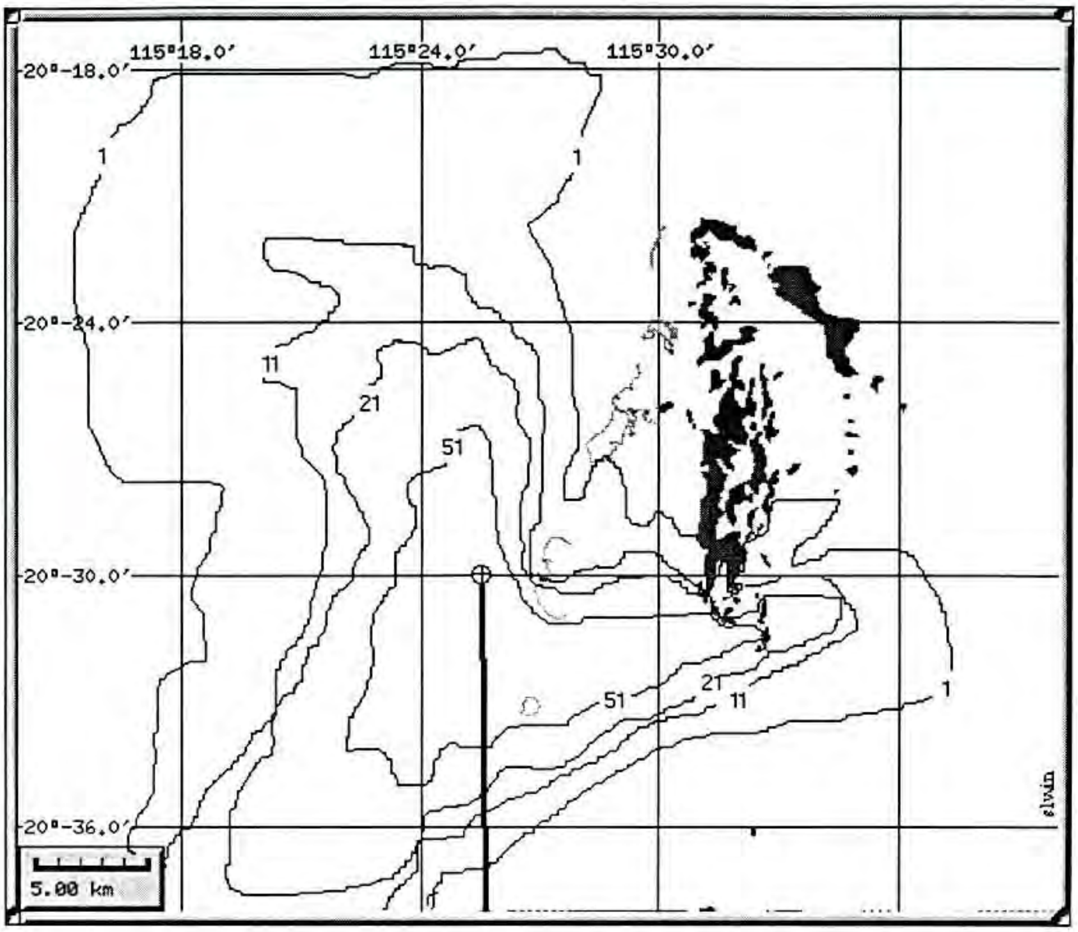
Probability contours showing the predicted risk (as %) of spills contacting particular locations.

Accident Scenario	Potential release (L)	Seasonal accident frequency*	Shallow sites contacted	Probability of contact	Overall risk to the site	Minimum time before contact
Small pipeline leak	121,532 over 2 days	2.35×10^{-5}	Western Reef	90%	2.1×10^{-5}	3.5 hours
			Northern Reef	70%	1.6×10^{-5}	7 hours
			Southern Reef	30%	7.0×10^{-6}	5 hours
			Crocus Island	6%	1.4×10^{-6}	>12 hours
			Alpha Island	2%	4.7×10^{-7}	>12 hours
			Primrose Island	2%	4.7×10^{-7}	>12 hours
			Norwest Island	2%	4.7×10^{-7}	>12 hours
			Hermite Island	15%	3.5×10^{-6}	9 hours
			Southern islands	30%	7.0×10^{-6}	9 hours

*Based on the summer lasting 63% of the year

Figure 23
Scenario 8 : Small (20 mm) perforation in pipeline during winter

Small hole in the export pipeline near the platform location during the winter wind season. Detection is by metering anomalies at Varanus Island gas processing plant with isolation by telemetry. Flow time is 2 days. Estimated release of inventory as condensate at atmospheric pressure is 121,532 litres at 2,532 L hr^{-1}. Air and water temperatures are 20 °C.



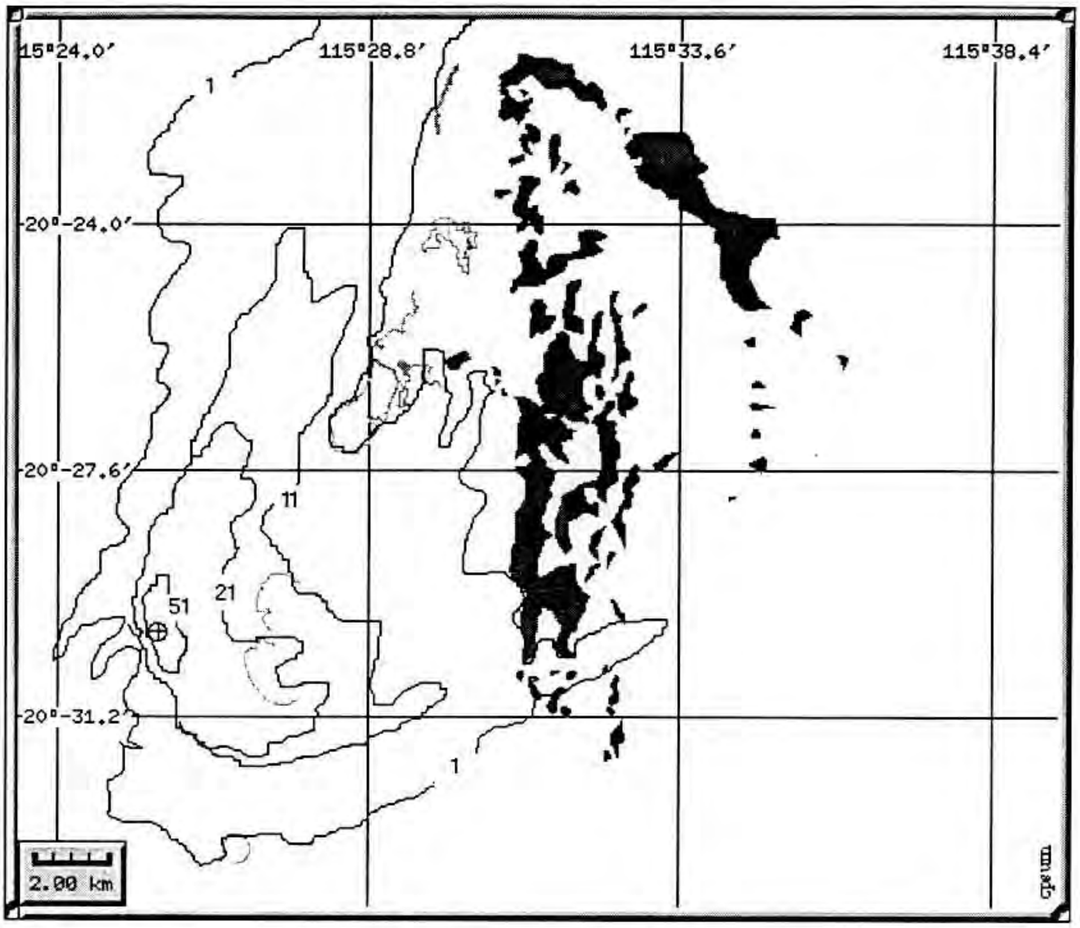
Probability contours showing the predicted risk (as %) of spills contacting particular locations.

Accident Scenario	Potential release (L)	Seasonal accident frequency*	Shallow sites contacted	Probability of contact	Overall risk to the site	Minimum time before contact
Small pipeline leak	121,532 over 2 days	1.38×10^{-5}	Western Reef	40%	9.4×10^{-6}	5.5 hours
			Southern Reef	40%	9.4×10^{-6}	5.5 hours
			Hermite Island	4%	9.4×10^{-7}	>12 hours
			Southern islets	40%	9.4×10^{-6}	9.5 hours

* Based on the winter lasting 37% of the year

Figure 24
Scenario 9 : Corrosion pitting (5 mm) in pipeline during summer

Corrosion pitting in the export pipeline near the platform location during the summer wind season. Detected during maintenance visit, with isolation by telemetry. Flow time is 10 days (actual visitation frequency is estimated to be each 5 days). Estimated release of inventory as condensate at atmospheric pressure is 19,470 litres at 81 L per hour. Air and water temperatures are 28 °C.



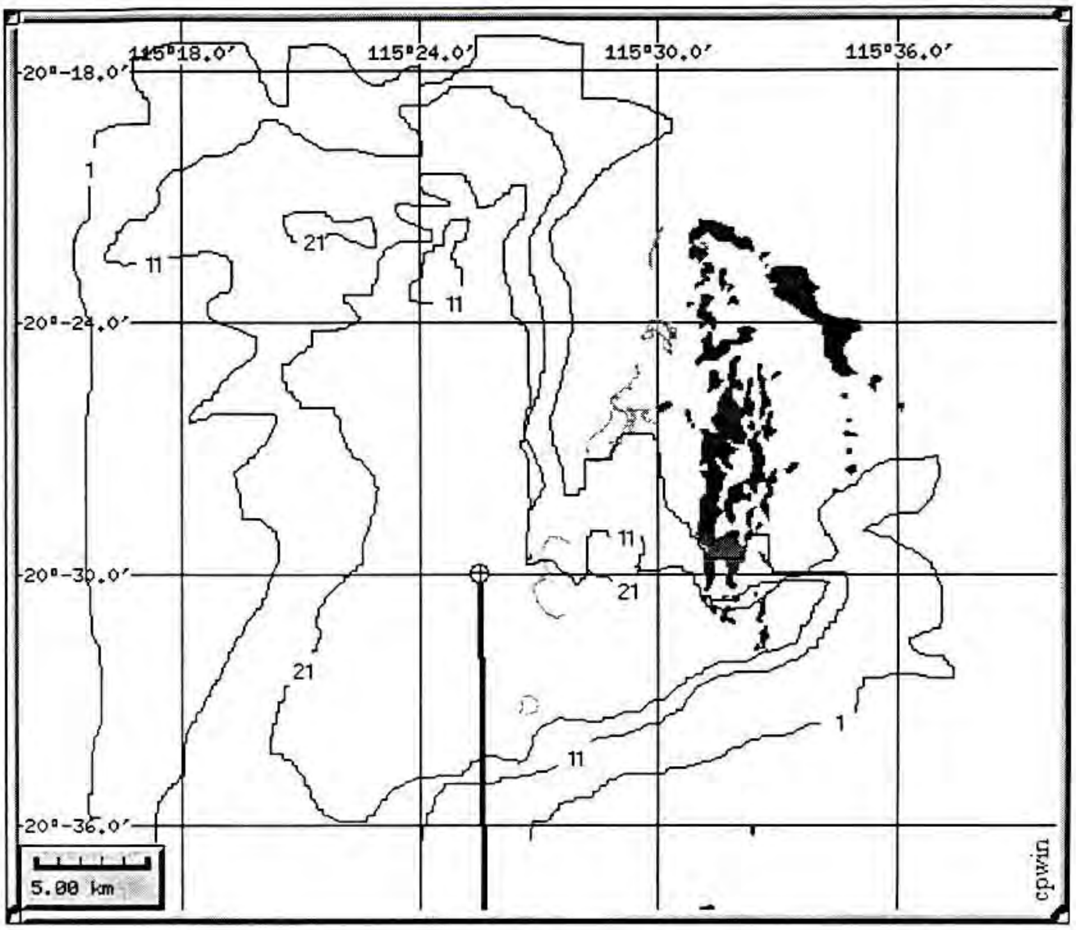
Probability contours showing the predicted risk (as %) of spills contacting particular locations.

Accident Scenario	Potential release (L)	Seasonal accident frequency*	Shallow sites contacted	Probability of contact	Overall risk to the site	Minimum time before contact
Corrosion pitting in pipeline	19,470 over 10 days	2.36×10^{-5}	Western reef	16%	3.8×10^{-6}	3 hours
			Northern reef	6%	1.4×10^{-6}	12 hours
			Hermite Island	4%	9.4×10^{-7}	9 hours
			Southern islands	2%	4.7×10^{-7}	9 hours

* Based on the summer lasting 63% of the year.

Figure 25
Scenario 10 : Corrosion pitting (5 mm) in pipeline during winter

Corrosion pitting in the export pipeline near the platform location during the winter wind season. Detected during maintenance visit, with isolation by telemetry. Flow time is 10 days (actual visitation frequency is estimated to be each 5 days). Estimated release of inventory as condensate at atmospheric pressure is 19,470 litres at 81 L hr^{-1}. Air and water temperatures are at 20 °C.



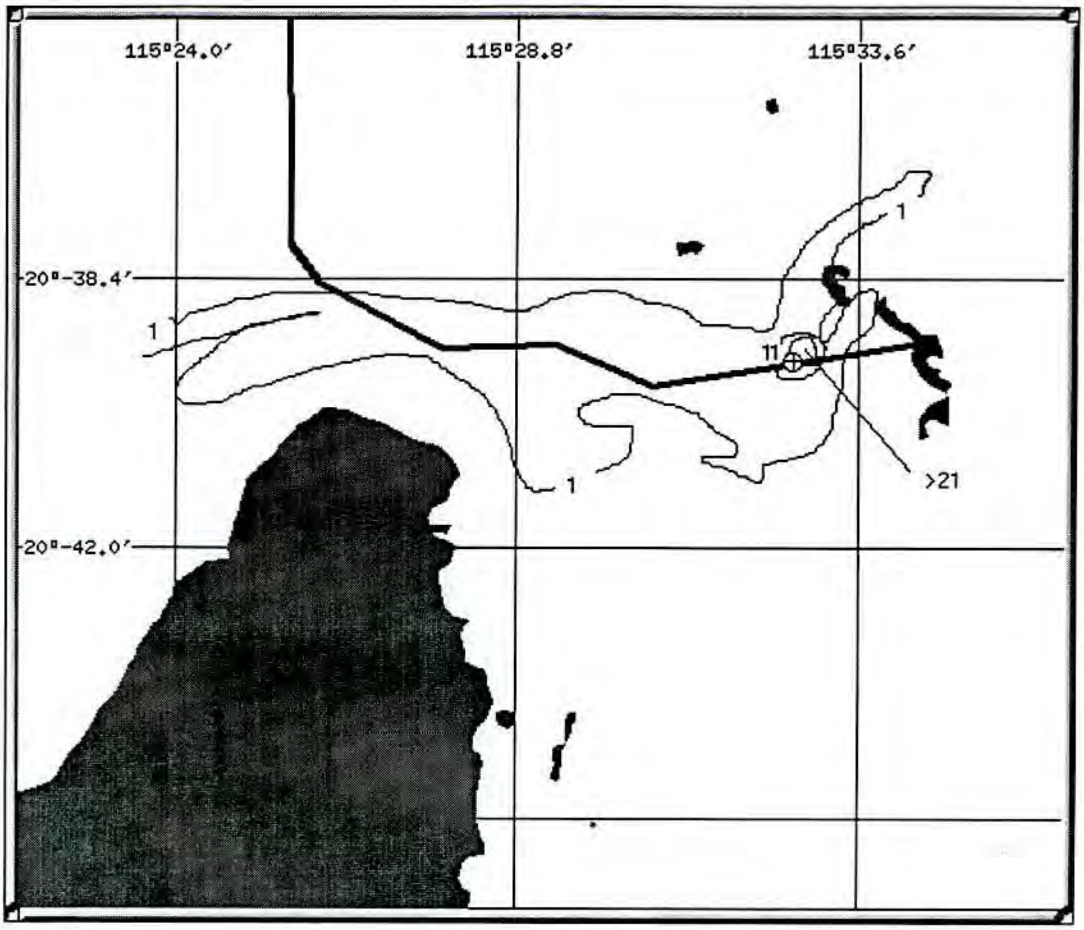
Probability contours showing the predicted risk (as %) of spills contacting particular locations.

Accident Scenario	Potential release (L)	Seasonal accident frequency*	Shallow sites contacted	Probability of contact	Overall risk to the site	Minimum time before contact
Corrosion pitting in pipeline	19,470 over 10 days	1.38×10^{-5}	Western reef	40%	3.8×10^{-6}	4 hours
			Southern reef	30%	1.4×10^{-6}	9 hours
			Hermite Island	10%	9.4×10^{-7}	9 hours
			Southern islands	40%	4.7×10^{-7}	9 hours

* Based on the winter lasting 37% of the year.

Figure 26
Scenario 11 : Full rupture of pipeline 2.5 km from Varanus Island during summer

Full rupture of export pipeline, 2-3 km from Varanus Island during the summer wind season. Immediate shut down of supply gas. Estimated release of inventory as condensate at atmospheric pressure is 18,237 L. Air and water temperatures are 28 °C.



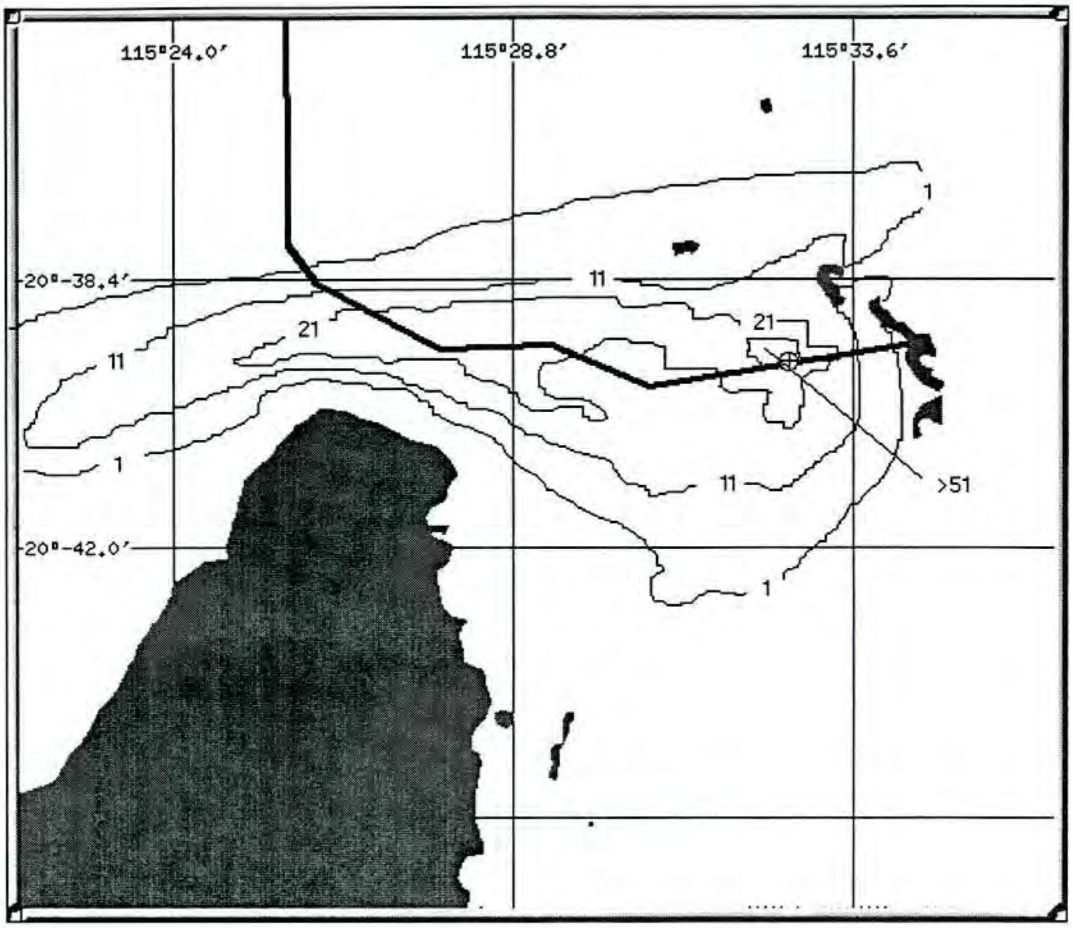
Probability contours showing the predicted risk (as %) of spills contacting particular locations.

Accident Scenario	Potential release (L)	Seasonal accident frequency*	Shallow sites contacted	Probability of contact	Overall risk to the site	Minimum time before contact
Full pipeline rupture	18,237	7.8×10^{-6}	Bridled Island	2%	1.5×10^{-7}	4 hours
			Varanus Island	2%	1.5×10^{-7}	2 hours

* Based on the summer lasting 63% of the year

Figure 27
Scenario 12 : Full rupture of pipeline 2.5 km from Varanus Island during winter

Full rupture of export pipeline, 2-3 km from Varanus Island during the winter wind season. Immediate shut down of supply gas. Estimated release of inventory as condensate at atmospheric pressure is 18,237 L. Air and water temperatures are 20 °C.



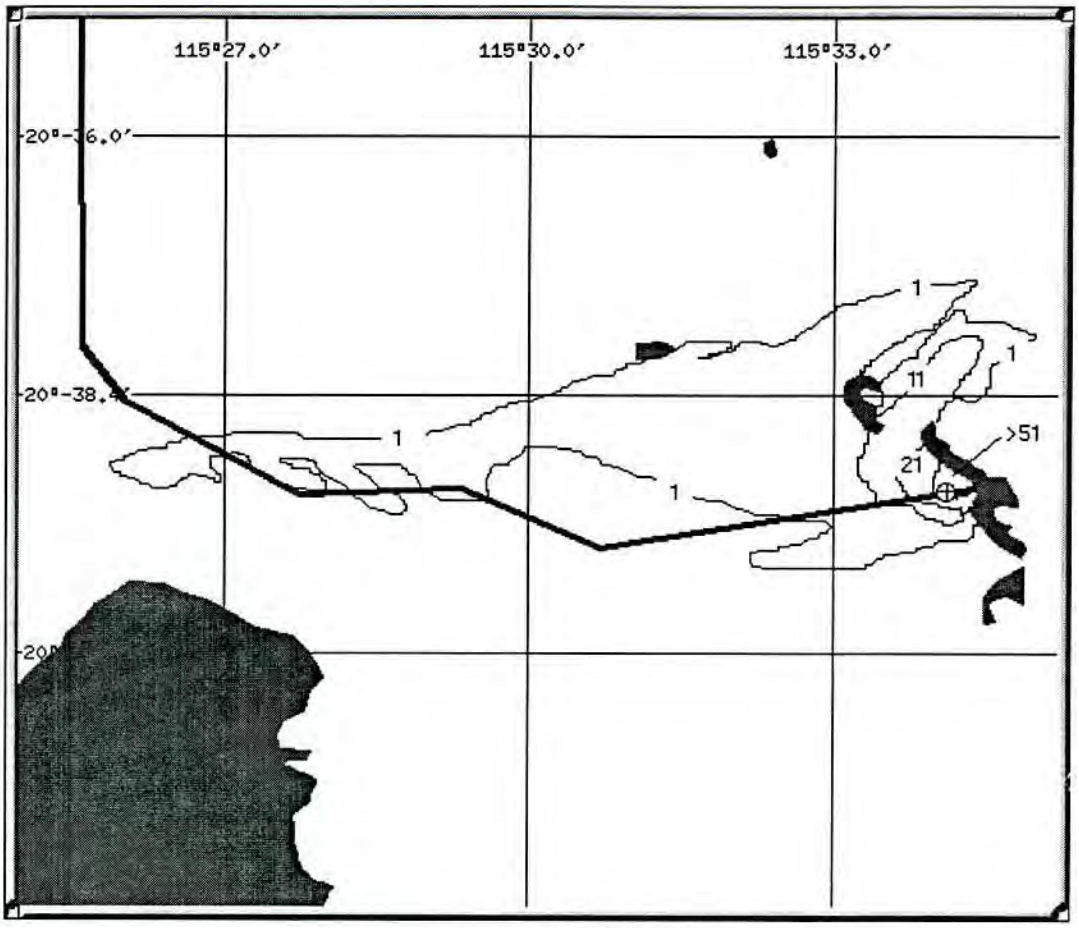
Probability contours showing the predicted risk (as %) of spills contacting particular locations.

Accident Scenario	Potential release (L)	Seasonal accident frequency*	Shallow sites contacted	Probability of contact	Overall risk to the site	Minimum time before contact
Full pipeline rupture	18,237	9.2×10^{-6}	Bridled Island	14%	1.3×10^{-6}	3 hours
			Varanus Island	4%	3.7×10^{-7}	3 hours
			Parakeelya Island	4%	3.7×10^{-7}	12 hours

* Based on the winter lasting 37% of the year

Figure 28
Scenario 13 : Full rupture of pipeline 500 m from Varanus Island during summer

Full rupture of export pipeline, 2-3 km from Varanus Island during the summer wind season. Immediate shut down of supply gas. Estimated release of inventory as condensate at atmospheric pressure is 18,237 L. Air and water temperatures are 28 °C.



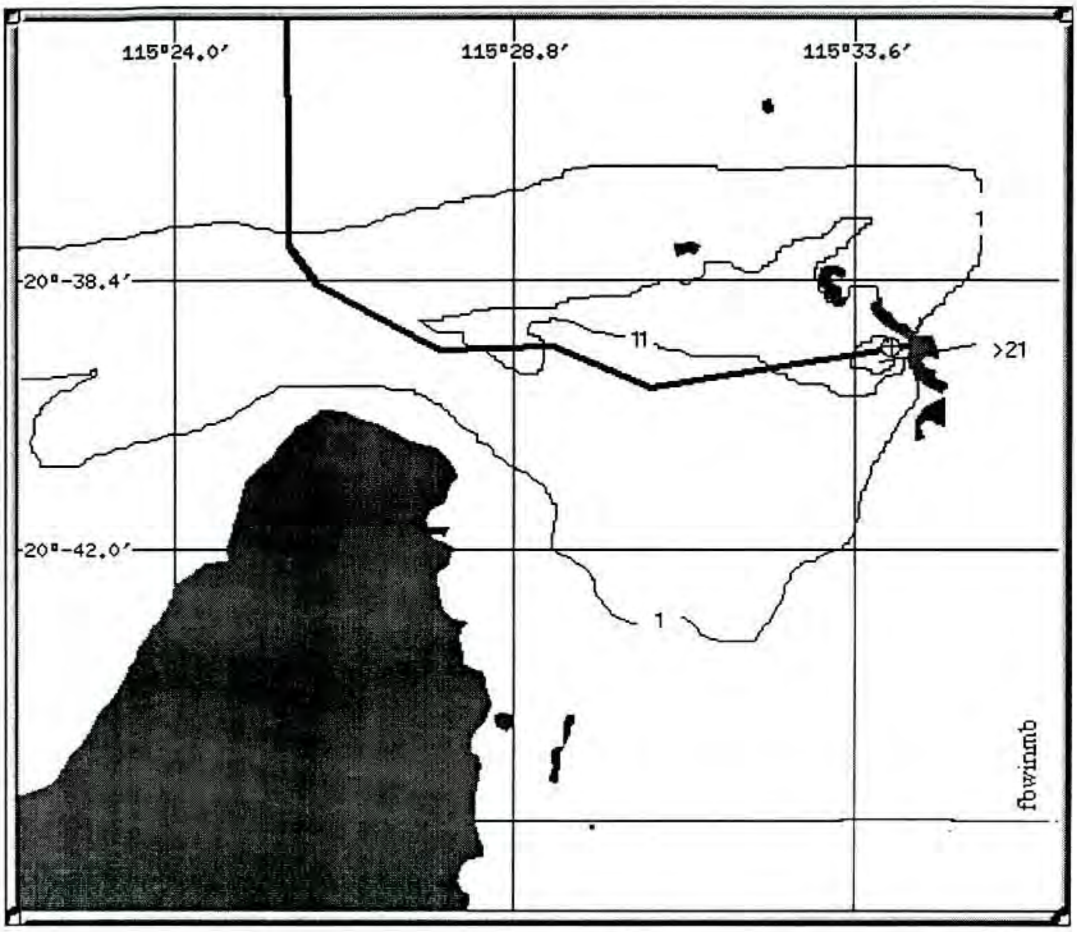
Probability contours showing the predicted risk (as %) of spills contacting particular locations.

Accident Scenario	Potential release (L)	Seasonal accident frequency*	Shallow sites contacted	Probability of contact	Overall risk to the site	Minimum time before contact
Full pipeline rupture	18,237	4.60×10^{-6}	Bridled Island	12%	9.4×10^{-7}	4 hours
			Varanus Island	60%	2.7×10^{-6}	2 hours
			Parakeelya Island	6%	2.7×10^{-7}	9 hours

* Based on the summer lasting 63% of the year

Figure 29
Scenario 14 : Full rupture of pipeline 500m from Varanus Island during winter

Full rupture of export pipeline, 400 m from Varanus Island during the winter wind season. Immediate shut down of supply gas. Estimated release of inventory as condensate at atmospheric pressure is 18,237 L. Air and water temperatures are 20 °C.



Probability contours showing the predicted risk (as %) of spills contacting particular locations.

Accident Scenario	Potential release (L)	Seasonal accident frequency*	Shallow sites contacted	Probability of contact	Overall risk to the site	Minimum time before contact
Full pipeline rupture	18,237	7.8×10^{-6}	Bridled Island	25%	1.9×10^{-6}	6 hours
			Varanus Island	35%	2.7×10^{-6}	2 hours
			Parakeelya Island	5%	3.9×10^{-7}	12 hours

* Based on the winter lasting 37% of the year

5. ENVIRONMENTAL MANAGEMENT

5.1 Introduction

The objective of the environmental management plan is to ensure that the environmental impacts of drilling and production activities are prevented or minimized, and that Australian and international best practices are used. At a broad scale, drilling and production will be managed to comply with Apache Energy's Environmental Management Policy (Appendix 9) and be consistent with the intent of the draft Australian Environmental Management System ISO 14000.

5.2 Education

All personnel will be educated on the environmental and safety aspects of the development by qualified members of staff. This education will consist of:

- environmental and safety inductions prior to the commencement of drilling, and installation of the monopod and pipeline;
- environmental and safety inductions for all new staff once production has commenced;
- provision of guidelines and fact sheets on the terrestrial and marine fauna of the region.

5.3 Environmental audit

Regular environmental audits will be undertaken by Apache during all phases of the development (installation, drilling, operations). The audits will involve the inspection of equipment and operations to ascertain if appropriate standards are being met. Any remedial actions required will be carried out immediately.

5.4 Monitoring

A survey of the seabed at the well site and adjacent area will be carried out immediately before and after the development drilling program, utilizing a ROV. This will give an indication of the condition of the seabed and associated epifauna. Any debris will be picked up and a visual assessment of the extent of the cuttings will be made.

5.4.1 Routine Monitoring Program

Apache and its predecessors have undertaken an ongoing environmental monitoring program since 1985 which centres on the ecological units considered to be of high conservation value in the vicinity of the Lowendal Islands (LeProvost Semeniuk & Chalmer 1986). These units are representative of the region. The baseline data collected from these studies constitutes a significant contribution to the knowledge of the biological resources of the region. In the event of an oil spill, this information can be used to quantify the extent of impact to these areas and to measure the rate of recovery.

The specific objectives of the monitoring program are:

- to confirm the predictions that marine resources that are considered to be of significant conservation value have not been adversely affected during the life of the development and operation of the project; and
- to be able to determine the nature and extent of the effects of an oil spill on the ecologically important elements of the biota if an accidental oil spill should occur.

The monitoring program was extended to cover the Montebello Islands in early 1996 and has been developed to be a regional- rather than project-based program. The range of programs presently being carried out includes the monitoring of corals, mangroves, sand beaches, turtles, seabirds and algae.

Apache's monitoring program will continue for the life of the Harriet oilfield project, East Spar project and the Wonnich gas development project.

5.4.2 Monitoring and Research Specific to the Wonnich Gas Development

- A pre-operational seabed survey will be conducted to confirm the physical characteristics of the sediments present at the drill site.
- A survey of the seafloor at the well site and adjacent will be carried out immediately before and after drilling utilizing a ROV. Any debris will be picked up.
- An aerial photographic record of the fringing reef to the west of the development site will be obtained before and after the installation of the monopod and drilling operations. This will be compared with a pre-Wonnich drilling and development photographic record to assist in confirming that no large scale changes in the condition of the reef has taken place over the installation and drilling period.
- Pre- and post- development marine monitoring surveys will be conducted on the adjacent coral fringing reefs. This program will be amalgamated with the long-term coral monitoring survey program routinely carried out for the nearby Harriet project (see Section 5.4.1).

5.4.3 Remote Sensing

Apache commenced a long term remote sensing program in November 1994 as a means of mapping and monitoring the changes in the shallow water marine habitats of the Montebellos and Lowendal Islands. Digital Multispectral Video technique is being used to acquire the data. The data is presently being entered onto a Geographical Information System (GIS) which is linked to Apache's OILMAP/OILTRAK computer model system.

In 1993/4, the Lowendal Islands were photographed and 'groundtruthed' and entered on the GIS. The southern section of the Montebello Islands was photographed in November 1995, and 'groundtruthed' and mapped in early 1996. The northern sector of the Montebello Islands are scheduled to be photographed in November 1996.

The information gathered from the remote sensing project will be entered into Apache's oil spill modeling system for oil spill contingency planning.

5.4.4 Condensate Chemical Composition and Toxicity

Condensate can be toxic to marine plants and animals due to the relatively high concentration of polycylic aromatic hydrocarbons (PAHs). What is yet to be determined is:

- what the actual toxicity of condensate is;
- what components of the condensate contribute to the toxicity; and
- how the toxicity changes over time.

Apache is presently conducting some detailed tests to answer these questions. This work includes:

- weathering of oil by fractional distillation to correlate with oil which has been on water for 1-2 hours, 1-2 days and 1 week, respectively;
- analysing the chemical composition of fresh condensate and each of the weathered fractions to determine individual and total volatile aromatic hydrocarbons, and individual and total PAHs; and
- determining the toxicity of fresh and each of the weathered fractions using various tropical test organisms.

5.5 Environmental Management Commitments

Apache, on behalf of the Joint Venture Partners, will undertake the following environmental management commitments for the Wonnich gas development program.

(1) Apache will comply with all applicable laws, regulations and conditions, and all necessary approvals and authorizations will be obtained.

(2) Apache will adopt the environmental guidelines and procedures outlined in this document and those specified in consultation with the appropriate regulatory bodies. These will be incorporated into the contracts of all contractors.

(3) Apache will recognize its responsibility for the prevention of any adverse environmental impact and any containment or clean-up should it occur. In the event of an oil spill, Apache will take every possible action possible to protect the surrounding and adjacent environmental resources. Each of the Participants will hold appropriate insurance for liability and clean-up.

(4) Prior to commencement of drilling and production, approval for the Oil Spill Contingency Plan and the Emergency Response Plan will have been obtained from the appropriate statutory agencies.

(5) A community consultation program involving the local townships will be conducted prior to and during construction of the production facilities to provide information on the Wonnich project.

(6) A detailed survey of the marine and terrestrial habitats along the final pipeline route will be made to ensure that no sensitive assemblages will be adversely affected.

(7) Apache will liaise with WA Museum personnel to ensure that the pipeline route will avoid areas which may contain identified shipwrecks.

(8) A detailed procedure for the pipeline trench excavation and subsequent rehabilitation will be given to the contractors prior to the commencement of installation. This procedure will be developed in consultation with CALM.

(9) Routine pipeline inspections will be carried out to ensure the integrity of the pipeline is maintained and that it hasn't caused undue sedimentation, especially in the shallow regions of the route.

(10) All conditions for the Wonnich gas development will be incorporated into Apache's integrated management plan for the Harriet project.

(11) Regular environmental audits of the management commitments, guidelines and procedures will be undertaken by Apache, and independent consultants from time to time, to ensure compliance.

5.6 Guidelines and Procedures

In undertaking the Wonnich gas development drilling and production program, Apache Energy, on behalf of the Joint Venture Partners in TP/8 will ensure that the guidelines and procedures listed below are followed. Where appropriate, guidelines and procedures will be developed to the satisfaction of the relevant government agencies.

- All personnel involved at the location will be given an induction course which will include an outline of the commitments, guidelines and procedures.
- All equipment associated with the Wonnich gas development will be subject to Apache's Quarantine Procedure.
- No anchoring will be allowed on or adjacent to coral reefs.
- Helicopters servicing the rig will remain at least one km offshore from the Montebello Islands. No personnel will be allowed on the islands unless permission is given by CALM.
- Installation of the monopod and pipeline will occur outside the coral spawning season.
- Hazardous substances and wastes will be stored in a safe manner. Material Safety Data Sheets will be available for all hazardous materials. Oil and chemical drums will be stored in bunded areas and on top of pallets where possible.
- Waste generation will be minimized. All materials will be recycled wherever possible.
- Waste will be segregated and the appropriate disposal method for each type of waste generated will be used. A record of the types and quantities of waste generated will be maintained on a monthly basis.
- Combustible waste materials will be returned to shore and disposed of at an approved waste disposal site.
- No disposal of debris, garbage or litter will occur into the sea. Particular care will be taken to ensure that synthetic materials such as plastic bags and sytrofoam cups are not disposed of into the ocean.
- Waste oil and grease from machinery will be returned to shore for recycling at an approved site for disposal. A log of these wastes will be maintained and submitted to Apache on a monthly basis.
- Prior to drilling and at the completion of the program before the rig moves off location, remotely operated vehicle surveys of the ocean floor will be conducted. This is to confirm that no debris had been left on the ocean floor.
- Transfers of fuel and drilling fluid from the supply vessels to the rig at the location will be undertaken using the following measures:

  - the rig will be fully fueled before being brought on site in order to minimize the number of refueling operations required at the drill site;

  - the transfer hoses will be fitted with 'dry' couplings;

  - a vacuum breaking system will be in place to drain the fuel left in the hose after completing the transfer, back to the supply vessel tanks;

  - drip trays will be provided beneath the refueling hose connections on the supply vessel and the rig;

- fuel transfer will be carried out in daylight hours;

- refueling will be permitted only at times when the prevailing currents are moving away from the adjacent reef system, in order to provide the maximum time for response in the event of an accidental spill;

- refueling will occur only at times when sea conditions are sufficiently calm for there to be minimal risk to the transfer lines;

- crew of both the rig and the workboat will stay in continuous contact during the whole of the operation via handheld radios and will actively monitor the operation for its entire duration; and

- suitable absorbent material will be held on the supply vessel and the rig to mop up any small spills.

- Sufficient oil spill clean-up material will be stored on the drilling rig, support vessels and production platform to clean up small oil spills.
- Drainage in areas where oil and chemicals are used or stored will be contained. Spills on the deck will be cleaned up immediately. Oil will be prevented from going down any drains by ensuring that the drains are closed to the marine environment.
- Drip trays will be used under machinery drip tubes and fuel points.
- All oils spills greater than 80 L will be reported to Apache Perth immediately by the relevant Supervisors.
- Prior to drilling and at the completion of the program before the rig moves off location, remotely operated vehicle surveys of the ocean floor will be conducted. This is to confirm than no debris has been left on the ocean floor.
- No antifouling paint containing tributyltin (TBT) will be used on the Wonnich facilities.
- Pipe doping with the lowest concentration of heavy metals will be used whenever practical.
- Chemical additives causing the minimal damage to the environment in relation to toxicity and bioaccumulation, but which meet safety and performance requirements, will be used.
- The type and quantity of chemical additives used will be maintained on a monthly basis.
- The relevant government agencies will be informed on the composition and quantity of hydrotest water which will be released into the environment prior to testing.

6. REFERENCES

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7. GLOSSARY

API gravity:	the universally accepted scale for expressing the specific gravity of oil
appraisal drilling:	drilling carried out to determine the likely physical extent, reserves and production rate of a field
aromatic:	the term used to describe organic compounds which contain one or more unsaturated ring structures, e.g. benzene (C_6H_6)
aerobic:	in the presence of oxygen
anaerobic:	in the absence of oxygen
annulus:	the space between the drill string and well bore
bbls:	barrels (1 barrel = 159 L)
benthic:	relating to communities of marine organisms which live on and have a direct dependence on the ocean floor
biota:	the animal and plant life found within an environment
blowout:	an uncontrolled kick. A blowout can occur at the surface or underground between two separate permeable formations
Blow Out Preventer:	a hydraulically operated wellhead device designed to ensure that a blow-out cannot occur
caisson:	the support column of the monopod
CALM:	Department of Conservation and Land Management
casing:	the steel pipe that is cemented into a well to prevent the wall from caving in and to stop unwanted fluids from entering the hole from the surrounding rocks
CER:	Consultative Environmental Review
community:	any naturally occurring group of different organisms sharing a particular habitat
crustaceans:	animals, most aquatic, with a hard, close fitting shell which is shed periodically
demersal:	refers to fish that live on or adjacent to the seafloor
DEP:	Department of Environmental Protection
DME:	Department of Minerals and Energy of Western Australia

drill string:	lengths of steel tubing roughly 10m long screwed together to form a pipe connecting the drill bit to the drilling rig; the string is rotated to drill the hole and also serves as a conduit for drilling fluids
ecosystem:	a natural complex of plant and animal populations and the particular sets of physical conditions under which they exist
EPA:	Environmental Protection Authority
fluid density:	weight of a certain volume of drilling fluid and is related to the pressure gradient
geomorphology:	the study of the form and development of the earth, especially its surface and physical features, and the relationship between these features and the geological structures underneath
habitat:	a physical potion of the environment that is inhabited by an organism or population
hydrocarbons:	organic compounds consisting of the elements carbon and hydrogen only
ingest:	take in (food) to the stomach
intertidal:	the part of the littoral zone which lies between mean high and mean low tide
kcm:	thousand cubic metres
kick:	the influx of formation fluids into the well bore. Occurs if the pressure within the formation is greater than the pressure or force exerted by the drilling fluid
m^3:	cubic metres - 1 m^3 = 1,000L
mangrove coast:	tropical or sub-tropical low-energy coast vegetated with mangroves
molluscs:	a group of soft bodied, unsegmented animals, usually with a hard shell such as shellfish
OSCP:	Oil Spill Contingency Plan
pelagic:	relating to communities of marine organisms which below to the open seas, living free from direct dependence on bottom or shore
permeable:	ability of rock to allow fluid movement
psia:	pressure per square inch absolute
spud:	to commence the actual drilling of the well
subtidal:	the littoral zone below the low tide mark

suratidal:	the part of the shoreline that lies above the high tide mark
toxic:	capable, through chemical action, of killing, injuring, or impairing an organism
weathering:	physical disintegration and chemical decomposition of oil

Appendix 1

WONNICH GAS DEVELOPMENT SOUTH WEST OF MONTE BELLO ISLANDS - APACHE NORTHWEST PTY LTD (1040)

CONSULTATIVE ENVIRONMENTAL REVIEW

GUIDELINES

Overview

The aim of environmental impact assessment is to protect the environment. This includes both the natural and social values in the project area. The process of environmental impact assessment is deliberately a public process in order to obtain broad-ranging comment and advice. In the Consultative Environmental Review (CER), the proponent is required to describe the proposal, receiving environment, and potential environmental impacts. The CER should also describe the proposed management of environmental impacts to ensure the environment is protected.

Contents of the CER

The contents reflect the purpose of the CER, which is to:

- communicate clearly with the public and government agencies so the EPA can obtain informed comment to assist in providing advice to the Minister for the Environment;
- describe the proposal adequately, so that the Minister for the Environment can consider approval of a well-defined project; and,
- provide the basis of the proponent's environmental management programme (EMP) showing that the environmental issues resulting from the proposal can be acceptably managed.

The language used in the body of the CER should be kept simple and concise, considering the audience includes non-technical people. Any extensive, technical detail should either be referenced or appended to the CER.

The CER would form the legal basis of the Minister's approval of the proposal and, hence, should include a description of all the main and ancillary components of the proposal.

The environmental management programme for the proposal should be developed in conjunction with the engineering and economic programmes of the proposal. Hence, the CER should be designed to be immediately useful at the start of the proposal. The basis of an environmental audit programme should be included as a concluding part of the CER.

The fundamental contents of the CER should include:

- a plain English executive summary;
- a summary table based on the key environmental factors;
- introduction to the proponent, the project and location;
- a summary of the regional setting of the project;
- the legal framework, decision making authorities and involved agencies;
- description of the components of the proposal and identification of the potential impacts, including short-term, long-term and cumulative impacts;

- a pollution source analysis;
- description of the receiving environment which may be impacted, including relevant quantitative data, species lists and marine habitat maps.
- discussion of the key environmental factors with reference to EPA objectives, national and international standards, the APEA Review, and any relevant Government reports or studies;
- discussion of the proposed management of each environmental factor, including commitments to appropriate action;
- a summary of the environmental management program (including oil spill prevention and contingency measures), including key commitments and environmental monitoring and audit arrangements; and,
- a consolidated list of all proponent commitments.

Key environmental factors

The CER should focus on the key environmental factors arising from the proposal (see table below). A description of the project component and the receiving environment should be directly included with, or referenced to, the discussion of each environmental factor. The technical basis for measuring the impact, and information on specific standards for assessing and managing the impact, should be provided.

Biophysical		
Environmental factor	**Environmental Objectives**	**Proposed management of environmental factor**
Introduced animals and plants	Protect offshore island ecosystems from introduction of feral animals or weeds.	No landings permitted on Monte Bello Islands. Approved quarantine procedures already in use on Varanus Island.
Coral reefs	Select pipeline route so as to protect the environment. Protect coral reefs and other sensitive marine habitats during pipeline installation.	Select pipeline route to avoid coral reefs and other sensitive habitats. Phase pipeline construction to avoid impacts during coral spawning time.
Dunes and mangroves	Protect sand dunes, mangroves and other vegetation from disturbance. Where disturbance is unavoidable, rehabilitate dunes and mangroves.	Shoreline crossing on Varanus Island to be designed in consultation with CALM. Rehabilitation to be carried out in consultation with CALM.

Biophysical cont'd

Environmental factor	Environmental Objectives	Proposed management of environmental factor
Shore line stability	Protect Varanus Island shoreline from erosion resulting from pipeline acting as a groyne.	Shoreline crossing on Varanus Island to be designed in consultation with CALM. Shore line monitoring program to be put in place to detect any erosion problems. Corrective action as required.
Decommissioning	Remove and rehabilitate as required consistent with the principle of nett environmental benefit. Remove infrastructure on Varanus Island as required by CALM.	Decommissioning to be considered at design phase.

Pollution

Factor	Environmental Objectives	Proposed management of environmental factor
Oil spills	Protect the environment from pollution	Management at level of international best practice. Approved oil spill contingency plan at level of international best practice.
Routine drilling discharges (drilling mud, cuttings, pipe dope)	Protect the environment from pollution.	Management at level of international best practice for drilling in sensitive locations
Pipeline test chemicals (hydrotest waters and pickle liquors used at commissioning stage)	Protect the environment from pollution.	Fluids to be pumped to bund on Varanus Island and allowed to evaporate.
Pipeline treatment chemicals (biocides, corrosion inhibitors, and antifouling used to maintain pipeline)	Protect the environment from pollution.	Select chemical treatments which have low impact on the environment, consistent with international best practice
Produced formation water	Protect the environment from pollution.	Alternatives to be evaluated
Greenhouse gases	Minimise greenhouse gas emissions.	Minimise greenhouse gas emissions in line with EPA provisional policy on greenhouse gas emissions.
Light overspill ("photo-pollution")	Protect turtles and other wildlife from impacts from artificial lighting.	Design lighting in consultation with CALM specialists

Social surroundings

Factor	Environmental Objectives	Proposed management of environmental factor
Heritage	Protect any historic shipwrecks from disturbance.	Consultation with WA Museum experts. Tender vessels to anchor away from reefs and known wrecks.

Further factors may be raised during the preparation of the CER, and on-going consultation with the Department of Environmental Protection and other relevant agencies is recommended.

The information presented should be based on best available data and, where uncertainty exists, provide best and worst case scenarios.

Assessments of the significance of an impact should be soundly based rather than unsubstantiated opinions, and the assessment should lead to a discussion of the management of the issue.

Information used to reach conclusions should be properly referenced, including personal communications.

Public consultation

The CER should include a summary of public participation and consultation activities undertaken by the proponent in preparing the CER. This should include the activities undertaken, the dates, the groups / individuals involved and the objectives of the activities. Cross reference should be made with the description of environmental management of the issues which should clearly indicate how community concerns have been addressed. Those concerns which are dealt with outside the EPA process (eg through WADME requirements) can be noted and referenced.

Environmental management commitments

The method of implementing the proposal and all the proponent's commitments listed in the CER would become legally enforceable under the environmental conditions imposed by the Minister for the Environment. The proponent's commitments should be presented as a consolidated list, with each commitment numbered and in the following form:

- **who** would do the work;
- **what** the work would be;
- **where** the work would be carried out; and
- **when** and to **whose satisfaction** the work would be carried out.

Key factors and environmental objectives, and the sections they are discussed in the CER are listed in the table below:-

BIOPHYSICAL			
Environmental Factor	**Environmental objectives**	**Proposed management of environmental factor**	**CER reference**
Quarantine	Protect offshore island ecosystems from introduction of feral animals or weeds.	No landings permitted on Montebello Islands. Standard approved quarantine procedures already in use on Varanus Island.	3.2.1 3.3.3
Protection of sensitive marine habitats	Ensure that the pipeline route is selected so as to protect the environment. Protect coral reefs and other sensitive marine habitats during pipeline installation.	Select pipeline route to avoid coral reefs and other sensitive habitats. Phase pipeline construction to avoid impacts during coral spawning time.	3.3.1 3.3.1
Dune and mangrove protection	Protect sand dunes, mangroves and other vegetation from disturbance. Ensure dunes and vegetation are rehabilitated appropriately where disturbance is unavoidable.	Shoreline crossing on Varanus Island to be designed in consultation with CALM.	3.3.1
Shoreline stability	Protect Varanus Island shoreline from erosion resulting from pipeline acting as a groyne.	Shoreline crossing on Varanus Island to be designed in consultation with CALM. Shoreline monitoring program to be put in place to detect any erosion problems. Corrective action as required.	3.3.1 5.5
Decommissioning	Ensure that appropriate decommissioning is carried out at end of project lifespan.	Decommissioning to be considered at design phase.	3.2.5

POLLUTION

Environmental Factor	Environmental objectives	Proposed management of environmental factor	CER reference
Routine drilling discharges (drilling mud, cuttings, pipe dope)	Protect the environment from pollution.	Management at level of international best practice for drilling in sensitive locations.	3.1.2
Pipeline testing chemicals (hydrotest waters and pickle liquors)	Protect the environment from pollution.	Fluids to be pumped to bund on Varanus Island and allowed to evaporate.	
Produced formation water	Protect the environment from pollution.	Alternatives to be evaluated.	3.2.2
Chemical treatment of pipeline (biocides/corrosion inhibitors/antifouling)	Ensure biocides, corrosion inhibitors and antifouling have minimal environmental impacts.	Select chemical treatments which have low impact on the environment, consistent with international best practice.	3.3.2
Gaseous emissions (eg. CO_2 , SO_2, NO_x	Ensure that emissions are controlled as required by Government policy.	Minimise gas emissions in line with Government policy.	3.2.4
Light pollution	Ensure that turtles and other wildlife are protected from impacts from artificial lighting.	Design lighting in consultation with CALM specialists.	3.2.1

SOCIAL SURROUNDINGS

Environmental Factor	Environmental objectives	Proposed management of environmental factor	CER reference
Cultural heritage	Protect any historic shipwrecks from disturbance.	Consultation with WA Museum experts. Tender vessels to anchor away from reefs and known wrecks.	5.5

Appendix 2

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Appendix 3

APPENDIX 3

1 DESCRIPTION OF THE ENVIRONMENT

The Montebello Islands and Lowendal Islands lie approximately 120 km west-northwest of the Port of Dampier. The Montebellos consist of about 200 islands, most of which are rocky islets only a few metres in diameter (Figure 3-1). The largest islands are Trimouille (429 ha) and Hermite (939 ha) Islands (IUCN 1988). Once attached to the mainland through a ridgeline extending from Northwest Cape, it is estimated that the islands have been separated by sea level rise from the mainland for approximately 8,000 years.

Prior to 1993, the Montebello Islands were Vacant Lands administered by the Department of Defense on behalf of the Federal Government. In July 1992, the islands were returned to Western Australia and vested in the National Parks and Conservation Authority as C-class reserves for the purposes of recreation and conservation. The Montebello Islands are gazetted to high water as A-class conservation park 42196. From high water to low water is gazetted C-class conservation park 42197.

Small sections of Northwest and Trimouille Islands are excised as leased to the Commonwealth for lighthouse operations.

Varanus Island, named after the goanna which inhabits the island, is the largest of the 34 islands, islets and rocks which make up the Lowendal Islands.

1.1 Physical Environment

Bathymetry

Bathymetry of the project area is shown in Figures 3-3 and 3-4. The information presented is based largely on information obtained during seismic surveys, data from a scouting survey of seabed features undertaken by RACAL Survey Australia Ltd in May 1994 and limited navigational hydrographic survey data.

The water depth at the proposed drilling site is about 27 m. To the east of the site, the seafloor rises from a depth of 27 m to 5 m over a relatively short distance (approximately 3 km). Much of the water surrounding the Montebello Islands and extending south to Barrow Island and the Lowendals ranges in depth from intertidal to approximately 5 m.

To the west of the well site the seafloor slopes away more gradually to reach depths of 40 m over a distance of some 6 km.

Geomorphology

The site of Wonnich is located on a shallow submarine ridge which extends north from the mainland near Onslow and includes Barrow Island and the Montebello Islands (IUCN 1988). The ridge contains extensive areas of intertidal and shallow subtidal limestone pavement surrounding the numerous, mostly small islands which are found in the region.

The proposed exploration well site lies on the eastern flank of this ridge adjacent to the southern Montebello Islands. It occurs in an open ocean environment where the relatively high wave and current energy gives rise to extensive areas of exposed limestone pavement and reef, interspersed with patches of sand veneer overlying the limestone pavement.

The nearest landfall to the site is the Montebello Islands. The Western Australian Museum (WAM 1993) describes these islands and associated reefs which make up the Montebello group as "being arrowhead shaped, comprising a central 'chain' of islands with unusually irregular or convoluted coastlines lying on a north-south axis. These islands are in close proximity to one another and are separated by narrow channels". They are low lying and include 95 islands larger than 50 metres in length and 170 smaller islets and reefs. They are composed of Pleistocene limestone and cross bedded sandstones, capped in places with consolidated or active sand dunes with elevations up to 40 m. Most islands are bare rocky terrain without any beaches.

The total shoreline of intertidal land within the Montebello group is approximately 210 km in length and significantly longer if the margins of intertidal areas, particularly the western barrier reef, are included. An extensive shallow intertidal zone is therefore contained within a relatively small total area.

The major physical environmental units are lagoons, channels, intertidal embayments, intertidal shorelines, barrier reef and shallow open ocean (see Table 3-1).

Climate

The climate of the neighbouring Lowendal Island region which is some 20 km to the south of the Montebellos is arid subtropical with hot summer temperatures, occasional cyclones and associated summer rainfall. The climate at the Montebello Islands would be expected to be similar. The annual average rainfall of the Lowendal Islands is approximately 330mm, mostly as a result of tropical cyclones.

Winds blow consistently for most of the year except during April and May. During winter (June - August), moderate to strong south-easterlies and easterlies prevail, while during summer moderately southerly, south-westerly and westerly winds dominate (Figure 3-5).

Tropical cyclones may occur any time between November and April. The annual average frequency of cyclones passing within 360 km of the project area is 2.4.

The frequency of occurrence of tropical cyclones is an important physical environmental factor influencing the marine fauna, particularly corals, in shallow water at the Montebellos. Examination of cyclone tracks provided by the Bureau of Meteorology showed that in the 16 years between 1977/78 and 1991/92, a total of 9 cyclones passed within approximately 90 km of the islands. Recent cyclone damage, evident in shallow areas of the lagoons, may have resulted from cyclones 'Ian' (Feb/March 92), 'Ilona' (Dec 1988), 'Orson' (April 1989), 'Bobby' (1994) and/or 'Olivia' (April 1996). Figure 3-6 shows the tracks of the three cyclones which occurred during the 1995/96 cyclone season.

Table 3-1

MONTEBELLO ISLANDS: MAJOR PHYSICAL UNITS (WAM 1993)

Physical Unit	Description
Lagoon	This may be divided into two sections: (1) a shallow western lagoon, between the western barrier reef and central island chain; and (2) a deeper eastern lagoon between Trimouille Island and series of islets to the south of it, and the central island chain. Both the western and eastern lagoons are shallowest and most protected in the north and become progressively deeper and exposed to the south. The lagoons, particularly in the north, are characterised by relatively high turbidity and low wave and current energy, resulting in extensive areas of sand substratum. Rubble substrates are also present in the more exposed areas.
Channels	These are mostly between the central island chain, connecting the eastern and western lagoons. Stephenson Channel is the exception in that it is a blind channel, approximately 8 km in length, leading into the interior of Hermite Island. The channels are characterised by high turbidity and very high current energy, resulting in coarse sand and rubble substrates with extensive exposures of limestone pavement when scouring occurs.
Intertidal Embayments	These are subject mainly to tidal energy and are characterised by fine, soft, sandy substrates, generally of low organic content.
Intertidal Shorelines	Shorelines are rocky or sandy, depending on their degree of exposure to wave and/or current energy. Rocky shores predominate at the Montebellos and typically have a double erosion notch.
Barrier Reef	This is characterised by very high wave energy. The outer reef slope is not steep and, where examined was not dissected by spur and groove formation, but became progressively more broken with depth. The crestal area is indistinct; in some places it has boulder accumulations, but there is no rubble crest. A typical reef flat, largely composed of consolidated coral slabs interspersed with sand, drops off steeply in parts where patch reefs occur. Several large breaks in the reefs form deep channels.
Shallow Open Ocean Habitat	Relatively high wave and current energy gives rise to extensive areas of exposed limestone pavement and reef, interspersed with patches of sand veneer overlying the pavement.

Tides and Currents

Water movement in the survey area is dominated by wind-modified tidal currents. Tides are semi-diurnal, that is, there are two high and two low tides in each 24 hours, with water movement during spring tides far more influenced by tidal currents than by local wind stress. The spring tidal range is approximately 3.5 m. Tidal currents of up to 4 knots can be experienced in the shallow channels of the Montebello group (Steedman Science & Engineering 1991).

Ocean currents in the vicinity of the Montebello Islands were measured using an acoustic doppler current profiler which records the speed and direction of current flows at discrete steps through the water column. The instrument was deployed between 15-22 March for approximately 24 hour periods at four locations around the Montebello Islands. This allowed the current metres to record over a number of tidal cycles at each site.

Ocean Currents

Ocean currents around the Montebello and Lowendal Islands were measured during a field program in March 1996. Electronic current meters (acoustic current meters and acoustic current doppler profilers) were moored at 12 locations for periods of 24 to 96 hours, sufficient time to sample a number of tidal cycles at each site.

The field sampling showed that the region experiences a complex pattern of currents, with locally strong flows, due largely to the tidally-forced migration of water from the deep surrounding shelf (30-40 m depth) across the shallow island chain (<5 m). Adding to this complexity, is the influence of strong flows through inter-island channels. The overriding influence of tidal forcing on these currents is demonstrated by a diurnal cycle in the current velocity and direction which corresponds with the tidal cycle experienced in the area. For example, the current velocity recorded in a channel to the south of Hermite Island is shown in Figure 3-7.

In general, flooding currents approach the Montebello Islands from the west-south-west, before speeding up and splitting into a northeast flow and a southeast flow (Figure 3-8). Water traveling along the southwards flow tends to be steered around the shallow reefs in this area and diverted to a deep channel that traverses south of Hermite Island. Water traveling across the shallow western platform of these islands flows at up to 1 knot but local flows between the islands can be greater than 5 knots. Water traveling across the shallow ridge separating the Montebello and Lowendal Islands can also attains speeds over 5 knots during spring tides. A common feature of this area is the presence of standing waves due to the speed of the water currents across the underlying reef. Moving further east, the speed of these flows diminishes and the currents begin to steer to the south-south-west where the water depth is over 15 m.

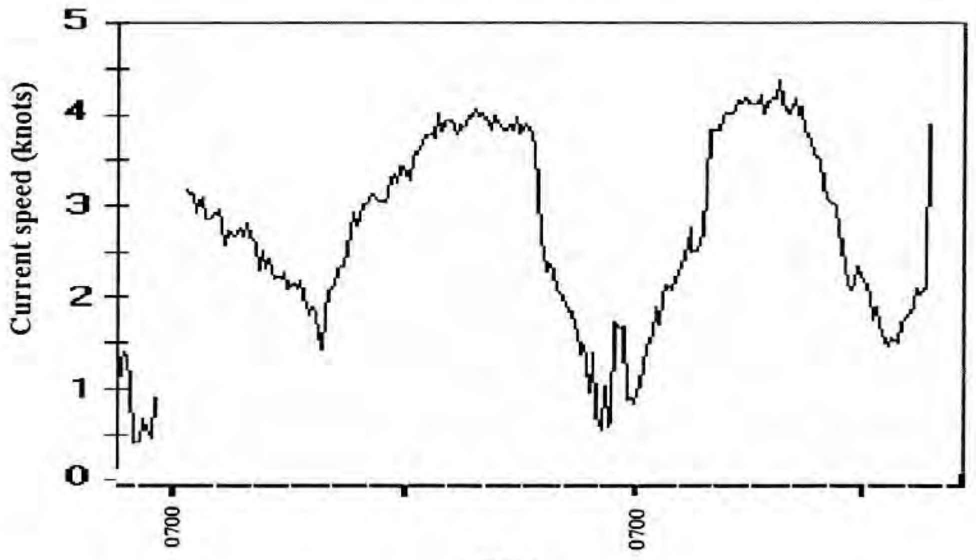

Figure 3-7: Current velocity sampled south of Hermite Island using an acoustic current meter.

Very strong currents (3-4 knots) are also experienced across the northern end of the Lowendal Islands and across the shallow sandy areas surrounding them (Figure 3-9). Currents through the inter-island chains of the islands can attain speeds of 3-4 knots and have a local influence on the flow of water along the Islands.

Water flows during ebb tides were generally found to be the reverse of the flood tides, except for areas that were influenced by local jets of water directed through currents or around islands (Figures 3-10 and 3-11).

The water temperatures at the Montebellos range from 20° - 33° C which in terms of biogeographical provinces places the Montebellos within the Dampier or Northern Australian Tropical Province (Wilson and Allen 1987, in WAM 1993).

The water in the Montebellos is frequently turbid due to the combination of wave action, relatively high tidal range and the shallowness of the area (WAM 1993). Despite their distance offshore, the Museum considered the turbidity conditions and the fauna of the Montebellos to be more typical of the mid-continental shelf than of the outer shelf edge, such as found at the Rowley Shoals, which are typically oceanic.

1.2 Flora and Fauna

The regional subtidal environment comprises predominantly limestone pavement at depths ranging from intertidal in excess of 20 m. The pavements are frequently veneered by sheets and ribbons of calcareous sands varying in thickness from less than 5 cm to greater than 1 m. The sands are mobilised and dispersed as sand waves by water currents and more dramatically, storm events such as cyclones. Pavement in exposed areas is often continuously swept clean of sand.

The Montebello Islands form the perimeter of a shallow lagoon and the indented islands form further sheltered embayments and channels which are not replicated elsewhere on the northwest coast (IUCN 1988).

The shallow waters and intertidal areas of the region support a range of habitats and wildlife (Figure 3-12). These include coral reefs, seagrass and algal beds, and mangroves.

The water column supports a range of marine mammals, reptiles, pelagic and benthic fish, drift species and plankton. The sea surface also supports some species of seabirds which feed at sea.

Macroalgae and Seagrasses

Macroalgae are abundant on the exposed limestone pavement and knolls surrounding the Montebello Islands and Lowendal Islands (Figures 3-13 and 3-14). Brown algae belonging to the genera *Sargassum, Zonaria, Dictyopteris* and *Padina,* and the green algae *Halimeda, Caulerpa* and *Cladophora* have been noted (WAM 1993; CSIRO in preparation). These algae are widely distributed across the Montebellos and the Lowendal Islands.

The first *in situ* collection of an endemic Australian seagrass, *Cymodocea angustata* Ostenfeld, was made in the Montebello Islands in 1979 (McMillan *et al.* 1983). This species was found on the western side of Hermite Island at a depth of 5m.

Seven seagrass species may occur in the area: *Cymodocea angustata, Cymodocea rotundata, Halophila ovalis, Halophila spinulosa, Halodule uninervis, Thalassia hemprichii* and *Syringodium isoetifolium* (Kirkman and Walker 1989). They mostly occur in areas of sandy seafloor ranging from intertidal to shallow subtidal. They tend to form small patches from 1 to 10 m in diameter and are very sparsely distributed.

Seagrass beds, and possibly algae beds, are important feeding grounds for green turtles and dugongs, both of which are found in the area. They are also important as nursery grounds for many fish and crustaceans.

Corals

A total of 235 species comprised of 60 genera of corals have been recorded from the Montebellos during surveys carried out by the WA Museum (WAM 1993) and Apache (LDM 1994, 1996). This has been compared to available data from other north Western Australian reefs: Rowley Shoals, Ashmore Reef, Dampier Archipelago, Barrow Island, Ningaloo Reef and Abrolhos Islands as presented in WAM (1993) (Table 3.2).

Table 3.2

Geographical Variation in the Number of Coral Genera and Species

Location	Genera	Species
Montebello Islands	60	235
Lowendal Islands	56	127
Ashmore Reef	56	255
Scott/Rowley Reefs	56	233
Barrow Island	17	32
Dampier Archipelago	57	216
Ningaloo Reef	54	217
Abrolhos Islands	42	201

The tropical reefs (with the exception of Barrow) have similar numbers of genera (54-60) but species numbers are apparently reduced on the more southerly reefs. Ningaloo, Scott/Rowley and Ashmore reefs and the Dampier Archipelago have similar recorded levels of coral diversity to the Montebello Islands. By comparison, the diversity of the Lowendal Islands is lower. However, it should be noted that the differences in numbers of coral species may be a function of sampling effort.

A list of the species found on various reefs on the central coast of the North West Shelf is given in Table 3.3. This list includes the data collected by Apache during the surveys of the coral reefs of the Lowendal Islands (1994, 1996) and the west fringing reef of the Montebello Islands (1996).

Veron (1995) identified three global latitudinal diversity sequences for the distribution of corals. One of these sequences occurs along the West Australian coast. The coral assemblages of Western Australia can be initially clustered into two groups: trpoical reefs, and temperate non-reef comunities. Tropical reefs form two groups, the offshore reefs of the Northwest Shelf, and the coastal islands and reefs of which the Montebello Islands are a part. Within this sequence, coral species attenuate moving from north to south.

Veron (1995) proposed that no individual reef is a dominant source of larvae for the other reefs to the south. Instead, individual reefs are regarded as 'stepping stones' along the southern flowing Leeuwin Current which originates in the region of Indonesia. Many of the corals found on the Northwest Shelf have been found to have a greater similarity to those of the Barrier Reef than to the adjacent mainland coast with the point of connectivity being via Indonesia.

Along the West Australian sequence, the boundary current runs in a southerly direction, taking entrained propagules towards the lower latitudes with little potential for dispersion in the opposite (northern) direction. Hence, the more southern reefs such as the Ningaloo Reef and those found on the Abrolhos Islands receive annual propagules from the northern reefs but there is little dispersion from these reefs back to the northern ones. This has lead to genetic isolation of some coral reefs. For example, the corals of the Abrolhos Islands are frequently dominated by species which are rare anywhere else pointing to genetic isolation of the Abrolhos Islands corals (Veron 1995).

Approximately 3 km to the east of drilling site lies the southern section of the Montebello fringing reef system (Figure 3-15). The following description of the segment of the fringing reef occurring closest to the development site is drawn from a survey of the reef conducted on 30 and 31 October 1995 by Michael Forde of Bowman Bishaw Gorham.

In describing the reef, Forde divided it into six sub-habitats as follows:

- reef crest and fore-reef;
- southern margin of the reef;
- the coral community on the south-eastern side of the reef;
- deep central channel and fringing reef edges;
- coral community on the north-eastern side of the reef; and
- back reef on the northern side and directly behind the reef crest.

In addition, a deeper (~4 m) coral community was located some 300 m to the north of the main reef complex.

Forde's description of each of these sub-habitats is as follows:

Reef crest

The reef crest is composed of low profile limestone, heavily bored by sea urchins below the intertidal, with bare limestone present within the intertidal. Stunted macroalgae, particularly *Halimeda* sp., become dominant with increasing depth along the fore-reef. Live coral is generally restricted to approximately 5% cover and consists of encrusting species. Coral cover was observed to increase to approximately 20% in one area where reef relief was greater, with *Porites* being dominant.

Coral community (south side of reef)

A coral community occurs along the southern side of the reef, composed of complex assemblages on limestone or coral patch reefs raised above a sand substrate. Coral cover was estimated at 30%, with *Porites*, *Acropora* and the hydrocoral *Millepora* being the most common genera. Soft corals are also very common. *Porites* `bommies' and *Acropora hyacinthus* plates, each of 3 m diameter, were the largest corals seen. Large fish were abundant in this area, with Red Bass (*Lutyanus bohar*), Coral Trout (*Plectropoma* sp.), Tusk Fish (*Choerodon* spp.), Flowery Cod (*Epinephelus fuscoguttatus*), Chinaman (*Symphorus nematophorus*) and Spangled Emperor (*Lethrinus nebulosus*) being observed.

Immediately adjacent to the reef are flat patchy coral communities dominated by arborescent *Acropora* alternating with sand patches, exposed bare limestone and small seagrass, *Thalassodendron ciliatum* patches. These patches are approximately 10 m^2 in area.

The shallow reef flat is bare of flora other than turf algae. Numerous large green turtles were observed feeding in this zone on the high tide.

Coral Community (south-east side of reef)

A large coral community occurs east of the shallow reef flat and was investigated at three different locations during the survey. The community is an extensive, diverse assemblage dominated by arborescent Acropora and the hydrocoral Millepora. Other common genera include *Galaxea, Favia, Favites, Montipora, Merulina, Pectinia* and *Porites*. The southern part of the coral community appears to have been affected by a recent storm event: much of the substrate consists of coral rubble and many of the *Acropora* appear to have generated through fragmentation.

A notable observation in this community was the abundance of Crown-of-Thorns starfish (*Acanthaster planci*). These were common at each location investigated and were observed feeding on most of the scleractinian coral. Coral deaths which could be attributed to *Acanthaster* were not abundant and, in combination with the relatively small size of the starfish, suggests that the abundance of seastars is a recent phenomenon. Evidence of the presence of *Acanthaster* and *Drupella* was observed on some of the coral reefs by LeProvost Environmental Consultants in 1992.

Deep Channel

The deep channel which bisects the reef was investigated at two sites. The floor of the channel is comprised of sand and is bare of coral or other attached benthos. The fringes of the channel support large *Porites* `bommies' and other massive corals such as *Lobophyllia* and *Oulophillia*. Coral cover increases as water depth decreases with *Millepora* becoming dominant. Coral cover decreases towards zero further into the reef flat, apparently because it is mainly intertidal.

Coral Community (north of the channel and east of the reef flat)

The coral community on the northern side of the deep channel and east of the reef flat is not as prolific as in the corresponding community on the southern side of the channel. The community appears to be strongly depth determined, with the shallow reef top (which is probably intertidal) being devoid of attached benthos other than very occasional small corals. The slightly deeper surrounds support approximately 20% live coral of low diversity. Dominant genera include *Favia, Leptoria, Montipora, Galaxea* and *Acropora* scleractinian coral genera, along with the hydrocoral *Millepora*.

The pavement immediately beyond the shallow, sloping reef supports a *Sargassum* (algae) community with very few live corals.

Back Reef (north-western end of the reef complex)

The back reef area at the north-western end of the reef complex was found to support dark-coloured turfing algae with live coral being virtually non-existent. Large areas of exposed back reef could be observed at low tide. This area appeared to dry well before low water, and parts would probably be exposed on most low tides. Coral communities in these areas appear most unlikely. However large green turtles (*Chelonia mydas*) were observed to be feeding in the area during high tide and the area may be regionally significant for this purpose.

Coral `Bommie' Community (north of the reef complex)

An extensive reef community occurs in about 4 m of water approximately 300 m north of the reef complex. This is a *Porites* `bommie' dominated community with soft corals being sub-dominant. Other corals were mainly found in association with the *Porites*, and included *Coscinaraea, Leptoria*, corymbose and tabular *Acropora, Goniastrea* and, on the sand/rubble substrate, *Sandalolitha*. Fish are common throughout this coral community, with large Coral Trout (*Plectropoma* sp.) and Flowery Cod (*Epinephelus fuscoguttatus*) being observed.

Much of the extensive area of shallow (<5 m) water occurring between the well site and the Montebellos and the area extending southward to the Montebellos is sand veneered pavement with occasional seagrass patches. These provide feeding sites for the green turtles and dugong which are observed in this area.

To date there have been no detailed investigations into the natural temporal variability on the Montebello reefs, although there is reason to believe that damage to corals has resulted from the passage of cyclones (WAM 1993). The coral reefs of the Montebello Islands, like those of the Dampier Archipelago are subject to extensive damage by cyclones through physical disturbance and sedimentation (Heinsohn & Spain 1974; Van Woesik *et al.* 1991; Stejskal 1992) and therefore may be seen at different stages at different times. In August 1993, the Museum reported that they appeared to be in fairly advanced recovery stage in some very large tabular *Acropora* plates in back, reef areas. Fast growing *Acropora* species can recover from severe damage in a few years while slow growing massive species may take up to 30 years to recover from major damage (WAM 1993). A survey of the corals of the Lowendal and Montebello Islands carried out in August 1996 showed that damage from cyclone 'Olivia' was patchy and varied in the degree of damage (LDM 1996).

Other natural events, such as sedimentation and predation, by species such as the Crown of Thorns Starfish, *Acanthaster planci*, and the corallivorous gastropods, *Drupella cornus* and *Drupella rugosa*, all of which have been recorded in the Montebellos, may also contribute to temporal variability.

Communities subject to frequent natural perturbation are likely to be either resilient or transient and highly dynamic in terms of cover and distribution (WAM 1993). The ability of such species to recolonize after large scale natural or human perturbation is also likely to be high.

Coral spawning usually occurs in March and April. In 1995, the major spawning occurred on 11-14 April and a smaller one occurred between 12-15 March (C. Simpson pers. com.). It is expected that the 1997 season will be similar.

Rocky Shores

Rocky shores are the dominant shoreline type on the western side of the Montebello Islands. For the most part, they are of the vertical or undercut cliff type, but differ on the more exposed Northwest and Primrose Islands.

The western end of Northwest Island is exposed to wave action from the north and is comprised predominately of large blocks of broken limestone, and consequently is not typical of the shorelines of the islands to the south. The western shore of Primrose Island is also exposed to waves from the north and is comprised of a sloping pavement of beach rock slabs.

From Bluebell Island to the southern end of Hermite Island, the rocky shores are protected from the extremes of wave action by the presence of the fringing reef and shallow lagoon. The shores are mostly vertical or undercut cliffs which are generally low (3-5 m), but occasionally rise to 10 m where erosion has cut into more elevated portions of the larger islands.

A description of the physical zonation which occurs on a typical rocky shore in the Lowendal and Montebello Islands is presented below. The rocky shore profile and the characteristic zonation of its fauna produces five zones which can be distinguished at all monitoring sites. The height of each zone is consistent with the tidal range data for the two closest hydrographic stations (Trimouille Island and WAPET landing at Barrow Island). The spring and neap tidal ranges at these stations are 2.4 m and 0.8 m (Trimouille Island) and 2.5 m and 0.6 m (Barrow Island) respectively (Department of Defence 1992). The five zones are as follows:

(i) Supratidal Zone

Located above the mean high water springs (MHWS) mark, the supratidal or 'wave-splash' zone is colonised by cyanobacterial films and littorinid snails, predominantly *Nodilittorina millegrana* (LEC 1992, 1993).

(ii) Upper Intertidal Zone

This is a relatively narrow zone located between MHWS and the top of the oyster bioherms, just above mean high water neaps (MHWN). The upper intertidal zone is typically 50-60cm high (vertical range 30 - 100 cm) and dominated by star barnacles (*Chthamalus malayensis*). Chitons (*Acanthopleura gemmata*) and limpets (acmaeids, patallids and *Siphonaria* spp.) are also commonly numerous in this zone, but at frequencies that are one or two orders of magnitude less than the star barnacles.

(iii) Mid-tidal Zone

This zone is relatively broad (up to 150 cm high), extends from 20-30cm above MHWN to 20-30 cm below mean low water neap (MLWN), and is dominated by rock oysters (*Saccostrea cuccullata*) and their biohermic development.

The rock oyster bioherms frequently produce a bulge in the rocky shoreline profile, typically along the floor of the wave-cut notch when present. Apart from the oysters, the mid-tidal zone is also characterised by the presence of black mussels (cf. *Musculista glaberrima*) and drupes such as *Thais aculeata* and *Morula granulata*. False limpets (*Siphonaria* spp.) and barnacles (C. *malayensis* and T. *squamosa*) are common, but usually at lower abundances than in the upper intertidal zone.

(iv) Lower Intertidal Zone

This zone is approximately 50-60 cm in height and occupies the narrow strip beneath the rock oysters and mean low water springs (MLWS) mark. It is colonised by a variety of fauna, which is typically dominated by boring mussels (*Lithophaga* sp.) and boring barnacles (*Lithotrya valentiana*).

(v) Lowest Intertidal Zone

The lowest intertidal zone extends from MLWS to LAT (lowest astronomical tide). It is approximately 40 cm high and usually remains submerged except during extreme low tides. This zone can have a steep or even vertical profile at headlands, but within small bays and notches it frequently comprises a narrow sloping platform (1-7 m wide) that extends from the cliff face. The platform is wider (up to 50 m) along the east side of Abutilon Island.

Hermit crabs are typically the most numerous components of a macrofauna otherwise dominated by molluscs, including a range of gastropods (cowries, drupes, trochids, turbans and top shells), and bivalves such as tridacnid clams and rock borers (*Lithophaga* (cf. L. *teres*)), and *Hiatella* (cf. H. *australis*). Algae and sponges are occasionally present, as are isolated coral colonies, although the latter occur less frequently.

Sandy Shores

Sandy beaches occur between the rocky headlands on most of the larger islands. They support a limited range of resident fauna, principally small burrowing fauna such as polychaete worms, bivalve molluscs and amphipod crustaceans (LeProvost Seminuik & Chalmer (LSC) 1986).

The sandy beaches and adjoining limestone pavements provide feeding grounds for wading birds and nesting sites for species of birds such as the pied oystercatcher and beach thick-knee as well as seabirds like the caspian, bridled and fairy terns. During summer, four species of turtles use these beaches for nesting.

Mangroves

Associated with the sand and mudflats in the bays of the Montebello Islands are mangals ranging in size from isolated mangrove trees to areas of more than 15 hectares. These are particularly prevalent on the east side of Hermite Island. At least four species are present with *Avicennia marina* occurring alone or in mixed assemblages in association with *Bruguiera exaristata, Ceriops tagal* and/or *Rhizophora stylosa* (Marine Parks and Reserves Selection Working Group 1994). The Crocus Island stand is reported to include the river mangrove *Aegiceras corniculatum* (WAM 1993).

Mangrove communities are normally associated with high biological productivity. Mud crabs turtles, rays, fish and bird life are supported by the stands along with a myriad of invertebrate animals.

Molluscs

Two commercially important species of bivalve molluscs occur within the waters of the Montebello Islands. Pearl oysters live on the sea bed from the low water mark to a depth of 85 m, inhabiting a range of substrates from mud and sand through deep water reefs (Kailola *et al.* 1993). The largest species, *Pinctada maxima* is harvested at depths from 10 m to 37 m between Exmouth Gulf and King Sound. Collected shell is farmed to produce cultured pearls. A pearl farm is operated within the Montebello Islands by Morgan & Co. Pty Ltd.

The western saucer scallop, *Amusium balloti*, also occurs in waters between 10 m and 75 m. There is no commercial fishing for scallops within the Montebellos, although there is a fishery based in Dampier.

In addition, there is one species of gastropod which is endemic to the area between Barrow Island and the Montebello Islands. This is the direct developing volutid *Amoria macandrewi* and its endemicity may indicate that this area has been isolated from other marine ecosystems for some time (Marine Parks and Reserves Selection Working Group 1994).

Crustaceans

A number of decapod crustaceans occur in the waters surrounding the Montebellos Islands and some of these are fished commercially. The western king and tiger prawns are the main component of the catch. Both species burrow into the sediments, but the western king prawn prefer relatively coarse sediments while tiger prawns select muddy areas. Other species may be harvested as by-catch include white banana prawns and the bay lobster or mud bug. Another species of lobster, the painted spiny lobster *Panulirus ornatus* is the target of a small localized dive fishery around the islands and reef chains between the Muiron and Montebello Islands (Kailola *et al.* 1993).

Fish

A diverse range of fish is found in the area. This includes commercially significant species such as sharks, snapper, Spanish Mackerel and Red Emperors, recreational species including sea perch and rock cod together with a variety of tropical reef species inhabiting coral areas. LSC (1986) described the fish fauna of the Montebello Islands as abundant around areas of limestone and coral reef, and moderate to low in seagrass patches and over limestone pavement.

The survey carried out by the WA Museum details fish species found in the Montebello Islands. It reports that a total of 457 fish species in 76 families are found in the area. Most of the species, with the exception of a few north-west regional endemics, have relatively wide distributions in the Indo-west Pacific Region. Nearly all species have either pelagic eggs or larvae and therefore are recruited as juveniles from areas outside the Montebello Islands (WAM 1993). Many of the species are found in the shallower reef areas.

Turtles

Four species of turtle populate the waters between the Lowendal and Montebello Islands: the green turtle (*Chelonia mydas*), loggerhead (*Caretta caretta*), flatback (*Chelonia depressa*) and hawksbill (*Eretmochelys australis*). Nearly all of the sandy beaches in the region are used for nesting during the summer months.

The green turtle feeds on seagrass and algae, and numbers have been observed in the shallow waters on the west side of Hermite Island and the shallows between the Montebellos and Barrow Island.

All species nest from late spring through summer (November-March) and may be seen together on beaches.

All four species of turtles are classified as endangered on a world wide basis and Australia is one of the few countries still to have relatively large turtle populations (Limpus 1990). Despite this, the numbers of loggerhead turtles in Australia is believed to be in decline (Limpus and Couper 1994). All four species are migratory and subject to exploitation in traditional fisheries in northern Australia and neighbouring countries. They may also incur significant mortality as a by-catch of commercial fishing in Western Australian waters (Prince 1990).

Seabirds

Seabirds feed in the waters of the area and use the islands for roosting and nesting. Some of the birds which use the islands for nesting include the wedge-tailed shearwater, osprey, white breasted sea eagle, caspian terns, crested terns, pied cormorants, bridled terns, silver gulls and brahminy kites (Dinara Pty Ltd 1985; LeProvost Environmental Consultants 1992).

No species is endemic only to the Montebello Islands.

Marine mammals

Marine mammals, including dolphins, whales and dugongs frequent the waters of the region.

Marine mammal species known to occur in the region include six species of toothed and three species of baleen whales. Of notable interest, Humpback Whales migrate through the North West shelf in the winter months between June and October. These migrate northward from the Southern Ocean into the region, passing the west and north coasts of Barrow Island and the Montebello Islands.

The following cetacean species are likely to be sighted in the region:

Baleen Whales (*Mysticeti*)

- Tropical Bryde's Whale
- Southern Minke Whale (winter only)
- Humpback Whale (winter only)

Toothed Whales (*Odontoceti*)

- Bottle Nosed Dolphin
- Common Dolphin
- Striped Dolphin
- Short-finned Pilot Whale
- False Killer Whale
- Killer Whale

Dugong (*Dugong dugong*) are known to occur in the shallow, warm waters around the islands, although not in the large concentrations seen further south in the Exmouth Gulf or Shark Bay (Prince 1989). This animal is entirely herbivorous and feeds on the seagrass and algae meadows. Current knowledge on the size and distribution of dugong populations and their migratory habits in the region between North West Cape and the Dampier Archipelago is limited. Dugongs are considered rare and endangered and are protected in Western Australia.

1.3 Social Environment

Aboriginal History

An extensive search for Aboriginal artifacts has located evidence of occupation in small caves on Campbell Island, located in the central part of the island chain. The occupation appears to date from time prior to the most recent sea level rises (+/- 7,000 years before present). There is no evidence of aboriginal occupation more recently than this (Veth 1993).

European History

The English ship *Tryal* was wrecked on what are now known as the Tryal Rocks just north of the Montebello Islands in 1622 (Figure 3-12). This ship wreck is protected by the *Marine Archaeological Act* 1973 and has `National Estate' status,

A further uncharted wreck, that of the 19th century ship the *Wild Wave* is understood to be located on the seaward side of the south-west section of the Montebellos barrier reef.

Two other wrecks, one believed to be of a lugger wrecked about 1915 and one of a more recent vessel, are reported in or near the vicinity of Willy Nilly Lagoon in the central part of the Montebellos.

In 1952 and 1956, three British nuclear weapon tests were exploded on and near the Montebello Islands (Figure 3-12). One of these was on a vessel, the HMS *Plym*, moored close to the western shore of Trimouille Island, while the other two took place on land. Continuing radiation hazards limit the recommended length of occupation times on Trimouille and Alpha Islands, the sites of the land-based tests (Morris 1991). Remains of activities include scrap steel, relics of the nuclear tests and the former British operational headquarters foundations on the south of Hermite Island. Due to atomic testing, access is restricted on parts of two of the islands (Trimouille and Alpha).

Present Land Use

Present uses of the Montebello Islands include pearl cultivation (Figure 3-12) and occasional recreational fishing and diving cruises.

The main commercial fishery in the vicinity is a trap fishery for reef fishes which mainly occurs about 5 nautical miles from the Montebellos in depths of 30-100 m. Coral reefs and shallow waters are generally avoided by trap fishermen. Currently the level of line fishing is thought to be low (WAM 1993).

The sheltered waters of the islands are also used on occasion as a protected mooring area during the passage of cyclones.

There is no permanent resident population on the Islands although the pearling operation run by Morgan & Co. Pty Ltd. maintains an active presence between Hermite and Campbell Islands.

1.4 Sensitive Resources

From the biological and human resources identified above, the following would be considered potentially sensitive to the effects of disturbance arising from either routine operations or accidental occurrences, in particular, oil spills:

- corals, in particular those found on the intertidal and shallow subtidal reefs;
- mangroves;
- intertidal and shallow sub-tidal algae and seagrass beds;
- faunal species including cetaceans, dugongs, turtles and seabirds;
- historic sites and shipwrecks; and
- pearl culture areas.

1.5 Conservation Value

Effective from 7 July 1992, the Montebello Islands were vested in the National Parks and Nature Conservation Authority as an A class (infra-tidal land 42196) C class reserve (intertidal land 42197) for the purpose of Conservation Park (*Conservation & Land Management Act* 1984). (The surrounding waters are not included in the vesting). Prior to this they were Vacant Crown Land administered on behalf of the Federal Government by the Department of Defense. A condition of the transfer of vesting to the State Government was that the State should reserve and manage the lands and waters of the Montebellos for conservation.

The Lowendal Islands are classified as a C-Class reserve (C-33902) for the conservation of flora and fauna.

The conservation values of the area have been recognised in a recently released report *A Representative Marine Reserve System for Western Australia,* (Marine Parks & Reserves Selection Working Group 1994). With respect to the Montebello Islands, the Working Group considered that "... appropriate protection and management can be achieved by reservation of parts of the area, combined with designation of the remainder as an environmentally sensitive area needing special management."

The marine waters surrounding the Montebello Islands and Lowendal Islands are currently being evaluated by the Australian Heritage Commission for listing as National Estate.

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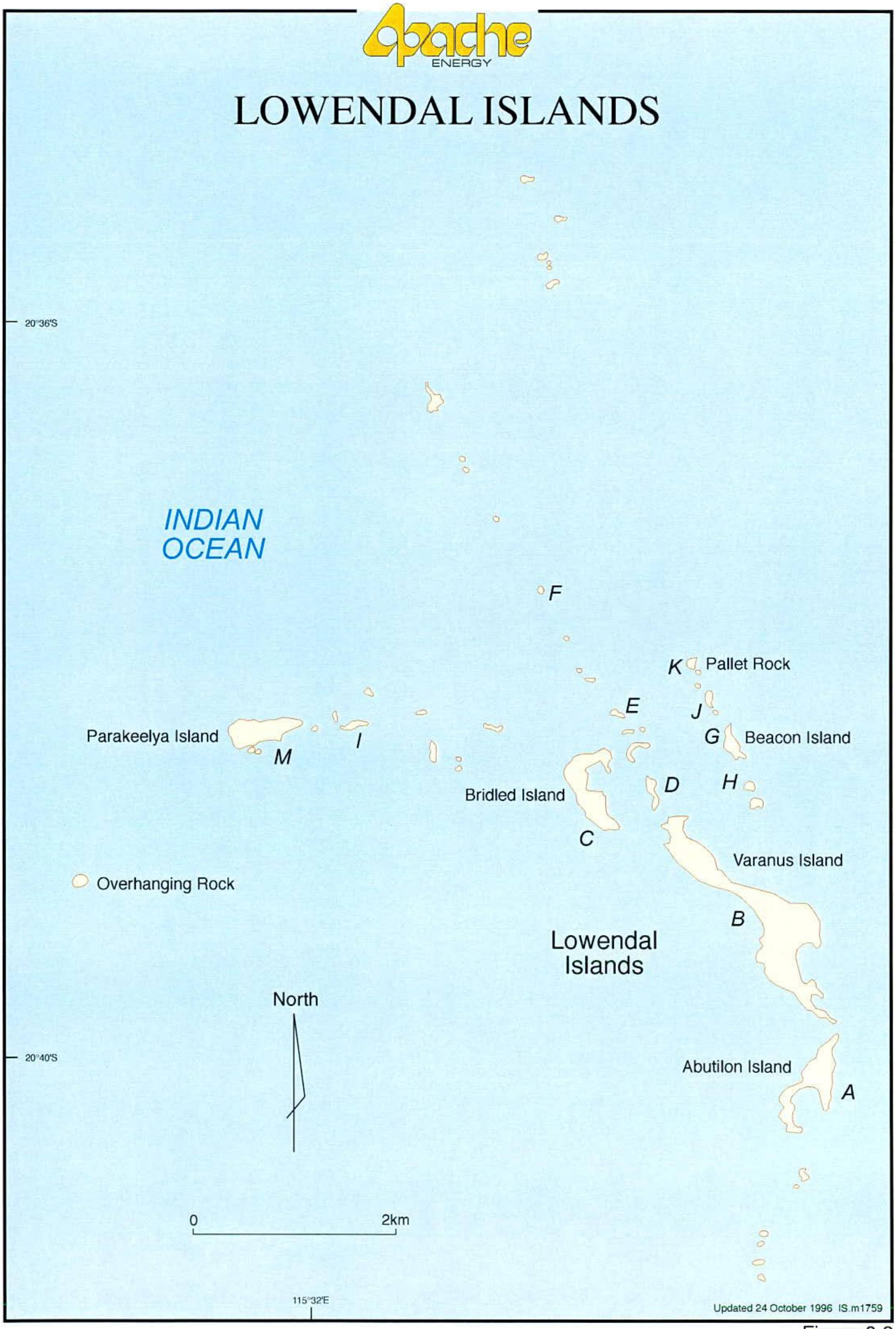
MAP OF MONTE BELLO ISLANDS

Figure 3.1



Apache
ENERGY
LOWENDAL ISLANDS
20°36'S
INDIAN
OCEAN
F
K
Pallet Rock
E
J
Parakeelya Island
I
G
Beacon Island
M
D
H
Bridled Island
C
Varanus Island
Overhanging Rock
B
Lowendal
Islands
North
20°40'S
Abutilon Island
A
0
2km
115°32'E
Updated 24 October 1996 IS.m1759

Figure 3.2

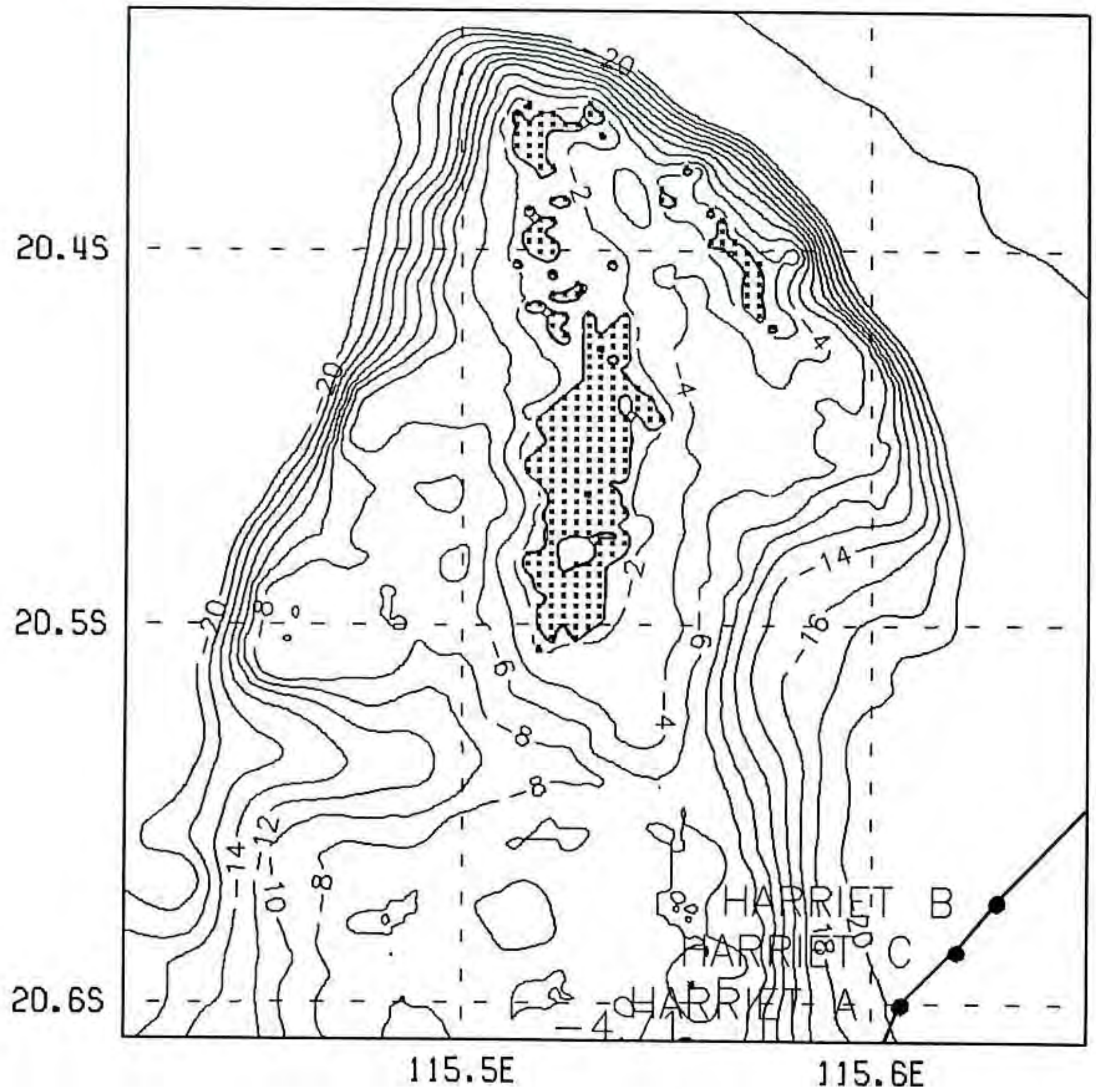


Figure 3-3 Bathymetry (m) of the region surrounding the Montebello Islands

Apache ENERGY

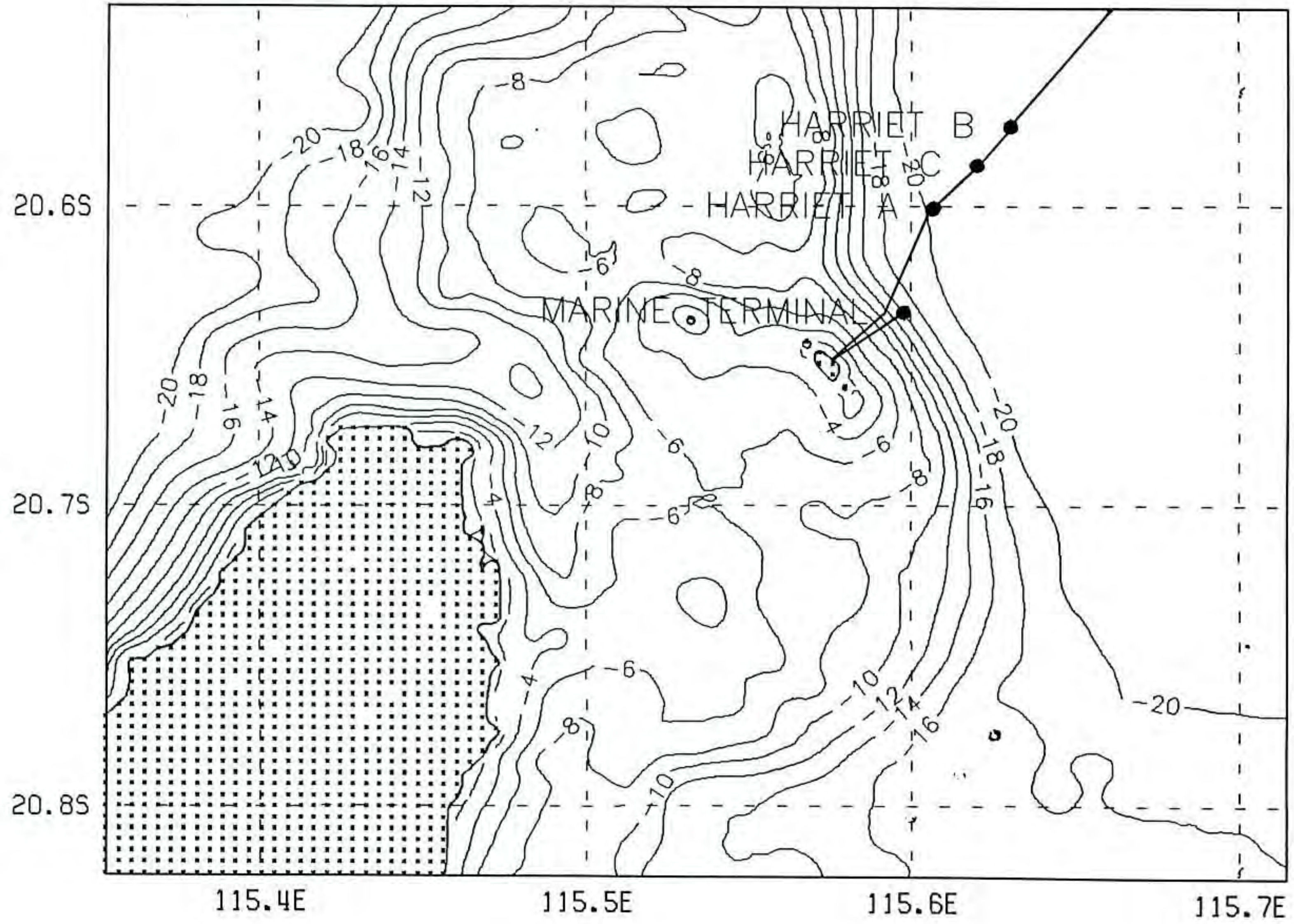
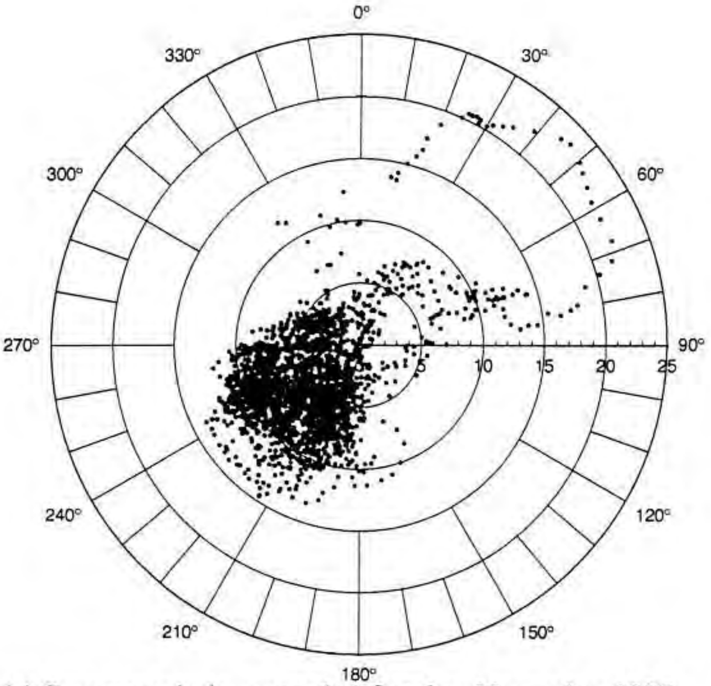
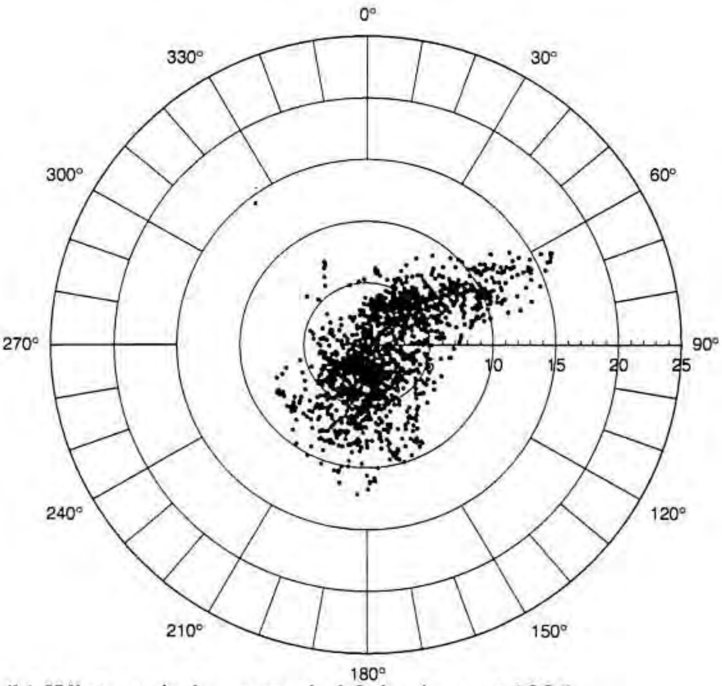


Figure 3-4 Bathymetry (m) of the region surrounding Barrow Island, Varanus Island and the Harriet field



(a) Summer winds - recorded October-November 1995



(b) Winter winds - recorded July-August 1995

Figure 3.5: Scatter plots of wind observations from Varanus Island. Orientation shows the direction the wind blew from. Distance from centre shows the speed in knots.

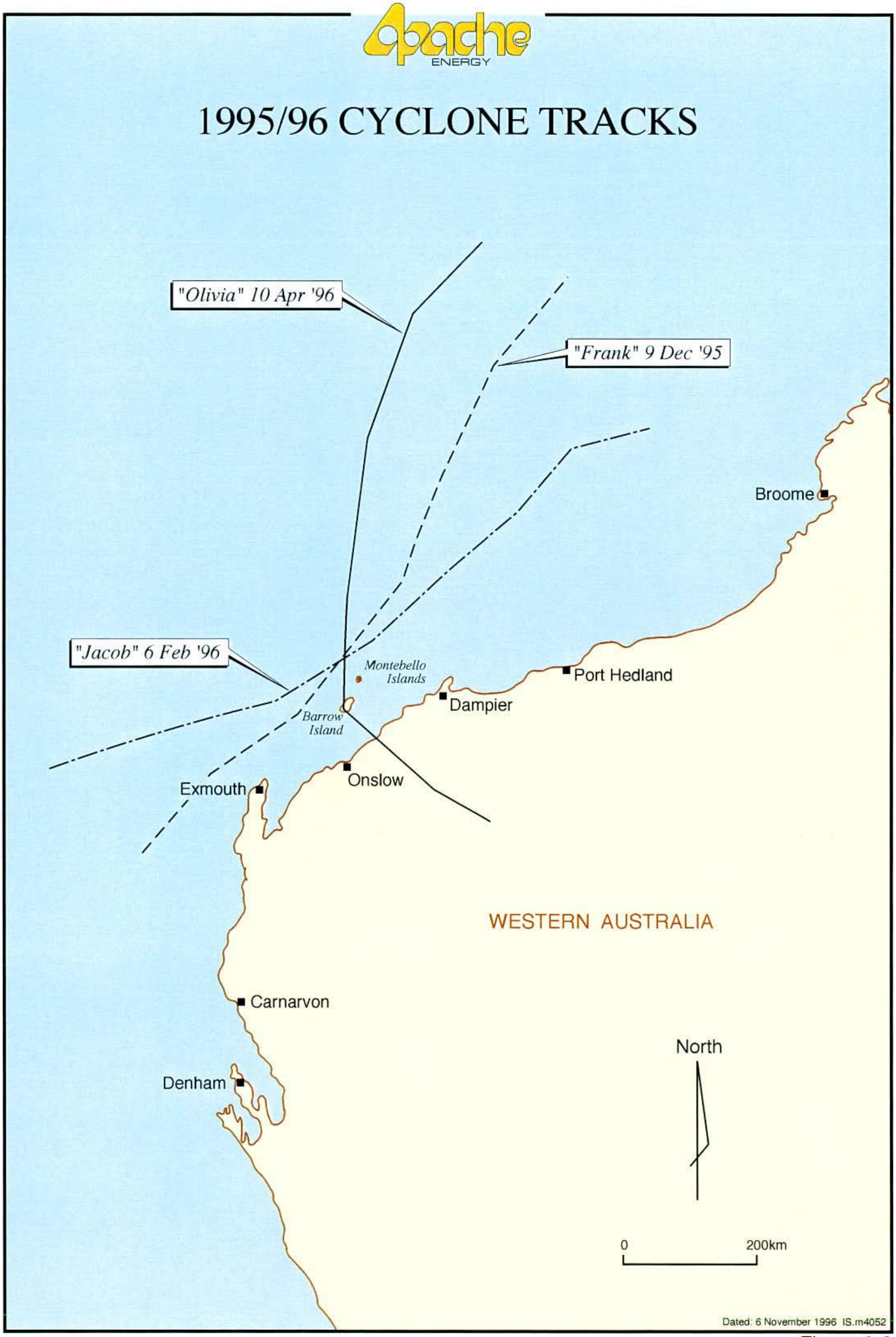

Apache ENERGY
1995/96 CYCLONE TRACKS
"Olivia" 10 Apr '96
"Frank" 9 Dec '95
"Jacob" 6 Feb '96
Montebello Islands
Barrow Island
Broome
Port Hedland
Dampier
Onslow
Exmouth
WESTERN AUSTRALIA
Carnarvon
Denham
North
0
200km
Dated: 6 November 1996 IS.m4052

Figure 3.6

Figure 3-8. Example of a flooding tide across the Montebello Island region, as predicted by the Oiltrak model

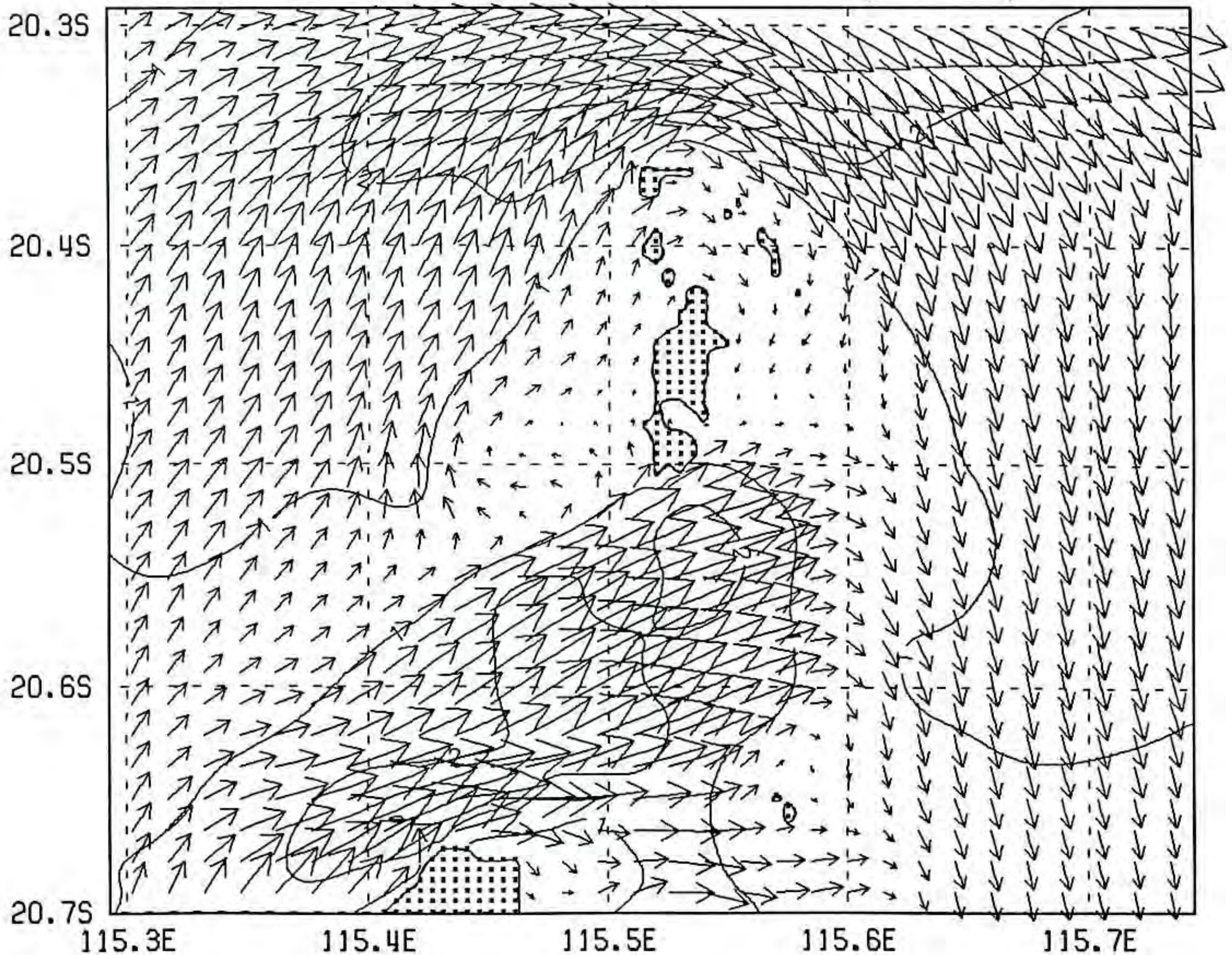
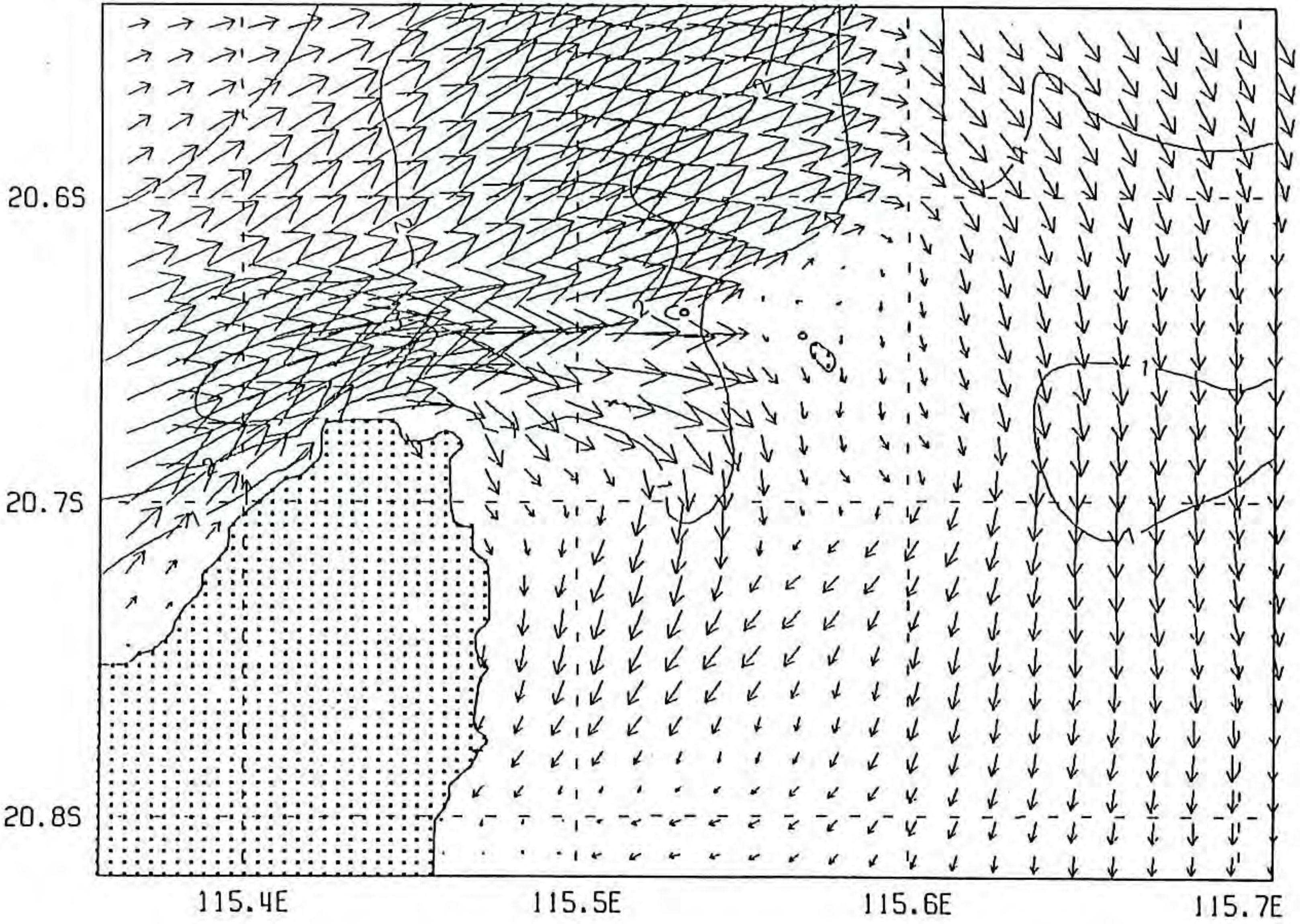
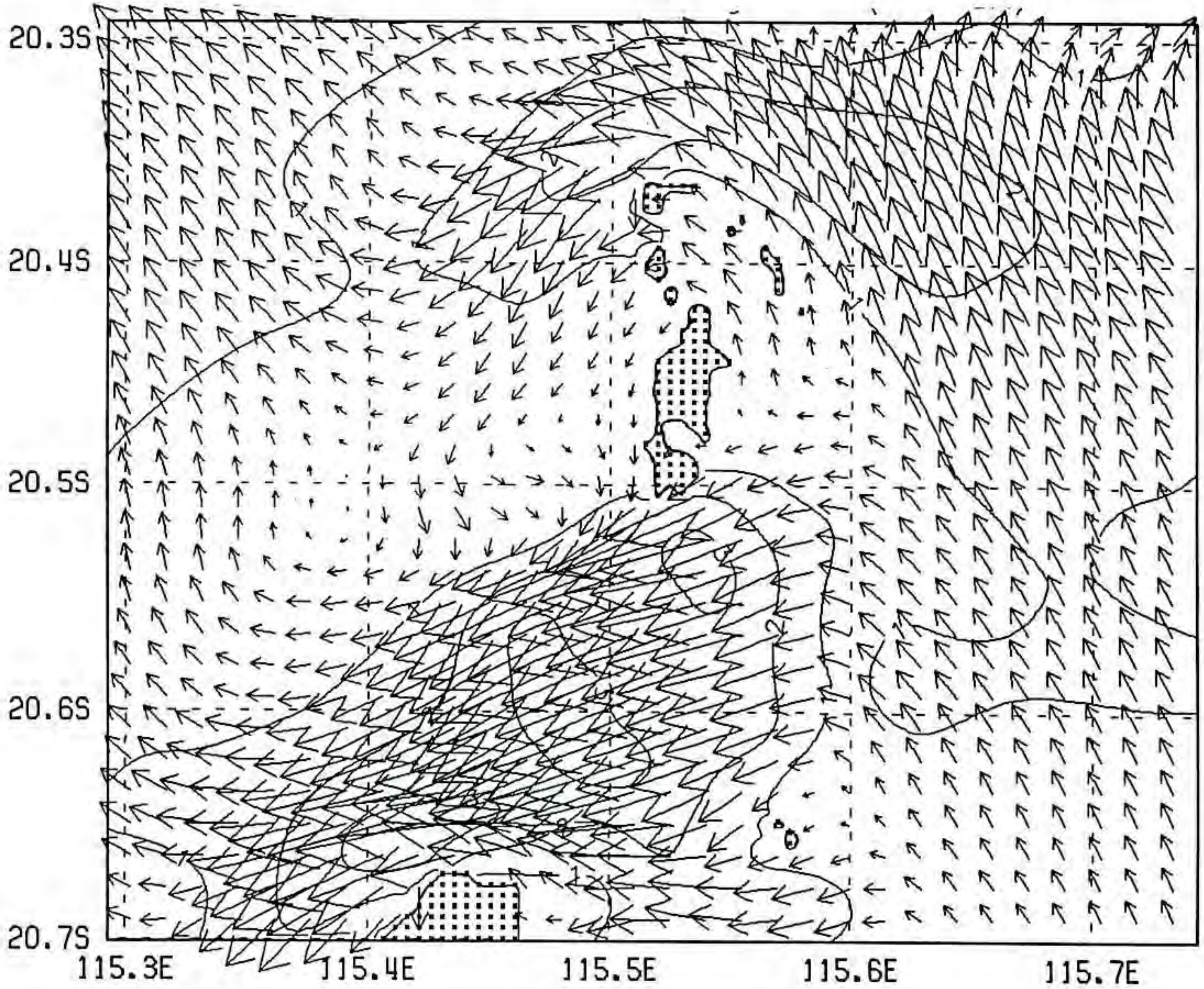


Figure 3-9. Example of a flooding tide across the Barrow Island-Lowendal Islands region, as predicted by the Oiltrak model



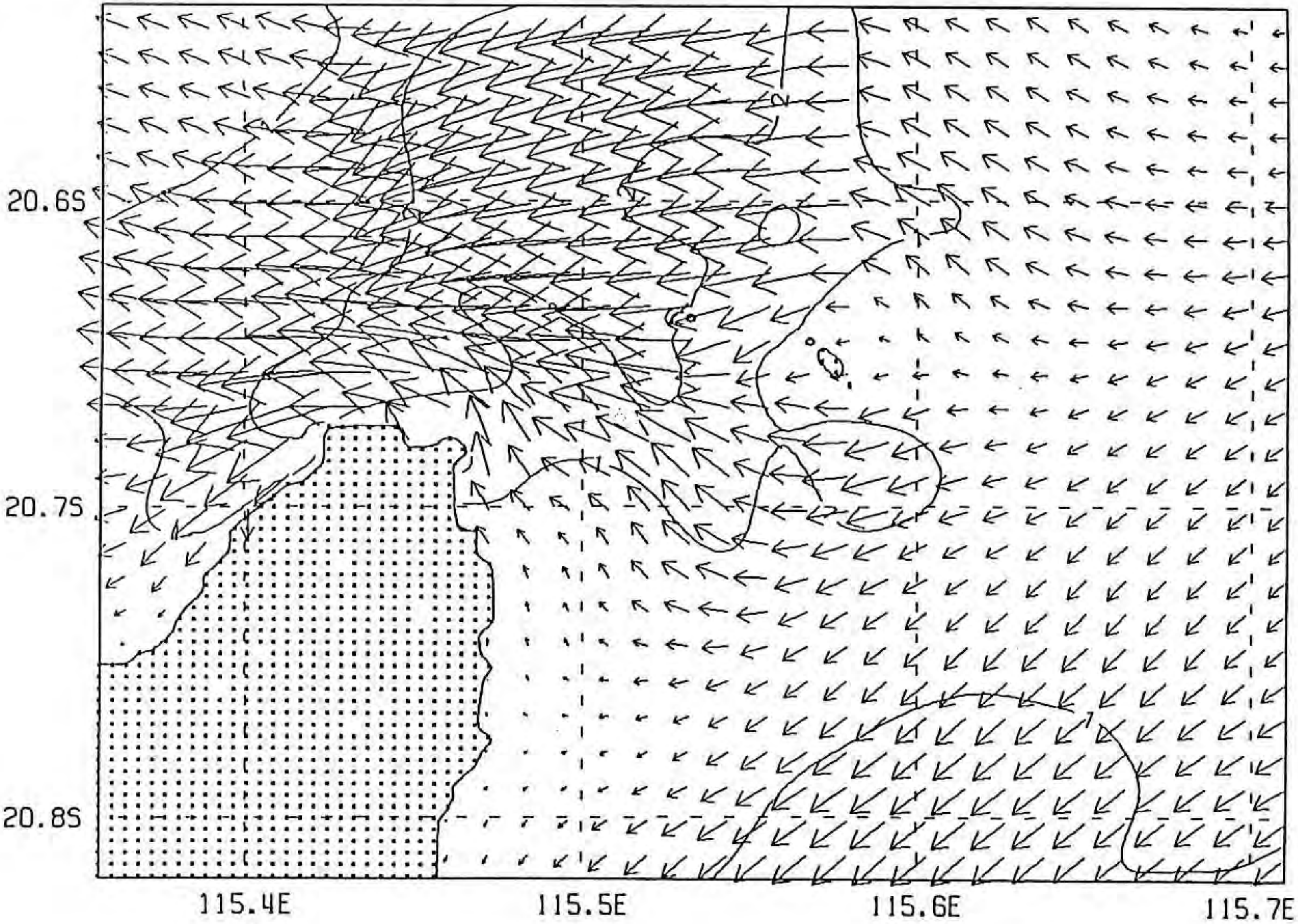
Apache ENERGY

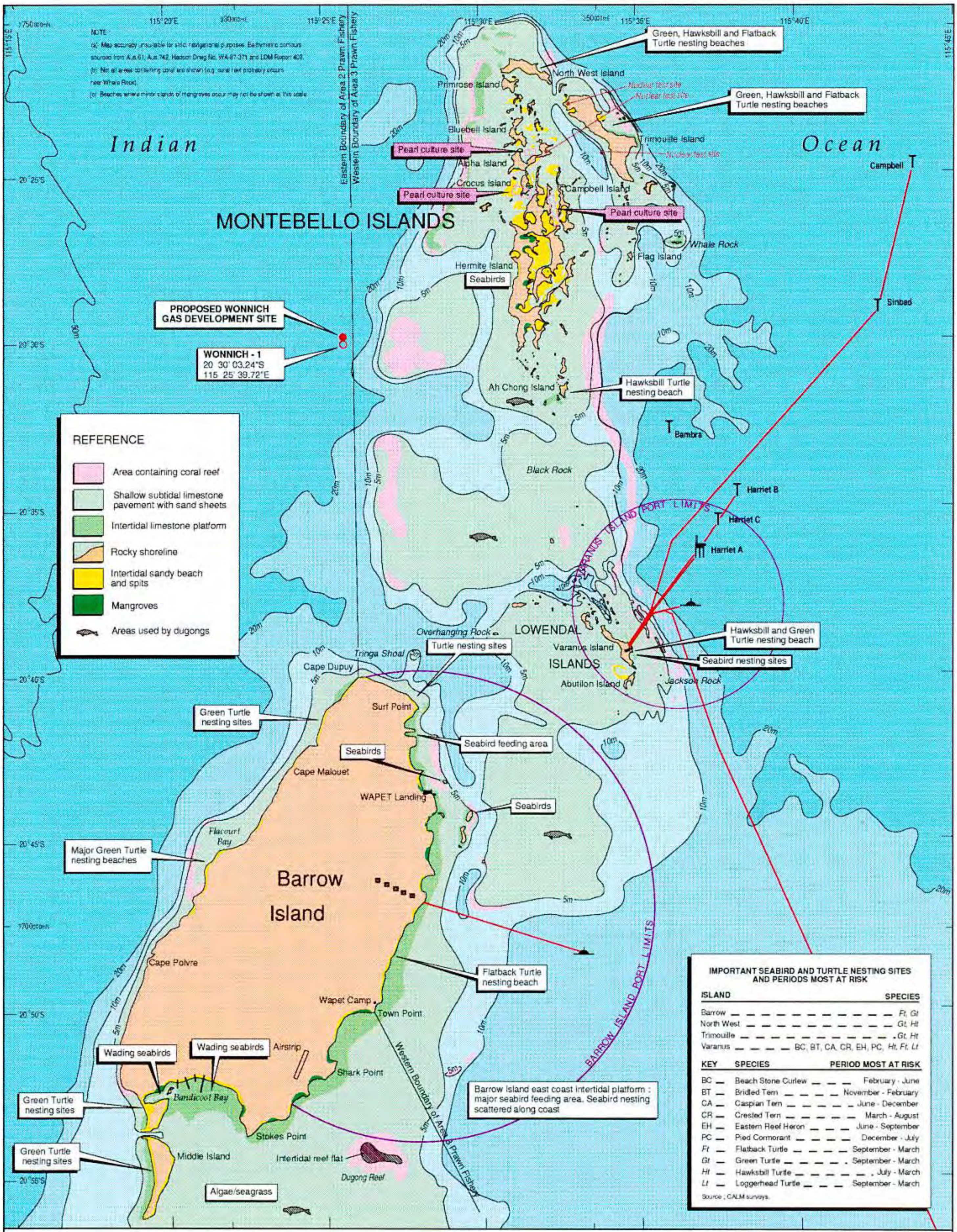
Figure 3.10 Example of an ebbing tide across the Montebello Island region, as predicted by the Oiltrak model



Apache ENERGY

Figure 3.11 Example of an ebbing tide across the Barrow Island-Lowendal Islands region, as predicted by the Oiltrak model





IMPORTANT SEABIRD AND TURTLE NESTING SITES AND PERIODS MOST AT RISK

ISLAND	SPECIES
Barrow	Ft, Gt
North West	Gt, Ht
Trimouille	Gt, Ht
Varanus	BC, BT, CA, CR, EH, PC, Ht, Ft, Lt

KEY	SPECIES	PERIOD MOST AT RISK
BC	Beach Stone Curlew	February - June
BT	Bridled Tern	November - February
CA	Caspian Tern	June - December
CR	Crested Tern	March - August
EH	Eastern Reef Heron	June - September
PC	Pied Cormorant	December - July
Ft	Flatback Turtle	September - March
Gt	Green Turtle	September - March
Ht	Hawksbill Turtle	July - March
Lt	Loggerhead Turtle	September - March

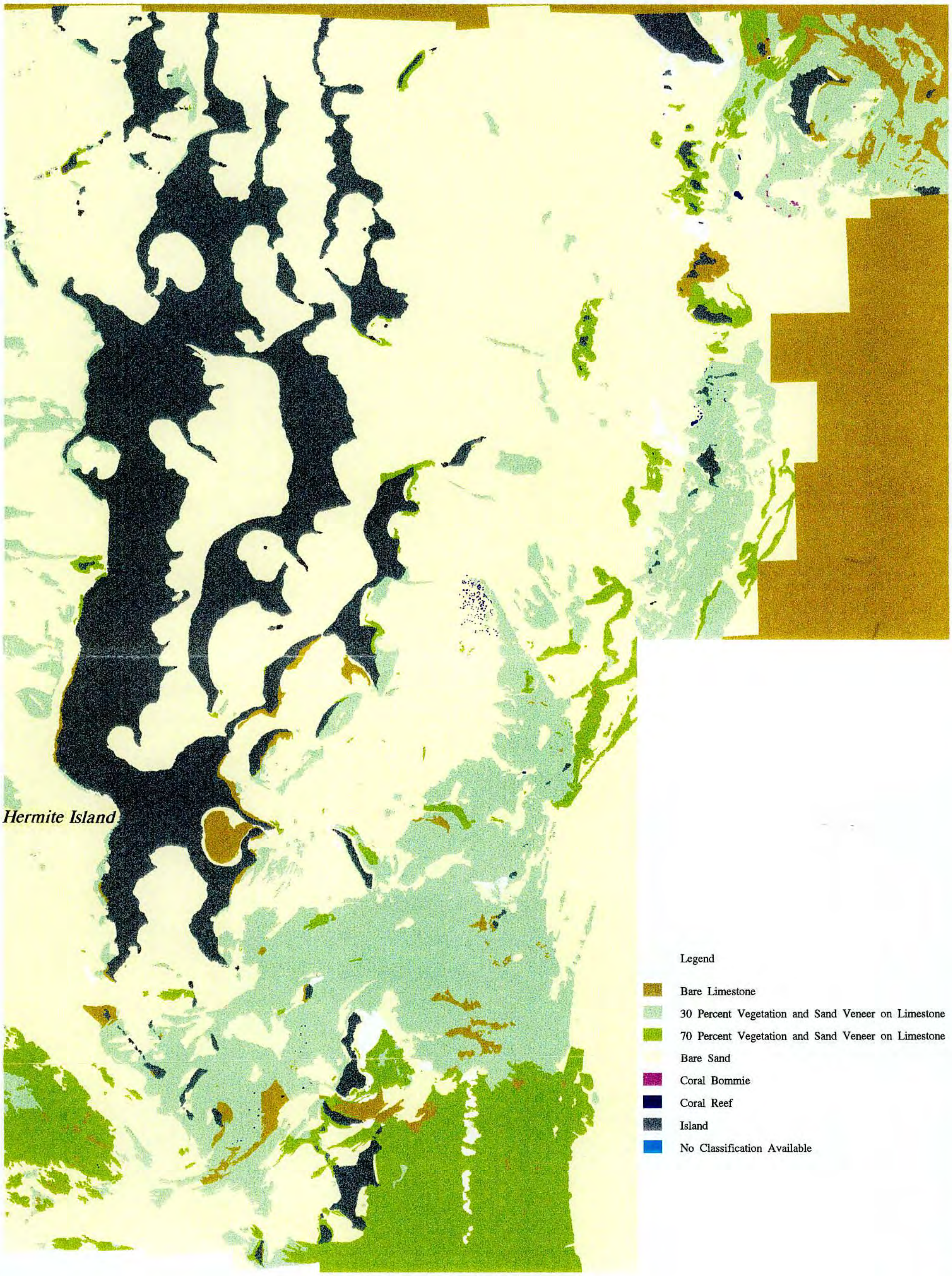
Source ; CALM surveys.

0 2 4 6 8 10
KILOMETRES

DISTRIBUTION OF COASTAL MARINE HABITATS NEAR BARROW ISLAND, THE LOWENDAL ISLANDS AND THE MONTEBELLO ISLANDS

S.M. October 1996

SHALLOW WATER HABITATS OF THE MONTEBELLO ISLANDS



DRAFT

WG96-052

Figure 3.13

SHALLOW WATER HABITATS OF THE LOWENDAL ISLANDS

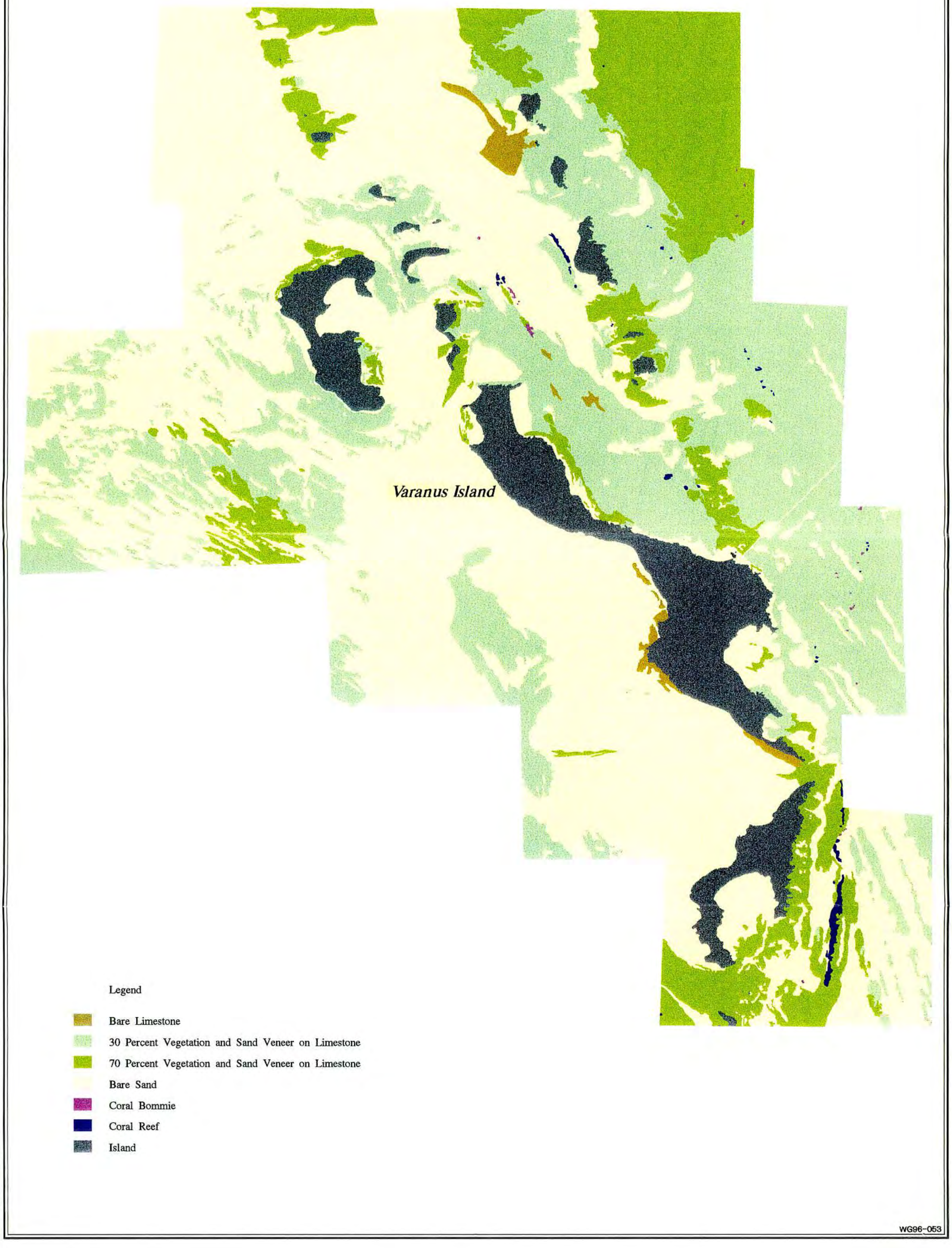
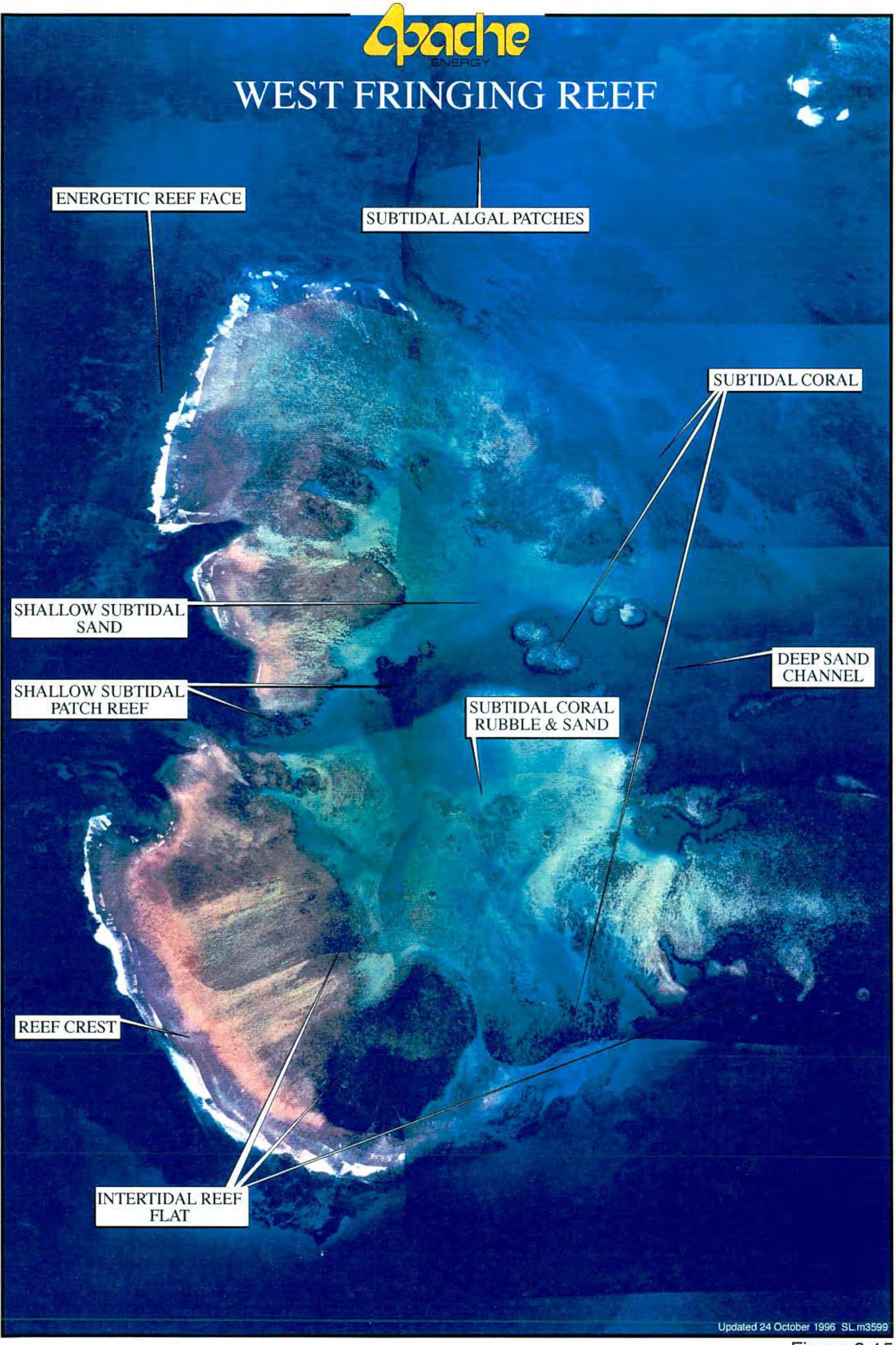


Figure 3.14



WEST FRINGING REEF
ENERGETIC REEF FACE
SUBTIDAL ALGAL PATCHES
SUBTIDAL CORAL
SHALLOW SUBTIDAL SAND
DEEP SAND CHANNEL
SHALLOW SUBTIDAL PATCH REEF
SUBTIDAL CORAL RUBBLE & SAND
REEF CREST
INTERTIDAL REEF FLAT
Updated 24 October 1996 SL.m3599

Figure 3.15

Appendix 4

PROPERTIES OF PETROFREE

1. Introduction

In hydrocarbon exploration and development, drilling fluid performs a number of functions including: carrying cuttings to the surface; providing hydraulic power to the drill bit; exerting hydrostatic head to prevent caving or sloughing of the formation, preventing the flow of formation fluids into the borehole (kicks and blowouts); and suspending cuttings and weight materials such as barite when circulation is interrupted - as when adding a new joint of drill-pipe.

Until recently, there were two broad classes of drilling fluids: oil-based and water based. Within the last few years, a new class of fluids has been developed which are formulated using a variety of synthetic organic based fluids. These fluids possess the performance properties of oil based and water based fluids, but avoid most of the environmental problems associated with the water and oil based fluids.

The synthetic ester-based drilling fluid, Petrofree ™ will be used for the Wonnich gas development wells.

2. Petrofree

Petrofree ™ is a biodegradable invert emulsion system (i.e. the ester based is emulsified within water) which is derived from vegetable oil and alcohol. It contains no aromatic hydrocarbons, is readily degradable under aerobic and anaerobic conditions and exhibits low toxicity. It also possesses no health risk to workers under normal conditions of exposure.

Biodegradation

Petrofree ™ has undergone testing both in Australia and overseas to determine its biodegradability and toxicity to marine life. Test results have been supplied by the manufacturers, Baroid, Australia Proprietary Limited. These results are summarised below.

The anaerobic biodegradability of vegetable oil esters was found to be 82.5 (± 13.9)% of organic carbon over a period of 35 days (Table 4.1). This may be compared to the result for a mineral oil which produced a degradation figure of 3.9 (± 11.0)% (European Centre for Ecotoxicology and Toxicology of Chemicals (ECETOC) No. 28 screening test (Figure 4.1).

Aerobic biodegradability, was found to be 89% over a 28 day period, with 57% degradation occurring in the first five days (US EPA 40 CFR 796.3200 protocol) (Figure 4.1).

Toxicity

Toxicity testing on Petrofree ™ has been carried out in the United States, at the centre for Petroleum Engineering, University of New South Wales and Curtin University, Perth. The results of testing conducted to date (Attachment 1) indicate that Petrofree ™ has a very low toxicity to subtropical and tropical marine organisms, including species found on the North West Shelf of Western Australia, as shown in Table 4.2, and Figures 4.2 and 4.3.

Table 4.1: Anaerobic biodegradability of Chemicals Examined in the ECETOC No. 28 Screening Test

Test Chemical	Test duration (days)	Degradation in the ECETOC test (% of organic carbon)		
		Net gas production	Net DIC production	Extent of ultimate degradation *
Vegetable oil ester	35	63.3	19.2	82.5 ± 13.9
Acetal-derivative (Ether II)	70	3.7	8.9	12.6 ± 19.2
Polyalphaolefin (PAO) I	70	4.4	10.0	14.4 ± 20.3
PAO II	50	-1.6	2.2	0.6 ± 16.0
Alkylbenzene (LAB)	50	0.9	-2.4	-1.5 ± 12.0
Mineral oil	35	0.7	3.2	3.9 ± 11.0

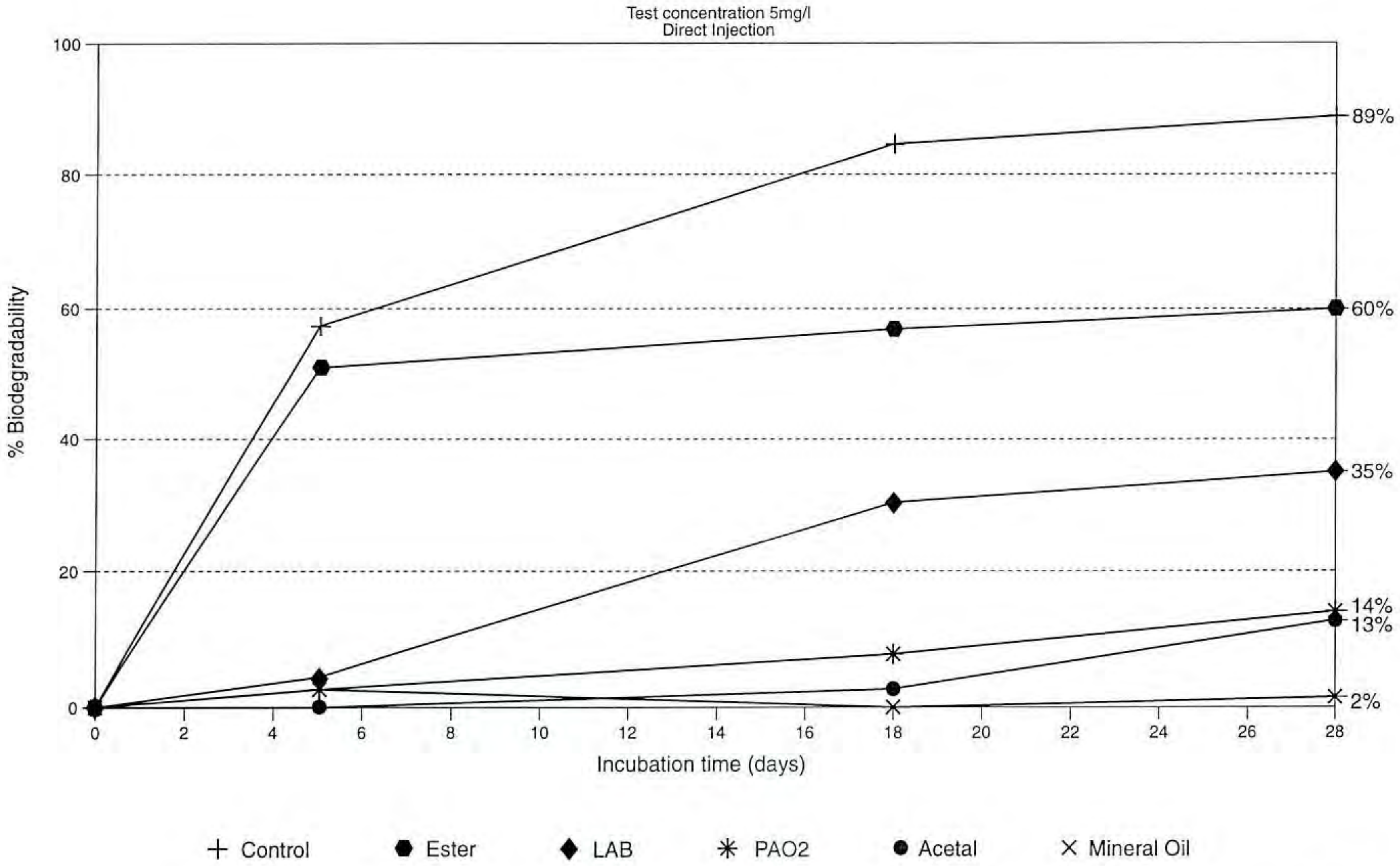
(DIC - dissolved inorganic carbon)
* mean value (from 5 replicates) and its 95% - confidence interval.

Table 4.2: Toxicity of Petrofree to Various Marine Organisms

SPECIES NAME	COMMON NAME	TEST	RESULTS mg/L
Penaeus monodon	prawn (juvenile)	96 hr LC_{50}	>256,000
Isochrysis sp.	algae	96 hr IC_{50}	177,000
Mysidopsis bahia	mysid shrimp	96 hr LC_{50}	>1,000,000
Allorchestes compressa	amphipod	96 hr LC_{50} (solid phase)	691,000

ENERGY

BIODEGRADABILITY OF SYNTHETIC BASE FLUIDS
AEROBIC METHOD 28 DAY TEST

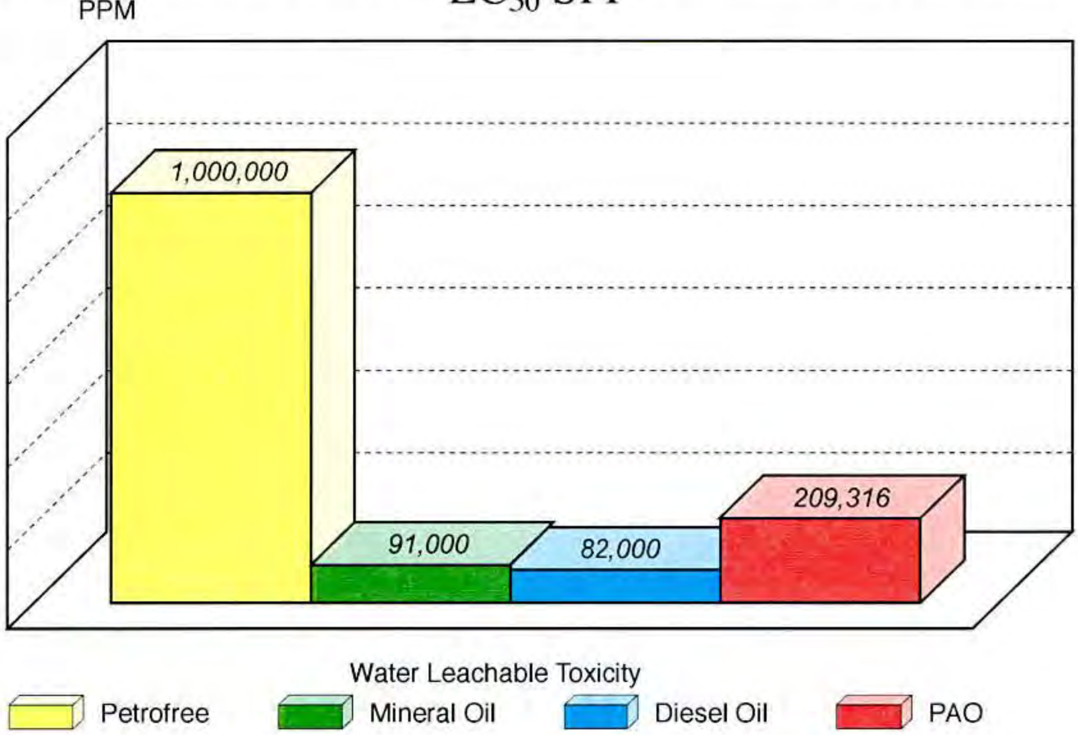


Updated 24 October 1996 IS.m4034

Figure 4.1

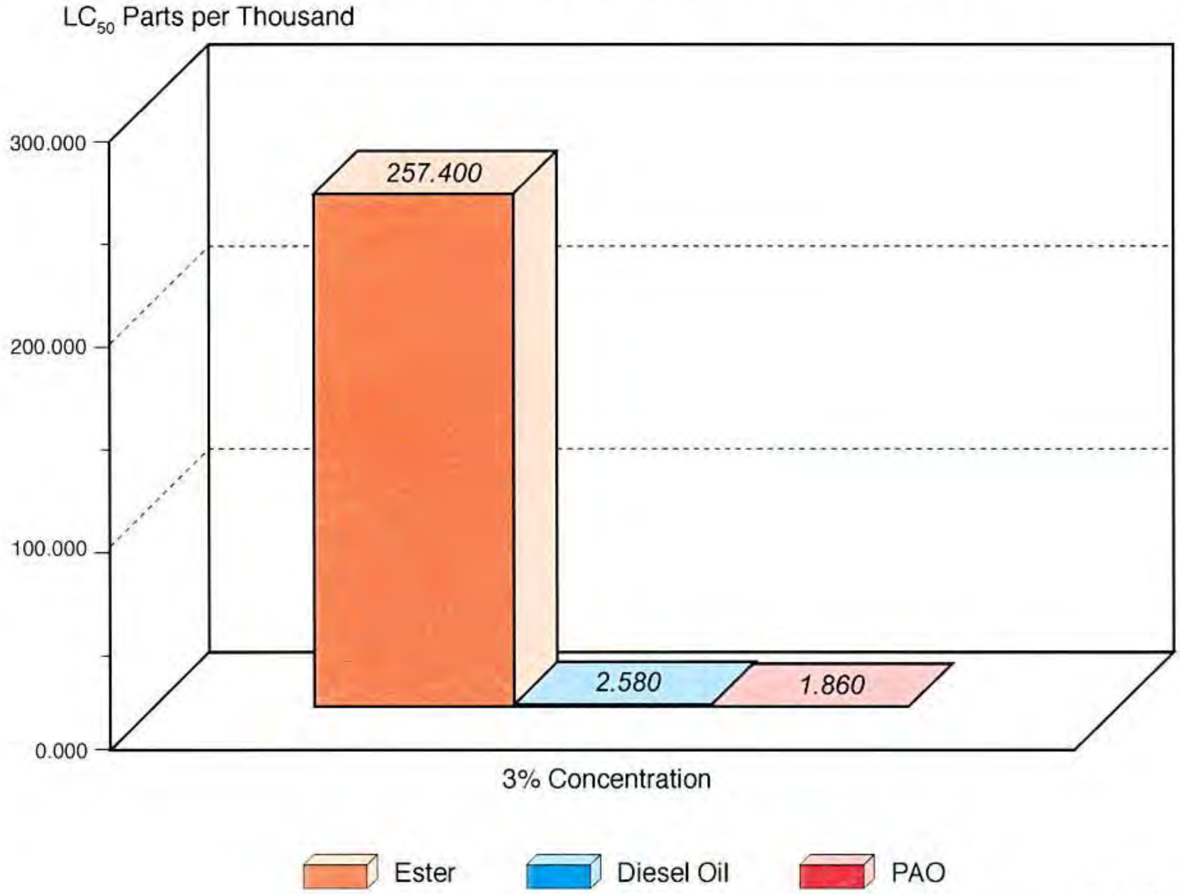
DRILLING FLUID TOXICITY COMPARISON

LC_{50} SPP



BASE FLUID TOXICITY COMPARISON

LC_{50} TEST IN A GEN#7 MUD SYSTEM

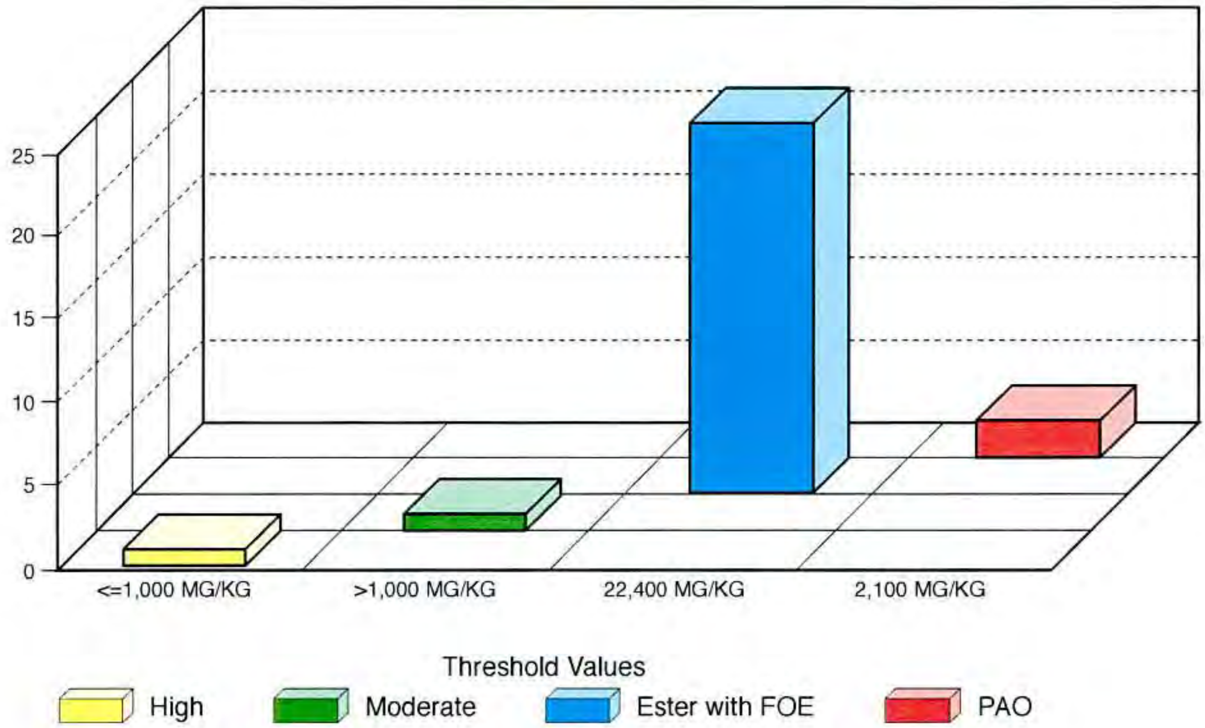


Dated: 18 October 1996 IS.m4032

Figure 4.2

TOXICITY TO *SKELETONEMA COSTATUM*

EC_{50} VALUES



PETROFREE TOXICITY

TEST	PETROFREE ESTER
Acute Oral Toxicity Water Rate OECD Guideline #401	LC 50 > 2,000 mg/l
Acute Dermal Toxicity OECD #402	'Slight Irritant'
Primary Eye Irritation (Rabbit) J. Am. Coll. Tox. 1/2 13-35 (1982) OECD #405	'Slight Irritant'
Skin Sensitization - Dermal OECD #408	Negative
Mutagenicity - Ames bacterial OECD #471	Not Mutagenic
Dermal Study Dermatological 129-37-46 (1964)	Not Irritant
Dermatological Test - Burckhardt Test - Closed epicutanious	 - no reaction - very good skin compatibility
Pre-Manufacture Notification	Not Mutagenic

Dated: 18 October 1996 IS.m4033

Figure 4.3

Appendix 5

Kvaerner R J Brown Pty Ltd

KRJB

CLIENT **APACHE ENERGY LTD**

PROJECT **WONNICH DEVELOPMENT PROJECT**

JOB NO.	DOCUMENT NO.	ORIGINATING OFFICE
4366	**P-4366-SSR-001**	**PERTH**

DOCUMENT TYPE

REPORT

DOCUMENT TITLE

WONNICH PIPELINE ROUTE INVESTIGATION

A	9/96	Issued for Comment				
REV	DATE	DESCRIPTION	BY	CHK'D	APPR'D	

WONNICH
PIPELINE ROUTE INVESTIGATION

TABLE OF CONTENTS

SECTION ONE

INTRODUCTION

1.0 INTRODUCTION

Apache Energy Limited (Apache) is planning to develop the Wonnich Field which is located approximately 23 km north west of Varanus Island. Transportation of the product from Wonnich to Varanus Island will be by pipeline.

In May 1996 Fugro Survey Pty Ltd (Fugro) carried out a geophysical pipeline route survey along three candidate routes for Tamboritha Consultants on behalf of Apache. The results of that survey are presented in Reference 1. Keith Binns was on board the survey vessel during the work as Apache's pipeline engineer in order to assess the routes from the point of view of pipeline installation and lifetime intervention.

This report describes the major features of the pipeline routes and addresses the subject of pipeline installation and lifetime maintenance difficulties. The main features of each route are presented in tabular form and a weighted score allocated to each in order to rank the routes in order of preference.

SECTION TWO

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

2.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

2.1 SUMMARY

Three routes for the Wonnich pipeline have been proposed:

The first route (Route 1) runs due south from Wonnich until reaching the existing East Spar pipeline at which point it turns eastwards and heads towards Varanus Island in relatively shallow water. Another route (Route 2) via the Bambra monopod wellhead crosses a reef in an area of shallow water south of Ah Chong Island before turning south towards Varanus Island where the pipeline would come ashore in the existing trench. The most direct route (Route 3) crosses areas of reef in very shallow water and the three sub routes may come ashore either on the east or west coasts of Varanus Island. The pipelines routes are illustrated on Figure 3.1.

2.2 CONCLUSIONS

Route 1 is concluded to be the optimum pipeline route from the point of view of:

- ease of installation
- ease of post installation stabilities
- least lifetime inspection and maintenance
- least environmental impact.

A weighted comparison of the routes was carried out and is presented in Section 5 of this report. Out of a possible 100 points Route 1 scored 78, Route 2 scored 46 and Route 3 scored 33.

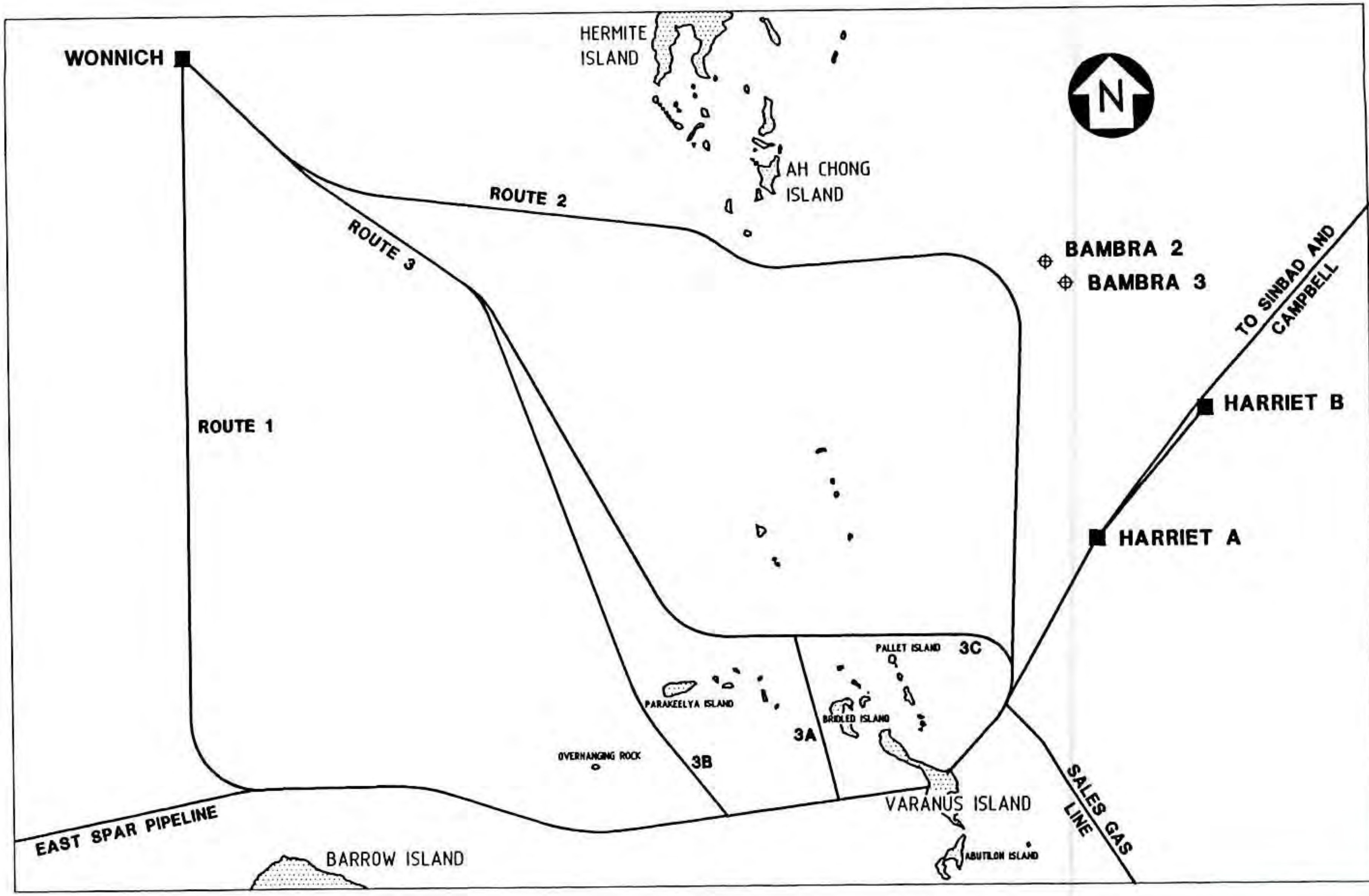
Route 1 offers limited environmental damage whilst Routes 2 and 3 cross living reefs and will almost certainly cause environmental damage of a greater magnitude. Although Route 1 is the longest route it is the simplest from the point of view of installation, stabilisation, and lifetime inspection and maintenance.

Route 2 is 1 km shorter than Route 1 and offers the advantage of being able to collect gas from the Bambra field by introduction of a branch line. However, its passage across the reef south of Ah Chong Island including the stretch of very shallow water will make installation, stabilisation and lifetime maintenance extremely difficult.

Route 3 which includes the three alternative routings 3A, 3B and 3C has all the problems associated with Route 2 and does not offer the possibility of picking up gas from Bambra. The material cost savings associated with the shorter route, up to 7 km shorter than Route 1, will almost certainly be balanced or exceeded by the extra costs associated with the extremely difficult installation and stabilisation requirements. Lifetime operating costs associated with inspection and maintenance will be much greater than for Route 1.

2.3 RECOMMENDATIONS

It is recommended that Routes 2 and 3 no longer be considered as potential routes for the proposed gas pipeline between Wonnich and Varanus Island.



4000427

KVAERNER R J BROWN

WONNICH DEVELOPMENT

TITLE

PROPOSED PIPELINE ROUTES

JOB No 4366

FIGURE No 3.1

DOCUMENT No. P-4366-SSR-001

SECTION THREE

DESCRIPTION OF ROUTES

3.0 DESCRIPTION OF ROUTES

3.1 GENERAL

The following sub-sections are based on the data presented graphically in Fugro Survey's Pipeline Route Survey Alignment Charts [Ref. 1]. Those alignment charts should be referred to for full details of seabed features, bathymetry, seabed mosaics, geological profiles and isopaches. The following narrative is intended to give a brief overview of the major features of each route as discovered during the pipeline route survey in May 1996.

The kilometre point (KP) system for all routes is based on KPO at Wonnich with KPs increasing towards Varanus Island. The water depths are all referenced with respect to lowest astronomical tide (LAT).

The lengths of the pipeline routes are as follows:

Route 1	33 km
Route 2	32 km
Route 3A	26 km
Route 3B	26.5 km
Route 3C	31 km

The proposed pipeline routes are illustrated in Figure 3.1.

3.2 ROUTE 1

Route 1 leaves Wonnich where the water depth is 31 m and heads in a southerly direction for approximately 17 km until reaching the existing East Spar pipeline. The water depth gradually reduces to about 13 m at this point, and the seabed for these 17 km is predominantly featureless. The pipeline will then turn left and head east where it will lie just north of the East Spar pipeline for a further 16 km before coming ashore in a sandy bay on the west side of Varanus Island. The majority of the seabed along this easterly heading part of the route is calcarenite with only the occasional overlying shallow pocket of sand. See Reference 2. The total length of Route 1 is 33 km. The last 7 km of this route, nearest the island, lies in very shallow water, with a depth of 2 m. The seabed is fairly flat and featureless although a small number of subsea pinnacles are present.

3.3 ROUTE 2

KPO to KP11

Route 2 runs in a south easterly direction for approximately 4 km from Wonnich before heading in an easterly direction to pass south of Ah Chong Island. The water depth decreases gradually from 31 m at Wonnich to about 14 m some 11 km from Wonnich. Over the first 3.5 km (to KP3.5) there is a sandy seabed with the sand veneer up to 10 m deep. There is then about 2.5 km (to KP6) of exposed calcarenite seabed until the sand cover returns for the next 5 km (to KP11). The sand veneer over this area varies from less than 0.5 m in places up to 6 m in patches averaging about 2 m overall.

KP11 to KP18.7

Between KP11 and KP18.7 the pipeline route runs due east and passes about 1 km south of Ah Chong Island. This whole area is reef where the water is particularly shallow. In the 3 km between KP14.5 and KP17.5 the water depth is less than 4 m with the 2 km between KP14.75 and KP16.75 having a water depth less than 2 m. In this area of shallow water the seabed is very irregular with the seabed mosaics showing complex contour patterns of depressions and mounds.

In the 4 km between KP14.5 and KP18.5 there are numerous prominent reef pinnacles standing between 2 and 2.5 m proud of the surrounding seabed. These occur on the centre line of the proposed pipeline route and within the 500 - 600 m wide swathe covered by the sidescan sonar. These are shown as seabed features on alignment chart drawing No. 11765-08 contained in Reference 1. Over 125 individual pinnacles were sighted and mapped within this particular stretch of reef.

KP19 to Varanus Island

By KP19 the pipeline route has reached the limit of its easterly path and exited the reef area. The pipeline route curves through about ninety degrees to pass within 1 km of Bambra and head southwards towards Varanus Island. By KP19 the water depth has increased to 20 m and a regular cover of sand overlying the harder subsurface appears. The pipeline continues south for a further 9 km until it meets the Sinbad-Campbell infield flowline and then runs parallel to it through the trench on the North East side of Varanus Island. Over this distance the sand cover thickness varies from 1 m along most of the route to 3 or 4 m in places.

The total length of Route 2 is 32 km.

3.4 ROUTE 3

Route 3 is intended to follow the shortest route between Wonnich and Varanus Island with the 3A, 3B and 3C alternatives cutting slightly different paths between the various islands to the west of Varanus Island. These follow a common path for the first 9 km in a generally south easterly direction from Wonnich.

At this point route 3B takes the most westerly path continuing on west of Parakeelya Island until it reaches the East Spar pipeline 4.5 km west of Varanus Island.

Route 3A runs past the north east of Parakeelya Island until reaching the East Spar pipeline 2 km west of Varanus Island.

Route 3C runs eastwards to the north of Parakeelya Island, Bridled Island, Pallet Island and Varanus Island before transcribing a curve and joining the Sinbad-Campbell infield flowline where it enters the trench which runs into the north east side of Varanus Island.

From approximately KP9 where Route 3B separates from Routes 3A and 3C all three routes pass over very shallow coral reefs for distances of 10 - 14 km. The water depth is less than 2 m for long stretches along each of these routes and the seabed is irregular in profile with negligible cover of sand apart from discrete localised pockets. Along the common part of Routes 3A and 3C between KP18 and KP23 the pipeline would traverse four subsea valleys which fall to a depth of 14 m before rising over a short distance to a depth of only 3 m. Along this part of the proposed route the seabed consists of exposed calcarenite forming a reef with intermittent patches of very shallow sand cover.

The lengths of Routes 3A, 3B and 3C are 26 km, 26.5 km and 31 km respectively.

SECTION FOUR

PIPELINE INSTALLATION, STABILISATION AND MAINTENANCE

4.0 PIPELINE INSTALLATION, STABILISATION AND MAINTENANCE

4.1 GENERAL

Several parameters have to be assessed when comparing different pipeline routes.

The major parameters would include the following:

- installation
- post installation stabilisation
- lifetime maintenance
- environmental impact.

These are covered in the following sub-sections.

4.2 PIPELINE INSTALLATION

The most severe restriction upon pipeline installation along the three proposed routes comes from areas of shallow water. The pipeline route survey was performed by the vessel "Mermaid Avenger", an aluminium hull vessel with 1.4 m draft. In areas of shallow water encountered along Routes 2 and 3 the procedure adopted for accessing the shallow water areas was to enter only on a rising tide in the hour or so before predicted high tide. The rationale was that the vessel would only be in the shallow water areas whilst the tide was rising and that the vessel would move back into deeper water before the tide peaked.

4.2.1 Route 1

Route 1 was selected as it appeared to offer the most straightforward installation. The first part of the route which leads southwards from Wonnich lies in water depths from 31 m to about 13 m. There are no shallow water installation problems along this part of the route. From the point where the pipeline turns through ninety degrees to run in an easterly direction towards Varanus Island it will run parallel to the existing East Spar pipeline. The Wonnich pipeline will not have to face any more severe challenges than the East Spar line which was successfully installed earlier in 1996. The shallow water problems along this part of the route can be dealt with by using a shallow draft laybarge like the Clough Challenge. In this area the seabed, whilst shallow, is not a reef area and has a more even profile than the shallow water areas of Routes 2 and 3. The route has only a few isolated subsea pinnacles which the route can avoid and which anchor handling tugs have previously worked around.

The presence of the East Spar pipeline will require all barge and vessel operations during the Wonnich pipeline installation to follow strict procedures to ensure the safety of the existing pipeline. Pipelaying procedures, survey procedures, anchor handling procedures and vessel activity procedures will need to be written specifically around the integrity of the existing pipeline and rigorously applied. This presents as much a challenge to management activities as to the installation itself. Correctly applied procedures will ensure the integrity of the East Spar pipeline.

Route 1 offers no shallow water challenges that have not been successfully overcome previously.

4.2.2 Route 2

Route 2 has one area of shallow water where installation will be difficult for the reasons outlined above. However, the extent of shallow water along Route 2 is only 2 -3 km in a straight line and it may be possible to install a single string of pipe over this distance without a barge having to traverse the very shallow water whilst laying. With a pull vessel anchored on one side of the very shallow water and a construction vessel anchored on the other side of the very shallow water continuously welding pipe, the pipe string could be pulled across this area. There are several difficulties associated with this installation method which could make it impractical. The seabed over this area is a very irregular reef formation providing a lot of physical obstructions and snagging hazards which could jeopardise both the pipeline and the pulling wire. The area is also dotted with subsea pinnacles which could further obstruct the pipe string or pulling cable during installation. Divers or an ROV would be required to monitor the pull head of the pipe string during the pull to ensure that it did not come up against obstacles. Whilst the divers could possibly operate from a small aluminium diving dinghy remote from the construction vessel an ROV would have to be supported from a significantly larger vessel. The draft of an ROV support vessel would not allow it to operate in the shallow water for any longer than about 1 hour at every high tide. The pull however would need continuous monitoring.

The installation of a pipe string across this shallow water section by towing is considered impractical as the leading tow tug will have to traverse the area. The pull forces required for such a tow are likely to dictate that a tug with substantial bollard pull and consequent deep draft will be required making the reef crossing impractical. The other problems with towing as discussed for Route 3 below will also apply to Route 2.

At least two installation methods and spreads will be required for Route 2. These will be a laybarge for the majority of the route and a pull spread for the shallow water area which crosses the reef.

4.2.3 Route 3

It became evident after a few days of the survey work that to survey Route 3 to the full extent specified, ie. one centre line and two offset wing line passes and cross runs at 1 km intervals would be impossible within the allotted time span. It was decided to abort any further survey work on Route 3 on 27 May 1996, the sixth day of the eleven day survey at which stage the Route 3 survey was only about one third complete. The inability of the 1.4 m draft survey vessel to work for extended periods (2 hours) in shallow water along Route 3 would mean that pipeline installation would be substantially more difficult as the lay vessel would need to be in the area for continuous periods of time over a number of weeks. The Clough shallow water lay barge also draws 1.4 m of water, the same as the survey vessel. It would need to be supported by anchor handling tugs, a supply vessel and a crew boat throughout the installation, all of which would be equally handicapped by the shallow water.

Alternative pipeline installation methods such as towing would face major problems in these shallow water areas. The seabed is very irregular and a tow along the bottom would be extremely risky. Any surface tow is always very weather sensitive and whilst it is outside the scope of this study to evaluate alternative installation methods it is important to recognise that surface towing is an installation method rarely used. Towed installations require tie-ins to be made between adjacent strings and this in itself leads to further difficulties. Diving in only a few metres of water is difficult and weather sensitive. Bringing the pipe ends up to surface in order to complete a tie-in in air will require a barge with lifting facilities. This too will need to operate in the shallow water and be supported by anchor handling tugs, crew boats and so on. It is thus concluded that whilst pipeline installation along Route 3 may be technically achievable by one or more methods, it has serious limitations and should not be considered further.

4.3 POST INSTALLATION STABILISATION

4.3.1 Route 1

This route should allow free access for the purposes of rock bolting, ploughing, or trenching activities.

The north-south section from Wonnich in water depths from 31 - 13 m has areas of deep sand cover where stabilisation by ploughing or trenching is probably the most cost effective solution. Remaining areas may require rock bolting. For any of these solutions the water depth does not pose a problem.

Along the west-east part of the route leading to Varanus Island a greater amount of rock bolting is likely to be required. The precedent of the East Spar pipeline shows that this can be done even in the shallow water areas which make up a significant portion of this part of the route. As was the case for pipeline installation, care will need to be taken when stabilising the Wonnich pipeline to guarantee the integrity of the existing East Spar pipeline.

Route 1 is not likely to have many pipeline spans in the north-south section of the route from Wonnich where the seabed is relatively smooth. In the west-east section which runs in towards Varanus Island a limited number of free spans can be expected as was the case with the East Spar pipeline. Span rectification should not pose a major problem as vessel access is not restricted by the shallow water areas and there is not a large number of subsea pinnacles.

4.3.2 Route 2

It has already been concluded that installation of the pipeline in the shallow water section of Route 2 will be extremely difficult. The same conclusion has to be reached for post installation stabilisation of the pipeline in this area.

Access to the area will be very difficult as will setting anchors and servicing the main stabilisation support vessel with various other vessels that make up the spread. The reef area along Route 2 is likely to generate a large number of pipeline spans which will require remedial attention over and above the stabilisation intervention necessary. This reef area includes not only the shallow water stretch but extends beyond that on both sides giving rise to likely free spans in those areas too.

Route 2 will be a very difficult route from the point of view of post installation pipeline stabilisation.

4.3.3 Route 3

The shallow water sections of Route 3 present major pipeline installation difficulties as discussed above. These difficulties will apply equally to post installation stabilisation. In addition a large number of pipeline spans can be expected due to the rough nature of the seabed. Intervention to correct unacceptable spans will increase the difficulty and costs associated with selecting Route 3 for the Wonnich pipeline.

4.4 LIFETIME INSPECTION AND MAINTENANCE

4.4.1 General

The requirements to inspect the pipeline are likely to be dictated by the pipeline licence and will be similar for each of the pipeline routes. The requirements will probably call for regular, perhaps annual, pipeline surveys by ROV and additional ROV surveys following particular cyclones depending upon their intensity and path. Although the inspection requirements will be similar the difficulty associated with any required maintenance will be dependent upon the pipeline route.

The ease of lifetime maintenance is directly related to the ease of access to the pipeline for any remedial works needed.

4.4.2 Route 1

Route 1 poses no serious inspection and maintenance problems. From Wonnich to the East Spar pipeline the water depth of 31 - 13 m allows easy access to the pipeline. The water depths near the East Spar pipeline can be worked by shallow draft vessels without major difficulty.

4.4.3 Routes 2 and 3

The reef and shallow water sections of both these routes are going to be extremely difficult to access for both inspection surveys and maintenance work. ROV inspections are likely to be limited to about 1 hour before each high tide and this means once a day if the vessel is operating in daylight hours only which is the usual case for a small vessel.

As these routes are expected to have a lot of pipeline spans the amount of ongoing span correction work is likely to be significant. One or two previously corrected spans may require rework due to failure of the span supports after the passage of severe tropical cyclones. This is likely no matter how well designed and installed those supports may be. Grout bag supports can topple over and the pipeline may be moved laterally by severe environmental forces. Similarly the occasional rock bolt failure can be expected for a variety of reasons. In particular, in the reef area it may be difficult to achieve a good grout bond between the rock bolt and the seabed where the competence of the reef may be poor.

Therefore Routes 2 and 3 are both undesirable routes from the points of view of difficulty of access and the likelihood of greater intervention works being required than for Route 1.

4.5 ENVIRONMENTAL IMPACT

Selection of any pipeline route, onshore or offshore, has as a high priority the avoidance of environmentally sensitive areas. In the case of an offshore pipeline, avoidance of reefs is always regarded as being most important.

The stretch of water going northwards from a line between Bridled Island and Overhanging Rock to Ah Chong Island and Hermite Island (see Figure 3.1) contains a broad band of reef. Established survey data from Australian Maritime Charts and data from more recent aerial surveys aimed at charting water depths in the area indicated that this was the case before the Wonnich pipeline route survey took place in May 1996.

The indications were that a channel running from west to east along the seabed about 1 km south of Ah Chong Island could provide a passage across the reef in slightly deeper water allowing access to construction vessels.

Route 2 was selected to take in this channel along part of the route between Wonnich and Bambra.

One of the objectives of the Wonnich pipeline route survey was to investigate this channel to see how viable it would be for a pipeline. The survey covered bathymetry, seabed materials and general bottom roughness and topography.

The basis of selecting Route 3, including branches 3A, 3B and 3C, was that this was essentially the shortest distance between Wonnich and Varanus Island. The shortest route would provide the lowest material costs as well as least friction losses through the pipeline for any given diameter.

The survey showed that both Route 2 and Route 3 pass across areas of reef and that the extent of the reef was such that it could not be by-passed. Route 1 however passes well clear of the west of the reef area at all points and then follows the East Spar pipeline in to the west coast of Varanus Island.

Pipeline installation would cause damage, which could perhaps be limited by modified construction techniques, to the reef from a number of activities. The pipeline is most likely to be laid from an anchored barge which moves itself along the pipeline route by pulling in on its bow wires and paying off on its stern wires whilst controlling its lateral position with its breast wires. The anchors weighing about 5 tonnes will cause local damage at the point where they are dropped and along the path which they are dragged through. Each of the eight anchors may be dropped at about 500 m intervals along the pipeline route as the barge moves ahead.

The anchor wires themselves have the potential to damage reef formations which lie in their path. With a 2" diameter steel anchor wire under 5-10 tonnes tension only the strongest reef structures would survive. The breast anchor wires in particular will sweep through an arc as the barge advances and will snag on any seabed irregularities in their path. The tall pinnacles may survive with limited damage but lesser growths would not offer such resistance.

The pipeline itself would be laid upon the reef causing local damage along its path.

During pipeline stabilisation the same construction related damage is likely to occur as the shallow draft barge supporting rock bolting will be operating with a multi-point mooring system. As the rock bolts are drilled into the reef the drill cuttings will settle on adjacent areas. Also the overflowing grout injected into the drill holes will become a waste product settling on to the reef.

The conclusion is that the reef areas along Routes 2 and 3 will suffer some degree of damage from pipeline installation and post-installation stabilisation.

Route 1 would be expected to suffer environmental damage no greater than for the majority of other North West Shelf pipelines. This damage can be contained within recognised and acceptable limits. For example, the area west of Varanus Island along which the East Spar pipeline was installed is known to regenerate and recover quickly from impact damage.

From the environmental point of view Route 1 is the optimum choice.

SECTION FIVE

PIPELINE ROUTE COMPARISON

5.0 PIPELINE ROUTE COMPARISON

The advantages and disadvantages of each pipeline route have been discussed in the previous sections of this report. In Table 5.1 the major features of each route are listed and a general description put into each box giving lengths, descriptions, etc., as appropriate.

Table 5.2 repeats the list of features of each route and allocates each feature a score based on a possible total figure shown in the right hand column of the table. The scores from each feature have been weighted in accordance with their perceived importance.

From a possible score of 100 points Route 1 is shown to be the preferred route with a score of 78 points, followed by Route 2 with 46 points and Route 3 with 33 points.

In Table 5.2 Route 3 has been presented as a single route although three variations of Route 3 were considered. Several features had to be taken as averages for the three sub-routes in order to present them as one. However, the three sub-routes do have significant differences with respect to lengths of shallow water, extent of reef and so on. Table 5.3 gives a more detailed breakdown of the differences between Route 2 and three Route 3 sub-routes. Another difference is that Route 3C comes in to Varanus Island alongside the five existing pipelines in the North East facing trench whilst Routes 3A and 3B will run parallel to the East Spar pipeline for 2 km and 4.5 km respectively. This feature is listed in Table 5.1 and scored in Table 5.2 to reflect the risks to the existing pipelines during installation of the future Wonnich pipeline.

Route 1 with its relatively deep sand cover, several metres or more, between Wonnich and the East Spar pipeline will allow the pipeline to be stabilised by lowering it below the seabed. Routes 2 and 3 (3A, 3B and 3C) follow a calcarenite or reef seabed along the majority of their length and the pipeline is likely to require substantial rock bolting to ensure its stability. This important feature "Ease of Post Installation Stabilisation" is included on Tables 5.1 and 5.2 and scored accordingly.

TABLE 5.1
FEATURES OF EACH PIPELINE ROUTE

	Route 1	Route 2	Route 3
Length of Route	33 km	32 km	27.7 km
Length of Shallow Water Section (< 3 m) over Reef	0 km	2.2 km	5.7 km
Length of Reef Along Route	0 km	8.6 km	8.1 km
Prevalence of Pinnacles	Low	High	High
Ease of Installation	Average	Difficult	Difficult
Bottom Roughness	Good	Bad	Bad
Ease of Post Installation Stabilisation	Average	Difficult	Difficult
Lifetime Survey and Maintenance	Average	Difficult	Difficult
Length Alongside East Spar Pipeline	15.5 km	0 km	3 km
Length Alongside Pipelines in Trench	0 km	2 km	0 km
Ability to pick up gas from Bambra	No	Yes	No
Environmental Impact	Low	High	High

TABLE 5.2
SCORES FOR EACH PIPELINE ROUTE

	Route 1	Route 2	Route 3	Total Possible
Length of Route	8	9	10	10
Length of Shallow Water Section (< 3 m) over Reef	10	2	0	10
Length of Reef Along Route	6	1	1	6
Prevalence of Pinnacles	6	0	0	6
Ease of Installation	9	4	2	10
Bottom Roughness	6	3	2	7
Ease of Post Installation Stabilisation	9	3	2	10
Lifetime Survey and Maintenance	9	4	3	10
Length Alongside East Spar Pipeline	2	7	5	7
Length Alongside Pipelines in Trench	4	2	4	4
Ability to pick up gas from Bambra	0	9	0	10
Environmental Impact	9	2	4	10
Total Points	**78**	**46**	**33**	**100**

TABLE 5.3
SHALLOW WATER AND REEF EXTENT OF ROUTES 2, 3A, 3B & 3C

	WD < 2 M	WD < 3 M	Reef
Route 2	KP 14.8 - 16.8 ie. 2 km	KP 14.7 - 16.9 ie. 2.2 km	KP 3.5 - 4.3 & KP 10.9 - 18.7 ie. 8.6 km
Route 3A	KP 22.1 - 24.2 ie. 2.1 km	KP 10.1 - 13.3 & KP 21.9 - 24.2 ie. 5.5 km	KP 9.8 - 18.6 & KP 22.4 - 23.4 ie. 9.8 km
Route 3B	KP 18.5 - 22.0 ie. 3.5 km	KP 10.1 - 17.3 & 18.3 - 22.0 ie. 11 km	KP 9.8 - 22.0 ie. 12.2 km
Route 3C	None	KP 20.6 - 20.75 & 21.8 - 22.25 ie. 0.6 km	KP 21.45 - 23.6 & 23.8 - 24.1 ie. 2.45 km

SECTION SIX

REFERENCES

6.0 REFERENCES

1. Wonnich Export Pipeline
   Wonnich Development to Varanus Island
   Pipeline Route Survey Report, August 1996
   Fugro Survey Pty Ltd

2. East Spar Development
   Pipeline Alignment Sheets
   ES-DWG-50-P-0112 to 0116

Appendix 6

APACHE ENERGY LTD - TECHNICAL NOTE - SINBAD/CAMPBELL FSA UPDATE FOR ENVIRONMENTAL RISK ASSESSMENT

REVISION BOX

REV	DESCRIPTION	ORIG	REVIEW	APPRVL	DATE	CLIENT APPRVL	DATE
A	For Client Review	BLucas	MWoods	PSutton	19Sept96		
0	Final	BLuças	PSutton	PSutton	3Oct96		
1	Re-issued as Final with Client Comments	BLucas	PSutton	PSutton	11Oct96		

APACHE ENERGY LTD

Technical Note
Sinbad/Campbell FSA update for Environmental Risks Assessment

PROJECT: 053/07107

DATE: 11 October 1996

DOCUMENT: 053/07107A02.RV1

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Contents

1 INTRODUCTION & SCOPE

Apache Energy wish to assess the environmental risk associated with a proposed new gas development on the North West shelf. This development is to be located approximately 33km off Varanus Island, and will be of similar design to the Sinbad/Campbell platforms.

Formal Safety Assessments have been carried out for the Sinbad/Campbell platforms (Refs 1, 2, 3), and it was decided to use these assessments as a basis for the environmental risks associated with the new development.

In order that Apache Energy can evaluate the environmental risks associated with the proposed development, the size of release, potential maximum inventory spilt, and frequency of release is required for various release scenarios. The scenarios to be considered are:

- Scenario set 1 - Hydrocarbon releases from the process area during operations
  - Large leak of unprocessed gas
  - Small leak of processed condensate
  - Large leak of processed condensate
- Scenario set 2 - Gas Blowouts
  - During drilling
  - During completion
  - During production
  - During wireline operations
- Scenario set 3 - Pipeline leakage or rupture
  - Corrosion pitting (5mm perforation)
  - Small leak (20mm perforation)
  - Large leak (80 mm perforation)
  - Total pipeline rupture (full bore = 250 mm perforation)

This Technical Note presents the size of release, and frequency of release for the above Scenario sets.

As a part of the assessment, the Sinbad/Campbell failure frequency data was reassessed using more up to date failure rate data bases that have become available since the original assessment was carried out in 1993.

2 DESCRIPTION OF THE PROPOSED FACILITY

The proposed production unit will be based approximately 33km off Varanus Island, and will be similar to the Sinbad/Campbell developments. It will be most similar to Campbell, having a pig launcher, but will operate with two production wells. The export gas pipeline is 10-12" diameter, and delivers gas to Varanus Island. The condensate:gas ratio has been calculated as 20 barrels per million cubic feet.

Drilling is assumed to take 60 days for both wells using a jack up rig. Completion of both wells is assumed to take 14 days. It is anticipated that there will be two wireline operations per well per year.

3 METHODOLOGY

3.1 Frequency Assessment

The Original Sinbad/Campbell FSA was carried out for a 'composite' platform, that represented both facilities. The composite platform was based upon the worst case configuration/operating conditions of both platforms. As the proposed facility is anticipated to have both a pig launcher, and two wells, then the parts count information that was generated for the Sinbad/Campbell composite, can be used directly for the new platform.

The parts count information for the Topsides was split into three areas:

- Well fluids
- Separated gas
- Separated condensate

This parts count information was used to derive the hydrocarbon release frequencies for the proposed development using the E&P forum Hydrocarbon Leak and Ignition Database (Ref 4). This database was compiled in 1992 specifically for use by the Offshore Oil Industry, and includes data sources from the North Sea (UK, Norwegian, Danish, & Dutch sectors), Gulf of Mexico, and Australia, and draws upon other sources such as Oreda (Ref 6), and WOAD (Ref 7). In the same manner as the original FSA, the data was grouped into two leak categories:

- Large leak, > 25 mm equivalent diameter
- Small leak, ≤ 25 mm equivalent diameter

The Blowout frequency assessment was also carried out using Ref 4. The majority (85-90%) of blowout data is drawn from the Gulf of Mexico, and utilises 20 years operating experience from 1970 onwards.

Pipeline/riser failure rate data was drawn from the AME '93 report (Ref 5).

3.2 Consequence Assessment

Consequences were assessed using both SuperChems, and Pipebreak software, and are reported in Section 4. For the purposes of assessment, the operating conditions (pressure, temperature, etc) of the new facility were assumed to be the same as for the Sinbad and Campbell facilities with the new uprated pressure. The well capacity, and inventory held on the Topsides was also assumed to be the same.

Event trees were developed to assess the frequency of isolated and unisolated releases. Failure/success probabilities for isolation were taken from Ref 1. These event trees are included as Appendix A, and also include logic for leak ignition. The results in the next section are presented on the assumption that the ignition probability in all cases is zero, in order to generate conservative frequencies for the environmental spill scenarios. However, if the split including ignition probability is required, the reader is directed towards Appendix A.

The maximum inventory released if isolation is successful is calculated using inventory data taken from Ref 1, plus an allowance of 10 seconds for isolation valve closure time. This allowance is based on the assumption of ESD isolation on automatic gas detection on the facility, isolation taking one second per inch of pipe diameter for valve closure. Gas detection is assumed to be virtually instantaneous. The fraction of the release that is condensate is based on the gas/condensate ratio for the well fluid release case, and for a condensate release, it is assumed that 80% of the condensate held in equipment will not flash off at atmospheric pressure. Calculations of released inventory are given in Appendix B.

4 RESULTS

4.1 Scenario Set 1 - Hydrocarbon Releases from the Process Area during Operations

The results for Scenario set 1 can be seen in the table below:

	Scenario B	Scenario C	Scenario D
Scenario description	Large leak of Unprocessed Gas	Small leak of processed condensate	Large leak of processed condensate
Equivalent diameter of release modelled (mm)	100	25	50
Release flowrate (kg/s)	110	35	140
Isolated event frequency (y^{-1})	1.97×10^{-3}	6.57×10^{-3}	3.15×10^{-4}
Maximum Inventory released if isolation successful (kg)	1515	1785	2835
=> Maximum condensate released at ambient conditions (kg)	150	1430	2270
Unisolated event frequency (y^{-1})	1.65×10^{-5}	5.50×10^{-5}	2.64×10^{-6}

It should be noted that the above frequencies do not take the effects of leak ignition into account. The full split of accident sequence frequencies can be found in the associated event trees in Appendix A.

The calculation of inventories spilt on release is covered in detail in Appendix B

4.2 Scenario Set 2 - Gas Blowouts

Well blowout total release rate is assumed to be 34.5kg/s, based on Campbell blowout release rates.

Assuming that a well blowout takes one hour to bring the blowout under control, the quantity of condensate spilt onto the surface of the sea is 14.5 tonnes based on the condensate:gas ratio.

The overall frequency of blowout is 4.47 x 10^{-3}/yr in the first year of drilling and production, and 2.81 x 10^{-4}/yr for subsequent years.

Blowout frequencies are as follows:

- Drilling blowout frequency = 1.6 x 10^{-3} per well drilled, or 3.2 x 10^{-3} for the drilling campaign of two wells.

  Drilling blowout location split is:

  - 22% subsea, or 3.52 x 10^{-4} per well drilled
  - 9% at the wellhead, or 1.44 x 10^{-4} per well drilled, and
  - 69% at the jackup rig drill floor, or 1.10 x 10^{-3} per well drilled

- Completion blowout frequency is 5.4 x 10^{-4} per well completion. Blowout location split is as follows:

  - 90% at the wellhead or christmas tree, or 4.9 x 10^{-4} per well completion
  - 10% at the jackup rig drill floor, or 5.0 x 10^{-5} per well completion

- Production blowout frequency is 1.18 x 10^{-4}/yr, per producing gas well, or 2.36 x 10^{-4}/yr, for the platform. Blowout location split is as follows:

  - 26%, or 6.14 x 10^{-5}/yr subsea,
  - 74%, or 1.75 x 10^{-4}/yr at the christmas tree/wellhead.

  For the platform, based on two operating wells.

- Wirelining blowout frequency is 2.24 x 10^{-5}/yr per well, or 4.48 x 10^{-5}/yr for the facility.

4.3 Scenario Set 3 - Pipeline Leakage or Rupture

For large pipeline releases, it has been assumed that automatic shutdown will occur due to pressure/flow fluctuations in the pipeline.

Corrosion pitting is expected to be undetectable except by visual observation of the sea surface near the failure site. It is assumed that this will take approximately 10 days, based on supply vessel movements in the area, and time for a sufficiently sized spill to build up for it to be detectable.

If it is assumed that a standard flow detection regime is installed, consisting of a process flowmeter on the platform with 5% metering accuracy, and fiscal metering onshore with 1% metering accuracy, then gas flowrate drops of greater than 20% are assumed to be picked up relatively quickly. If leak detection metering is installed, then smaller flowrate drops can be detected. As the production flowrate is assumed to be 120 MMSCFD, or 39.3 std m^3/sec, Scenario B represents approximately 15% of the overall leakage rate. This leakage rate will be seen as a fluctuation that will take approximately 2 hours to detect.

Frequency of release and consequence data are given in the following table:

Scenario	Equiv Diam mm	Total release rate kg/s	Condensate release rate kg/s	Duration of release	Mass of Condensate released, Kg(3)	Scenario frequency - riser failure per year	Scenario frequency - pipeline failure per km year
A. Corrosion pitting	5	0.25	0.03	10 days	38280	2.9×10^{-4}	3.74×10^{-5}
B. Small leak	20	4	0.47	2 hours	15744	2.1×10^{-4}	3.73×10^{-5}
C. Large leak	80	64	7.5	10 secs	12435	5×10^{-4}	3.74×10^{-5}
D. Full bore rupture	250	6000(1)	700(1)	10 secs	14050(2)	1×10^{-3}	2.49×10^{-5}

Notes

1 Flowrate is instantaneous rate immediately after rupture

2 Inventory is based on depressuring flowrate over 10 seconds. See Figure 1

3 Inventory spilt includes condensate inventory held in pipeline.

4 No SSIV is installed

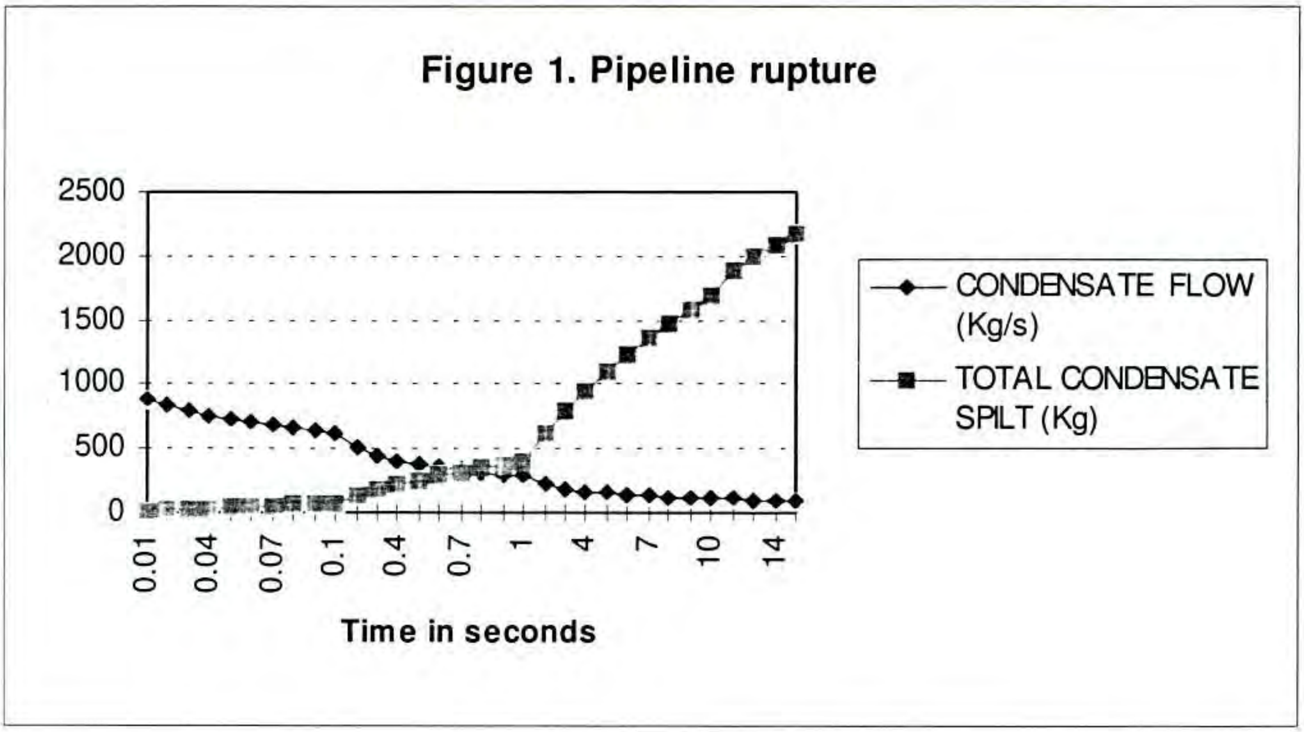


Figure 1. Pipeline rupture
2500
2000
1500
1000
500
0
0.01
0.04
0.07
0.1
0.4
0.7
1
4
7
10
14
Time in seconds
CONDENSATE FLOW (Kg/s)
TOTAL CONDENSATE SPILT (Kg)

5 MITIGATING MEASURES

Mitigating measures that can be employed to reduce either the frequency or consequence of equipment failure on the proposed facility include:

- Simplification of topsides processing, to minimise the number of flanged connections and possible leaksites and reduce the inventory held in equipment;
- Use of high integrity gaskets rather than standard gasket types reduces the size of leak anticipated on failure;
- The use of drain and sump systems on the facility will collect some leaks, reducing the likelihood of spillage to sea. However, due to the operating pressure of the facilities this is anticipated to have an effect on small condensate leak sizes only, and no effect on unprocessed gas leaks. In actuality, a jet release of condensate will be vapourising on release with rain-out of liquid droplets occurring, some of which will fall to sea level. However, if it is assumed that 2/3 of all condensate leaks are sourced close to the test separator which sits over a plated area, bunded and drained to the sump, and that leaks of size up to 10 mm have insufficient jet length to extend beyond the bunded area, and therefore fall to sea level, then the frequency of small leaks of condensate falling to sea level can be reduced from 6.57×10^{-3}/yr to 3.19×10^{-4}/yr if isolated, and from 5.5×10^{-5}/yr to 2.67×10^{-6}/yr if unisolated. This assessment assumes that all other areas of the deck will be grated to reduce the likelihood of explosion on this gas processing facility, and will therefore not have the potential to collect any pressurised condensate leaks.

6 REFERENCES

1. Formal Safety Assessment of the Sinbad/Campbell A platforms. Stratex Worley.
2. Addendum to the Formal Safety Assessments of the Harriet field platforms. Stratex Worley.
3. Safety Assessment - Simultaneous Drilling and Production at Sinbad and Campbell Platforms. Stratex Worley.
4. E&P Forum Hydrocarbon Leak and Ignition database, May 1992.
5. Advanced Mechanics and Engineering Ltd. The update of Loss of Containment Data for Offshore Pipelines. February 1993.
6. Offshore Reliability Data Handbook 1992 2nd Edition.
7. World Accident Database.

APPENDIX A

Event Trees

EVENT TREE FOR WELL FLUID FROM PROCESS DURING PRODUCTION
LARGE RELEASE

	NO IGNITION	NO EXPLOSION	ISOLATION SUCCESFUL	NO ESCALATION	ACCIDENT SEQUENCE FREQUENCY
FREQ (/yr)= 1.99E-03	0.97		0.9917		1.92E-03
			0.0083		1.61E-05
	0.03	0.7	0.9917		4.15E-05
			0.0083	0	0.00E+00
				1	3.48E-07
		0.3	0.9917		1.78E-05
			0.0083	0	0.00E+00
				1	1.49E-07
				total	1.99E-03

EVENT TREE FOR CONDENSATE FROM PROCESS DURING PRODUCTION
SMALL RELEASE

	NO IGNITION	NO EXPLOSION	ISOLATION SUCCESFUL	NO ESCALATION	ACCIDENT SEQUENCE FREQUENCY
FREQ (/yr)= 6.63E-03	0.997		0.9917		6.56E-03
			0.0083		5.48954E-05
	0.003	0.88	0.9917		1.73679E-05
			0.0083	0	0
				1	1.4536E-07
		0.12	0.9917		2.36835E-06
			0.0083	0	0
				1	1.98218E-08
				total	6.63E-03

EVENT TREE FOR CONDENSATE FROM PROCESS DURING PRODUCTION
LARGE RELEASE

	NO IGNITION	NO EXPLOSION	ISOLATION SUCCESFUL	NO ESCALATION	ACCIDENT SEQUENCE FREQUENCY
FREQ (/yr)= 3.18E-04	0.992		0.9917		3.13E-04
			0.0083		2.61993E-06
	0.008	0.88	0.9917		2.22153E-06
			0.0083	0	0
				1	1.85931E-08
		0.12	0.9917		3.02937E-07
			0.0083	0	0
				1	2.53542E-09
				total	3.18E-04

APPENDIX B

Inventory calculation

Appendix B. Inventory calculation

GOR ratio

At STP, assumed gas density = 0.72 kg/m^3

assumed condensate density = 850 kg/m^3 (conservative)

Condensate /gas ratio = 20 barrels/million ft^3

= (20 x 35 x .1605)ft^3/million ft^3

= (112.4 x 850)/(0.72 x 1,000,000)

= 0.133

=> For every kg of gas released, 0.133 kg of condensate is released.

Inventory held in the Topsides

From Ref 1, the inventory held on the Sinbad/Campbell topsides is 160 kg of gas (assuming that the test separator is not isolated) plus 1275 kg of condensate. It was assumed for the Sinbad/Campbell FSA that 80% of the condensate held in the topsides would be flashed off, leaving a total inventory available for release of:-

(0.2 x 1275) +160 = 415 kg.

It has been assumed that the proposed development will have similar inventory to Sinbad/Campbell

It is conservatively assumed for scenario 1B that the gas inventory of 160 kg will consist of unseparated gas carrying 0.133kg of condensate per kg of gas.

Inventory held in the Pipeline

The pipeline is 10" diameter, 33 km length.

It has been assumed that the density of gas in the pipeline is approx 65kg/m^3 at an assumed operating pressure of 90 barg.

Gas held in pipeline = $33000 \times \Pi \times (.25/2)^2 \times 65$ = 105300 kg.

Condensate held in pipeline = 105300 x (.133/1.133) = 12360 kg.

Appendix 7

OILMAP - OILTRAK

Oil Spill Prediction and Response Management System

developed by

Applied Science Associates

Global Environmental Modelling Services

and the

Australian Institute of Marine Sciences

System Description

and

Verification

May 1996

1. INTRODUCTION

OILTRAK and OILMAP are the oil spill prediction systems used by a majority of the Australian offshore oil industry. OILTRAK has been used by a large number of oil companies in Australia (e.g. Woodside, BHP, WAPET, Apache, Comalco, Command, Discovery, Hadson, Lasmo, Teikoku) for operations on the north-west shelf, Bass Strait and in the Gulf of Carpentaria. OILMAP is now considered to be the world standard oil spill management model with over one hundred users worldwide. Exxon, Chevron, Mobil and Amoco use OILMAP for their operations internationally. OILMAP includes an interactive graphical display system linked to GIS datasets which provides an important decision support system for oil spill response and contingency planning. OILMAP can be used to provide evidence of 'best practice' in the event of a spill and has been used to hindcast the Persian Gulf spill, the Exxon Valdez spill and the Braer spill. The OILTRAK and OILMAP systems are however, more complimentary in nature than competitive.

In the past, for real-time oil spill modelling, OILMAP has used predicted wind forecasts in conjunction with historic current databases. Whilst historic data on water currents may be suitable for training and contingency planning, it has no application to real time modelling. This problem arises because OILMAP does not attempt to model the ocean physics but relies on being given the surface ocean currents as input to map the path of the oil spill and incorporate weathering, chemistry and important natural resource environmental data.

OILTRAK is a fully three-dimensional ocean model with a proven capability of predicting near-surface ocean currents around the continental shelf. OILTRAK focuses on predicting the particle trajectory path produced by the surface ocean currents during an oil spill. This is precisely the input data that OILMAP requires for response predictions. OILTRAK concentrates on predicting the physical oceanography of the region driven by winds and tides and OILMAP can take this information and provide an interactive management facility to model the fate of the oil spill taking into account chemistry, weathering, oil types and up to 50 layers of GIS data locating sensitive environmental concerns and other physical resources.

About 18 months ago Graeme Hubbert (GEMS) and Brian King (AIMS) first discussed the linking of the two systems to provide a powerful tool to industry and government agencies. This linking has now been achieved. Initiated from within the OILMAP user interface (figure 1), OILTRAK now supplies fully three-dimensional ocean model predictions of near-surface currents for a specified time period. This current data is then used by OILMAP to drive the oil spill trajectory models. This combined system is now in use by WAPET and Apache Energy on the North West shelf, by BHP throughout Australia and South-east Asia and by the Australian Maritime Safety Authority (AMSA) for the National Oil Spill Response Plan and for Search and Rescue operations in the Australian region. The capabilities of this combined OILTRAK-OILMAP system are unmatched by any other oil spill prediction system.

The OILMAP-OILTRAK system is relocatable, relying only on wind forecasts, quality bathymetric data, tidal information and a detailed coastal map for the given geographic area. The system as set up for BHP, Apache and WAPET only requires the operator to input the wind forecast and specify (with the mouse) the region over which oil spill modelling will be carried out. These functions require only a few minutes of operator time. The current field is then generated automatically by running the 3D ocean model (OILTRAK) over the defined region. During the OILTRAK run, the predicted trajectory of particles are shown on the screen (the standard OILTRAK output) to give a first approximation to the fate of the oil spill. At the completion of the OILTRAK run the surface current predictions are imported to OILMAP to allow it to to predicte the path that a specific oil type would take.

The system has been designed for accurate prediction by users with little or no knowledge of hydrodynamics. Redesign of the OILMAP menu structure presents the two systems as an integrated package (see Figure 1), thus eliminating any confusion for the operators. A short training session allows the user to be confident and able to run this system in house.

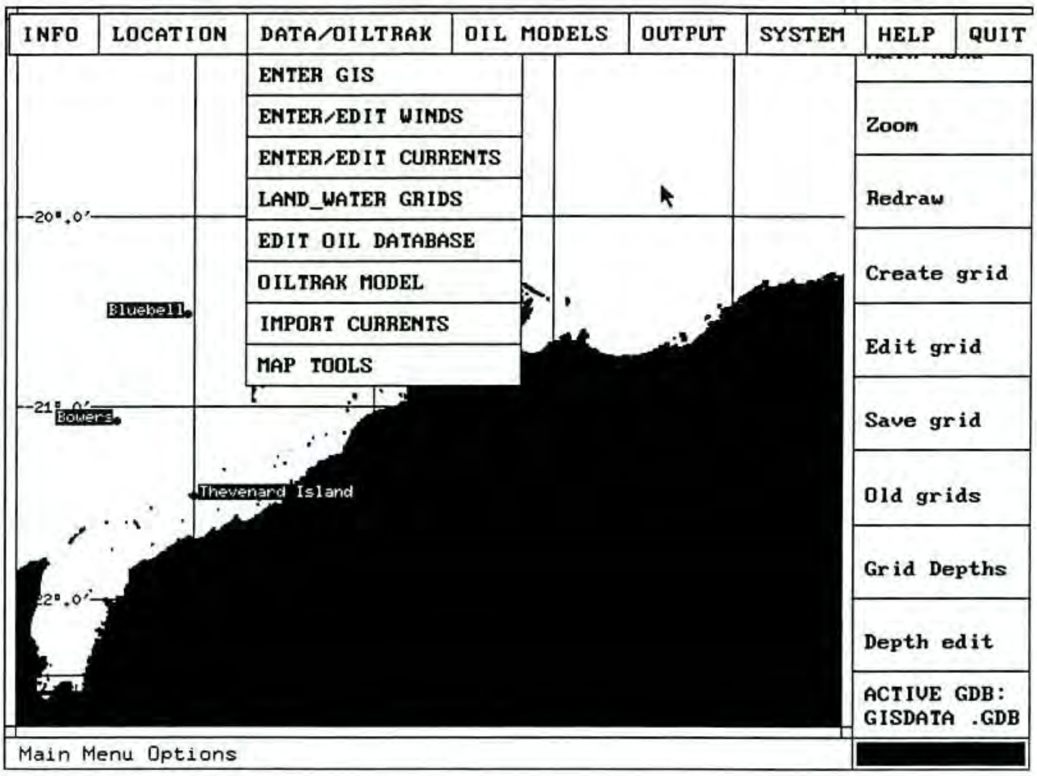


Figure 1: Redesigned OILMAP menu structure which includes OILTRAK in the DATA module

2. OILMAP - An Overview

OILMAP was developed by Applied Science Associates of Rhode Island (ASA). The Australian Institute of Marine Science (AIMS) has provided OILMAP to the Australian/Asian region since 1992. This service by AIMS is provided to industry and government agencies as an Australian owned non-profit project which aims to benefit industry and government agencies through the introduction of new and advanced marine technologies for better environmental management.

The OILMAP system is continually being developed to further meet the requirements of the people and companies using it. The system is currently available in the form of version 3.6.

2.1 OILMAP - The International Standard

OILMAP is a comprehensive Oil Spill Environmental Management System for oil spill response decision support and impact assessment, contingency planning, risk assessment and training purposes. OILMAP runs on a low-cost IBM compatible PC in the Windows or DOS environment. The OILMAP software possesses a suite of models that predict the behaviour of oil on the water surface together with a geographical information system (GIS) that can be used to assess the resources that may be at risk from the spill. These are all combined into an easy to use, menu-driven system. A powerful feature of the system is it's graphical display of the spill behaviour and GIS information.

OILMAP is designed to operate anywhere in the world and its user-friendly design is suitable for non-technical users. OILMAP can be set up to operate for any geographic area and at any scale. The system has a powerful zoom capability and finer resolution maps can be embedded as required. OILMAP is modular in design and can be set up as a stand-alone system or integrated with other ASA modelling systems (such as SARMAP) as required.

Subsequently, OILMAP has become the defacto standard software for oil spill management around the world. OILMAP currently supports companies such as Exxon, Chevron, Mobil, Amoco, ESSO Australia, BHP Petroleum, BHP Transport, US Army Corp. of Engineers, Environment Canada, The Canadian Petroleum Association, Saudi Aramco, BP, and others. OILMAP coverage exceeds 100 applications and exists in Africa, Europe and the UK, Asia, both America's. The benefits for Australia in using an internationally recognised standard system such as OILMAP are significant, and ensure long-term support for the product.

2.2 The Coastal Resource Atlas

OILMAP uses the latest information technology to store data required for oil spill response, planning, training, and crisis management. Resource information, wind data, current data, oil chemistry, over flight observations and response equipment capability and position can be imported quickly from many sources and retrieved using the OILMAP GIS and DATA menu. This information can be displayed in combination with the oil spill prediction for decision support purposes (e.g. with dispersant use maps) and impact assessment (environmental sensitivity index and cleanup response priority maps).

The data formats used by OILMAP allow data to be incorporated from many existing systems such as ARCINFO and AUTOCAD relatively simply and inexpensively. Data from other existing and new OILMAP systems set up by industry can also be transferred to any other OILMAP system immediately if required. Thus OILMAP provides the ability to have a national resource atlas in operation which makes use of other atlas developments, regardless of origin.

2.3 Oil Spill Modules

OILMAP uses a range of verified models (Spaulding *et al.*,1993; Kolluru *et al.*,1993; Spaulding *et al.*,1994) and associated tools to provide oil spill predictions for emergency response, planning situations, risk and impact assessment, training and crisis management. The models have successfully predicted the surface and sub-surface oil spill trajectories and fates of major spills worldwide. Kolluru *et al.* 1993, and Spaulding *et al.*,1994 show that OILMAP can successfully model the movement of an oil spill in 3 dimensions and predict within a few percent, the mass and chemistry of the spill as it weathers in time.

The models within OILMAP can be purchased together or individually. Each model has different functions as follows:

a) TRAJECTORY ONLY: The model predicts the oil spill trajectory and is very quick to run and set up. It is designed to provide predictions of oil spill trajectories and impacts in minutes from notification of a spill. This rapid response from OILMAP allows quick decision support for spill managers at the beginning of a response operation. This model comes within OILMAP and can be used for operational use, training of operational staff, for contingency planning and running "what-if" hypothetical scenarios of different weather and sea conditions.

b) TRAJECTORY AND FATE: The model provides a quantitative prediction of the oil spill trajectory and how it will weather with time, depending on the oil type, metocean conditions and sea state. The algorithms in the model calculate the mass of oil which will evaporate; how it will spread; if, when and how it will emulsify or mix into the water column; and how much will beach on different types of shorelines. This information is invaluable in establishing cleanup operations, for pre- and post-impact assessments, for dispersant effectiveness evaluations, etc. The model also uses observations of actual spill positions, when available, to update predictions. This feature is important to achieve the greatest accuracy of predictions during a real spill event. At the end of a spill response, this model can provide a complete report analysis, using both field observations and model best-estimate predictions, of the path, quantity and impacts of a spill for litigation purposes and public relations management. This model is a standard module of OILMAP and can be used for operational use, training of operational staff, for contingency planning and running "what-if" hypothetical scenarios of different weather and sea conditions.

c) STOCHASTIC MODEL: This model applies a Monte-Carlo simulation procedure to calculate the probability that a spill will contact particular locations on the water or shore. Using the same models as the trajectory and fates model, a large number of discrete trajectories are run from randomly selected start times within a period of interest (e.g. a season, or proposed operational period). The model then calculates the frequency with which a particular location is contacted by oil, the time-lapse before contact and the amount of oil that may arive. If the model is supplied with representative wind records for the period of interest, and sufficient trajectories are run, the results provide a statistically valid prediction of the risks for forward predictions. The stochastic model is most valuable for forward assessment of the risks associated with oil spills from particular locations, or with different seasonal weather patterns.

d) RECEPTOR MODEL: This model functions in a similar way to the Stochastic model but focusses on the destination of a spill rather than it's source. The model performs risk assessment to valuable resources by predicting whether a highly sensitive area is vulnerable to a likely spill from industry operations. Alternatively, the model can also predict likely source locations for a spill of unknown origin for litigation purposes, such as the prosecution of vessels discharging oil at sea. The model can also be used for maritime search and rescue operations for determining the origin and path of located floating debris.

e) RESPONSE MODEL: This model is similar to the Trajectory and Fates model, but also incorporates the use of response equipment into the oil spill prediction calculations. Therefore, different response strategies can be simulated in OILMAP to determine the most effective. This provides valuable decision support for the managers of an oil spill by providing justification for deploying any particular response strategy. It also ensures maximum benefit from equipment usage (particularly if stockpiles must be sourced from distant locations). This model can also be used to determine stockpile locations, based on what equipment is effective in any given region.

f) SUBSURFACE MODEL: This model provides a complete 3-dimensional capability in predicting impacts of oil spills on both the surface (birds, shorelines, mangroves) and within the water (sea-grass beds, coral reefs, fish communities). This is extremely valuable in that it is unlikely that observations of subsurface impacts will be available and post-spill monitoring programs can be designed using model predictions.

g) CHEMICAL SPILL MODEL: A chemical spill model (currently 450 different chemicals can be modelled) is also available for integration within the OILMAP system which will give the capability to obtain decision support for oil and chemical spills.

2.4 Other Benefits to the User

In addition to its database management capabilities and its range of sophisticated models, OILMAP uses animation or hard-copy printouts to show the movement of the oil spill predictions over the resource atlas. This capability assists spill managers in a number of ways, including providing:

- substantial decision support for spill managers during spill responses and in contingency planning;
- easily interpreted information that can be used by work teams responding to the spill;
- information that can be transmitted to the public or other agencies.

3. OILTRAK - An Overview

OILTRAK is a three-dimensional "primitive equation" ocean model which has been specifically developed by Global Environmental Modelling Services (GEMS) to study and predict ocean currents in order to calculate oil spill trajectories. OILTRAK has been installed in stand alone mode in the Perth and Brisbane offices of the Bureau of Meteorology Special Services Unit (SSU) to provide oil spill trajectory predictions, both for operations and planning, to a number of operators on the north-west shelf and in the Gulf of Carpentaria. The SSU also provides weather forecasts to the operators which are used to drive OILTRAK in a real-time situation. As described previously, OILTRAK has also been integrated into the OILMAP package to provide a comprehensive system for oil spill management. Current users of the combined system include Apache Energy, WAPET, BHP and the Australian Maritime Safety Authority.

Since OILTRAK is a fully three-dimensional ocean model it can also be used to predict current flows and trajectories at any depth. This facility has, for example, been used to predict the fate of formation water and dredge spoil from drilling operations.

Detailed verification studies of the current predictions from OILTRAK have been carried out in Exmouth Gulf (mat track), the Onslow-Barrow Island region (2 mat tracks), Mermaid Sound (current meter), the Montebello Islands (acoustic doppler current profilers) and off Sydney (current meters). Verification of the tidal predictions has been carried out in the Gulf of Carpentaria (Weipa tide gauge), Bonaparte Gulf (Cape Domett tide gauge) and Barrow Island (WAPET tide gauge). In each case, the agreement between model predictions and observation has been extremely good (see section 4). As a result, a high level of confidence can be attached to the ability of OILTRAK to accurately predict near-surface currents on the continental shelf anywhere around Australia.

3.1 Description of OILTRAK

For oil spill trajectory modelling it is important to model the surface ocean current. This cannot be obtained accurately from two dimensioal or depth-averaged two-dimensional models. The major deficiency of two-dimensional models is that they yield no information about the vertical structure of the currents, nor can they model the thermodynamics of the ocean. Two-dimensional models include a simple parameterisation of the bottom shear stress which is assumed to be a function of the vertically averaged flow. This can lead to quite erroneous results, especially in regions of large vertical variation in the ocean currents. In a two-dimensional model, the depth-averaged current is constrained by the bottom friction and is always less than the surface current and usually in the wrong direction because the bottom friction will tend to direct the current along topographical gradients (particularly in shallow water). In addition, the bottom stress is usually over-predicted because it is calculated using the depth-averaged current and not the near-bottom current.

A further problem arises in areas of strong tidal current where the bottom current will reverse direction before the surface current at the end of the flood or ebb tides as a result of bottom friction. A two-dimensional model can introduce apparent phase errors into the prediction of the surface tidal currents under these conditions. A three-dimensional model, however, overcomes these problems by predicting the near-bottom current and allowing the surface current to be decoupled from the bottom friction due to the vertical layers in the model. A three-dimensional numerical model is therefore required to obtain information concerning the vertical variation of currents and the thermodynamic properties of the ocean.

There have been a number of significant contributions in the area of three-dimensional regional ocean models and a full review will not be attempted here. One of the first important contributions to three-dimensional regional ocean modelling came from Leendertsee (1973) who developed a "z" coordinate model for studies in small bays and estuaries. Another important contribution came from Blumberg and Mellor (1983) who developed a three-dimensional, primitive equation, sigma coordinate model with an embedded, turbulent closure submodel. Three-dimensional ocean modelling technology has therefore been available for at least the past thirteen years and the speed of modern desktop computers has now enabled the application of three-dimensional models to a range of coastal engineering problems.

OILTRAK is a state-of-the-art three-dimensional ocean model which has been developed to study and predict ocean currents on or near continental shelves anywhere on the globe. The basic model formulation has been described previously (Hubbert, 1991) and the discussion here is limited to some of the important features for modelling near-surface currents. OILTRAK includes the non-linear advection terms and is driven by wind stress, atmospheric pressure gradients, astronomical tides, quadratic bottom friction and ocean thermal structure (if there are any temperature or salinity data). For high resolution studies the system can be nested to reduce the uncertainties associated with the specification of the boundary conditions at open boundaries. The system will run on any modern computer (e.g. DOS or UNIX machines).

To set up OILTRAK, horizontal and vertical grids must be chosen. OILTRAK simulates the vertical distribution of ocean currents by breaking the vertical water column up into a specified number of layers at specified depth levels. It is also desirable to have a variable vertical grid spacing so that the resolution can be adjusted to physical requirements. Much greater resolution is generally required in the vertical dimension than in the horizontal dimension. For coastal waters OILTRAK may typically be run on a horizontal grid of resolution 1 km and with up to 10 vertical levels. In complex bathymetric areas (such as the Montebello Islands), resolution of a few 100 metres is required.

OILTRAK is quite fast and efficient largely due to the numerical integration procedure which is split into three separate explicit steps. This split-explicit approach is very efficient in oceanographic models with free surfaces because of the large disparity between advective speeds and gravity wave phase speeds in deep water. The first step, which is usually referred to as the adjustment step, considers the effects of the gravity wave and Coriolis terms and solves the full continuity equation. Then follows the advective step which accounts for the remaining non-linear terms. Finally, the "physics" step accounts for the effects of surface wind stress, bottom friction stress and atmospheric pressure.

OILTRAK simulates the tidal and wind-forced flow in the region of interest, driven by any number of tidal constituents (usually at least seven - M2, S2, N2, K2, O1, K1 and P1) and observed or forecasted winds. Twenty-four hour forecasts of surface ocean currents and particle trajectories are produced in about 30 minutes on a Pentium PC, allowing advice to be returned to operators within one hour of notification of a spill.

3.2 Meteorological Forcing

A critical component of the real-time system is the specification of the wind forecasts. The meteorological forcing can be derived from the lowest-level of a mesoscale atmospheric prediction model (Hubbert, 1991), or from observations and manual forecasts. With the system running in the Perth and Brisbane offices of the Special Services Unit of the Bureau of Meteorology, the duty forecaster is well placed to provide this input to the model. On site operators can obtain forecasts from the SSU by phone or fax.

3.3 Ocean Thermodynamics

On the continental shelf, the major forcing mechanisms are predominantly tidal and meteorological. In some cases, however, the thermodynamic structure of the ocean induces significant density currents and stratification can allow internal tides to propogate. In deeper waters, off the continental shelf, the influence of the tides diminishes and the dominant forcing is meteorological and thermodynamical.

It is therefore necessary to include thermodynamics in the modelling process in continental shelf regions affected by currents with significant temperature differences to ambient conditions (e.g. Leeuwin Current off West Australia and the East Australian Current). Fortunately there is a large amount of sea surface temperature (SST) data available from satellite observations. AVHRR satellite SST data is available around the Australian continental shelf at a resolution of at least 4 km. Other satellites provide global SST data at a resolution of one degree. These data can be assimilated into OILTRAK to produce a good representation of the surface thermodynamic currents. This procedure has been tested with good success in studies of the East Australian Current for the Sydney Ocean Outfalls.

3.4 OILTRAK Setup

For OILTRAK to achieve operational status, the following tasks must be completed:

a) Establish a 5 minute resolution bathymetry data set to cover the entire region of interest;

b) Establish the amplitudes and phases of the major tidal component throughout the region on a 5 minute grid, and;

c) Establish high resolution bathymetric and tidal data for specified embedded regions

a) Bathymetry

To set up OILTRAK for the entire region, a 5 minute resolution digital bathymetric data set is generated. High resolution embedded regions are achieved by manually coding depth data from any available source These may include Admiralty charts, digital sounding data obtained from industry, port authorities etc. or direct measurements made for the purpose of the model. This information may be of varying quality, however, a high quality bathymetric data set will allow the model to more clearly resolve the physical oceanography of the region. This database is automatically accessed by OILMAP/OILTRAK once the user specifies the boundaries of the grid for current prediction.

b) Tides

To accurately model the tidal regime anywhere in the region of interest, it is necessary to use at least four, and often more, tidal constituents (e.g. M2, S2, N2, K2, O1, K1, P1) to simulate the tidal flow accurately. To establish a high resolution, embedded, tidal-constituent data set the tidal components are modelled throughout the region of interest and the variation of the amplitude and phase of each constituent established using Fourier analysis techniques.

4. OILTRAK VERIFICATION

Oil spill trajectories predicted by the model have been tested against several experimental data sources. These include "mat" tracks obtained by Lasmo Oil near Exmouth Gulf and by Command Petroleum near Onslow. In Mermaid Sound, Woodside Petroleum provided current meter data for verification of the model. Apache Energy undertook a high resolution verification study around the Montebello Islands using an Acoustic Doppler Current Profiler (ADCP). In all of these cases, good agreement was obtained between model predictions and observations. Most of the earlier results have been reported either in the proceedings of the 1993 Australasian Coastal Engineering Conference (Hubbert, 1993a,b) or in the 1994 APEA Journal. The more recent work carried out by Apache Energy has not yet been published and the results of this work are described in some detail.

4.1 The Montebello Islands

The Montebello Islands represents a higly-complex bathymetric region for modelling of water currents. To model this area, high quality bathymetric data were obtained from several sources. These included remote sensing surveys over the shallow areas, and extensive bathymetric and seismic surveys in the deeper waters and inter-island channels. This data provided files describing the depth at each 100 m, allowing OILTRAK to resolve underwater features that strongly affect the predicted flows.

Apache Energy has undertaken a high resolution verification study around the Montebello Islands to test the predictions of the OILTRAK model in this region. Verification was carried out using an Acoustic Doppler Current Profiler (ADCP), which measures vertical profiles of the currents. Standard acoustic current meters were also used to measure currents at specific depths. These observations were then compared with predictions made by OILTRAK driven by the tides and wind observations from Varanus Island to assess the model's accuracy in the region.

4.1.1 Field work

Ocean currents in the vicinity of the Montebello Islands were measured using a short-term instrument mooring (figure 2). The mooring consisted of an ADCP (supplied and operated by CSIRO) which was held near the water surface by a floatation package and suspended on a tight line from a heavy mooring block. The vertical pull between the floatation and mooring block was sufficient to keep the ADCP oriented toward the sea-floor under the force of the water currents experienced ($\leq$ 1 knot). The ADCP was set to record horizontal water velocities and directions at each 1 m interval from approximately 3.5 m below the water surface to approximately 3 m above the sea-floor. A conventional acoustic current meter (supplied by WNI), capable of measuring at a single depth, was suspended from a surface buoy to record velocities and directions at approximately 1.5 m below the surface. Both instruments measured each 60 seconds and recorded 5 minute averages.

The instrument mooring was deployed between 15 and 22 March 1996 for approximately 24 hour periods at four key locations around the Montebello Islands (Figure 3). This allowed the current meters to record over a number of tidal cycles at each site. The vertically-profiled data collected by the ADCP can be used to verify the predictions of the OILTRAK model at different depths. These verifications are underway. For the purposes of this comparison, measurements from the two shallowest depths (nominally 3.5 and 4.5 m depth) were averaged and compared with OILTRAK predictions at 4 m depth.

4.1.2 OILTRAK predictions and comparison to field observations

OILTRAK was used to generate predictions of the water currents at 4 m depth over a 1600 km^2 area encompassing the Montebello Islands (Figure 3). For modelling, this area was divided into 100 by 100 grid cells (10,000 total), each of which was 400 m on each side. Bathymetric data for this area was supplied at a scale of 100 m, providing up to 16 measures of depth per cell. Hourly recordings of wind speed and direction made at the Varanus Island weather station over the field sampling period (15 to 22 March 1996) provided the data for generating the wind-induced component of the water currents.

Figures 4 to 7 show the wind and tidal driven currents that were predicted by OILTRAK at 4 m depth during one full tidal-cycle (flood, slack, ebb, slack) in the experimental period. These currents account for both tide and wind forces at this time. These plots illustrate the complexity of the flow around the Island chain and, in particular, the large predicted variation in current velocity and direction associated with inter-island channels and with sharp changes in bathymetry (e.g. moving from deep water over the shallow area south of Hermite Island). This highlights the importance of modelling in this area at fine spatial scales, and with accurate bathymetric data.

Figure 8 compares the observed tidal heights with those predicted by OILTRAK for WAPET tanker mooring. The good agreement in both phase and magnitude between predicted and observed values indicates that the tidally-forced component of the water currents was being modelled with good accuracy.

Figures 9 to 12 compare the east-west and north-south components of the water currents measured by ADCP and predicted by OILTRAK at the two sites adjacent to the proposed Wonnich well (ADCP1 and ADCP2). These comparisons show that the model is simulating the north-south and east-west structure of the current flow with good (but not perfect) accuracy. The complexity of the current flow near ADCP1, for example, where the currents reach speeds of 2 knots whilst crossing the shallow reef areas south of Hermite Island makes the prediction at ADCP1 a good result. In general, the ebb currents flow south-west through the this site while the flood currents flows east-north-east. The flow is reasonably complex, however, due to eddies shed near the coral reefs close to this site.

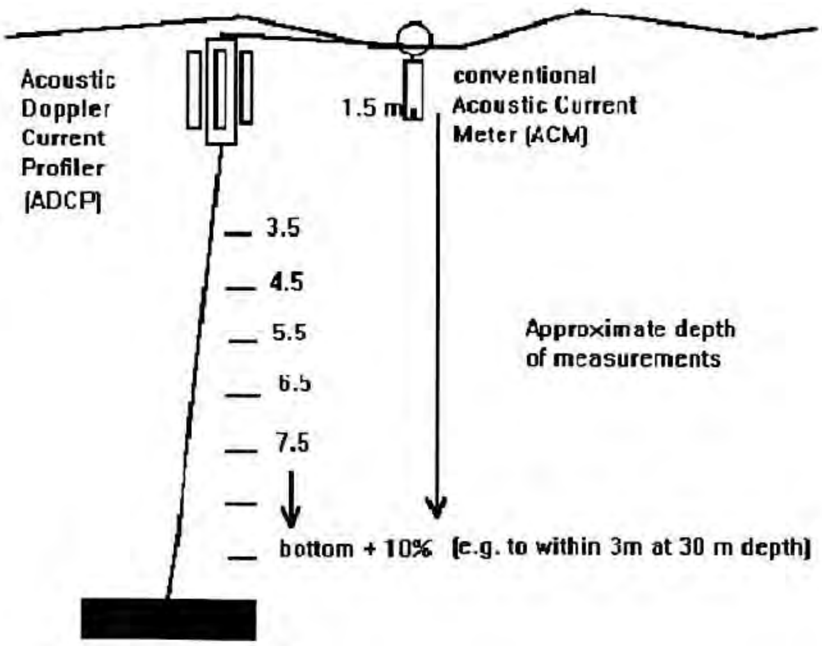


Figure 2: Arrangement of instruments used to profile ocean currents at the deep sites

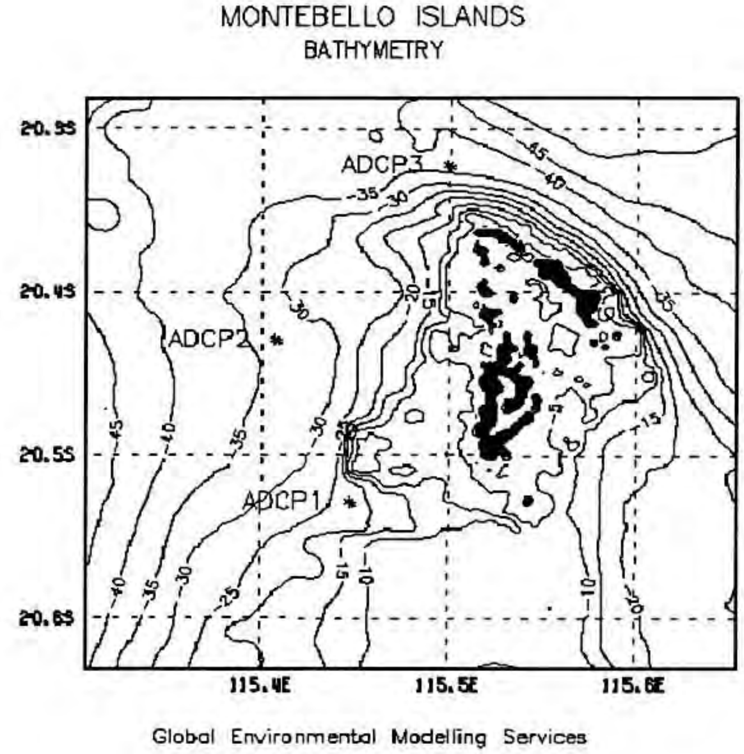


Figure 3: Bathymetry used by OILTRAK in the Montebello Island region. Note that the position of ADCP4 is outside the area of this model.

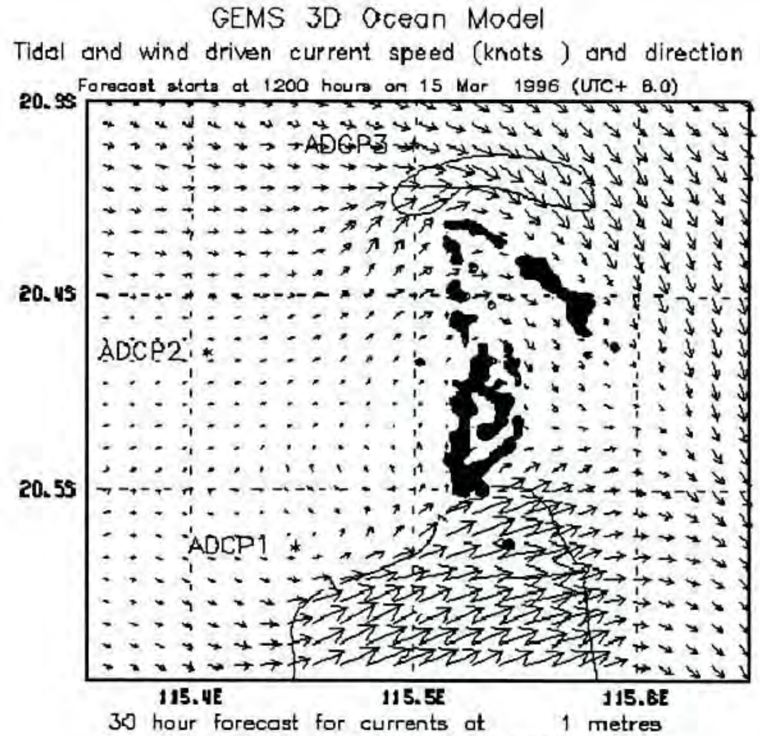


Figure 4: OILTRAK forecasts for wind and tidal driven near-surface currents during a flood tide 30 hours into the ADCP experimental period

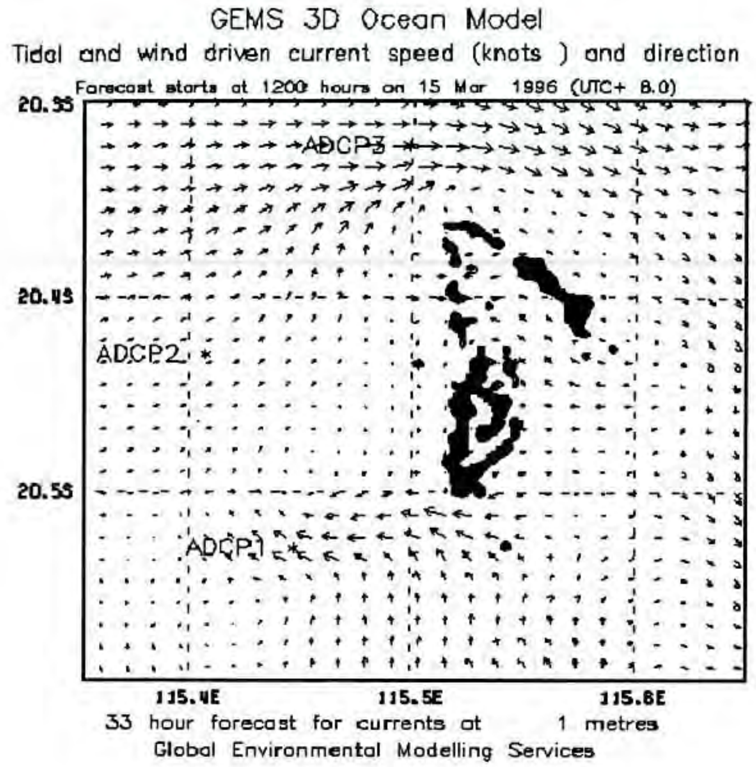


Figure 5: OILTRAK forecasts for wind and tidal driven near-surface currents at the turn of a flood tide 33 hours into the ADCP experimental period

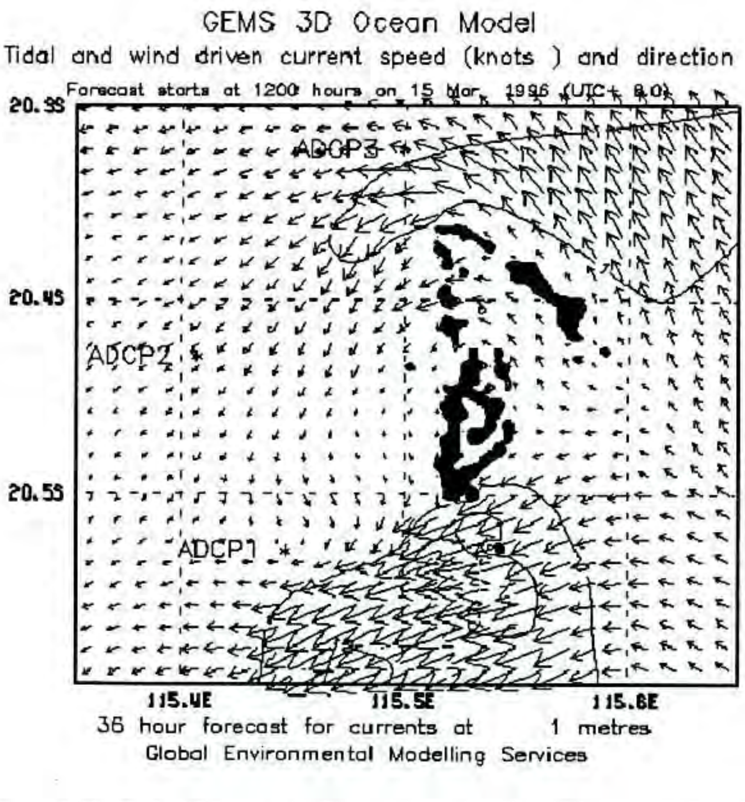


Figure 6: OILTRAK forecasts for wind and tidal driven near-surface currents during an ebb tide 36 hours into the ADCP experimental period

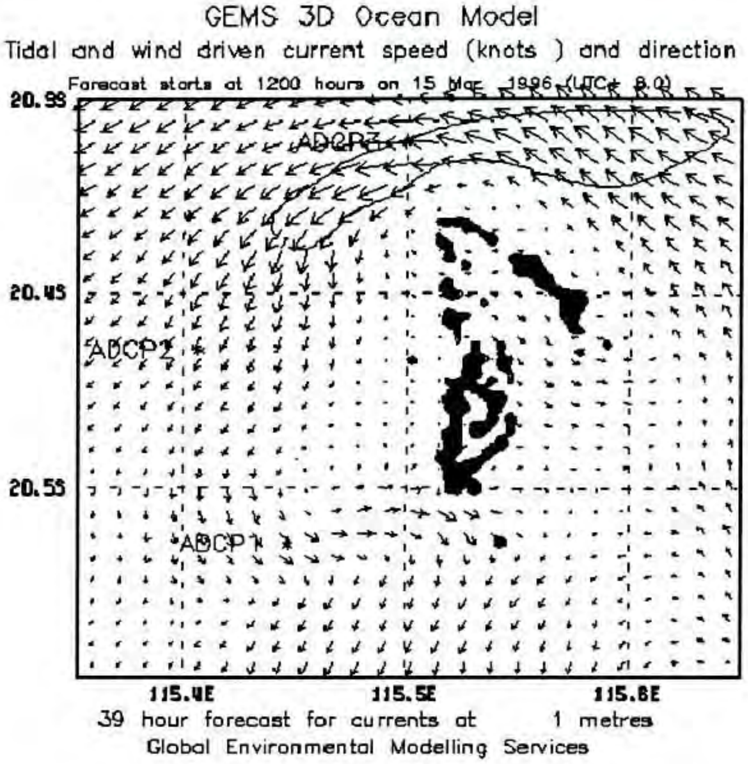


Figure 7: OILTRAK forecasts for wind and tidal driven near-surface currents at the turn of an ebb tide 39 hours into the ADCP experimental period

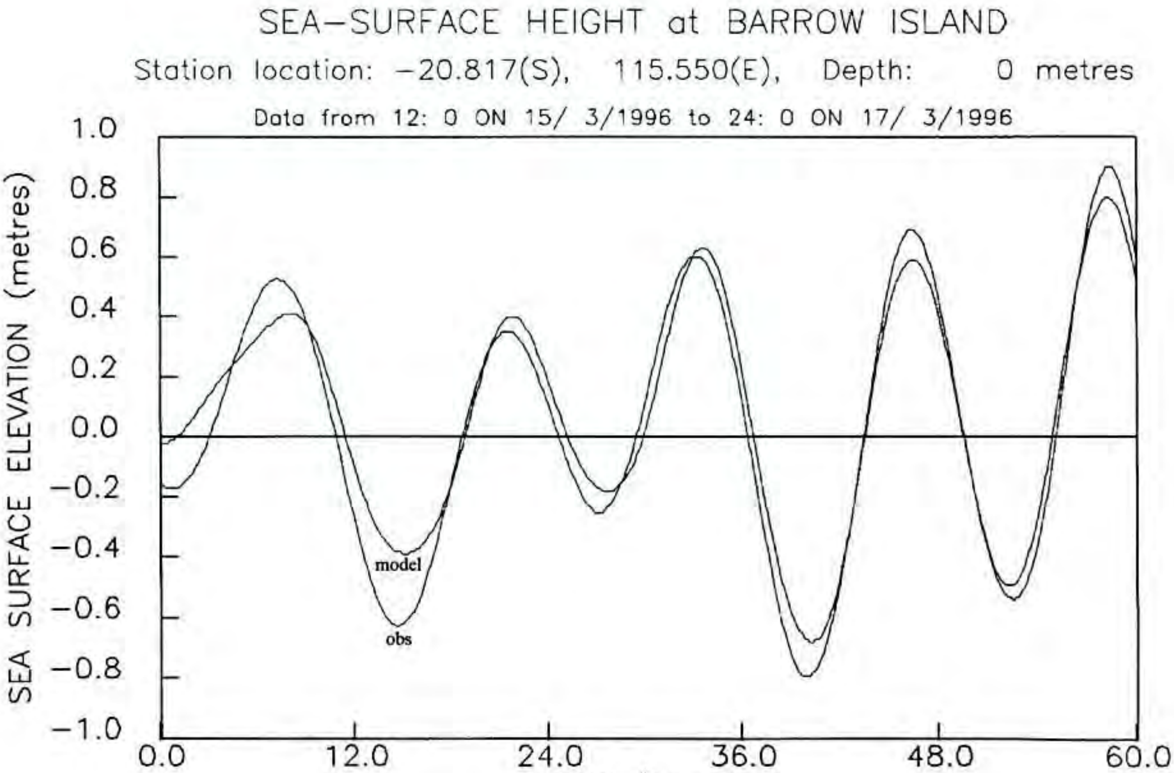


Figure 8: Model predictions of tidal heights compared with observations on April 16 and 17, 1996 at WAPET tanker mooring on Barrow Island

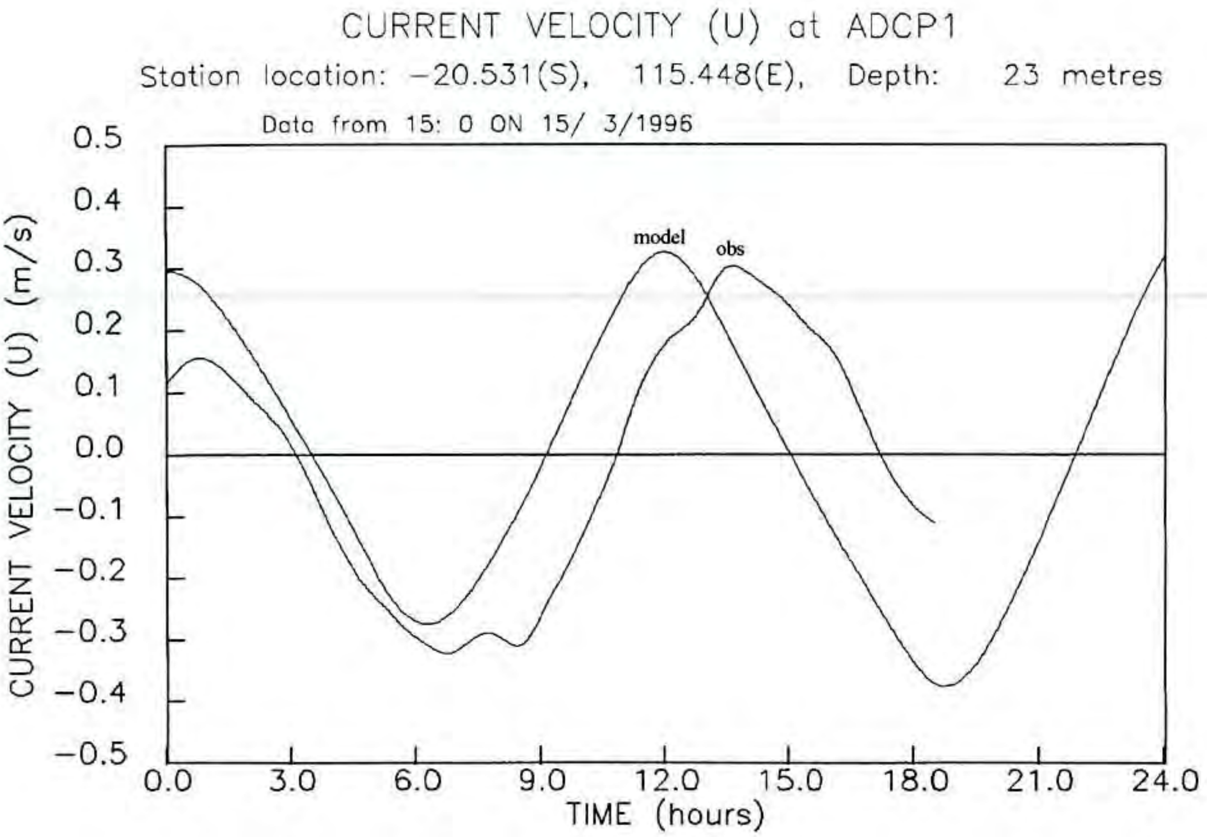


Figure 9: Model predictions of the west-east current component compared with observations on April 16 1996 at site ADCP1 near the Montebello Islands

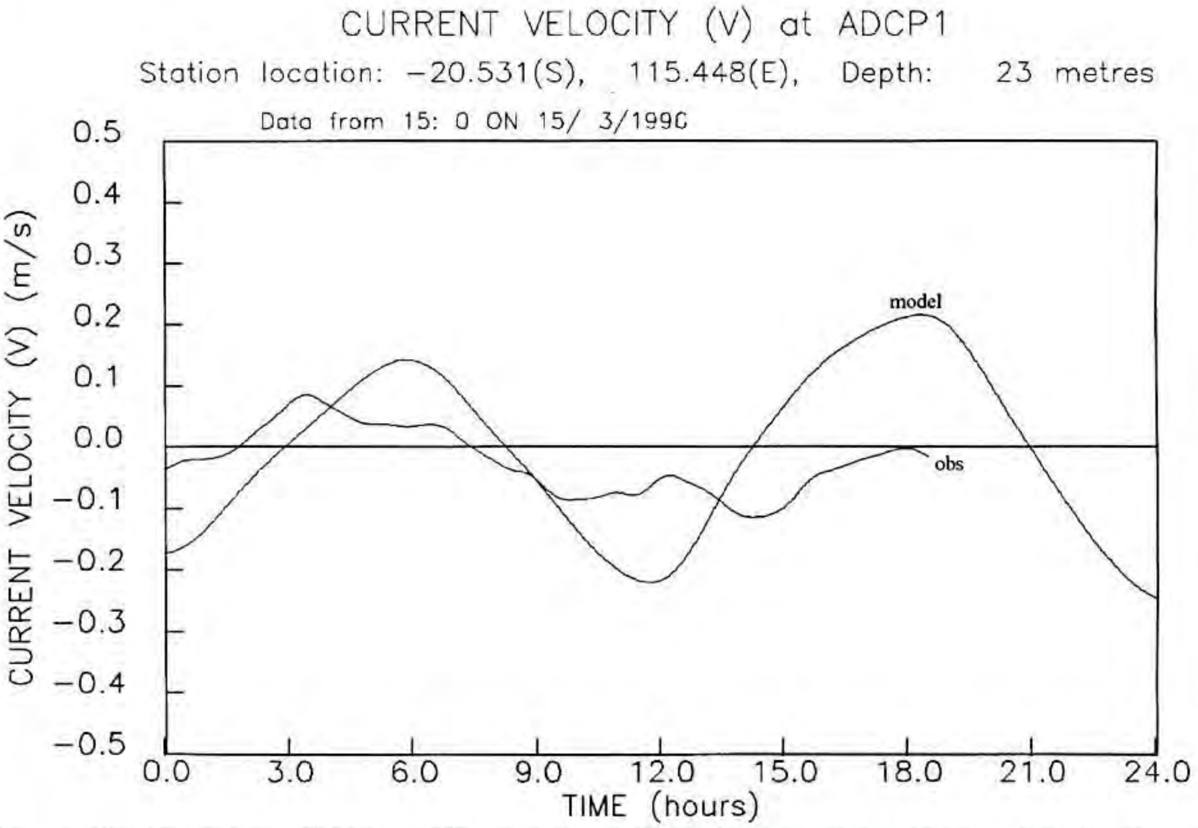


Figure 10: Model predictions of the south-north current component compared with observations on April 16 1996 at site ADCP1 near the Montebello Islands

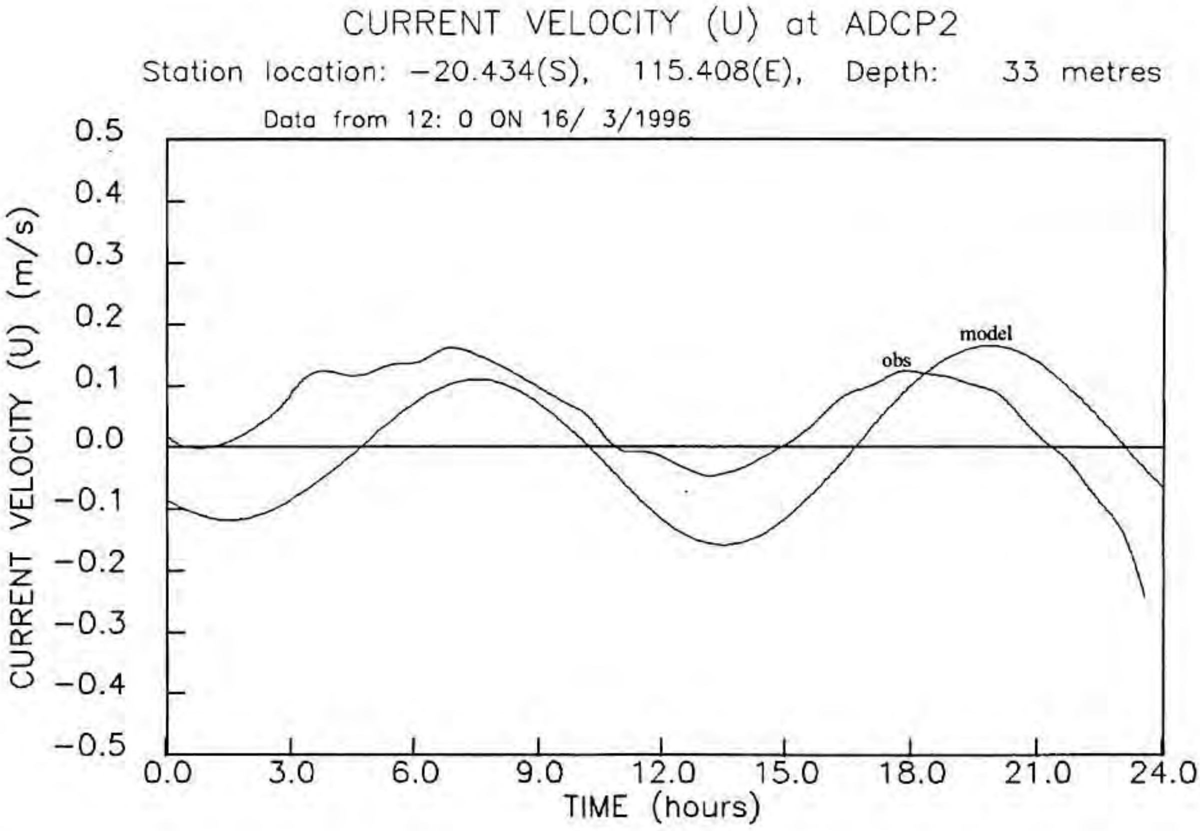


Figure 11: Model predictions of the west-east current component compared with observations on April 17 1996 at site ADCP2 near the Montebello Islands

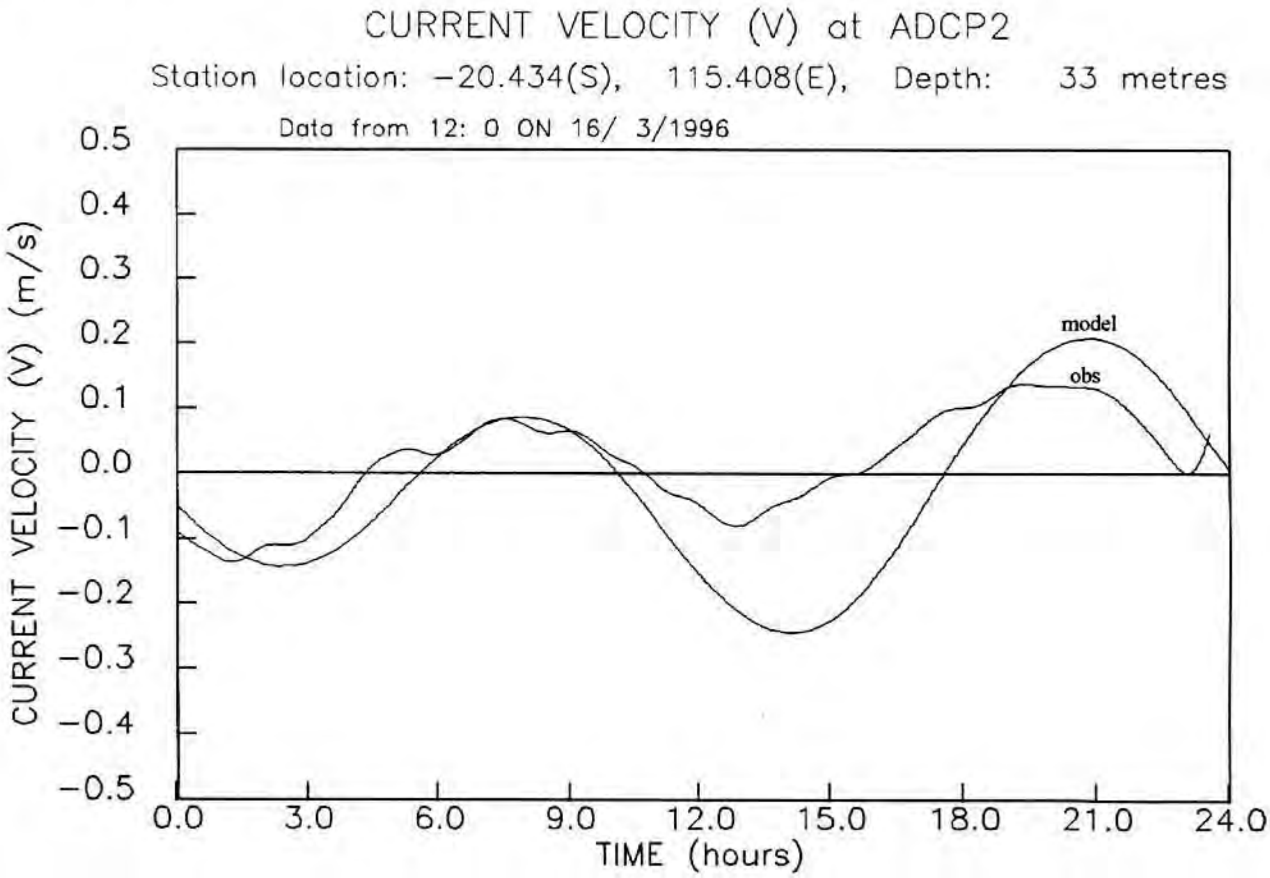


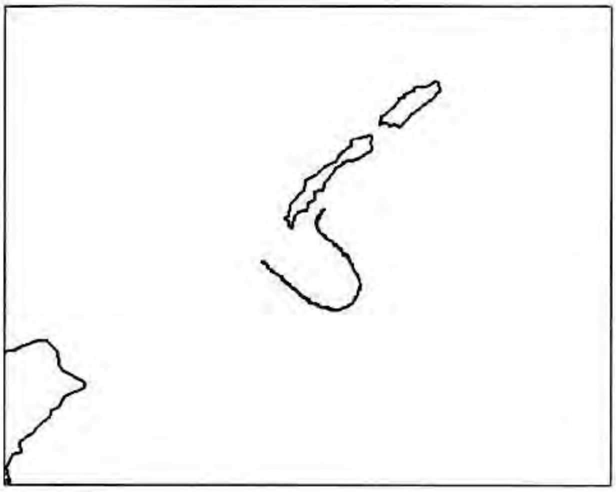
Figure 12: Model predictions of the south-north current component compared with observations on April 17 1996 at site ADCP2 near the Montebello Islands.

4.2 Exmouth Gulf Verification

Lasmo Oil requested the simulation of a "mat" track near the Muiron Islands in the mouth of Exmouth Gulf as a test of the model's ability to simulate surface ocean currents and particle trajectories, within acceptable errors. A "mat" was dropped at 7:45 a.m., September 28, 1992 local time and tracked using a ship's Global Positioning System (GPS) until 6:00 p.m. the same day. The winds observed on the ship were approximately 15 knots from the south-south-west in the morning dropping to 8 knots from the south-west in the afternoon .These winds together, with seven tidal constituents (M2, S2, N2, K2, O1, K1 and P1), were used to drive the oil spill trajectory model on a grid of resolution 700 metres and with 8 vertical levels (the surface layer was four metres thick). The 700 metre horizontal resolution was chosen so as to resolve the gap between North and South Muiron Islands. The observed and predicted tracks are shown in figures 13 and 14.

Buoy Drift Track

Buoy released at 23:40 on 27 Sept 1992 (UTC)

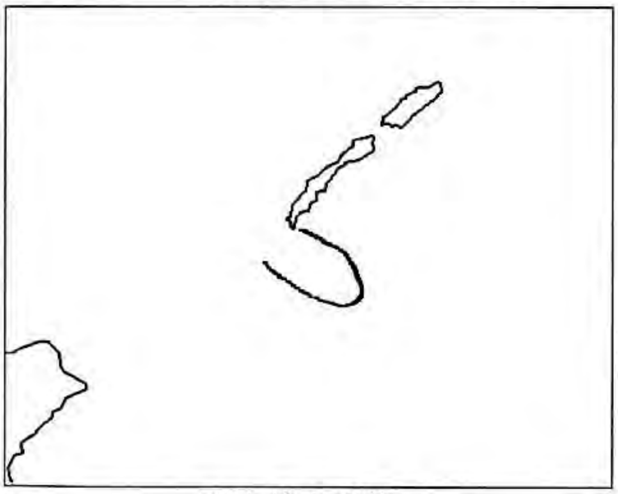


Global Environmental Modelling Services

Figure 13: Observed track of spill mat near Muiron Islands

OILTRAK - 3D Regional Ocean Model

Particle Released at 23:40 on 27 Sept 1992 (UTC)



Particle drifted for 11:30 hours

Global Environmental Modelling Services

Figure 14: Predicted path of spill mat near Muiron Islands using OILTRAK

4.3 Onslow Region Verification

Command Petroleum requested the simulation of two mat tracks in the Onslow Barrow Island region to test the model's ability to predict surface ocean currents and particle trajectories. Two mat tracks and wind speed and direction data were provided for successive days (16th and 17th) in April, 1992. The oil spill model was set up on a grid with 2km resolution and 8 vertical levels (with a surface layer 4m thick). OILTRAK was driven by observed winds and by seven tidal constituents to simulate the trajectories of the two mats. The observed and predicted tracks for each of the two days are shown in figures 15 to 18.

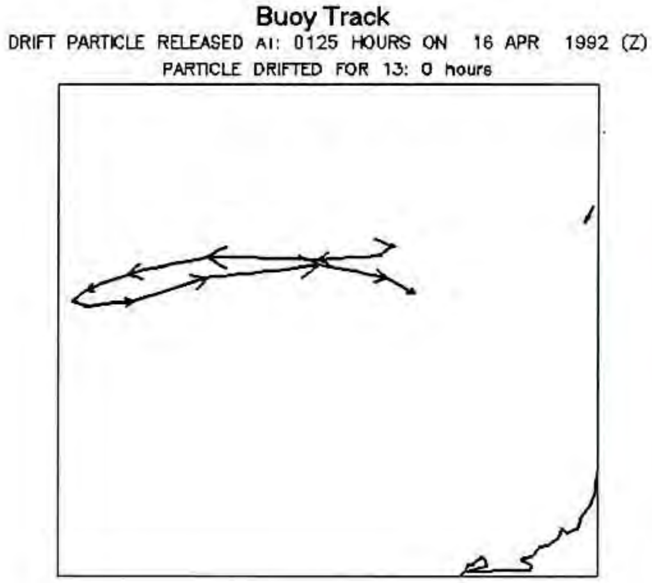


Figure 15: Track of spill mat observed by Command Petroleum on 16th April 1992 between Onslow and Barrow Island

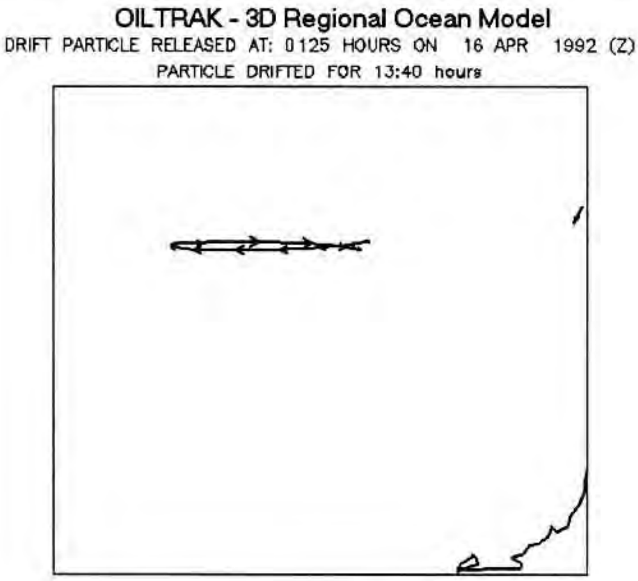


Figure 16: Track of spill mat predicted by OILTRAK on 16th April 1992 between Onslow and Barrow Island

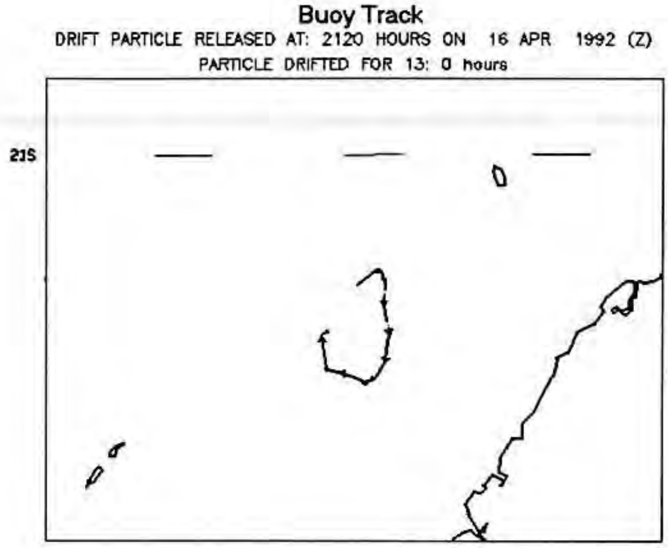


Figure 17: Track of spill mat observed by Command Petroleum on 17th April 1992 between Onslow and Barrow Island

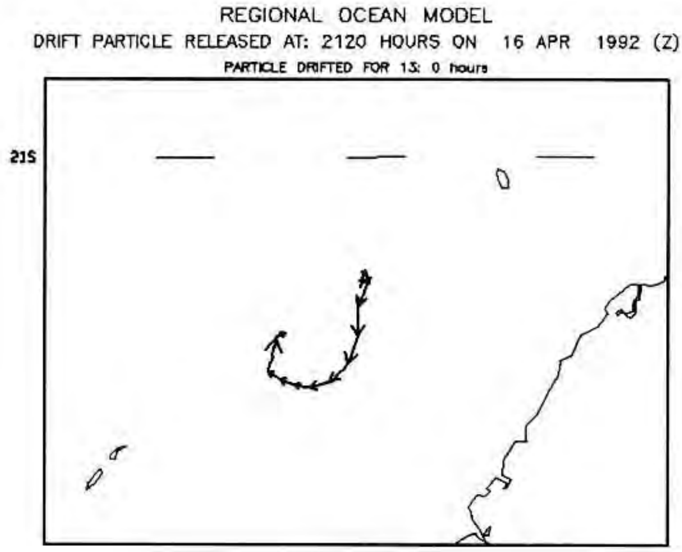


Figure 18: Track of spill mat predicted by OILTRAK on 17th April 1992 between Onslow and Barrow Island

4.4 Mermaid Sound Verification

The Oil spill trajectory model predictions in Mermaid Sound were verified against existing current meter data provided by Woodside Petroleum. At the site chosen for the verification (latitude 20 deg 31.4 mins, longitude 116 deg 43.7 mins, depth 14 m) the current meter was at a depth of 6 m. The Perth office of the SSU provided historical hourly wind data for a three day period (April 27 - 29, 1986) during the current meter observations. OILTRAK was run for this 72 hour period driven by winds and by five tidal constituents (M2, S2, K2, K1, O1) with vertical levels set at 2, 6, 10, 14, 18, 25 and 40 metres. The second level coincided with the depth of the current meter observations. A comparison of the observed current speed time series with the model predictions is shown in figure 19.

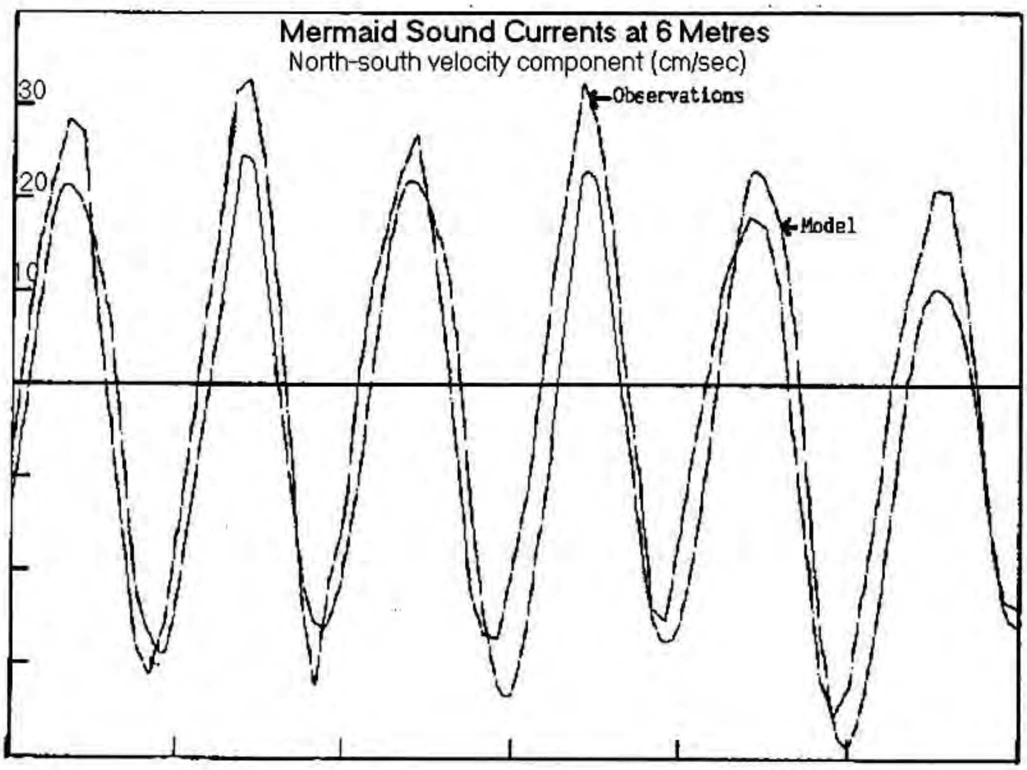


Figure 19: Comparison of observed currents and predictions from OILTRAK at a depth of 6 metres in Mermaid Sound for the period April 27 to 29, 1986.

4.5 Sydney

The three-dimensional ocean model has also been used for other applications such as predicting the currents near the Sydney ocean outfalls for the New South Wales EPA via a contract with Australian Water and Coastal Studies Ltd (AWACS). Comparison has been made between model predictions of currents off Sydney with measurements at the Ocean Reference Station (ORS) installed by the Sydney Water Board as part of the ocean outfall monitoring program. Comparison of model trajectory predictions were also made with the track of a drifting buoy released by the Australian Navy. Good agreement was obtained in both cases (Figures 20 to 23).

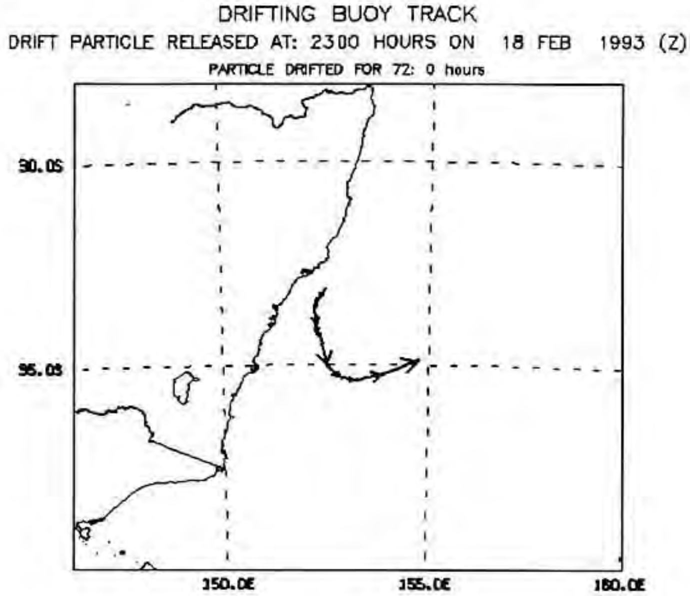


Figure 20: Satellite track of drift buoy observed for three days after release by the Australian Navy on February 19, 1993.

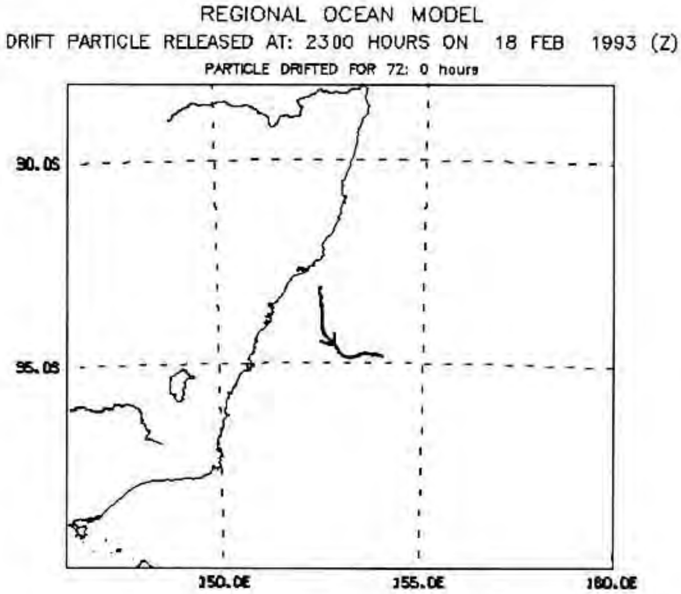


Figure 21: Track predicted by OILTRAK for the three days after release on February 19, 1993.

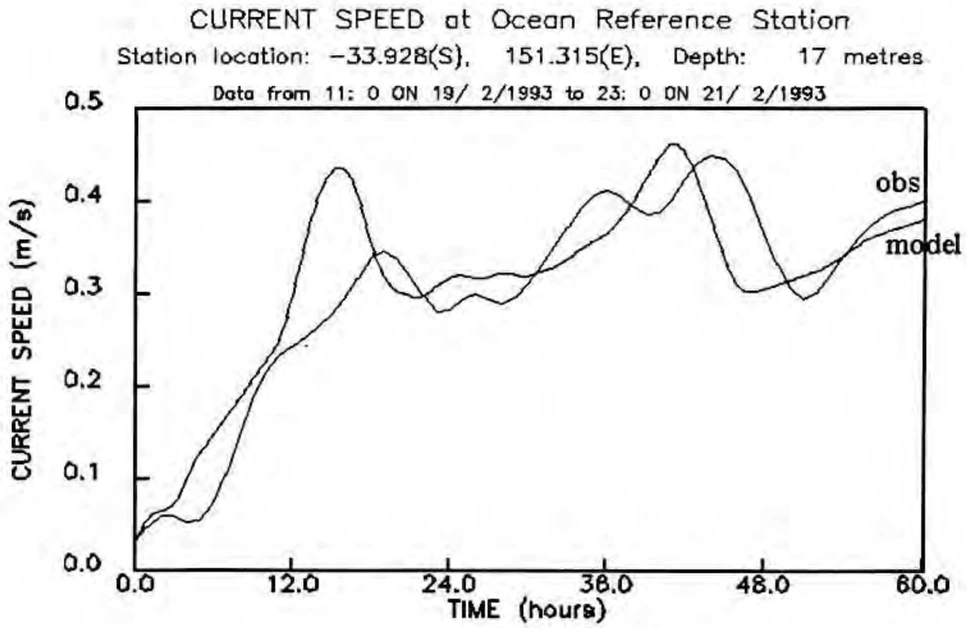


Figure 22: Comparison of observed current speeds with predictions from OILTRAK at a depth of 17 metres at the Sydney Water Board Ocean Reference Station (near Sydney) for February 19 to 21, 1993.

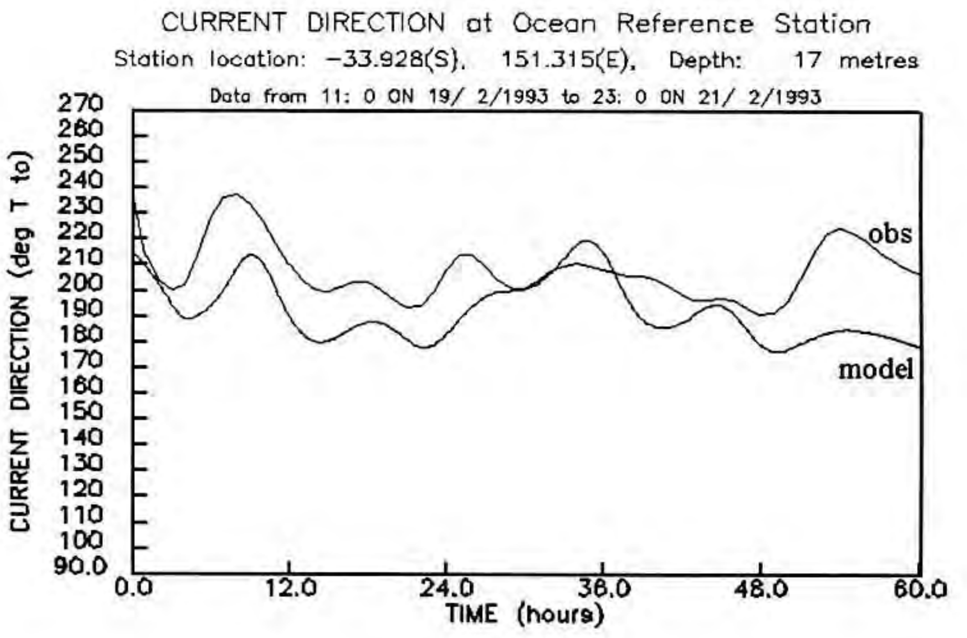


Figure 23: Comparison of observed current directions with predictions from OILTRAK at a depth of 17 metres at the Sydney Water Board Ocean Reference Station (near Sydney) for February 19 to 21, 1993.

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Appendix 8

APPENDIX 8

EFFECTS OF OIL ON NATURAL AND SOCIAL RESOURCES

1. Introduction

There is no clear-cut correlation between the size of the spill and extent of damage. The environmental effects of oil pollution on marine organisms varies greatly depending on the volume of oil, the type and physical state of the oil, the capacity of sediment penetration, location of the spill, climate and seastate, the life history of the species involved and the level of exposure. Impacts can be caused by physical contamination, smothering, toxicity bioaccumulation, and tainting (Jones 1986). These effects can be short term or long-term, lethal or sublethal. Damage by oil can result in changes in behaviour, biochemical attributes, physiological attributes which may impact the flora and fauna at an individual level through to the ecosystem level (Sheehan 1984). Commercial, recreational and social interests can be impacted.

An overview of the impacts of a light oil on various resources is presented in Table 8-1.

Oil pollution will exert its most severe consequences in shallow, sheltered waters where dilution and dispersion is limited. The impact is of a lesser degree in open water or areas of high energy.

As there have been no significant spills of Western Australian oils which have reached nearshore or onshore resources, predictions for the potential impact of spills on the local marine communities has been based on spill incidents referred to in the literature.

2. Sources of Disturbance

In evaluating the potential impacts of an oil spill, it is necessary to place the impact of a spill within the context of existing disturbances as it is against these variables that the consequences of an oil spill must be compared.

Potential anthropogenic and natural sources of disturbance are listed in Table 8-2.

3. Biological Recovery Process

The biological recovery of an ecosystem which has been damaged by oil begins as soon as the toxicity of the oil has degraded to a level which is tolerable to the most robust colonising organism (Baker *et al.* 1990). This recovery time can vary from a few days to more than a decade, but recovery will occur. Considerable variation in tolerances and sensitivities to oil have been observed among different species and different life stages which. Generally, the effects increase in intensity and persistence from pelagic (open ocean) to subtidal to intertidal communities. The reproductive strategy of each type of animal is also an important factor in the recovery of a species.

The water mass is dynamic and rarely static. It moves with the wind, tides and currents. Large scale oceanic processes such as the Leeuwin current and local processes such as tides influence and affect the distribution, recruitment and survival of marine flora and fauna.

The majority of marine plants and invertebrate animals produce millions of gametes (eggs and sperm) which drift and develop in the water mass. Marine species with planktonic larvae are rarely site dependent - similar benthic communities are likely to occur wherever appropriate conditions are present. Such locations may be miles away, but the communities are likely to be closely related genetically and in community structure. Species with planktonic larvae are most likely to recover quickly after an oil spill.

A few marine invertebrate species reproduce by generating and caring for a relatively small number of eggs or young. These species may become endemic to a particular habitat. If the habitat has been destroyed, the local population may take a long time, if ever, to recover.

The initial phase of recovery after some disturbance or organic enrichment, is characterised by a small number of species, but in very high abundances (Pearson & Rosenberg 1978; Kingston 1987). As conditions improve, other less hardy species are able to establish themselves, and by competition, reduce the numbers of the initial colonizers. In time, the flora and fauna characteristic of the area are restored.

Marine communities, whether they are soft sandy bottom, rocky shore, coral reef or mangrove, are in a constant state of flux and change due to natural physical and biological factors such as predation, competition, recruitment success, cyclones and sandwave migration. Studies investigating the temporal trends in marine soft bottom and rocky shore habitats have reported wide variations in population abundances and diversity from season to season (Lewis 1972; Gray *et al.* 1984). This complicates predicting or assessing the impact of oil as is it difficult to distinguish oil induced effects from natural fluctuations.

Much of the work carried out to date on the effects of oil has concentrated on single species. However, no one species lives in isolation. Ecosystems are composed of a multitude of different plants and animals which have developed a relationship between themselves and the physical attributes which surround them (air, water, soil). An oil spill could cause a major disruption to this relationship resulting in changes in the composition and functioning of the ecosystem, or in key processes such as primary production or nutrient cycling.

The re-establishment of a biological community after some perturbation is unpredictable as it depends on various factors including the availability of recolonizing organisms, biological interactions and climatic variables, food availability and suitable substratum for settlement.

Recovery is marked by the re-establishment of a healthy biological community in which the plants and animals characteristic of the community are present and are functioning normally (Clark 1989). A re-established community may not have exactly the same composition, diversity, biomass or age structure as that which was present before the damage. This change does not necessarily diminish the biological importance of that community. It must also be considered that it is impossible to determine if a community which has recovered from an oil spill is the same or different from the community which would have persisted had the spill not occurred.

4. Impacts of Oil on Natural Resources

A brief overview of the impact oil would have on the different types of resources found in and around the Montebello Islands is given below.

In general, the effects of hydrocarbons on marine life may include:

- lethal toxic effects - where death of an organism results from direct interference of a component of the oil;
- sub-lethal effects - chronic, biological effects of oil through disruption of physiological and/or behavioural responses, but not resulting in immediate death;
- bioaccumulation - where oil may be transferred through the food web;
- tainting - uptake of oil or certain fractions of oil;
- direct smothering and suffocation;
- physical or chemical alteration to a habitat resulting in a change in population or community structure.

4.1 Plankton

Plankton are the minute animals and plants floating about in the oceans, forming a component of the food chains in the marine environment. Plankton provide an important source of food to animals living in all types of marine habitats: mud, sand, coral reefs, mangroves, rocky shores. Suspension feeders (e.g. barnacles, corals, some polychaete worms) feed on live and dead particles suspended in the water column. Other animals feed on the dead plankton which has settled on the seabed (e.g. crabs, sea urchins, prawns). The larvae of many marine organisms spend time in the plankton during the early stages of their life cycle (e.g. corals, fish, crayfish). Plankton exhibit high natural mortality and are very patchy both spatially and temporally.

In the event of an oil spill, the plankton within the immediate area of the spill would undoubtedly suffer high mortality but repopulation is likely to be rapid due to high reproductive rates and immigration from areas outside the impacted area (Davenport 1982). Plankton is free floating and abundant in surface waters and so can be swept into previously contaminated areas from neighbouring unpolluted waters by surface currents. In open waters, populations may return to normal within days of a spill, although recovery may take longer in enclosed bays where water movement is less and oil may persist.

From a literature review, Volkman *et al.* (1994) concluded that there was general agreement that oil toxicities to plankton showed little or transient effects in both experimental and field experiments.

4.2 Benthic and Intertidal Communities

Subtidal communities

The risk of an oil spill affecting the seabed of offshore waters is minimal, but in shallow water, oil droplets may reach the bottom, particularly in rough weather. Fresh crude with a high proportion of toxic light components can cause local damage to the flora and fauna of shallow benthic habitats. The incorporation of heavier oil into the sediment can lead to a residence time of several years. However, sediment resuspension from tide, current and storm activities will help in the degradation process and allow recovery of the community. If the oil is not persistent, the recovery time can be within a few years, depending on the reproductive strategy of the various marine organisms.

Rocky Shores

Many of the animals of the rocky shore lay eggs directly into the sea. These eggs develop into larvae and become a component of the plankton. The larvae may eventually settle onto a suitable substratum and develop into an adult. As a part of the plankton, larvae can move great distances as they are swept by currents, tides and winds and hence their numbers are highly variable from both temporally and spatially (Underwood & Chapman 1995).

The effect of oil on the rocky shore tend to be minimal and recovery rates are rapid (2 years) due to the high energy level which helps break down the oil and because oil does not stick easily to rock (IPIECA 1991). The recovery of rocky shore plants and animals depends on the settlement of the young stages out of the plankton. Settlement and subsequent growth depends on adequate reduction in the volume and toxicity of oil residues.

Mudflats and Sand Beaches

The faunal diversity of mud and sand beaches can be correlated to the size and composition of the sediment, and the tide and wave energy. In general, mudflats consist of small particles and low energy, but of a range of sizes while sandy beaches consist of larger particles and higher energy and a small range of sizes. In terms of diversity, mudflats will generally have a higher diversity of animals than sandy beaches.

There is a characteristic fauna of fish that are usually associated with sand beaches (ref) which includes bait fish and juvenile fish. Infauna will be low in diversity and abundance and consist mainly of amphipods and ghost crabs. Some of this fauna is a source of food for some species of seabirds, and turtles use the sand beaches for nesting.

The main impact from oil results if the hydrocarbon is stranded on the beach. Sheltered shores, or low energy coastal habitats may retain oil for long periods of time affecting the recovery rate. Tidal flushing, currents and fauna which turn the sediment over (bioturbation) will help to decrease the amount of time for the oil to degrade.

Seagrasses and Algae

Algae and seagrasses are photosynthetic organisms which use the energy of sunlight to reduce carbon dioxide to organic compounds which they use as food. Unlike seagrasses, algae do not have roots. They receive all their nutrients directly from the water. Algae do not produce flowers, but rather spores which are released directly into the water by the adult plant. Algae provide food for a host of different marine organisms and some species form large floating mats which act as habitats for a flotilla of marine animals. Both are important as sediment stabilizers and fauna habitats.

The effects of oil on algae will be dependent on its distribution. Intertidal species in low energy, sheltered sites are the most at risk due to direct contact and the potential residence time of the oil. The response to seagrass to oil spills appears to vary considerably (Thorhaug 1987).

Seagrass beds and algae will survive a spill provided that no actual coating. Coating causes considerable destruction (Thorhaug & Marcus 1987) but reasonably rapid recovery of these areas through recolonisation (algae) or regeneration (seagrass) has been observed following oil spills (AGC Woodward-Clyde 1992).

The fauna associated with seagrass beds appear to be quite susceptible to oil (Jackson *et al.* 1989). Intertidal and shallow subtidal assemblages are most at risk, due to the direct effects of coating. Shallow sediments may also be affected, damaging the rhizomes of seagrasses and so preventing long-term recovery. Deeper assemblages will escape the effects of surface oil in all but extreme weather conditions or where oil is heavy.

Corals

The response of corals to oil spills varies according to geographic locations and the species of coral (Harrison *et al.* 1990; Guzman *et al.* 1990). See the detailed review of oil on corals in Attachment A.

Potential effects of oil on the west fringing reef is presented in Figure 8-1.

Mangroves

Mangrove communities are potentially the most sensitive of the marine environments to coating by oil (Lai *et al.* 1984; Wardrop 1987). Oil spills may result in the immediate destruction of all flora and fauna within the community. The mangroves themselves are highly susceptible to even light coating by oil and suffer permanent damage and mortality due to loss of leaves through chemical burning, or smothering of the breathing pores (lenticels) or the aerial roots (pneumatophores). Mangroves are also known to take up the light end component from the oil through their roots and leaves, causing tissue damage and eventual death (Woodside 1989; Klekowski *et al.* 1994). Oil retained in the sediment may also inhibit the germination of mangrove propagules, resulting in the slow recovery of the affected area.

Mangrove communities typically occur in sheltered areas of low wave energy, making retention of oil within the sediments a potentially long term problem. The retention of oil in the substrate may result in chronic exposure to oil due to the flushing of retained oil out of the sediment over each tidal cycle. The burrows of organisms and the roots of trees also act as a conduit for light oils, allowing the penetration of oil deep into the sediment.

In open, aerobic sediments, the loss of light oil appears to take about 18 months (Woodside 1989). However, in areas where the sediments were anaerobic, with a high organic content and poorly flushed, degradation is slow and the oil persists over 20 years or more (Burns *et al.* 1994). Re-emergence of young trees will be unlikely until at least the toxic components of the oil are lost. Estimates of recovery rates range from tens to hundreds of years to regain a mature forest (Burns *et al.* 1993).

Fin Fish

The death of adult fish has been attributed to toxic effects after of water or tainted food, ingestion and to suffocation caused by clogging of the gills (Clark 1982; Jones 1989). Large kills of adult fin fish in open water would not be expected due to their mobility and ability to avoid oil contaminated water. Mortality of adults in sheltered, enclosed bays, especially demersal fish, would be higher if oil became mixed through the water column or settled in the bottom substratum.

The greatest damage to fin fish would be during and just after the spawning period when the more sensitive eggs and larvae may float on the surface of the ocean. This may result in a short term decrease in fish stocks. However, the literature indicates that mortalities among pelagic fish and larvae are limited in size and will have no measurable impact on fish stocks. For example, 10 months after the Exxon Valdz spill, there was a record catch of pink salmon. The reason for this increase was attributed to the oil acting as a fertilizer, helping to prolong an algal bloom which provided food for the fry (Anon 1990). On the negative side, the oil spill killed off diving seabirds which fed on the salmon fry.

4.3 Seabirds, Marine Reptiles and Mammals

Seabirds

The most serious effect of oil is on the birds plumage. Birds rely on the air trapped in their feathers to provide insulation and buoyancy and oiled feathers mat down and lose their water repellent properties. This leads to death by drowning or hypothermia.

Lightly oiled birds are able to clean themselves by preening within two weeks (Birkhead *et al.* 1973) but in doing so ingest oil. This ingested oil may cause liver, kidney and other tissue damage, may reduce the fertility of eggs that are laid (Grau *et al.* 1977), or result in death. Although highly mobile and potentially capable of avoiding polluted areas, seabirds may be attracted to dive into oil slicks, mistaking the sheen for fish.

Many pelagic tropical species feed by picking or snatching prey from at or near the sea surface without settling on the water (e.g. Bridled Terns, Sooty Terns, noddies, frigatebirds). Wedge-tailed Shearwaters, Bulwar's Petrels, gadfly petrels, storm petrels feed while paddling on the surface of the water. Boobies and Tropicbirds plunge dive to about a metre or so below the surface.

On the North West Shelf, seabirds are often associated with large floating rafts of the brown algae *Sargassum*. A range of juvenile and larval fish, crustaceans and terrestrial insects shelter in the rafts and act as a food source for the birds. Bridled Terns in particular appear strongly reliant on *Sargassum* (Wooller 1995). In the event of an oil spill, oil may become entrained into the rafts with the potential of toxic effects (Butler *et al.* 1983).

The movement of pelagic predatory fish, particularly tuna, are important to many seabirds. Species such as the Sooty Tern may be totally dependent on tuna to bring prey to the surface of otherwise deep ocean. Platforms and monopods function as fish aggregators, attracting fish such as tuna and mackerel. As a consequence, the seabirds also tend to concentrate to varying degrees around these structures where they may be vulnerable to localised spills (Dunlop *et al.* 1995).

Many seabirds have a yearly, single egg clutch and chicks with relatively long fledgling periods (e.g. Wedge-tailed Shearwater, Bridled Terns). In Bridled Terns, the minimum age of first breeding is four and a reproductive life extending 6-15 years. Wedge-tailed shearwaters have a reproductive life of 10-20 years.

In terms of impact from an oil spill, the concern in not the deaths brought on by oiling, but the number and fate of the survivors. Recovery of a population depends either on (i) the existence of a reservoir of young breeding adults from which breeding colonies can be replenished or (ii) a high reproductive rate. Animals with a large breeding potential may rapidly regain their losses. Mortality is only significant if it results in a substantial decrease in the breeding population.

Turtles

Little is known about the direct effects of oil on turtles. Eye infections may result from direct contact with oil, however most animals would be expected to avoid polluted areas. The lighter oils produced by the Harriet oilfield may be capable of penetrating the sandy sediments found on nesting beaches and subsequently interfering with egg-laying or egg development. However egg laying and development usually occur high on the beach beyond the reach of stranded oil. Nesting females and young hatchling turtles might be coated with beached oil as they emerge from and enter the water.

Marine Mammals

Information on the impact of oil on marine mammals is limited. However, Baker *et al.* (1990) believe that these species appear to ignore floating oil and are unharmed when they encounter it.

Like turtles, marine mammals may suffer eye infections after direct contact with oil (NRC, 1985). Other potential effects include surface fouling, direct and indirect ingestion and inhalation of toxic fumes (Volkman *et al.* 1994). Whales and dolphins have been observed to avoid surface oil slicks and dugongs are presumed to be able to do so, although no information on their response to oil is currently available (Baker *et al.* 1989). As marine mammals move freely in open water, they would not be exposed to prolonged or sustained exposure to oil.

Work carried out by Hellou *et al.* (1990) found low concentrations of polycyclic aromatic hydrocarbons (PAHs) in the skeletal tissue of ten species of marine mammals in eastern Canada, implying that PAHs can accumulate in mammalian tissue. However, the data mist be interpreted with caution as the concentration and retention of hydrocarbons will depend on the level of exposure, sex, body organ and ability of the animal to depurate.

Dugongs may be indirectly affected by ingestion of coated seagrass leaves.

5. Effects of Oil Spills on the Social Environment

5.1 Commercial Fisheries

A large oil spill could have significant effects on local fisheries, but because most fishing activity occurs south of the permit area and most surface water movement is offshore, this risk is minimal. The prawn fishery operating adjacent to Onslow may be at risk from an oil spill. The pelagic larval stages and the benthic juvenile and adult stages of prawns are more sensitive to oil than fin fish or molluscs and catches may be reduced due to mortality or to reduced fishing effort in polluted areas. Pelagic fish are able to avoid spills but benthic fish may suffer from pollution of substrates.

In the event of an oil spill under appropriate conditions, there could be some impact on pearl farming to the northeast of the island group. As filter feeders, pearl oysters will ingest oil particles if they sink through the water column and this may cause mortality.

5.2 Tourism

An oil spill spreading to the south of the permit area may have a temporary effect on the operations of charter boats and recreational fishing. The actual recreational fish stocks are unlikely to be affected as game fish are highly mobile and so able to avoid the effects of a spill. An oil spill spreading to the Lowendal or Montebello Islands would similarly disrupt recreational fishing and day trips in those areas.

6. Bacteria

This group of organisms is given separate recognition due to their natural occurrences and their potential to help in the remediation process after an oil spill.

Biodegradation is a natural process whereby bacteria or other micro-organisms alter and breakdown the organic molecules of oil.

The natural population of bacteria found in the marine environment has the potential to degrade hydrocarbons very rapidly, especially if additional nutrients are added. These bacterial populations have been found to be very complex and a number of different species work together to degrade the hydrocarbons. Extensive bioremediation techniques were developed after the *Exxon Valdez* spill and results have been very promising. One finding was that background microbial degradation occurred at very fast rates (Hoff 1993) supporting the claim that under certain circumstances, natural cleansing may be the best clean-up option. However, the technique still needs refining before it can be used large scale clean-up technique.

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Table 8-1: Overview of the consequences of an oil spill on natural and social resources. A light crude oil is used as the source of impact.

Resource	Importance	Impact	Recovery time
Plankton	Component of marine food chain. Primary producers. Many marine species have larval stage in plankton.	Major impact will be to plankton on surface of the water where oil is located. Plankton in water column may be affected as light crude is quite soluble.	Immediate Spatial movement and effective reproductive strategies will result in rapid recovery.
Subtidal seabed communities	Potentially high biological productivity. Feeding grounds for turtles, dugongs and fish.	Effect minimal except in shallower waters where oil may reach the seabed. Toxic components in oil may affect flora and fauna. Heavier oil may persist in sand sediment for period of time.	1 year. Rapid recovery due to spatial movement of animals and high reproductive capacity of colonizing species.
Rocky intertidal shores	Dominated by oysters and barnacles. Includes array of other fauna and flora. Rock platforms used by birds.	Damage by smothering or toxic effects. Oil may not adhere to rock for long period of time. Low potential for oil accumulation except in crevices and pools. Natural cleansing by waves reduces persistence of oil.	1-2 years.

Resource	Importance	Impact	Recovery time
Mud tidal flats	Supports mangrove communities. High productivity. Feeding grounds for wading birds.	Oil may not penetrate very deep due to fine sediment, but may accumulate at high tide level. Burrows of animals may act as pathways for oil, assisting penetration. Severe impact to fauna may lead to reduced food supply for wading birds.	2-10 years. Dependent on penetration of oil and tolerance of animals.
Algae and seagrass beds	Stabilize shoreline and seabed. Highly productive. Food source for turtles and dugongs. Nursery grounds for marine invertebrates. Provide shelter.	Algae is considered to be relatively resilient to oil. Intertidal seagrass beds most prone to damage. Tolerance to oil varies amongst species. Depressed growth rate, leaves turning brown, covering by algae are reported responses. Animals associated with seagrasses could be heavy impacted.	Algae: 1 year Seagrass: 1 year - decades
Corals	Provide habitat for high density and diversity of animals. Nurseries for many fish. Important for tourism.	Minimal impact of coral remains submerged and oil is mixed in the water column. Localised tissue rupture, increased algae growth, excessive mucous production are potential responses. If coral dies, habitat composition may change to predominately algae. Some corals long lived and slow growing. Recovery dependent on recruitment success.	1 year - decades
Mangroves	Highly productive. Source of food and shelter for wide diversity of organisms. Nursery grounds for some marine species. Stabilize shoreline.	Oil may persist for long time in sediment, especially where penetration has occurred (i.e. down animal burrows). Response range from defoliation, chlorisis and death of trees due to toxic impact. Infauna may be decimated by oil due to its toxicity.	Trees: 10-50 years Fauna: 2-5 years
Fin fish	Commercial and recreational value. Contribute to food chain.	Low risk of impact to adults in open water due to mobility. Toxic component may cause tainting or death to fish in sheltered waters. Larvae and eggs floating on surface prone to impact.	Years in enclosed waters.

Resource	Importance	Impact	Recovery time
Seabirds	Lovely to observe. Add to biodiversity of area.	Damage to plumage and ingestion especially to seabirds.	Slow to medium recovery depending on reproductive potential.
Turtles	Add to conservation status and biodiversity to area. Food source to indigenous people.	May be prone to eye infections if contact made with oil. Mobile and can therefore avoid oil. Greatest impact will be to nesting turtles and hatchlings.	Slow recovery.
Marine mammals	Add to conservation status and biodiversity of area.	Appear to be able to avoid oil. However, if come into contact, may suffer eye infections, skin irritations, inhalation of fumes, ingestion of oil. Dugongs may be affected if food source impacted.	Slow recovery.
Commercial fisheries	Economic value.	Decimation of stocks may result in economic impact.	Slow to medium.
Tourism	Economic value.	Access to oiled beaches to be avoided, fishing may be restricted and some natural resources used for diving may be restricted for access.	Medium

Table 8-2: Potential Man-Induced & Natural Stressors

Anthropogenic Sources	**Potential Impact - Comments**
Shipping	Accidental spillage of oil. Illegal operational discharges.
Tourism	Tourism to the islands is still fairly limited due to their distance from the shore. Visitors come to the islands mainly in the winter and seek sheltered anchorage in the sheltered bays.
Recreational Fishing	Overfishing and depletion of stocks. Damage to coral reefs from anchoring. Charter vessels visit the islands on a regular basis, but numbers are relatively low compared to other offshore islands.
Pearl Farming	Increased organic matter load in sheltered waters.
Global Warming	Increase in water temperature and water level. Increased temperatures may be cause of mass coral bleaching.
Natural Sources	**Potential Impact**
Crown-of-Thorns Starfish	Destruction of coral through feeding. A recent outbreak is thought to have occurred on the west fringing reef of the Montebello Islands. Some have been observed on the Lowendal Islands also. No reason for outbreaks determined as yet.
Drupella cornus	Mortality of coral through feeding. Another coral predator (gastropod) which aggregates in large numbers and causes death of coral. The cause of outbreaks is unknown. *Drupella* has been observed on the reefs around the Lowendal Island.
Phytoplankton Blooms	Invertebrate animals and fish mortality due to oxygen depletion or release of toxins. Occurs mainly in shallow, sheltered waters.
Insect Infestation Boring Organisms	Defoliation. Loss of branches. Death. Affects predominantly mangrove trees.
Parasitic protozoans	A naturally occurring protozoan causes 25-50% mortality to oysters by destroying connective tissue in gastric system.
Cyclones	Extensive physical damage to corals and mangroves. Beach erosion. Algal blooms due to release of nutrients in resuspended sediments.
Cyclonic Rainfall	Short-term reduction in salinity of shallow waters. Freshwater run-off from land.

ATTACHMENT A

REVIEW OF THE EFFECTS OF OIL ON CORALS

1. INTRODUCTION

The following document is a review of the reported effects of oil on corals and coral reefs, incorporating findings from laboratory and field experiments, and studies of major oil spill events.

As with many other biological systems which have been investigated, the transfer of findings from laboratory studies and field experiments to prediction of response to actual oil spill events has proven difficult, with the resilience of natural systems frequently exceeding that which might be anticipated on the basis of experimental results.

Consequently, for the purposes of this review the document has been divided into three sections, laboratory studies, field experiments and studies of actual spill events, with the consolidated findings from the three sections presented in the synthesis at the end of the review.

2. EXPERIMENTAL STUDIES

2.1 LABORATORY STUDIES

2.1.1 Larvae

Studies on the effect of oil on coral larvae suggest that larvae may be more susceptible to the effects of spilt oil than mature corals. Harrison (1993), in a report on coral spawning on the Great Barrier Reef, reported the results of unpublished experimental data which indicated that relatively low concentrations of the water accommodated fraction of bunker oil reduced fertilization rates or completely inhibited fertilization in the species of coral tested.

2.1.2 Adult Corals

In one of the early experiments on the effect of oil on corals, Lewis (1971) tested four Caribbean coral species, *Porites porites, Agaricia agaricites, Favia fragum* and *Madracis asperula,* with various concentrations of crude oil in sealed 350 mL glass containers. The corals were exposed to oil for 24 hours and then examined for damage. The results indicated that all of the species tested were sensitive to oil but that the encrusting forms tested were less sensitive than the branching forms and also tended to recover more quickly.

Experiment has also shown that direct immersion of corals in oil will cause tissue necrosis, although the extent to which this will occur varies from species to species. Reimer (1975) immersed four Panamanian coral species, *Pocillopora* cf. *damicornis, Pavona gigantea, Psammocora (Stephanaria) stellata* and *Porites furcata,* in marine diesel and bunker oil for a period of one minute. Specimens of *Pocillopora* cf. *damicornis* were also immersed in oil for a period of 30 minutes. The corals were then placed in clean running seawater and finally transferred to aerated 3 L seawater containers. After one week, the one minute treatments and controls exhibited similar degrees of tissue necrosis. After 13 days differences in *Pocillopora* became apparent, with most live tissue lost from the treatments in 16 days. The other species tested showed little change for almost three months. However, marked change in the amount of live tissue in the treatments compared to the controls became apparent after 114 days. *Pocillopora* colonies immersed in oil for 30 minutes survived exposure but underwent expulsion of zooxanthellae, tissue rupture and flaking of tissue within hours to days of exposure. Seventy percent of the polyps died within 17 days. In related experiments, behavioral changes (e.g. tentacular retraction and feeding behaviour) by corals in containers to which diesel or bunker oil had been added were also observed (Reimer, 1975).

Eight hour exposure of the coral *Diploria strigosa* to Arabian light crude oil in a flowing seawater system had no impact on photosynthesis, as measured by total carbon fixation, by symbiotic zooxanthellae (Cook & Knap, 1983).

Thorhaug *et al* (1989) tested various combinations of oil and oil/dispersant mixtures on three Jamaican coral species, *Porites porites, Acropora palmata,* and *Montastrea annulata.* Significant differences were found between species with respect to their susceptibility to pollutants, with *A. palmata* found to be consistently more susceptible to pollutants than the other species tested.

Experiments by Elgershuizen & de Kruijf (1976), with the Caribbean stony coral *Madracis mirabilis* showed that the coral was not permanantly damaged by oil at concentrations ranging between 10 and 10,000 ppm over a 24 hour immersion period, and that floating oil was less toxic than oil-water mixtures. The oil was applied both as a surface layer and as oil-seawater mixtures, prepared by combining known quantities of oil and seawater and mixing for 24 hours.

Hough (1995) conducted a series of tank experiments to examine the effects of Bunker C Fuel Oil 467, a dispersant (Ardrox 6120) and oil/dispersant mixtures on the corals *Acropora formosa* and *Pocillopora damicornis.* Corals directly exposed to oil (simulating low tidal conditions) exhibited severe stress and most became bleached at the areas of tissue/oil contact. The pattern of coral response under all treatments followed the following sequence:

- polyp tentacular retraction;
- mucous discharge;
- zooxanthellae expulsion with localised bleaching;
- tissue disintegration; and
- death

For oil only treatments, Hough (1995) found as follows:

- fuel oil (and oil/dispersant mixtures) are toxic to corals of the species tested;
- the *Acopora* was found to be more sensitive to all treatments than the *Pocillopora;*
- the availability of the toxic components is significantly influenced by the hydrodynamic regime: rough seas increase physical dispersion and weathering of oil, but mixing oil into the water column increases the potential for exposure;
- direct contact to oil as a result of exposure from low tides disintegrates tissue at the area of contact (noting that oil is less adherent than dispersed oil);
- deleterious effects of oil predisposes coral to bacterial infection and colonisation by algae; and
- water quality factors, especially water temperature, introduce significant synergistic effects.

However, colonies of the octocoral *Heteroxenia fuscescens* in 1,500 L tanks exhibited zero mortality when exposed to oil at concentrations of 10 mL/L over a period of seven days (Cohen *et al*, 1977). Comparison of the results of experiments carried out in 3 L glass jars versus 2 m deep containers demonstrated a depth protective effect, the number of colonies exhibiting signs of stress decreasing with increasing distance from the oil film at the surface. Petroleum derived hydrocarbons were however incorporated into the tissues suggesting that exposure to high sub-lethal oil concentrations may result in long term deleterious effects.

In longer term laboratory tests, chronic exposure to hydrocarbons has been shown to cause tissue atrophy, zooxanthellae and reduced reproductive capacity. An experimental study of long term (six-month) oil pollution on the hermatypic coral *Stylophora pistillata* conducted by Rinkevich & Loya (1979) showed a significant decrease in the number of female gonads per polyp in 75% of colonies in oil polluted experimental tanks, leading to the conclusion that chronic oil pollution damages the reproductive system of scleractinian corals. Over the six month period of the experiment, a higher percentage of the corals in the oil polluted tanks (80%) died compared to the control tanks where 10% mortality was recorded. There was no injury or mortality recorded during the first two months of the experiment, all mortality being recorded during the following four months.

Also in a long-term experiment, Peters *et al* (1981) conducted a histopathological study on the effects of water dispersed oil on the coral *Manicina areolata* over a three month period. This study showed cellular degeneration and atrophy of coral tissues in addition to reduction in ability to reproduce. Other observations included death of zooxanthallae and lack of depuration of hydrocarbons up to two weeks after removal from oil exposure.

Dodge *et al* (1984), conducted a laboratory/field experiment with the coral *Diploria strigosa* to assess the long term effects of brief low-level concentrations of oil (and oil/dispersant mixtures) which might occur when a slick passes over a reef. The treatments were carried out in the laboratory and the corals subsequently put into the field for a period of one year. At the end of that time no differences in growth for any of the treatments were found compared to the controls.

The effects of oil contaminated sediments on corals and their ability to reject contaminated sediments have also been tested experimentally. Bak & Elgershuizen (1976) tested 19 species of Caribbean coral for oil-sediment rejection. They found that the efficiency of removal of oil-sediment particles was the same as for clean particles of the same size and/or quantity. Oil droplets of <0.06 mm in diameter were found not to adhere to living coral surfaces and were not ingested, leading to the hypothesis that the water-soluble toxic fraction of oils in seawater is more harmful to corals *in situ* than physical contact with oil-sediment particles.

2.2 FIELD STUDIES

2.2.1 Larvae

No reports have been located on effects of oil on coral larvae in the field. However, Guzman & Holst (1993) have reported a reduction in gonal tissue in mature corals. A similar finding was also made by Rinkevich & Loya (1979) in laboratory experiments.

2.2.2 Mature Corals

The results of field studies show general agreement with the experimental studies reviewed above, but have highlighted a range of environmental factors that may affect the impact of a spill on corals. More recent laboratory studies have attempted to factor some of these variables into experimental design (refer to Hough, 1995, in the previous section).

In one of the first field experiments undertaken, Johannes *et al* (1972), exposed 32 species of coral to a 0.6 mm thick layer of St. Maria crude oil at Eniwetok Atoll. The corals were placed on platforms where they were partially exposed to air. Oil was then added to the surface of the water around the corals from where it gradually accumulated on the corals due to the rocking action of the platform in the waves. The corals remained in the oiled water for a period of 90 minutes after which time they were placed in 2 m of water and observed over a period of four weeks. Oil adhered particularly to branching species such as *Acropora* sp.and *Pocillopora* sp. and these were severely damaged where the oil adhered. In *Fungia* and *Symphyllia*, species with large fleshy polyps with abundant mucus, most of the oil disappeared after submersion for a day and no damage was observed. The affect on other species lay between these two extremes. Complete breakdown of tissue occurred on areas to which oil had adhered but areas to which oil did not adhere did not appear to be visibly affected in any species. The possible effect of elevated temperature (32°C) in the oil film was considered a potential contributing cause to tissue damage, but this was not investigated.

A number of field studies have indicated that corals may be protected from floating oil by the overlying water column. Knap (1987) reported on a series of experiments into the effects of chemically dispersed oil on the coral *Diploria strigosa*. While the experiments were principally to determine the effects of dispersed oil, tests were also conducted using undispersed oil, the conclusions of which are described here. The general conclusion reached from the studies conducted was that '... in the long term, *Diploria strigosa* appears relatively tolerant to brief (6-24 hour) exposures to crude oil dispersed in the water column.' Responses to un-dispersed oil were generally less than those for dispersed oil.

Studies carried out using Arabian light crude (API gravity between 30° and 48^0) on an Arabian Gulf coral reef, indicated that healthy coral reefs can tolerate relatively short (one to five days) exposure to floating oil with no observable effects (LeGore *et al,* 1989). Twenty four hour and five day (120 hour) exposure experiments were undertaken and the effects monitored immediately after exposure and at three month intervals for a period of one year. The exposed section of the reef was located immediately landward of the reef edge, with depth varying between one and three metres depending on tidal state. During a one year observation period, no visible effects on growth rate or physiology were exhibited by corals of the genera *Acropora, Goniopora, Porites* or *Platygyra* to floating crude oil corresponding to a slick thicknesses of 0.25 mm for a period of 24 hours and 0.10 mm for a period of 120 hours.

A field experiment on the effects of untreated and chemically dispersed oils on tropical marine communities conducted on the Caribbean coast of Panama (Ballou *et al,* 1989), concluded that untreated oil had relatively minor effects on corals, seagrasses and related organisms. The untreated oil, Prudhoe Bay crude oil, was released in the study area in an unweathered condition at an application rate of 1 L/m^2, representative of the amount of oil that would strand from a spill of 100 to 1,000 bbl (16,000 to 160,000 L). The oil was contained by boom over the coral site for a period of approximately 48 hours. Average water depth over the coral sites was 63 cm. There was a minor, but not statistically significant, decline in coral cover within the first four months after treatment, however a similar pattern was observed at the untreated reference site, indicating that factors other than oil treatment were responsible.

3. STUDIES OF ACTUAL OIL SPILL EVENTS

The major difficulty in interpreting the results of investigations of the effects of oil from real spills on coral reefs is lack of pre-spill data by which to assess effects which may be subtle and disguised by natural variation.

However, in the case of two major spills, there existed pre-spill data which were subsequently used to assess oil pollution impact and subsequent recovery. These are the spill from an oil refinery storage tank off the Caribbean coast of Panama which occurred in 1986 and the 1991 Gulf War oil spills which are reviewed below.

3.1 CHRONIC POLLUTION EVENTS

3.1.1 Gulf of Eilat, Red Sea

Many parts of the Red Sea, particularly in the vicinity of refinerys and tanker terminals have been subject to chronic oil pollution as a result of frequent spills. In a study of coral recolonisation following a natural mortality event (an extreme low tide), Loya (1976) found that coral recolonisation occurred more quickly on a reef not subject to human perturbation than one which was subject to chronic pollution from oil and mineral spills.

Mergner (1981), in a study of permanent oil pollution in the Eilat region of the Red Sea, reported reduced coral settlement on the reef flat, colony numbers and bottom cover attributable to chronic pollution.

3.1.2 Bahia Las Minas, Panama

Background

On 27 April 1986, at least 60,000 to 100,000 barrels (9,600,000 to 16,000,000 L) of medium weight (27°API) crude oil spilled from a ruptured oil refinery storage tank into Bahia Las Minas, on the central Caribbean coast of Panama (Guzman *et al,* 1994). A relatively small amount of dispersant (21,000 L of Corexit 9527) was sprayed from aircraft over the initial spill, but this was considered by Burns & Knap (1989) to have been insufficient to have dispersed the large amount of oil spilled and consequently that chemical dispersion would not have accounted for the mortality seen in subtidal corals over the extended areas documented in the study of the spill.

In addition to the immediate spillage, the study area was subject to ongoing exposure to hydrocarbons. Oil slicks were observed over the reefs in subsequent years emanating from landfill beneath the refinery and the adjacent mangrove sediments. Further, in December 1988 and in June 1990, spillage of diesel oil occurred from another storage tank located approximately 1 km from the site of the initial spill (Guzman *et al,* 1994). Earlier, a major

(3,200,000 L) spill of diesel and Bunker C fuel oil had occurred following the wreck of the tanker "Witwater" in December 1968 (Rutzler & Sterrer, 1970).

Reports on the effects of these spills on impacted coral reefs in the region are presented below, in chronological sequence.

The short term effects of the refinery storage tank spill are summarised by Cubit *et al* (1987), who reported that between two and three weeks after the spill, between 10 and 19 May 1986, extreme low tides exposed the reef flats above water level during a period of warm weather and oil blown inshore remained against the seaward edge of the reef flats throughout this period. By June 1986, Cubit *et al*, (1987) reported that a band of substratum between 1 and 3 m wide was nearly barren of the normal assemblage of algae and invertebrates (including corals). This was initially replaced by a thin algal mat which gradually became thicker and covered a larger area of the substratum. The original species of macroalgae present on the reef fringe returned to their original (pre-spill) coverage between 5 and 12 months, depending on species, after the spill. The reef flat coral, *Porites* sp., present with low coverage before the spill, was not detected in surveys conducted 2 and 5 months after the spill. In August 1986, some four months after the spill, shallow (1-2 m) subtidal corals were found to be dead or dying in heavily oiled areas.

From surveys conducted some 18 months after the Bahia Las Minas spill, Jackson *et al* (1989) concluded that the type and magnitude of the effects varied greatly with coastal topography and location, habitat and taxa. Complex shoreline structure was found to have resulted in significant difference in exposure to oil over relatively short distances. On shallow and intertidal reef flats, algae were initially reduced well below their original abundance but had regained or exceeded their original abundance within 12 to 18 months. Hydrocorals (*Millepora* sp.) and scleractinian corals (*Porites* sp.) were severely reduced and had not returned to original abundance after 18 months. On subtidal reefs, monitored some four months after the spill, there was substantial loss of coral on heavily oiled reef, 51 to 96% at depths of less than 3 m decreasing to 45% at depths of 9 to 12 m. Reductions were less on lightly oiled reef and generally absent on un-oiled reef. The relationship between the amount of oiling and decrease in coral cover was found to be statistically significant for depths of 0-3 m but not deeper.

Sublethal effects were also noted by Jackson *et al* (1989). These included bleaching or swelling of tissues, copious production of mucus, recently dead areas devoid of tissue, and globules of oil. In some areas there was evidence of bacterial infection. The effects were most evident on the heavily oiled reefs and decreased with depth. They were also found to be species specific.

Two years after the spill, Guzman *et al* (1991) found that there was a marked decrease in the cover size and diversity of corals at the control reefs previously studied (see Jackson *et al*, 1989). Comparing oiled and un-oiled reefs, the number of species and species diversity based on colonies showed no significant relation to oiling but a significant effect was detected for the total number of corals present. Species specific effects were also noted. Recent injury to corals was still being detected two years after the spill.

Burns & Knap (1989) reported on the uptake of hydrocarbons by reef building corals impacted by the Bahia Las Mina oil spill. Significant hydrocarbon uptake was found to have occurred and this was correlated with areas of coral mortality. It was concluded that changes in the protein/lipid ratios in the tissues indicted that oiling had affected the lipid biochemistry of surviving corals.

Sublethal effects on the reproduction of the reef coral *Siderastrea siderea* some 39 months after the initial spill were found to include reduction in gonad size. However, the numbers of colonies with gonads at any stage of development, numbers of gonads per colony and percentage of reproductive colonies was found to be similar for both oiled and un-oiled reefs Guzman & Holst (1993). The occurrence of re-oiling as a result of slicks from beneath the refinery and the adjacent mangroves was noted.

A further summary of the Bahia Las Minas spill impacts is presented in Cubit & Connor (1993). In this report a description of an extreme low tide resulting in severe exposures of the reef flat which occurred in 1988, two years after the initial spill. This event resulted in a microalgal bloom similar to that which occurred immmediately following the spill, and a similar pattern of death and recovery of both macroalgae and reef fauna.

After some five years of monitoring, Guzman *et al* (1994), reported the effects on injury, regeneration and growth in four common species of massive reef-building corals in relation to sedimentation and petroleum contamination. Injury levels were found to be higher at oiled than un-oiled reefs. This was most evident in the year following the initial spill but persisted for most of the five year period of the study, reflecting the persistent nature of the pollution. Regeneration was faster at oiled than un-oiled sites. Although growth rates were lower at both oiled and un-oiled sites in the three years following the spill, the rates for the two species measured differed, reflecting species specific response.

3.1.3 Aruba, West Indies

Bak (1987) studied the effects of long-term (approximately 60) years of chronic pollution of a shore fringing coral reef adjacent to an oil refinery on the Caribbean island of Aruba. Effects of oil on the relatively uniform coastline and reef were inferred from contemporary cover and distribution of coral species in relation to the location of the refinery and prevailing longshore currents. It was concluded that unspecified spills and clean-up operations over the period of refinery operation had resulted in deterioration in the spatial structure of the reef, reduction in coral cover and reduction in juvenile numbers adjacent to and down current of the refinery, discernible over a distance of 10-15 km along the reef.

3.2 SINGLE IMPACT POLLUTION EVENTS

3.2.1 "*Witwater*" Tanker Spill, Panama

Approximately two months after the wreck of the "Witwater", off the Panamanian coast, Ruzler & Sterrer (1970) undertook a qualitative survey of the impacts of the tropical communities in the area impacted by oil. They concluded that the coral reefs were the least impacted of the marine communities and that shallow coral patches dominated by the species, *Porites furcata, P. asteroides, Sidastrea radians* and *Millepora complanata,* showed no evidence of impact. This was attributed by the authors to the fact that the corals were subtidal and did not come into direct contact with the oil.

3.2.2 The (Arabian) Gulf War

The 1991 Gulf War imposed a number of stresses on the marine environment of the Arabian Gulf. These included multiple oil sources with extended coverage periods, secondary sources (fallout from burning oil), physical impacts on reefs (collisions, explosions,) and lowered sea temperatures as a result of smoke cloud shading. Estimates of the amount of oil spilt into the ocean are 6-8 million barrels (1,000,000,000-1,250,000,000 L) and burnt to form the heavy smoke cloud responsible for the heavy shading at the end of the war, 500 million to 1.12 billion barrels (80,000,000,000-190,000,000,000 L), making it the largest recorded spill in history.

In addition, the corals in the Gulf are at the extremes of their temperature range with winter water temperatures of 14°C and summer temperatures as high as 40°C (Coles & Fadlallah, 1991). Periodic exposure of shallow water corals in the Gulf has also been reported to result in severe mortalities (Loya, 1976).

Despite the magnitude of the spills, and the compounding effect of other human induced and natural impacts, the coral of the Arabian Gulf have reportedly suffered little impact as a result of the Gulf War oil spills. The first post-war study of the effects of the Gulf War oil spills on the coral reefs of the Arabian Gulf were conducted by a team of scientists aboard the MV Greenpeace in August-October 1991, approximately six months after the end of the war (Greenpeace, 1992). In that study, reefs in Bahrain, Saudi Arabia, Kuwait and Iran previously investigated, were inspected and video records made. None of the reefs inspected showed any sign of oil coverage or bleaching or abnormally high numbers of dead corals. Comparing the data with the results of earlier surveys indicated little change in coral cover.

A survey undertaken by Downing & Roberts (1993), some 18 months after the Gulf War concluded that the offshore island reefs had suffered virtually no damage from Gulf War pollution, confirming the findings of previous surveys by Greenpeace (1992) and Fadlallah *et al* (1992). A follow-up post-war survey by the same authors concluded that some changes had occurred to the coral reefs offshore Kuwait, but that other than some partial coral mortalities the reefs looked healthy. Inshore reefs inspected in Saudia Arabia and Kuwait either looked healthy or had been impacted but showed signs of recovery.

In Downing and Robert's study, two Saudi Arabian areas of shore fringing reef at Abu Ali separated by a distance of 2-3 km were examined. The reefs consisted of a narrow band of coral and rock of coral origin approximately 20 m and 40 m in width. Both reefs lay approximately 50 m offshore. Both areas had been heavily oiled by both the Gulf War spill and previous spills. The reefs themselves had been covered by a floating layer of oil for some time during the Gulf War spill. The shoreward part of the reefs lay in approximately 1.5 m of water and consisted predominantly of eroded reef rock covered in algae. The corals present were evidently healthy, with no sign of bleaching or coral disease. In Kuwait, a small, inshore platform reef had been partially impacted, however, the corals were said to be recovering. The report concluded that natural variability, resulting largely from causes other than the Gulf War, was likely to have effectively masked any supposed impact of the Gulf War, the scale of impact being small in comparison to previously recorded events.

Vogt (1995a) outlined the monitoring procedures and reviewed the findings of the Greenpeace voyage and subsequent follow-up surveys in which reefs described prior to the war were re-surveyed to assess the impact of the war, and in particular the oil spills. The findings of those studies was that there was no impact on the corals from the oil spill. Vogt also described a follow-up study designed to detect possible changes in coral cover as a consequence of delayed effects. Comparison of live coral cover between June 1992 and July 1993, some two and a half years after the Gulf War, on 10 permanent study sites established on Saudi Arabian inshore and offshore coral reefs, indicated that the live coral cover at both inshore and offshore sites were in a stable state with very limited change detectable.

In a follow-up survey of the same sites, conducted three and a half years after the war, Vogt (1995) found that live coral cover had increased by 6.9% between the summers of 1992 and 1994. It was concluded at that time that the Saudi Arabian corals reefs showed no signs of any late effects from the Gulf War oil spill.

4. SYNTHESIS

A recent, 1994, summary of the effects of oil on corals, presented in the Great Barrier Reef and Torres Strait Shipping Study (1994), has noted:

> "Few causal relationships have been established between corals and oil and oil/dispersants despite a number of laboratory and "good" field experiments (Guzman & Holst, 1993). While deleterious effects on corals have been measured with oil, oil/dispersants and water soluble fractions of oil, the variation in experimental concentrations (where measured), exposure times and experimental design ("short"-term, "long"-term) make difficult the building of a coherent matrix of hard data useful for the assessment and prediction of the likely effects of reefal responses to a specific oil spill (Keller & Jackson, 1994).
>
> Generally, effects measured in laboratory experiments have addressed coral mortality, physiology and biochemistry of the animal-zooxanthellae symbiosis, reproduction and recruitment, and behavioural responses. Results are often conflicting, reflecting differences in the use of a number of species, exposure times, oil types, dispersant types and concentration, criteria for measurement of effects, treatment apparatus and conditions (open and closed containers; static and flow through) and post-treatment assessment periods."

Laboratory experiments have documented a number of lethal and sub-lethal responses of corals to oil exposure. Sub-lethal responses include:

- uptake and depuration in mucous (Neff & Anderson, 1981 Knap *et al.*, 1982);
- zooxanthellae expulsion (Birkeland *et al.*, 1976, Neff & Anderson 1981);
- decreased calcium uptake and zooxanthellae production (Neff & Anderson, 1981, Bak *et al.*,1976, Reimer, 1975);
- impaired feeding response (Reimer, 1975, Lewis, 1971);
- impaired polyp retraction (Dhinn, 1972, Cohen, 1977, Neff & Anderson, 1981);
- coenosarc tissue damage (Peters *et al.*, 1981);
- muscle atrophy (Peters *et al.*, 1981);
- impaired sediment clearance ability (Bak *et al.*, 1976);
- increased mucous production (Mitchell & Chett, 1975);
- gonal tissue damage (Rinkevich & Loya, 1977, Peters *et al.*, 1981);
- premature expulsion of planulae larvae (Loya & Rinkevich, 1979);
- impaired larval settlement (Rinkevich & Loya, 1977); and
- larval death (Rinkevich & Loya, 1977).

Experimental studies have shown that direct contact with oil is generally not immediately fatal to corals but that it may lead to rapid necrosis of contacted tissue (Johannes, 1972), and a review of field and laboratory experiments by Connell & Miller (1981) reported in Swan *et al* (1994) concluded that oil that is immersed, solubilised and dispersed in water has a much greater effect than oil floating at the surface.

Translation of these sub-lethal effects measured in the laboratory to field situations has generally proven difficult (ASTM, 1995), but studies of oil spills in a number of regions have shown a range of coral species to be sensitive to oil, with emergent corals being more vulnerable due to the potential for direct contact with the floating oil. Sensitivity to oil has been found to vary from species to species with factors such as structural complexity and natural mucous production affecting oil response.

The effects of spilled oil on coral reefs are dependant on both physical and biotic factors, including:

- physical contact;
- depth of immersion;
- tidal movement;
- wind generated surface currents;
- weathering of the oil before impact;
- tide level;
- sea state (wind and waves) at the time of impact;
- composition of the oil;
- degree of weathering; and
- coral species present.

Under field conditions, subtidal corals have been found to be less sensitive to oil, with corals at depths greater than 3 m exhibiting no significant differences in cover over time when compared to control sites (Jackson, *et al*, 1989). As a consequence, cause and effect in studies of the effects of oil spills are sometimes not clearly demonstrable.

One of the most widely studied events, the 1986 Bahia Las Minas storage tank rupture, revealed damage to shallow reef flat corals, but long term recovery has been hampered by persistent re-oiling as a result of oil leaching from sediments beneath the original leak site and from subsequent exposure to oil and from natural events.

The more recent (1991) Gulf War oil spills have reportedly shown little impact from the 8-16 million barrels of oil spilt into the ocean at the end of the war. Studies conducted over a period of three and a half years after the war showed little short or long-term effect on coral cover and growth.

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Figure 8.1 Major habitats found on the fringing reef west of the Montebello Islands, showing the potential consequences of contact with oil.

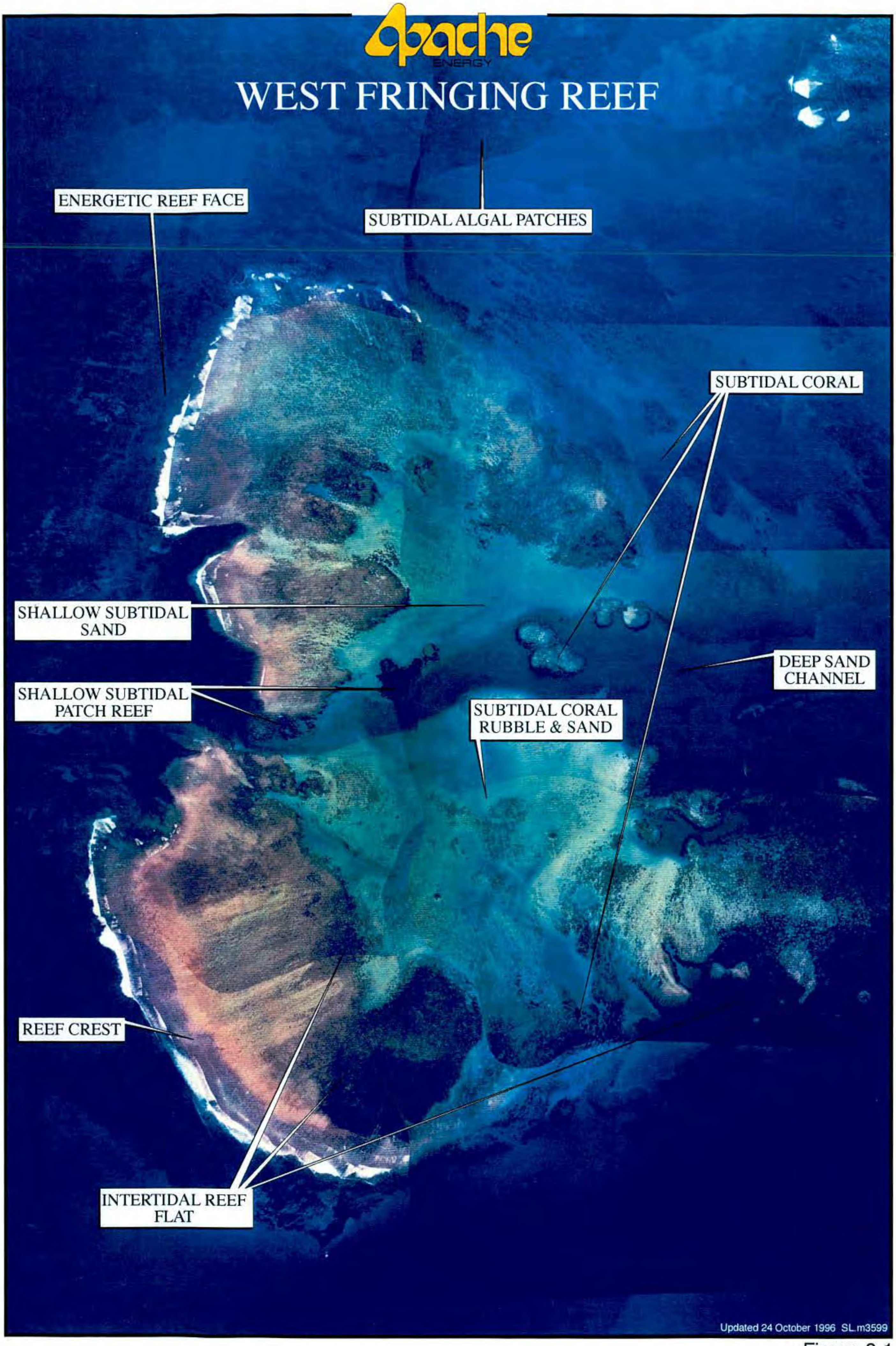
Apache ENERGY
WEST FRINGING REEF
ENERGETIC REEF FACE
SUBTIDAL ALGAL PATCHES
SUBTIDAL CORAL
SHALLOW SUBTIDAL SAND
SHALLOW SUBTIDAL PATCH REEF
DEEP SAND CHANNEL
SUBTIDAL CORAL RUBBLE & SAND
REEF CREST
INTERTIDAL REEF FLAT
Updated 24 October 1996 SL.m3599

Figure 8.1

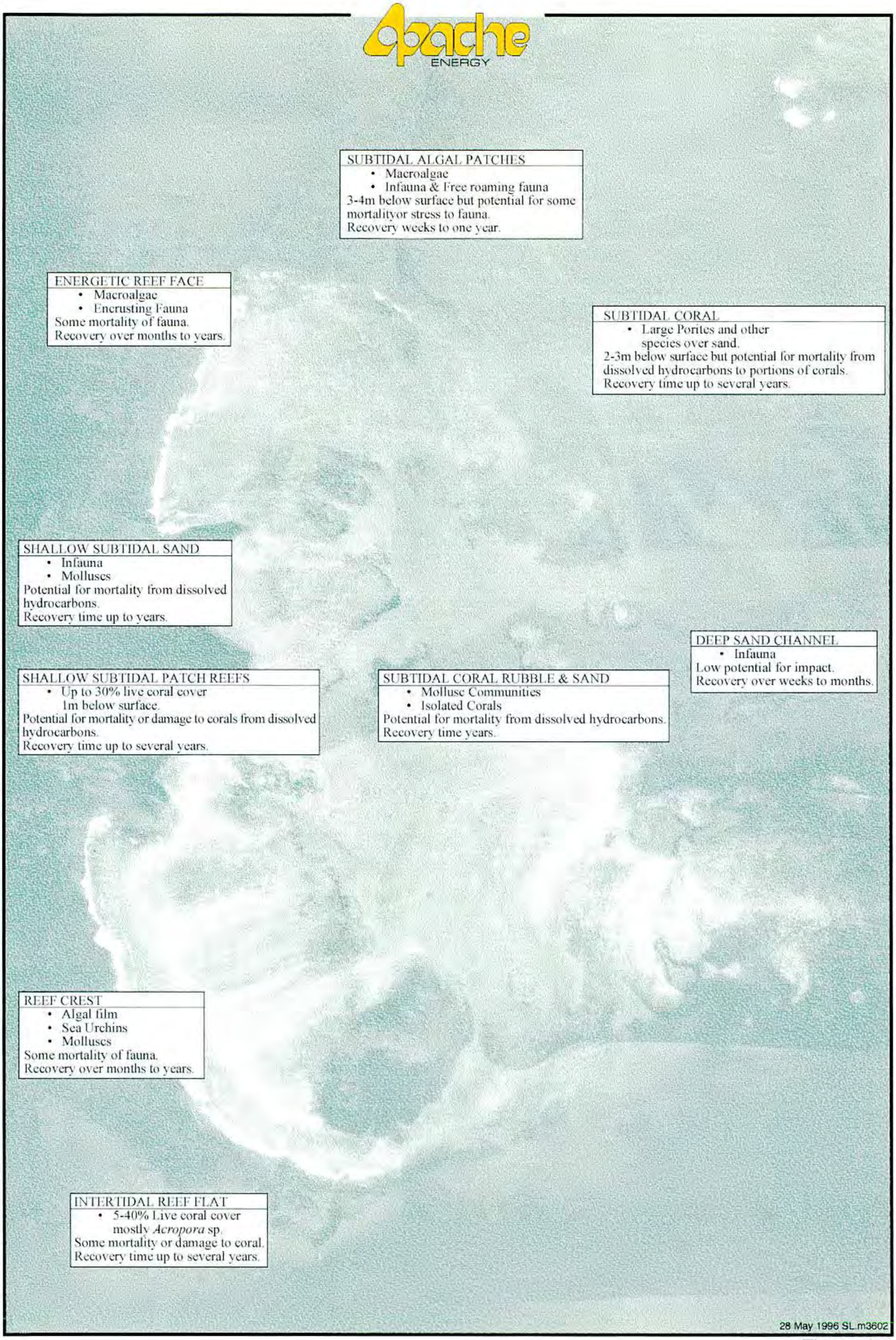
Apache ENERGY
SUBTIDAL ALGAL PATCHES
• Macroalgae
• Infauna & Free roaming fauna
3-4m below surface but potential for some mortalityor stress to fauna.
Recovery weeks to one year.
ENERGETIC REEF FACE
• Macroalgae
• Encrusting Fauna
Some mortality of fauna.
Recovery over months to years.
SUBTIDAL CORAL
• Large Porites and other species over sand.
2-3m below surface but potential for mortality from dissolved hydrocarbons to portions of corals.
Recovery time up to several years.
SHALLOW SUBTIDAL SAND
• Infauna
• Molluscs
Potential for mortality from dissolved hydrocarbons.
Recovery time up to years.
DEEP SAND CHANNEL
• Infauna
Low potential for impact.
Recovery over weeks to months.
SHALLOW SUBTIDAL PATCH REEFS
• Up to 30% live coral cover 1m below surface.
Potential for mortality or damage to corals from dissolved hydrocarbons.
Recovery time up to several years.
SUBTIDAL CORAL RUBBLE & SAND
• Mollusc Communities
• Isolated Corals
Potential for mortality from dissolved hydrocarbons.
Recovery time years.
REEF CREST
• Algal film
• Sea Urchins
• Molluscs
Some mortality of fauna.
Recovery over months to years.
INTERTIDAL REEF FLAT
• 5-40% Live coral cover mostly *Acropora* sp.
Some mortality or damage to coral.
Recovery time up to several years.
28 May 1996 SL.m3602

Figure 8.1

Appendix 9

ENVIRONMENTAL MANAGEMENT POLICY

Apache Energy shares the community's concern for the proper care and custody of our environment for present and future generations.

We recognise that human activity despite being a legitimate and integral part of our global environment, has the potential to disturb the balance of nature and must be planned and managed with the utmost diligence.

We believe that by demonstrating leadership in environmental management our efforts will clearly show a concern for, and commitment to, ensuring that our oil and gas operations are performed in a manner which will have the absolute minimum effect on all animal and plant species and their surroundings.

This will be achieved by:

- advancing and promoting an environmental awareness and ethic in the workforce through education and training;
- developing and implementing systems to thoroughly identify, review and manage all activities which have the potential to affect the surrounding biological, chemical and physical environment;
- promoting research into and facilitating the monitoring of biological and physical processes to develop baselines, measure environmental change and to expand and broaden our scientific knowledge base;
- rehabilitating and restoring disturbed areas to a condition compatible with their prior use or status;
- reducing the production of waste products and energy through conservation, recycling and the use of renewable resources;
- maintaining an emergency response capability to mitigate any potentially damaging effect of an accident; and
- maintaining open community and government consultation regarding our work and accomplishments, and the development of meaningful and science based laws, regulations and environmental standards.

This policy has been reviewed and endorsed by Apache Energy management who foresee benefits in, and take responsibility for, its successful implementation. By accepting employment with Apache Energy, each employee acknowledges that he/she is responsible for the application of this policy. Success will be achieved when each project is completed without pollution and disturbed areas have been rehabilitated.

John A Crum, Managing Director

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